PHYSICAL QUALITY OF AN ALFISOL AS INFLUENCED BY CULTIVATION OF *JATROPHA CURCAS* L. AT SAMARU, NORTHERN NIGERIA

BY

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DECLARATION

I hereby declare that the work in this thesis titled **"Physical quality of an Alfisol as influenced by cultivation of *Jatropha curcas* L. at Samaru, Northern Nigeria"** was performed by me in the Department of Soil Science, under the supervision of Professors J.O. Ogunwole, A.C. Odunze and I.Y. Amapu.

Information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree or diploma at any institution.

…….. ……...

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CERTIFICATION

This thesis report titled "**Physical quality of an Alfisol as influenced by cultivation of *Jatropha curcas* L. at Samaru, Northern Nigeria**" by Shehu, Bello Muhammad meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

Dedicated to my late grandmother Hajiya Maimuna who died after prolong illness just few days to the completion of the first draft of this work. May her gentle soul rest in perfect peace (Amen.)

AKNOWLEDGEMENTS

All praises and thanks to Almighty Allah, The Lord of everything and the Master of the Day of Judgment for granting me life and for making this work a reality.

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ABSTRACT

The decline in soil quality is increasingly seen as a form of soil degradation and is often related to land use and soil/crop management practices. The research was conducted at the Research and Experimental Farm of the Institute for Agricultural Research (**IAR**) Samaru, Zaria with the aim of evaluating the influence of *Jatropha curcas* L. (**JCL**) plantation and varied management practices under **JCL** on soil physical quality. To achieve this aim the research was divided into two trials. The first trial involved five adjacent land uses: Arable Land (**AL**), Fallow Land (**FL**), One Year **JCL** plantation (**OYJ**), Two Years **JCL** plantation (**TYJ**) and Three Years **JCL** plantation (**RYJ**). The second trial comprised of three **JCL** spacing rates (1.5 m x 1.0 m, 1.5 m x 2.0 m and 1.5 m x 3.0 m) and four nitrogen levels (0 kg/ha, 60 kg/ha, 120 kg/ha and 180 kg/ha). Soil samples were collected at four depths (0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm) from the various treatments under study and subjected to field and laboratory investigations for soil physical quality indicators such as infiltration, organic carbon, bulk density, aggregate stability, moisture retention, S-index etc. Result revealed that most of the parameters were significantly affected by land use. Cultivation of JCL averagely increased total nitrogen, infiltration, dry large macro-aggregates (>2 mm), dry macro-aggregates (2-0.25 mm), dry mean weight diameter (**MWD**) and dry geometric mean diameter (GMD) by 47%, 26.1%, 28.3%, 13.4%, 18.8% and 12.2% respectively relative to land under continuous arable cultivation (**AL**). Fallow soils (**FL)** recorded high organic carbon, high soil water retention between -2 to -1500kPa and, high total residual pores. Infiltration model evaluation showed Kostiakov's model was more efficient and proved to be an excellent predictor of infiltration over Philip's model. This was manifested as Kostiakov's model gave value closed to unity for coefficient of determination-r^2 (0.96), Nash-Sutcliffe Efficiency-E (0.94) and lower value for Root Mean

Square Error-RSME (22.37) and Coefficient of Variability-CV (6.76%). Applications of different spacing and nitrogen rates to JCL did not significantly influence most soil physical parameters within the three years of plantation establishment.

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CHAPTER ONE

INTRODUCTION

Soil is a living and dynamic natural reservoir and source of plant nutrients that play numerous key roles in terrestrial ecosystems. For most agrarian settlements, the primary function of soil has been production of food, fodder, timber, fiber and fuel (Lal and Shukla, 2004). Plant roots penetrate and explore soil in order to acquire water, oxygen, nutrients and gain structural support for above-ground growth. Demographic pressure with its attendant increase in food demand has resulted in the expansion and intensification of land use systems in the Nigerian Savanna. The intensification of land use systems in the Nigerian Savanna is facing increased abiotic pressure of which soil quality is among the most important. Shorter duration or absence of fallow, unsuitable crop rotation and inappropriate management practices have resulted in degradation of soil quality (Lal, 1993a).

Soil quality degradation, which can be defined as increasing inability of a soil to perform its ecosystem functions, is manifested in persisting problems of erosion, compaction, acidification, organic matter losses, nutrient losses, desertification and chemical contaminations which reduce agricultural production capacity and food security (Larson and Pierce, 1991). Eleven percent of vegetative area and 38 percent of cultivated area of the world have been classified as degraded since 1945 (Hammond, 1992; Gardner and Miller, 2004). Steiner (1996) reported that in Africa, 12 percent of potential agricultural land has been severely degraded, 18 percent has lost substantial productivity and 0.5 percent has become unsuitable for cropping. Comparably in Nigeria, human induced soil

degradation is a common phenomenon, where the severity is light for about 37.5 percent and high for 27.9 percent of the total area (FAO, 2005).

Northern Guinea Savanna zone of Nigeria holds great potentials for agriculture in the country, with Alfisols, Inceptisols and Ultisols (in that order) as dominant soil orders. These soil orders are dominated by low activity clays, inherently low in fertility, high organic matter decomposition rates, limited water availability and soils degrade rapidly under continuous intensive cultivation (Adeoye, 1984; Lombin, 1987; Odunze *et al.*, 1992). Human activities such as high grazing intensity, indiscriminate tree cutting, inappropriate cropping systems and soil mining have resulted in serious degradation of these soils. Therefore, sustainable agricultural management systems need to be employed for the improvement and maintenance of these soils.

Evaluating impact of agricultural practices on agro-ecosystem functions is essential for determining the sustainability of management systems (Liebig *et al.*, 2001). Soil quality is considered a key element for evaluating the sustainability of land management practices (Warkentin, 1995; Wander and Bollero, 1999; Carter, 2002). Numerous physical, chemical and biological properties can be used as indicators for assessing the effect of ecosystem disturbance by human activity on soil quality (Gregorich *et al.*, 1994). Although these properties are interdependent, soil physical quality strongly affects water availability, nutrient adsorption, aeration, rooting ability and thus crop performance; therefore it plays a central role in studies on soil quality (Dexter, 2004a). The study of soil response to different management systems provide valuable information concerning the practices that can improve quality of these soils.

1.1 JUSTIFICATION

The severity and negative consequences of land degradation characterized by decreased land productivity, diminution of biodiversity and loss of CO_2 sink are global in nature and requires reinvigorated attention. Rehabilitation is therefore considered an important remedial approach. Rehabilitation of degraded lands through the establishment of vegetation cover and soil fertility management by application of organic materials are sustainable strategies (Lal, 2004). These measures replenish soil nutrients and organic matter through additional litter fall and root inputs, thus creating favourable microclimate for microbial activities (Fisher, 1995). The rehabilitation process can only be successful if it involves plant species that can withstand adverse conditions and of economic value in such a way that it reduces or alleviates poverty particularly among resource-poor farmers (Lan *et al.*, 1997, Ogunwole *et al.*, 2008)

Limited reserves, greenhouse gas (GHG) emissions and geopolitical challenges associated with fossil fuel resources have necessitated the consideration for alternatives. Biofuels as source of renewable energy have been found to be one of the possible options for development and sustenance of civilization because they derived from biomass and do not significantly contribute to greenhouse effect (Divakara *et al.*, 2009). The unique biological nature (low viscosity and good oxidation stability) and high content of the seed's oil as well as non-palatable nature of the plant brought *Jatropha curcas* L. (JCL) from obscurity to prominence as a potential biofuel feedstock (Kanshik *et al.*, 2007).

Despite keen interest in the development of biofuels, there is much concern on their competing need with food crop production for land and water resources (Ravindranath, 2009). This is one reason why advice on the production of biofuel feedstocks (fuel farming)

has been to focus on "degraded, marginal or wastelands", but these terms may create some confusion. According to Bustamante *et al.* (2009), desirable lands for biofuel feedstock production might be better referred to as lands of low competition, which currently produce little food or are ill-suited for enhanced food production.

Jatropha curcas L. (JCL) is acclaimed to be a hardy shrub that can grow in marginal lands (or lands ill-suited for enhanced food production) with potential for reclaiming degraded soil by checking erosion. In theory, the shrub's roots would recycle nutrients; provide cover to the soil thereby, reducing the impact of raindrops and possibility of soil erosion (Spaan *et al.*, 2004). Furthermore, JCL sheds its leaves in winter (or non-rainy season) which form mulch around the plant base; thus increasing soil organic matter content and promoting soil quality (Singh *et al.*, 2010). There are hypes on the shrub's ability to thrive on almost all soils including gravelly and acidic soils (Openshaw, 2000). These potentials touted for JCL are based on sparse evidence, calling for systematic analysis of the claims. There is a dearth of information on soil quality response under JCL cultivation in the Savanna biome of Nigeria.

Therefore a study to ascertain the impact of JCL cultivation on soil quality in the Savanna biome is needed for production policy, management and sustainability of lands ill-suited for enhanced food crop production.

1.2 OBJECTIVES

The overall goal of the current research was to evaluate the effect of cultivation of JCL on soil quality indicators with the aim of contributing to current efforts being made toward recommendation of best agronomic options for JCL production and its soil rehabilitation potentials in the semi-arid region.

The specific objectives were

I. To determine the effect of JCL plantation on physical quality of Nigerian Alfisol.

II. To evaluate the effect of plant spacing and nitrogen rates on soil physical quality under JCL cultivation.

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCEPT OF SOIL QUALITY

Larson and Pierce (1991) defined soil quality as "the capacity of soil to function within the ecosystem". Three soil functions are considered essential viz. (i) provide a medium for plant growth, (ii) it regulates and partition water flow through the environment and, (iii) serves as an effective environmental filter. Arshad and Coen (1992) defined soil quality as " the sustaining capability of a soil to accept, store and recycle water, nutrients and energy for production of crops at optimum level while preserving a healthy environment. Gregorich *et al.* (1994) defined soil quality as "a composite measure of both a soil's ability to function and how well it functions relative to a specific use" or "degree of fitness of soil for a specific use". Soil Science Society of America Ad Hoc Committee on Soil Quality proposed soil quality as " the capacity of a reference soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen *et al.*, 1997). This definition identifies five functions

I. Sustaining biological activity, diversity and productivity.

II. Regulating and partitioning water and solute flow.

III. Filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials including industrial and municipal by-products and atmospheric deposition.

IV. Storing and cycling nutrients and other elements within the earth biosphere.

V. Providing support for socioeconomic structures and protection for archaeological treasures associated with human habitations.

The concept of soil quality emerged in literature in the early 1990s (Doran and Safely, 1997; Wienhold *et al.*, 2004) but concerns on soil quality are not new because early scientific activities acknowledged the importance of categorizing soil type and soil properties in relation to land or soil use, especially for agricultural purpose (Carter *et al.*, 1997). Soil quality measurement is considered important for the assessment of the extent of land degradation, amelioration and for identifying management practices which promote sustainable land use (Campbell *et al.*, 1998; Carter and Rennie, 1982; Lal, 1993b; Roldan *et al.*, 2003). In general, soil quality consists of three main aspects i.e. physical, chemical and biological quality.

2.2 SOIL PHYSICAL QUALITY INDICATORS

The physical quality of an agricultural soil refers primarily to the soil strength and fluid transmission and storage characteristics in the crop root zone (Topp *et al.*, 1997; Reynolds *et al.*, 2002). Soil physical quality affects chemical and biological processes in the soil, and therefore plays central role in studies on soil quality (Dexter, 2004a). An agricultural soil with good physical quality maintains a good structure, holds crop upright, resists erosion and compaction, allow unrestricted root growth and proliferation of soil flora and fauna while permitting the correct proportions of water, dissolved nutrients and air for both maximum crop performance and minimum environmental degradation (Topp *et al.*, 1997; Reynolds *et al.*, 2002).

The indicators of soil quality are properties and processes that can be measured to monitor changes in the soil (USDA and NRCS, 1996). Not all the soil properties can be regarded as soil quality indicators. The scientific relevance of an indicator of soil quality was suggested by Paris *et al.* (2005) to depend on:

I. Good correlation with the beneficial soil functions
II. Helpfulness in revealing ecosystem processes
III. Comprehensibility and utility for land managers
IV. Cheap and easy to measure

Physical indicators commonly used to assess soil function and quality (USDA and NRCS, 2008) include

I. Infiltration
II. Bulk Density
III. Soil Porosity and Pore Size Distribution
IV. Soil Water Retention and Transmission Characteristics
V. Aggregation and Aggregate Stability

2.2.1 Infiltration

Infiltration is the movement of water into the soil from the surface by downward or gravitational flow (Osuji, 1984). Infiltration rate is defined as the volume flux of water flowing into the profile per unit of soil surface area.

$$i = \frac{Q}{A * T}$$

where,

i=infiltration rate (LT^{-1})

Q=volume of water (L^3) infiltrating

A=area of the soil surface (L^2) exposed to infiltration and

T=time (T)

Infiltration capacity, on the other hand, is defined as the maximum rate at which a given soil, within a given condition, can absorb rain or irrigation water as it falls (Hillel, 1980).

Infiltration is one of the most important indicators of soil physical quality because it is an index of soils' ability to allow water movement into and through the soil matrix and/or profile. Soils temporarily stores water, making it available for root uptake, plant growth and habitation for soil organisms (USDA, 2008). A decrease in infiltration rate will result in increased runoff volume, greater flooding potential and reduced groundwater recharge within the watershed (Gregory *et al.*, 2006).

2.2.1.1 Measurement of Infiltration

Over years, numerous methods have been developed for measuring infiltration rates of soils in the field. The common method has been the use of infiltrometers, which are generally categorized into two types: (1) Rainfall Infiltrometers (2) Flooding Infiltrometers

Rainfall Infiltrometers

A rainfall infiltrometer simulates rainfall with the use of special spray nozzles set at certain distance (usually 2 to 3 m) above the soil surface. The soil surface tested is usually enclosed so that once runoff commences, it can be collected at an opening and the volume measured with time. The difference between the application rate and the runoff rate is taken

to be the infiltration rate. Bertrand (1965) listed four conditions that should be met to produce accurate and representative measurements of the soil infiltration rate using rainfall infiltrometers:

I. The distribution of drop sizes must be uniform over the plot area;

II. The artificial rainfall must be similar to the natural rainfall being simulated in respect of drop size, drop velocity, intensity range, and total energy value.

III. The plot area must be large enough to sample the population and give reproducible results (approximately 1 m^2) and;

IV. The artificial rainfall must be applied not only to the plot but also to an adequate buffer area around the plot.

The aggressive nature of rainfall in the semi-arid region with intensity of more than 300 mm hr^{-1} within 6 minutes as reported by Hoogmoed (1986) can be very difficult to simulate. Another limiting factor to the use of rain simulator is that a lot of water and a large power generation are required for rainfall simulation covering just an area of $10m^2$ or more (Hoogmoed *et al.*, 1991).

Flooding Infiltrometers

Flooding infiltrometers enclose an area and pond water to a specified depth. The infiltration rate is calculated from the drop in water level per unit time or the amount of water required in maintaining the specified depth or head of water per unit time. Flooding infiltrometers measure the maximum rate of entry of water into the soil. They do not simulate raindrop activity; they measure water penetration rather than rainfall infiltration. Usually there is a buffer zone of water around an inner compartment of water to correct for lateral movement

of water (due to matric potential); so that the inner compartment can be a measurement of the true vertical infiltration rate. There are two types of flooding infiltrometers; the basin infiltrometer which uses earth retaining walls; and the ring infiltrometer which uses metal rings inserted into the ground to retain the water.

Basin Infiltrometer: The basin infiltrometer uses soil from the outside of the basin to construct the paired dykes, thus ensuring zero or near zero disturbance for the soil within the dyked areas. The size of the plots, $1m^2$ up to 0.2 ha usually accounts for any local soil variation thus reducing the need for replication. These sizes also reduce errors due to lateral flow especially when a buffer compartment is built. The disadvantages to this type of infiltrometer are the site disturbance and the necessary power equipment and labour to construct the basins and to supply the water.

Ring-Type Infiltrometer: The ring infiltrometer is perhaps the most common type of infiltrometer used. It is inexpensive to construct and operate, and requires relatively little water compared with the basin infiltrometer. The simplicity of its design allows for ease of replication and operation.

Two concentric rings (double ring) of stainless steel are commonly employed; the larger ring forms a buffer compartment around the inner to prevent lateral flow (Fig. 2.1). The rings are jacked or hammered into the ground 5 to 10 cm. Care is taken to minimize disturbance of the soil surface and the soil structure during installation. Measurements are made on the rate of fall of water in the inner ring, while water infiltrating into the soil between the two rings ensures one-dimensional vertical flow (FAO, 1979). The length of time required to achieve steady infiltration rate ranges from 2 to 6 hours depending upon soil type, texture, and antecedent soil moisture conditions.

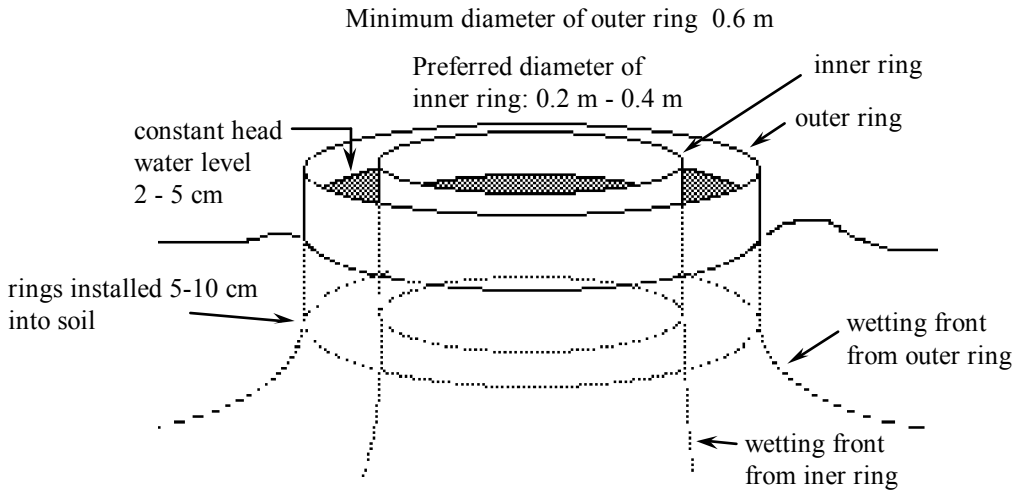


Fig. 2.1: Schematic representation of a double ring infiltrometer

Despite the advantages of ring infiltrometers over other infiltrometers, it has the following demerits (Tricker, 1978; Clemmens, 1981)

I. 'Edge effects' caused by local soil disturbance along the edges and internal stresses set up in the inner ring as a result of installation. Avoidance of rocking during installation of the rings could minimize this problem.

II. It is difficult to maintain accurate water head when manually pouring-in water. This could lead to over estimation especially where measuring scale is a float. A constant head device such as the marriotte bottle will ameliorate this problem.

III. In dry climates, infiltration rates especially in low permeable soils may be overestimated due to contribution of evaporation losses.

IV. Air may become entrapped during ponding, thereby creating internal air cushions which impedes infiltration. As a result, infiltration rate may drop, appear stationary, or seen to increase after the escape of the encapsulated air.

V. The method is not suitable for soil with larger fractions of macropores where flow cannot be one-dimensional, or for soils with fragile surface crusts which will break when the rings are pushed into the ground.

VI. There is possibility of overestimating infiltration rate when the wetting front goes beyond the end of the rings.

2.2.1.2 Factors Affecting Infiltration

The infiltration rate of soil depends on the texture and structure of the soil, the antecedent soil moisture content, continuity and stability of pores and soil matric potential (Lal and Vandoren, 1990). Soil management including tillage, rotations, residue management etc., influences these factors (Lal and Shukla, 2004).

Soil Texture

Infiltration rate has been reported to exponentially increase as particle size increased (Babaji, 1982). Kohnke (1968) found infiltration rate in loamy sand to be ten times higher than in clay loam, while it was three times higher in silt loam than in clay loam. More recently, Phene (2004) reported that clay soil had the slowest infiltration rate followed by fine sandy loam while the sand had the fastest infiltration rate. This trend has been attributed to (i) the abundance of large and continuous aeration pores in coarse-textured soils, and (ii) the tendency of colloidal particles in fine-textured soils to swell upon hydration thereby reducing cross-sectional area available for flow (Babaji, 1982; Babalola, 1986).

Soil Structure

High infiltration rate is associated with well aggregated soil, while structurally weak soils are characterized by low infiltration. Hillel (1968) reported soils that are highly porous and of "open" structure, having initial infiltrability that exceeds that of soils whose surface is crusted. Removal of layers suspected to be crusted, resulted in significant increase in infiltration at Samaru (Babaji, 1982; Adeoye, 1986). Soil surface covered with mulch improves soil aggregation by reducing the raindrop impact which in turn resulted in high infiltration as opposed to bare soil surface (Adeoye, 1986). Alhassoun (2009) observed that higher soil infiltration rates were associated with higher soil aggregate stability in the forest compared to arable land. This result is in accordance with Schnug and Haneklaus (2002) who indicated a positive association between soil mechanical stability and infiltration rate.

Porosity

For water to infiltrate into the soil there must be a conduit through which it must be conveyed. These conduits could be pores formed because of structural arrangement of soil particles. Features such as cracks, fissures, and root channels could also make a soil porous. These features contribute to total soil porosity and affect infiltration and hydraulic conductivity (Kureve, 1991). Previous studies revealed that infiltration of water into soils is directly related to soil macroporosity (Edwards *et al.*, 1979; Dick *et al.*, 1989; Blevins *et al.*, 1990). These studies showed that runoff is much less when soil contains a large number of macropores compared with soil that has few macropores. Similarly, studies to quantify macropore flow under rainfed condition by Watson and Luxmore (1986) indicated that more than 70 per cent water flux can move through the macropores. Hillel (1982) reported

compaction and surface crusting as infiltration inhibitors that reduce infiltration in the largest soil pores resulting in diminished infiltration rate.

Antecedent Soil Moisture Content

Infiltration rate tends to be higher in a soil which was initially dry. Water moves slowly in to the soil when moisture conditions are high (Babaji, 1982; Babalola, 1986). Ward (1967) attributed this to reduction of the soil capacity to receive any additional moisture, reduction of the hydraulic gradient across the wetting front and swelling of soil particles. The influence of initial moisture content becomes less and ultimately negligible as infiltration proceeds. This means, the initial moisture content does not influence the equilibrium rate except that soils which are already wet when rain falls upon them attain final infiltration rate more quickly (Philip, 1957).

2.2.2 Bulk Density

Bulk density of soil which is also called apparent density is the ratio of mass of solid to the total volume (solids and pore together) of the soil (Lal and Shukla, 2004). Bulk density reflects the soil's function for structural support, water and solute movement and soil aeration. High bulk density is an indicator of low soil porosity and compaction (Arshad *et al.*, 1996). It may cause restriction to root growth and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth. Furthermore, by reducing water infiltration into soils, compaction can lead to increased runoff and erosion from sloping land. Arshad *et al.* (1996) described various bulk density values which affect plant growth in different textural classes (Table 2.1).

Soil bulk density depends on natural soil characteristics such as texture, organic matter content, soil structure (Cassel, 1982; Chen *et al.*, 1998) and gravel content (Frazen *et al.*, 1994). Bulk density varies between and within the year due to the action of several processes: freezing and thawing (Blevins *et al.*, 1983; Unger, 1991), settling by desiccation and kinetic energy of rainfall (Cassel, 1982), and loosening by root action and animal activity.

Land use and crop management practices also influence soil bulk density. For instance, continuous cultivation and removal or burning of residues increase soil bulk density while continuous cropping and addition of organic amendments lower soil bulk density (USDA and NRCS, 1996). Jiao *et al.* (2011) observed that re-vegetation had a positive effect on soil bulk density by decreasing the values. Furthermore, among five land uses (shrub land, farm land, natural grassland, wood land and artificial grassland) studied by these workers, shrub land had the highest bulk density of 1.35 g/cm^3 compared to artificial grassland with the lowest value of 1.24 g/cm^3. Huang *et al.* (2002) also found that bulk density significantly increased in continuously cropped land compared to a grass conservation land. Lampurlanes and Cantero-Martinez (1997) observed that bulk density was lower in fallow (1.26 g/cm^3) than in the continuously cropped plots (1.32 g/cm^3). Organic matter-rich land was found to have lower soil bulk density (1.26 g/cm^3) value compared to a conventional land with bulk density of 1.34 g/cm^3 in an Udic soil (Liebig and Doran, 1999).

Table 2.1: General relationship between soil texture, bulk density and root growth

Soil Texture	Ideal Bulk Densities (g/cm^3)	Bulk Densities That May Affect Root Growth (g/cm^3)	Bulk Densities That Restrict Root Growth (g/cm^3)
Sands, Loamy Sands	<1.60	1.69	>1.80
Sandy Loam, Loams	<1.40	1.63	>1.80
Sandy Clay Loams, Clay Loams	<1.40	1.60	>1.75
Silts, Silt Loams	<1.30	1.60	>1.75
Silt loams, Silty Clay loams	<1.40	1.55	<1.65
Sandy clays, Silty clays, Some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Source: Arshad *et al.* (1996)

2.2.3 Soil Porosity and Pore Size Distribution

Generally, soil pores can be expressed in two ways i.e. quantitative and qualitative characterization (Adonis-Habib, 1985). Quantitatively, soil pores can be expressed as total porosity which is the ratio of soil fluid volume (air and water) divided by the total volume. It is commonly calculated as unity minus the fraction of bulk density by particle density (Hillel, 1998).

$$f = \frac{v_f}{v_t} = \frac{v_a + v_w}{v_a + v_w + v_s} \qquad \text{(A)}$$

$$f = 1 - \frac{\rho_b}{\rho_p} \qquad \text{(B)}$$

To verify whether equation B=A,

$$f = 1 - \frac{\rho_b}{\rho_p}$$

By substituting the relative definitions of f, ρ_b, ρ_p, we can rewrite the equation as

$$\frac{v_f}{v_t} = 1 - \frac{\left(m_s / v_t \right)}{\left(m_s / v_s \right)}$$

Simplifying the right hand side, we obtain

$$\frac{v_f}{v_t} = 1 - \left(\frac{v_s}{v_t}\right) = \frac{(v_t - v_s)}{v_t}$$

But since v_t-v_s = v_f we have

$$\frac{v_f}{v_t} = \frac{v_f}{v_t}$$

f = Total porosity (L^3 L^{-3}), v_a = Volume of air (L^3), v_w = Volume of water (L^3),

v_s = Volume of solids (L^3), ρ_b = Bulk density (Mg L^{-3}), ρ_s = Particle density (Mg L^{-3})

Additionally, total porosity is sometimes partitioned into microporosity and macroporosity which are determined by the following formulae (Bonneau and Levy, 1982).

$$m = c \times f$$
$$M = f - m$$

m = Microporosity (L^3 L^{-3}), M = Macroporosity (L^3 L^{-3}), c = Field capacity (L^3 L^{-3}), f = Total porosity (L^3 L^{-3})

Total porosity varies with texture and structure. It tends to be lower in coarse-textured than fine-textured soils and decreases when soil is poorly aggregated (Adonis-Habib, 1985).

Macropores are large tubes involved in soil drainage and aeration while micropores serve to retain water after drainage has taken place. Macropores are associated with the movement of excess water and gravimetric potential. On the other hand, micropores relate to unsaturated flow and matric potential (Hillel, 1982; Meriaux, 1982).

In the same vein, Nimmo (1997) and Meriaux (1982) divided porosity into textural (intra-aggregate) and structural porosity (inter-aggregate). Textural porosity means very fine pores which result from size, shape and disposition of mineral particles in elementary assemblies. Structural porosity corresponds to large pores existing between aggregates (gap porosity) and clods influenced by tillage, climate and biological activities. It is more dynamic part of porosity and is commonly used to study soil structural changes after tillage (Guerif *et al.*, 2001). Scientists have recognized various types of pores (Table 2.2) and different diameters are used to distinguish between macropores and micropores (Luxmoore, 1981).

Tisdale and Oades (1982) noted that aggregates need to contain enough pores to remain aerobic and enough small pores to hold plant-available water. Macroporosity (structural porosity) is sensitive to variation in cultivation practices and can increase under no-till management (Elliot and Coleman, 1988). These large pores play an important role in allowing roots, gas and water penetration in the soil (Perret *et al.*, 1999).

In agricultural lands, soil compaction is one of the environmental factors that adversely affect soil function. Heavy machinery used for tillage and other operations can compact the soil, resulting in increased soil bulk density, a decrease in total porosity and a change in the pore size distribution. Rasumssen (1999) reported differences in total porosity at topsoil and subsoil layers with varied types of tillage practices. Also, Shipitalo *et al.* (2000) found that total porosity often increased with the adoption of reduced tillage compared with conventional tillage. Liebig and Doran (1999) observed a decrease in bulk density of organic soil relative to conventional land which simultaneously resulted in an increase in total porosity of the organic soil.

Table 2.2: Some classification systems of soil pores based on their size distribution

Reference	Equivalent cylindrical diameter (ECD, μm)	Pore category
Brewer (1964)	>5000	Coarse macropores
	2000-5000	Medium macropores
	1000-2000	Fine macropores
	75-1000	Very fine macropores
	30-75	Mesopores
	5-30	Micropores
	0.1-5	Ultramicropores
	<0.1	Cryptopores
Jongerius (1957)	100-5000	Macropores
	30-100	Mesopores
	0.002-30	Micropores
IUPAC[a] (1972)	0.1-5000	Macropores
	0.005-0.1	Mesopores
	<0.005	Micropores
Mclntyre (1974)	500-5000	Superpores
	50-500	Macropores
	0.1-50	Minipores
	<0.1	Micropores
Smart (1975)	100-5000	Macropores
	30-100	Minipores
	<30	Micropores
Kay (1997)	<30	Macropores
	0.2-30	Mesopores
	<0.2	Micropores

[a] International Union of Pure and Applied Chemistry

2.2.4. Soil Water Retention and Transmission Characteristics

The amount of water absorbed before surface runoff starts and the amount of water a particular soil supplies to maintain optimum plant growth is strongly determined by soil water content (Kamara *et al.*, 1992). A parameter often used to describe soils' ability to supply plants with the water they need is the available water capacity (AWC). Available water capacity (AWC) is the amount of water a soil can store that is available for use by plants (Lipsius, 2002). It is defined as the water held between field capacity (FC) and the water content at permanent wilting point (PWP). Field Capacity represents the upper limit of water available to plants and equilibrium pre-saturated soil samples with a matric potential value between -10 kPa and -33 kPa for light to heavy textured soils respectively (Jury *et al.*, 1991). While permanent wilting point (PWP) represents the lower limit of plant available water which is retained by soil particles with -1500 kPa matric potential value. Soil texture especially clay content, porosity, pore size distribution, and soil organic matter content have been reported to influence FC (Lal and Shukla, 2004), where all the aforementioned soil characteristics have a positive influence on FC (Lal, 1979a). Permanent Wilting Point is primarily determined by the amount and nature of clay (Lal, 1979b); the PWP is higher in soils with high clay content. It is higher in 2:1, expanding – lattice/more surface area clay minerals than the soils with 1:1, fixed-lattice /low surface area clay minerals.

The availability of soil moisture to plants is a function of water input, moisture retention and root depth of a given soil, which are governed by the inherent soil properties and management practices. Earlier works revealed that soil moisture retention and plant available water were affected by various management practices. Alliaume *et al.* (2010)

reported 17% reduction in plant available water on cropped fields compared to their fallow pairs due to higher organic matter content in the latter. In another research the high organic matter stored in forest soil resulted in high amount of water retained at FC (179±2 mm) when associated with lower content (106±9 mm) observed in arable land (Wahren *et al.* 2009). Also, higher soil moisture content was observed under conservation tillage than conventional tillage systems (Ohiri *et al.*, 1990; Khan *et al.*, 1999). Liebig and Doran (1999) reported that organic matter application improve water-holding capacity of soil.

2.2.5 Aggregation and Aggregate Stability

Aggregation is defined as the process whereby individual soil particles are joined into compound particles, clusters or aggregates (Sullivan, 2004). Aggregation is an important indicator for the soils' overall quality (Boix-fayos *et al.*, 2001; Oades, 1984). It has potential benefits on soil moisture status, nutrient dynamics, tilth maintenance and erosion reduction (Oades, 1984; Kemper and Rosenau, 1986). The term aggregate stability is used by soil physicists to refer to the ability of the bonds of aggregation to resist stress upon exposure (Rohoskova and Valla, 2004). In determining the stability of soil aggregates, soil physicists generally subject samples of aggregates to artificially induced forces designed to stimulate phenomena which are likely to occur in the field (Hillel, 1980). Resistance of soil solids to mechanical abrasion arising from the two forces of destruction i.e. water and air has for long been used to measure stability of aggregates. The technique for aggregate stability analysis is described by Kemper and Rosenau (1986). Wet sieving technique discussed by Angers and Mehuys (1993) and dry sieving by White (1993) are the common methods employed to simulate aggregate resistance to water and wind erosion respectively.

Numerous factors affect stability of soils (Hamblin, 1985; Kay, 1997), most of which can be broadly grouped into two: endogenous and exogenous factors. The endogenous factors are those that are due to inherent soil properties. These factors include soil characteristics such as texture, clay mineralogy and nature of exchangeable cations, and quantity and quality of humus fraction (Lal and Shukla, 2004). The exogenous factors that affect soil aggregate stability include weather, biological processes, land use and management. Soil management or land use has been reported to influence soil aggregation and aggregate stability (Six *et al.*, 2000).

Pinheiro *et al.*, (2004) found at soil surface (0-5 cm), aggregates >2 mm formed 50 per cent of soil under no-tillage, which was greater than that under animal traction (35 per cent) and conventional (30 per cent) tillage. Soil organic carbon (SOC) was higher under no-tillage (19g kg^{-1}) than conventional tillage (11g kg^{-1}), and SOC was attributed as reasons for the difference in aggregate fraction. Similarly, Gajic *et al.* (2006) reported that conversion of forest to continuous cropping by conventional cultivation significantly decreased the water stability of soil aggregates in the plough horizon. In another work, mean weight diameter (MWD) was significantly higher in un-cultivated land, whereas addition of compost to the cultivated land improved stability of the soil (Adesodun and Odejimi, 2010).

As it has been reported, soil organic matter and clay content are the main soil properties affecting soil aggregation as they bind individual particles (Skidmore and Layton, 1992; Fryrear *et al.*, 1994). Therefore, practices that reduce organic matter and disturb clay particles reduce soil aggregation.In general the concept of aggregate stability depends on both the forces that bind particles together and the nature and magnitude of the disruptive stress (Beare and Bruce, 1993).

2.3 S-INDEX OF SOIL PHYSICAL QUALITY

Efforts have been made for quite sometimes to quantify the soil physical environment, but one parameter found sensitive to a particular soil may not be suitable for another. Recently, to integrate major physical indicators that influence soil quality, a unified soil physical quality index (S) had been proposed by Dexter (2004a). S-index is defined as the slope value or inclination of the soil water retention curve (SWRC) at its inflection point. This curve must be plotted as the logarithm to base e (log e) of the water potential against the gravimetric water content (kg kg^{-1}). The symbol S had been used because it is a measure of the slope of the water retention curve and therefore a measure of soil structure (particularly, the microstructure). It was suggested that the use of soil physical properties for the quantification of soil physical quality be called S-theory. Furthermore, it was proposed that the index S provides a scale that can be used to compare easily the physical quality of different soils or the effects of different soil management systems (Dexter, 2004b).

Though it is possible to obtain values of S from the slope at the inflection point by measuring directly on a graph, the moisture retention data can be fitted into a mathematical function and the slope at the inflection point of the SWRC is calculated from the estimates of the parameters of the used function. The Van Genuchten (1980) function is one of the most frequently used and in many studies, their parameters can be described from pedotransfer functions. Pedotransfer functions (PTF) to estimate SWRC have been widely developed and used in temperate climate soils (Wösten *et al.*, 1999; Tormena *et al.*, 1999) and to certain extent for Brazilian tropical soils (Tormsella *et al.*, 2000; Hodnett and Tormasella, 2002).

Dexter (2004b) suggested the following categories of the index-S of soil quality; S<0.020 as very poor; 0.020<S>0.035 as for poor and S>0.035 as good. Garg *et al.* (2009) concluded that management practices that led to decreased bulk density and increase in organic carbon content, available water capacity resulted in larger values of S.

2.4 *JATROPHA CURCAS* L. AND SOIL QUALITY

Jatropha curcas L. (JCL) is a deciduous, monoecious and perennial shrub belonging to the botanical family of Euphorbiaceae, and tribe Jatropheae of the subfamily Crotonoideae. Common names vary according to the region. In English, it is called 'Physic nut' or 'Barbados nut'. The plant is indigenous to parts of Central America, however, it has spread to the tropical and subtropical regions in Africa and Asia (Henning, 1996). It is easy to establish and can grow up to 5-7 m tall with life expectancy of up to 50 years (Achten, 2010).

Jatropha curcas L. (JCL) is a multipurpose plant with numerous valuable attributes and considerable economic potentials. The seeds of JCL contain 46-58 per cent of oil on kernel weight and 30-40 per cent on seed weight (Subramanian *et al.*, 2005; Halilu *et al.* 2011). In recent years, the shrub has drawn attention as a source of oil seed that can provide an economically viable substitute and /or complement for motor engines (Openshaw, 2000; Adebowale and Adedire, 2006; Chen *et al.*, 2006). Aside from this, JCL oil has high saponification value in the range of 169.9 to 208.3 KOH/g of oil (Adebowale and Adedire, 2006; Akbar *et al.*, 2009; Kywe and Oo, 2009) and is used in India and other countries for soap making. Preparations of all parts of the plant, including seed, leaf and bark; fresh or as a decoction are used in traditional medicine and veterinary purposes. It is non-edible or

toxic and can be used as live fence, especially to contain or exclude farm animals (Heller, 1996).

Jatropha curcas L (JCL) has remarkable capacity to survive in diverse climatic conditions (such as in areas of low rainfall) and almost on any type of soil whether gravelly, sandy or fairly saline and thrives even on the poorest stony soils and rock crevices (Singh *et al.*, 2010). Nevertheless, due to poor aeration caused by waterlogging or saturation, clay soils are unsuitable for the plant (da Sachio, 2010). Some evidence indicates the possibility of JCL in reclaiming marginal soils by re-anchoring the soil with its substantial root system. In theory, the plant's deep roots could recycle nutrients, provide shade to soil thereby reducing the possibility of erosion (Spaan *et al.*, 2004). Reubens *et al. (*2010) demonstrated that the root structure of JCL could be promising to control erosion by water and wind on arid land. The lateral roots could decrease soil erodibility through additional soil cohesion while the tap root and sinkers may enable exploitation of subsurface soil moisture and enhance vegetative cover, even in very dry environment. Cultivation of JCL resulted in 11 per cent increase in mean weight diameter (MWD) and 2 per cent increase in macro-aggregate turnover in a degraded Indian Entisol (Ogunwole *et al.*, 2008), implying improvement in the surface integrity of the soil.

Jatropha curcas L. (JCL) sheds its leaves in winter which form mulch around the plant base, thereby increasing organic matter and enhancing earthworm population around root zone, thus increasing soil fertility and quality (Singh *et al.*, 2010). The shrub produced 2.27 ton/ha, 1.10 ton/ha and 0.79 ton/ha of leaf litter in a year when planting spaces of 1 m x 1 m, 2 m x 1 m and 3 m x 1 m respectively were adopted (Abugre *et al.*, 2011). The leaf

biomass shed can be used as a source of nutrients rather than mulch due to biomass rapid decomposition.

There are further reports that the plant can remediate heavy metals in polluted soil particularly Zn, Cu and Cr (Ahmadpour *et al.*, 2010) Cd and Pb under greenhouse condition have also been reported (Mangkoediharjo and Surahmaida, 2008).

CHAPTER THREE

MATERIALS AND METHODS

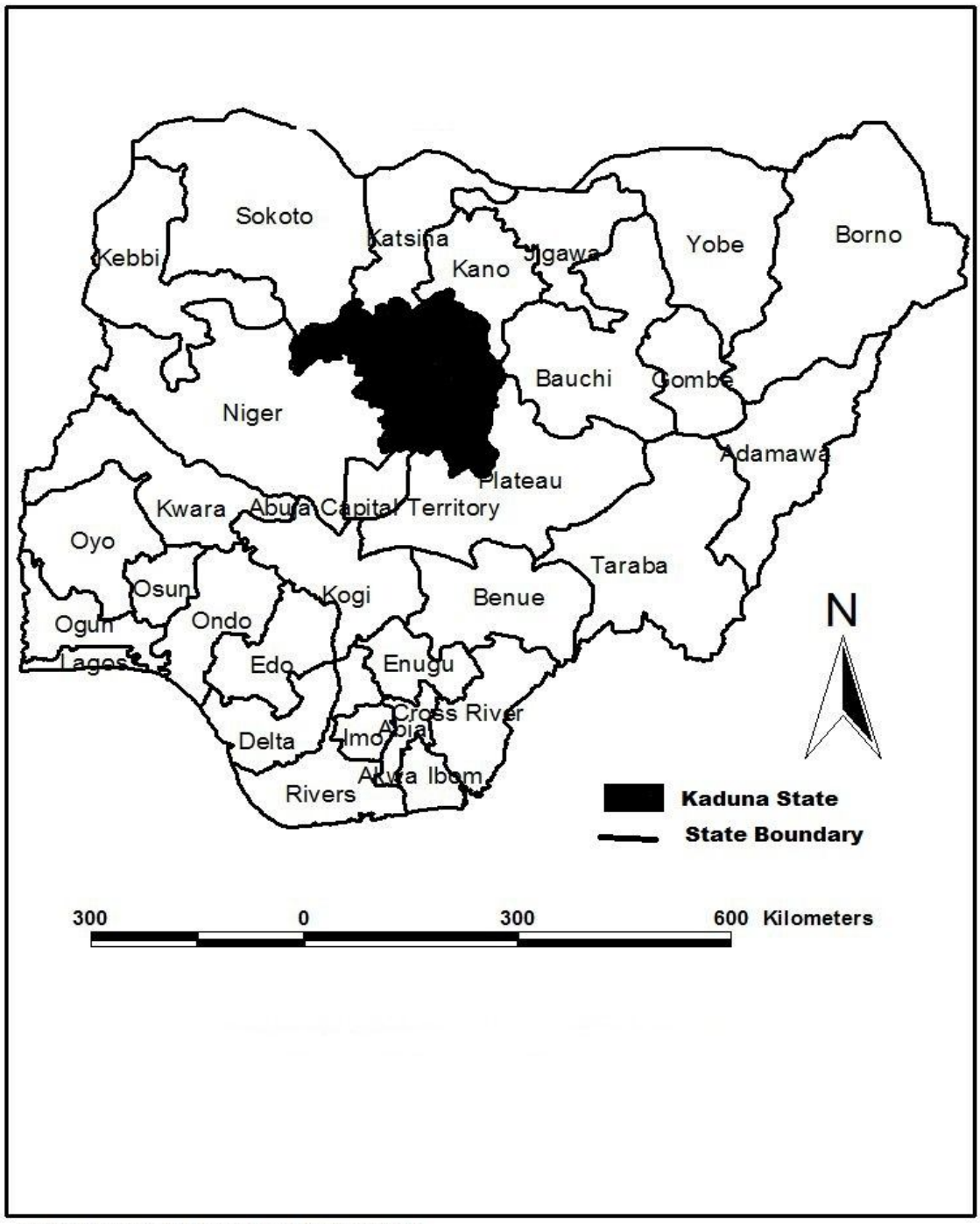
3.1 PHYSICAL SETTING OF THE STUDY AREA

3.1.1 Location

The research was conducted at the experimental farm of the Institute for Agricultural Research (IAR), Samaru-Zaria, Kaduna State, Nigeria located at coordinates $11^0$11□19.3□□N and $007^0$37□02.16□□E, and 686 m above the sea level (Figures 3.1 and 3.2). The area is situated in the Northern Guinea Savanna agro-ecology of Nigeria with a monomodal rainfall pattern and long-term mean annual rainfall of about 1011±161 mm concentrated almost entirely in five months (May/June to September/October) and mean daily temperature of 24 ^{0}C (Oluwasemire and Alabi, 2004). A total rainfall of 877.3 mm, 26.5 ^{0}C mean daily temperature and 46.3 % mean daily relative humidity were recorded in the research year 2011 (Table 3.1).

3.1.2 Geology and Soil

The soil type in the study area is leached tropical ferruginous soil classified as Typic Haplustalf according to USDA Soil Taxonomy (Ogunwole *et al.*, 2001). The soil also falls into the order Acrisol in the FAO-UNESCO legend (Valette and Ibanga, 1984; Uyovbisere *et al.*, 2000) and is developed on deeply weathered pre-Cambrian Basement complex overlain by Aeolian drift of varying thickness.



Source:Carto unit Geo Dept. BUK (2011)

Fig. 3.1: Map of Nigeria showing Kaduna State

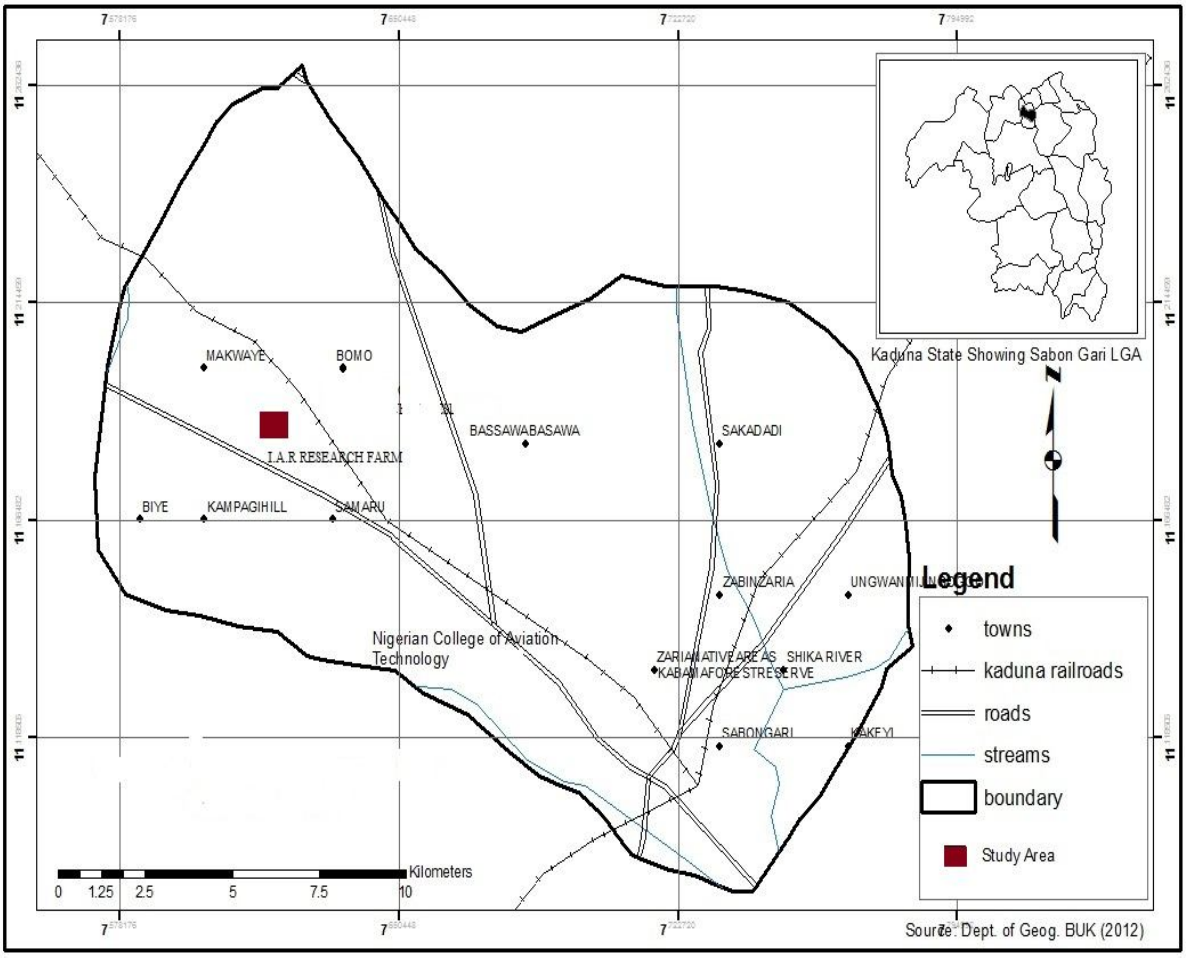


Fig. 3.2: Map of Sabon Gari LGA of Kaduna State showing the study area

Table 3.1: Samaru Mean Monthly Weather Record (2011)

Month	Average Relative Humidity (%)	Average Air Temperature (^{0}C)	Total Rainfall (mm)
January	16.0	21.6	0
February	18.3	27.4	0
March	11.1	29.1	0
April	26.1	30.2	13.9
May	55.9	28.7	123.3
June	68.8	26.6	162.5
July	78.0	25.5	223.9
August	76.2	25	239.9
September	66.7	24.6	113.8
October	-	-	-
November	-	-	-
December	-	-	-
	Average	**Average**	**Total**
	46.3	**26.5**	**877.3**

3.2 RESEARCH DESCRIPTION AND SOIL SAMPLING

The research was divided into two trials.

3.2.1 Trial One: Land use effect on soil physical quality

Trial one evaluated the effect of five adjacent land uses on soil physical quality. The land uses were: (i) One Year JCL plantation (**OYJ**) (Plate I) (ii) Two Years JCL plantation (**TYJ**) (Plate II) (iii) Three Years JCL plantation (**RYJ**) (Plate III) (iv) Arable Land (**AL**) (Plate IV) which was cropped to maize in 2008 and 2009, and cowpea in 2010 rainy season (v) Fallow Land (**FL**) (Plate V) which had been under natural vegetation for more than five years and dominated by the following grass and shrub species: *Cyperus rotundus* L., *Andropogon gayanus* L., *Loudetia annua*, *Piliostigma reticulatum*, *Daniellia oliveri* and *Guera senegalensis*.

Soil samples were evaluated at four depths 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm in May, 2011. A stratified random sampling technique (Peterson and Calvin, 1986) was adopted, where each area under the various land uses was divided into five equal sub-divisions (pseudo-replicates). Four random samples were taken from each sub-division at each depth and bulked to give one composite sample. This gave 400 random points and 100 composite samples.

3.2.2 Trial Two: Effect of spacing and nitrogen rates under JCL on soil physical quality

The second trial evaluated the effect of spacing and nitrogen rates under JCL on soil physical quality. The trial was laid out in a split-plot design involving three spacing rates (1.5 m x 1 m, 1.5 m x 2 m and 1.5 m x 3 m) as main-plot treatments and four nitrogen levels (0 kg ha^{-1}, 60 kg ha^{-1}, 120 kg ha^{-1} and 180 kg ha^{-1}) as sub-plot treatments, replicated

three times (Plate VI). Soil samples were collected at four depths 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm from each of the treatment combinations giving a total of 144 samples.



Plate I: One year *Jatropha curcas* plantation
($007^0$36'59.4"E, $11^0$11'21.6"N)



Plate II: Two years *Jatropha curcas* plantation
($007^0$37'03.66"E, $11^0$11'20.4"N)



Plate III: Three years *Jatropha curcas* plantation (007^{0}37□00.01□□E, 11^{0}11□16.8□□N)



Plate IV: Arable land (007^{0}37□02.46□□E, 11^{0}11□19.2□□N)



Plate V: Fallow land ($007^0$37□02.46□□E, $11^0$11□19.2□□N)



Plate VI: *Jatropha curcas* plantation under different spacing and nitrogen rates ($007^0$37□00.84□□E, $11^0$11□20.4□□N)

3.3 MEASUREMENT OF SOIL PARAMETERS

3.3.1 Infiltration

Infiltration study was carried out only in Trial One of the research where 50 runs were carried out at two randomly selected points in each sub-division (pseudo-replicate) by means of double ring infiltrometer (plate VII). Antecedent moisture content was equally measured at each of these points by gravimetric method.

The double ring infiltrometer is a set consisting of a large outer ring and a small inner ring. Three sets of different diameters were used. The first set had an outer ring of 60 cm and an inner ring of 35 cm in diameter. The second set had an outer and inner ring of 58 cm and 33 cm diameter respectively, while the third set had an outer and inner ring of 55 cm and 30 cm diameter, respectively. Other accessories used include impact absorbing hammer, driving plate, calibrated ruler and stop watch.

The infiltration study was commenced by first adding water to the outer ring and allowing the water to infiltrate into the soil for sometimes before water was added to the inner ring. This was done with the aim of providing buffer to discourage lateral flow and encourage one-dimensional flow (Clemmens, 1981). The depth of water infiltrating into the soil was measured using calibrated ruler attached to the inside of the inner ring at 5, 10, 20, 30, 40 and 60 minutes time intervals which is equivalent to 5, 15, 35, 65, 105 and 165 minutes respectively.



Plate VII: Field infiltration study using double ring infiltrometer

3.3.2 Infiltration Models Fitting

Kostiakov (1932) and Philip (1957) infiltration models were tested, The Kostiakov's model is given as follows

$F = Kt^{n}$, where F = cumulative infiltration (mm/hr), t = time (hr), K and n are constant

Philip's model is given as

$F = St^{\frac{1}{2}} + At$, where F = cumulative infiltration (mm/hr), S= sorptivity (constant), A= constant

A comparison between measured and model predicted infiltration rate was used to determine best fitting model using Coefficient of Determination (r^2), Root Mean Square Error (RMSE), Coefficient of Variability (CV) and Nash-Sutcliffe Efficiency (E). The statistical tools were given as (Moriasi *et al.*, 2007; Krause *et al.*, 2005).

$$r^2 = \left[\frac{\sum_{i=1}^{n} \left(O_i - \bar{O} \right) \left(P_i - \bar{P} \right)}{\sqrt{\sum_{i=1}^{n} \left(O_i - \bar{O} \right)^2} \sqrt{\sum_{i=1}^{n} \left(P_i - \bar{P} \right)^2}} \right]^2$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 \right]^{0.5}$$

$$CV = 100 * \frac{\left[\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 \right]^{0.5}}{\bar{O}}$$

$$E = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} \left(O_i - \bar{O} \right)^2}$$

where P_i = predicted values, O_i = observed values, $\bar{O}$ = observed mean values, $\bar{P}$ = predicted mean values

The coefficient of determination (r^2) which describes the degree of collianearity between observed and predicted data range between 0 and 1. A value of 0 means no correlation at all whereas a value close to 1 means that the dispersion of the prediction is equal to that of the observation. The RMSE is a measure of precision while CV (%) is a measure of variability between predicted and observed data. As the precision between predicted and observed value increases, RMSE tends towards 0. Also, lower CV is an indication of good fit model because the lower the CV, the smaller the error relative to the predicted value (Moriasi *et al.*, 2007). Nash-Sutcliffe Efficiency (E) lies between 1 (perfect fit) and - ∞, an efficiency lower than 0 indicates that the mean value of the observed data would have been a better predictor than the model.

3.3.3 Particle Size Distribution

Particle size distribution of the soil less than 2-mm fine earth fraction was analyzed using Bouyoucos (1951) hydrometer method as described by Gee and Bauder (1986). Fifty grams of sieved soil was weighed into plastic bottle, 100 ml of sodium hexametaphosphate (Calgon) was added into the bottle and the mixture placed on a mechanical shaker and agitated for 10 minutes. The mixed sample was then transferred into one-litre capacity measuring cylinder and made up to mark with water. The suspension was stirred with a plunger before inserting the hydrometer. The hydrometer reading after 40 seconds was

recorded for determining silt and clay content, and the second reading after 2 hours was recorded in order to determine the clay content. The temperature of the suspension at first and second hydrometer readings was recorded and used for the correction of hydrometer readings. The value, 0.36 was added for any degree above 20^0C or removed for any degree of temperature below 20^0C. The particle sizes were calculated as follows

$$\% \text{ (clay + silt)} = \frac{\text{corrected 40 seconds hydrometer reading}}{\text{Weight of soil taken}} \times 100$$

$$\% \text{ clay} = \frac{\text{corrected 2 hours hydrometer reading}}{\text{Weight of soil taken}} \times 100$$

% silt = % (clay + silt) - % clay

% sand = 100 – % (clay + silt)

3.3.4 Total Organic Carbon

Soil organic carbon was determined by the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). One gram of 2 mm sieved soil sample was weighed into a 250 ml conical flask and 5 mls of 1N potassium dichromate ($K_2Cr_2O_7$) solution was added and the flask gently swirled. 10 ml of concentrated sulphuric acid (H_2SO_4) was added into the flask and allowed to stand for 30 minutes. Then 100 ml of distilled water was added and allowed again to cool for 30 minutes. The organic carbon (OC) was determined by titrating this digest with 0.5N ferrous ammonium sulphate [$(NH_4)_2SO_4.FeSO_4.6H_2O$] to a red (maroon) end point. The organic carbon content and organic matter content were calculated using the following formulae:

$$\text{OC (\%)} = \frac{\text{(Blank titre – Actual titre) x 0.3 x m x f}}{\text{Weight of air dried soil taken}}$$

where f = Correction factor = 1.33

m = Concentration of $FeSO_4$ = $\frac{\text{Concentration of } K_2Cr_2O_7 \text{ x Volume of } K_2Cr_2O_7}{\text{Blank titre}}$

OC (g/Kg) = OC (%) x 10

The stratification ratios were calculated from the organic carbon content at 0-5 cm divided by those at 5-10 cm, then at 5-10 cm divided by those at 10-15 cm and at 10-15 cm divided by those at 15-20cm.

3.3.5 Total Nitrogen

Total nitrogen was analyzed by micro Kjeldahl digestion method (Bremmer and Mulvancy, 1982). 1 gram of soil was digested for 2 hours with concentrated H_2SO_4 and catalyst to raise the temperature and hasten the reaction respectively. The mixture was transferred into a 100 ml volumetric flask and made to mark. Ten mls of the digest was transferred into a distillation flask and 10 ml of NaOH was added. Twenty mls of 2% Boric acid was transferred into a conical flask and was introduced to the bottom of the distillation condenser. The digest was distilled and about 50 ml of the distillate was collected which was then titrated with 0.05N H_2SO_4 to pink end point. The nitrogen content was calculated by the formula:

$$N\ (\%) = \frac{0.014 \text{ x (Titre value} - \text{Blank titre value) x NA x Vol. of digest x } 100}{\text{Weight of soil x Aliquot taken}}$$

where NA = Concentration of acid used

N (g/Kg) = N (%) x 10

3.3.6 Soil Water Retention Characteristics

The soil moisture retention characteristics for undisturbed core samples from Trial One were measured using pressure plate extractors (Klute, 1986). The moisture content of the soil was evaluated at matric potentials of -2, -5, -10, -33, -100, -500 and -1500 kPa. The saturated moisture content of the soil was determined by equilibrating the soil on the tension table without suction (i.e. at 0 kPa). The available water holding capacity (AWHC) was calculated as the difference between moisture content at field capacity (-33 kPa) and permanent wilting point (-1500 kPa).

3.3.7 Bulk Density

Bulk density was measured using core method (Blake and Hartge, 1986). Undisturbed cores were taken from the field and placed in the oven to dry at 105^0C for 24 hours. The oven-dried weights were obtained and used in the calculation of bulk density expressed as the ratio of the mass of dried soil to its total volume (solid and pores together).

$\rho_b =$ Ms/Vt

where Ms = mass of oven-dried soil (g)

Vt = Volume of soil, equivalent to volume of core ring, cm^3.

3.3.8 Total Porosity

Total porosity was evaluated by core method (Ibitoye, 2008). A saturated undisturbed soil core was weighed, volume of core determined and thereafter oven dried at 105^0C for 24 hours. The total pore space is the volume of the water at soil saturation obtained from its mass using the following equations

$$\text{Total Porosity } (f) = \frac{\text{Total pore volume}}{\text{Bulk soil volume}} \times 100$$

where pore volume = Mass of water lost (Weight at saturation – Oven dried weight) g / Density of water (1g/cm^3)

3.3.9 Particle Density

Particle density defined as the mass per unit volume of soil solids was determined by substitution from the regular equation of total porosity $\left[f = 1 - \frac{\rho_b}{\rho_s} \right]$ as

$$\rho_s = \left(\frac{\rho_b}{1 - f} \right)$$

where

ρ_s =Particle density (g/cm^3)

ρ_b = Bulk density (g/cm^3)

f = Total porosity (cm^3/cm^3)

3.3.10 Effective Pore Sizes

Total porosity includes both macro and micro pores present in the soil. An effective pore diameter which determines pore sizes that emptied water at each pressure step was calculated by the capillary rise equation

$$EPD = \frac{4\sigma \cos\alpha}{\rho g h}$$

where σ is the surface tension of water; cos α is the cosines of the angle α displayed by the water meniscus; ρ is the water specific weight, g is gravity acceleration and h the matric pressure. At 22^{0}C, the value of σ was 0.07357 kg s^{-2} and α is equal to zero. The capillary rise equation can be reduced to the following expression (Marshall and Holmes, 1988)

$$EPD = \frac{300}{h}$$

Where the equivalent pore diameter (EPD) of the smallest pore (μm) drained at water suction of h (kPa). The EPD was grouped according to Greenland (1981) into transmission pores [($\mathbf{P_T}$) 30 to 150 μm diameter corresponding to 20-100cm of water], storage pores [($\mathbf{P_S}$) 0.2 to 30 μm diameter corresponding to 100-15,000cm of water] and residual pores [($\mathbf{P_B}$) <0.2 μm corresponding to water retained at >15,000cm matric suction].

3.3.11 Soil Physical Quality Index (S)

The S as proposed by Dexter (2004a) was computed by the equation

$$S = -n\left(\theta_{sat} - \theta_{res}\right)\left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]}$$

where θ_{sat} is saturated soil moisture content ($m^3\ m^{-3}$), θ_{res} is residual moisture content or moisture content at PWP ($m^3\ m^{-3}$), and n is Mualem-Van Genuchten equation parameter (Van Genuchten, 1980; Mualem, 1986) and was estimated from continuous pedotransfer functions derived by Tormena *et al.* (1999) as:

$$n = 2.5181 - 2.064 * Db + 0.7373 * Db^2$$

Db= bulk density (Mg m^{-3})

3.3.12 Aggregate Stability

After the sample was passed through 5mm sieve, the aggregate stability was determined by both wet and dry sieving as described by Van Bavel (1950) and modified by Kemper and Rosenau (1986).

Dry Sieving

Two hundred grams of bulk soil was weighed and transferred into nest of sieves consisting of diameters 2.0 mm, 0.25 mm and 0.053 mm. The nest of the sieves was placed on a

mechanical shaker and shaken for 2 minutes after which the weight of soil retained in each sieve was determined.

Aggregate size distribution was calculated as the proportion of soil retained in each sieve, i.e.

Aggregate size distribution = $\frac{\text{Weight of soil retained in a sieve}}{\text{Total weight of soil taken}}$

The mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated as follows

$$MWD_{dry} = \sum_{i=1}^{n} w_i x_i$$

x_i = the mean diameter of the class (mm)

w_i = is the proportion of each size class with respect to the total sample

$$GMD_{dry} = \exp\left[\frac{\sum_{i=1}^{n} w_i \log x_i}{\sum_{i=1}^{n} w_i}\right]$$

w_i =weight of aggregate of each size class (g)

log x_i = logarithm of the mean diameter of the size classes

Wet Sieving

Wet aggregate size distribution was measured by slaking method (Elliot, 1986).Two hundred grams of the sample was sieved in a bucket containing water using 2.0 mm diameter sieve for 50 strokes. Then filtrate was sieved using 0.250 mm for 35 strokes, then

again the filtrate was sieved using 0.53 mm diameter sieve for 10 strokes. The soils retained in the sieves were transferred into cans and labeled >2.0 mm, >0.250 mm and >0.053 mm. The last filtrate was then allowed to settle overnight and decanted, where the soil collected was transferred into a can and labeled <0.053 mm. The samples in the can were oven dried at 60^0C after which the temperature was raised to 105^0C for 24 hours until the samples become completely dried. Weight of the sample was calculated as weight of the can with the sample minus weight of the empty can. The sand content of the aggregate fractions was determined by Bouyoucos (1951) hydrometer method as described by Gee and Bauder (1986)

Aggregate size distribution was calculated as in dry sieving i.e.

$$\text{Aggregate size distribution} = \frac{\text{Weight of soil retained in a sieve}}{\text{Total weight of soil taken}}$$

The mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated as follows:

$$MWD_{wet} = \sum_{i=1}^{n} w_i x_i$$

x_i = the mean diameter of the class (mm)

w_i = the sand corrected proportion of each size class with respect to the total sample

$$w_i = \frac{\text{weight of soil retained - \% sand}}{\text{Total weight of soil taken - \% sand}}$$

$$GMD_{wet} = \exp\left[\frac{\sum_{i=1}^{n} w_i \log x_i}{\sum_{i=1}^{n} w_i}\right]$$

w_i =weight of sand corrected aggregate of each size class (g)

log x_i = logarithm of the mean diameter of the size classes

3.4 DATA ANALYSIS

In order to counteract the effect of heterogeneity, all the parameters were tested for linearity and normality before being subjected to statistical analysis. All the parameters were transformed using logarithm plus ten {log(x+10)} before the analysis. The data were subjected to analysis of variance (ANOVA) using SAS 9.0 software (SAS, 1996). Means were compared using least significant difference (LSD) where the analysis of variance (F-test) was significant at $P<0.05$ (Gomez and Gomez, 1984). Bivariate correlation, linear and polynomial regression analyses were used to establish relationships between the parameters.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INFLUENCE OF LAND USE AND SOIL DEPTH ON SOIL ORGANIC CARBON, NITROGEN AND PARTICLE SIZE DISTRIBUTION

4.1.1 Organic Carbon

The organic carbon content of the study area was generally low (<10 g/kg). The land under natural fallow (FL) recorded higher organic carbon content (8.24 g/kg) relative to other land uses which had statistically similar values (Table 4.1). The high organic carbon in FL might be due accumulation of plant roots, deposition of plant litter and limited soil disturbance that aided accumulation of organic carbon. Other findings corroborating this observation have been reported by Singh and Ghoshal (2011) who observed highest organic carbon in forest soil, followed by JCL plantation and lowest in agroecosystems.

Organic carbon content consistently decreased with soil depth (Table 4.1) which could be related to high accumulation of litter and roots in the upper surface of the soil than the lower ones. Esu (1999) explained that in grassland ecosystems where most of the grasses with fibrous root systems die and decay each year, a substantial supply of organic matter is provided at surface soil horizon. Organic carbon stratification ratios were not significantly ($P \leq 0.05$) varied among the land uses, yet higher ratios of 1.28 and 1.23 for 0-5 cm: 5-10 cm and 5-10 cm: 10-15 cm respectively were recorded in FL, and 1.62 for 10-15 cm: 15-20 cm observed in RYJ (Fig. 4.1).

Table 4.1: Influence of land use and soil depth on soil organic carbon, nitrogen and particle size distribution

Treatments	OC(gkg^{-1})	TN(gkg^{-1})	Clay (%)	Silt (%)	Sand (%)	Textural Class
Land uses						
Arable land (AL)	6.52b	0.33c	17.98	33.63ab	46.02ab	Loam
Fallow land (FL)	8.33a	0.36bc	18.56	36.36a	42.87bc	Loam
One year JCL plantation (OYJ)	6.29b	0.45ab	20.03	39.04a	39.20c	Loam
Two years JCL plantation (TYJ)	6.03b	0.49a	17.24	30.34b	50.70a	Loam
Three years JCL plantation (RYJ)	5.69b	0.53a	19.44	35.12ab	42.95bc	Loam
Significance level	**	**	NS	*	*	-
SE±	0.011	0.001	0.013	0.019	0.020	-
Depth						
0-5 cm	7.20a	0.42	15.36c	33.98	48.54	Loam
5-10 cm	6.99a	0.44	17.06c	36.47	44.47	Loam
10-15 cm	6.68a	0.43	19.23b	35.27	43.20	Loam
15-20 cm	5.37b	0.44	23.51a	35.55	40.93	Loam
Significance level	**	NS	**	NS	NS	-
SE±	0.009	0.001	0.011	0.017	0.018	-
Interaction						
Land use x Depth	NS	NS	NS	NS	NS	-
CV (%)	3.88	0.60	3.86	5.06	5.15	-
Mean	**6.55**	**0.43**	**18.63**	**34.80**	**44.23**	Loam

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

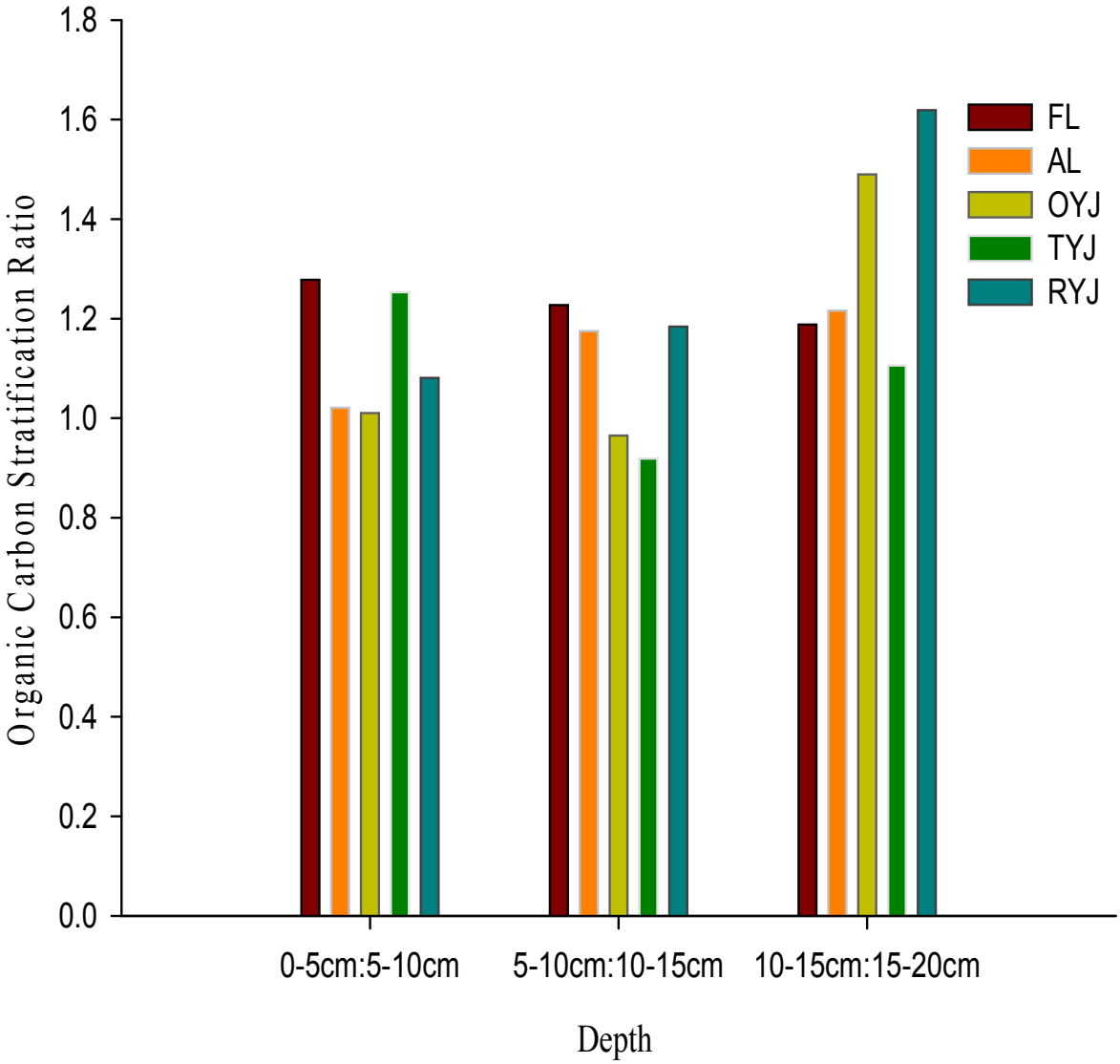


Fig. 4.1: Organic Carbon Stratifications within Soil Depth among Land Uses

Franzluebbers (2002) explained that high stratification ratio of organic carbon reflects relatively undisturbed soil with a good quality soil surface that leads to improved infiltration, more stable aggregates and an abundant supply of organically bound slow-release nutrients.

4.1.2 Total Nitrogen

Nitrogen content of the soil significantly varied among the land uses. Arable land (AL) recorded the lowest nitrogen content (0.33 g/kg). Nitrogen content consistently increased as JCL land use ages increased from one to three years (Table 4.1). When averaged across the JCL land uses, nitrogen content of the soil was 47% higher than that of AL. The high soil nitrogen content in JCL could be associated with the fact that JCL is a deciduous xerophyte that sheds its leaves at a particular period of the year. Abugre *et al.* (2011) reported that JCL can produce litter material up to 2.27 tons/ha in a year, and the litter material has a relatively low carbon (C) to nitrogen (N) ratio. Organic matter with low C: N will decompose faster than a material with a high C: N. The lower the ratio, the more available nitrogen and quicker decomposition and mineralization.

4.1.3 Particle Size Distribution

Apart from clay, sand and silt content were significantly affected by the land uses. The highest silt content was observed in OYJ (39.04%) and FL (36.36%), followed by RYJ (35.12%) and AL (33.63%); with lowest content (30.34%) observed in TYJ (Table 4.1). The sand content significantly decreased in the following order, TYJ > AL > RYJ = FL > OYJ. Along the soil depth, clay content significantly increases with depth; this affirming clay illuviation into the lower depth in the study area as similarly reported by Ogunwole *et al.* (2001).

4.2 INFLUENCE OF LAND USE AND SOIL DEPTH ON SOIL BULK DENSITY, PARTICLE DENSITY AND TOTAL POROSITY

4.2.1 Bulk Density and Particle Density

Bulk and particle densities were shown to be significantly affected by land use (Table 4.2). Fallow land (FL) and OYJ resulted in higher mean bulk density value of 1.63 Mg/m^3, followed by RYJ (1.56 Mg/m^3) and OYJ (1.53 Mg/m^3), with a low mean value (1.48 Mg/m^3) observed in AL (Table 4.2). Generally the soil texture in all the land use treatments was loam (Table 4.1) and based on this texture all the bulk densities were less than or equal to 1.63Mg/m^3 threshold value as reported by Arshad *et al.*(1996) that may affect crop root growth. The low bulk density value in AL compared to FL may be associated with the incorporation of crop residues in AL by tillage (Bhattacharyya *et al.*, 2005). This might be supported by the fact that the sampling depth was limited to upper 20 cm only. The layer expected to be relatively compacted by tillage could be below the studied depth. Several studies had reported higher bulk density in undisturbed or no till at the soil surface compared with tilled soil (Wu *et al.*, 1992; Hill, 1990; Klute, 1982). Higher and statistically similar particle density values were recorded in AL, FL and TYJ compared to low values observed in OYJ and RYJ (Table 4.2). Both particle density and bulk density values were found to increase with increasing depth (Table 4.2). The values of particle density range from 2.54 Mg/m^3 at the surface to 2.77 Mg/m^3 in the lower horizons. The low particle density at the soil surface might be the influence of high organic carbon content as Hillel (1980) explained that organic matter tends to lower particle density value.

Table 4.2: Influence of land use and soil depth on soil bulk density, particle density and total porosity

Treatment	Bulk Density (Mg/m^3)	Particle Density (Mg/m^3)	Total Porosity (%)
Land uses			
Arable land (AL)	1.48c	2.78a	46.47a
Fallow land (FL)	1.63a	2.70a	39.40b
One year JCL plantation (OYJ)	1.53bc	2.49b	38.68b
Two years JCL plantation (TYJ)	1.63a	2.72a	39.64b
Three years JCL l plantation (RYJ)	1.56ab	2.50b	37.37b
Significance level	**	**	**
SE±	0.001	0.002	0.007
Depth			
0-5 cm	1.51b	2.54b	40.09
5-10 cm	1.56ab	2.63b	40.02
10-15 cm	1.56ab	2.62b	39.85
15-20 cm	1.62a	2.77a	40.92
Significance level	*	*	NS
SE±	0.001	0.002	0.007
Interaction			
Land use x Depth	NS	NS	NS
CV (%)	0.46	0.79	1.92
Mean	**1.56**	**2.64**	**40.22**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

4.2.2 Total Porosity

The results presented in Table 4.2 revealed that the total pore spaces in the study area were within the range of 38-46%. Arable land (AL) resulted in significantly higher total pore spaces in comparison to the other land uses which were statistically similar. Furthermore, non-significant variation in total pore spaces along the depth was noticed. The high total pore space in AL may be attributed to its low bulk density. Several scientists had documented high bulk density is a strong indicator of low soil porosity and high compaction (Arshad *et al.*, 1996; Liebig and Doran, 1999).

4.3 INFLUENCE OF LAND USE AND SOIL DEPTH ON DRY AGGREGATE CHARACTERISTISCS

4.3.1 Dry Aggregate Distribution

From the result (Table 4.3), greater dry aggregate fractions (41.7%) were obtained for 2-0.25 mm aggregate size while, the lowest dry aggregate fractions (0.8%) were recorded for <0.05 mm aggregate size in all the treatments considered. With the exception of <0.05 mm (silt+clay) aggregates, land use significantly influenced dry aggregate size distribution (Table 4.3). Three years old *Jatropha curcas* plantation (RYJ) recorded the highest proportion of dry large-macro aggregates (27.4%) and macro-aggregates fractions (46.9%). However, when averaged across JCL plantations, large macro-aggregates and macro-aggregates increased over AL by 28.3% and 13.4% respectively. The proportion of micro-aggregates under the land uses however, was in the following decreasing order: AL > OYJ > TYJ > FL > RYJ.

Table 4.3: Influence of land uses and soil depth on dry aggregate size distribution

Treatment	Large macro - aggregates (5-2mm)	Macro-aggregates (2-0.25mm)	Micro-aggregates (0.25-0.05mm)	Silt+Clay (<0.05mm)
Land uses				
Arable land (AL)	0.159c	0.372c	0.459a	0.009
Fallow land (FL)	0.242b	0.447ab	0.306c	0.005
One year JCL plantation (OYJ)	0.180c	0.375c	0.436ab	0.006
Two years JCL plantation (TYJ)	0.157c	0.423b	0.409b	0.011
Three years JCL plantation (RYJ)	0.274a	0.469a	0.246d	0.009
Significance level	**	**	**	NS
SE±	0.0004	0.0005	0.0007	0.0001
Depth				
0-5 cm	0.165c	0.418	0.405a	0.011a
5-10 cm	0.177c	0.398	0.419a	0.006ab
10-15 cm	0.209b	0.421	0.359b	0.011a
15-20 cm	0.263a	0.432	0.301c	0.005b
Significance level	**	NS	**	*
SE±	0.0004	0.0004	0.0007	0.0001
Interaction				
Land use x Depth	**	NS	NS	NS
CV (%)	0.186	0.209	0.326	0.035
Mean	**0.202**	**0.417**	**0.371**	**0.008**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

The distribution of large macro-aggregates, micro-aggregates and silt+clay ($P \leq 0.05$) fractions were significantly different along the studied soil depths. Large macro-aggregates decreased with depth as opposed to micro-aggregate distribution. The distribution of silt+clay aggregates was higher in 0-5 cm and 10-15 cm with low value obtained in 15-20 cm. Interaction between land use and depth was however significant for large macro-aggregates distribution, where higher proportions were obtained in RYJ and FL in lower and upper depths, respectively (Fig. 4.2).

The high proportion of large macro-aggregates and macro-aggregates fractions in JCL plantations might be attributed to the addition of litter materials and probably the symmetrical nature of plant root with the lateral root positively aiding aggregate stability through additional cohesion of the soil particles (Reubens *et al.*, 2010). Exudates from JCL roots and microbial excretions into the soil might have also aided the aggregation process by acting as cementing agents (Haynes and Francis, 1993). The result supports the earlier findings of Ogunwole *et al.* (2008) who reported 11% increased turnover of macro-aggregates turnover under JCL plantation on a degraded Indian Entisol over native vegetation. The inability of both FL and JCL plantation to increase the stability of micro-aggregates might be due to the non-sensitivity of micro-aggregate stability to management practices. Tisdall and Oades (1982) concluded that cultivation causes the reduction in the amount of macro-aggregates but does not affect micro-aggregates stability. The non-significant effect observed in the distribution of the silt+clay fraction signifies that JCL had influence only at macro-aggregate level.

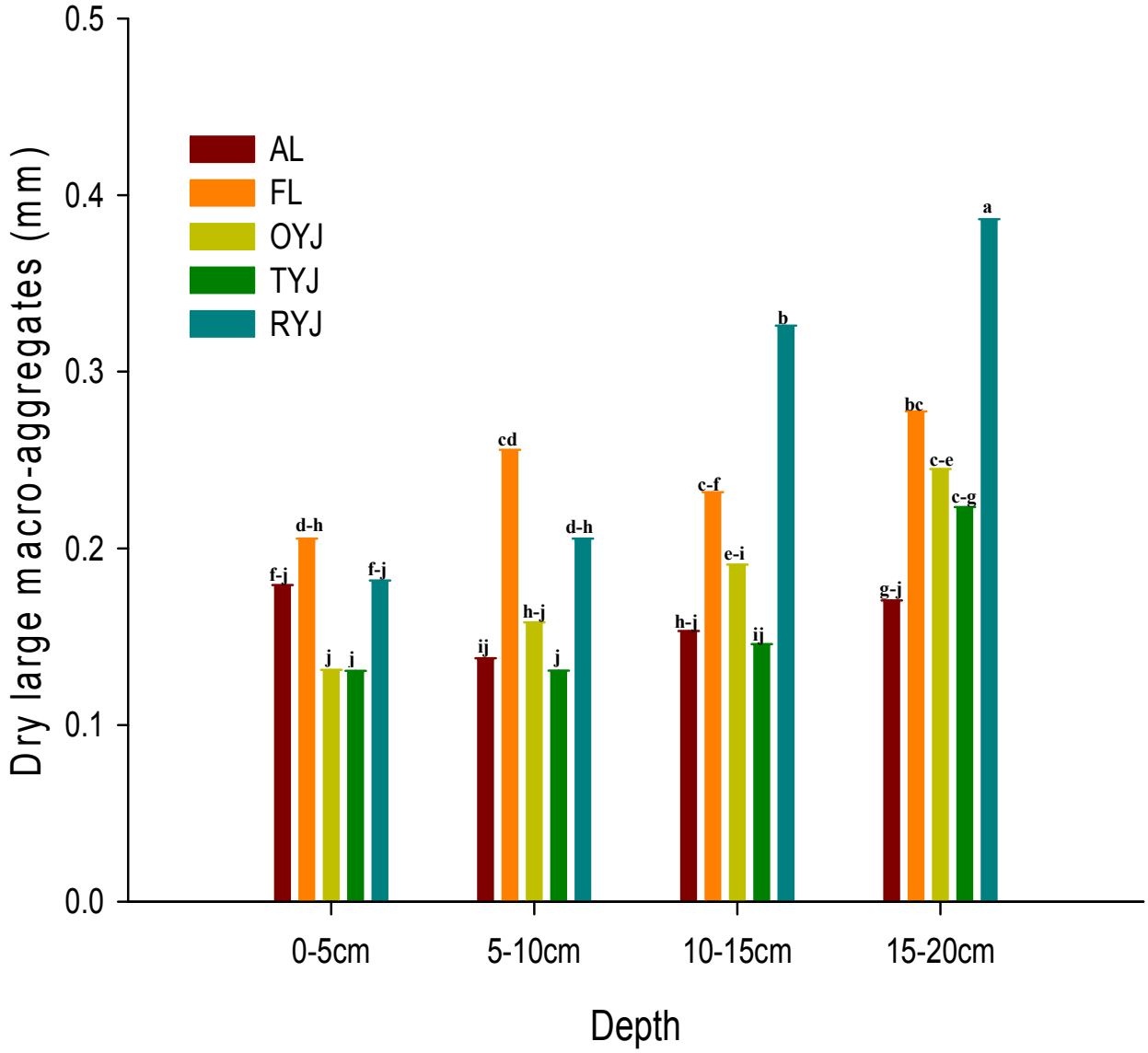


Fig. 4.2: Effect of interaction between land uses and soil depth on distribution of dry large macro-aggregate (5-2 mm) fraction

4.3.2 Dry Mean Weight Diameter and Geometric Mean Diameter

The dry mean weight diameter (MWD) and dry geometric mean diameter (GMD) were significantly affected by the land use, with RYJ having the highest value, followed by FL and other land use systems being statistically similar (Table 4.4). When averaged across JCL plantations, dry MWD and dry GMD in the plantations increased by 18.8% and 12.2% respectively over AL. Both MWD and GMD increased with depth. Further significant interaction effects were observed between land use and soil depth for GMD and MWD (Table 4.4). Higher values were recorded in RYJ at 10-15 cm and 15-20 cm, while at 5-10 cm, the FL treatment recorded the highest mean value (Fig 4.3 and 4.4).

The increase in dry MWD under JCL is an index of its ability to withstand wind erosion (Unger, 1991) and it was similarly reported by Ogunwole *et al.* (2008) who obtained 11% increase turnover in MWD in JCL plantation compared to native vegetation. This could be related also to its rich leaf litter deposition and symmetrical root architecture as earlier stated.

4.3.3 Relationship between Dry Aggregates and Clay

Dry large macro-aggregates, dry mean weight diameter and dry geometric mean diameter were significantly and positively correlated with clay content (Table 4.5). The polynomial regression model better explained the relationship. The positive relationship between dry aggregates and clay, portrays clay to be an important binding agent. This is in agreement with Tayel (2010), Skidmore and Layton (1992) who reported aggregate stability was positively correlated with clay content

Table 4.4: Influence of land use and soil depth on dry mean weight diameter and geometric mean diameter

Treatment	Mean weight diameter (MWD) mm	Geometric mean diameter (GMD) mm
Land uses		
Arable land (AL)	1.05c	0.75c
Fallow land (FL)	1.39b	0.90b
One year JCL plantation (OYJ)	1.12c	0.78c
Two years JCL plantation (TYJ)	1.09c	0.78c
Three years JCL plantation (RYJ)	1.52a	0.97a
Significance level	**	**
SE±	0.001	0.001
Depths		
0-5 cm	1.11c	0.79c
5-10 cm	1.13c	0.79c
10-15 cm	1.26b	0.85b
15-20 cm	1.44a	0.92a
Significance level	**	**
SE±	0.001	0.001
Interaction		
Land use x Depth	**	**
CV (%)	0.63	0.30
Mean	**1.23**	**0.84**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

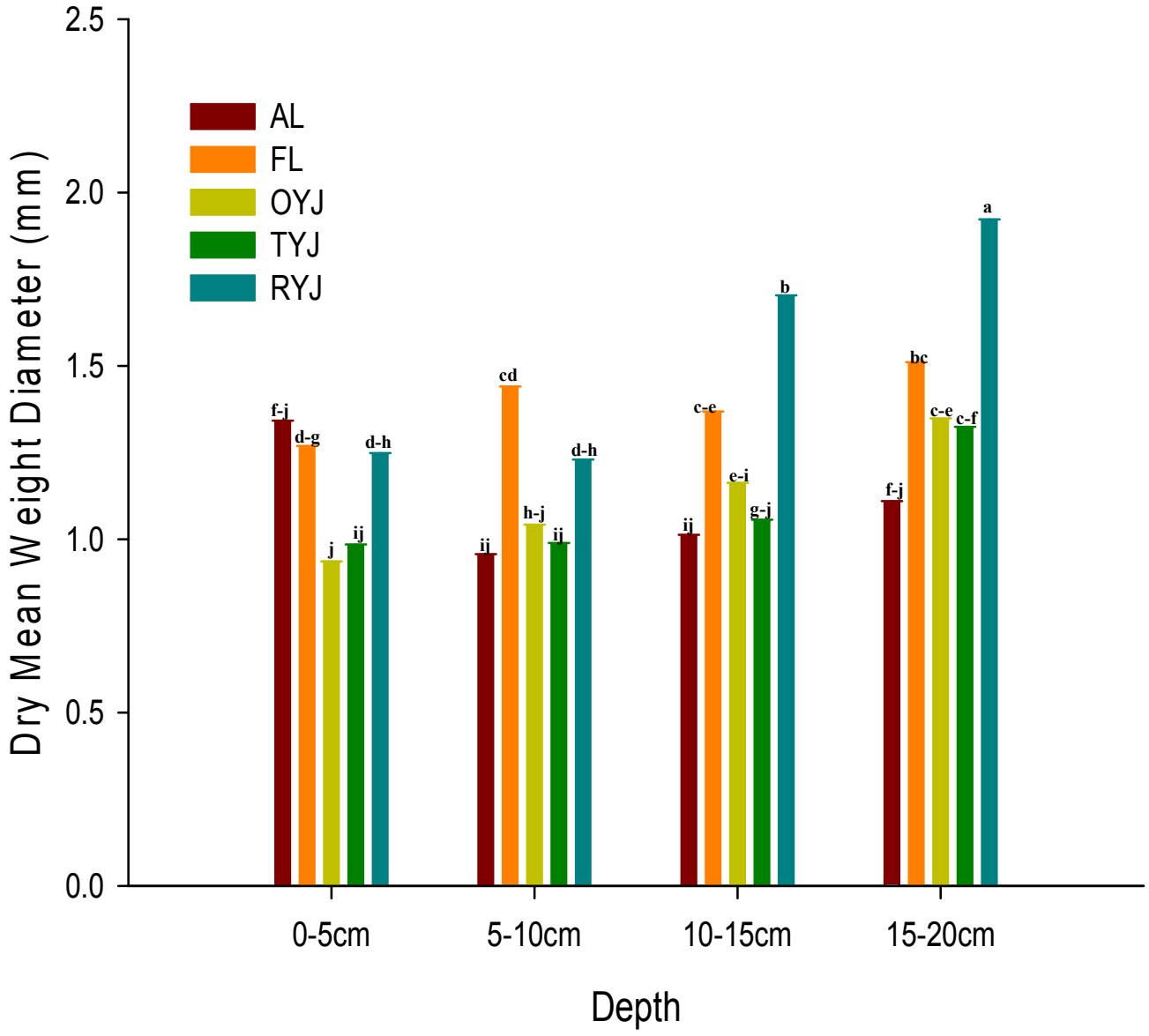


Fig.4.3: Effect of interaction between land uses and soil depth on dry mean weight diameter

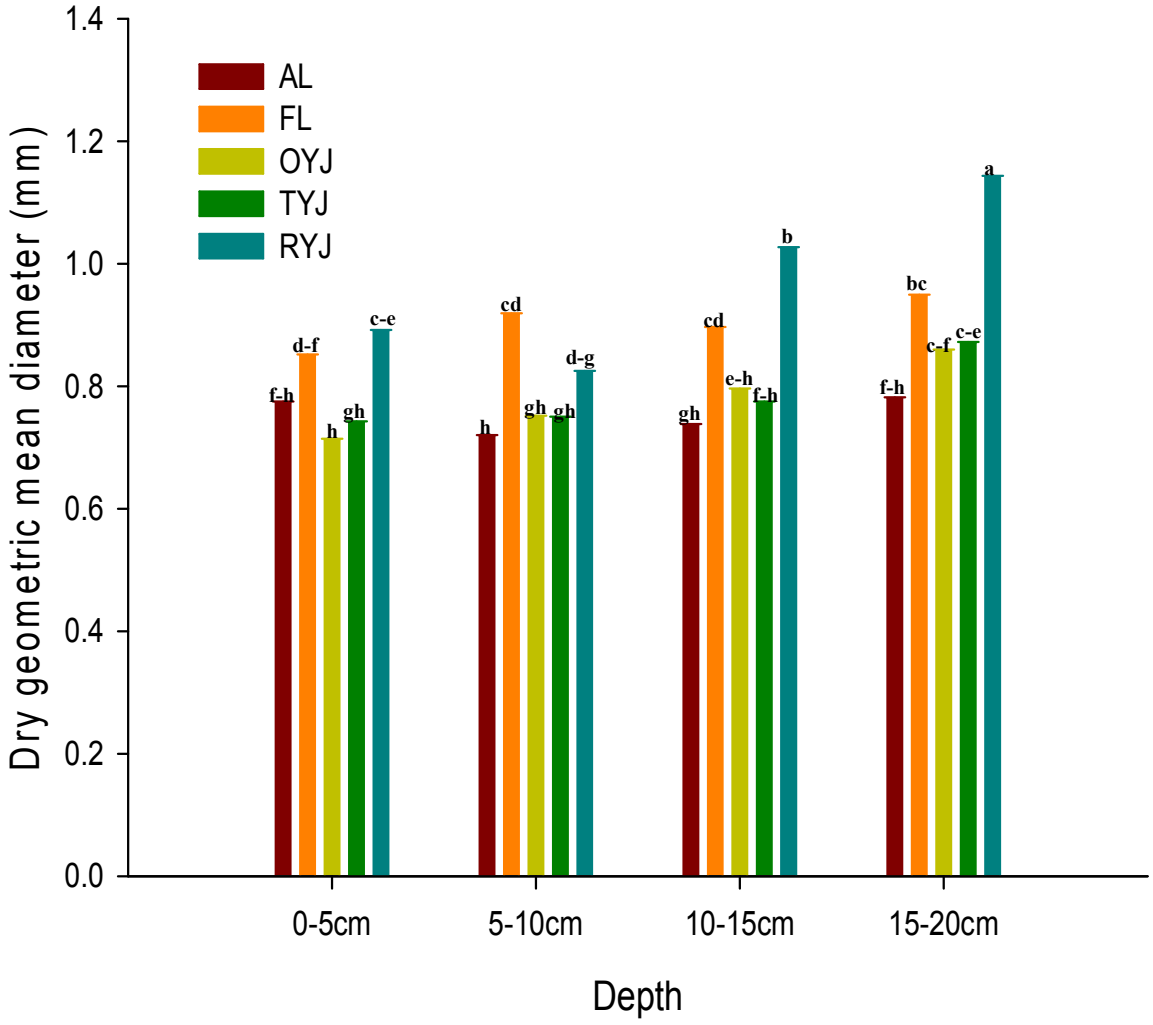


Fig. 4.4: Effect of interaction between land uses and soil depth on dry geometric mean diameter

Table 4.5: Relationship between dry aggregate distribution and clay content

Variables				
Dependent (Y)	Independent (X)	Equation	r	r^2
Dry large macro aggregates	Clay	$Y=0.0002X^2-0.00003X+0.1198$	0.51^{**}	0.27
Dry mean weight diameter	Clay	$Y=0.0007X^2+0.0042X+0.8884$	0.49^{**}	0.25
Dry geometric mean diameter	Clay	$Y=0.0003X^2+0.0003X+0.7116$	0.46^{**}	0.22

r correlation coefficient, * significant at 5%, ** significant at 1%, r^2 coefficient of determination

4.4 INFLUENCE OF LAND USE AND SOIL DEPTH ON WET AGGREGATE CHARACTERISTICS

4.4.1 Wet Aggregate Distribution

The mean water-stable aggregate was highest at 50.1% for <0.05 mm (silt+clay), followed by 34.4% for 0.25-0.05 mm (micro-aggregates), and 13.2% for 2-0.25 mm (macro-aggregates) and lowest value of 2.3% was obtained for 5-2 mm (large macro-aggregates). In large macro-aggregates, significantly ($p \leq 0.05$) higher water-stable aggregate fraction was recorded in AL, followed by FL and TYJ with lowest value recorded in OYJ (Table 4.6). Considering macro-aggregate fraction, significantly ($p \leq 0.05$) higher water-stable aggregate fraction was recorded in TYJ, followed by FL and lowest value recorded in OYJ. Micro-aggregates and silt+clay fractions were not significantly affected by land use. In addition, there was no significant land use versus depth interaction effect on water-stable aggregate size distribution (Table 4.6).

Historical information of the AL indicated that cowpea was grown in the preceding seasons and phosphorus fertilizer might have been applied to boost production. Calcium usually contained in phosphate fertilizers (Hadas *et al.*, 1990) might have contributed to the improvement of water-stable large macro-aggregates in AL. The high proportion of water-stable macro-aggregates in TYJ and FL might have been the result of the accumulation of organic matter through leaf litter deposition and root biomass that greatly enhanced the formation and stabilization of soil aggregates (Silva and Mielniczuk, 1997).

4.4.2 Wet Mean Weight Diameter and Geometric Mean Diameter

Arable Land (AL), FL and TYJ recorded significantly higher and similar mean weight diameter (MWD) of water-stable aggregates, while OYJ and RYJ recorded the least and

statistically similar values (Table 4.7). The land uses were not significantly different in geometric mean diameter (GMD) of water-stable aggregates. However, depth and all possible interactions did not significantly influenced MWD and GMD of water-stable aggregates. The high MWD of water-stable aggregates in AL, FL and TYJ was possibly due to the high values of large macroaggregates and microaggregate fractions.

Table 4.6: Influence of land use and soil depth on wet aggregate size distribution

Treatment	Large macro -aggregates (5-2mm)	Macro-aggregates (2-0.25mm)	Micro-aggregates (0.25-0.05mm)	Silt+Clay (<0.05mm)
Land uses				
Arable land (AL)	0.027a	0.123bc	0.282	0.504
Fallow land (FL)	0.022ab	0.125b	0.362	0.417
One year JCL plantation (OYJ)	0.014c	0.107d	0.334	0.467
Two years JCL plantation (TYJ)	0.021ab	0.146a	0.318	0.461
Three years JCL plantation (RYJ)	0.017bc	0.112cd	0.312	0.488
Significance level	**	**	NS	NS
SE±	0.0001	0.0002	0.001	0.001
Depth				
0-5 cm	0.021	0.127	0.351	0.444
5-10 cm	0.018	0.124	0.357	0.433
10-15 cm	0.019	0.118	0.271	0.519
15-20 cm	0.023	0.121	0.308	0.473
Significance level	NS	NS	NS	NS
SE±	0.0001	0.0002	0.001	0.001
Interaction				
Land use x Depth	NS	NS	NS	NS
CV (%)	0.044	0.077	0.530	0.542
Mean	**0.020**	**0.123**	**0.322**	**0.467**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

Table 4.7: Influence of land use and soil depth on mean weight diameter and geometric mean diameter of water stable aggregates

Treatment	Mean weight diameter (MWD) mm	Geometric mean diameter (GMD) mm
Land uses		
Arable land (AL)	0.29a	0.34
Fallow land (FL)	0.28a	0.36
One year JCL plantation (OYJ)	0.23b	0.34
Two years JCL plantation (TYJ)	0.30a	0.36
Three years JCL plantation (RYJ)	0.24b	0.33
Significance level	**	NS
SE±	0.0005	0.0004
Depth		
0-5 cm	0.28	0.36
5-10 cm	0.27	0.35
10-15 cm	0.25	0.33
15-20 cm	0.27	0.34
Significance level	NS	NS
SE±	0.0004	0.0004
Interaction		
Land use x Depth	NS	NS
CV (%)	0.21	0.18
Mean	**0.27**	**0.35**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

4.5 INFLUENCE OF LAND USE AND SOIL DEPTH ON SOIL WATER INPUT CHARACTERISTICS

4.5.1 Infiltration

Cumulative soil water infiltration was significantly ($p \leq 0.05$) different across the land use with higher value observed in RYJ, next was TYJ and lowest value recorded in OYJ (Table 4.8). However, among the JCL plantations, cumulative infiltration was consistently increased with duration of land use. Infiltration was averagely increased by 26. 1% in JCL over arable cultivation (AL). The high infiltration in JCL land use might be the result of its high dry aggregate stability since soil water infiltration positively correlated with dry large macro-aggregate, dry mean weight diameter and dry geometric mean diameter (Table 4.9). The result is in agreement with Schnug and Haneklaus (2002) who reported relationship between the improved soils mechanical stability and increased infiltration rate. Well aggregated soil with large pores generally favour high infiltration rate, tilth and adequate aeration for plant growth; and the continued existence of the large pores depends on the stability of soil aggregates (Kemper and Rosenau, 1986).

4.5.2 Infiltration Models Fitting

Tables 4.10 and 4.11 presented the observed and predicted infiltration characteristics among the land use based on Kostiakov and Philip models, respectively. The model evaluation result (Table 4.12) revealed that r^2 and RMSE were 0.96 and 22.37 for Kostiakov's model compared to 0.85 and 88.39 obtained for Philip's model.

Table 4.8: Influence of land use and soil depth on soil infiltration characteristics

Treatments	Antecedent moisture content (%)	Cumulative infiltration (F) (mm)	Elapse time (hr)
Arable land (AL)	11.70	289.68bc	2.75
Fallow land (FL)	8.32	270.10bc	2.75
One year JCL plantation (OYJ)	6.55	226.20c	2.75
Two years JCL plantation (TYJ)	9.66	401.57ab	2.75
Three years JCL plantation (RYJ)	12.98	467.62a	2.75
Significance level	NS	*	-
SE±	0.06	0.08	-
CV (%)	9.58	6.80	-
Mean	**9.86**	**331.03**	-

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

Table 4.9: Relationship between infiltration and selected parameters with significant correlation coefficient

Variable				
Dependent (Y)	Independent (X)	Equation	r	r^2
Cinfi	Dry large macro-aggregates	$Y=-9460.7X^2+4687X-177.32$	0.47^*	0.11
Cinfi	Dry mean weight diameter	$Y=-421.5X^2+131.5X-592.39$	0.40^*	0.15
Cinfi	Dry geometric mean diameter	$Y=-2058.6X^2+4187X-1666.2$	0.42^*	0.16
Cinfi	Residual pores	$Y=-9460.5X^2+5394.8X-269.03$	0.58^{**}	0.44

r correlation coefficient, r^2 coefficient of determination, * significant at 5%, ** significant at 1%, Cinfi = Cumulative infiltration.

The coefficient of variability (CV) was 6.76% in Kostiakov's and 26.70% in Philip's model (Table 4.12) that explained the high and significant variability between observed and predicted infiltration in Philip's model. Therefore, the result showed Kostiakov's model to be the best fitted model for infiltration prediction in the study area. The Nash-Sutcliffe Efficiency (E) was also closed to unity (0.94) for Kostiakov's prediction compared to 0.45 recorded for Philip's model. This indicates more perfect fit of Kostiakov's model in predicting infiltration in the study area over the Philip's model. However, the E value observed in Philip's model suggested that the observed infiltration mean value was superior and better than the predicted mean value.

4.5.3 Water Retention Characteristics

The soil water content at the various matric potential studied was significantly different ($p \leq 0.05$) across land uses (Table 4.13). At -0 kPa, AL retained higher moisture than the other land use treatments which were statistically similar. However, at -2 kPa, AL, FL and TYJ retained significantly greater moisture when compared to RYJ and OYJ. The observation may be supported by the presence of high water stable large-macro and macro aggregates in AL, FL, and TYJ as these variables significantly correlated with moisture content at -2 kPa (Appendix 1). At -5 kPa, -10 kPa, -33 kPa (FC), -100 kPa, -500 kPa and -1500 kPa (PWP) generally, the moisture retention ability was highest in FL, followed by RYJ with low retention recorded in AL (Table 4.13). The available water holding capacity (AWHC) was greater in RYJ and AL with the least value obtained in TYJ.

Table 4.10: Kostiakov's Prediction

Treatments	K	n	r^2	Predicted F (mm)	Observed F (mm)	Elapse time (hr)
AL	140.56	-0.43	0.98	249.36	289.68	2.75
FL	131.20	-0.31	0.90	280.65	270.10	2.75
OYJ	118.23	-0.38	0.99	222.76	226.20	2.75
TYJ	199.59	-0.37	0.98	375.55	401.57	2.75
RYJ	255.68	-0.44	0.99	458.91	467.62	2.75

F cummualtive infiltration, K and n are Kostiakov's contants, r^2 coefficient of determination

Table 4.11: Philip's Prediction

Treatments	S	A	r^2	Predicted F (mm)	Observed F (mm)	Elapse time (hr)
AL	114.76	24.95	0.98	258.90	289.68	2.75
FL	52.71	77.84	0.88	301.50	270.10	2.75
OYJ	76.88	39.82	0.99	237.00	226.20	2.75
TYJ	136.97	57.88	0.98	386.30	401.57	2.75
RYJ	219.69	107.29	0.98	659.40	467.62	2.75

F cummualtive infiltration, S and A are Philil's contants, r^2 coefficient of determination

Table 4.12: Infiltration Models Evaluation Results

Statistical tool	Kostiakov Model	Philip Model
Coefficient of determination (r^2)	0.96	0.85
Root mean square error (RMSE)	22.37	88.39
Coefficient of variation (CV) %	6.76	26.70
Nash-Sutcliffe efficiency (E)	0.94	0.45

Table 4.13: Influence of land use and soil depth on soil water retention characteristics (m^3m^{-3})

Treatment	0 kPa	-2 kPa	-5 kPa	-10 kPa	-33 kPa(FC)	-100 kPa	-500 kPa	-1500 kPa(PWP)	AWHC
Land uses									
AL	0.48a	0.38a	0.25d	0.25dc	0.21d	0.20d	0.16d	0.14d	0.07a
FL	0.41b	0.36a	0.34a	0.33a	0.32a	0.28a	0.27a	0.27a	0.05ab
OYJ	0.40b	0.29c	0.29c	0.26c	0.25c	0.22dc	0.20c	0.19c	0.06ab
TYJ	0.401b	0.39a	0.25d	0.23d	0.22d	0.23bc	0.19c	0.19c	0.03c
RYJ	0.39b	0.32b	0.32b	0.31b	0.28b	0.26ab	0.23b	0.22b	0.07a
Significance level	**	**	**	**	**	**	**	**	**
SE±	0.0004	0.0003	0.0003	0.0003	0.0003	0.0005	0.0004	0.0004	0.0002
Depth									
0-5 cm	0.41	0.34	0.27c	0.26c	0.24c	0.22b	0.20b	0.19b	0.05
5-10 cm	0.42	0.35	0.28bc	0.26bc	0.24bc	0.22b	0.19b	0.18b	0.06
10-15 cm	0.41	0.35	0.29b	0.28b	0.26b	0.24b	0.21b	0.20b	0.06
15-20 cm	0.43	0.36	0.31a	0.30a	0.28a	0.27a	0.24a	0.23a	0.05
Significance level	NS	NS	**	**	**	**	**	**	NS
SE±	0.0004	0.0003	0.0002	0.0003	0.0003	0.0004	0.0005	0.0004	0.0002
Interaction									
Land use x Depth	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	0.19	0.15	0.12	0.13	0.14	0.20	0.18	0.179	0.10
Mean	**0.42**	**0.35**	**0.29**	**0.28**	**0.25**	**0.24**	**0.21**	**0.200**	**0.05**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar, FC field capacity, PWP permanent wilting point.

Among the different depth considered in this study, soil moisture retention at -5 kPa, -10 kPa, -33 kPa, -100 kPa, -500 kPa, -1500 kPa matric potentials showed a proportional increase with depth. Similarly, interaction between the land use and depth did not yield significant effect on soil moisture retention property.

Water retention at -33 kPa and -1500kPa was positively correlated with dry large macro aggregates, macro aggregates, MWD and GMD (Table 4.14), between -5 kPa to -1500 kPa the soil moisture content was generally high in FL and was succeeded by RYJ. The observation could be linked to high organic carbon content and greater dry aggregate stability observed in FL and RYJ, respectively. This was supported by Lal and Shukla (2004) and Alliaume *et al.* (2010) who reported increase in moisture retention as organic matter and structural stability increases. Soil organic matter positively improves soil moisture retention especially at high tensions. This is because as the soil begins to dry, characteristics of surface of soil particles becomes more important than the pore geometry (Lipsius, 2002). The high available water holding capacity (AWHC) in AL and RYJ was also related to the low bulk density/high total pores and significantly greater structural stability recorded in AL and RYJ, respectively. The water retention at -33 kPa and 1500 kPa were positively correlated with clay content and the relationship was better explained by linear regression (Table 4.14). Therefore, consistent increase in soil moisture retention ability with depth was an attribute of increase in clay content with depth due to illuviation process in the study area.

4.6 INFLUENCE OF LAND USE AND SOIL DEPTH ON PORE SIZE DISTRIBUTION AND SOIL PHYSICAL QUALITY INDEX (S-INDEX)

4.6.1 Pore Size Distribution

Generally, results on the average, showed transmission pores, storage pores and residual pores constituted 20.5%, 22.5% and 57.0%, respectively of the total pore spaces. Land use significantly ($p \leq 0.05$) affected distribution of the three pore sizes (Table 4.15).The transmission pores important for air movement and drainage of excess water, were greater in TYJ, next was AL and then followed by other three land use treatments that were statistically similar (Table 4.15). Storage pores which help in retention of water against gravity and release were significantly varied among the land use treatments and were in the following decreasing order AL > RYJ = OYJ > FL > TYJ. Retention and diffusion of ions in solutions are facilitated through the residual pores (Lal and Shukla, 2004) and were greater in FL, followed by RYJ, then TYJ & OYJ and, AL being the lowest. Along the soil depth, transmission pores significantly decreased with depth, while an opposite trend was detected in the distribution of residual pores (Table 4.15). However, interaction between the land uses and depth yielded significant effect in the distribution of transmission pores. The greatest mean value was observed in TYJ at the upper 0-5 cm depth and the lowest value recorded in RYJ at the lower 15-20 cm depth (Fig. 4.5). The transmission pores were significantly and positively correlated with sand particle content (Table 4.16). The high distribution of transmission pores in TYJ was related to its higher sand content (50.7%) as coarser soil possessed larger pores that allow high air movement and drainage (Brady and Weil,1999).

Table 4.14: Relationship between water retention characteristics and selected parameters with significant correlation coefficient

Variables				
Dependent (Y)	Independent (X)	Equation	r	r^2
FC	Dry large macro aggregates	$Y=-0.7299X^2+0.767X+0.133$	0.61^{**}	0.40
FC	Dry macro-aggregates	$Y=-1.8134X^2+2.0401X-0.2744$	0.37^{**}	0.24
FC	Dry mean weight diameter	$Y=-0.06X^2+0.2725X+0.0144$	0.61^{**}	0.38
FC	Dry geometric mean diameter	$Y=-0.539X^2+1.2202X-0.3806$	0.58^{**}	0.37
FC	Clay	$Y=0.004X+0.1769$	0.35^{**}	0.13
PWP	Dry large macro aggregates	$Y=-0.3338X^2+0.5421X+0.106$	0.50^{**}	0.25
PWP	Dry macro-aggregates	$Y=-1.7921X^2+2.0757X-0.3469$	0.40^{**}	0.23
PWP	Dry mean weight diameter	$Y=-0.0423X^2+0.219X-0.0019$	0.52^{**}	0.27
PWP	Dry geometric mean diameter	$Y=-0.5027X^2+1.1479X-0.4003$	0.51^{**}	0.28
PWP	Clay	$Y=0.00037X+0.1303$	0.29^{**}	0.08
AWHC	Storage pores	$Y=-1.7446X^2+0.9082X-0.0023$	0.65^{*}	0.84

r correlation coefficient, r^2 coefficient of determination, * significant at 5%, ** significant at 1%, FC =field capacity, PWP=permanent wilting point and AWHC = available water holding capacity.

Table 4.15: Influence of land use and soil depth on pore size distribution and S-index

Treatment	Transmission Pores	Storage pores	Residual pores	S-index
Land uses				
Arable land (AL)	0.130b	0.105a	0.140d	0.028a
Fallow land (FL)	0.031c	0.068bc	0.265a	0.028a
One year JCL plantation (OYJ)	0.029c	0.088ab	0.191bc	0.024b
Two years JCL plantation (TYJ)	0.156a	0.043c	0.187c	0.031a
Three years JCL plantation (RYJ)	0.014c	0.089ab	0.216b	0.023b
Significance level	**	**	**	**
SE±	0.0003	0.0005	0.0004	0.0001
Depth				
0-5 cm	0.083a	0.069	0.187b	0.024b
5-10 cm	0.081a	0.096	0.182b	0.027b
10-15 cm	0.069ab	0.074	0.201b	0.027b
15-20 cm	0.054b	0.075	0.229a	0.030a
Significance level	**	NS	**	**
SE±	0.0003	0.0004	0.0004	0.0001
Interaction				
Land use x Depth	*	NS	NS	NS
CV (%)	0.129	0.201	0.179	0,024
Mean	**0.072**	**0.079**	**0.200**	**0.027**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

The presence of high storage pores in the AL was attributed to its low bulk density compared to the other land use, as high bulk density is an indicator of low soil water storage and high compaction (Arshad *et al.*, 1996). The high organic carbon content observed in FL was responsible for its high residual pores. Residual pores are the pores that retain water at high tensions where surface characteristics of the soil particles are more important in water retention than their geometry (Lipsius, 2003).

4.6.2 Soil Physical Quality Index (S-index)

Soil physical quality index (S-index) significantly varied among the land use treatments and depth (Table 4.15). The S-index value was greater in TYJ, FL and AL compared to the lower and statistically similar values obtained in OYJ and RYJ. S-index was greater also at lower 15-20 cm depth compared to the upper depths that were statistically similar. The values of S-index in the study area were generally in the range of 0.020>S>0.035 which according to Dexter (2004b) considered the soils to be in moderately degraded condition for optimal root growth.

There was high and positive correlation between S-index and soil bulk density (Table 4.17). Also water stable aggregates and total pore spaces were positively correlated with S-index. The positive relationship between S-index and bulk density (0.70**) was in disagreement with S-index theory developed by Dexter (2004a) and was attributed to inefficiency of the pedotransfer function used. Therefore, Tormena *et al.* (1999) pedotransfer function used in the study was not sensitive in the study area.

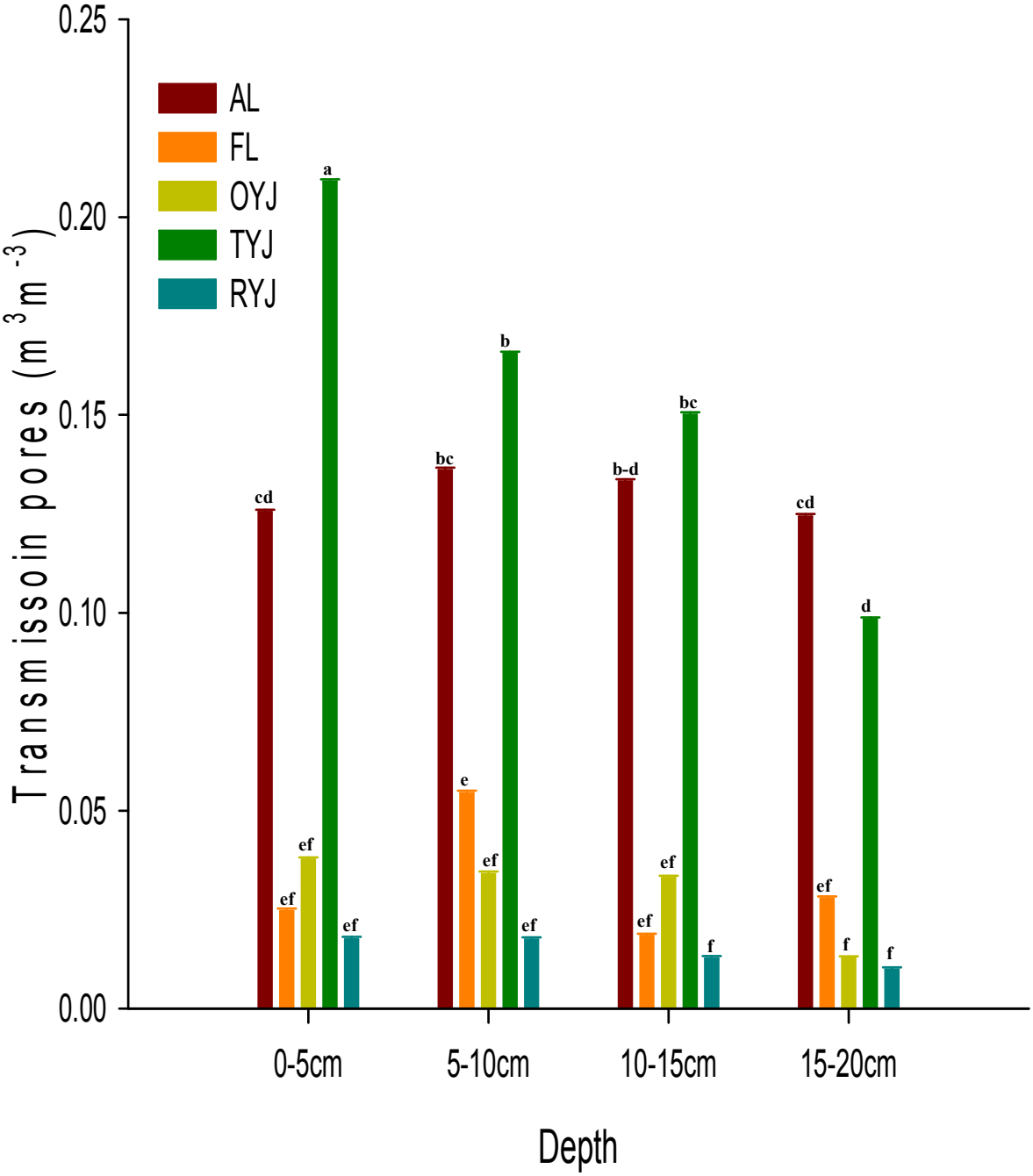


Fig. 4.5: Effect of interaction between land use and soil depth on soil transmission pores

Table 4.16: Relationship between pore size distribution and selected parameters with significant correlation coefficient

Variables				
Dependent (Y)	Independent (X)	Equation	r	r^2
TP	Dry micro-aggregates	Y=0.22X-0.0097	0.41**	0.17
TP	Sand	Y=0.0021X-0.0217	0.34**	0.12
SP	Silt	$Y=0.0001X^2-0.0064X+0.1606$	0.20*	0.06
RP	Dry large macro-aggregates	$Y=-0.5153X^2+0.0779X+0.2502$	0.50**	0.25
RP	Dry macro-aggregates	$Y=-1.7921X^2+2.0757X-0.3469$	0.40**	0.23
RP	Dry mean weight diameter	$Y=-0.0423X^2+0.219X-0.0019$	0.52**	0.27
RP	Dry geometric mean diameter	$Y=-0.5027X^2+1.1479X-0.4003$	0.51**	0.28
RP	Clay	Y=0.00037X+0.1303	0.29*	0.087

r correlation coefficient, r^2 coefficient of determination, * significant at 5%, ** significant at 1%, TP = transmission pores, SP = storage pores, RP = residual pores.

Table 4.17: Relationship between S-index and selected parameters with significant correlation coefficient

Variables				
Dependent (Y)	Independent (X)	Equation	r	r^2
S-index	Bulk density	$Y=0.123X^2-0.3463X+0.2642$	0.70^{**}	0.66
S-index	Wet large macro-aggregates	$Y=-3.401X^2+0.3383X+0.0218$	0.25^{**}	0.08
S-index	Wet macro-aggregates	$Y=-0.1585X^2+0.0381X+0.0197$	0.28^{**}	0.08
S-index	Wet mean weight diameter	$Y=-0.1372X^2+0.1088X+0.008$	0.26^{**}	0.08
S-index	Porosity	$Y=0.0004X+0.0115$	0.29^{**}	0.08

r correlation coefficient, r^2 coefficient of determination, * significant at 5%, ** significant at 1%.

4.7 INFLUENCE OF SPACING AND NITROGEN APPLICATION TO *JATROPHA CURCAS* L. ON SOIL ORGANIC CARBON, NITROGEN AND PARTICLE SIZE DISTRIBUTION

4.7.1 Soil Organic Carbon and Nitrogen

Nitrogen and organic carbon content across all the treatments were generally low according to NSPFS (2005) thematic soil fertility maps. Unlike the soil nitrogen content, organic carbon content was significantly affected by different spacing rates (Table 4.18). The 1.5 m x 2.0 m spacing recorded higher soil organic carbon content when compared with 1.5 m x 1.5 m and 1.5 m x 3.0 m that were statistically similar. Application of nitrogen to JCL did not significantly influence accumulation of soil organic carbon and nitrogen. The result indicates that soil nitrogen and organic carbon content significantly decreased with depth. Interactions between spacing and depth as well as nitrogen application and depth on the soil nitrogen content were significant (Table 4.18). High soil nitrogen content was obtained at lowest spacing rate (1.5m x 1.5m) in the upper depth and the lowest content recorded for 1.5m x 3.0m in the lower depth (Fig. 4.6). Zero application of N treatments produced higher nitrogen content at the upper depth 0-5cm and the low content recorded in 180kgN/ha at the lower depth 15-20cm (Fig. 4.7). The non-significant effect of spacing on soil nitrogen content and application of nitrogen on both soil organic carbon and nitrogen content accumulation was probably due to the relatively young age of the plantation (<3 years) and increased influence of treatments may produce expected result in coming years. This result was also similar to the findings of Chaudhary *et al.* (2006) who observed a non-significant difference among five spacing treatments (1 m x 1 m, 2 m x 1 m, 1.5 m x 1.5 m, 2 m x 2 m and 3 m x 2 m) on soil organic carbon and nitrogen content. The high soil

nitrogen and organic carbon contents in the soil surface was due to contributions from senesced leaves and root biomass in the soil surface compared to the lower depths. Yang *et al.* (2010) in grassland and Lawal *et al.* (2009) in forest plantation recorded greater nitrogen and organic carbon in the upper depth than the lower depth.

4.7.2 Particle Size Distribution

Spacing rates in JCL did not significantly influence distribution of soil particle sizes (Table 4.18). Application of nitrogen to JCL significantly affected the distribution of clay and sand particle fractions. The percentage of sand was greater when 60kgN/ha and 180kgN/ha were applied, with low content observed in 0 kgN/ha and 120 kgN/ha. Although particle size distribution is an intrinsic soil property, the presence of high sand in 60 kgN/ha and 180 kgN/ha could probably be the result of aggradation of silt and clay size particles to sand sizes. Clay content increased with depth while, sand decreased with soil depth. The downward eluviation of clay into the subsurface fits well with an Alfisol soil type in USDA soil taxonomy.

Table 4.18: Influence of spacing and nitrogen under *Jatopha curcas* L. on soil organic carbon, nitrogen and particle size distribution

Treatments	OC(gkg^{-1})	TN(gkg^{-1})	Clay (%)	Silt (%)	Sand (%)
Spacing (S)					
1.5m x 1.5m	6.33b	0.56	26.16	38.27	33.31
1.5m x 2.0m	7.20a	0.50	26.41	38.34	32.74
1.5m x 3.0m	6.23b	0.54	25.99	37.78	34.03
Significance level	*	NS	NS	NS	NS
SE±	0.008	0.001	0.010	0.008	0.013
Nitrogen (N)					
0kg/ha	5.59	0.55	28.10a	38.56	31.24b
60kg/ha	7.01	0.54	24.00b	36.60	37.51a
120kg/ha	6.51	0.54	26.18ab	39.71	31.69b
180kg/ha	6.22	0.51	26.59a	37.70	33.25ab
Significance level	NS	NS	*	NS	*
SE±	0.009	0.001	0.011	0.010	0.015
Depth (D)					
0-5cm	7.52a	0.64a	19.82d	40.85a	38.24a
5-10cm	6.98ab	0.53b	23.37c	39.93a	35.20ab
10-15cm	6.55b	0.47b	28.76b	36.82b	32.17bc
15-20cm	5.34c	0.49b	34.47a	35.14b	28.43c
Significance level	**	**	**	**	**
SE±	0.009	0.001	0.011	0.010	0.015
Interaction					
S x N	NS	NS	NS	NS	NS
S x D	NS	**	NS	NS	NS
N x D	NS	*	NS	NS	NS
S x N x D	NS	NS	NS	NS	NS
CV	4.32	0.74	4.37	3.45	5.63
Mean	**6.58**	**0.53**	**26.19**	**38.13**	**33.36**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

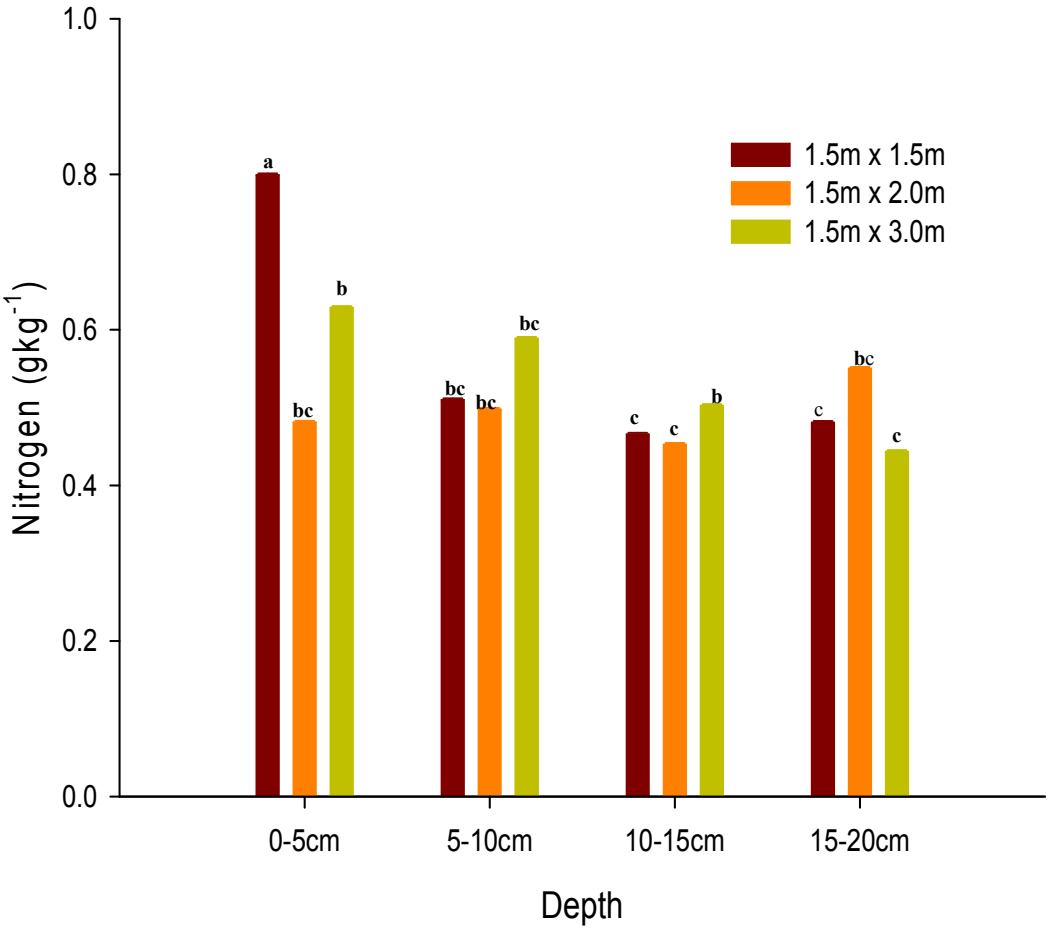


Fig. 4.6: Effect of interaction between spacing rates and soil depth on soil nitrogen content

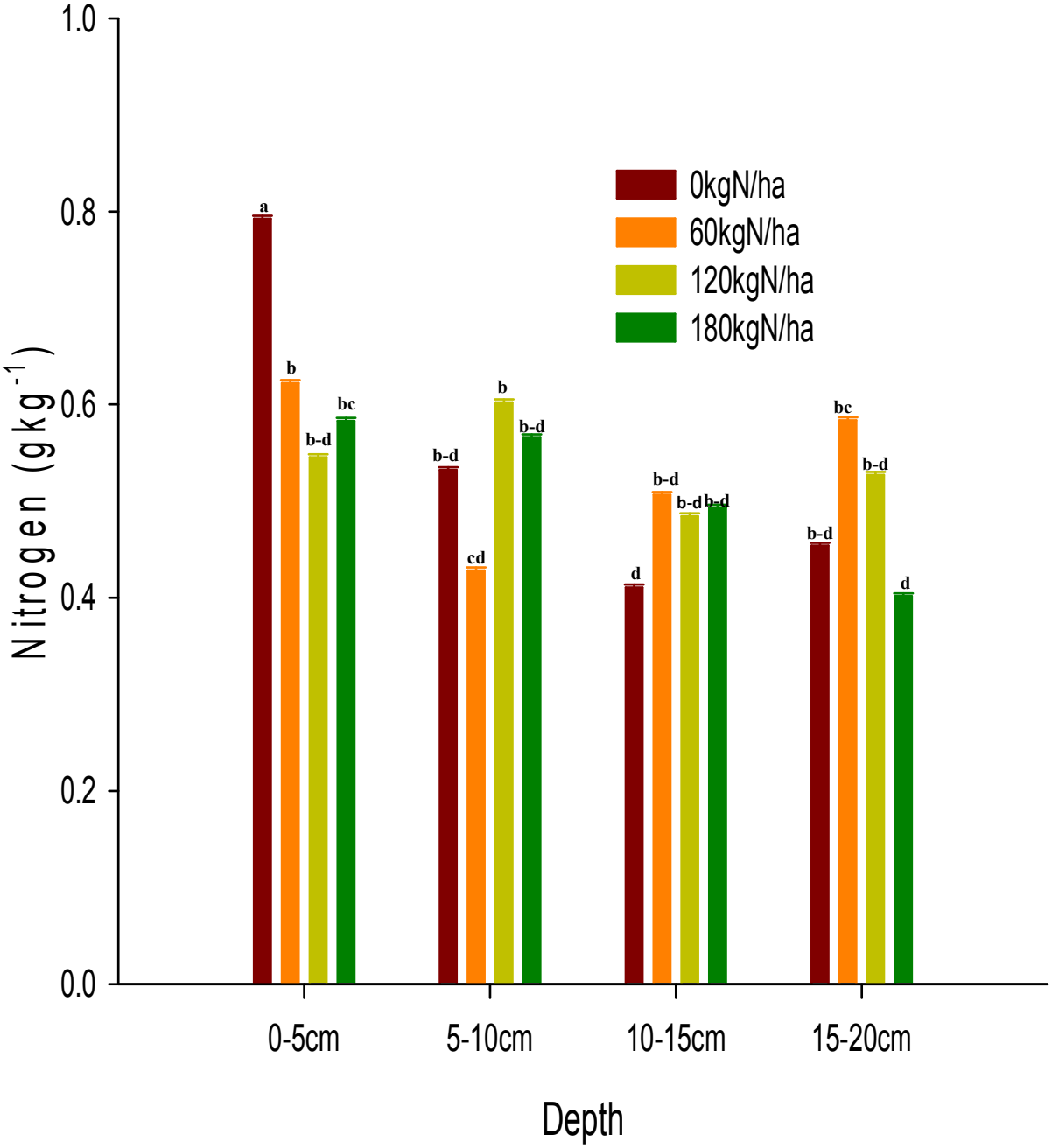


Fig. 4.7: Effect of interaction between nitrogen rates and soil depth on soil nitrogen content

4.8 INFLUENCE OF SPACING AND NITROGEN APPLICATION TO *JATROPHA CURCAS* L. ON SOIL DRY AGGREGATE CHARACTERISTICS

Table 4.19 shows that application of different spacing and nitrogen levels did not significantly influence the distribution of dry aggregates, dry mean weight diameter (MWD) and dry geometric mean diameter (GMD). The distribution of dry large macro- aggregate, MWD and GMD was significantly different along the soil depth. Large macro-aggregates, MWD and GMD were increased with soil depth, while an opposite response was observed in the distribution of macro- and micro-aggregate fractions (Table 4.19). All the possible interactions did not significantly affect the distribution of the aggregate fractions. The result indicates the inability of the spacing rates and nitrogen application to significantly improve the dry aggregate stability of soil under JCL plantation and this could be linked to the age of plantation and its probable different result may be realized in coming years, as Hadas *et al.* (1990) reported that long term nitrogen and zero fertilizer addition affect and stabilize larger soil structural unit at air dryness.

4.9 INFLUENCE OF SPACING AND NITROGEN APPLICATION TO *JATROPHA CURCAS* L. ON SOIL WATER STABLE AGGREGATES

Spacing rates in JCL did not significantly influence the wet aggregate size distribution, mean weight diameter and geometric mean diameter (Table 4.20). Application of 0 kg N/ha to JCL resulted in significantly higher large macro-aggregates fraction, MWD and GMD compared to the low fraction observed in the other nitrogen managed treatments that were statistically similar (Table 4.20). Therefore, water stable aggregate characteristics were not influenced by the application of spacing and nitrogen fertilizer under JCL. However, wet large macro-aggregate, MWD and GMD were found to significantly increase with soil depth, while macro-aggregate, micro-aggregate and silt+clay were decreased with depth in the study area (Table 4.20).

Table 4.19: Influence of spacing and nitrogen under *Jatropha curcas* L. on dry aggregates characteristics

Treatment	Large macro -aggregate (5-2mm)	Macro-aggregates (2-0.25mm)	Micro-aggregates (0.25-0.05mm)	Silt+Clay (<0.05mm)	MWD (mm)	GMD (mm)
Spacing (S)						
1.5 m x 1.5m	0.395	0.376	0.209	0.022	1.836	1.031
1.5m x 2.0m	0.387	0.374	0.221	0.017	1.807	1.024
1.5m x 3.0m	0.376	0.376	0.229	0.018	1.773	1.011
Significance	NS	NS	NS	NS	NS	NS
SE±	0.0003	0.0003	0.0004	0.0001	0.0009	0.0005
Nitrogen (N)						
0kg/ha	0.392	0.371	0.217	0.019	1.822	1.028
60kg/ha	0.376	0.385	0.220	0.019	1.782	1.018
120kg/ha	0.385	0.378	0.216	0.021	1.803	1.021
180kg/ha	0.391	0.365	0.225	0.017	1.813	1.021
Significance	NS	NS	NS	NS	NS	NS
SE±	0.0004	0.0004	0.0005	0.0001	0.001	0.0005
Depth (D)						
0-5cm	0.306c	0.414a	0.262a	0.015b	1.581c	0.955b
5-10cm	0.370b	0.367b	0.238a	0.025a	1.743b	0.985b
10-15cm	0.427a	0.357b	0.194b	0.022ab	1.924a	1.059a
15-20cm	0.441a	0.361b	0.184b	0.014b	1.977a	1.100a
Significance	**	**	**	*	**	**
SE±	0.0004	0.0004	0.0005	0.0001	0.001	0.0005
Interaction						
S x N	NS	NS	NS	NS	NS	NS
S x D	NS	NS	NS	NS	NS	NS
N x D	NS	NS	NS	NS	NS	NS
S x N x D	NS	NS	NS	NS	NS	NS
CV	0.215	0.215	0.284	0.080	0.592	0.303
Mean	**0.386**	**0.375**	**0.220**	**0.019**	**1.805**	**1.022**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

Table 4.20: Influence of spacing and nitrogen under *Jatropha curcas* L. on wet aggregate characteristics

Treatment	Large macro -aggregates (5-2mm)	Macro-aggregates (2-0.25mm)	Micro-aggregates (0.25-0.05mm)	Silt+Clay (<0.05mm)	MWD (mm)	GMD (mm)
Spacing (S)						
1.5m x 1.5m	0.062	0.096	0.267	0.481	0.376	0.353
1.5m x 2.0m	0.067	0.096	0.287	0.456	0.395	0.365
1.5m x 3.0m	0.063	0.089	0.256	0.499	0.370	0.347
Significance	NS	NS	NS	NS	NS	NS
SE±	0.0003	0.0001	0.0006	0.0007	0.0009	0.0003
Nitrogen (N)						
0kg/ha	0.084a	0.096	0.262	0.463	0.451a	0.374a
60kg/ha	0.051b	0.096	0.277	0.482	0.341b	0.347b
120kg/ha	0.060b	0.090	0.259	0.494	0.361b	0.346b
180kg/ha	0.061b	0.093	0.282	0.474	0.370b	0.354b
Significance	**	NS	NS	NS	**	*
SE±	0.0003	0.0001	0.0007	0.0008	0.001	0.0003
Depth (D)						
0-5cm	0.014d	0.109a	0.307a	0.493ab	0.230c	0.329c
5-10cm	0.038c	0.090b	0.254b	0.532a	0.285c	0.324c
10-15cm	0.090b	0.085b	0.274ab	0.463bc	0.463b	0.372b
15-20cm	0.114a	0.091b	0.246b	0.427c	0.547a	0.396a
Significance	**	**	*	**	**	**
SE±	0.0003	0.0001	0.0007	0.0008	0.001	0.0003
Interaction						
S x N	NS	NS	NS	NS	NS	NS
S x D	NS	NS	NS	NS	NS	NS
N x D	NS	NS	NS	NS	NS	NS
S x N x D	NS	NS	NS	NS	NS	NS
CV	0.177	0.089	0.418	0.464	0.584	0.195
Mean	**0.064**	**0.094**	**0.270**	**0.478**	**0.381**	**0.355**

* Significant at 5% level of probability, ** Significant at 1% level of probability, NS not significant at 5%, SE standard error, CV coefficient of variability, values within the same column having same letter are statistically similar.

CHAFTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The study was conducted with aim of assessing influence of *Jatropha curcas* L. (JCL) cultivation and varied cultural practices (spacing and nitrogen rates) under JCL on soil physical quality. In order to achieve this, the study was divided into two trials. The first trial involved a comparison of five adjacent land uses: Arable land (AL), Fallow land (FL), One year JCL plantation (OYJ), Two years JCL plantation (TYJ) and Three years JCL plantation (TYJ). The second trial comprised of three spacing rates (1.5 m x 1 m, 1.5 m x 2 m and 1.5 m x 3 m) and four nitrogen levels (0 $kgha^{-1}$, 60 $kgha^{-1}$, 120 $kgha^{-1}$ and 180 $kgha^{-1}$) under JCL. The treatments were tested under field and laboratory conditions for soil physical quality attributes. Soil samples were collected from four depths (0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm). The data collected were analyzed with SAS 9.0 statistical software to test for the significant difference of mean values at 5%. Means with significant difference were separated using least significant difference (LSD). Bivariate correlation, linear and polynomial regression analyses were used to establish relationship among the parameters.

The result showed that land use had significant effect on soil organic carbon content, total nitrogen, percentage silt and sand, bulk density and total pore spaces. Other parameters significantly affected by land use were dry and water aggregate stability characteristics, soil water retention, pore size distribution and soil physical quality index (S). Fallow land (FL) recorded higher soil organic carbon, soil water retention (between -2 to -1500 kPa) and total residual pores. When averaged across JCL plantation, the plantation had by 47%, 26.1%, 28.3%, 13.4%, 18.8%, and 12.2% higher total nitrogen, infiltration rate, dry large macro-aggregates (>2

mm), dry macro-aggregates (2-0.25 mm), dry mean weight diameter (MWD) and dry geometric mean diameter (GMD), respectively over land under continuous arable production (AL). However, the land use treatments did not significantly influence clay content, dry <0.05 mm aggregates and water stable 0.25-0.05 and <0.05 mm aggregate sizes.

Infiltration model evaluation showed that Kostiakov's model was a more accurate predictor of infiltration over Philip's model. This was manifested by value closed to unity for coefficient of determination-r^2 (0.96), Nash-Sutcliffe Efficiency-E (0.94) and lower value for Root Mean Square Error-RSME (22.37) and Coefficient of Variability-CV (6.76%) with Kostiakov's model.

Application of different spacing rates did not significantly influence the response of soil physical quality attributes except soil organic carbon content which was found to be higher under 1.5 m x 2.0 m JCL spacing treatment. Organic carbon, nitrogen, percentage silt, dry aggregate characteristics, water stable 2 - 0.25 mm, 0.25 - 0.05 mm and <0.05 mm sized aggregates were not significantly affected by nitrogen application. Zero N/ha (control) recorded significantly high water stable large macro-aggregates (>2 mm), MWD and GMD.

Along the studied soil depths, organic carbon, total nitrogen, dry micro-aggregates, water stable macro- and micro-aggregates, transmission pores and percentage silt were decreased with soil depth. In contrast, percentage clay, bulk density, dry large macro-aggregates, dry MWD and GMD, water retention properties, water stable large macro-aggregates, wet MWD and GMD, residual pores and S-index increased with soil depth.

Correlation and regression analysis showed that infiltration rate, water retention at field capacity and permanent wilting point and residual pores were positively correlated with dry aggregate stability. Dry aggregates were positively associated with clay content and transmission pores

were positively related to dry micro-aggregates. The S-index was found to be positively correlated with soil bulk density, water stable aggregates and total pore spaces. Majority of the relationships were better explained by the polynomial regression model.

5.2 CONCLUSION

Jatropha curcas L. (JCL) plantation has the potential of improving soil nitrogen content, infiltration and dry aggregate stability indexes (which strongly help towards soil resistance to wind erosion) of Nigerian Guinea Savanna Alfisol. Application of different spacing and nitrogen to JCL did not significantly influence soil physical conditions within three years of plantation. Kostiakov's model was more efficient and superior in soil infiltration rate prediction over Philip's model in the study area. The Tormena *et al.* (1999) pedotransfer function used in the study was not sensitive in predicting S-index due to the positive and significant correlation observed between S-index and bulk density.

5.3 RECOMMENDATIONS

- *Jatropha curcas* L. (JCL) should be grown in marginal, degraded or land ill-suited for enhanced production in such a way to derive its economic value and exploits soil rehabilitation potential without a serious competition with food production.
- There is a need for a long term study for the response of soil to nitrogen and spacing application to JCL in the study area, because it is probable that different results may be obtained over longer periods.
- There is also need to evaluate the validity of Tormena *et al.* (1999) pedotransfer functions and others used in predicting S-index parameters in the study area.

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APPENDICES

APPENDIX 1

PEARSON CORRELATION ANALYSIS

Abbreviation

OC = Organic carbon

N = Nitrogen

DAGFA = Dry large macro-aggregates (5-2mm)

DAGFB = Dry large macro-aggregates (2-0.25mm)

DAGFC = Dry micro-aggregates (0.25-0.05mm)

DAGFD = Dry silt+clay fractions (<0.05mm)

DMWD = Dry mean weight diameter

DGMD = Dry geometric mean diameter

CL = Clay

ST = Silt

SN = Sand

ZE = Soil water content at 0 kPa matric potential

TW = Soil water content at 2 kPa matric potential

FI = Soil water content at 5 kPa matric potential

TE = Soil water content at 10 kPa matric potential

TTR = Soil water content at 33 kPa matric potential

HUN = Soil water content at 100 kPa matric potential

FHUN = Soil water content at 500 kPa matric potential

OFHUN = Soil water content at 1500 kPa matric potential

AWHC = Available water holding capacity

BD = Bulk density

PD = Particle density

PO = Porosity

WAGFA = Water stable large macro-aggregates (5-2mm)

WAGFB = Water stable large macro-aggregates (2-0.25mm)

WAGFC = Water stable micro-aggregates (0.25-0.05mm)

WAGFD = Water stable silt+clay fractions (<0.05mm)

WMWD = Water stable mean weight diameter

WGMD = Water stable geometric mean diameter

TP = Transmission pores

SP = Storage pores

RP = Residual pores

S = S-index

CORRELATION ANALYSIS

The CORR Procedure
Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OC	N	DAGFA	DAGFB	DAGFC	DAGFD	DMWD	DGMD	CL
OC	1.00000	-0.01896	-0.07845	0.15994	-0.02872	-0.04295	-0.03603	-0.02836	-0.18791
OC		0.8515	0.4379	0.1119	0.7767	0.6714	0.7219	0.7794	0.0612
N	-0.01896	1.00000	0.15647	0.18047	-0.19413	0.02543	0.17405	0.18172	0.09581
N	0.8515		0.1200	0.0724	0.0530	0.8017	0.0833	0.0704	0.3430
DAGFA	-0.07845	0.15647	1.00000	0.52286	-0.89629	-0.16169	0.98476	0.94395	0.51674
DAGFA	0.4379	0.1200		<.0001	<.0001	0.1080	<.0001	<.0001	<.0001
DAGFB	0.15994	0.18047	0.52286	1.00000	-0.84238	-0.05346	0.66313	0.76370	0.22035
DAGFB	0.1119	0.0724	<.0001		<.0001	0.5973	<.0001	<.0001	0.0276
DAGFC	-0.02872	-0.19413	-0.89629	-0.84238	1.00000	0.06333	-0.95865	-0.98238	-0.43416
DAGFC	0.7767	0.0530	<.0001	<.0001		0.5314	<.0001	<.0001	<.0001
DAGFD	-0.04295	0.02543	-0.16169	-0.05346	0.06333	1.00000	-0.15625	-0.17995	-0.13544
DAGFD	0.6714	0.8017	0.1080	0.5973	0.5314		0.1206	0.0732	0.1791
DMWD	-0.03603	0.17405	0.98476	0.66313	-0.95865	-0.15625	1.00000	0.98481	0.49887
DMWD	0.7219	0.0833	<.0001	<.0001	<.0001	0.1206		<.0001	<.0001
DGMD	-0.02836	0.18172	0.94395	0.76370	-0.98238	-0.17995	0.98481	1.00000	0.46717
DGMD	0.7794	0.0704	<.0001	<.0001	<.0001	0.0732	<.0001		<.0001
CL	-0.18791	0.09581	0.51674	0.22035	-0.43416	-0.13544	0.49887	0.46717	1.00000
CL	0.0612	0.3430	<.0001	0.0276	<.0001	0.1791	<.0001	<.0001	
ST	0.16128	-0.07580	-0.03022	0.06689	-0.00567	-0.13644	-0.01239	-0.00028	0.39750
ST	0.1089	0.4535	0.7653	0.5085	0.9553	0.1759	0.9026	0.9978	<.0001
SN	-0.04248	0.01680	-0.19505	-0.14337	0.18732	0.16005	-0.20097	-0.19674	-0.72153
SN	0.6747	0.8682	0.0518	0.1547	0.0620	0.1117	0.0450	0.0498	<.0001
ZE	0.01254	-0.29499	-0.08796	-0.21091	0.16967	-0.08174	-0.11996	-0.14145	0.01193
ZE	0.9014	0.0029	0.3842	0.0352	0.0915	0.4188	0.2345	0.1604	0.9062
TW	0.02515	-0.09409	0.02586	0.03408	-0.03849	0.06694	0.02942	0.02186	-0.05421
TW	0.8038	0.3518	0.7984	0.7364	0.7038	0.5081	0.7714	0.8291	0.5922
FI	0.11919	0.08147	0.62483	0.32571	-0.55672	-0.14250	0.61524	0.58013	0.36595
FI	0.2376	0.4204	<.0001	0.0009	<.0001	0.1573	<.0001	<.0001	0.0002
TE	0.14569	0.06108	0.63185	0.34408	-0.57087	-0.13870	0.62515	0.59047	0.35750
TE	0.1481	0.5460	<.0001	0.0005	<.0001	0.1687	<.0001	<.0001	0.0003

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	ST	SN	ZE	TW	FI	TE	TTR	HUN	FHUN
OC	0.16128	-0.04248	0.01254	0.02515	0.11919	0.14569	0.12709	0.05872	0.11038
OC	0.1089	0.6747	0.9014	0.8038	0.2376	0.1481	0.2077	0.5617	0.2743
N	-0.07580	0.01680	-0.29499	-0.09409	0.08147	0.06108	0.12550	0.13493	0.13316
N	0.4535	0.8682	0.0029	0.3518	0.4204	0.5460	0.2135	0.1808	0.1866
DAGFA	-0.03022	-0.19505	-0.08796	0.02586	0.62483	0.63185	0.60585	0.46748	0.51192
DAGFA	0.7653	0.0518	0.3842	0.7984	<.0001	<.0001	<.0001	<.0001	<.0001
DAGFB	0.06689	-0.14337	-0.21091	0.03408	0.32571	0.34408	0.36770	0.30554	0.37286
DAGFB	0.5085	0.1547	0.0352	0.7364	0.0009	0.0005	0.0002	0.0020	0.0001
DAGFC	-0.00567	0.18732	0.16967	-0.03849	-0.55672	-0.57087	-0.56951	-0.45291	-0.51810
DAGFC	0.9553	0.0620	0.0915	0.7038	<.0001	<.0001	<.0001	<.0001	<.0001
DAGFD	-0.13644	0.16005	-0.08174	0.06694	-0.14250	-0.13870	-0.09135	-0.03627	-0.00175
DAGFD	0.1759	0.1117	0.4188	0.5081	0.1573	0.1687	0.3660	0.7201	0.9862
DMWD	-0.01239	-0.20097	-0.11996	0.02942	0.61524	0.62515	0.60699	0.47270	0.52531
DMWD	0.9026	0.0450	0.2345	0.7714	<.0001	<.0001	<.0001	<.0001	<.0001
DGMD	-0.00028	-0.19674	-0.14145	0.02186	0.58013	0.59047	0.57719	0.44806	0.51058
DGMD	0.9978	0.0498	0.1604	0.8291	<.0001	<.0001	<.0001	<.0001	<.0001
CL	0.39750	-0.72153	0.01193	-0.05421	0.36595	0.35750	0.35403	0.26013	0.29016
CL	<.0001	<.0001	0.9062	0.5922	0.0002	0.0003	0.0003	0.0090	0.0034
ST	1.00000	-0.92214	-0.04817	-0.27619	0.09222	0.09075	0.04491	-0.07371	0.01870
ST		<.0001	0.6341	0.0054	0.3615	0.3692	0.6572	0.4661	0.8535
SN	-0.92214	1.00000	0.03132	0.23126	-0.22386	-0.21919	-0.18314	-0.05405	-0.13644
SN	<.0001		0.7571	0.0206	0.0252	0.0284	0.0682	0.5933	0.1759
ZE	-0.04817	0.03132	1.00000	0.59433	-0.11336	-0.07769	-0.17941	-0.12473	-0.20766
ZE	0.6341	0.7571		<.0001	0.2614	0.4423	0.0741	0.2163	0.0382
TW	-0.27619	0.23126	0.59433	1.00000	0.08236	0.13607	0.09297	0.20450	0.11219
TW	0.0054	0.0206	<.0001		0.4153	0.1770	0.3576	0.0413	0.2664
FI	0.09222	-0.22386	-0.11336	0.08236	1.00000	0.97715	0.95343	0.77030	0.82674
FI	0.3615	0.0252	0.2614	0.4153		<.0001	<.0001	<.0001	<.0001
TE	0.09075	-0.21919	-0.07769	0.13607	0.97715	1.00000	0.95927	0.76887	0.83883
TE	0.3692	0.0284	0.4423	0.1770	<.0001		<.0001	<.0001	<.0001

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OFHUN	AWHC	BD	PD	PO	WAGFA	WAGFB	WAGFC	WAGFD
OC	0.11544	-0.00463	-0.04851	0.00414	0.06249	0.06396	0.10359	0.07852	-0.09281
OC	0.2527	0.9635	0.6317	0.9674	0.5368	0.5273	0.3051	0.4374	0.3584
N	0.14990	-0.09040	0.09898	-0.16133	-0.29004	-0.00714	0.02551	0.00913	0.00146
N	0.1366	0.3711	0.3272	0.1088	0.0034	0.9438	0.8011	0.9281	0.9885
DAGFA	0.49818	0.10256	0.20882	0.06666	-0.11168	0.09132	-0.27042	-0.03264	0.02491
DAGFA	<.0001	0.3099	0.0371	0.5099	0.2686	0.3662	0.0065	0.7472	0.8057
DAGFB	0.38697	-0.14002	0.15756	-0.04779	-0.22276	0.00654	0.05655	0.10996	-0.12050
DAGFB	<.0001	0.1647	0.1174	0.6368	0.0259	0.9485	0.5763	0.2761	0.2324
DAGFC	-0.51630	0.01834	-0.21809	-0.01749	0.19063	-0.05698	0.14755	-0.01930	0.03069
DAGFC	<.0001	0.8563	0.0293	0.8628	0.0575	0.5734	0.1429	0.8489	0.7618
DAGFD	-0.00509	-0.18285	0.05789	-0.01055	-0.07772	-0.07104	-0.05152	-0.23813	0.22248
DAGFD	0.9599	0.0686	0.5673	0.9171	0.4422	0.4824	0.6107	0.0170	0.0261
DMWD	0.51615	0.06203	0.21520	0.04877	-0.14320	0.08171	-0.22555	-0.00536	-0.00351
DMWD	<.0001	0.5398	0.0315	0.6299	0.1552	0.4190	0.0241	0.9578	0.9723
DGMD	0.50413	0.02715	0.19988	0.02202	-0.16426	0.06452	-0.17762	0.01202	-0.02241
DGMD	<.0001	0.7886	0.0462	0.8279	0.1025	0.5236	0.0771	0.9055	0.8248
CL	0.28674	0.07038	0.17475	0.13764	0.00994	0.12082	-0.10178	-0.02931	-0.00351
CL	0.0038	0.4865	0.0821	0.1720	0.9218	0.2312	0.3136	0.7722	0.9724
ST	0.01360	0.06338	-0.06771	-0.13626	-0.09929	-0.13367	-0.19143	0.13479	-0.07748
ST	0.8932	0.5310	0.5033	0.1765	0.3257	0.1849	0.0564	0.1812	0.4436
SN	-0.13115	-0.07749	-0.02258	0.04478	0.07073	0.04993	0.18735	-0.08935	0.05994
SN	0.1934	0.4435	0.8235	0.6582	0.4844	0.6218	0.0620	0.3767	0.5536
ZE	-0.25482	0.22609	-0.24233	0.52931	0.90365	0.18539	0.05218	0.01929	-0.04182
ZE	0.0105	0.0237	0.0151	<.0001	<.0001	0.0648	0.6061	0.8489	0.6795
TW	0.10387	-0.04980	0.30540	0.63930	0.50037	0.36089	0.37466	-0.05686	-0.02635
TW	0.3038	0.6227	0.0020	<.0001	<.0001	0.0002	0.0001	0.5742	0.7947
FI	0.80499	0.11119	0.42576	0.17502	-0.19299	0.01469	-0.25269	-0.05297	0.04682
FI	<.0001	0.2707	<.0001	0.0816	0.0544	0.8847	0.0112	0.6007	0.6437
TE	0.81058	0.11029	0.40119	0.18699	-0.15495	0.08757	-0.21829	-0.05918	0.04075
TE	<.0001	0.2747	<.0001	0.0625	0.1237	0.3863	0.0291	0.5587	0.6873

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	WMWD	WGMD	TP	SP	RP	S
OC	0.10966	0.11547	-0.08831	-0.06838	0.11544	-0.06021
OC	0.2774	0.2526	0.3823	0.4990	0.2527	0.5518
N	0.00950	0.00560	-0.11970	-0.07085	0.14990	-0.11808
N	0.9253	0.9559	0.2355	0.4836	0.1366	0.2420
DAGFA	-0.06659	-0.07371	-0.46275	0.00513	0.49818	0.01499
DAGFA	0.5104	0.4661	<.0001	0.9596	<.0001	0.8823
DAGFB	0.05871	0.11196	-0.23591	-0.20941	0.38697	-0.01002
DAGFB	0.5618	0.2674	0.0181	0.0365	<.0001	0.9212
DAGFC	0.02179	0.00492	0.40636	0.11435	-0.51630	-0.00822
DAGFC	0.8296	0.9613	<.0001	0.2573	<.0001	0.9353
DAGFD	-0.13667	-0.22268	0.15357	-0.15605	-0.00509	0.05563
DAGFD	0.1751	0.0260	0.1271	0.1210	0.9599	0.5825
DMWD	-0.04597	-0.04105	-0.45474	-0.03771	0.51615	0.01091
DMWD	0.6497	0.6851	<.0001	0.7095	<.0001	0.9142
DGMD	-0.03185	-0.01682	-0.43364	-0.06555	0.50413	-0.00561
DGMD	0.7531	0.8681	<.0001	0.5170	<.0001	0.9558
CL	0.02728	-0.00644	-0.31769	0.08033	0.28674	0.14286
CL	0.7876	0.9493	0.0013	0.4269	0.0038	0.1562
ST	-0.13521	0.01906	-0.28071	0.20522	0.01360	-0.18583
ST	0.1798	0.8507	0.0047	0.0405	0.8932	0.0642
SN	0.09052	-0.01166	0.34575	-0.18872	-0.13115	0.07999
SN	0.3704	0.9083	0.0004	0.0601	0.1934	0.4289
ZE	0.15284	0.07796	0.50992	0.21266	-0.25482	0.22499
ZE	0.1290	0.4407	<.0001	0.0337	0.0105	0.0244
TW	0.39002	0.13921	0.64987	-0.06916	0.10387	0.54019
TW	<.0001	0.1672	<.0001	0.4941	0.3038	<.0001
FI	-0.11625	-0.10278	-0.68731	0.02470	0.80499	0.15367
FI	0.2494	0.3089	<.0001	0.8073	<.0001	0.1269
TE	-0.05398	-0.07976	-0.66364	0.02936	0.81058	0.16751
TE	0.5938	0.4302	<.0001	0.7718	<.0001	0.0957

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OC	N	DAGFA	DAGFB	DAGFC	DAGFD	DMWD	DGMD	CL
TTR	0.12709	0.12550	0.60585	0.36770	-0.56951	-0.09135	0.60699	0.57719	0.35403
TTR	0.2077	0.2135	<.0001	0.0002	<.0001	0.3660	<.0001	<.0001	0.0003
HUN	0.05872	0.13493	0.46748	0.30554	-0.45291	-0.03627	0.47270	0.44806	0.26013
HUN	0.5617	0.1808	<.0001	0.0020	<.0001	0.7201	<.0001	<.0001	0.0090
FHUN	0.11038	0.13316	0.51192	0.37286	-0.51810	-0.00175	0.52531	0.51058	0.29016
FHUN	0.2743	0.1866	<.0001	0.0001	<.0001	0.9862	<.0001	<.0001	0.0034
OFHUN	0.11544	0.14990	0.49818	0.38697	-0.51630	-0.00509	0.51615	0.50413	0.28674
OFHUN	0.2527	0.1366	<.0001	<.0001	<.0001	0.9599	<.0001	<.0001	0.0038
AWHC	-0.00463	-0.09040	0.10256	-0.14002	0.01834	-0.18285	0.06203	0.02715	0.07038
AWHC	0.9635	0.3711	0.3099	0.1647	0.8563	0.0686	0.5398	0.7886	0.4865
BD	-0.04851	0.09898	0.20882	0.15756	-0.21809	0.05789	0.21520	0.19988	0.17475
BD	0.6317	0.3272	0.0371	0.1174	0.0293	0.5673	0.0315	0.0462	0.0821
PD	0.00414	-0.16133	0.06666	-0.04779	-0.01749	-0.01055	0.04877	0.02202	0.13764
PD	0.9674	0.1088	0.5099	0.6368	0.8628	0.9171	0.6299	0.8279	0.1720
PO	0.06249	-0.29004	-0.11168	-0.22276	0.19063	-0.07772	-0.14320	-0.16426	0.00994
PO	0.5368	0.0034	0.2686	0.0259	0.0575	0.4422	0.1552	0.1025	0.9218
WAGFA	0.06396	-0.00714	0.09132	0.00654	-0.05698	-0.07104	0.08171	0.06452	0.12082
WAGFA	0.5273	0.9438	0.3662	0.9485	0.5734	0.4824	0.4190	0.5236	0.2312
WAGFB	0.10359	0.02551	-0.27042	0.05655	0.14755	-0.05152	-0.22555	-0.17762	-0.10178
WAGFB	0.3051	0.8011	0.0065	0.5763	0.1429	0.6107	0.0241	0.0771	0.3136
WAGFC	0.07852	0.00913	-0.03264	0.10996	-0.01930	-0.23813	-0.00536	0.01202	-0.02931
WAGFC	0.4374	0.9281	0.7472	0.2761	0.8489	0.0170	0.9578	0.9055	0.7722
WAGFD	-0.09281	0.00146	0.02491	-0.12050	0.03069	0.22248	-0.00351	-0.02241	-0.00351
WAGFD	0.3584	0.9885	0.8057	0.2324	0.7618	0.0261	0.9723	0.8248	0.9724
WMWD	0.10966	0.00950	-0.06659	0.05871	0.02179	-0.13667	-0.04597	-0.03185	0.02728
WMWD	0.2774	0.9253	0.5104	0.5618	0.8296	0.1751	0.6497	0.7531	0.7876
WGMD	0.11547	0.00560	-0.07371	0.11196	0.00492	-0.22268	-0.04105	-0.01682	-0.00644
WGMD	0.2526	0.9559	0.4661	0.2674	0.9613	0.0260	0.6851	0.8681	0.9493
TP	-0.08831	-0.11970	-0.46275	-0.23591	0.40636	0.15357	-0.45474	-0.43364	-0.31769
TP	0.3823	0.2355	<.0001	0.0181	<.0001	0.1271	<.0001	<.0001	0.0013

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	ST	SN	ZE	TW	FI	TE	TTR	HUN	FHUN
TTR	0.04491	-0.18314	-0.17941	0.09297	0.95343	0.95927	1.00000	0.82792	0.92178
TTR	0.6572	0.0682	0.0741	0.3576	<.0001	<.0001		<.0001	<.0001
HUN	-0.07371	-0.05405	-0.12473	0.20450	0.77030	0.76887	0.82792	1.00000	0.83731
HUN	0.4661	0.5933	0.2163	0.0413	<.0001	<.0001	<.0001		<.0001
FHUN	0.01870	-0.13644	-0.20766	0.11219	0.82674	0.83883	0.92178	0.83731	1.00000
FHUN	0.8535	0.1759	0.0382	0.2664	<.0001	<.0001	<.0001	<.0001	
OFHUN	0.01360	-0.13115	-0.25482	0.10387	0.80499	0.81058	0.90842	0.82181	0.99211
OFHUN	0.8932	0.1934	0.0105	0.3038	<.0001	<.0001	<.0001	<.0001	<.0001
AWHC	0.06338	-0.07749	0.22609	-0.04980	0.11119	0.11029	-0.03661	-0.19695	-0.40366
AWHC	0.5310	0.4435	0.0237	0.6227	0.2707	0.2747	0.7176	0.0495	<.0001
BD	-0.06771	-0.02258	-0.24233	0.30540	0.42576	0.40119	0.39568	0.32346	0.32854
BD	0.5033	0.8235	0.0151	0.0020	<.0001	<.0001	<.0001	0.0010	0.0008
PD	-0.13626	0.04478	0.52931	0.63930	0.17502	0.18699	0.10337	0.09231	0.01812
PD	0.1765	0.6582	<.0001	<.0001	0.0816	0.0625	0.3061	0.3610	0.8580
PO	-0.09929	0.07073	0.90365	0.50037	-0.19299	-0.15495	-0.25367	-0.20083	-0.29091
PO	0.3257	0.4844	<.0001	<.0001	0.0544	0.1237	0.0109	0.0451	0.0033
WAGFA	-0.13367	0.04993	0.18539	0.36089	0.01469	0.08757	0.06326	0.11207	0.07813
WAGFA	0.1849	0.6218	0.0648	0.0002	0.8847	0.3863	0.5318	0.2669	0.4397
WAGFB	-0.19143	0.18735	0.05218	0.37466	-0.25269	-0.21829	-0.16142	-0.09471	-0.08947
WAGFB	0.0564	0.0620	0.6061	0.0001	0.0112	0.0291	0.1086	0.3486	0.3760
WAGFC	0.13479	-0.08935	0.01929	-0.05686	-0.05297	-0.05918	-0.05061	-0.12510	-0.08792
WAGFC	0.1812	0.3767	0.8489	0.5742	0.6007	0.5587	0.6171	0.2149	0.3844
WAGFD	-0.07748	0.05994	-0.04182	-0.02635	0.04682	0.04075	0.02242	0.09238	0.06707
WAGFD	0.4436	0.5536	0.6795	0.7947	0.6437	0.6873	0.8247	0.3606	0.5073
WMWD	-0.13521	0.09052	0.15284	0.39002	-0.11625	-0.05398	-0.04363	-0.00160	-0.01154
WMWD	0.1798	0.3704	0.1290	<.0001	0.2494	0.5938	0.6665	0.9874	0.9093
WGMD	0.01906	-0.01166	0.07796	0.13921	-0.10278	-0.07976	-0.05908	-0.09703	-0.07810
WGMD	0.8507	0.9083	0.4407	0.1672	0.3089	0.4302	0.5593	0.3368	0.4399
TP	-0.28071	0.34575	0.50992	0.64987	-0.68731	-0.66364	-0.66476	-0.43454	-0.55777
TP	0.0047	0.0004	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OFHUN	AWHC	BD	PD	PO	WAGFA	WAGFB	WAGFC	WAGFD
TTR	0.90842	-0.03661	0.39568	0.10337	-0.25367	0.06326	-0.16142	-0.05061	0.02242
TTR	<.0001	0.7176	<.0001	0.3061	0.0109	0.5318	0.1086	0.6171	0.8247
HUN	0.82181	-0.19695	0.32346	0.09231	-0.20083	0.11207	-0.09471	-0.12510	0.09238
HUN	<.0001	0.0495	0.0010	0.3610	0.0451	0.2669	0.3486	0.2149	0.3606
FHUN	0.99211	-0.40366	0.32854	0.01812	-0.29091	0.07813	-0.08947	-0.08792	0.06707
FHUN	<.0001	<.0001	0.0008	0.8580	0.0033	0.4397	0.3760	0.3844	0.5073
OFHUN	1.00000	-0.45105	0.34868	0.00200	-0.33144	0.06101	-0.04753	-0.07747	0.05259
OFHUN		<.0001	0.0004	0.9843	0.0008	0.5465	0.6386	0.4436	0.6033
AWHC	-0.45105	1.00000	0.01125	0.21590	0.25073	-0.01078	-0.23099	0.07715	-0.07784
AWHC	<.0001		0.9116	0.0310	0.0119	0.9152	0.0208	0.4455	0.4414
BD	0.34868	0.01125	1.00000	0.62401	-0.22820	0.14528	0.17286	-0.02344	-0.05637
BD	0.0004	0.9116		<.0001	0.0224	0.1493	0.0855	0.8169	0.5775
PD	0.00200	0.21590	0.62401	1.00000	0.60894	0.29312	0.20622	-0.00031	-0.08683
PD	0.9843	0.0310	<.0001		<.0001	0.0031	0.0395	0.9976	0.3903
PO	-0.33144	0.25073	-0.22820	0.60894	1.00000	0.22589	0.07789	0.01598	-0.04328
PO	0.0008	0.0119	0.0224	<.0001		0.0238	0.4411	0.8746	0.6690
WAGFA	0.06101	-0.01078	0.14528	0.29312	0.22589	1.00000	0.36577	-0.04097	-0.05281
WAGFA	0.5465	0.9152	0.1493	0.0031	0.0238		0.0002	0.6857	0.6018
WAGFB	-0.04753	-0.23099	0.17286	0.20622	0.07789	0.36577	1.00000	0.32837	-0.45204
WAGFB	0.6386	0.0208	0.0855	0.0395	0.4411	0.0002		0.0009	<.0001
WAGFC	-0.07747	0.07715	-0.02344	-0.00031	0.01598	-0.04097	0.32837	1.00000	-0.96727
WAGFC	0.4436	0.4455	0.8169	0.9976	0.8746	0.6857	0.0009		<.0001
WAGFD	0.05259	-0.07784	-0.05637	-0.08683	-0.04328	-0.05281	-0.45204	-0.96727	1.00000
WAGFD	0.6033	0.4414	0.5775	0.3903	0.6690	0.6018	<.0001	<.0001	
WMWD	-0.00205	-0.08823	0.16392	0.28488	0.19050	0.82375	0.77166	0.39106	-0.49661
WMWD	0.9838	0.3827	0.1032	0.0041	0.0576	<.0001	<.0001	<.0001	<.0001
WGMD	-0.05932	0.01567	0.07206	0.13672	0.09224	0.26784	0.63867	0.90653	-0.95817
WGMD	0.5577	0.8771	0.4762	0.1750	0.3614	0.0071	<.0001	<.0001	<.0001
TP	-0.54237	-0.12270	-0.08271	0.33626	0.49849	0.20943	0.45172	0.00147	-0.05091
TP	<.0001	0.2239	0.4133	0.0006	<.0001	0.0365	<.0001	0.9884	0.6149

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	WMWD	WGMD	TP	SP	RP	S
TTR	-0.04363	-0.05908	-0.66476	-0.13593	0.90842	0.14139
TTR	0.6665	0.5593	<.0001	0.1775	<.0001	0.1606
HUN	-0.00160	-0.09703	-0.43454	-0.24168	0.82181	0.16985
HUN	0.9874	0.3368	<.0001	0.0154	<.0001	0.0911
FHUN	-0.01154	-0.07810	-0.55777	-0.34793	0.99211	0.17301
FHUN	0.9093	0.4399	<.0001	0.0004	<.0001	0.0852
OFHUN	-0.00205	-0.05932	-0.54237	-0.39241	1.00000	0.18153
OFHUN	0.9838	0.5577	<.0001	<.0001	<.0001	0.0707
AWHC	-0.08823	0.01567	-0.12270	0.64779	-0.45105	-0.13209
AWHC	0.3827	0.8771	0.2239	<.0001	<.0001	0.1902
BD	0.16392	0.07206	-0.08271	-0.01818	0.34868	0.70591
BD	0.1032	0.4762	0.4133	0.8576	0.0004	<.0001
PD	0.28488	0.13672	0.33626	0.17055	0.00200	0.81246
PD	0.0041	0.1750	0.0006	0.0898	0.9843	<.0001
PO	0.19050	0.09224	0.49849	0.23121	-0.33144	0.29047
PO	0.0576	0.3614	<.0001	0.0206	0.0008	0.0034
WAGFA	0.82375	0.26784	0.20943	-0.05107	0.06101	0.24600
WAGFA	<.0001	0.0071	0.0365	0.6139	0.5465	0.0136
WAGFB	0.77166	0.63867	0.45172	-0.19593	-0.04753	0.28075
WAGFB	<.0001	<.0001	<.0001	0.0507	0.6386	0.0047
WAGFC	0.39106	0.90653	0.00147	0.11053	-0.07747	-0.10674
WAGFC	<.0001	<.0001	0.9884	0.2736	0.4436	0.2905
WAGFD	-0.49661	-0.95817	-0.05091	-0.08011	0.05259	0.01864
WAGFD	<.0001	<.0001	0.6149	0.4282	0.6033	0.8539
WMWD	1.00000	0.70730	0.33898	-0.08925	-0.00205	0.25674
WMWD		<.0001	0.0006	0.3772	0.9838	0.0099
WGMD	0.70730	1.00000	0.16699	0.02472	-0.05932	0.05608
WGMD	<.0001		0.0968	0.8071	0.5577	0.5794
TP	0.33898	0.16699	1.00000	-0.07635	-0.54237	0.27571
TP	0.0006	0.0968		0.4502	<.0001	0.0055

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OC	N	DAGFA	DAGFB	DAGFC	DAGFD	DMWD	DGMD	CL
SP	-0.06838	-0.07085	0.00513	-0.20941	0.11435	-0.15605	-0.03771	-0.06555	0.08033
SP	0.4990	0.4836	0.9596	0.0365	0.2573	0.1210	0.7095	0.5170	0.4269
RP	0.11544	0.14990	0.49818	0.38697	-0.51630	-0.00509	0.51615	0.50413	0.28674
RP	0.2527	0.1366	<.0001	<.0001	<.0001	0.9599	<.0001	<.0001	0.0038
S	-0.06021	-0.11808	0.01499	-0.01002	-0.00822	0.05563	0.01091	-0.00561	0.14286
S	0.5518	0.2420	0.8823	0.9212	0.9353	0.5825	0.9142	0.9558	0.1562

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	ST	SN	ZE	TW	FI	TE	TTR	HUN	FHUN
SP	0.20522	-0.18872	0.21266	-0.06916	0.02470	0.02936	-0.13593	-0.24168	-0.34793
SP	0.0405	0.0601	0.0337	0.4941	0.8073	0.7718	0.1775	0.0154	0.0004
RP	0.01360	-0.13115	-0.25482	0.10387	0.80499	0.81058	0.90842	0.82181	0.99211
RP	0.8932	0.1934	0.0105	0.3038	<.0001	<.0001	<.0001	<.0001	<.0001
S	-0.18583	0.07999	0.22499	0.54019	0.15367	0.16751	0.14139	0.16985	0.17301
S	0.0642	0.4289	0.0244	<.0001	0.1269	0.0957	0.1606	0.0911	0.0852

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	OFHUN	AWHC	BD	PD	PO	WAGFA	WAGFB	WAGFC	WAGFD
SP	-0.39241	0.64779	-0.01818	0.17055	0.23121	-0.05107	-0.19593	0.11053	-0.08011
SP	<.0001	<.0001	0.8576	0.0898	0.0206	0.6139	0.0507	0.2736	0.4282
RP	1.00000	-0.45105	0.34868	0.00200	-0.33144	0.06101	-0.04753	-0.07747	0.05259
RP	<.0001	<.0001	0.0004	0.9843	0.0008	0.5465	0.6386	0.4436	0.6033
S	0.18153	-0.13209	0.70591	0.81246	0.29047	0.24600	0.28075	-0.10674	0.01864
S	0.0707	0.1902	<.0001	<.0001	0.0034	0.0136	0.0047	0.2905	0.8539

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	WMWD	WGMD	TP	SP	RP	S
SP	-0.08925	0.02472	-0.07635	1.00000	-0.39241	-0.08575
SP	0.3772	0.8071	0.4502		<.0001	0.3963

CORRELATION ANALYSIS

The CORR Procedure

Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

	WMWD	WGMD	TP	SP	RP	S
RP	-0.00205	-0.05932	-0.54237	-0.39241	1.00000	0.18153
RP	0.9838	0.5577	<.0001	<.0001		0.0707
S	0.25674	0.05608	0.27571	-0.08575	0.18153	1.00000
S	0.0099	0.5794	0.0055	0.3963	0.0707	