SOIL NUTRIENT STATUS UNDER *Acacia senegal* Wild PLANTATION IN THE SAHEL ZONE OF JIGAWA STATE, NIGERIA

By

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A THESIS IN THE DEPARTMENT OF FOREST RESOURCES MANAGEMENT SUBMITTED TO THE FACULTY OF AGRICULTURE AND FORESTRY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF THE UNIVERSITY OF IBADAN, IBADAN, NIGERIA.

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ABSTRACT

Soils in sahel zone of Jigawa state have been reported to have poor fertility status due to soil erosion and desertification. *Acacia senegal* is generally planted in plantations in the state for the production of Gum Arabic and control of soil erosion. However, documentation of the potential of *Acacia senegal* to improve soil nutrient under plantation is scanty. Nutrient status under *Acacia senegal* plantation in sahel zone of Jigawa state was therefore investigated.

Four 30 x 30m plots were randomly chosen within the plantation with adjacent open woodland of the same size used as control in a randomized complete block design. Decomposition and mineralisation of monthly litterfall collected from each plot for six months were measured using litterbag technique. Litter fractions were collected, oven-dried and analysed for Nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) using standard procedures. Measurement of Diameter at Breast Height (DBH) and height of two mean trees per plot were taken. Representative trees were sampled for biomass estimation. Fresh samples of tree foliage, branch, stem and root were weighed and analysed for macro- and micro-nutrients. Soil samples were taken from 0-15, 15-30 and 30-60cm depths in a Randomized Complete Block Design (RCBD) and analysed for micro- and macro- nutrients. Soil acidity was determined in water and 0.01M $CaCl_2$ solution using a soil solution ratio of 1:2.5. Data were analysed using descriptive statistics, linear correlation and ANOVA at $p = 0.05$.

Total litterfall was 3.1 kg/ha/yr and litter decomposition rate was faster in early stages of decomposition with 43.6% mass loss. Mean macro-nutrients concentrations for the decomposed litter were: P (0.16 ±0.22 mg/kg); K (0.32 ±0.28 cmol/kg); Ca (3.1 ±1.2

cmol/kg); Mg (0.49 ±0.16 cmol/kg) but highest at soil depth 0-15cm: P (34.1 ±11.5 mg/kg); K (0.32 ±0.12 cmol/kg); Ca (6.5 ±1.8 cmol/kg) and Mg (3.3 ±0.76 cmol/kg). Basal area of the plantation was 22.0 m^2/ha, while tree biomass was 1,232.9 kg/ha. Tree micro-nutrients concentration had significant relationship with tree components but not with diameter class. Nitrogen (3.5cmol/g) and copper (0.02 mg/kg) concentrations were higher in foliage with calcium in root (2.6 cmol/g). The concentrations of macro-nutrients in soil: N (0.09-0.03 cmol/g); Ca (3.8-2.4 cmol/g) and K (0.18-0.09 cmol/g) decreased as soil depth increased except for magnesium (0.28-0.72 cmol/g) and sodium (0.11-0.15 cmol/g). Soil macro-nutrients concentration were higher in plantation: N (0.25 cmol/g); K (0.14 cmol/g); Ca (3.9 cmol/g) and Mg (0.66 cmol/g) than in open woodland: N (0.03 cmol/g); K (0.12 cmol/kg); Ca (2.9 cmol/kg) and Mg (0.35 cmol/kg). Positive correlation was observed between soil depth and clay (r= 0.64) as well as between silt and calcium (r= 0.74). Soil acidity in $CaCl_2$ solution ranged from 4.2 to 5.6 and from 4.7 to 5.9 in water.

Soil nutrients were higher in the plantation than in the open woodland as a result of litter decomposition and mineralisation. This implied enhanced soil nutrient status under *Acacia senegal* plantation in the study area.

Key words: Soil nutrient status, *Acacia senegal*, Mineralisation of litterfall, Plantation and Biomass

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DEDICATION

This work is dedicated to my wife Mrs. Stella Iyabo Ampitan, my children Abigail Abosede, Fiona Tayelolu, Ronald Kehinde and Sunday Ayodeji, my late sister, Mrs. Victoria Aduke Barnabas and my late brother Mr. Gideon Abiodun Ampitan.

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CERTIFICATION

I certify that this study was carried out by Mr. Titus Ayodele, Ampitan in the Department of Forest Resource Management, University of Ibadan, Ibadan, Nigeria.

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TABLE OF CONTENTS

Chapter 3

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1

1.0 Introduction

Approximately 55% of Africa's land surface is arid and semi-arid, characterized by an annual rainfall of 100-600 mm in a short wet season of 2-4 months (Didier and Ben, 2005). Land degradation, resulting from inappropriate land use is a common phenomenon. The dry African forest covering much of this area is home to many of the world's poorest people. Trees and shrubs, especially multipurpose species such as *Acacia* are essential for the survival of both people and animals under these harsh climatic conditions. Climate challenges are often aggravated by human-induced factors such as unsustainable agricultural practices, overgrazing and deforestation (Didier and Ben, 2005).

The West African savanna is a hot, dry, wooded savanna composed mainly of scattered trees and tall grasses. The habitat has been greatly reduced, degraded and fragmented by agricultural activities, fire, and clearance for wood and charcoal. It stretches across West Africa south of the Sahel, from Senegal and Gambia to the eastern border of Nigeria (World Wildlife Fund, 2001). Rainfall is highly seasonal, the dry season can last for several months, during which time most trees loose their leaves and the grasses dry up and may get burnt.

The Nigeria savanna covers about three-quarters of the country's total land use area (Kowal and Knabe, 1972). The soils are derived mainly from aoilian deposits (Jones and Wild, 1975), while Kaolinite is dominant in the clay fraction. Various soil classes have been described by Jones and Wild (1975) and Kowal and Kassam (1978). According to Odunze and Ogunwole (2002), the savanna soils are generally sandy,

sandy-loam or loamy sand in texture, have very low organic carbon, total nitrogen, available phosphorus, basic cations, very low moisture retention capacity and have extremely low organic matter content in the Northern Sahel but slightly higher in the Guinea savanna (Rowland, 1993; Ofori 1995). The soils therefore, have inherently poor fertility status and are very susceptible to soil erosion and desertification. This claim was corroborated by Jones and Wild (1975) that the low level of organic matter made the savanna soils susceptible to the major chemical, physical and biological limitations which reduce crop yields.

Awodola (1991) reported that the semi-arid region of Nigeria is also characterized by low but torrential rainfall, higher potential evapotranspiration and turbulent wind erosion and has been classified as belonging to Sahel savanna zone. Currently, this ecological region is faced with problems of soil erosion and desert encroachment from the Sahara.

Under the present system of continuous cultivation, these soils rapidly lose their fertility and productivity as a result of rapid decline of organic matter, extensive leaching, and these have aggravated rapid soil degradation in the zone. The free-range livestock husbandry generally practiced in the zone has also resulted in severe over-grazed bare-soil surface that also yield readily to soil erosion by water and wind.

Acacia species dominate many of the semi-arid ecosystems of tropical Africa (Didier and Ben, 2005). They provide a source of fodder, fuel, timber and gum as well as a potential solution to the declining soil fertility caused by shortened fallow periods (as their fertilizing properties generally allow the soil to recover more rapidly than under natural fallows). *Acacia senegal* Wild is particularly important because it is the source of the multipurpose commodity, Gum-Arabic which is traded on both local and international markets, and it is already used in several Sub-Saharan African agricultural production systems. As a raw product, Gum-Arabic is worth US$0.5 per kg to the local community. Families can collect up to 10 kg per day yielding a potential and substantial income of US$150 per month (Didier and Ben, 2005).

1.1 Research problem

Several studies have reported the positive influence of trees on soil fertility and conservation (Kellman, 1979, Belsky *et al*, 1989; Dunhaam, 1991; Kessler, 1992; Bill, 2007). Trees perform a dynamic role of maintaining soil organic matter levels through the supply of litter and root residues, which in turn improve the fertility of the soil. Trees take up different amounts and different proportion of nutrients from a soil according to their species and the amounts taken depend on the soil conditions and the rooting pattern of the tree species (Russell, 1973). Unfortunately, there is dearth or inadequate information on identifying any inherent constraints which might affect soil productivity and its influence on *Acacia senegal* growth in the study area where it is found in the wilds and plantations. The slow growth rate of *Acacia senegal* in this plantation and its inability to produce gum exudates in large quantities as expected therefore, make this research necessary.

In most forests, the major source of nutrients for trees is the process of decomposition, which refers to the processes that convert dead organic matter into smaller and simpler compounds (Kuers and Simmons, 2003). Consequently, the growth and productivity of forest ecosystems mainly depend on the amount, the nature and the rate of decomposition of forest litter (Kavvadias *et al.*, 2001). Considering this important factor, it is critical to understand the amount and pattern of litterfall, litter decomposition, nutrient immobilization and mineralization under *Acacia senegal*. Although numerous studies on amount and pattern of litterfall in plantations has been conducted in rain and savanna forests of Nigeria (Ola-Adams, 1978; Egunjobi and Onweluzo, 1979; Kadeba, 1994), few attempts or none have been made to measure litterfall and pattern under *Acacia senegal* plantations in the Sahel savanna of Nigeria.

The accurate estimation of biomass in tropical forests is crucial for many applications (Basuki *et al*., 2009). Estimates of tree biomass are useful in assessing forest structures and conditions (Chave *et al.*, 2003; Houghton and Goodale, 2004*);* forest productivity, carbon stocks and fluxes based on sequential biomass measurements and sequestration of carbon in biomass components, including wood, leaves and roots as well as being a useful indicator of site productivity (Jose, 2009). It is worrisome that despite the importance of biomass estimation as a factor of productivity in plantations, many studies have not been carried out to estimate the biomass of *Acacia senegal* in plantations and its influence on soil productivity. The need for this cannot be overemphasized especially when viewed against the realization that such information forms the background to an efficient and judicious use of land and its management.

1.2 Justification

Most African soils are of ancient origin and have been subject to leaching for a very long time. Furthermore, most of the soils come from rocks of low nutrient contents and are therefore typically impoverished even in an undisturbed state; most are seriously deficient in phosphate (Zake, 1995). A large proportion of the available nutrients are retained in the vegetative cover and the soil organic matter accumulates on the surface and subsequently mixes with the upper part of the soil. If the vegetative cover is removed for cultivation and the soil is put under intensive use without ensuring that the soil organic matter is maintained at the appropriate level, the fertility of the soil declines rapidly. Leaching results in progressive deterioration of fertility, an increase in acidity of the soil and sometimes toxic effects due to an alteration or imbalance in the chemical components of the soil.

Tree species vary in their nutrient uptake rates and recycling capacity (Montagnini *et al*, 1993). Litter production is a major process in the transfer of organic matter and nutrients from aboveground tree parts to the soil (Szott *et al*, 1991). The addition of tree leaves and branches to soils have been shown to improve site microenvironment conditions (Budelman, 1989). The nutrient content and the lignin and polyphenol concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Palm and Sanchez, 1990; Szott *et al*, 1991). Understanding the regulatory mechanisms of decomposition and nutrient release therefore is necessary for the prediction of mass loss and nutrient release patterns.

According to Nwoboshi (2000), the establishment of tree plantations on sites with inadequate amounts of nutrients to sustain good growth usually proves difficult. Almost invariably, such efforts result in either failure of such plantations or poor yield. Evidence is fast accruing that light-yield forest plantations, because of their uniform characteristics and feeding habits, are generally more exacting on the soil nutrient capital than the natural forest composed of heterogeneous species that can feed at different soil layers. Maintaining soil fertility therefore is an important step in creating a sustainable production of large-scale plantation forestry in the tropics.

Large areas of *Acacia senegal* plantation are currently being established in the northern part of Nigeria especially in States like Kano, Jigawa, Kebbi, Bauchi, Borno, Sokoto and Yobe. Information given by different authors (Ofori, 1995; Taffa 2002) reported that many soils in the tropics where this study falls are marginal, requiring meticulous handling. A design for plantation soil management can hardly be conceived without detailed investigation of the plant – soil relation under *Acacia* species plantations on a given soil type. For the manpower and material requirement for the establishment of these plantations are often difficult and expensive to acquire and these make it imperative for a research like this to be carried out.

1.3 Objectives

The main objective of this study is to determine the soil nutrient status under *Acacia senegal* plantation with a view to improving marginal and degraded lands in the study area, while the specific objectives are:-

1. To determine soil physical and chemical properties under *Acacia senegal* plantation in the Sahel zone of Nigeria;
2. Investigate litterfall dynamics of *Acacia senegal* plantation, and quantify the rate of litter decomposition and nutrient release through litter mineralization processes; and
3. Assess biomass and nutrient partitioning among the tree components of *Acacia senegal*.

CHAPTER 2

2.0 Literature review

2.1 Soil

Soil has been defined as the loose materials of the earth's surface, a layer distinctly different from the underlying bedrock. Alexander (1977) and Rhoades (1997) defined soil as the complex expression of physical, chemical and biological processes occurring across spatial and temporal scales, while Wild (1993) defined soil as the loose material composed of weathered rock, and other minerals and also partly decayed organic matter, that covers large parts of the land surface of the earth. However, agriculturists define soil as that region supporting plant life and from which plants obtain their mechanical support and many of their nutrients.

Soil is one of the factors of environment that influences the growth of plants (Wild, 1993). Basically, it is the medium in which plants grow. Apart from its traditional role of providing physical support for the plants and acting as a source of water to them, soil is more importantly a major source of nutrient supply to the plants (Encarta Encyclopedia, 2003). Plants are anchored in the soil by their roots and the soil contains various organic matters, including dead materials from plant and animals as well as animals adapted to live in the soil. The soil is therefore a store of major nutrients such as carbon and nitrogen and plays an important role in global nutrient cycles and in regulating hydrological cycles and atmospheric system. This implies that plant will always manifest in growth what it takes from the soil. This does not in anyway suggest that plants obtain all their nutrients from the soil as some important nutrients like carbon, hydrogen and oxygen are obtained from the atmosphere, but that the condition of the soil will go along way to dictate the yield from the soil (Nwoboshi, 2000).

If a soil is to be productive, it must have among other things adequate supply of all the necessary nutrients that plants take from the soil. Not only must required nutrients be present in forms that plant can use, but also there should be a near balance between them in accordance with the amount needed by plants. If any of these elements is lacking or if it is not present in proper proportion, normal plant growth and productivity will not occur. As the plants grow, there is continuous nutrient cycling until at a certain age when equilibrium is reached. Plants take up different amounts and different proportions of nutrients from a soil according to their species. The exact amounts taken, however, depend on the soil conditions (Russell, 1961: Russell, 1971).

2.2 Tropical soils

Soils are diverse in the tropical regions as they are in the temperate regions. However, forty three percent of the tropical soils belong to the acid low fertility group classified as oxisols and ultisols as opposed to 7% in the temperate regions (Palm and Sanchez, 1990). Analysis of the relative frequency of different soil grouping indicates that the highly weathered, leached soil (oxisols and ultisols) and the less leached alfisols cover more than half of the land area in the tropics. According to Kang and Atta-Krah (1990), the humid forest zone is dominated by the kaolinitic low base status ultisols, the drier forest and sub-humid zone is dominated by the kaolinitic high base status alfisols. The soils are generally low in cation exchange capacity (CEC) due to their low clay activity (Rowland, 1993).

2.3. The savanna soils

Various soil classes have been described by Jones and Wild (1975) and Kowal and Kasam (1978). Most of the soils have a low cation exchange capacity and are weakly buffered. While soil texture ranges from sandy in the Sahel to sandy loam and clay loam in the Southern Guinea savanna, the organic matter content of soils is extremely low in the Northern Sahel, but is slightly higher in Guinea savanna. Immobilization of phosphate is pronounced, due to a high content of free metallic oxides (Rowland, 1993). Most crops therefore respond favourably to the application of phosphatic fertilizers. Contents of other major and minor plant nutrients in these soils range from low to moderate, due to leaching, runoff or soil erosion. Deficiencies of micronutrients and even macronutrients such as potassium, which was previously considered adequate, are now frequent in the savanna.

2.3.1 Soil formation

The thin surface layer of the earth, known as the soil is formed by the breakdown of the rocks in various ways and by various processes. The set of factors that control the processes of soil formation include climate, organisms, topography, relief, parent material and time (Jenny, 1941; Monkhouse, 1975). Jenny (1980) broadened the list of factors to include anthropogenic effects such as tillage or soil contamination. However, soils vary from place to place due to various conditions such as climate, rock type, topography, and the local soil-forming processes. Over time, soils develop characteristics specific to their locations that relate closely to the climate and vegetation of the area (Encarta Encyclopedia, 2003). The particular climate affects the type of soil; both directly by means of its weathering effects and indirectly as a result of the vegetation cover for which climate is largely responsible. The major world biomes reflect a clear association between vegetation and soil that has developed in responses to the prevailing climate. Each soil type has a distinct combination of soil horizons and associated soil properties. A soil therefore, consists of mineral particles, a certain proportion of decayed organic material, soil water, soil atmosphere, and living organisms which exist in a complicated and dynamic relationship one with another (Monkhouse, 1975).

2.3.2 Soil fertility

Soil fertility is the ability of the soil to produce high yield consistently, provided environmental factors such as light, temperature and moisture are not limiting. Also soil fertility implies the potential of a soil to supply nutrient elements in amounts, forms and proportions required for maximum plant growth (Onwueme and Sinha, 1991; Uduak, 1991). The fundamental components of soil fertility of a given soil are the essential nutrients. Nutrients which are immediately available to plants constitute the potential fertility. Plant depends on the amounts of nutrient transfer from the potential to the active fertility. If any form of soil degradation occurs, the fertility of the soil will become less and might be lost altogether.

Individually, soils vary in their fertility. The variations may often be traced to the nature of the parent materials from which the soil developed (Alexander, 1977). The physical properties of a soil largely determine the way in which it can be used effectively for the transport of air, heat, water and solutes through the soil. Those that influence soil fertility are rooting depth, texture, structure, porosity, bulk density, temperature, air and moisture (Onwueme and Sinha, 1991).

2.3.3 Soil depletion

Soil fertility depletion is the fundamental cause of low per capita food production in Africa (Sanchez, 2003) and it is quite severe (Stroovegel and Smalling, 1991). According to Zake (1995), in all the thirty-eight countries in Africa studied, more than 10 kg of nitrogen, 4 kg of phosphorous and 10 kg of potassium per hectare per year are lost from the soil. Sanchez (2003) supported the above statement and stated that over the past decades small-scale farmers have removed large quantities of nutrients from their soils as harvests, without returning them as manure or fertilizer insufficient quantities, a problem which increases with increased yields. In a series of studies, it was noted that this has resulted in a very high average rate of fertility depletion that amounted to 22 kg of nitrogen (N), 25 kg of phosphorus (P) and 15 kg of potassium (K) per hectare of cultivated land per year over the past 30 years in thirty-seven African countries. At a scale like this, it is no longer a marginal loss, but a massive "soil mining". The most frequently limiting nutrients in soils in Africa are nitrogen, phosphorus and potassium, whereas in West Africa the limiting nutrients in soils are nitrogen and phosphorous (Roa *et al.*, 1998.)

Farmers are aware of the severity of soil fertility depletion, but rarely use fertilizers for food crops because they are often not available and because of their high cost and low profits. With growing populations, the need for productive soils is increasing. Soil loss in many developing countries is a major cause for concern and will become a major issue in the future (Encarta Encyclopedia, 2003). The process of soil loss can have a detrimental effect on other systems as it produces sediments that can cause siltation of river systems and reservoirs, set off flooding downstream and contribute to pollution and damage to wetlands. Soil is a complex, multi-component system of interacting materials, and the properties of soil result from the net effect of all these interactions.

2.3.4 Soil organic matter

The term soil organic matter refers to the organic fraction of the soil that is composed of both living organisms and once-living residues in various stages of decomposition (Sullivan, 1999). Agriculturists, since ancient times have recognized the significant benefits of soil organic matter to crop productivity. These benefits have been the subject of controversy for centuries and some are still debated today. Many of the benefits of soil organic matter (SOM) have been well documented scientifically, but some effects are so intimately associated with other soil factors that it is difficult to ascribe them uniquely to the organic matter. In fact, such soil material is continually being broken down as a result of the work of soil micro-organisms. Consequently, it is a rather transitory soil constituent and must be renewed constantly by the addition of plant residues (Brady, 1974). Contrary to the commonly held view that tropical soils have low organic matter contents because of high temperatures and decomposition rates, organic matter contents in tropical soils are similar to those of the temperate regions (Onwueme and Sinha, 1991).

Although, most cultivated soils contain only 1-5 percent by weight of organic matter, mostly in the top 25 cm of soil, this small amount can modify the soil's physical properties and strongly affect its chemical and biological properties. It has a nutritional function in that it serves as a source of phosphorus and sulphur, and essentially the sole source of nitrogen. Through its biological function, it profoundly affects the activities of microflora and microfauna organisms. Its physical and physio-chemical function promotes good soils structure, thereby improving soil porosity, aeration and retention of soil moisture, increasing buffering and exchange capacity of soils and reduces soil erosion by both wind and water.

Soil organic matter is frequently said to consist of two general groups: humic substances and non-humic substances. Non-humic substances are all those materials that can be placed in one of the categories of discrete compounds such as sugar, amino acids, fats and so on, while the humic substances are the other unidentifiable components. Humus has a profound effect on the structure of many soils. The deterioration of soil structure that accompanies intensive tillage is usually less severe in soils adequately supplied with humus. When humus is lost, soils tend to become hard, compact and cloddy.

2.4 Importance of trees to soil

The influence of tree species on ecological processes is fundamental to the understanding of ecosystem functioning. Vegetation plays a major role in soil formation (Jenny, 1941) and species differ in their effects on soil characteristics and processes (Alban, 1969; Pastor *et al.*, 1984; Gower and Son, 1992; Vinton and Burke, 1995; Rhoades and Binkley, 1996) in ways that influence ecosystem functioning and structure (Pastor *et al.*, 1984). Soil organic matter quality is one of the main soil properties that can be directly influenced by species through the incorporation of dead tissue with different chemical composition (Melillo *et al.*, 1982; Pastor *et al.*, 1984; Gower and Son, 1992; Constaninides and Fownes, 1993), which may alter nutrient cycling throughout the ecosystem. The nature and amount of organic matter produced after decomposition of the litter depends on the dominating tree species present and the site characteristics of the area which regulates the physical and chemical properties of soil (Singh and Suri, 1987). Thus the morphology of the organic horizons is affected by the nature of the organic matter added to the soil (Handley, 1954), while the addition of water-soluble compounds from leaves or decaying litter to the soil solution influences the leaching process (Davies, 1977). The protective influence of forest when removed results in changes in the status of the soil (Lal *et al.*, 1975).

Gracia - Montiel and Binkley (1995) reported that the use of fast growing tropical tree plantations to rehabilitate and restore many degraded tropical forest ecosystem is based on the potential of different species to influence soil fertility and ecological processes. However, different forest tree species are known to exert varied influence on soil properties (Russell, 1973; Singh and Suri, 1987).

2.5 Litterfall, litter decomposition and nutrient turnover

Trees in forests absorb nutrients from the soil to support their growth. At the same time some part of the nutrient uptake is returned to the forest floor via litterfall (Guo and Sims, 1999). The faster the tree grows the more litter it produces. The litter accumulation on the forest floor provides energy, nutrients and a living environment to the soil fauna and micro-organisms. Bada (1984); Bargali *et al.*, (1993) and Didham (1998) reported that litter decomposition and nutrient mineralization are vital processes to nutrient cycling and productivity of the forests. They are also important components of the global carbon budget (Aerts, 1997).

The rates at which forest litter falls and subsequently decomposes contribute to the regulation of nutrient cycling and primary productivity (Wang *et al.*, 2008) and the maintenance of soil fertility in the forest ecosystems (Onyekwelu *et al.*, 2006; Pandey *et al.*, 2007). The rate at which litter is decomposed and mineralized depends on a variety of environmental parameters; the most important of which are the litter quality and climate (Berg *et al.*, 2000) but the place of soil fauna and micro-organisms cannot be underestimated. For instance, environmental conditions such as climate may have a strong influence on soil fauna (David *et al*., 1999) such as earthworm, centipedes, millipedes, slugs, snails and micro-organisms including bacteria, fungi, protozoa and nematodes (Sullivan, 1999).

Feeding activities of soil fauna have a direct effect on decomposition through their own metabolism and an indirect effect by increasing the activity of decomposer microorganisms (Hanlon and Anderson, 1980; Hassall *et al*., 1987; Zimmer and Topp, 1991). In a study in Mediterranean ecosystems Rodriguez *et al*. (1999) found that soil fauna consumed between 10 and 37% of the produced litter and a large proportion of it is returned to soil as faecal pellets (Hassall *et al*., 1987), which have higher capacity to retain water and a higher surface-to-volume ratio than litter (Bertrand and Lumaret, 1992).

In a tropical environment, the climatic seasonality characterized by alternating wet and dry periods also plays a vital role in regulating the rates of litter decomposition (Tripathi and Singh, 1992) by changing the population of microbial community on decomposing organic matter (Arunachalam *et al*., 1997). Rapid organic matter decomposition in tropical forests however, is mediated by the generally high bacterial cells counts and fungal hyphal lengths in their soils compared to those in temperate and boreal forests (Swift *et al*., 1979). While in the Mediterranean forests, there is a strong seasonality of invertebrate populations. Both abundance and diversity of soil fauna often decrease mainly during summer droughts (Hornung and Warburg, 1995). Tropical forests generally contain a more diverse soil fauna than do temperate and subalpine forests, but they often have smaller numbers and biomass of meso- and macro-fauna (Swift, *et al.*, 1979), probably because of the lack of substantial litter layer in many tropical forests (Golley, 1983). The functional characteristics of soil fauna such as earthworms also differ markedly between global regions (Anderson and Swift, 1983), probably because of differences in the nature of litter and soil organic matter (Jordan, 1985). There are evidences which proved that there is a regional difference within the tropics in decay rates with more rapid decomposition occurring in West African forests than in the America and Southeast Asian forests.

Initial substrate quality of litter such as concentrations of cellulose, hemi-cellulose, lignin, nitrogen, phosphorous and potassium have also been found to play a major role in litter decomposition in different ecosystems (Tripathi and Singh, 1992; Adejuyigbe, 2000; Osono and Takeda, 2004). Litter with high lignin and low nitrogen concentrations has a slower decomposition rate and immobilizes more nitrogen than litter with low lignin and high nitrogen content (Hendricks and Boring, 1992). As litter decomposes, concentrations of lignin and nitrogen increase (Berg *et al.*, 1997). Site factors also contribute to nitrogen immobilization in the decomposing litter, therefore, nitrogen accumulation in litter maybe enhanced by soil nitrogen level (Virzo De Santo *et al.*, 1998).

Decomposition process of leaf litter is generally divided into early and late stages with different dominant organic chemical compounds (Virzo De Santo *et al.,* 2009) limiting the decomposition rate. In the early stages of decomposition, soluble components decay or are leached away very rapidly: cellulose and hemi-cellulose decompose faster in nutrient rich litter, thus the length of the early stage may range from a few weeks to more than a year. The late stages may encompass a large part of the litter decomposition process. Lignin and modified lignin like humification products make up an important fraction of the litter in the early stages in which their degradation dominates the litter decomposition (Fogel and Cramack, 1977; Berg *et al*., 1993). The rate limiting factors during the late stages include concentrations of nitrogen, manganese and calcium as well as climatic and edaphic conditions.

2.5.1 The role of nutrients on plant growth

The role of nutrients in physiological processes involved in plant growth and development is very vital. Of the over ninety elements (macronutrients and micronutrients) that have so far been identified in plants, only about sixteen are at present considered essential for healthy and vigorous growth of plants. Of these sixteen elements, three (carbon, hydrogen and oxygen) are obtained from the air, while the remaining thirteen, (nitrogen, phosphorous, iron, potassium, calcium, magnesium, sulphur, boron, manganese, molybdenum, zinc, copper and chlorine) come from the soil (Bada, 1984; Wild, 1993; Nwoboshi, 2000 and Encarta Encyclopedia, 2003). Kramer and Kozlowski (1960) and Nwoboshi (2000) claimed that it is probable that every element in the root environment may appear as a plant constituent and hence essential for plant growth.

According to Nwoboshi (1973), each of the mineral elements has a specific role to play in the metabolism of plants. The availability of nutrients and rate of absorption within the soil are influenced by several factors, hence absence of one or more of the mineral nutrients usually leads to distortions in the vegetative and reproductive cycles of the plant. These distortions are shown outwardly as deficiency symptoms that can only be corrected by the application of any of the mineral nutrient that might be lacking.

2.5.2 Some essential nutrient elements

Essential nutrient elements are those mineral elements that have been proved to be required by the plants as essential to their growth and reproduction. Such nutrient elements include carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, calcium, magnesium and sulphur, which are required in relatively larger amounts and are referred to as macro-nutrients while those required in smaller or trace amounts are referred to as micro-nutrients.

2.5.3 The role of nitrogen

Nitrogen was apparently the first nutrient element to be specifically recognized as necessary for plant growth (Russell, 1961). It is now generally accepted that all life processes depend on nitrogen (Nwoboshi, 2000). However, nitrogen is the most commonly deficient nutrient in most cultivated soils in Africa. It plays several important roles. It is an essential part of chlorophyll needed for photosynthesis. It is therefore, needed in abundant supply for reproduction, growth and respiration. According to Nwoboshi (2000), trees need it mainly for wood production and protein synthesis in cells and seeds. It is generally taken up by plants either as ammonium (NH^{+}) or as nitrate ($N0^{-3}$) ions, but the absorbed nitrate is rapidly reduced, probably to ammonium, through a molybdenum-containing enzyme (Russell, 1973).

Deficiency of nitrogen causes a considerable decrease in tree growth. It blocks chlorophyll synthesis, causes some reduction in size and premature senescence of leaves, and its deficiency tends to impede plant growth more than the deficiency of any other macro-nutrient.

2.5.4 Role of phosphorus

Phosphorus plays a central role in the tree growth process and exerts a beneficial effect on root formation and early growth, flowering, fruiting and seed formation (Nwoboshi, 2000). It is a constituent of the cell nucleus and is essential for cell division and for the development of meristem tissue.

Phosphate deficiency is very wide spread in the world. Phosphate deficiency can be difficult to diagnose, and plants can be suffering from severe starvation without there being any obvious signs that lack of phosphate is the cause (Russell, 1973).

2.5.5 Role of potassium

Potassium is one of the essential elements in the nutrition of the plant, and one of the three that is commonly in short supply in the soil to limit crop yield (Rao *et al.*, 1998). Potassium differs from nitrogen and carbon, in not being a constituent of the plant fabric. It is important in the synthesis of amino acids and proteins from ammonium ions. Plants growing in solutions high in ammonium and low in potassium can have their tissues killed by the high concentration of the ammonium ions that accumulate in them under this condition.

When nitrogen and potassium are simultaneously in short supply, the plants are stunted, their leaves are small and rather ashy-gray in colour, dying prematurely, first at the tips and then along the outer edges, and the fruit and seed are small in quantity, size and weight. These effects are general, and are seen on all soils, but best on light sandy or chalky soils and on certain peaty soil.

2.5.6 Role of calcium

Calcium is not only an important plant nutrient, but is also used as a liming material to lessen acidity. Calcium appears to be essential for the growth of meristem and particularly for the proper growth and functioning of root tips. It is also present as calcium pectate, which is a constituent of the middle lamellae of the cell walls, and possible for these reasons it tends to accumulate in the leaf.

Calcium deficiency appears to have two effects on the plant. It causes a stunting of the root system and it gives a fairly characteristic appearance to the leaf. Calcium deficiency also may have an indirect effect in the plant by allowing other substances to accumulate in the tissues so much that they may either lower the vigour or actually harm the plant. Thus a good calcium supply helps to neutralize the undesirable effects of an unbalanced distribution in the soil of nutrients and other compounds that can be taken up by the plant (Russell, 1971; Russell, 1973).

2.5.7 Role of magnesium

Magnesium is needed by all green plants as it is a constituent of chlorophyll (Nwoboshi, 2000). It also seems to play an important role in the transportation of phosphate in the plant, and possibly as a consequence of this, it accumulates in the seeds of plants rich in oil. The oil is accompanied by an accumulation of lecithin, in a phosphate containing fat. Magnesium deficiencies are most likely to occur in sandy, acid soils usually below pH 5.5.

2.5.8 Role of sulphur

Sulphur is used in protein synthesis and by the nitrogen-fixing rhizobia bacteria. It also forms part of several vitamins and is used in soil formation. Sulphur is absorbed from the soil as sulphate ions, but reduced to sulphydril groups in the formation of sulphur-bearing amino acid and other molecules. In some species, it gives colour and odour to the fruits (Nwoboshi, 2000).

Sulphur deficiency affects plant metabolism particularly protein synthesis. Amino acids and other soluble nitrogenous compounds tend to accumulate in the deficient tissues owing to some lag in protein synthesis. Lack of sulphur also prevents the fixation of atmospheric nitrogen by root nodule bacteria and frequently shows in a yellowing of the plant leaves (Banle and Frisker, 1974).

2.6. Soil degradation

Land degradation may be defined as the loss of utility or potential utility or the reduction, loss or change of features which cannot be replaced (Taffa, 2002). All countries, rich or poor, arid or humid, suffer land degradation; however, Sub-Saharan Africa is often singled out as particularly prone to environmental and developmental problems.

2.6.1 Soil erosion

Accelerated soil erosion is the greatest hazard in most environments and has hindered long-term maintenance of soil fertility in most part of Africa (Wild, 1993; Zake, 1995). The main effect of soil erosion is to reduce the soil depth and hence its capacity to store the water and nutrients which plants require for growth (Rowland, 1993). Soil erosion exposes underlying soil horizons, bringing them to the surface as topsoil vanishes. Loss of topsoil means loss of the layer with most nutrients, most organic matter (Zake, 1995) and the best structure for root growth and plant survival. Although, the differences between soil horizons are not as great in semi-arid areas as in wetter climates, topsoil is usually more fertile than the underlying horizons. As fine soil is eroded more easily than coarse materials, the concentration of nutrients in the soil washed away is usually greater than in the coarse soil left behind (Barnett *et al.,* 1972). Erosion, therefore, usually reduces soil fertility in the root zone as well as the total store of nutrients in the soil profile. The bulk density of surface horizons is usually lower and the organic matter content generally higher, and so if surface soil is removed it becomes more difficult for roots to develop, penetration of rainfall is reduced, and surface run-off is increased. Therefore, erosion is usually accompanied by reduction in crop yields and economic productivity (Stocking, 1984), as well as cause environmental degradation.

Besides the problem of erosion, there is also the problem of soil hardening especially the heavy soils resulting in hardpan. This is called soil laterization and this is as a result of the presence of aluminium sesquioxides. Zake (1995) noted that the tillage of the highly leached soils causes problems of soil compaction and hardening on drying. The problem with soil hardening is that when the dry season sets in, the surface soil becomes very hard making it impervious to the first rains, resulting in initial erosion. Moreover, this situation leads to some loss of nitrogen through denitrification, loss of phosphorous through positional unavailability, and loss of water retention capacity. The constraints caused by compaction basically affect the soil's physical conditions, whereas the constraints caused by soil hardening seem to affect the chemical, physical and biological properties of the soil. Globally, accelerated erosion is the most obvious form of soil degradation. The principal causes of soil erosion are deforestation, overgrazing, shortened cycles of shifting cultivation, too frequent burning, excessive gathering of firewood, or the traffic of vehicles or livestock along dirt tracks (Evans, 1992) and cultivation of slopes in absence of conservation (Woomer and Muchena, 1995).

The importance of vegetative cover in reducing soil erosion cannot be over-emphasized. Small plants absorb some of the energy of raindrops and so reduce splash erosion. They also increase the friction of the soil surface, decreasing the velocity of runoff. Their roots help to bind the soil and to keep it in place (Rowland, 1993).

The influence of trees is not as straight forward as that of other plants. Trees are generally thought to decrease erosion because they maintain good soil fertility and organic matter content and because their roots help to bind the soil particles together. Trees intercept a certain amount of rain during a storm and water is retained on the tree by surface tension, resting on leaves. However, if there is very little vegetation or little cover beneath the trees and the soil is susceptible to erosion, the dripped water, and possible the stem flow, may actually contribute to soil erosion (Geiger, 1966; De Ploey, 1987; Tafa, 2002). However, there is no doubt that trees are very effective in reducing wind erosion, especially when planted in rows as windbreaks.

2.7. Desertification

Taffa (2002) has defined desertification as land degradation in arid and dry sub-humid areas resulting mainly from adverse human impacts. Within historical times the area of desert and semi-desert, especially in the tropics, has greatly increased. Much of this is attributable to man’s destruction of vegetation for fuel, fodder and grazing, and timber for building. According to Evans (1992), desertification is overwhelmingly a man-made process. The effects of climatic change on land (and such change is continually taking place) are aggravated and ever become irreversible if combined with over-grazing, brining, firewood gathering or excessive cultivation. Though, man's clearance of natural vegetation and forest in the tropics and subtropics is less than in the temperate regions, the effects have mostly been much more damaging, especially on the soil.

UNEP (1984) opined that loss of vegetation in semi-arid desert regions is leading to increasing areas of desert. In Africa for example, roughly 12 million hectares of sub-Saharan Africa is arid or semi-arid. Africa's physical environment is deteriorating daily (Taffa, 2002), while Evans (1992) reported that 18 per cent of the productive land in Sahelian Zone of Africa is severely decertified and the situation is probably deteriorating everyday (Grainger, 1990).

The indicators or symptoms of desertification can be physical, biological, social or economic (Reining, 1978; Olsson, 1983). The physical indicators are decrease in soil depth, decrease in soil organic matter and soil fertility, soil crust formation/compaction, appearance or increase in frequency or severity of dust or sand storms or dune formation and movement, salinization or alkalinization, decline in quantity and quality of ground water, increased seasonality of springs and small streams.

The biological indicators include decrease in above ground biomass, decrease in plant and animal yields, vegetation cover and animal population, alteration of key plant and animal species distribution and frequency, and failure of animal and plant species to successfully reproduce. The social and economic indicators are change in land and water use, settlement pattern, increased conflicts between groups or tribes, marginalization, migration, decrease in income, assets, change in relative dependence on cash crops and subsistence crops, and the associated need for outside help (relief aid) or for seeking haven elsewhere (environmental refugees) as occurred in Niger Republic in 2005.

2.7.1 Characteristics of Acacias

The Acacias are trees, medium sized to gigantic or erect shrubs. They are very rarely herbs. A few are scandent shrubs or woody climbers like *A. lujae* De Willd., *A. kamerunensis* Gandoger, *A. ciliolate* Brenan and Exell and *A. tortilis*. *Acacia galpinii* reaches 71 m high and 26 m girth at breast height with a crown diameter of about 60 m in north-western Transvaal, South Africa (Sanusi, 1992).

Most of the African species are dry season deciduous as are some of the American species. The notable exception in Africa is *Faidherbia albida* (*Acacia albida*) which loses all its leaves during the rains but retains them and also produces pods during the dry season. In Central America, several *Acacia species* flower during a short part of the dry season and after pollination, the inflorescences are retained with very small pods throughout the following rainy season (Janzen, 1974). The ant-acacias are evergreen or produce leaves throughout the year.

2.7.2 Armature

The stems and branches of acacias are either armed or unarmed. The armature may be spines or prickles. Whereas a spine is a sharply pointed, hardened and modified stipule with a vascular supply, a prickle is only an epidermal outgrow, which lacks a vascular supply. They are also known as spinescent stipules (stipular spines) or non-spinescent stipules respectively.

The very long spines of some African acacias such as *Acacia karoo* Hayne, which measured 17-18 cm long, may have some protective function against grazing and also limit their use as forage. Notwithstanding the armature, browsers like elephants and camels readily feed on them without much hindrance.

2.7.3 Phenology

Many species have a well defined phenology reflected in phases of leafing, flowering, fruiting and seeding. These phenomena are seasonally correlated with temperature, moisture regimes or day length. In general, they are deciduous during the dry season, either regularly or irregularly but Australian members of series phyllodinae are typical evergreen (Davies, 1976).

2.7.4 Flowers and inflorescences

Acacia flowers are small and largely pentamerous. Tetramerous flowers also occur in some phyllodineous members (Sanusi, 1992). They are bisexual or mixed with unisexual one. The ovary is unilocular. The sweet scented flowers are usually bright yellow but yellowish-white flowers characterize *Acacia borrida* (L) Willd. *A. gerrarsii* Benth and *A. adenocalyx* Brenan and Exell. However, *Acacia galpidii* Burtt Davy and *Acacia persiciflora* Pax have red or purplish flowers. Insects as well as nectar seeking birds commonly pollinate acacias. The inflorescences are axillary (solitary or fascicled), racemose or paniculate at the end of the branchlets with the flowers in spikes, spiciform racemes (spicate) or round heads (capitate) (Sanusi, 1992).

2.7.5 Foliage

The genus Acacia shows variable foliage. Some have soft and feathery leaves or are foliferious, while others have the leaves modified into phyllodes. These may be further reduced to small whorled thorns in many arid or semi arid zone species. The adult leaves in foliferous species are bi-pinnately compound or consist of a variable number of paired leaflets (pennules) arising from a number of pinna pairs arranged along a central rachis. This foliar type is characteristic of species in the series Gummiferae, vulgares of

Bentham and the American series Filicinae. Only Australian members in the series Pulchellae and Botryocephalae are foliferous (New, 1984).

All the African acacias are foliferous in which pubescence, number of pinna and leaflet pairs as well as leaflet size and shapes are of taxonomic significance. Some African species in addition to primary leaves also produce secondaries (Ross, 1979). The two types differ in size, the primaries are usually larger and they sometimes have more pinna pairs. Whereas the primaries occur singly at the nodes on actively growing branchlets and coppice shoots, secondary leaves are fascicular and arise from dwarf lateral shoots at the nodes. This facility is probably an adaptation to enable the plant to develop new leaves, particularly in unfavourable seasons without having to draw on limited resources in developing branchlets to carry primary leaves (Sanusi, 1992).

2.7.6 Fruit

The fruit of Acacias are monocarpellary two-halved dry legume or pod. However, Acacia pod shows considerable variation in form or shape (linear, falcate, crescentic, flattened, variously contorted, continuous or constricted between seeds), texture is membranous, leathery or woody while the surface adornment is smooth, hairy or glandular between species.

In general, Acacia pods lack special seed dispersal mechanisms and the seeds posses external or seed coat dormancy. Seed dispersal is usually initiated naturally by gravity or propulsion from drying dehiscent pods. However, since the seeds are heavy, they are dropped not far away from the parent trees. Water may transport seeds over short distance in dry stream habitats. Browsing animals and birds are the most important dispersal agents, for wider distribution of acacias, the latter especially important for the attractively coloured arillate seeds of some species in Central America and Australia (Janzen, 1974; Ashton, 1979). Wildlife, especially elephants and antelopes, and livestock in Africa play a major role in seed dispersal. These animals also facilitate germination by their enzymes acting as an adequate pretreatment for the otherwise dormant seeds. For example, Wickens (1969) was of the opinion that livestock can disperse *Faidherbia albida (Acacia albida)* some 150 km from the source in the Sudan. In addition, stable deer fed on *Faidherbia albida* but defaecated sixty-five percent of the seeds in germinable condition (Radwanshi and Wickens, 1967).

2.7.7 Uses of Acacias

Few plant genera have been utilized by man in such broad contexts as has Acacia. Many of these uses are of considerable antiquity (Sanusi, 1992). The Ark of the Tabernacle in the Bible (Exodus 25:8-10) was ordained to be made of "Shitim" wood, the Hebrew word for acacia. Although, the exact species is not known with certainty, *Faidherbia albida*, *Acacia nilotica A. seyal* and *A. tortilis* are leading contenders which could provide timber of suitable lengths for construction (Ross, 1979). Flour from *A. aneura* F.V. Mueller ex Bentham seeds is used by the Aborigines in Australia for nourishment and Hottentots in Africa have been known to survive on acacia gum for several days. Acacia species were also known and used by the ancient Egyptians to prepare mummies using *A. senegal*. *A. nilotica* wood was an important timber, its flower heads infunerary garlands and the wood to clamp shut mummy coffins. Currently, acacias are used for multiple purposes such as tannin, forage, gum, wood, etc. which are of considerable ecological and socio-economic importance (Sanusi, 1992).

2.8 Taxonomy and nomenclature of *Acacia senegal* (L) Wild

Kingdom:	Plantae
Sub-kingdom:	Tracheobionta
Super-division:	Spermatophyta
Division:	Magnoliophyta
Sub-class:	Rosidae
Order:	Fabales
Family:	Fabaceae
Sub-family:	Mimosoideae
Genus:	Acacia
Species:	*Acacia senegal*
Synonyms:	*Acacia circummarginata* Chiov.; *A. oxyosprion* Chiov.; *A. rostrata* Sim.; *A. rupestris* Stocks ex Boiss.; *A. spinosa* Marloth & Engl.; *A. verek* Guill. & Perr.; *A. volkii* Suesseng.; *Mimosa senegal* L.; *M. senegalensis* Houtt.
Variety:	*Acacia senegal* var. ***rostrata*** Brenan; *A. senegal* var. ***kerensis*** Schweinf.; *A. senegal* var. ***leiorhachis*** Brenan; *A. senegal* var. ***senegal***.

Vernacular/common names: Three-thorned acacia; gum arabic tree (Eng.); gommier blanc, verek (Fr.); gummibaum (Ger.); goma arábica (Sp.).

Acacia senegal is a multipurpose African tree. It is highly valued for its gum arabic production but plays a secondary role in agricultural systems, restoring soil fertility and providing fuel and fodder (NFTA, 1994).

2.8.1 Botany and description of *Acacia senegal*

Acacia senegal is an important constituent of the natural vegetation of the Sudan and Sahel zones. It is a deciduous shrub or small tree, usually grows to 2-6 m high, occasionally reaching 10-20 m tall under very favourable conditions (NFTA, 1994; Le Houerous, 2000), with a flat to rounded crown. The tree has a short stem, usually low branched and many erect twigs spreading within the upright part. The bark is typically yellow or brown and smooth on younger trees, changing to dark grey, gnarled and cracked on older trees. The branchlets have thorns up to 5 mm long just below the nodes, the central one sharply curved downwards, while the other two are more or less straight and directed forward.

The leaves are small, grey-green, alternate and bipinnate. The pinnae occur in 6-20 pairs and leaflets small, 7-25 pairs, rigid, leathery, glabrous, linear or elliptic –oblong, ciliate on margins, pale grey-green and apex obtuse to subacute. The rachis sometimes has prickles. The flowers are very fragrant, creamy white (red in bud), usually appearing before the leaves in pedunculate spikes 3-10 cm long, either solitary or two to three together. The calyx is bell – shaped, glabrous, deeply toothed; corolla white to yellowish, fragrant, and sessile (Le Houerous, 2000). The pods are straight or slightly curved, retrap – shaped, 7 – 18 cm long by 2 cm wide, yellowish to brown, flat and thin, papery, attenuated at both ends, containing 3-6 flat, round light-brown to brown –greenish seeds and 8-12 mm in diameter. The pods are dehiscent (open by splitting at maturity). The tree flowers during the rainy season from April to October (Duke, 1983). Both the tap and lateral roots are well developed. The latter may spread many metres from the tree, particularly in sandy terrain (Le Houerous, 2000).

The tree is deciduous, dropping its leaves in November in the Sudan. It is drought resistant and tolerates dry periods of 8-11 months. The species prefers sandy soils, but grows well also on slightly loamy sand (Eisa *et al.*, 2008). It is highly suitable in agroforestry systems in combination with watermelon, millet, forage grasses and others. In the Sudan, it is grown in gum gardens for gum production as well as to restore soil fertility (Joker, 2000).

Plate 2.1: *Acacia senegal* plantation during the rainy season – September.

Plate 2.2: *Acacia senegal* plantation during the dry season - March

CHAPTER 3

3.0 Materials and methods

3.1 Study area

The study was carried out in Maifari Gum Arabic plantations in Maigateri Local Government Area of Jigawa State. The Maifari experimental plantation is located along Gumel - Mallam-Madori - Hadejia road and is about 35 km from Hadejia and 10 km from Mallam-Madori. The plantation was established in 1983 by the then Kano State Government before being taken over by Jigawa State Government after the State creation (Jigawa State Diary, 1999). The plantation covered an area of 20 ha with an espacement of 6 x 6 m between and within the rows.

Jigawa State lies between latitudes 11^0 and 13^0N and longitudes 8^0 and 10^0 E and covers a total land area of about 22,410 km^2 with a population of about 3.6 million (National Population Commission, 2006). The State is bordered on the west by Kano State and on the east by Bauchi and Yobe States and on the north by Katsina and Yobe States as well as Niger Republic (Wikipedia the free Encyclopedia, 2007a).

The State came into being on Tuesday 27^{th} August, 1991 when it was carved out of the former Kano State. Jigawa State, with its capital at Dutse, has twenty seven local government areas (Nigeria, 2005).

3.2 Geology and soils

The northwest and southern parts of the State are underlain by granites, schists, biotite and hornblende-bearing gneisses of the basement complex. The ancient Precambrian rocks of the basement complex are separated from the younger sediment of the Chad Formation by a hydrological divide, which runs through Kiyawa, Dutse and Yarkwa (Kowal and Knabe, 1972).

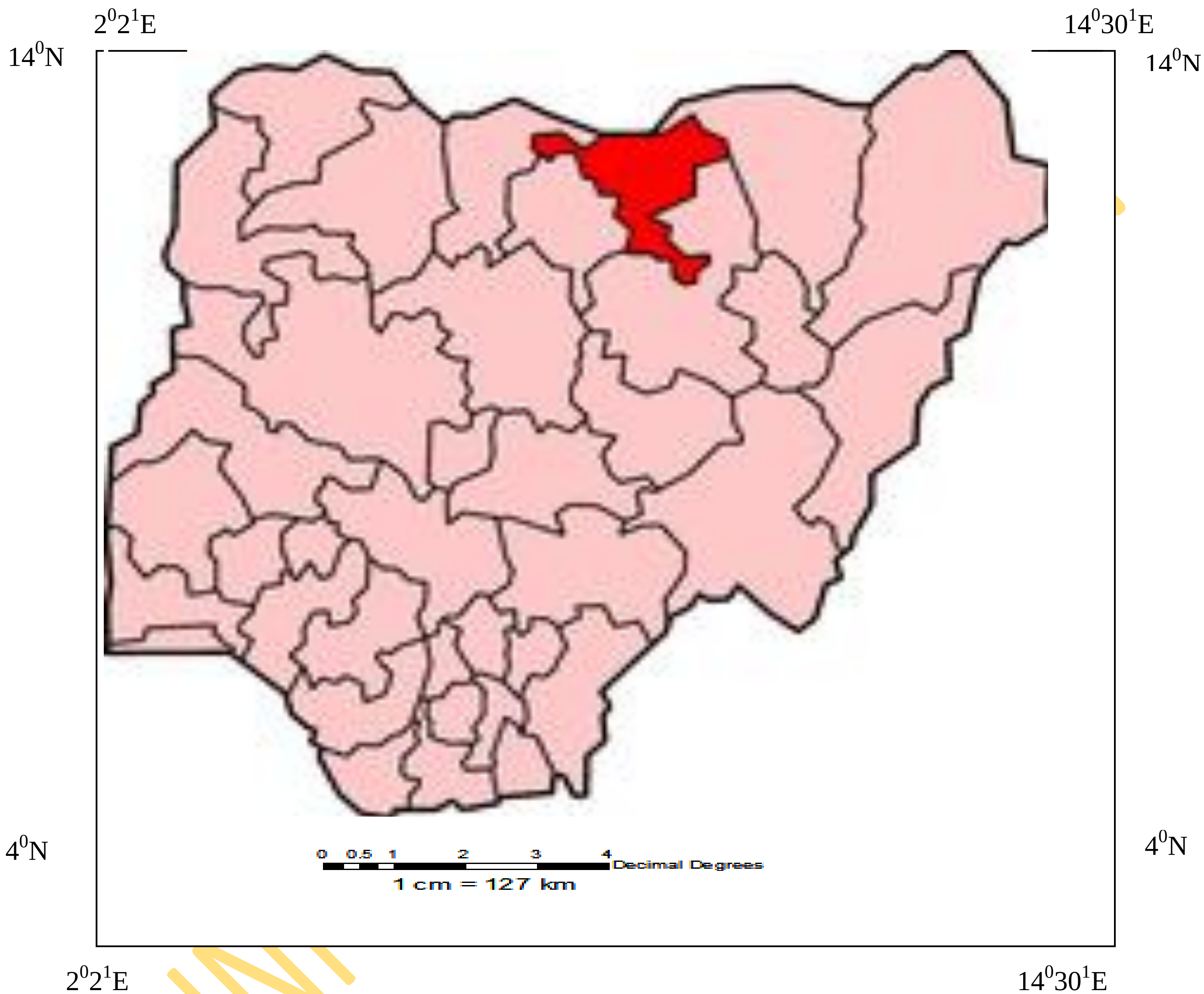

Fig. 3.1: Map of Nigeria showing the location of Jigawa State (in red colour).
Source: Wikipedia the free Encyclopedia (2007b).

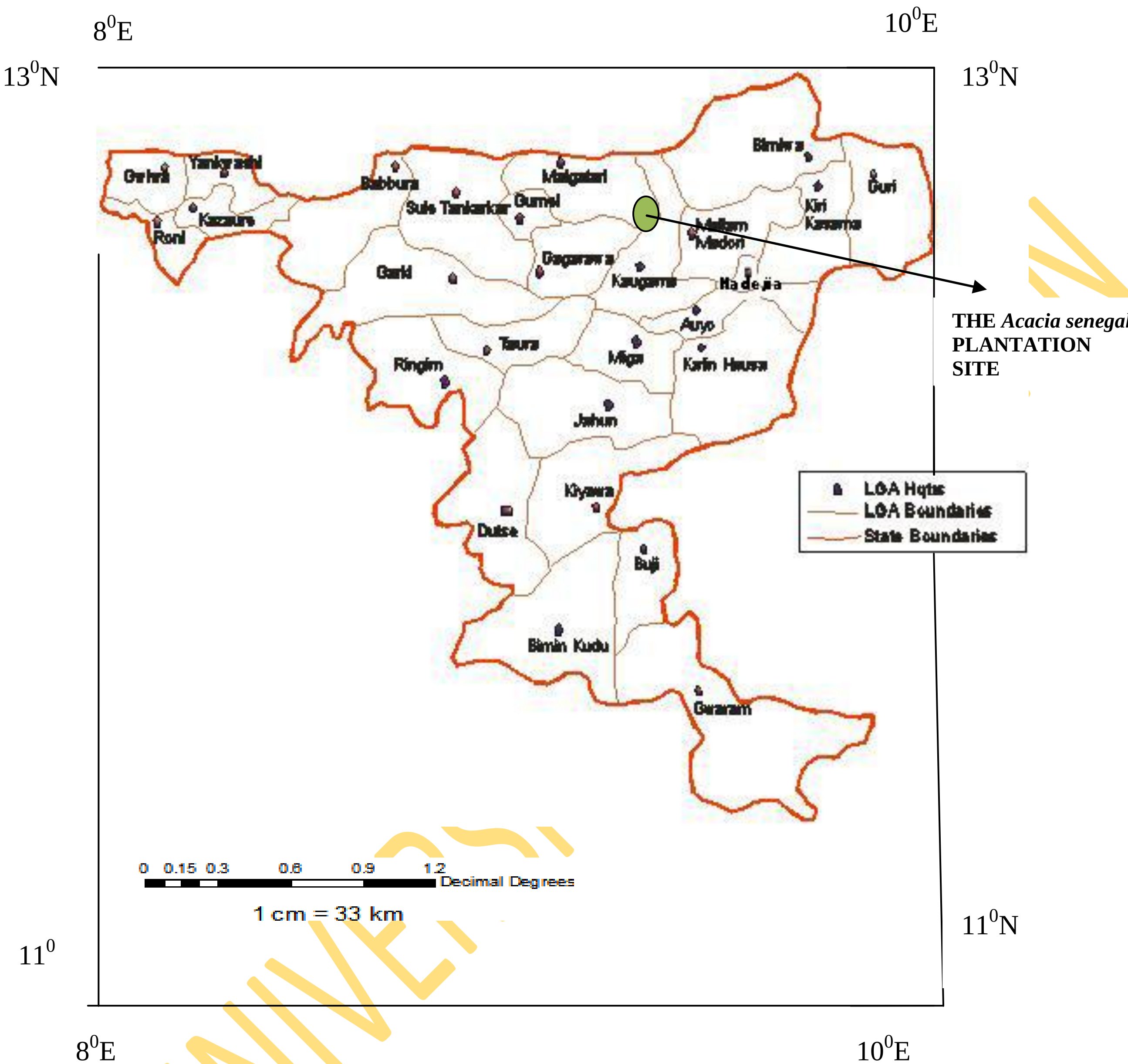

Fig. 3.2: Map of Jigawa State: Arrow showing the location of Maifari Gum Arabic plantations along Gumel – Mallam Madori – Hadejia road.
Source: Wikipedia the free Encyclopedia (2007a)

The Chad Formation occupies the northeastern parts of the State. However, the basement complex rocks have undergone weathering to give rise to fairly deep soils which are often covered by a sheet of laterite which has been exposed by denudation in some places.

The Chad sediments are concealed by sand dunes with no surface outcrops. The sandy beds formed over the impervious clays of the Chad Formation form the main source of water supply in the dry season. The soils are generally sandy at the top and compact at lower depths with hardpans.

Aeolian deposits from the Sahara desert form substantial part of soils in the State especially towards its northern parts. The mixing of the subsoil in these deposits has given rise to clayey subsoil, which dominates the northern parts of the State. The soils are generally low in organic matter, total nitrogen and available phosphorus (Sobulo, 1985).

3.3 Relief and drainage

The relief is generally undulating, but rock outcrops are common in areas of basement complex rocks. In the Southern part of the State, the elevation is about 500 - 600 m above sea level. Some of the hill formations in the areas underlain by these old hard rocks consist of lateritic-capped erosional survivals on deeply weathered soils. Surface outcrops are absent in the areas covered by sedimentary rocks of the Chad Formation and the elevation is usually below 400m above sea level (Iloeje, 2001). Any undulations in the relief of such areas consist of fossils, dunes, and dune ridges separated by depressions that contain water during the rainy season. Broad shallow valleys are characteristic of the crystalline rock areas where the riverbeds have huge rocks but the valley formation hardly exists (Iloeje, 2001; Eroarome, 2005).

The water of the Hadejia River meanders through numerous channels that constitute part of the Hadejia-Nguru wetlands. Many of the water channels dry up during the dry season, when water for domestic use is obtained by digging holes in the sand filled riverbeds. It is suspected that the construction of the Tiga and Challawa river dams in Kano State, have drastically reduced the flooding regime of the Hadejia river and water supply to Lake Chad.

3.4 Climate

The climate of Jigawa State is semi-arid, characterized by a long dry season of about 7-8 months and a short wet season of about 3-4 months (Iloeje, 2001). The climatic variables vary considerably over the year and are erratic. The temperature regime is warm to hot. The mean annual temperature is above 25^0C but the mean monthly values range between 21^0C in the coolest and 31^0C in the hottest month. However, the mean daily temperature could be as low as 20^0C during the months of December and January when the cold dry harmattan wind blows from the Sahara desert. The long dry or harmattan season which continues from November to mid-March usually has the morning of the day cool and misty, however the mist disappears after sunrise. The afternoons are full of haze due to dust in the air brought by winds from the Sahara desert. At this period of the year grasses die off and leaves of some trees turn brown and later fall (Oyenuga, 1967; Iloeje, 2001). Evapotranspiratrion is very high and relative humidity is highest in August (up to 80%) and low in January through March (23-30%) when it is moderated by the harmattan (Iloeje, 2001).

The year is characteristically well marked by dry and wet seasons. According to Eroarome (2005), wet season lasts roughly between three and four months (June -

September) and dry season spans seven to eight months (October - May). The rainy season may start in May, but early rains in April are not unusual. The bulk of the rainfall comes in June through September. Violent dust storms followed by tornadoes and lightening usually herald the onset of the rains in May /June and their retreat in September or early October.

The total annual rainfall ranges from 600 mm in the north to 1000 mm in the southern parts of the State. Great variations occur in the annual total rainfall and may result in severe and prolonged droughts which cause crop failures, death of livestock and overall human sorrow.

3.5 Vegetation

The ecological zone referred to in this study was primarily defined by species assemblages and annual rainfall. Most of the State falls within the Sudan savanna vegetation belt, but traces of Guinea savanna vegetation are found in parts of the southern districts. Extensive open grasslands, with few scattered stunted trees (4-9m) are characteristics of the vegetation, most of them fine leaved and thorny. The original vegetation has long since been removed, giving rise to farm parkland of vegetation. Due to annual cultural land clearing, almost all the original tree species were removed. As for most parts of the state, only few trees mostly of the Mimosoideae and Caesalpinioideae families existed. The grass species found in the state are the quick growing annuals that reseed easily. The grass species found include *Cenchrus species, Schoenefeldia gracillis, Aristida and Loudetia species, Andropogon gayanus and Andropogon pseudapricus* (Onifade and Agishi, 1988).

The neem tree (*Azadirachta indica*), a native species of India and Burma has naturalized in the State to the extent of replacing the original native trees especially in towns and villages. Despite deforestation, there still exist remnants of former climatic climax vegetation in some sparsely settled districts, especially near water courses. *Acacia species* tend to be plentiful in such areas.

3.6 Ecological problems

The major ecological problems in Jigawa State are drought, desertification and the menace of soil and wind erosion. As the State is located in a relatively dry part of the country, the sparse vegetation renders the bare surface deposits very susceptible to erosion (Nigeria, 2005).

Gullies are rampant, resulting in soil removal from farmlands and the collapse of roads, bridges and other structures. Gullying is particularly a problem of Dutse Local Government Area where more than sixteen gully sites have been identified. However, the State government has embarked on a comprehensive programme to tackle the problems posed by gully erosion. Such programmes include massive afforestation, channelization and well planned land-use schemes (Nigeria, 2005).

3.7 Materials used during the field work

- Manual excavation tools (hoe, digger, shovel, axe and cutlass)
- Weighing balance for weighing stems, foliage, branches and root
- Haga altimeter for tree height measurements
- Diameter tape for measuring diameter of trees at dbh (1.3m)
- Distance tape
- 2 mm wire mesh for collecting litter fall

- Polythene bags
- Auger for collecting soil samples at different soil depths

3.7.1 Methods of data collection

Data were collected on the following variables: soil, biomass (above and below–ground), leaf litter, litter decomposition, roots, stem and foliage.

3.7.2 Plot selection and demarcation

A reconnaissance survey of the study area was carried out in July and August 2005 for the purpose of establishing the experimental plots.

The experimental site of 20 hectares consisted of *Acacia senegal* plantation with espacement of 6 x 6 m between and within rows and was established in 1983. Four plots of 30 x 30m size were randomly chosen within the plantation using a table of random numbers with the adjacent natural woodland of the same size selected as a control. In each plot, twenty five quadrats of 6 x 6m were established and three quadrats were randomly chosen using a table of random numbers. These three quadrats were used for the collection of soil samples, litter decomposition studies and destructive sampling.

3.7.3 Experimental design

The study was conducted using a randomized complete block design with three treatments and four replicates in the plantation and one in the adjacent natural woodland. Total area used for the study within the plantation was 0.36 hectares and 0.09 hectares in the natural woodland. The mathematical model for the randomized complete block design (RCBD) used is:

$Y_{ij} = U + B_i + T_j + e_{ij}$

Where

Y_{ij} = individual observation

U= General mean

B_i = Effect of ith block

T_j = Effect of the jth treatment

e_{ij} = experimental error (Akindele, 1996)

The Hypotheses:

Null hypothesis (Ho) = There is no significant difference in the effect of *Acacia senegal* leaf litter, mineralization and nutrient release on the nutrient status of the soil of the plantation.

Alternative hypothesis (Ha) = There is significant difference in the effect of *Acacia senegal* leaf litter, mineralization and nutrient release on the nutrient status of the soil of the plantation.

Null hypothesis (Ho) = There is no significant difference in the nutrient contribution of the tree components to the biomass nutrient pool.

Alternative hypothesis (Ha) = There is significant difference in the nutrient contribution of the tree components to the biomass nutrient pool.

3.8 Litterfall estimation

Leaf litter was collected from each plot using rectangular litter traps made of wooden frame (100 x 100 cm) with four legs, 15 cm high and screen bottom of 1 mm^2 mesh sizes. Each litter trap was set 15 cm above the ground level to avoid contact with the soil. The traps were located randomly in the plots but avoided the edges. A total of 12 traps were set in four plots. They were emptied monthly for six months during October, 2006 to March, 2007 and their contents air dried.

3.8.1 Litter decomposition and chemical analyses

Leaf litter decomposition rates and patterns of nutrient dynamics in decomposing litter were quantified using the litterbag technique. The litterbags (20 x 20 cm) were constructed using polyester mesh of 1 mm opening screen. Samples of bulked air dried litter of 100 g were taken and placed in each bag. The bags edges were sewn with fishing line and numbered. The bags were randomly placed on the floor of the plantation and pinned to avoid the displacement of the bags. A total of 24 bags were distributed randomly in July, 2007 at the rate of 6 bags per plot. Each month, 2 bags were randomly removed from each plot, cleaned, placed in polythene bags and transported to the laboratory. Litterbags were cut open and the contents were examined for extraneous materials such as macro-fauna, roots and soil which were none evident. The plant residues were placed in an envelope and dried at 70^0C. Oven-dried weights of the residues were recorded, ground to pass through 1 mm sieves and then analysed for N, P, K, Ca and Mg. The collection lasted for three months.

Nitrogen was estimated by semi- micro Kjeldahl procedure using selenium catalysts (Bremner, 1982). Phosphorous and cations (K, Ca and Mg) were determined after dry ashing. Phosphorous was determined colorimetrically and potassium by flame photometer. Calcium and magnesium were estimated by EDTA titration method using EBT and Pattern and Readers reagents as two indicators (Allen *et al.*, 1974).

3.8.2 Rate of litter decomposition

Annual decay rate constants were calculated from data on the percent mass remaining after litter decomposition, using a single negative exponential decay model below.

$$\frac{X}{Xo} = e-kt$$

Where Xo = the original weight of litter at the beginning of study.

X= the amount of litter remaining at a later time

e = the base of natural logarithms

t= the time that elapsed between Xo and X

K= the litter decomposition constant (Nwoboshi, 2000).

3.8.3 Soil sampling under decomposing litter

The soil of the floor where the litter bags were placed was sampled. A 20 x 20 cm wooden frame was used to demarcate the area where the decomposed litter bag was removed. The soil (0-15 cm depth) within the frame was collected, oven dried and weighed. This was then analyzed in the laboratory for N, P. K, Ca and Mg.

3.9. Soil sampling in the plantation and natural woodland

Soil samples were collected in July, 2007 at three randomly locations using an auger at the depths of 0-15 cm; 15-30 cm and 30-60 cm; from each of the three quadrats established within the experimental plots and the control. Therefore, fifteen quadrats were used and a total of 45 soil samples collected.

The soil samples were collected in polythene bags and transported to Jos where they were air-dried in the laboratory of the Federal College of Forestry, Jos for several days. Samples were gently crushed with porcelain pestle and mortar and sieved through a 2 mm sieve to remove coarse fragments. The fine soils separated were stored in polythene bags and taken to the Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria for laboratory analyses.

3.9.1 Particle size distribution

The particle size distribution was determined by using the hydrometer method (Gee and Baunder, 1986). Sand, silt and clay were determined by dispersing the soil samples in 5% calgon (sodium hexametaphosphate) solution. The sample was then shaken on a reciprocating shaker, after which particle size distribution was determined with the aid of the Bouyoucos hydrometer and the textural classes were determined with the aid of USDA textural triangle.

3.9.2 Bulk density

Core soil samples were taken from three randomly chosen points in three quadrats using 100 cm^3 metal cylinders from the centre of 0-15 cm depths for bulk density determination. The cores were oven-dried to constant weight at 105^0C for two days and expressed as mass of dry soil per unit volume of moist soil (Campbell and Henshall, 1991).

3.9.3 Chemical analysis

3.9.4 Soil pH

The soil pH was determined both in water and 0.01M $CaCl_2$ solution using a soil solution ratio of 1:2.5 (11TA, 1979). On equilibration pH was read with a glass electrode on a Pye Unicam model 290mk pH meter. Delta pH (dpH) values were determined as follows:

dpH=pH ($CaCl_2$)- pH (H_20).

3.9.5 Cation exchange capacity (CEC)

Cation exchange capacity of the soil was determined with 1M NH_4OAC (1M ammonium acetate) buffered at pH 7.0 (Chapman, 1965; Rhoades, 1982). The excess acetate was removed by repeated washing with alcohol. The absorbed ammonium ions were displaced with 10% sodium chloride (pH 2.5) and determined by Kjeldahl procedure (Soil Survey Staff, 1972). Cation exchange capacity of the clay fraction was estimated following Sombroek and Zonneveld (1971) as follows:

$$CEC\ (Clay) = \frac{CEC\ (soil - 3.5 \times \%0.C}{\%\ clay} \quad X \quad \frac{100}{1}$$

3.9.6 Effective cation exchange capacity (ECEC)

ECEC was calculated from the summation of exchangeable bases determined by 1M NH_40Ac extraction and the exchange acidity by 1M KCl extraction (Anderson and Ingram, 1998).

ECEC (me/100g) = exch K* + exch Ca^{2+} + exch Mg^{2+}+ exch acidity ($A1^{3+}$ + H^{+}).

3.9.7 Organic carbon

The organic carbon content was determined by the wet oxidation method of Walkley and Black (1934) as described by Nelson and Summer (1982). The reaction was activated with the addition of concentrated sulphuric acid as a catalyst.

3.9.8 Total nitrogen

The total nitrogen content of the soil was determined using the micro-Kjeldahl digestion technique as described by Bremner (1982). Free ammonia liberated from the solution by steam distillation in the presence of 10m NaOH was collected. The distillate was then titrated with 0.1M $H_2\ S0_4$.

3.9.9 Available phosphorus

Available phosphorous was extracted using Bray No 2 method (Bray and Kurtz, 1945). Phosphorous in the extract was estimated colorimetrically by the molybdo-phosphoric- blue method using ascorbic acid as a reducing agent (Murphy and Riley, 1982; Anderson and Ingram, 1998).

3.9.10 Total sulphur

Total sulphur in the soil water was determined by the conversion of sulphur containing compounds into SO_4-S by oxidation as described by Agbenin (1995). The sulphur in the extract was turbidimetrically determined on a colorimeter at 470nm.

3.9.11 Extraction of micronutrients

Extractable Zn, Cu, Fe, Mn, B and S were extracted with 0.1M HCl solution (11TA, 1989). Five grammes of soil samples were shaken with 50 ml 0.1M HCl for 30 minutes on a shaker. The mixtures were centrifuged and analyzed directly for Zn, Cu, Fe, Mn, B and S with atomic absorption spectrophotometer (AAS).

3.10 Above and below ground biomass estimation

In the four selected experimental plots, all trees within each plot were numbered with blue paint. The trees were measured for heights with Haga altimeter and diameter at breast height (1.3m dbh) using the diameter tape. These measurements were used for calculating the tree stand density, basal area, and biomass.

3.10.1 Stand density

The density of *Acacia senegal* per hectare (0.09 ha) was calculated using the espacement of 6 x 6 m.

Area per tree = (6 x 6) m^2

$$= 36 \text{ m}^2$$

$$\text{Density per hectare} = \frac{100 \text{ x } 100}{36}$$

$$= 277.78 \text{ trees}$$

$$\text{Density per 0.09 ha} = \frac{30 \text{ x } 30}{6 \text{ x } 6}$$

$$= 25 \text{ trees per plot}$$

3.10.2 Basal area determination

Basal area determination was achieved by summing up the values (diameter at breast height and total height measurements) for every individual tree within each plot using the formula B.A. = $0.7854D^2$. Where:

B.A. = Basal Area

D = Diameter at breast height (dbh).

Stand basal area was calculated in m^2/ha and the result obtained extrapolated to hectare of land.

3.10.3 Selection of sample trees for destructive sampling

The trees measured in the four plots were grouped into two diameter classes and the tree closet to the mean tree of each diameter class was selected for destructive sampling. The total number of trees selected was eight.

3.10.4 Destructive sampling

Each sample tree was felled and the stump height measured, after which the roots were excavated using hoe, digger, spade, axe and cutlass. The roots were traced to the last point of exposure before digging started. The trees were bucked into sections and weighed *in-situ*.

The individual tree weight and weights of various components (foliage, live branches, stem and roots) were regressed against the independent variables visa: dbh, height and $(dbh)^2$ x h using an allometric model of the form LnY = a + b x LnX. Where Y = Total weight of trees (stem weight, root weight, live branch weight and leaf weight) on independent variable (X):d^2h

h= Tree heights

d= Tree diameter $\sum d^2$= the sum of the square of all diameters of the stems.

A and b are regression coefficients for *Acacia senegal* plantation.

Plate 3.1: Excavation of the roots of an *Acacia senegal* tree in one of the plots in the plantation

Plate 3.2: Excavation of the roots of an *Acacia senegal* tree in one of the plots in the plantation

3.10.5 Foliage, stem and branch analyses

The aim here was to determine the total nutrient content of the above ground parts of the plant. Two trees selected from the diameter classes were used. The foliage was carefully collected, weighed fresh in the field and sub samples of 100g taken. The sub samples were oven dried at 70^0C and kept for chemical analysis of N, P, K, Ca and Mg. The same method was used for stem and branch.

3.10.6 Root analysis

The lateral and tap roots of plants that were used for chemical analysis in the four experimental plots were dug up carefully. Dead roots were discarded while live roots were carefully cleaned from adhered soil and weighed fresh in the field. Sub – samples (150 g) were oven-dried at 70^0C and analysed in the laboratory for N, P, K, Ca and Mg elements

Plate 3.3: Determination of the fresh weight of the foliage of *Acacia senegal* tree using weighing balance.

Plate 3.4: Determination of the fresh weight of the stem of *Acacia senegal* tree using weighing balance.

3.10.7 Statistical analyses of field data

Field and laboratory data generated were subjected to analysis of variance (ANOVA). Differences in mean values were tested at 0.05 level of significance with analysis of variance and Duncan's multiple range tests (DMRTs). Regression and correlation techniques were used to determine various relationships between soil depth and soil variables and also among other variables.

CHAPTER 4

4.0 Results

This Chapter presents the outcome of data analyses which were carried out in line with the objectives and aims of the research. The results obtained are presented in form of tables and figures.

4.1 Soil physical properties

The soil physical characteristics which were considered for the study include soil texture, particle size distribution and bulk density.

4.2 Soil texture and particle size distribution

The general soil texture of the plantation is loamy sand. However, under the open woodland used as the control, the soil had a slight textural differentiation. The texture of the soil is sandy, especially at the top soil (0-15 depth). Data obtained on particle size distribution at different soil depths are presented in Table 4.1.

Table 4.1: Mean soil physical properties at different depths under *Acacia senegal* plantation and natural woodland at Maifari, Jigawa State

Plot	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (kg)	Textural Class
1	0-15	853	100	47	Loamy sand
	15-30	860	80	60	Loamy sand
	30-60	840	73	87	Loamy sand
2	0-15	847	107	47	Loamy sand
	15-30	873	73	53	Loamy sand
	30-60	847	87	67	Loamy sand
3	0-15	833	147	20	Loamy sand
	15-30	847	100	53	Loamy sand
	30-60	853	93	53	Loamy sand
4.	0-15	867	100	33	Loamy sand
	15-30	827	107	67	Loamy sand
	30-60	840	67	93	Loamy sand
Natural woodland (Control)	0-15	887	87	27	Sand
	15-30	867	87	47	Loamy sand
	30-60	873	73	53	Loamy sand

The mean percentage sand of the plantation topsoil (0-15cm) and the natural woodland (control) ranged from 833 to 887g/kg. Plot 3 had the least sand content of 833 g/kg, while the control had the highest value of 887 g/kg.

The sand distribution at 15-30cm soil depth in all the plots and the control was high in plots 1 and 2, (860 g/kg) and (873 g/kg) respectively but dropped in plots 3 (847 g/kg) and 4 (827 g/kg) before rising again in the control to 867 g/kg. Nevertheless, the mean value at this depth: 15-30cm (855 g/kg) was slightly less than at the topsoil (857 g/kg).

The sand content at 30-60cm increased across the plots and the control varying from 84.0 to 873 g/kg, with an overall mean of 851 g/kg. However, the sand content decreased with increasing soil depth from 857 g/kg at the topsoil to 851 g/kg at 30-60 cm (Figure 4.1).

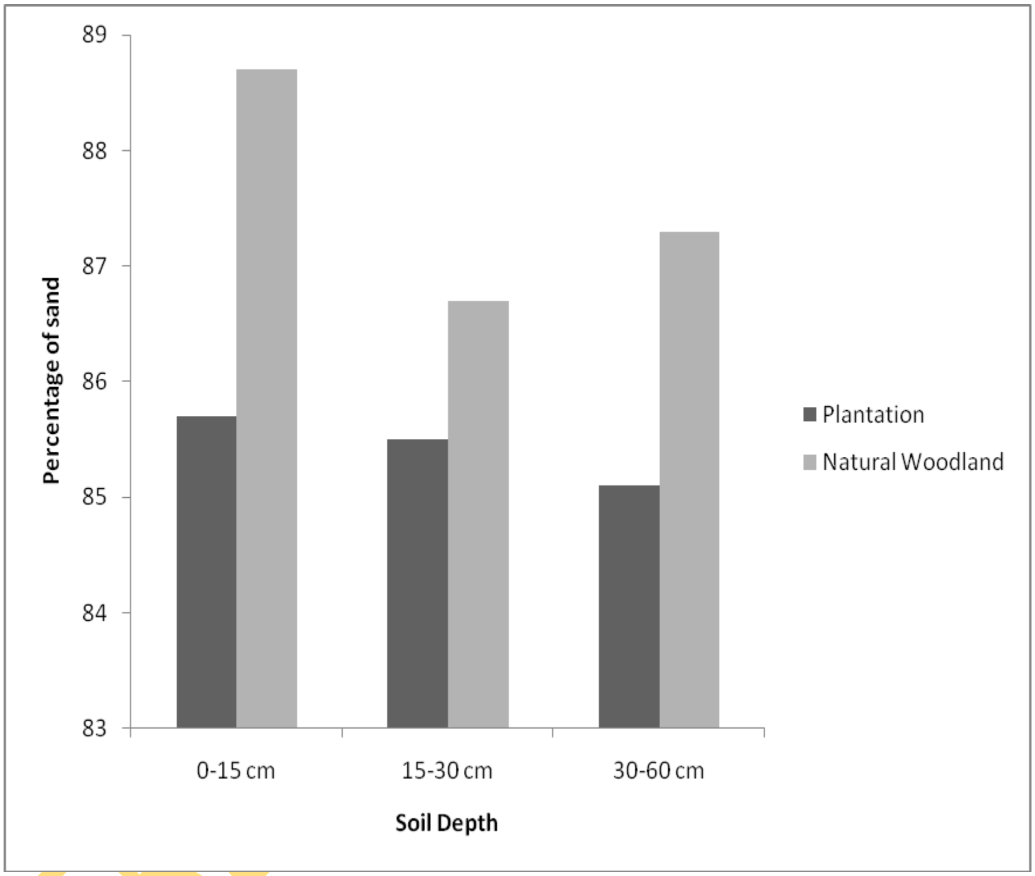

Fig. 4.1: Mean values of sand contents at different soil depths under *A. senegal* plantation and natural woodland

The silt content of the top 0-15cm in all plots and the control ranged from 87 to 147 g/kg. There was a slight increase from plots 1 to 3, and a slight drop in plot 4 with the control plot having the least value of 87 g/kg.

The silt content at 15-30cm soil depth was lowest (73 g/kg) in plot 2 but the same in Plot 1 (100 g/kg) and 3 (100 g/kg) with a slight increase in plot 4 (107 g/kg). The control plot had a value of 87 g/kg while; the mean value at this depth was 89 g/kg which was less compared to 100 g/kg at 0-15cm depth.

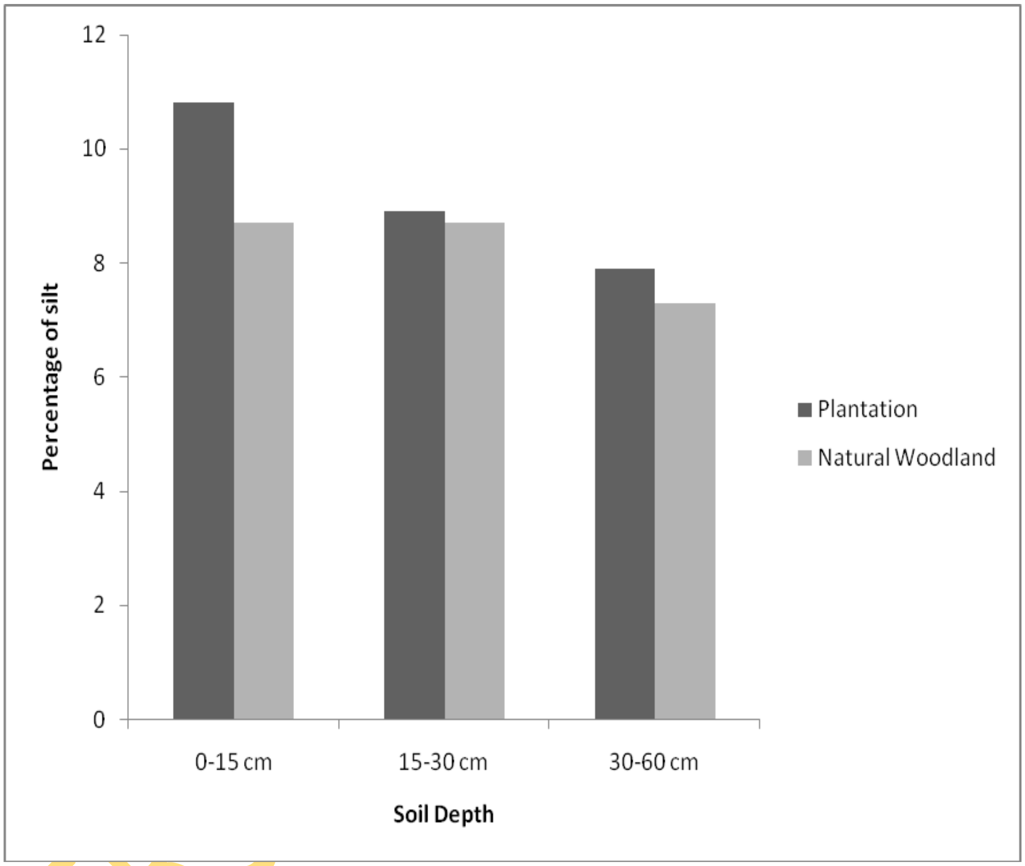

Fig. 4.2: Mean values of silt content at different soil depths under *A. senegal* plantation and natural woodland

There were fluctuations in values of silt content at 30-60cm soil depth across the plots and control. The values ranged from 67 at plot 4 to 93 g/kg at plot 3, increasing from plots 1 to 3 before decreasing sharply at plot 4 and the control, while its mean value was 79 g/kg. However, there was a general decrease of silt down the soil depth (Figure 4.2).

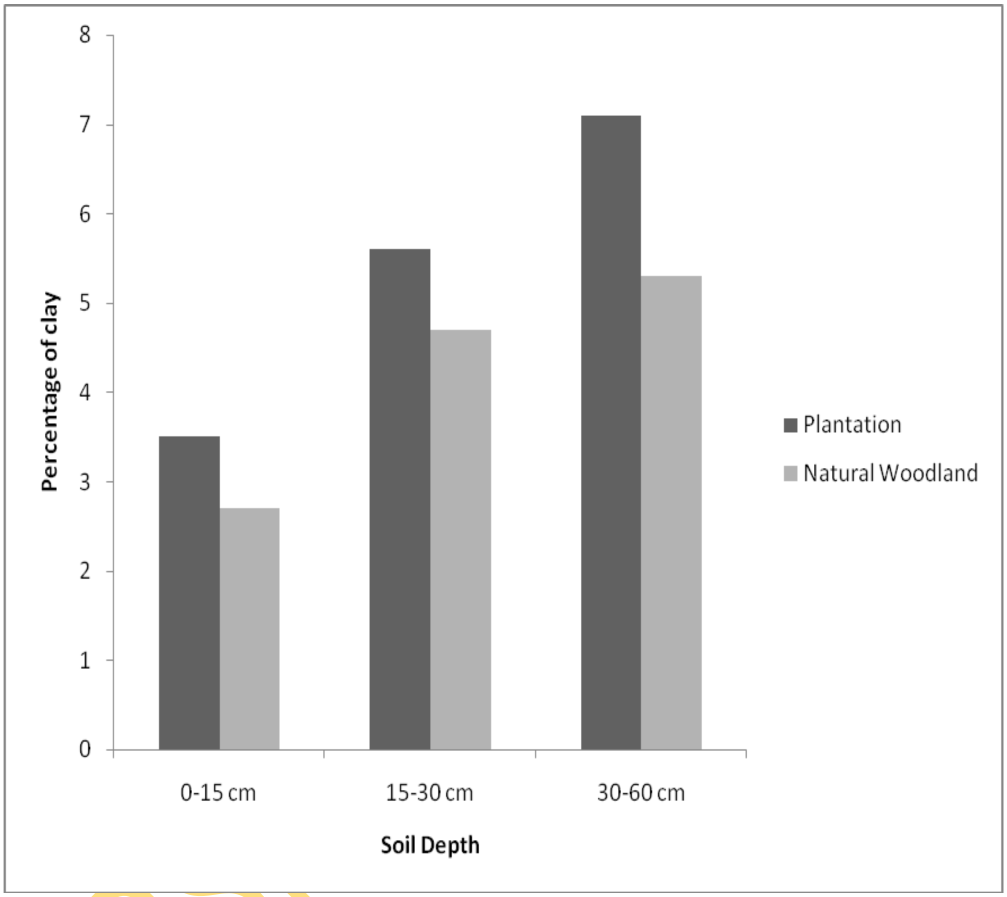

Fig. 4.3: Mean values of clay content at different soil depths under *A. senegal* plantation and natural woodland

The mean percentage clay content at the top 0-15cm in plots 1 to 4 and the control generally decreased with plots, except in plot 4 where the value was slightly higher (33 g/kg) and plot 3 having the least value of 20 g/kg. The clay content increased with soil depth (Figure 4.3 and Table 4.4).

The proportions of clay at 15-30cm soil depth showed a decrease in mean values from plot 1 to the control, except for plot 4 (67 g/kg) which had a rise in value. The values of the clay varied from 47 to 67 g/kg, and the mean value of 89 g/kg was lower, compared to 108 g/kg at the 0-15cm soil depth.

The clay content at 30-60cm on the other hand showed significant decrease, varying from 53 to 93 g/kg across the plots and control except for plot 4 where it rose to 93 g/kg. The mean value for clay at this depth was 71 g/kg., which is higher than clay values at the two other soil depths. The analysis of variance showed a highly significant difference in silt and clay contents along the soil depth. The result showed that the clay content increased with increasing soil depth.

4.3 Bulk Density

The mean values of soil bulk density under the *Acacia senegal* plantation are presented in Table 4.2.

Table 4.2: Mean, standard deviation and standard error of mean of soil bulk density under *Acacia senegal* plantation and natural woodland

Treatment	Mean (g/cm^3)	Std. Deviation	Std. Error of Mean
Plot 1	1.6	.051	.026
Plot 2	1.6	.061	.035
Plot 3	1.7	.053	.031
Plot 4	1.6	.021	.012
Woodland (Control)	1.8	.056	.032

Table 4.3: ANOVA result for the mean soil bulk density of *Acacia senegal* plantation and natural woodland

Parameter	Df	MS	F	P-level
Plot	4	.021	8.532	0.003*
Error	10	.002		

* = Significant

The mean soil bulk density ranged from 1.6g/cm^3 in plot 1 to 1.8 g/cm^3 in the control (natural woodland). It was observed that the mean values increased progressively from plot 1 to the control except for plot 4 where it dropped to 1.6 g/cm^3. The results of analysis of variance indicated a positively high significant value, $P < 0.05$ (Table 4.3).

Table 4.4: Soil physical and chemical properties as influenced by soil depth under *Acacia senegal* plantation in Jigawa State

Soil Depth	Clay	Silt	Sand	pH H_2O	pH ($CaCl_2$)	OC	TN	C:N	AP	Ca	Mg	K	Na	BS	S	Al	ECEC	CEC
0-15cm	3.467a	10.800b	85.733a	5.947c	5.553c	0.352b	0.086a	11.227b	5.251b	3.787b	0.280a	0.177b	0.114a	0.727b	4.451b	0.267a	4.626b	5.967a
15-30cm	5.600b	8.933a	85.467a	5.160b	4.553b	0.127a	0.035a	4.915a	3.327a	2.886a	0.473b	0.107a	0.116a	0.649a	0.946a	0.440b	4.020ab	5.567a
30-60cm	7.067c	7.867a	85.067a	4.713a	4.233a	0.075a	0.025a	3.465a	3.209a	2.377a	0.716c	0.089a	0.145b	0.575a	1.209a	0.600c	3.928a	5.773a

Mean values with the same letters are not significantly different at 5% probability level by DMRT

Table 4.5: Soil physical and chemical properties as influenced by plot under *Acacia senegal* plantation in Jigawa State

Plot	Clay	Silt	Sand	pH H_2O	pH ($CaCl_2$)	OC	TN	C:N	AP	Ca	Mg	K	Na	BS	S	Al	ECEC	CEC
1	6.444b	8.444a	85.111a	5.567c	4.822b	0.207ab	0.127b	3.341a	2.139a	2.231a	0.292a	0.088a	0.106a	0.630b	2.147ab	0.467a	3.183a	4.344a
2	5.556ab	8.889a	85.556a	5.189b	4.800b	0.1889ab	0.029a	7.977ab	3.891b	2.680a	0.540b	0.138b	0.102a	0.638b	2.118ab	0.333a	3.793a	5.478b
3	4.222a	11.333b	84.444a	5.500bc	5.111b	0.253b	0.027a	9.772b	3.988b	3.874b	0.660c	0.139b	0.111a	0.770c	2.884b	0.333a	5.117b	6.167bc
4	6.444b	9.111a	84.444a	5.378bc	4.844b	0.162ab	0.035a	5.236ab	4.473bc	3.809b	0.611bc	0.134b	0.148b	0.700bc	2.151ab	0.356a	5.058b	6.822c
Control	4.222a	8.222a	85.556b	4.733a	4.322a	0.111a	0.026a	6.354ab	5.154c	2.489a	0.346a	0.123b	0.159b	0.516a	1.710a	0.689b	3.806a	6.033bc

Mean values with the same letters are not significantly different at 5% probability level by DMRT

4.4 Soil chemical properties

4.5 Soil pH

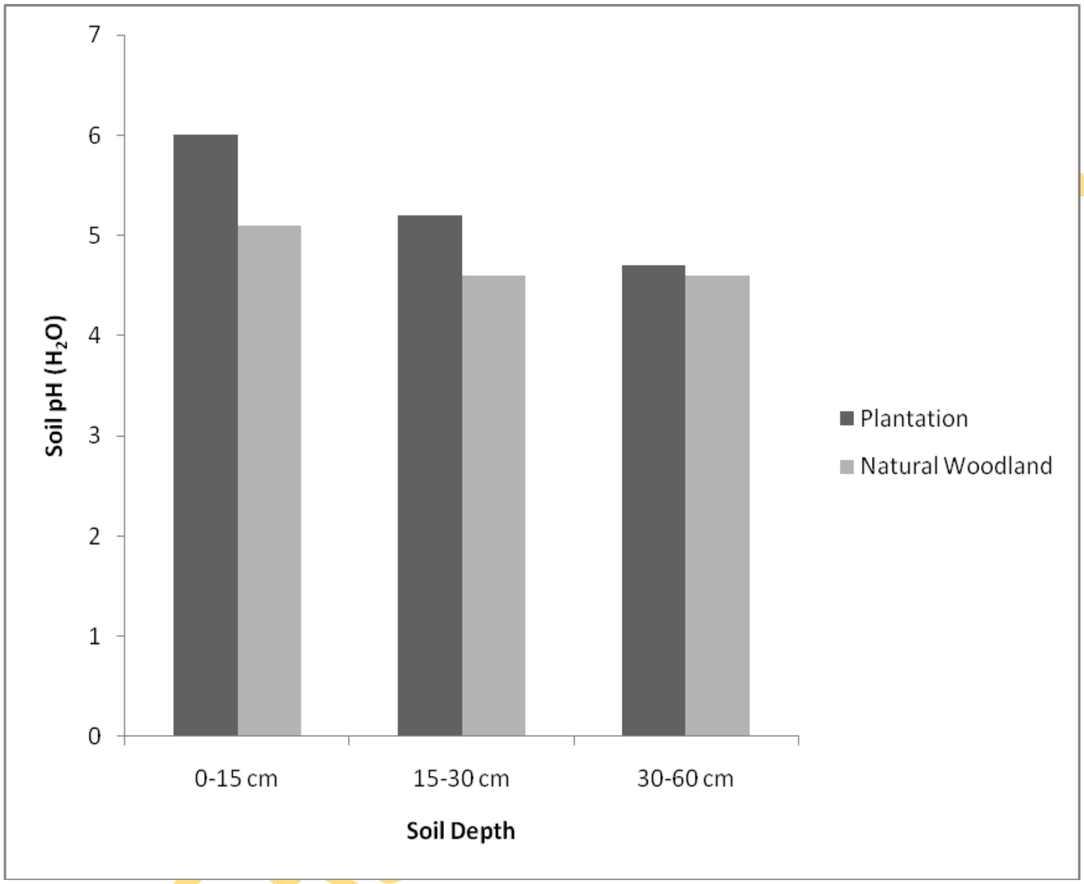

Fig. 4.4: Variation in pH (H_2O) at different soil depths under *A. senegal* plantation and natural woodland

The results (Figure 4.4) obtained for the mean values for pH (H_20) for the plots and control ranged from 4.5 (30-60cm) to 6.4 (0-15cm), while for pH ($CaCl_2$) ranged from 4.0 (30-60cm) to 6.0 (0-15cm). The results revealed that the soils were strongly to moderately acidic.

. The general distribution trend was a decrease from the top (0-15cm) to the lower soil depth (30-60cm) for both pH (Figures 4.4 and 4.5).

The results of analysis of variance tests for pH (H_20) indicated significant differences at different soil depths, while, across the plots, there was no significant difference at p= 0.05. Also, for the pH ($CaCl_2$), there were significant differences among soil depths but not across plots.

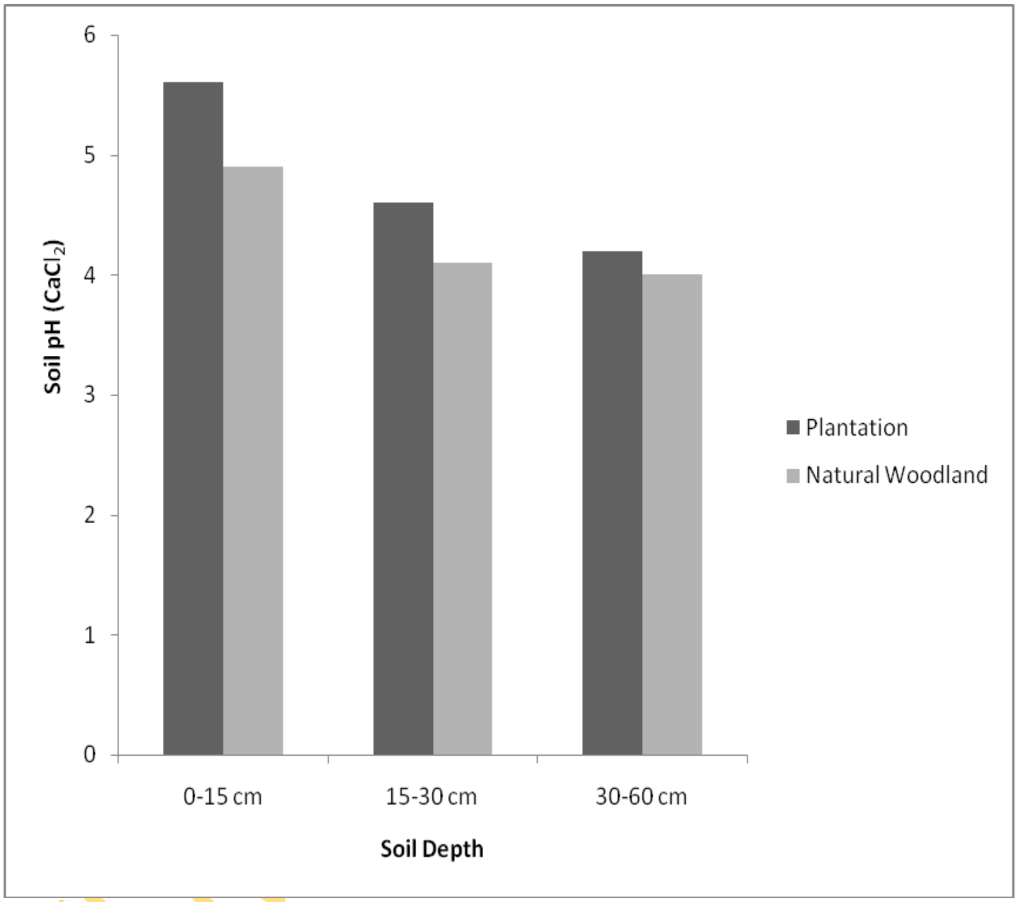

Fig. 4.5: Variation in pH ($CaCl_2$) at different soil depths under *A. senegal* plantation and natural woodland

4.6 Organic Carbon

The organic carbon (OC) contents in the treatments (soil depths) and across the plots were generally low. The results showed that the organic content of the top 0-15cm was 0.35%, while at 15-30cm it was 0.13%, and at 30-60cm it was 0.07% (Figure 4.6). Across the plots, the mean percentage organic carbon content in plot 1 at 0-15cm was 0.39%, 15-30cm 0.15%; plot 2 at 0-15cm 0.35%; 15-30cm 0.11% and 30-60cm 0.39%. In plot 3, the mean value at 0-15 was 0.48%; 15-30cm 0.19% and 30-60cm 0.09%, while in plot 4 at 0-15cm it was 0.34%; while at 15-30cm it was 0.09% and at 30-60cm it was 0.05%.

In the control, the organic carbon values were lower than in those of other plots, ranging from 0.20% (0-15cm); 0.09% (15-30cm) to 0.04% (30-60cm). However, the values decreased with soil depth (Table 4.4). The analysis of variance obtained showed that there were no significant differences in the mean proportional values among the treatments (soil depth) and the plots.

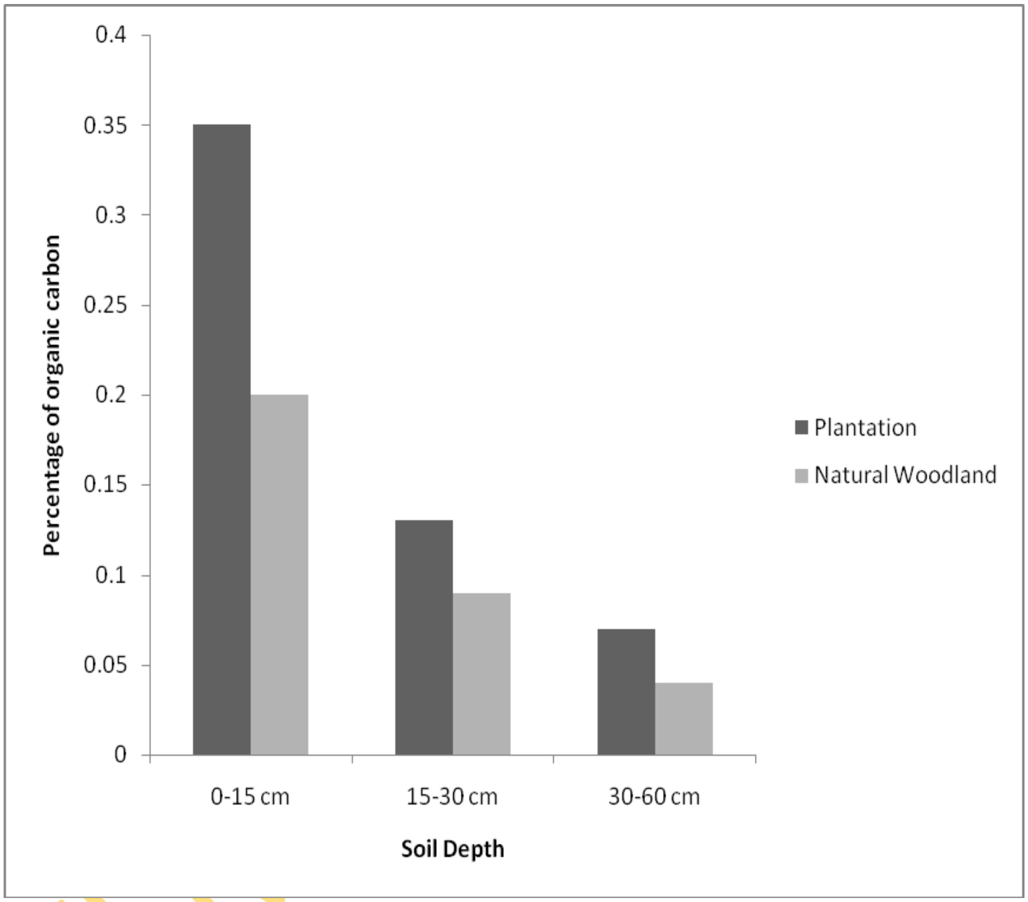

Fig. 4.6: Mean values of Organic Carbon content at different soil depths under *A. senegal* plantation and natural woodland

4.7 Total Nitrogen

The total nitrogen (TN) content of the soil was generally low ranging from 0.09 to 0.04 cmol/g with increasing soil depth (Figure 4.7), while across the five plots it varied from 0.03 to 0.14 cmol/g (Table 4.5). The results showed that total nitrogen decreased with increasing soil depth in the plantation while in the natural woodland both soil depths 0-15cm and 15-30cm had the same values, but there were no significant variations at P = 0.05.

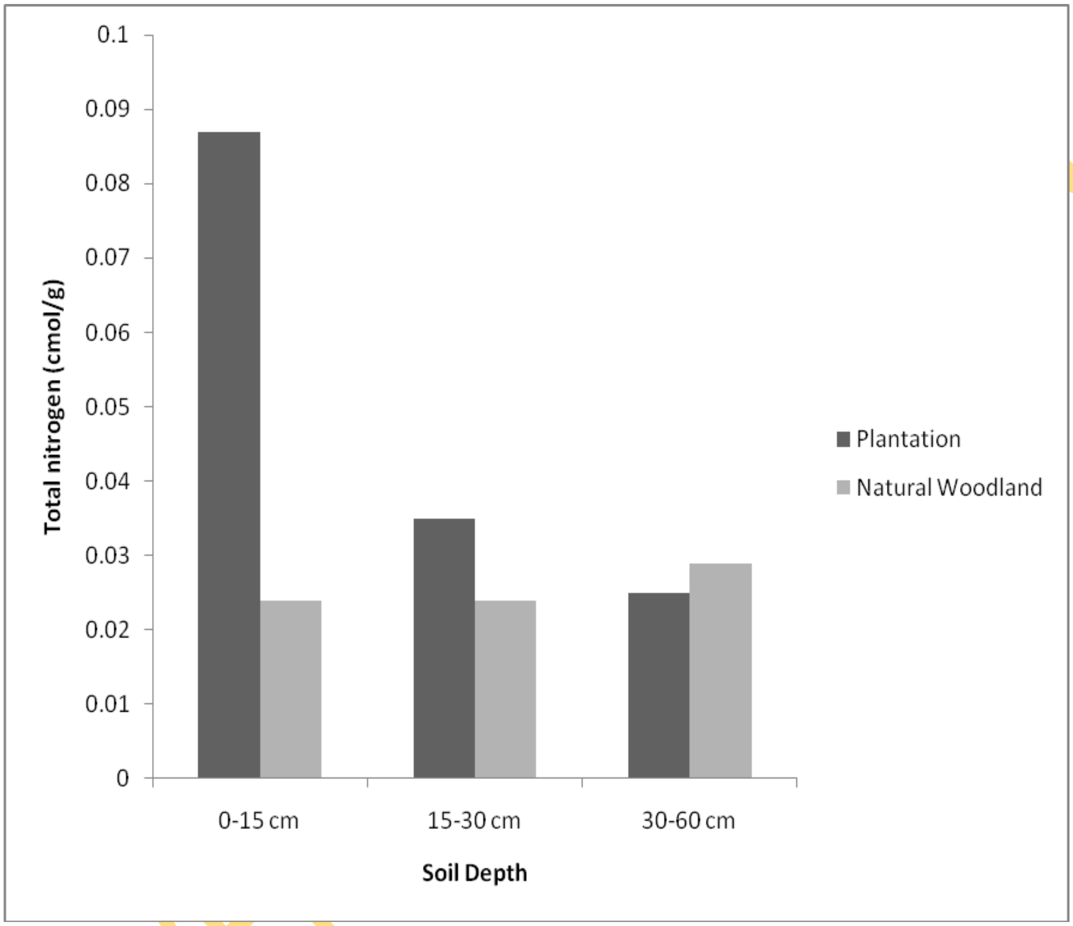

Fig. 4.7: Mean values of Total Nitrogen at different soil depths under *A. senegal* plantation and natural woodland

4.8 Carbon-Nitrogen ratio

The carbon-nitrogen ratio (C/N) is shown in Table 4.4. The mean values ranged from 3.5 to 11.2 along the soil depths, while across the plots 1 to 4 and control it ranged from 3.3 to 9.8 (Table 4.5). The results showed that carbon-nitrogen in the plantation and natural woodland decreased with increasing soil depth (Figure 4.8).

The analysis of variance showed that differences in the C/N ratio were statistically significant across the soil depths.

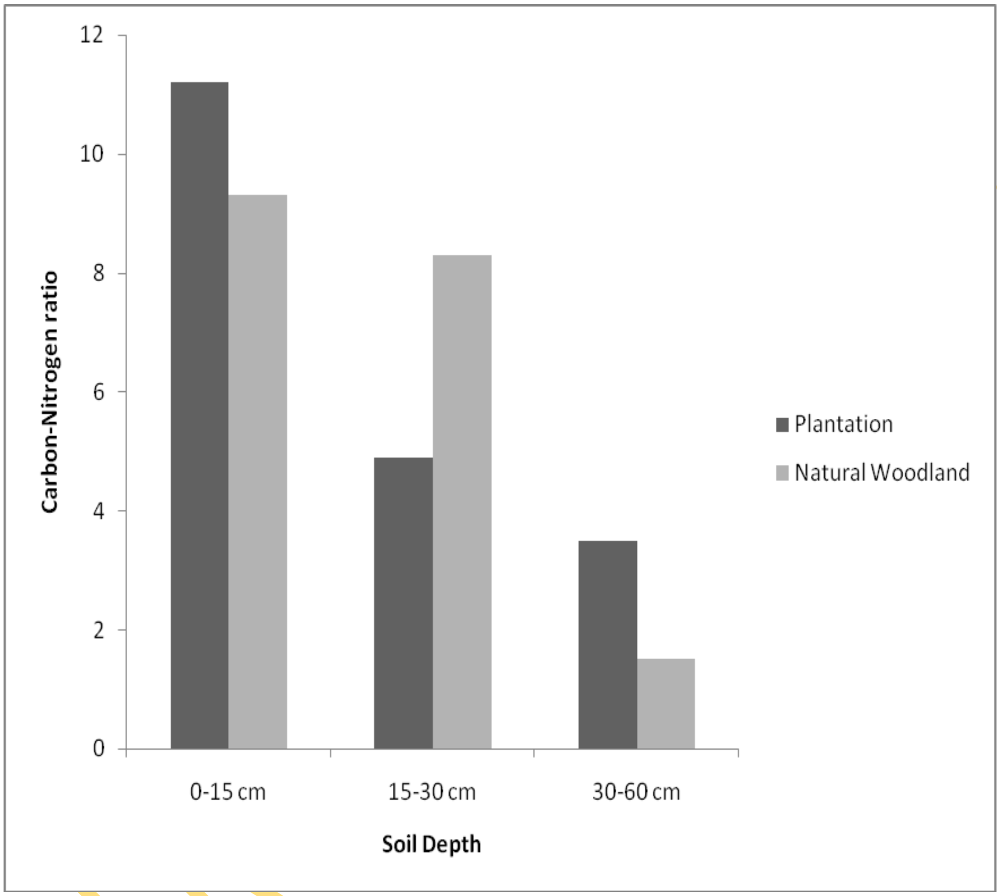

Fig. 4.8: Mean values of Carbon-Nitrogen ratio at different soil depths under *A. senegal* plantation and natural woodland

4.9 Available Phosphorous

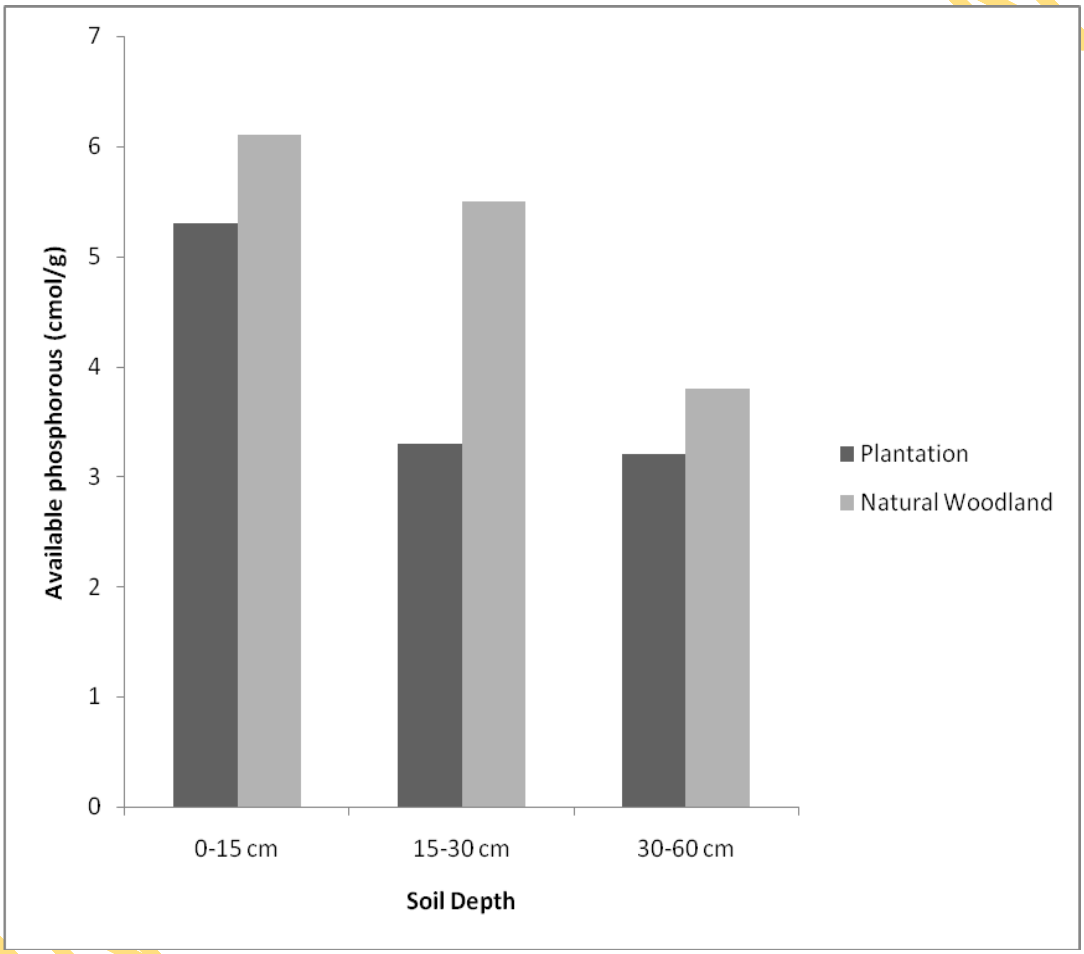

Fig. 4.9: Mean values of Available Phosphorous at different soil depths under *A. senegal* plantation and natural woodland

Significantly higher available P was recorded within the 0-15cm soil depth, followed by 15-30cm and 30-60cm (Figure 4.9). The mean differences were statistically significant at P = 0.05 both for the soil depths and the plots.

4.10 Exchangeable cations

4.11 Calcium

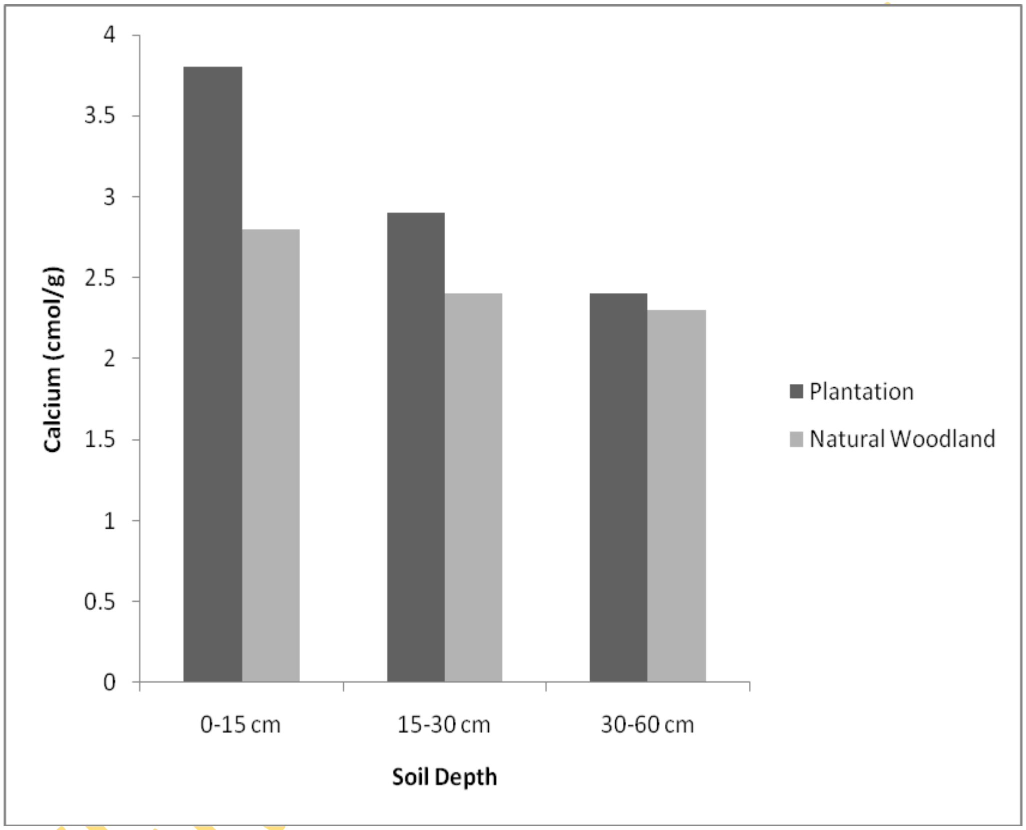

Fig. 4.10: Mean values of Calcium contents at different soil depths under *A. senegal* plantation and natural woodland

The mean soil calcium (Ca) concentration ranged from 2.4 to 3.4 cmol/g along the soil depth (Figure 4.10 and Table 4.4), while it ranged from 2.2 to 3.9 across plots 1 to 4 and the control (Table 4.5). The Ca concentration showed a decrease with increasing soil depth both in the plantation and the natural woodland (control). The control plot had higher mean values than others. The analysis of variance showed significant differences in the mean Ca values along soil depth and across the plots.

4.12 Magnesiun

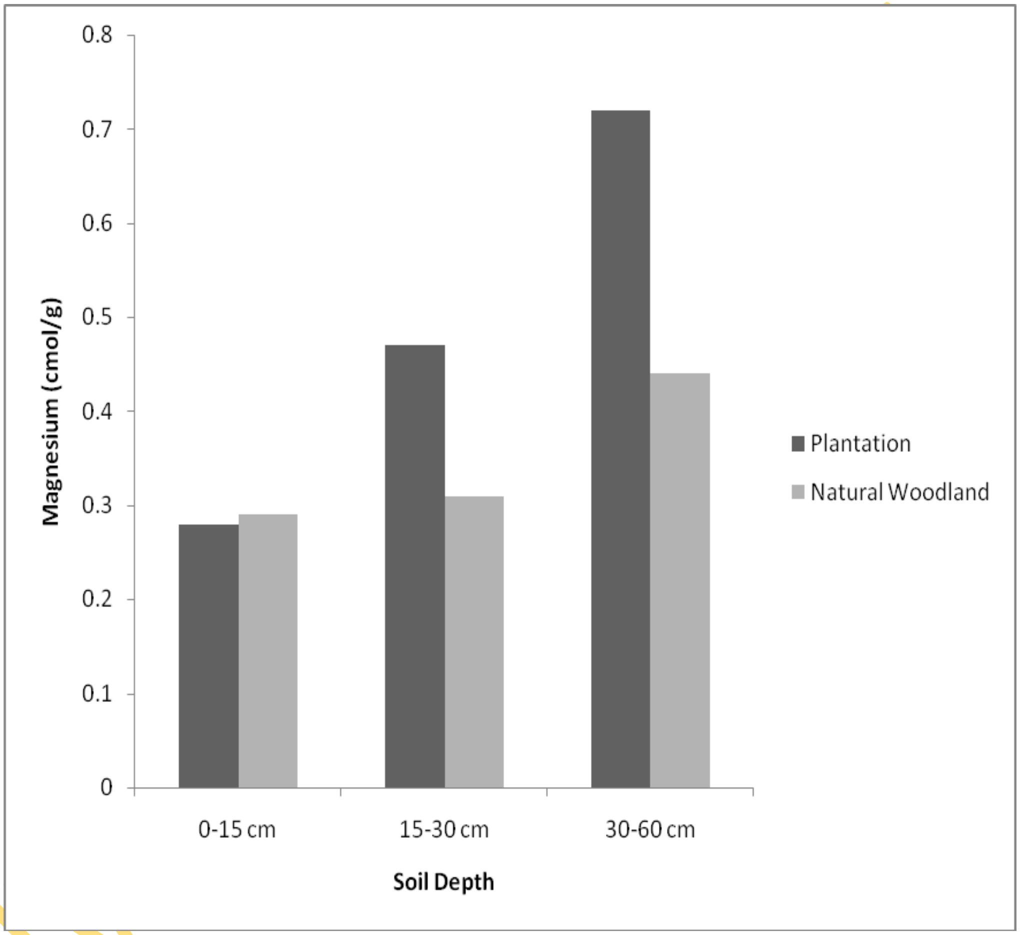

Fig. 4.11: Mean values of Magnesium content at different soil depths under *A. senegal* plantation and natural woodland

The mean values for magnesium (Mg) increased with increasing depth (Figure 4.11) ranging from 0.28 to 0.72 cmol/g; though the control had lower values at all the soil depths. There are significant differences among the soil depths and across plots.

4.13 Potassium

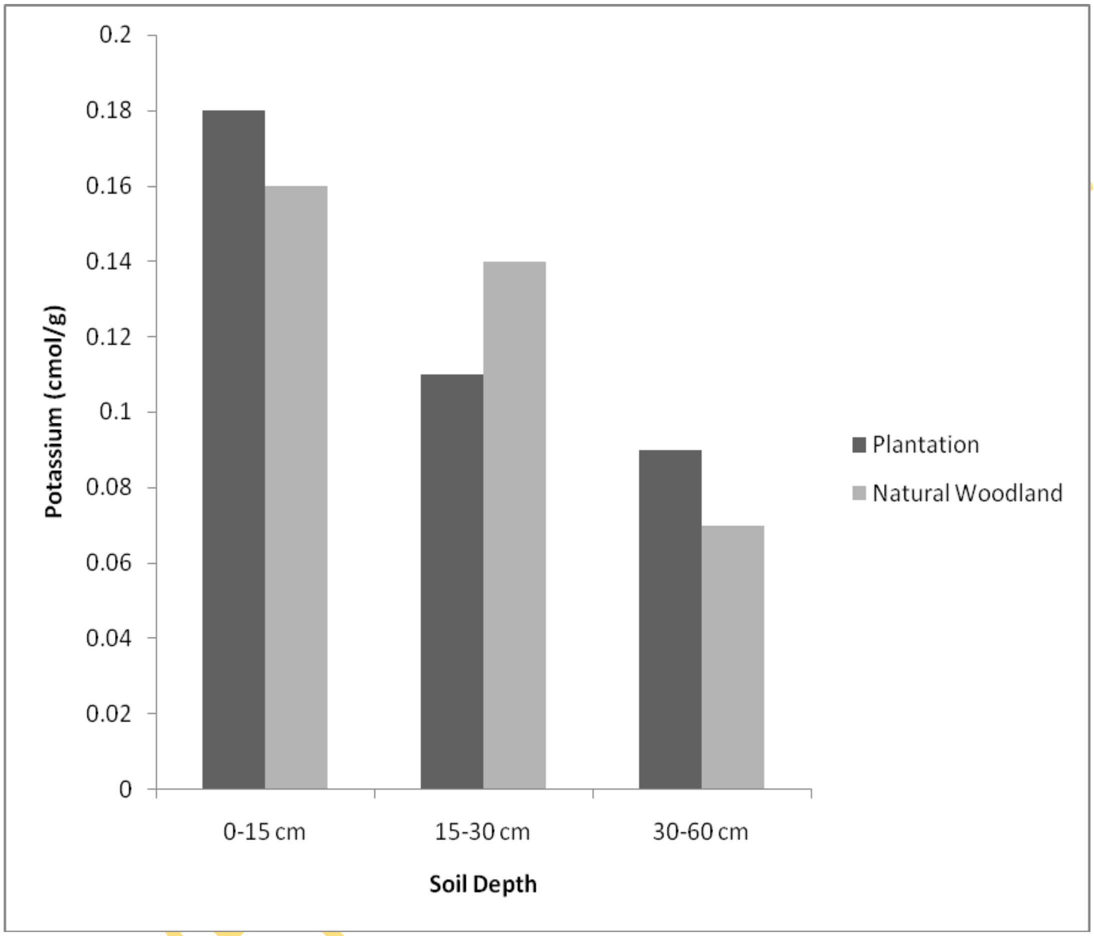

Fig. 4.12: Mean value of Potassium content at different soil depths under *A. senegal* plantation and natural woodland

The exchangeable potassium (K) content ranged from 0.09 to 0.18 cmol/g (Figure 4.12 and Table 4.4) across the soil depth and decreased with increasing depth. However, K ranged from 0.073 to 0.16 cmol/g in the natural woodland (control), and these values decreased as the soil depths increased. There were high significant differences along the soil depth and across the plots.

4.14 Sodium

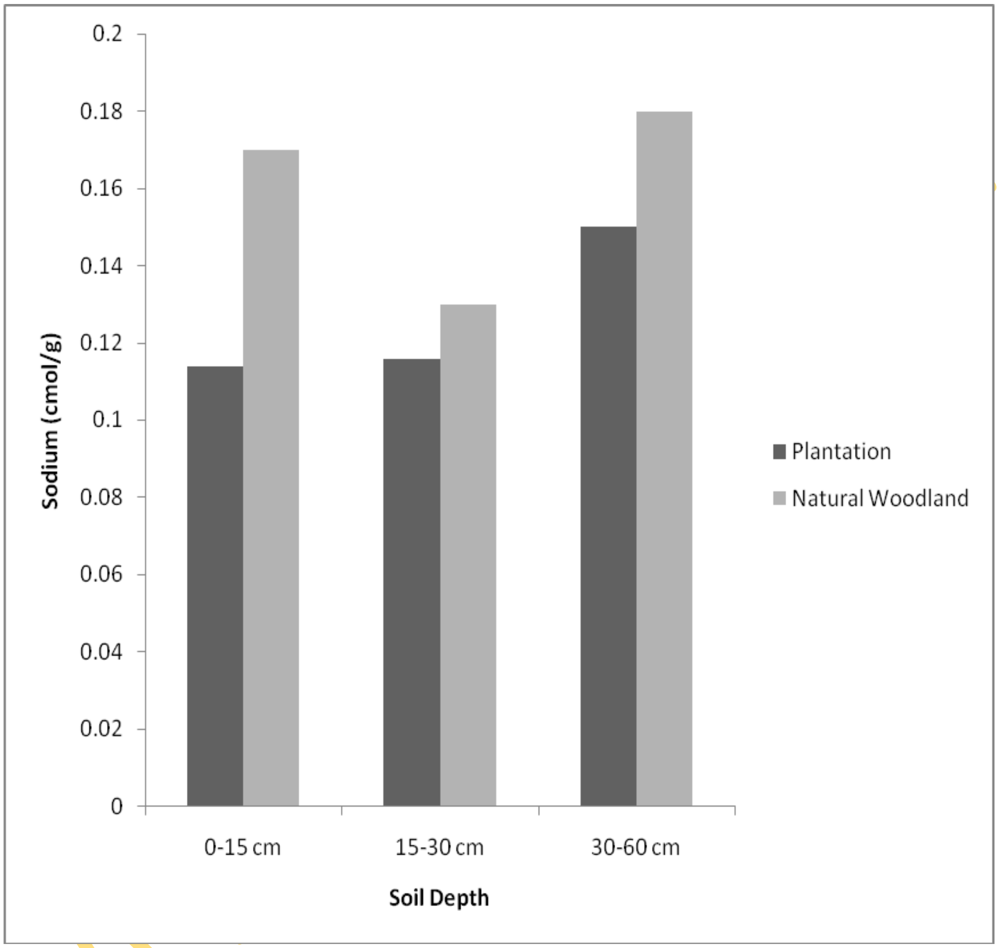

Fig. 4.13: Mean values of Sodium content at different soil depths under *A. senegal* plantation and natural woodland

The mean sodium (Na) level ranged from 0.11 to 0.15 cmol/g. The top soil (0- 15 cm) value was 0.12 cmol/g a little higher than the value in the 15-30 cm soil depth (Figure 4.15), however, the value for the 30-60 cm was highest (0.15 cmol/g). Across the plots, the control had the highest value of 0.16cmol/g while plot 2 had the lowest value of 0.10 cmol/g (Table 4.5). It was observed in the natural woodland that Na values fluctuate as the soil depths increased (Figure 4.13), while the values increased as the soil depth increased in the plantation.

4.15 Base saturation

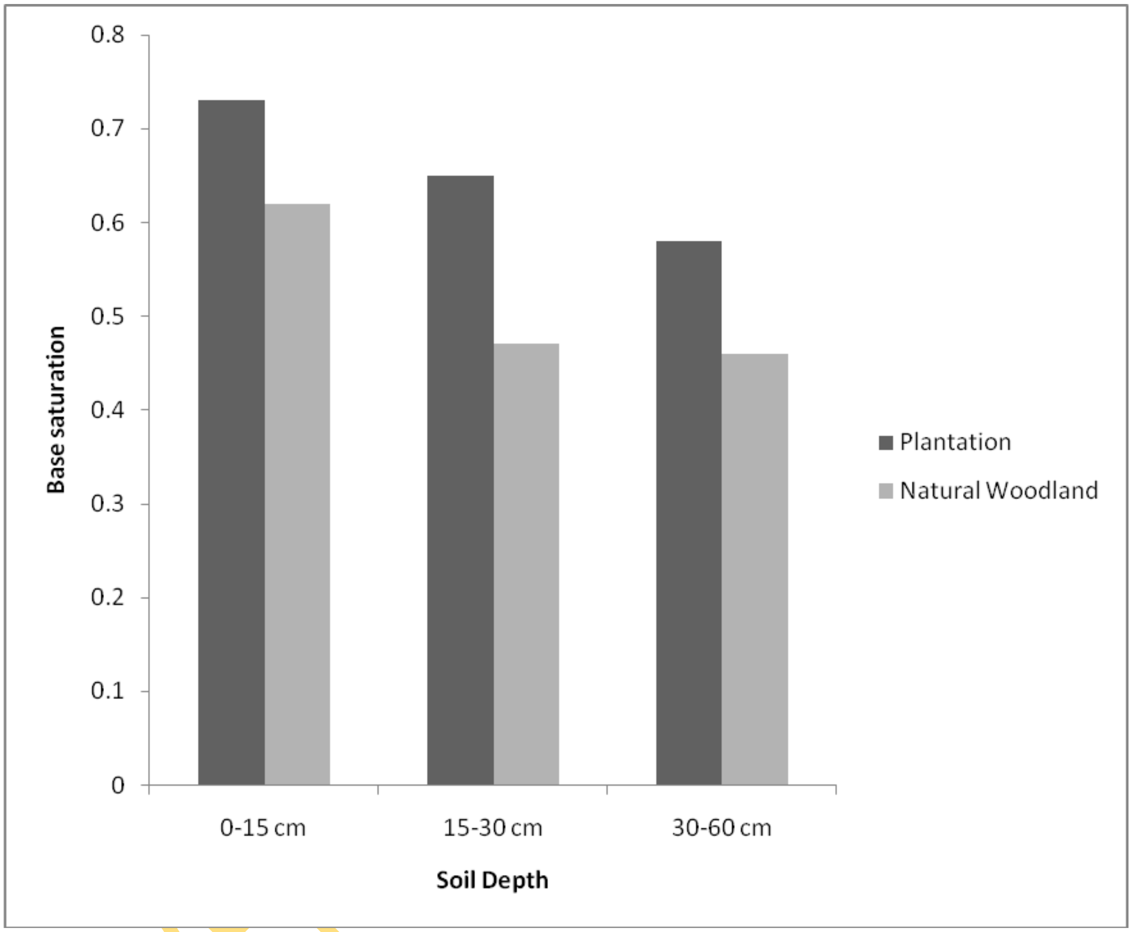

Fig. 4.14: Mean values of Base Saturation content at different soil depths under *A. senegal* plantation and natural woodland

The base saturation (BS) ranged from 0.56 to 0.73 across the soil depth. It decreased with increasing soil depth (Figure 4.14 and Table 4.4). However, there were slight differences in the base saturation content across the plots, with the control having slightly lower value (Table 4.5).

Analysis of variance showed that the mean values were statistically significant along the soil depths and across the plots.

4.16 Sulphur

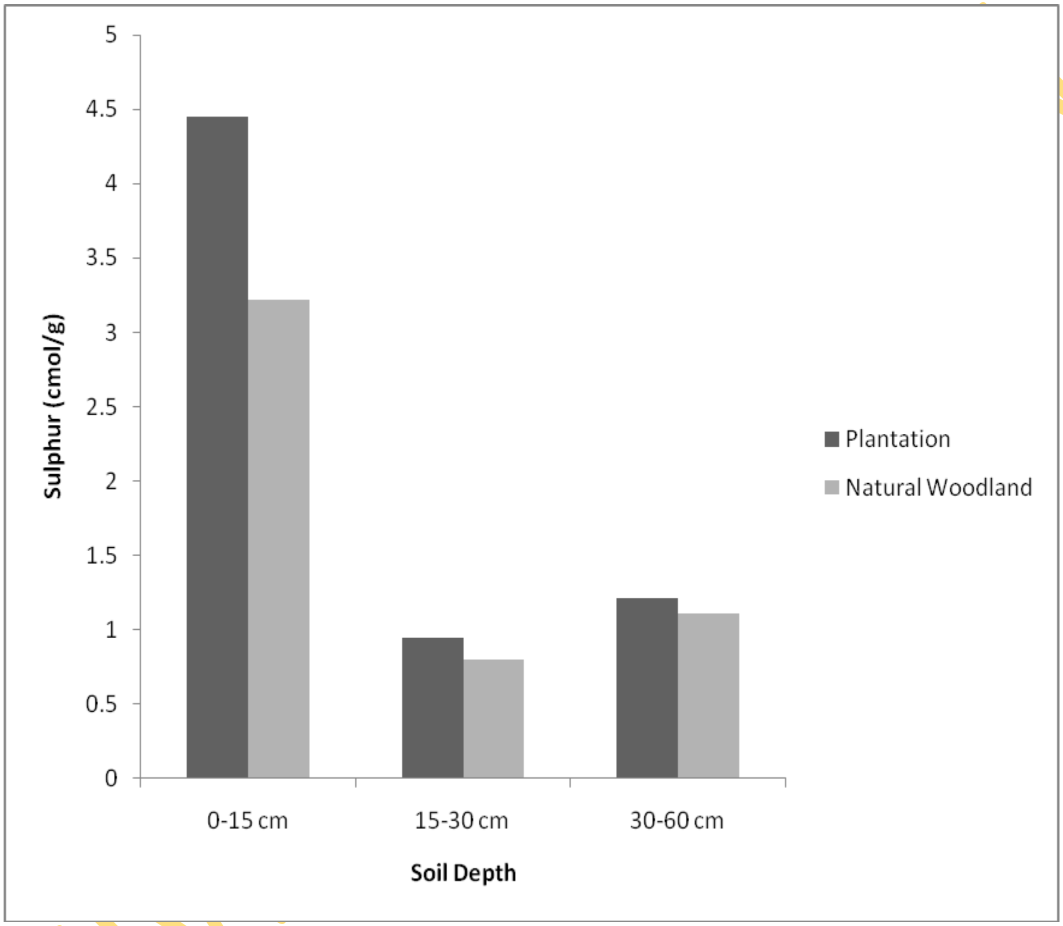

Fig. 4.15: Mean values of Sulphur content at different soil depths under *A. senegal* plantation and natural woodland

The mean values for sulphur (S) were slightly high ranging from 1.71 to 2.88 across the plots (Table 4.5), but differed sharply across the soil depths, ranging from 0.95 to 4.5 (Figure 4.15 and Table 4.4). There were significant differences along the soil depth but not across the plots.

4.17 Aluminium

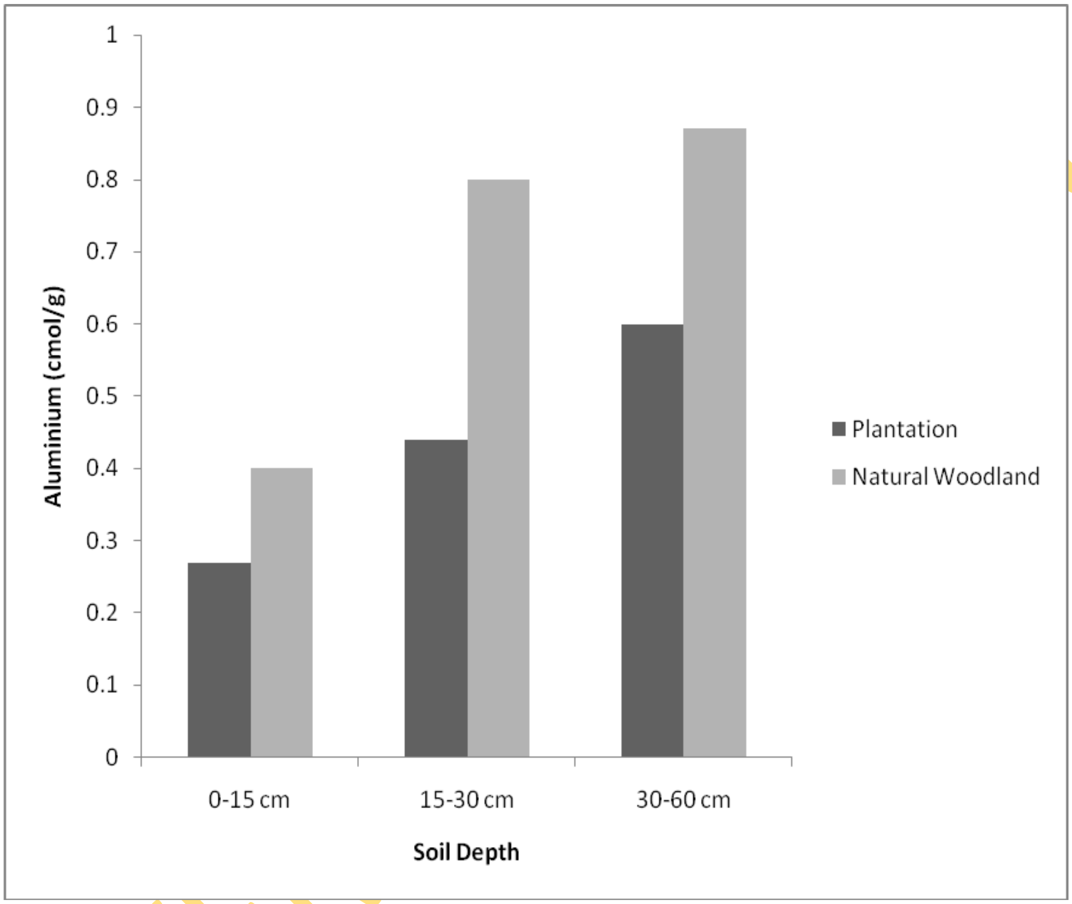

Fig. 4.16: Mean values of Aluminium content at different soil depths under *A. senegal* plantation and natural woodland

The mean values for aluminium (Al) content ranged from 0.27 to 0.60 with increasing soil depth (Figure 4.16 and Table 4.4). The control had the highest mean value and was followed by plot 1 (Table 4.5). The analysis of variance results showed that there were significant differences among the soil depths and across the plots.

4.18 Effective Cation Exchange Capacity (ECEC)

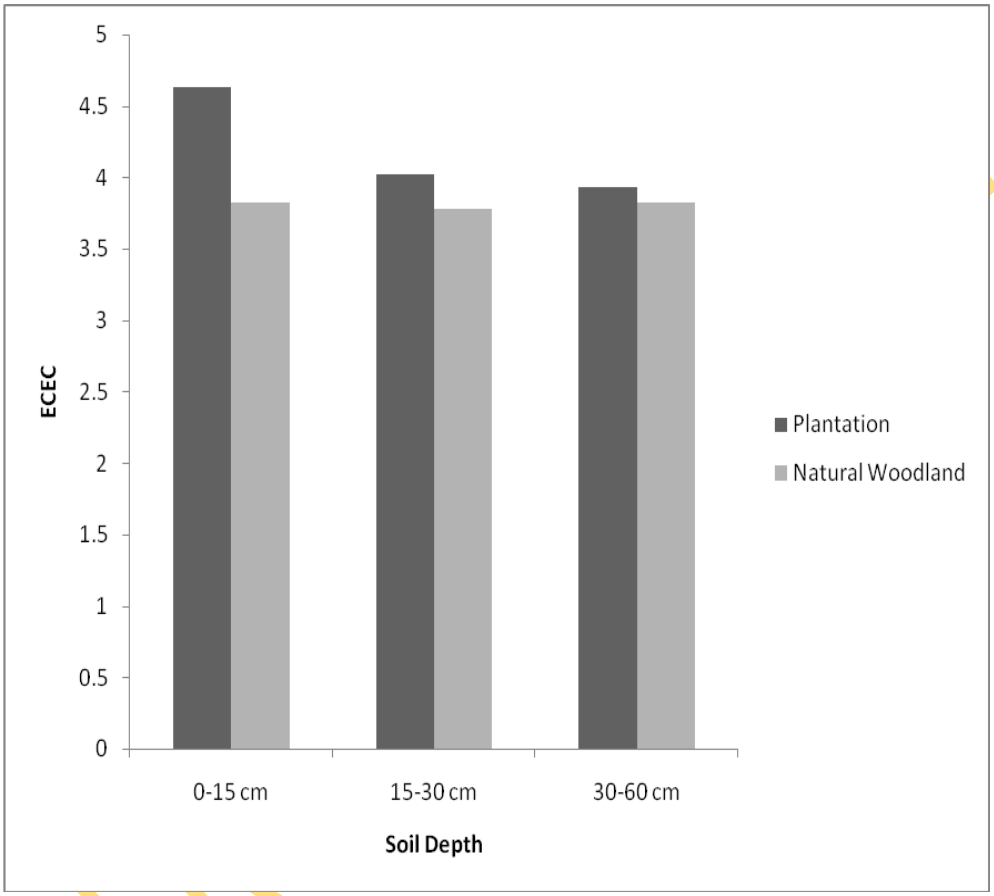

Fig. 4.17: Mean values of ECEC content at different soil depths under *A. senegal* plantation and natural woodland

The ECEC across the soil depths showed that the mean values decreased as soil depth increased both for the plantation and natural woodland (Figure 4.17). Across the plots, there were fluctuations in values with the control having the lowest (Table 4.5).

The differences in mean values were not statistically significant across the soil depths, but were significant across the plots.

4.19 Cation Exchange Capacity (CEC)

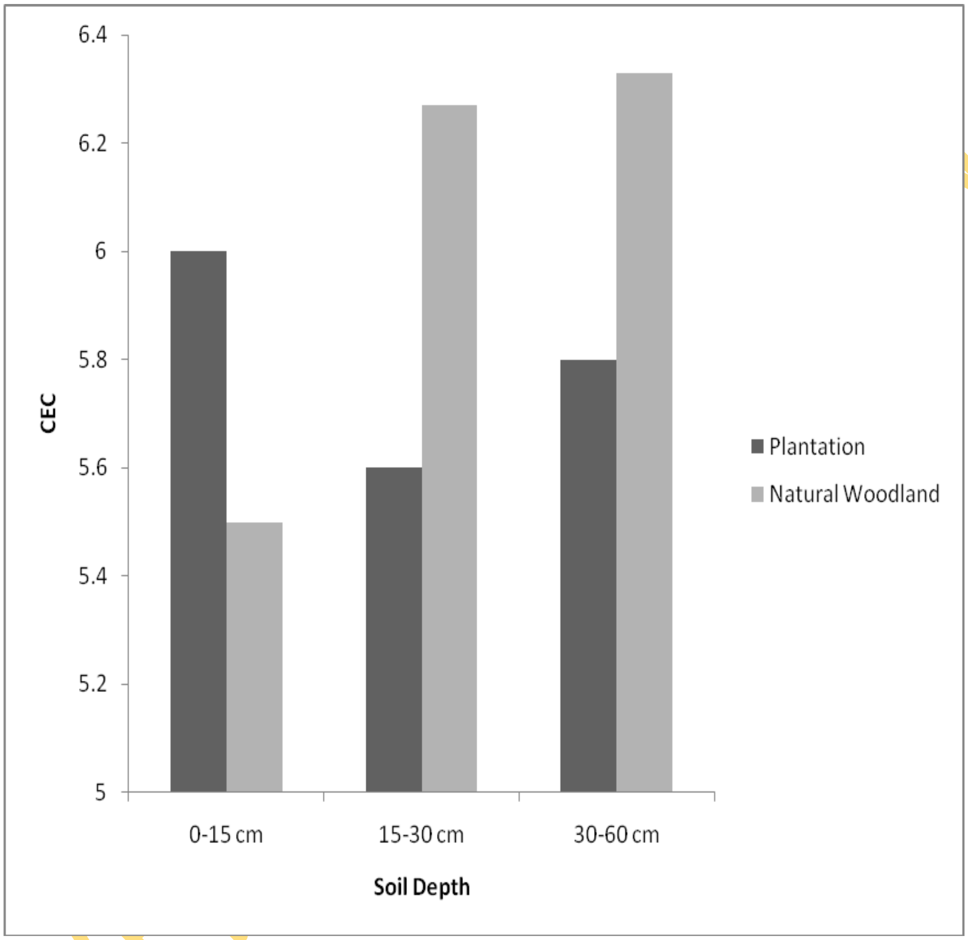

Fig. 4.18: Mean values of CEC content at different soil depths under *A. senegal* plantation and natural woodland

The mean values of cation exchange capacity (CEC) obtained were very low and ranged from 5.6 to 6.0 across the soil depths and 4.3 to 6.8 across the plots (Table 4.5). The values increased with soil depth (Figure 4.18 and Table 4.4).

The analysis of variance showed that along the soil depth, there were no significant differences among the mean values, while there were significant differences in the mean values across the plots.

4.1.0 Micronutrient Elements

4.1.1 Iron

The Iron (Fe) content in the topsoil was 13.4 $mgkg^{-1}$, decreasing down the soil depth to 12.5 $mgkg^{-1}$(Table 4.6). Across plots 1 to 4 and the control, the mean values ranged from 9.8 $mgkg^{-1}$ to 20.0 $mgkg^{-1}$. The analysis of variance was not statistically significant at soil depth and across the plots.

4.1.2 Manganese

The mean values of Manganese (Mn) across the plots 1 to 4 and control varied from 5.6 mg kg-1 to 14.1 $mgkg^{-1}$, while along the soil depth the mean values ranged from 7.5 $mgkg^{-1}$ to 9.6 $mgkg^{-1}$ (Table 4.6). The mean values of manganese in this soil were not significant at soil depth and across the plots.

4.1.3 Copper

The mean values of Copper (Cu) at soil depth 0-15cm were 1.31$mgkg^{-1}$, 15-30cm (2.0 $mgkg^{-1}$) and 30-60cm (1.3 $mgkg^{-1}$ Table 4.6). Across the plot the mean values varied from 0.19 $mgkg^{-1}$ to 4.0 $mgkg^{-1}$. There was a slight increase down the soil depth at 15-30cm soil depth and a drastic change at 30-60cm to 1.3 $mgkg^{-1}$. The mean values were significant at the soil depth.

4.1.4 Zinc

The mean values of Zinc (Zn) across the plots ranged between 1.7 to 11.8 $mgkg^{-1}$ (Table 4.6), while along the soil depth mean values ranged from 4.1 to 6.4 $mgkg^{-1}$. These means were slightly high and were statistically significant. However, the value was lower at the topsoil but suddenly increased down the soil depth.

4.1.5 Boron

Boron (B) mean values (Table 4.6) decreased down the depth, 0-15cm (1.3 $mgkg^{-1}$), 15-30cm (1.1 $mgkg^{-1}$) and 30-60cm (1.1 $mgkg^{-1}$). Across the plots, the mean values ranged from 0.86 to 1.5 $mgkg^{-1}$. The mean values were significant for the soil depths and across the plots.

Table 4.6: Mean values of micro-nutrients in the soil under *A. senegal* plantation

Soil Depth (Treatment)	Fe	Mn	Cu	Zn	B
0-15cm	13.4a	9.0a	1.3a	5.2ab	1.3b
15-30cm	14.0a	7.5a	2.0b	4.1a	1.1ab
30-60cm	12.5a	9.6a	1.3a	6.4b	1.1a

Mean within a column followed by the same letters are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

4.2.0 Stepwise multiple linear regression

The stepwise multiple linear regression was used to examine the relationships between the soil Organic Carbon (dependent variable) and some other soil variables (soil depth, TN, Na, K, pH($CaCl_2$), Mg, Ca and AP) known as independent variables (Appendix 3). The results obtained showed what each independent variable contributed to the fertility of the soil using the organic carbon as dependent variable. Table 4.7 shows the various selections and the corresponding P-value, t-value, SE, R^2 and level of significant that each of the nutrient elements contributed to the stepwise coefficients.

Table 4.7: Coefficients of determination

Models	1	2	3	4	5	6	7	8
Constant	.439	-.260	-.158	-.276	-.252	-.272	-.285	-.288
Soil Depth	-.130	-.056	-.053	-.036	-.030	-.020	-.014	.003
T-value	-5.96	-1.863	-2.233	-1.372	-1.120	-.715	-.415	-.085
P-value	0.000**	0.070	0.031*	0.170	0.270	0.479	0.681	0.933
pH($CaCl_2$)		.166	.086	.093	.091	.085	.087	.076
T-value		3.211	2.958	3.212	3.107	2.950	2.895	2.417
P-value		0.003**	0.005*	0.003**	0.004**	0.005**	0.006**	0.021*
TN			.672	.734	.746	.741	.739	.762
T-value			5.104	5.388	5.436	5.499	5.407	5.564
P-value			0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
AP				.012	.150	.007	.007	.005
T-value				1.489	1.714	1.698	1.703	1.499
P-value				0.144	0.095	0.489	0.487	0.621
Na					-.287	.342	-.336	-.398
T-value					1.895	1.080	1.044	1.231
P-value					0.377	0.287	0.303	0.227
K						.515	.521	.510
T-value						1.558	1.553	1.530
P-value						0.128	0.129	0.135
Mg							-.018	-.070
T-value							1.263	1.895
P-value							0.794	0.377
Ca								.022
T-value								1.235
P-value								0.225
SE	.022	.036	.132	.008	.321	.331	.067	.018
R^2	.458	.567	.738	.752	.757	.772	.772	.782

Dependent variable: Organic Carbon

* Significant at p = 0.01

**Significant at p = 0.05

Model 1: The organic carbon was regressed against some soil parameters at soil depth 0-15cm. The T value ranged from -5.96 to -.085, while that of P value ranged from 0.00 to .985. The relationship of soil depth with other parameters was significant at models 1 and 3. Thus, organic carbon normally decreases with increase in soil depth. The resulting equation is as shown below:

OC = 0.439 -.130 soil depth

SE = 0.022;

R^2 = 0.458

Model 2: In model 2, an additive of pH ($CaCl_2$) to the soil nutrient pool further increase the concentration of hydrogen ions in soil solution, thereby exerting a great influence on the soil ion exchange equilibrium through its effect on the processes of mineral weathering and organic matter mineralization and mobilization of nutrients. The resulting equation from this interaction is as given below:

OC = -.260 -.056 soil depth + .116 pH ($CaCl_2$).

SE = 0.036;

R^2 = 0.567

Model 3: In this model organic carbon was regressed against all other soil parameters at a soil depth 0-15 cm. The addition of TN to the combination has a significant relationship on soil nutrient pools which affect the accumulation of soil organic carbon. The T-value ranged from 5.1 to 5.6, while the P-value ranged from 0.00 to 0.00 an indication of TN significant relation with other soil parameters. The amount of Nitrogen in the topsoil is normally found to be higher. The resulting equation is as follows:

OC = -.158 -.053 soil depth + .086 pH ($CaCl_2$) + .672 TN

SE = 0.132;

R^2 = 0.738

Model 4: The regression of OC with AP at 0-15 cm soil depth shows no significant contribution to the nutrient pools. This may be attributed to lower release rate of AP into the nutrient pools. The process of immobilization and mineralization regulated the pattern of P release. The equation for this model is as below:

OC = -.276 -.036 soil depth + .093 pH ($CaCl_2$) + .734 TN + .012 AP.

SE = 0.008;

R^2 = 0.752

Model 5: There was an addition of Na to the analysis. An increase in Na into the pool will cause a decrease in Potassium availability. However, there is usually redistribution and accumulation of these nutrients at certain periods. The regression show the T-value ranged from -.287 to .342 and the P-value ranged from 0.227 to 0.377. There is however, no significant relation of Na with other soil parameters. The equation derived is as below:

OC = -.252 -.030 soil depth + .091 pH ($CaCl_2$) + .746 TN + .150 AP - .287 Na.

SE = 0.321;

R^2 = 0.757

Model 6: In this analysis, there was a relative increase of K in the soil nutrient pools which affected the OC in the soil. K therefore does not contribute significantly to the nutrient in the pools. The resulting equation from this is given below:

OC = -.272 - .020 soil depth + .085 pH ($CaCl_2$) + .741 TN + .007 AP + .342 Na + .515 K.

SE = 0.331;

R^2 = 0.772

Model 7: The contribution of Mg was not significant. The T-value for the contribution ranged from 1.263 to 1.895 while the P-value ranged from 0.794 to 0.377. The equation derived is as below:

OC = -.285 - .014 soil depth + .087 pH ($CaCl_2$) + .739 TN + .007 AP - .336 Na + .521 K - .018 Mg.

SE = 0.067;

R^2 = 0.772

Model 8: The last model shows OC regressed against Ca. The contribution of Ca was not significant to the nutrient pools. Calcium is believed to check the effect of organic acids within plants and many root exudates increase the organic acid level of the soil. The equation for the analysis is as shown below:

OC = -.288 + .003 soil depth + .076 pH ($CaCl_2$) + .762 TN + .005 AP -.398 Na + .510 K - .070 Mg + .022

SE = 0.018;

R^2 = 0.782

4.2.1 Result of correlation analysis

In order to understand the relationship and association among some selected soil physical and chemical properties, correlation matrix was employed (Appendix 4.3). The result shows a high positive significant relationship between clay and soil depth, a high negative significance between silt and soil depth, pH (H_20), pH ($CaCl_2$), Organic Carbon, Carbon-Nitrogen, Available Phosphorus, Calcium, Magnesium, Potassium, Base Saturation and Sulphur relationship.

Organic carbon had high positive correlation with Clay, Silt, pH ($CaCl_2$) and pH (H_20), while C:N ratio had positive correlation with clay, silt, pH ($CaCl_2$), pH (H_20) and organic carbon. In the case of Al, it has positive correlation with clay but have high negative correlation with silt, pH ($CaCl_2$), pH (H_20), OC, C:N, Ca, and K.

4.3.0 Litterfall

The litterfall of trees in the sample plots was collected for six months (October to March) and the values recorded (Table 4.8). The Duncan's Multiple Range Test showed that the periodic means obtained for the litterfall were statistically significant at P = 0.05.

Table 4.8: Mean monthly litterfall under *Acacia senegal* plantation

Period	Mean (g)	Std. Deviation
October	41.4c	2.9
November	57.8e	3.0
December	70.6f	2.1
January	53.5d	5.8
February	38.6b	2.4
March	18.7a	1.7

Mean values with the same letter(s) are not significantly different at p = 5% by DMRT

4.3.1 Pattern of litterfall.

Litterfall pattern was observed for the four plots within the plantation. The month of December recorded the peak in Plot 1 with an average of 70.6 g and was followed by the months of November (57. 3 g) and January (52.2 g). The month of March had the lowest litterfall with an average of 19.8 g.

In Plot 2, the month of December maintained the highest litterfall with an average of 71.0 g, and was followed by November (60.3 g) and January (50.2 g), while the lowest litterfall was recorded in March with an average of 18.2 g.

Plot 3 had the month of December with a peak of 70.9 g, followed by the month of November with an average litterfall of 55.2g, while, January had 49.3 g. The month of March still had the lowest litterfall with an average of 17.9 g. The months of October and February had 41.6 g and 36.7 g respectively.

The pattern of litterfall in Plot 4 was slightly different from others with the month of December maintaining the peak of litterfall with an average of 69.8 g and was closely followed by the month of January with an average of 68.5 g, while, the month of March had the lowest litterfall of 18.8 g.

Using the results of litterfall obtained, the litterfall for the month per hectare was estimated at 259.7 g/ha, and the annual litterfall was estimated at 3.1 kg /ha.

4.3.2 Litterfall prediction

Multiple regressions was carried out for litterfall prediction using litterfall as dependent variable with different combinations of total litterfall, traps and time in week as independent variables.

Thus the regression equation derived is as follows:

Y = -0.497 – 0.022 weeks

Where R^2 = 0.69; R^2adj. = 0.67, SE = 0.052

4.3.3 Rate of decomposition

The rate of litter decomposition was estimated and the linear estimation for the final loss of the litter was given as:

$$\frac{X}{Xo} = 0.6053 + e^{-0.0209T}$$

$R^2 = 0.6634$

Figure 4.19 shows the quantity of litter mass remaining in relation to time of decomposition. It is represented by an exponential function.

The coefficient describing the decay rate overtime was positively correlated (R^2 = 0.663 at P = 0.05) while, the decay rate was 0.605. The dry mass remaining (% of initial litter) at the end of the study was 47.8% (Table 4.9). There is a positive significant relationship between duration of decomposition and the final disappearance of litter.

Table 4.9: Rate of litter disappearance under *Acacia senegal* plantation.

Initial wt Xo (gm)	Wt at a later time X (gm)	Monthly rate of decay X/Xo (gm)	Time (Month)
100	56.4	0.56	1
100	50.0	0.50	2
100	47.8	0.48	3

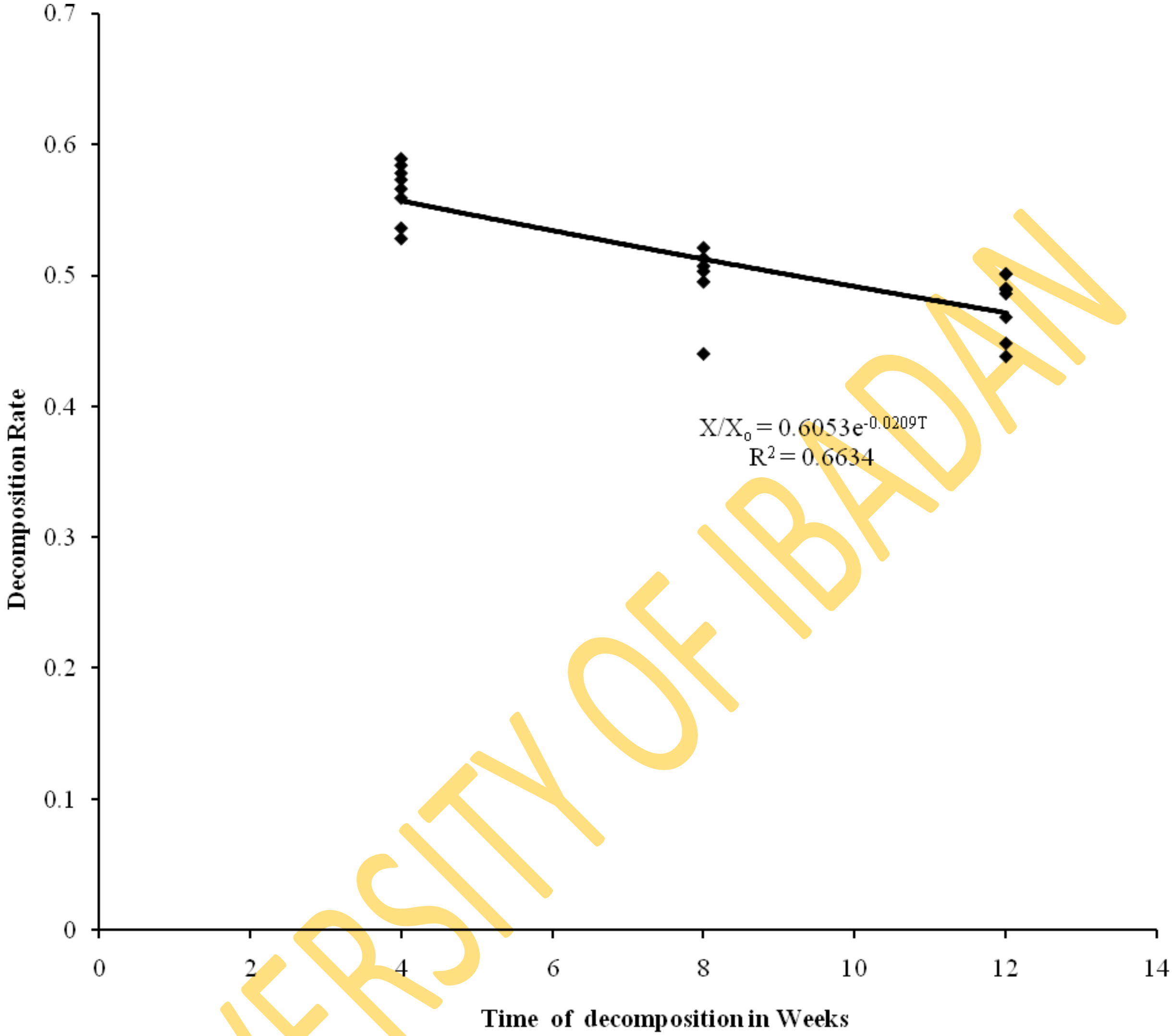

Fig. 4.19 : Relationship between decomposition rate and time of decomposition for *Acacia senegal* litter (Initial litter weight = 100g)

4.3.4 Nutrient concentration in litterfall

The concentrations of the macronutrients of the litterfall were in the following order: calcium (3.1 cmol/g), nitrogen (2.9 cmol/g), magnesium (0.49 cmol/g), potassium (0.32 cmol/g), and phosphorus (0.16 mg/g). However, the results obtained indicate non-significance of nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc and boron concentrations except for copper (Tables 4.10 and 4.11).

Table 4.10: ANOVA results of monthly macro-nutrient concentration in decomposed litter of *A. senegal*

Parameter	Df	MS	F	P-level
Nitrogen				
Months	2	75.7868	0.8722	0.4370 (ns)
Error	16	86.8909		
Phosphorous				
Months	2	0.1032	2.3407	0.1283 (ns)
Error	16	0.0441		
Potassium				
Month	2	0.0217	0.2447	0.7858 (ns)
Error	16	0.8890		
Calcium				
Month	2	0.0119	0.0077	0.9923 (ns)
Error	16	1.5337		
Magnesium				
Month	2	0.0331	1.1084	0.3542 (ns)
Error	16	0.0299		

ns = Not significant

The nitrogen content increased from 2.7% in the first month of decomposition to 8.7% in the final month, while potassium content decreased with increasing duration of decomposition, though, with some fluctuations. The values of phosphorous, magnesium and copper all increased with increase in time of decomposition of the litter.

Table 4.11: ANOVA results of monthly micro-nutrient concentrations in decomposed litter of *A. senegal*

Parameter	Df	MS	F	P-level
Iron				
Months	2	0.0055	0.7566	0.4853 (ns)
Error	16	0.0073		
Manganese				
Months	2	0.0001	0.2944	0.7489 (ns)
Error	16	0.0002		
Copper				
Month	2	0.0001	13.3016	0.0004*
Error	16	0.0000		
Zinc				
Month	2	0.0001	1.4683	0.2598 (ns)
Error	16	0.0000		
Boron				
Month	2	11.8752	0.08592	0.9181 (ns)
Error	16	138.2180		

ns Not significant
* Significant

4.3.5 Nutrient concentrations in 0-15 cm soil depth under the decomposed litter.

The results show the concentrations of nitrogen to be 0.77 cmol/g, phosphorous (34.1 cmol/g), potassium (0.32 cmol/g), calcium (6.5 cmol/g) and magnesium (3.3 cmol/g). However, the ANOVA results show that only phosphorus and magnesium were significant at $p = 0.05$ (Table 4.12).

Table 4.12: ANOVA results of macro-nutrient concentrations in soil under decomposed litter of *A. senegal* at 0-15 cm depth.

Parameter	df	MS	F	P-level
Nitrogen				
Months	2	0.0002	0.1765	0.8395 (ns)
Error	20	0.0014		
Phosphorous				
Months	2	512.6535	5.4498	0.0129*
Error	20	94.1516		
Potassium				
Month	2	0.0060	0.3754	0.6918 (ns)
Error	20	0.0161		
Calcium				
Month	2	6.3159	2.1735	0.1399 (ns)
Error	20	2.9059		
Magnesium				
Month	2	2.1953	5.2688	0.0145*
Error	20	0.4167		

ns Not significant
* Significant

Table 4.13 : Comparison of macronutrients under different conditions in *Acacia senegal* plantation at Maifari, Jigawa State

Macro-nutrients	Soil under decomposed litter (0-15 cm)	Topsoil (0-15 cm)	Decomposed Litter	Foliage
N	0.76	0.087	2.9	3.5
P	34.1	5.3	0.16	0.34
K	0.32	0.18	0.32	1.8
Ca	6.5	3.8	3.1	1.9
Mg	3.4	0.28	0.48	0.49

Under different conditions in the plantation there was varying degree of macro-nutrients obtained (Table 4.13). Foliage of *Acacia senegal* had the highest N while soil under the decomposed litter had the highest P, Ca and Mg but shared the same value with K.

4.3.6 Biomass estimation of the plantation

The enumeration of the plantation was carried out and the tree data are presented in Table 4.14.

Table 4.14 : Growth data of 28 years old plantation of *Acacia senegal* at Maifari, Jigawa State

Parameter	Plot 1	Plot 2	Plot 3	Plot 4
Sample plot size (ha)	0.09	0.09	0.09	0.09
Expected tree Density	25	25	25	25
Obs. Tree Density	23	21	23	22
No. of trees Missing	2	4	2	3
Tree Ht (M) Range	2.8-6.5	2.0-5.6	2.5-5.7	2.1-5.1
DBH (cm) Range	17.3-52.5	17.0-45.3	17.3-60.3	17.1-47.5
Total weight Kg (per plot)	121.7	107.0	103.6	111.6

Table 4.15: ANOVA result for the mean DBH of *A. senegal* trees felled for biomass estimation

Parameter	df	MS	F	P-level
Plot	3	236.491	3.829	0.011*
Error	215	61.764		

* = Significant

Table 4.16: Follow-up test of the mean DBH of *A. senegal* trees felled for biomass estimation

Plot	Mean
1	34.4 b
2	30.7 a
3	40. 0b
4	31.0 a

Mean values with the same letter(s) are not significantly different

The rate of mortality in the plantation was low. Only plot 2 had 4 missing trees, while, others had between 2 and 3 out of a total of 25 trees per plot while the DBH ranged from 17.1 cm to 60.3 cm.

The total number of trees per hectare was 277 and the tree height ranged from 2.0 – 6.5 m while, the test carried out at P = 0.05 for the mean DBH of felled trees (Table 4.15) and means of tree height for felled trees (Table 4.17) were highly significant. The follow up test (Table 4.16) for the tree DBH show that mean values for plots 1 and 3; 2 and 4 are not significantly different while, for the tree height (Table 4.18) only plot 1 was statistically different from other plots.

Table 4.17: ANOVA result for the mean tree heights of *A. senegal* trees felled for biomass estimation

Parameter	df	MS	F	P-level
Plot	3	3.595	6.568	0.000*
Error	215	0.547		

* = Significant

Table 4.18: Follow-up test of the mean height of *A. senegal* trees felled for biomass estimation

Plot	Mean
1	4.4 b
2	3.9 a
3	4.1 a
4	3.9 a

Mean values with the same letter(s) are not significantly different

Table 4.19: Computed total above and below ground biomass of *A. senegal* in kilograms

Plot	Root	Stem	Branch	Foliage	Total (kg)
1	20.8	26.3	44.0	30.7	121.7
2	19.6	24.1	43.1	20.3	107.0
3	21.6	24.5	35.9	21.6	103.6
4.	22.6	26.2	35.2	27.7	111.6
Total	84.5	101.0	158.2	100.2	443.9
Percentage (%)	19.04	22.76	35.64	22.56	

Table 4.19 shows the summary of the below and above ground biomass of the felled trees. The total biomass of a hectare of trees in the plantation was 1,232.9 kg/ha. Generally, the tree components contributed to the total weight in the following order: root (19.0%), foliage (22.6%), stem (22.8%) and branch (35.6%), though the percentage of contribution of the components changed with tree size.

4.3.7 Basal area of the plantation

The basal area of the plantation was determined using formula B.A. = $0.7854D^2$. The result obtained for the mean plot was 0.82 m^3/ha while the total basal area was 22.0 m^3/ha (Appendix 4.2).

4.3.8 Allometric relationship

The results of the allometric regression showing the relationship between the height – diameter of the trees are illustrated by Figure 4.20.

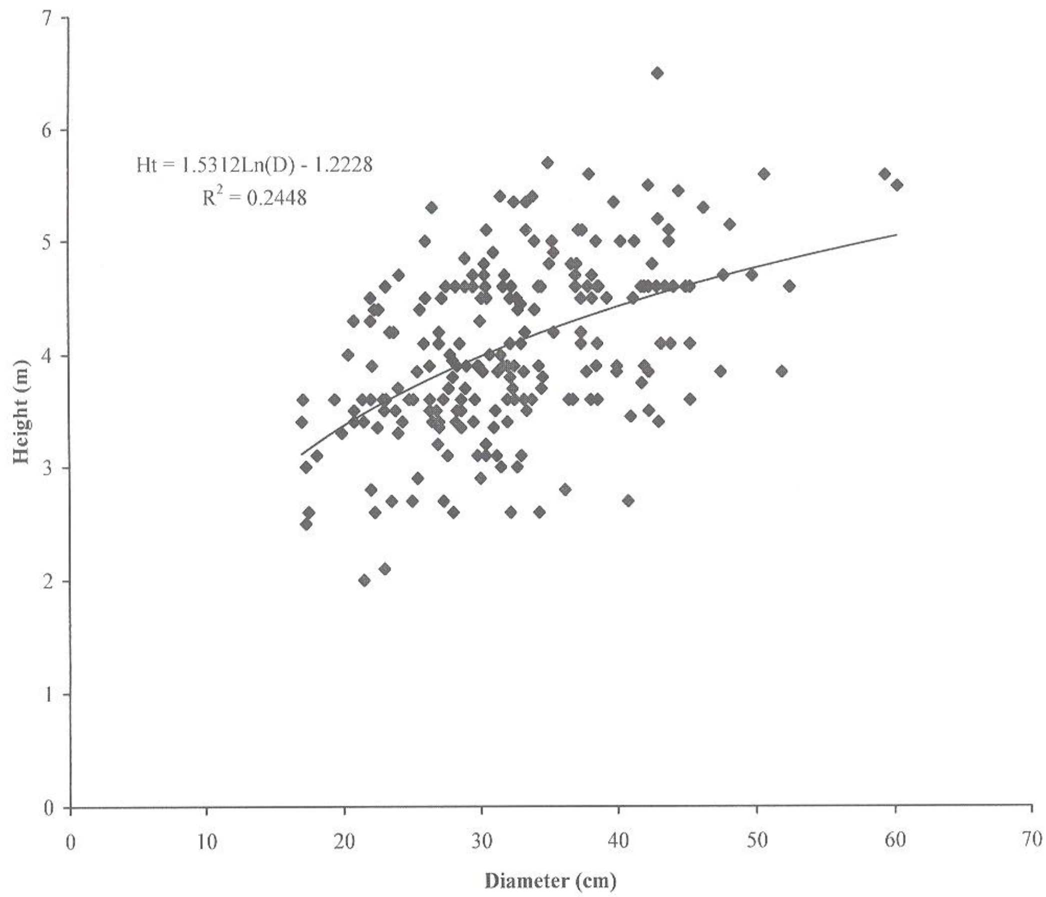

Fig. 4.20: Height-diameter relationship of *Acacia senegal* trees in the Maifari, Jigawa State

The relationship between the tree biomass and the DBH was given by the regression equation below.

DBH = 4.399 + 0.088 D

$R^2 = 0.027$;

SE = 0.121

The relationship between the tree biomass and the DBH is not statistically significant, which showed that the tree biomass has low or little relationship with the DBH of the trees. The R^2 (2%) which showed the level of relationship was quite low.

Relationship between tree height (Ht) and the DBH (Figure 4.19) was taken into consideration and the result obtained was as below.

Ht = 2.525 + 0.047 D

$R^2 = 0.24$

SE = 0.670

The relationship between the Ht and the DBH was statistically significant at P = 0.05. However, the relationship was not strong; the coefficient of determination was 24%.

The relationship between biomass and the Ht of the tree was considered and result showed that the relationship was not statistically significant and the relationship was very weak, because the coefficient of determination was 15%.

4.3.9 Nutrient concentrations in the component parts of *Acacia senegal* tree

The ANOVA results for the nutrient concentrations for both the macro and micronutrients are shown in Tables 4.20 and 4.23. The results of ANOVA for the macronutrient concentrations (Table 4.20) showed that diameter class and tree components have highly significant calcium but not nitrogen, phosphorous, potassium and magnesium.

Data on the mean macro and micronutrient contents of the foliage, branch, stem and root of *Acacia senegal* are presented in Tables 4.24 and 4.25.

Table 4.20: ANOVA results of macronutrients from the foliage, branch, stem and root of *A. senegal* trees felled for biomass estimation

Parameter	Df	MS	F	P-level
Nitrogen				
Diameter class	1	0.0351	0.1908	0.665762(ns)
Tree components	3	13.3514	72.5343	0.00000 *
Error	27	0.1841		
Phosphorous				
Diameter class	1	0.000128	0.03470	0.853628 (ns)
Tree components	3	0.067098	18.18761	0.000001*
Error	27	0.003689		
Potassium				
Diameter class	1	0.042778	0.059476	0.809169 (ns)
Tree components	3	3.489295	4.851325	0.007930 *
Error	27	0.719246		
Calcium				
Diameter class	1	1.143828	6.134912	0.019810 *
Tree components	3	1.209379	6.486489	0.001896 *
Error	27	0.186446		
Magnesium				
Diameter class	1	0.000002	0.00022	0.988169 (ns)
Tree components	3	0.119800	17.52511	0.000002 *
Error	27	0.006836		
Boron				
Diameter class	1	113.9673	4.15894	0.051313 (ns)
Tree components	3	305.8699	11.16194	0.000061*
Error	27	27.40294		

ns = Significant
* = Significant

The nutrient concentrations varied considerably in the tree components. However, the nutrient concentrations held in the biomass were relatively higher than what was obtained in the soil under the plantation.

Table 4.21: Results of follow-up test for the means of macronutrients from the foliage, branch, stem and root of *A. senegal* trees felled for biomass estimation

Tree Part	N	P	K	Ca	Mg	B
Foliage	3.5 a	0.34 a	1.77 a	1.9 a	0.49 a	22.3a
Branch	1.0 b	0.13 bc	0.49 b	2.0 a	0.20 b	10.7 b
Stem	0.8 b	0.16 bc	0.56 b	1.7 a	0.23 b	8. 6 b
Root	1.1 b	0.20 b	1.54 a	2.6 b	0.45 a	11.0 b

Means under the same section with the same letter(s) are not significantly different

Macronutrient concentrations in the tree components were high and in the following order: foliage > root > branch > stem (Table 4.21). Similar observation was made for the micronutrient concentrations except that the increase was in the order: root > foliage > stem >branch (Table 4.22).

Table 4.22: Results of follow-up test for the means of micronutrients from the foliage, branch, stem and root of *A. senegal* trees felled for biomass estimation

Tree Part	Fe	Mn	Cu	Zn	S
Foliage	626.1a	62.5a	0.02a	139.1a	648.5a
Branch	486.7b	21.2bc	0.02a	138.8a	365.0b
Stem	559.7b	35.0bc	0.02a	117.2a	226.0c
Root	780.7a	49.9ac	0.00a	148.8a	651.0a

Means under the same section with the same letter(s) are not significantly different

The ANOVA result (Table 4.23) for micronutrients of the tree components showed that the concentrations of Fe, Mn, Cu, Zn and S had no significant relationship with the diameter class of the trees, while concentrations of Fe, Mn and S had high significance with the tree components.

Table 4.23: ANOVA results of micronutrients from the foliage, branch, stem and root of *A. senegal* trees felled for biomass estimation

Parameter	Df	MS	F	P-level
Iron				
Diameter class	1	756.3	0.021667	0.884070 (ns)
Tree components	3	125563.4	3.597187	0.026269 *
Error	27	34906.0		
Manganese				
Diameter class	1	113.477	0.1436808	0.514268 (ns)
Tree components	3	2575.942	9.915583	0.000140 *
Error	27	259.7873		
Copper				
Diameter class	1	0.001953	2.259944	0.144367 (ns)
Tree components	3	0.000553	0.640016	0.595872 (ns)
Error	27	0.000864		
Zinc				
Diameter class	1	555.111	0.414992	0.524882 (ns)
Tree components	3	1426.011	1.066063	0.379887 (ns)
Error	27	1337.642		
Sulphur				
Diameter class	1	2604.4	0.7657	0.784113 (ns)
Tree components	3	360266.4	10.59127	0.000089 *
Error	27	34015.41		

ns = Significant
* = Significant

Table 4.24: Results of the means of macronutrients in the diameter class 0-30 cm of *A. senegal* tree components

Tree Diameter class 0-30 cm					
Tree Components	**N**	**P**	**K**	**Ca**	**Mg**
Foliage	0.45	0.33	1.3	2.1	0.46
Branch	0.92	0.13	0.50	2.3	0.29
Stem	0.83	0.18	0.55	1.9	0.24
Root	0.31	0.21	2.2	2.8	0.48

Table 4.25: Results of the means of macronutrients in the diameter class 30-60 cm of *A. senegal* tree components

Tree Diameter class 0-60 cm					
Tree Components	**N**	**P**	**K**	**Ca**	**Mg**
Foliage	0.60	0.35	2.3	1.8	0.52
Branch	0.23	0.13	0.49	1.8	0.30
Stem	0.79	0.15	0.56	1.5	0.23
Root	0.92	0.20	0.90	2.5	0.42

A comparison of nutrient concentrations was carried out using the plant diameter class as a factor (Tables 4.24 and 4.25). Results showed that macronutrient concentrations of the plant stem and root were higher in diameter class 0 -30 cm, while the concentrations for foliage and branch were higher in the diameter class 30 – 60 cm. As the diameter at breast height (DBH) of the trees increased, the concentration of N, P, K, Ca and Mg in the foliage increased, while, those of the branch, stem and root decreased. However, the partitioning of these nutrients was found to be higher and in the order: foliage > branch > root > stem in 0-30 cm diameter and foliage > root > stem > branch for the 30-60 cm diameter (Tables 24 and 25).

Table 4.26: Correlation matrix of nutrient concentration of *Acacia senegal* components

	Diameter Class	Foliage	N	P	K	Ca	Mg	B
Diameter Class	1.000							
Foliage	0.000	1.000						
N	-0.028	-0.690**	1.000					
P	-0.021	-0.420*	0.777**	1.000				
K	-0.038	0.071	0.501**	0.603**	1.000			
Ca	-0.342	0.342	-0.042	0.064	0.125	1.000		
Mg	0.001	-0.157	0.613**	0.666**	0.491**	0.299	1.000	
B	-0.254	-0.542**	0.718**	0.543**	0.303	0.219	0.502**	1.000

** Significant at 0.01 level
* Significant at 0.05 level

A correlation matrix was employed to show some relationships of some nutrient concentration parameters (Table 4.26). The results obtained showed P and K having positive relationships with N at P = 0.01, while Mg and B had positive correlation with P, K and Mg respectively. Only N, P, and B had negative correlations with the tree components.

CHAPTER 5

5.0 Discussion

This Chapter discusses the results obtained and is based on the variables assessed in the course of the study.

5.1 Soil physical properties under *Acacia senegal*.

The soil of the plantation showed variations in texture compared to the one obtained under the natural woodland used as the control. The soil obtained from the plantation was loamy sand and that of the natural woodland was sandy. This may likely be as a result of selective removal of silt and clay particles by run-off water during accelerated water erosion in the rainy season from the natural woodland as suggested by Harris (1998). Another reason may be as a result of annual removal of fine soil particles by windstorms during the dry season, leaving the coarse and rough sand.

The soil in the plantation has high bulk density. The high mean values obtained might be ascribed to the loss of organic matter through constant exposure of the plantation to sandstorms that usually blow away the rich fine particles of the top soil and the compaction of the soil by the roaming animals that were usually found grazing in the plantation. The case of the natural woodland (control) is a good example of a plot devoid of vegetation that could hardly prevent the sandstorms from blowing away the fine soil particles that are rich in organic matter.

5.2 Soil pH and macronutrients

The low soil pH values may be attributed to intense leaching. These results could depict a decrease in organic matter content, basic cations uptake by trees and leaching of cations with increasing soil depth as noted by Samndi (2005) who worked on characterization and classification of soils under *Tectona grandis*.

The amount of organic carbon was significantly higher in the topsoil and decreased with soil depth and following the same trend for total nitrogen. This is in line with some studies (Jackson *et al.*, 1996; Carter *et al.*, 1997; Mohamed, 2005). Since *A. senegal* is a deciduous tree that sheds its leaves during the dry season and is adapted to harsh environmental conditions, the accumulation of organic carbon in the topsoil may be as a result of leaf litter decomposition. According to Schlesinger *et al.* (1996) and Burke *et al.* (1998), soil organic carbon storage and distribution are controlled by the balance of carbon inputs from plant production and outputs through decomposition.

Next to water availability, nitrogen seems to be the most important factor limiting productivity in arid land ecosystem (Gutierrez and Whitford, 1987). The amount of nitrogen in the topsoil was higher than at other soil depths. This is in line with other studies that have shown that nitrogen availability is highest in the topsoil, declining strongly with depth (Jobbagy and Jackson, 2001; Mohamed, 2005). This probably explains the high concentration of lateral and fine roots of the *A. senegal* near the soil surface.

The low C/N values of the 0-15cm soil depth may be ascribed to higher fresh litter accumulation, which lowers the rates of mineralization. The carbon to nitrogen ratio also decreased with soil depth following the pattern of organic matter distribution.

The mean value of available phosphorous was statistically significant both for the soil depth and across the plots. It should be noted that available P under the natural woodland (control) was low and also decreased with soil depth. The decrease with depth is ascribed to decrease in organic matter levels as noted by Samndi (2005) under *Tectona grandis* plantation in Nimbia forest, Kaduna State, Nigeria. This phenomenon was observed by Ogunyebi (2008) in the study of decomposition of *Gmelina arborea* leaf litter in the lowland rainforest of Nigeria.

5.3 The exchangeable cations

The Exchangeable Cations investigated in the soil of the plantation and open woodland are calcium, magnesium, potassium and sodium. While the calcium and potassium decreased as the soil depth increased, both magnesium and sodium increased as the soil depth increased. The results of decreasing calcium and potassium with soil depth were in agreement with the findings of Oyun (1991) and could be a result of large uptake and storage of Ca and K by the trees. The increase of Mg and Na down the soil depths might be attributed to less utilization of these nutrients by *Acacia senegal* and this increase along the soil depths as noted by Tedela (2004). However, the increase of Na along the soil depth could cause soil salinity which is a common phenomenon in dry areas, such as the study area.

The ECEC decreased as the soil depth increased and is low. According to Nwachokor *et al* (2009), a low ECEC less than 4 cmol/kg implies a low capacity for the soil holding cations against leaching. The CEC of soils commonly range from 3 to 50cmol/kg, comparatively therefore, the soil of the study area had low CEC. The low CEC values could probably be as a result of low organic matter in the soil. This could be attributed to the fact that the soil of arid zones is characterized by low organic matter and clay, oxides and hydroxides of iron and aluminium; all these could lead to poor growth of *Acacia senegal* in the plantation.

Aluminium increased with soil depth, while sulphur did not show any clear pattern along the soil depth. The increase in Al in the soil could lead to soil toxicity which will directly affect the growth and development of the plant.

5.4 Soil nutrient status under plantation and natural woodland

A comparison of soil nutrient contents of the study area showed that under the plantation, the nutrient contents were higher than what were obtained in the natural woodland. The higher nutrient contents obtained under the plantation plots may be as a result of mineralization resulting from higher number of *Acacia senegal* trees which shed their leaves making the leaves available for decomposition. This is not the case with the open woodland, where the land is almost devoid of vegetation.

The decline in soil fertility in the natural woodland therefore, is often related to the depletion of the nutrient pool of organic matter. The improvement of soil properties under *Acacia senegal* indicates that planting of well adapted tree species can gradually improve soil quality and regenerate degraded lands.

5.5 Litterfall and pattern

Plant litter production and decomposition are the two important processes which provide the main input of organic matter in soil and regulate the pattern of nutrient cycling in forest ecosystems (Singh *et al.*, 1999; Weltzin, *et al.*, 2005). Litter production depends on site fertility, but other factors such as air, temperature, soil water and nutrient availability also limit the production of litter (Pandey *et al.*, 2007).

The litterfall in the present study was concentrated in the cool dry period of the year (October to March). This was strongly influenced by harmattan wind and a combination of decreased temperature and soil moisture and probably due to inherent nature of the *Acacia senegal* species which normally shed its leaves during the dry period (Jha and Mohapatra, 2010). Moore (1980), quoted by Wang *et al.* (2008) reported that water stress could initiate the synthesis of abscissic acid in the foliage of plants which could stimulate senescence of leaves and other plant parts. Other authors have reported that changes in temperature and photoperiod as well as within plant properties such as leaf age or possible endogenous rhythms are also important triggers of leaf fall (Wright and Cornejo, 1990; Zhou *et al*., 2007).

The pattern of litterfall was broadly comparable to other savanna ecosystems (Singh *et al*., 1999). The peak of the litterfall was in December and this corresponded almost with the peak of harmattan period in the study area. During the month of March when air temperature almost reached its peak, the *Acacia senegal* became leafless thus resulting in low litterfall.

Litterfall rates varied among forest types and plant species. This study is not an exception. The total annual litterfall of *Acacia senegal* recorded in this study (3.1 kg/ha/yr) is low and very low compared to (11.5 kg/ha/yr) recorded by Triadiati *et al* (2011) for a natural forest and Cacao agroforestry system in Central Sulawesi, Indonesia. The value is however, higher than 0.24 to 0.79 and 0.45 to 1.04 kg/m/yr obtained by Wang *et al* (2008) in a monoculture of *Cunningharnia lanceolata* and a mixed stand in southern China respectively. It should be noted that the annual litterfall would probably have been higher than what was obtained if the spacing of the trees had been closer.

5.6 Litter decomposition and nutrient use

In tropical ecosystems where soils are of low natural fertility, soil nutrient status and tree growth depend strongly on litter decomposition for the release of plant nutrients sequestered in the litter layer (Okeke and Omaliko, 1992). The litter on the forest floor acts as an input – output system of nutrient and the rates at which forest litter falls and subsequently, decomposes contribute to the regulation of nutrient cycling and primary productivity as well as the maintenance of soil fertility in forest ecosystem (Onyekwelu *et al*., 2006; Pandey *et al.,* 2007).

The litter decomposition in the study area followed an almost uniform pattern of weight loss from the early phase to the end with a turnover time of three months. However, at the early phase, the rate of decomposition was faster which might be due to the heavy rain that might have increased the activities of the microbes in the soil leading to increased decomposition of litter. Several studies have shown that during the initial stages of litter decomposition, when the soil is moistened by rainfall, decomposition rates are high due to heavy losses of water soluble labile compounds through leaching (Whitford, 2002; Xu and Hirata, 2005; Martinez-Yrizar *et al.*, 2007). This mechanism may explain the initial rapid loss of litter mass observed in this study during the early stage of measurement, although, other causes acting simultaneously are also possible, such as the effects of physical fragmentation, solar irradiance, dry/wet cycles (Kemp *et al.*, 2003) and the activity of soil detritivores (Nutting *et al.,* 1987).

The concentrations of elements in the decomposed litter were high however, the result of the study indicated that the levels of nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc and boron were generally not significant except for that of copper. The content increased from the first month of decomposition to the final month. This observation agrees with the work of Li *et al.* (2009) that worked on mixed litter decomposition in a managed forest ecosystem and observed that the concentration of nitrogen in the residual litter increased throughout decomposition by as much as 2.5 times the initial values.

Potassium concentration was high in the decomposed litter, but decreased as the duration of decomposition increased; though, there was fluctuation in the increase. Similar fluctuations of foliar potassium in some tropical tree species were reported by Sharma (1983) and Abdulhameed *et al.* (2004). The results of the current study also agree with the study of Gwaram and Umar (2006) who studied the leaf elemental concentration of four indigenous trees in the Sudan savanna area in Nigeria. The high concentration of potassium may be due to the fact that potassium moves freely in plants and can be leached from the litter to the soil during heavy rains.

According to Gwaram and Umar (2006), the observations of non-significant effects of the tree litter on the concentration of P, K, Ca, Mg and Zn are not uncommon among plant species. These authors claimed that Umar *et al*. (2006) made similar observations on *Azadirachta indica* and *Eucalyptus camaldulensis* where P. K, Ca and Mg concentrations were not significant. The observations may be accounted for by the effects of some factors that include climatic, age of the tree, edaphic, genetic, stage of growth of the tree or leaves, age of leaves and some other factors that cause variations in foliar and litter mineral elements.

The significant effect of Cu may be due to the preference for this element by the tree based on its importance to its metabolic processes. Gwaram and Umar (2006) noted that Cu and Fe have some basic roles to play in the overall growth and development of plants.

The values of phosphorous, magnesium and copper all increased with increase in time of decomposition of the litter. According to O'Connell and Sankaran (1997), the relative increase in P in decomposing litter is caused by non-symbiotic N-fixation, uptake from surroundings by fungal hyphae growing in litter and atmospheric precipitation or deposition of insect frass and plant material from the canopy.

5.7 Nutrient concentration in the topsoil.

Nutrient release from decomposing litter is important for the maintenance of soil fertility (Triadiati *et al.*, 2011). The well known general mode for this pattern involves initial leaching of nutrients followed by a phase of nutrient immobilization and finally the release of nutrients into the soil (Weerakkody and Parkinson, 2006).

The mean nutrient concentration in the soil under the decomposed *Acacia senegal* litter revealed a pattern similar to that of the decomposed litter. The mean concentration of nitrogen (N) in the soil under the decomposed litter increased throughout the period of decomposition, except for a fluctuation in the second month of decomposition. However, the N concentration in the soil under the decomposed litter was low compared to the N concentration in the decomposed litter, and almost the same with what was obtained in the soil sample at 0-15 cm depth. The ANOVA result showed that the mineralized N was not statistically significant. The low N concentration may be a result of leaching, since the study was carried out during the rainy season, and this may probably cause easy mineralization and immobilization of N element to be taken up by the roots of the trees.

Phosphorous (P) mean concentration was higher in soil under the decomposed litter (0-15 cm) than in the decomposed litter. It was also found to be higher in the tree foliage and of topsoil. The mineralization of P increased as the time of decomposition increased. The increased P concentration may be a result of increase in microbial activities that caused high mineralization and immobilization of P element. This agrees with the work on the dynamic of nutrient supply in plantation soils by Folster and Khanna (1997).

Potassium (K) mean concentration was a little higher in the soil under the decomposed litter than that of the decomposed litter but less than that of the foliage. Just as the concentration of K decreased with duration of decomposition of the litter, it was observed that the concentration of K in the soil under the decomposed litter equally decreased with litter decomposition. The little difference in K concentrations between the different periods of decomposition may be a result of low leacheability of K. According to O'Connell and Sankaran (1997); Howell (2008), K is most mobile and a large proportion leaches out during the initial phase of mineralization.

The relative mean concentration of calcium (Ca) in the soil under the decomposed litter was twice that observed in the decomposed litter and thrice the mean value obtained for the tree foliage. The Ca concentration appeared to decrease as the duration of decomposition increased however, the concentration was not statistically significant.

The concentration of magnesium (Mg) increased substantially in the soil under the decomposed litter compared to the decomposed litter and tree foliage. The concentration however, decreased with time.

5.8 Biomass estimation

The accurate estimation of biomass in tropical forest plantation is crucial for many applications (Basuki *et al.*, 2009), from the commercial exploitation of timber to the global carbon cycle.

The mean contribution of the root to the total biomass in the plantation is the lowest and this is in line with the result of Anderson and Ingram (1992). Ogunyebi (2008) obtained a contribution of 17.8%/ha for the below ground biomass for *Gmelina arborea* in a lowland rainforest of Nigeria. However, the proportions of the tree components (root, stem branch and foliage) change as the size of the tree changes.

The low biomass figure obtained for the plantation may probably be a result of the shorter growing period of the tree and its slow growth rate. A similar observation was made by Kadeba (1994) on the growth and nutrient accumulation of *Pinus caribaea* in savanna area of northern Nigeria.

The nutrient concentrations held in the biomass were relatively higher compared with the nutrient concentration obtained by Kadeba (1994) in *Pinus caribaea* on three savanna sites in northern Nigeria. Macronutrient concentrations were high and are in the following order: foliage > root > branch > stem. Similar observation was made for the micronutrient concentrations except that the order of increase in concentration was in the pattern of foliage > root > stem >branch.

CHAPTER 6

6.0 Summary and conclusions

The research has provided basic information on the soil nutrient status and potentials of *Acacia senegal* especially through litterfall production and consequent nutrient released.

In carrying out the research, a randomized complete block design (RCBD) with four replicates was employed. Four 30 x 30m plots in the plantation and another plot in open woodland were randomly laid and soil samples were collected .from 0-15 cm, 15-30 cm and 30-60 cm soil depth and analyzed for micro and macronutrients. Litterfall was collected for six months and the decomposition rate of the litter was determined using the litterbag method, while, the tree above and below ground biomass were estimated.

Data collected were analyzed statistically using analysis of variance (ANOVA) techniques, while Duncan's Multiple Range Test (DMRT) was employed in separating the mean values of treatments especially those whose F-tests were significant at 5% probability level. Apart from using the ANOVA, correlation and regression analyses were applied to explain the nature and strength of relationships between some pairs of variables.

The findings which were based on the objectives of the study provide the following:

1. At the natural woodland (control), it was observed that the nutrient pool in the soil was not as much as was found under the *Acacia senegal* plantation. This has negative implications on the soil especially during heavy rainfalls and windstorm which usually blow away the rich organic matter of the topsoil.

2. There was a textural difference between the plantation and the natural woodland used as the control
3. The soil of the plantation has a moderate to high bulk density, while, chemical properties of the soil indicated that the soil was strongly to moderately acid.
4. The micro and macronutrients of the soil generally decreased with increased soil depth. This is ascribed to the fact that as the *Acacia senegal* exploits the soil to meet its nutritional demands, the soil is depleted of basic cations.
5. The comparatively fast decay rates of the litter and the high nutrient output of the litter to the soil and the mineralization of these nutrients are useful evidences that *Acacia senegal* can be planted to improve degraded soil especially in the semi-arid zone of the northern part of Nigeria. Also, improvement of soil properties under *Acacia senegal* indicates that this plant can gradually improve soil quality.
6. Tree enumeration provides the contributions of each different macronutrient to the total biomass of trees at different diameter classes.

6.1 Contribution to knowledge

The major findings of this study are:

a. Most of the micro and macronutrients of the soil are concentrated in the 0-15 cm topsoil.

b. *Acacia senegal* improved soil nutrient status and productivity through litter decomposition and mineralization.

c. The quantity of nutrients produced for the growth of the trees is found in the topsoil and this is usually through mineralization.

d. Macronutrient concentrations of *Acacia senegal* are found to be increasing in the foliage and branches as the diameter of the trees increased.

e. The root of *Acacia senegal* trees contributed less to the total biomass than other components.

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Appendix 4.2: Tree measurements in the sampled plots of *Acacia senegal* at Maifari Plantation, Jigawa State

	PLOT	1	PLOT	2	PLOT	3	PLOT	4
S/No	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)
1.	37.0	4.7	44.1	4.6	33.4	5.1	37.5	5.1
2.	37.0	4.6	22.6	4.4	33.9	5.4	27.2	4.5
3.	26.5	5.3	30.5	4.5	33.4	5.35	32.5	3.6
4.	30.3	4.8	32.7	4.5	26.5	3.4	22.0	4.3
5.	38.5	5.0	20.8	4.3	35.0	5.7	29.6	3.6
6.	43.8	5.0	40.0	3.85	32.5	5.35	17.5	2.6
7.	42.3	5.5	31.2	3.1	32.0	3.9	26.9	3.2
8.	38.0	5.6	25.1	3.6	49.8	4.7	42.9	4.6
9.	31.5	5.4	19.9	3.3	22.0	3.6	38.6	4.1
10.	41.3	5.0	59.4	5.6	34.0	5.0	35.4	4.2
11.	21.5	3.4	28.0	2.6	37.1	4.8	35.4	4.9
12.	43.5	4.6	24.0	3.3	34.5	4.6	36.5	3.6
13.	33.4	3.5	41.8	4.6	28.6	3.35	37.4	4.2
14.	43.2	4.1	32.3	4.6	32.0	3.4	32.2	4.1
15.	33.8	3.6	22.0	4.5	32.7	3.0	34.3	4.6
16.	44.5	5.45	41.2	4.5	34.3	2.6	30.7	4.0
17.	43.0	6.5	20.8	3.4	23.5	2.7	27.7	3.7
18.	50.7	5.6	48.2	5.15	29.5	4.6	27.6	3.1
19.	30.3	4.7	35.3	5.0	34.0	4.4	24.0	3.3
20.	42.3	4.6	31.0	4.9	23.7	4.2	23.0	2.1
21.	23.4	4.2	24.1	4.7	27.0	4.1	32.4	3.7
22.	28.2	4.6	32.2	3.8	27.0	4.2	36.8	3.6
23.	29.5	4.7	43.0	3.4	42.0	4.6	35.1	4.8
24.	37.4	4.5	41.0	3.45	24.3	3.4	33.0	3.1
25.	31.5	4.0	28.3	3.9	40.8	2.7	31.5	3.0
26.	30.4	4.6	28.0	3.95	25.6	4.4	25.0	2.7
27.	47.7	4.7	29.8	3.9	37.9	4.6	30.0	2.9
28.	32.2	4.5	32.5	3.9	33.3	4.2	33.0	4.1
29.	30.0	4.3	18.1	3.1	28.9	4.6	28.9	3.7
30.	46.3	5.3	34.6	3.8	39.8	5.35	21.4	3.6
31.	43.9	4.1	34.5	3.7	28.9	4.85	26.3	3.5
32.	27.5	4.6	28.6	3.5	42.6	4.8	24.8	3.6
33.	39.3	4.5	23.1	3.6	40.3	5.0	37.4	4.1
34.	52.5	4.6	22.9	3.6	31.0	3.35	26.8	3.5
35.	28.3	3.5	45.3	4.6	32.8	4.4	33.8	3.6
36.	30.1	4.5	25.4	3.85	24.0	3.7	30.5	5.1
37.	31.7	4.6	27.8	4.0	38.2	4.5	31.8	4.7

38.	26.3	3.9	38.6	3.6	60.3	5.5	28.6	3.6
39.	26.3	3.6	33.2	3.85	38.2	4.7	43.0	5.2
40.	23.0	3.5	25.4	2.9	36.7	4.8	23.1	4.6
41.	31.1	3.5	29.8	3.1	27.3	3.6	26.0	5.0
42.	22.0	2.8	23.8	3.5	38.1	3.6	37.2	5.1
43.	17.3	3.0	27.0	3.4	36.2	2.8	43.8	5.1
44.	28.2	3.4	22.5	3.35	27.3	2.7	25.9	4.1
45.	30.4	3.2	17.0	3.4	51.9	3.85	31.7	3.9
46.			33.0	4.45	33.2	3.6	42.0	3.9
47.			22.1	3.9	38.6	4.6	47.5	3.85
48.			22.3	4.4	42.3	3.5	17.1	3.6
49.			45.3	4.1	29.5	3.4	22.3	2.6
50.			37.8	3.85	30.2	3.85	32.0	3.6
51.			45.3	3.6	42.3	3.85	32.2	2.6
52.			29.9	3.9	34.3	4.6	20.4	4.0
53.			19.4	3.6	38.7	4.6	28.5	4.1
54.			27.0	3.35	26.0	4.5	38.5	3.9
55.			40.0	3.9	45.0	4.6	29.0	3.9
56.			31.3	3.85	32.5	3.6	28.0	3.8
57.			20.8	3.5	41.8	3.75		
58.			21.5	2.0	30.4	3.1		
59.					17.3	2.5		
60.					34.3	3.9		