TITLE PAGE

HYDRAULIC CHARACTERISTICS AND TEMPORAL VARIABILITY OF SOIL PROPERTIES UNDER A LONG-TERM TRIAL IN SAMARU, NORTHERN GUINEASAVANNA OF NIGERIA

BY

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M.Sc./AGRIC/11280/2011-2012

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER DEGREE IN SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE,

FACULTY OF AGRICULTURE,

AHMADU BELLO UNIVERSITY ZARIA

JANUARY, 2015.

DECLARATION

I hereby declare that this thesis titled ‘’**Hydraulic characteristics and temporal variability of soil properties under a long-term trial in Samaru, Northern Guinea Savanna of Nigeria**’’ was written by me and it is a record of my own research work. It has not been presented in any previous application for a higher degree. References made to published and unpublished literature have been duly acknowledged.

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ABUBAKAR Girei Halilu DATE

CERTIFICATION

This thesis titled ‘’**Hydraulic characteristics and temporal variability of soil properties under a long-term trial in Samaru, Northern Guinea Savanna of Nigeria**’’meets the regulations governing the award of the Master of Science of AhmaduBello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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This work is dedicated to Almighty ALLAH who inspired me to higher ideas of life

ACKNOWLEDGEMENT

All praises be to Allah Almighty, the most Affectionate, the most Merciful, Who created the universe and countless salutation be upon His beloved and last Prophet Muhammad (peace be upon him), who declared that it is an obligatory duty of every Muslim to seek and acquire knowledge. I am highly indebted and express my gratitude to Allah, the most Beneficent, and the most Merciful, Who granted me the ability to undertake this research work and complete the dissertation. This gives me the privilege to acknowledge few of those people whose sincerehelp, guidance and prayers enabled me to accomplish my research work in a congenialand serene environment.

First of all, I would like to extend my gratitude to my supervisor, Dr. Aisha Abdulkadir, whose abled supervision, guidance, stimulating suggestions, positive criticism andencouragement helped me all through my research and for writing this thesis. I ardently extend my warmest and sincere thanks to my supervisory committee member Dr. Nafiu Abduin his excellent guidance, invaluable advice, kindness and support in carrying out thisresearch work. Also the support and encouragement of my HOD in person of Dr. Ado Yusuf is well appreciated. I am highly appreciative to Mrs H.M. Lawal, Mal. Ibrahim Aliyu, Ibrahim Muhammed, Jabir Abdulkareem, Jamila Aliyu, Yakubu Muhammed and Fatima Abubakar for their timely support, guidance and sharing their knowledge with me. My gratitude goes to all the academic staff of the Department of Soil Science for their guidance, suggestions, and encouragementthroughout this research work. Thanks to all the technical staff of the Department of Soil Science and IAR. I must say thanks to allmy family members and friends who have been constantly propellingme to complete this important task. It is, by the virtue of their accepted prayers by Allah (SWT) and moral support that I have been able to accomplish this thesis research work.

Finally this work was supported financially by Volkswagen foundation Stiftung through the Urban food project of University of Kassel, Witzenhaussen, Germany.Your support is highly appreciated.

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ABSTRACT

Land use and soil management practices, affect soil physical quality indicators. Ten plots from the long-term DNPK trial field of Samaru were selected and soils analyzed to assess the hydrological and physico-chemical properties after a long period of cultivation and fallow. The plots were subjected to different fertilization regime from 1950 to 1998 under continuous cultivation. Surface and subsurface (0-15 cm and 15-30 cm) soil properties of these ten plots were studied under different rates and combination of fertilizer regime.These plots include inorganic fertilizers Nitrogen (N), Phosphorus (P), Potassium (K) in combination with organic fertilizer Dung (D) that is (D+NPK), (D+N), (D+P), (D+K), NPK only and a Control,that received no fertilizer NPK nor D.Sand fractions were found to be more dominating than any other fraction. On the surface soil, plots treated with N (1.29%), DNPK (1.24%) and DP (1.23%) were found to be recording higher values of total soil organic carbon than other selected plots.Bulk density rangedfrom 1.84 Mg m^{-3}(DNPK) to 1.34 Mg m-^{3}(N) across all the plots. Plots amended with DK, P and K recorded a near neutral soil pH values of 7.2, 7.13 and 7.15 respectively. More water conducting pores were observed in plots treated with organic manure singly or in combination with inorganic fertilizer among others. Mean weight diameter (MWD) indicates higher water stable aggregates of 1.26 and 1.25 mm in N and DNPK than in other plots, and low dry macroaggregates of 0.34 mm for control and DN plots.Most of the moisture was retained in soils with histories of dung treatments and the control, while it was lowest for single inorganic fertilizer treated plots across all the matric suction points. Evaluation of three infiltration models showed the Kostikov's model to be more efficient and proved to be excellent predictor of infiltration over Philip's and Horton's model,because Kostiakov's model gave coefficient of determination r^2, close to unity (0.99). Relational expression otherwise pedo-transfer functions(PTFs) were generated between field capacity moisture content (FC), moisture contentat permanent wilting point (PWP), available water holding capacity (AWHC) and dry mean weight diameter (DMWD) and small macroaggregate stability (SMS) because of the significant relationship between them ($p<0.05$). Soil organic carbon content was found to increase over time with increased rates of organic matter application, both during cultivation and over the fallow period. The complimentary application of organic and inorganic fertilizer over a long period of time is viewed to have excellent potentials of improving soil quality for sustainable agricultural production.

CHAPTER ONE

1.0 INTRODUCTION

Soil is a natural resource that serves as the upper most layer of earth crust, and it supports all terrestrial life. It provides the basis of food chain that ends with human consumptions and waste disposal (Lawal and Girei, 2013).With increasing trend of human population, sustainable food production will be achieved with intensive cultivation on the same piece of land but under good agricultural management practices. Soils under intensive agricultural uses are however prone to degradation or decline in its quality, despite its inherent resilience. Sustainable use of soil resources therefore, requires thorough understanding of properties and processes that govern soil quality to satisfactorily perform its functions of value to humans over a long time. Thus, information on soil physical, mechanical and hydrological properties is useful in addressing issues related to sustainable management of soil and water resources.

Soil hydraulic properties govern transport processes and water balance in soils. Water retention capacity, infiltration rate, and saturated hydraulic conductivity are important soil hydraulic properties. Soil water retention and saturated hydraulic conductivity (Ks) are necessary input data for the simulations of water flow in soil and water engineering and in many other hydrological models. Knowledge of soil infiltration characteristics and other hydraulic properties are required for increased irrigation water use efficiency, the design of irrigation systems, decreased water and soil losses which are important factors in agriculture (Haghighi *et al*., 2002). Thus, infiltration rate is an important factor in sustainable agriculture, especially in design for watershed management. In general, characterizing hydrological behaviour of a catchment requires knowledge of hydraulic parameters (Haghighi *et al*., 2011).

1.1 PROBLEM STATEMENT

The current increase in human population, requires a complimentary increase in food production, thus, the need for intensive cultivation on the same piece of land under careful soil management practices. Different management practices influence greatly on soil physical and chemical properties. There exist a dearth of data on soil hydro-physical properties to provide a basis for soil quality assessment of the DNPK trials located in Samaru. Moreover, measurement of soil hydrological properties both in the field and laboratory are cumbersome, expensive, time-consuming, labour-intensive and give only local scale results (Lake *et al.*, 2009), thus the consideration of PTFs as an alternative. Little or no data exists in assessing the temporal effect of soil management practices adopted in the said longterm trials especially during a fallow.

1.2 JUSTIFICATION

A lot of research has been conducted on the DNPK trials located in Samaru, since 1950 till 2008, with fallow periods between 1994 to 2003 and 2009 to 2012 (Muhammed, 2010). Research focused on nutrient imbalances resulting from increasing use of mineral fertilizer on some buffered soils, improved and optimized productivity of these soils under intensive agricultural land use (Ogunwole *et al.*, 2004). From 2001 to 2008 and from 2009 till date, many of these researches focused on physico-chemical aspect of the DNPK trials while these plots are under fallow. Yet, little or none of these studies reported measurements of hydraulic properties especially infiltration. The current study will evaluate the effect of temporal variations of soil properties on selected DNPK plots and measure the hydraulic properties (infiltration, water retention and saturated hydraulic conductivity) of selected DNPK trials.

The need for knowledge and understanding of soil properties and soil processes are crucial for good management to sustain food production. Thus, to fill in gaps for missing data on hydro-physical properties and to reduce the rigor of field measurements, remains the focus of many researches today. Indirect estimation of these hydro-physical soil characteristics have been proposed with the use of empirical functions with basic soil information such as pedotransfer functions. Pedotransfer functions (PTFs) emerged as the relationship between soil hydraulic and other more available measured properties (Bouma, 1989) which can be used to estimate hydraulic properties. PTFs are useful tools for modelling applications in hydrology-related studies (Haghighi *et al.*, 2011). Development of prediction methods such as PTFs, that use cheap secondary information to spatially extend limited and expensive soil measurements has been a sharpening focus of research (Bishop and McBratney, 2001).

The study aims at determining best-fit infiltration model for these soils from measured infiltration data.With the wealth of data from several researches on these plots, simple equations that relate readily available soil properties to hydraulic characteristics of these soils would be a useful and cheap tool to avoid repeated and labourious tasks involved in field measurements. The study will also evaluate effect of temporal variations of soil properties on selected DNPK plots and measure the hydraulic properties (infiltration, water retention and saturated hydraulic conductivity) of selected DNPK trials.

1.2 OBJECTIVES:

Specific objectives of this study are to:

1. Measure field infiltration and determine water retention properties of soils in these plots;
2. Develop simple relational expressions from regression analysis between measured infiltration and water retention with readily available soil properties;
3. Determine the effect of temporal variability on some soil properties of the selected DNPK plots studied;

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Infiltration

Infiltration is the entry of water from the soil surface into the top layer of the soil. The source of this water may be from rainfall, snowmelt or irrigation. Generally, it refers to vertical infiltration, where water movement is either by downward or gravitational flow from the soil surface (Osuji, 1984; Turner, 2006; Shahsavar *et al.*, 2010). Water applied to the soil in the form of rain or irrigation may either infiltrate into the soil profile or run over the soil surface. Those that infiltrate may either serve as source of sustenance to plant and microorganism growth in the soil or replenishment of groundwater supply to wells, streams and springs (Rawls *et al.*, 1993; Oram, 2005) while those that runoff over the surface have the potentials of causing erosion, flooding and decreasing groundwater recharge within the watershed (Gregory *et al.,* 2006).This runoff water eventually end up reaching streams, rivers, lakes and oceans. A plot of either cumulative infiltration(I) or infiltration rate (i) against time shows the pattern of Infiltration processes.

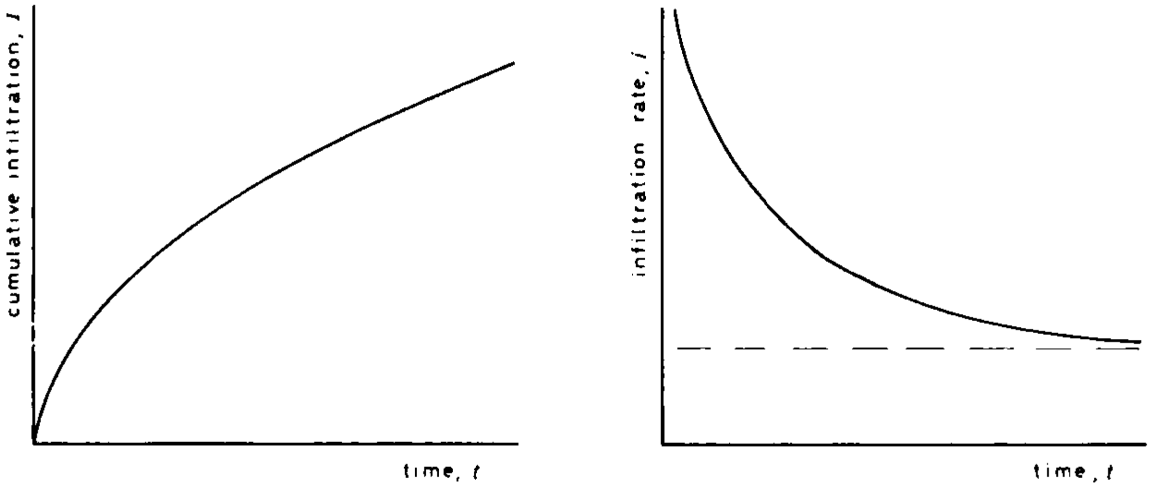


Figure 2. 1: Schematic representation of cumulative infiltration; I, and infiltration rate; i, as functions of time (Adopted from Koorevaar (1999)).

2.2Movement ofwater in the soil

The movement of water in the soil and associated solute transport perform a role of primary importance in many applications in the field of hydrology and agriculture (Comegna *et al*., 2012). Movement of water occurs from a higher energy state to lower energy state and the driving force for the movement is the potential difference between energy states (Turner, 2006).This potential difference is caused by gravity, osmosis and capillarity.

Water moving through the profile is either held in pore spaces within the soil particles for plant use, or percolate to underground water (Abdulkadir, 2000). When water is applied at the soil surface in the form of flood irrigation or rainfall, it enters the soil profile and changes water content distribution with depth. If irrigation continues for some time, the following zones can usually be distinguished in the water content profile (Hillel, 1980):

- saturated zone
- transition zone
- transmission zone
- wetting zone
- wetting front.

This phenomenon occurs under both saturated and unsaturated conditions.

2.3Infiltration rate

Infiltration rate (also called infiltration velocity) [$V_{i;}$ f(x(t))] refers to the quantity of water that enters the soil through its surface in a given time, t (Paredes *et al*., 2006). This rate depends on soil texture (amount of sand, silt, and clay) and on soil structure.

The infiltration rate is generally highest when the soil is dry. As the soil becomes wet, infiltration rate slows down to a steady or constant rate through the most restrictive layer, such as a compacted layer or a layer of dense clay (Williams, 1983; Nizeyimana and Olson,1988). Infiltration rates decline as water temperature approaches freezing and little or no water penetrates the surface of frozen or saturated soils.

2.4 Infiltration process

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil (Hogan, 2010; Ahuja *et al*., 1998) and the rate at which previously infiltrated water can move away from the surface through the soil(Mbagwu,1995). The maximum rate that water can enter a soil in a given condition is the infiltration capacity (Hillel,1980). If the arrival of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, ponding begins and is followed by runoff over the ground surface, once depression storage is filled (Abdulkadir, 2000). This runoff is called Horton overland flow (Horton, 1940).

Infiltration of water into the soil is an unsaturated flow phenomenon involving two essentially immiscible fluids, air and water (Brustkern and Morel-Seytoux, 1975).Water moves because of force of gradient in the soil caused mostly by gravity, osmosis and capillarity.

Generally an initial high rate of infiltration will be observed for a relatively dry soil profile in response to a very steep moisture gradient. This will steadily decline as the moisture gradient decreases until when it becomes vanishingly small at which point the infiltration rate settles to a constant rate. This point is referred to as final or constant or steady state infiltration rate.

The entire hydrologic system of a watershed is sometimes analyzed using hydrologic transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality.

2.5 Measurement of infiltration

Cumulative infiltration and infiltration rate is determined by measurements using infiltrometers or by estimation through hydrographs or use of equations (Abdulkadir, 2000). Based on these manners of measurements, the methods of infiltration measurements are discussed below.

2.5.1 Ring infiltrometer

This measures the infiltration behaviour of soils and in particular the soil's infiltration capacity. The ring infiltrometer consists of a cylinder driven into the soil to a desired depth (normally from few centimeters to more than 10cm) to prevent divergent flow. Single rings have a problem of lateral flow resulting in high infiltration rates. Double ring infiltrometer have an outer cylinder to provide a buffer that prevents lateral water movement from the inner ring, in which the measurements are made (Annon,1991).

This method have the limitation of high tendency to disturb the natural structure of the soil during insertion and from adding water (Anderson and Ingram,1998).Unnatural seepage may be observed at the interface between the soil and the wall of the ring which may alter the infiltration rate. Also, with single ring infiltrometers, water spreads laterally as well as vertically and the analysis is more difficult (Barryman, 1979).

Plate 2.1: A set up of double ring infiltrometer ponded with water used in this study.

Other methods of measuring infiltration include the use of Sprinkler infiltrometer, Tension Disk infiltrometer, Hydrograph method, Rainfall infiltrometer, Flooding infiltrometers and the Basin infiltrometer.

2.6 Factors affecting infiltration

Soil is a reservoir that stores water for plant growth. The water in soil is replenished by infiltration. The infiltration rate can be restricted by poor management practices. Under these conditions, water does not readily enter the soil and it moves down slope as runoff or ponds on the surface, where it evaporates.

Soil infiltrability depends on the following factors:

2.6.1 Texture

Soil texture refers to the proportion of sand, silt, and clay that a soil comprises and this directly affects the hydraulic conductivity, diffusivity and water holding capacity of the soil (Hillel, 1980). Soils water moves more quickly through the large pores and spaces in a sandy soil (Babaji,1982) than it does through the small pores in a clayey soil

(Kohnke, 1968). Where the content of organic matter is low, texture plays a significant role in the susceptibility of the soil to physical crusting.

2.6.2 Porosity

Features such as cracks, fissures and root channels could make a soil porous. This features are observed to be contributing to total soil porosity which have a significant effect on infiltration and hydraulic conductivity (Kureve,1991).Relationship between macroporosity and infiltration were also reported by (Edward *et al.*, 1979; Dick *et al.*, 1989; Blevins *et al.*, 1990).

2.6.3 Bulk density

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 which may cause restriction of root growth and poor movement of air and water through the soil (Arshad *etal.*, 1996). A large decrease in infiltration rate resulting from a little increase in soil bulk density was observed by Gumbs and Warkentin (1972).

2.6.4 Organic matter and soil biota

Incorporation of plant material, dead or alive, generally improves infiltration (Berry *et al.*, 1985). As organic matter is broken down by soil organisms, it binds soil particles into stable aggregates that enhance pore space and infiltration.

2.6.5 Aggregation and structure

Soil structure affects the path by which water moves through the soil (Brady and Weil, 1999).Good soil structure improves infiltration. Soils with good structure have more pores for the movement of water than soils with poor structure (Conolly, 1998). This may lead to the conclusion that soils with good structure can be characterized by elevated water infiltration rates and decreased runoff, flooding and erosion potential (Jones and Wild, 1975). If aggregates are stable, the structure remains intact throughout a rainstorm and therefore, high infiltration rate is expected (Alhassoun, 2009)

2.6.6 Physical crusts

Physical crusts form when poorly aggregated soils are subject to the impact of raindrops and/or to ponding. Particles broken from weak aggregates can clog pores and seal the surface, thus limiting water infiltration and increasing surface runoff (Sparovek *et al.*, 2002). Removal of layers suspected to be crusted resulted in significant increase in infiltration at samaru (Babaji, 1982; Adeoye, 1986).

2.6.7Pores and channels

Continuous pores connected to the surface convey water. Earthworms contribute to the formation of stable aggregates, thus they enhance soil structure (Edwards and Bohlen, 1996). Moreover, the burrowing of earthworms produces channels and increases macropores that facilitate water flow, improving water infiltration into the soil (Zachmann and Linden, 1989). Termites, however, can decrease the infiltration rate by reducing the amount of litter cover, and some ant species seal the surface around their nests.

2.6.8Vegetation

A high percentage of plant cover and large amounts of root biomass generally increase the infiltration rate by protecting the soil aggregates from breakdown by reducing the impacts of rain drops and by continuing to supply cementing agents for soil aggregates (Adeoye,1986). Living and dead plant material also add organic matter to the soil which improves soil structure and water holding capacity and provide habitat for earthworms which further enhance the soil constitution and increase infiltration rates (Poudel *et al.*, 2001; Turner, 2006).

2.6.9 Land use and management practices

Numerous studies revealed that land use and management practices are the essential factors affecting soil structure and infiltration characteristics. Organic farming for instance is viewed to produces sustainable soil structure and high biological activity and enhances water infiltration rates and soil water holding capacity (Poudel *et al.*, 2001). Moreover, organic farming has an important role in counteracting anthropogenic soil sealing which can lead to increased floods as a result of diminished infiltration. Furthermore, soils under organic farming will support the biological activity and have plenty of bio-pores, which in turn enhance water infiltration rates into the soil (Schnug and Haneklaus, 2002).

2.6.10 Initial water content

The wetter the soil is initially, the lower will be the initial infiltrability (Babaji,1982; Babalola,1986) because of low suction gradients and the more rapid will be the attainment of the final (constant) rate, which itself, however, is generally independent of the initial water content. But for dry soil, the initial infiltration rate will be high when water is applied (Shukla and Lal, 2006).

2.6.11 Surface condition

When the soil surface is highly porous and of "open" structure, the initial infiltrability is greater than that of a uniform soil (Hillel, 1968), but the final infiltrability is unchanged (being limited by the conductivity of profile in depth). On the other hand, compaction of the soil surface zone lowers the infiltration rate (Rogasik *et al.*, 2004). A dense surface zone acts as a hydraulic barrier, or bottleneck, impeding infiltration.

2.7Pedotransfer functions

Moosavi and Sepaskhah (2012) reported that Modelling of water flow and chemical transport in the vadose zone is recommended as an inexpensive approach to study the problems related to soil and environmental remediation as reported by Merdun *et al.* (2006). They also reported that models require knowledge of soil hydraulic attributes such as soil water retention curve $\theta(\psi)$, and unsaturated hydraulic conductivity function $K(\psi)$ as reported by Mermoud and Xu, (2006). Direct field or laboratory measurements of hydraulic attributes are tedious, costly, time-consuming, labour intensive and give only local scale results (Mermoud and Xu, 2006).

Due to the highly spatial and temporal variability, point measurement may not produce accurate results (Heuvelink and Webster 2001). Therefore, it necessitates a large number of soil samples to be collected to accurately characterize the field or the watershed systems. Furthermore, published information for soils around the world may have data on soil particle size distribution, organic matter content and bulk density, but the data on soil hydraulic properties may be incomplete or missing. Due to these reasons, a great deal of research has been devoted to developing alternative indirect approaches to estimate the soil water retention or unsaturated hydraulic conductivity curves either from widely available or more easily measured basic soil properties, and/or limited data (Timlin *et al.*, 2004).This indirect approach is called pedotransfer functions; PTFs (Rawls *et al.,* 2004).

2.8. Infiltration Equations

Evaluation of soil infiltration characteristics and determination of the final steady infiltration rate are required for increased irrigation water use efficiency, the design of irrigation systems, and decreased water and soil losses which are important factors in agriculture (Haghighi *et al.*, 2010). Since measuring the final infiltration rate is time consuming, several models have been proposed to determine this parameter. Empirical models such as those of Kostiakov (1932), Horton (1940), and physical models such as that of Philip (1957) are the most commonly used models to estimate final infiltration rates. Otherinfiltration equations are Green and Ampt (1911), Talsma-Parlange (1972), Holtan (1961), Smith and Parlange (1978).

The physical principles governing infiltration for simplified boundary and initial conditions is applied by approximate models such as those of Philip(1957) and Green and Ampt(1911), which implies ponded surface conditions from time zero onward (Hillel, 1998).They are based on assumptions of uniform movement of water from the surface down through deep homogenous soil with a well defined wetting front; assumptions that are more valid for sandy soils than for clay soils (Haverkamp *et al.*, 1987).

Parameters must be obtained from measured infiltration data or roughly estimated by other means for other equations that are partially or entirely empirical. Kostiakov and Horton' equations are empirical and less restrictive to the mode of water application because they do not require the assumptions regarding soil surface and soil profile conditions that the physically-based equations are built upon (Hillel, 1998).

A general characteristic of infiltration is that, all the equations predict an initially rapid decrease in rate with time for ponded surfaces (Skaggs and Khaleel, 1982).

2.8.1 Horton (1940) equation

This is one of the most popular empirical models for simulating infiltration of water into soils (Philips,1957). Here it is observed that infiltration capacity (fp) decreases with time until it approaches a minimum constant rate (fc). This decrease in infiltration is attributed primarily to factors operating at the soil surface rather than to flow processes within the soil (Xu, 2003).

The equation is a three parameter equation commonly expressed as:

$$f_p = f_c + (f_0 - f_c)e^{-\beta t} \qquad (2.1)$$

Where:

f_p = the infiltration capacity or potential infiltration rate; (LT^{-1})

f_c = the final constant infiltration rate; (LT^{-1})

f_0 = the infiltration capacity at t = 0; (LT^{-1})

β = a soil parameter (T^{-1})

t = time after start of infiltration (T).

The parameters, f_c, β, and f_o must be evaluated from measured infiltration data. Subtracting f_c from both sides of Eq. 2.1 and then taking the natural logarithm of each side gives the following equation for a straight line.

$$\mathbf{\ln(f_p - f_c) = \ln(f_0 - f_c) - \beta t} \qquad \mathbf{(2.2)}$$

When experimental value f_c is subtracted from experimental values for $f_p$and the natural logarithm of the resulting values are plotted as a function of time, β can be determined from the slope of the line and f_o can be determined from the intercept. Other methods for finding parameters include a least squares method (Blake *et al*., 1968).

Horton’s equation has been widely used because it generally provides a good fit to data. Although the Horton (1940) equation is empirical in that β, f_c and f_o must be calculated from experimental data, rather than measured in the laboratory, it does reflect the laws and basic equations of soil physics (Chow *et al*., 1988).

Turner (2006) reported that, the Horton's(1940) equation is cumbersome in practice because it contains three parameters that must be evaluated experimentally (Hillel, 1998). Another constraint to the use of this equation is its requirement of rainfall intensity to exceeds f_c (Rawls *et al*., 1993). Neglecting the role of capillary potential gradients in the decline of infiltration capacity over time and the attribution of control almost entirely to surface conditions, attract criticism of the equation (Bevin, 2004). The assumption in the model that hydraulic conductivity is independent of the soil water content also led to other criticism (Novotny and Olem, 1994).

2.8.2 Kostiakov (1932) equation

Kostiakov empirical equation assumes that the intake rate declines over time according to a power function. It is widely used because of its simplicity, ease of determining the two constants from measured infiltration data and reasonable fit to infiltration data for several researches.

It is expressed as:

$I = Bt^n$ (2.3)

Where I is cumulative infiltration(L)

t is time (T);

B and n are fitting parameters.

The parameters B and n, must be evaluated from measured infiltration data, since they have no physical interpretation. The equation describes the measured infiltration curve and given the same soil and same initial water condition, allows prediction of an infiltration curve using the same constants developed for those conditions. The logarithmic form of the equation is:

$\text{Log } I = \text{Log } B + n \text{ Log } t$ (2.4)

The parameter values for B and n can be determined from the logarithmic equation above by plotting log I against log t, which results in a straight line if the data fits into the equation. The intercept of the equation (cumulative infiltration at time t = 1) is log B and the slope is n. Turner (2006) reported that the value of n has an influence on the steepness of the slope and the rate of decline of infiltration. Also, the initial infiltration value is affected by the value of B in that the greater the value of B, the greater the initial infiltration value (Naeth, 1991). The Kostiakov equation (1932) satisfies the evaluation criteria better than other equations (Dixon *et al.*, 1978) and it can also be applied under wide range of conditions.

The major limitation of this expression is its reliance on the zero final intake rate. In most cases the infilration rate instead approaches a finite steady value, which in some cases may occur after short periods of time. Difficulty in the adjustment of the expression for different field conditions known to have profound effects on infiltration, such as soil texture and organic mater content (Philip, 1957). It does not predict final and constant infiltration rates (Davidoff and Selim,1986).

Turner (2006) reported that Naeth (1991) found that the Kostiakov equation fit double ring infiltrometer data very well for all three ecosystems that he studied. Sensitivity of the equation to changes in infiltration capacity brought about through different grazing treatments was also found by Naeth (1988). However, Gifford (1976) found that the Kostiakov equation did not fit infiltrometer data collected from semi-arid rangelands in Australia and the United States.

The inability of the equation to predict a final and constant infiltration rate led to the modification of the equation into two different forms as reported by Davidoff and Selim (1986)

2.8.3 Philip equation(1957)

$I = St^{1/2} + At$ (2.5)

Where

I is cummulative infiltration rate, L

t is time, T

S is sorptivity, $L/T^{0.5}$ which is a measure of capillarity uptake of water and a function of initial and final soil water content, θ_i and θ_n.A is a parameter depending upon the ability of the soil to transmit water which is governed by both soil properties and θ_i and θ_n.

Philip (1957) defined sorptivity (S) as the measurable physical quantity that expresses the capacity of a porous medium for capillary uptake and release of a liquid. S is constant provided the water content at the inflow end is constant (Jury *et al*., 1991).

However at large times, parameter A is assumed to approach the value of saturated hydraulic conductivity (K_S) of the soil (Davidoff and Selim, 1986). As a result, the parameter A of saturated soil was equated to K_S by Hanks and Ashcroft (1980) thus the modified Philip's equation as given below

$I = St^{1/2} + K_S t$ (2.6)

A shortcoming of the Philip infiltration model is that the assumptions for which the equation is applicable are rarely found in the field on a large scale. Soil types vary both spatially and with depth, as does vegetation and surface conditions (Turner, 2006). Although parameter values can be obtained by making point measurements in the field, variability limits the worth of test results for application to larger areas such as watersheds (Sullivan, 1996).

Soil moisture 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 plant 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, 2000).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 -10kPa and -33 kPa for light to heavy textured soils respectively (Jury *et al.,* 1991). While permanent wilting point represent 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 mater 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.

2.9. Variability in soil

Spatial and temporal variability of the natural environment is its inherent and unavoidable feature. Every element of the environment is characterized by its own variability, and at the same time each element affects one or more other elements of the environment (Ahmed *et al*., 2011). Environmental variation is a phenomenon that comprises processes leading to a given physical, chemical or biological conditions. An example of variability in natural environment is that of the soil which is affected by changes in space and time of soil-forming factors and anthropogenic activities (Usowicz *et al*., 2004). Soil physical and hydraulic properties vary over space and time from field to field as well as within fields (Nielsen *et al.,* 1973; Sisson and Wierenga, 1981; Byers and Stephens,1983; Hopmans *et al*., 1988; Strock *et al*., 2001). These variations are affected and controlled by many factors such as vegetation, agricultural management practices, previous farming practices and weather conditions (Sydney *et al*., 2011).

2.9.1Spatial variability

Spatial variability results from a combination of intrinsic (natural variations in soil characteristics) and extrinsic factors (variations caused by lack of uniformity in management practices). Examples of intrinsic spatial variability include variations in soil texture that may result from either weathering, erosion, or deposition processes and variability in organic matter content. Those of extrinsic spatial variability include lack of uniformity in management practices such as chemical application, tillage, and irrigation.Spatial variability in soil physical properties, nutrient levels and water content has been well documented by Fulton *et al*. (1996); Chung *et al*. (2001); and Gaston *et al*. (2001).

2.9.2 Temporal variability

Temporal variability is caused mainly by changes in soil characteristics and rainfall patterns over time (Rao and Wagenet, 1985). For example, soil surface characteristics undergoing temporal changes induced, for instance, by irrigation and tillage practices, rain and wind weathering and biological activity which can drastically modify soil structure (Imeson and Kwaad, 1990; Angulo-Jaramillo *et al*., 2000). Temporal scale can span from seconds to decades and longer.

In general, an understanding of the spatial and/or temporal variability of soil and hydraulic properties can provide a framework for developing effective sampling strategies for future site management and efficient experimental designs for research approaches (Ahmed *et al*., 2011).

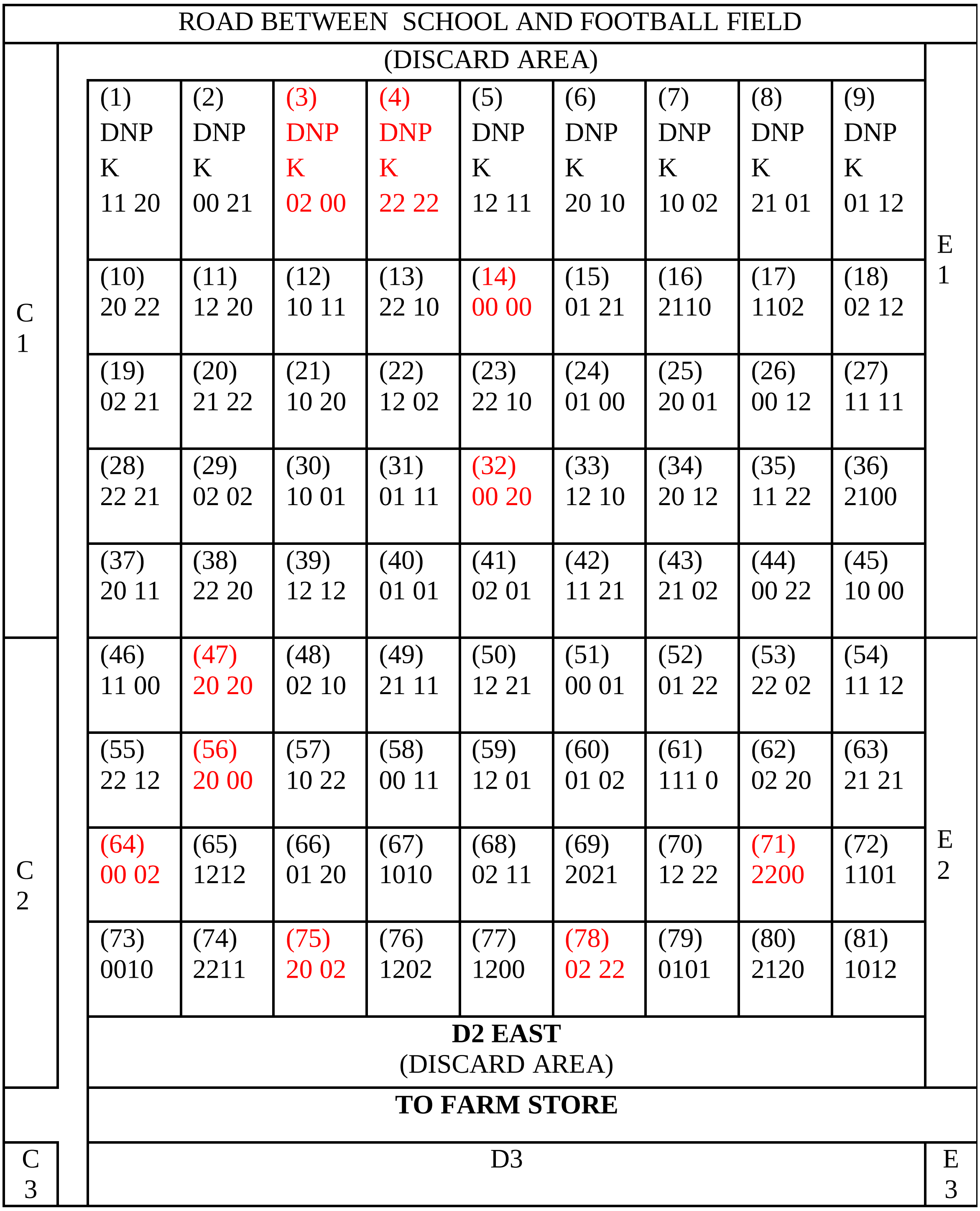
Determining the source of variation can also help in the achievement of more effective site-specific management (Mzuku *et al*., 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The studies was carried out on the long-term dung (D) and mineral fertilizer (NPK) trial field (That is, DNPK) of the Institute for Agricultural Research, Samaru (11^0 16’ N, 07^o 64’ E., 686m altitude) in the Northern Guinea Savanna ecology zone of Nigeria. Soils are leached tropical ferruginous classified as Typic Halplustalf according to USDA soil taxonomy (Jones and Wild,1975). The long-term DNPK trial at Samaru is about the oldest manure and fertilizer experiment in West Africa. Field plots consist of 81 treatment combinations randomly arranged in nine plots of 220 m^2 sizes. Each plot has been fertilized with FYM, N, P, and K or their combinations; cultivation history of the plots is given in Table 3.1.



ROAD BETWEEN SCHOOL AND FOOTBALL FIELD

(DISCARD AREA)

C 1

C 2

E 1

E 2

(1) DNP K 11 20	(2) DNP K 00 21	(3) DNP K 02 00	(4) DNP K 22 22	(5) DNP K 12 11	(6) DNP K 20 10	(7) DNP K 10 02	(8) DNP K 21 01	(9) DNP K 01 12
(10) 20 22	(11) 12 20	(12) 10 11	(13) 22 10	(14) 00 00	(15) 01 21	(16) 2110	(17) 1102	(18) 02 12
(19) 02 21	(20) 21 22	(21) 10 20	(22) 12 02	(23) 22 10	(24) 01 00	(25) 20 01	(26) 00 12	(27) 11 11
(28) 22 21	(29) 02 02	(30) 10 01	(31) 01 11	(32) 00 20	(33) 12 10	(34) 20 12	(35) 11 22	(36) 2100
(37) 20 11	(38) 22 20	(39) 12 12	(40) 01 01	(41) 02 01	(42) 11 21	(43) 21 02	(44) 00 22	(45) 10 00
(46) 11 00	(47) 20 20	(48) 02 10	(49) 21 11	(50) 12 21	(51) 00 01	(52) 01 22	(53) 22 02	(54) 11 12
(55) 22 12	(56) 20 00	(57) 10 22	(58) 00 11	(59) 12 01	(60) 01 02	(61) 111 0	(62) 02 20	(63) 21 21
(64) 00 02	(65) 1212	(66) 01 20	(67) 1010	(68) 02 11	(69) 2021	(70) 12 22	(71) 2200	(72) 1101
(73) 0010	(74) 2211	(75) 20 02	(76) 1202	(77) 1200	(78) 02 22	(79) 0101	(80) 2120	(81) 1012

D2 EAST
(DISCARD AREA)

TO FARM STORE

C 3

D3

E 3

Figure 3. 1: Layout of the DNPK Field Plan

3.2 Description of Site

A brief detail of the study sites are given below as:

Site: Field D1 and D2 Agronomy farm.

Layout: 81 plots, 3^4 factorial arrangement, singly replicated

Plot size: 30.25 m X 8.23 m, i.e. 1/45th hectare plot (222 m^2)

Discards: one yard around each plot and additional un-manured ridge between plot

3.2.1Plot Selection and Layout

Figure 3.1 shows a schematic representation of the field layout of the DNPK plots with respect to fertilizer combinations and location with respect to National Agricultural Extension Research Liaison Service (NAERLS) building, Samaru, Zaria. In the selected plots for this study (Table 3.1), Dung was previously applied at the rate of 2500-5000 kg/ha, nitrogen 67.5-135.0 kg/ha, phosphorus 13.5-27.0 kg/ha and potassium 29-58 kg/ha. The trial had been under natural fallow from 1997 to 2008. However cultivation of the field resumed from September 2008, cropped to cowpea in 2008 and maize in 2009. Urea, single super phosphate and muriate of potash were source of N, P, and K, respectively where applicable (Lawal and Girei, 2013).

Table 3. 1: Fertilizer combinations for the various treatments in the experimental plots

Treatment	Abbreviation	Rates (kg ha^{-1})		
Dung	D	0	2500	5000
Urea	N	0	67.5	135.0
Single Super Phosphate (SSP)	P	0	13.5	27.0
Muriate of Potash	K	0	29.0	58.0

Each fertilizer applied at 3 levels of 0, 1, 2, (3 x 3 x 3 x 3 = 81). Each row of the application rates represents the level number 0, 1, 2 respectively

(Source : Abdulkadir and Habu, 2013).

The history of cultivation and management practices carried out at various periods at the study site is presented in table 3.2

Table 3. 2: Cultivation and Management practices History of the field since inception.

Periods	Management Practice	Crop Grown
1950 – 1968	Ammonium sulphate was the N-fertilizer source, which is usually not applied whenever g/nut mono-cropping is practiced	Cotton in rotation with groundnut and sorghum
1967	Lime was applied to each plot on basis of the actual lime requirement. Micro nutrients (Zn, Mo, B and Cu) were also sprayed on crop growing on the field.	Cotton
1981	Each plot was divided into four subplots, which maize were either subjected to sub-soiling or left as control	Maize
1950 – 1991	Single superphosphate and Muriate of potash were the sources of P and K respectively, while calcium ammonium nitrate became N- source from 1969. As a management practice, all crops is harvested and burnt in nearly trench	Cotton, maize, g/nut, sorghum, cowpea
1992 – 1996	Urea became source of N from 1992. Single superphosphate and Muriate of potash still remain the source of P and K, respectively.	Maize, cowpea
1997 – 2000	The trial went under natural fallow, no treatment went into any plot and no crop was cultivated.	Fallow
2008-2009	Urea , Single Super Phosphate and Muriate of Potash were used as sources of N, P, and K respectively	Maize, Cowpea
2010-2012	The trial went under natural fallow, no treatment went into any plot and no crop was cultivated.	

Source: Ogunwole and Ogunleye 2005

The history of fertilizer application in the selected plots in this study is presented in table 3.3 below.

Table 3. 3: Fertilizer application history of the selected study plots

S/N	Treatment combination	Acronym	Rates (kg ha^{-1} yr^{-1})
1	Dung + Nitrogen +Phosphorus + Potassium	DNPK	Dung = 5000; N = 48-135; P = 18-54; K = 29-58
2	Dung +Nitrogen	DN	D = 5000; N = 48-135
3	Dung + Phosphorus	DP	D = 5000; P = 18-54
4	Dung + Potassium	DK	D = 5000; K = 29-58
5	Nitrogen + Phosphorus + Potassium	NPK	N = 48-135; P = 18-54; K = 29-58
6	Nitrogen	N	N = 48-135
7	Phosphorus	P	P = 18-54
8	Potassium	K	K = 29-58
9	Dung	D	D = 5000
10	Control	CT	NIL

3.3 Soil Sample Collection and Preparation

Disturbed surface soil (0 – 15 cm and 15 – 30 cm) of the 10 selected plots were collected in three (3) replicates after sub-dividing each of the main plots into three equal sized sub-plots. The samples were bulked to obtain 3 composite replicate sample per soil depth and plot. Similarly, undisturbed soil samples were collected from the ten (10) selected plots (Table 3.1). The samples were appropriately labeled for easy identification. The soil samples collected were air dried and divided into two parts; one part was passed through 5 mm mesh sieve and stored in polythene bags for bulk soil aggregate stability determination and the second part was grinded and passed through 2 mm sieve for subsequent routine physical and chemical analysis.

3.4 Field and Laboratory Studies

3.4.1 Infiltration measurements

A double ring infiltrometer consisting of an inner ring of 300 mm in diameter and an outer ring of 550 mm in diameter both of 300 mm in height were inserted 100 mm into the ground (Plate 2.1). Two replicate measurements were conducted for each plot/trial. The rings were ponded with water to the brim. The depth of water percolation/infiltration in the inner ring was measured with a ruler at 1 minute interval for the first 5 minutes, 5 minute interval for the next 15 minutes, 30, 60 and 120 minutes to give a total of 120 minutes for each of the two replicate measurements within a plot. The time was read from a stop watch and all infiltration measurements were carried out in February, 2013 and March, 2014, during dry season. Data collected were used to calculate infiltration rate and cumulative infiltration. Measured infiltration data were fitted into 3 different infiltration models to determine the best-fit model for soils of the study plots. The models include Kostiakov’s, Philip’s and Horton’s infiltration models.

Horton's Equation

Initial infiltration rate, $f_o$and steady-state(final) infiltration rates, $f_{c,}$were estimated from the plot of infiltration rate against time, as the intercept and steady state values,respectively, adopted from Abdulkadir *et al*. (2011).

Linearized form of Horton equation was obtainedas equation. 3.4 or 3.5, where the left hand side of the equation is plotted against time, with β at the slope.

$$f - f_c = (f_o - f_c)e^{-\beta t} \quad (3.1)$$

Taking the natural logarithm of both sides,

$$\ln(f - f_c) = \ln(f_o - f_c) - \beta t \quad (3.2)$$

$$\ln(f - f_c)/ \ln(f_o - f_c) = - \beta t \quad (3.3)$$

Converting to log,

$$2.3 \log(f - f_c) = 2.3 \log(f_o - f_c) - \beta t \quad (3.4)$$

Or

$$\log(f - f_c) = \log(f_o - f_c) - \beta t / 2.3 \quad (3.5)$$

After knowing β, the predicted infiltration rate was calculated using Eq 2.1.Infiltration rate was calculated for each plot and later compared with the field measurement using linear regressions from Microsoft Excel.

Kostiakov's Equation

Kostiakov Equation (1932) is a two-parameter equation given in Eq 2.3.:

The parameter values for B and n were determined from the logarithmic equation (Eq 2.4) by plotting log I against log t, which results in a straight line if the data fits into the equation. The intercept of the equation (infiltration rate at time t = 1) is log B and the slope is n.

Philip's Equation

Philip equation(1957) is a two-parameter equation given in Eq 2.5

The non-linear least square regression analysis was employed to determine the parameters of the infiltration model of Philip. A linear graph of cumulative infiltration divided by $t^{0.5}$ was plotted against the successive time to obtain the parameters A and S as the intercept and slope. After knowing A and S, the new infiltration rate was calculated by fitting these parameters into the Philip equation. Infiltration rate was calculated for each plot and later compared with the field measurement using linear regressions from Microsoft Excel.

3.4.2 Determination of soil texture

The hydrometer method was used in determining particle size distribution of the 2 mm sieved soil (Gee and Bauder, 1986). 50g of a 2 mm – sieved soil was weighed into a 250ml plastic container and 100 ml of sodium hexa-meta-phosphate (calgon) was added to the soil and shaken for 10 minutes. The calgon was prepared by adding 40g of calgon per litre of water.

The suspension was transferred into a 100 ml glass cylinder and made up to mark with water. The suspension was thoroughly stirred using a plunger and a hydrometer was inserted immediately. Readings were recorded at 40 seconds and at 2 hours.

A blank of the reagent was also run. The percentage of clay, silt and sand were determined using the formula:

Percentage of clay, silt and sand were determined from the formula:

$$\% \text{ clay} = \frac{corrected\ \ 2\,hours\ ydrometer\ \ reading}{weig\,ht\ of\ \ soil\ taken} \text{x } 100 \qquad (3.6)$$

$$\% \text{ silt} = \frac{corrected\ \ 40\, seconds\ \ reading}{weig\, ht\ of\ \ soil\ \ taken} \text{x } 100 - \% \text{clay}$$

(3.7)

$$\% \text{Sand} = 100 – (\% \text{silt} + \% \text{ clay}) \qquad (3.8)$$

Corrected reading = (Actual reading – Blank reading) + 0.37

Where T = Room Temperature Minus 20°C

3.5.3 Determination of dry bulk density (ρ_b)

Dry soil bulk density (ρ_b) was determined by the core method described by Blake and Hartge, (1986). Undisturbed soil samples were obtained from the field with the aid of a 5cm by 5cm core and a core sampler. The buried cores were carefully dug out of soil, taking care that the cores were uniformly filled with soil. The undisturbed soils were oven dried at 105°C to a constant weight. The bulk density was thus determined by the formula:

$$\rho_b = \frac{Mass of Oven\ \ dry soil}{Bulk volume of soil\ \ \ (volume of core\ \ )} \qquad (3.9)$$

where; bulk soil volume is calculated as the volume of the cylindrical soil core (cm^3) from the formula of volume i.e. $\pi r^2 h$ (h= height of soil core; r= radius of core).

3.4.4 Determination of aggregate sizes

3.4.4.1 Dry Sieving

The dry-sieving method of soil aggregate separation was performed as described by Mendes *et al*. (1999) and Schutter and Dick (2002).

Field-moist soils were air dried for 7 to 10 days. Aggregates were separated by placing 200g of air-dried soil fragments (5mm) in a nest of sieves (20-cm diameter) containing

2.00- and 0.25-mm sieves attached to a sieve shaker. These sieve sizes were chosen to separate soil aggregates as large macro aggregates (2.00 mm), small macro aggregates (0.25 mm), micro aggregates(0.05 mm) and less than 0.05 mm fractions made up of silt + clay fractions (Six *et al.*, 1999, 2000). Sieves were shaken at 200 oscillations min^{-1} for 3 minutes and the aggregates retained in each sieve and those that passed through the last sieve were weighed. The soils were air dried at room temperature and stored in plastic bags. Data was used in the calculation of mean weight diameter (MWD) as indicator of soil structural quality.

3.4.4.2 Wet Sieving

The wet sieving method of aggregate separation was performed as described by Elliott (1986) and Six *et al.* (1999, 2000). Air-dried soil (200 g) was submerged for 5 min in a 2-mm sieve. Aggregates were separated by moving the sieve up (3 cm) and down with 50 repetitions for 2 minutes. Aggregates retained in the sieve (2 mm) were air dried at room temperature, weighed, and stored in a plastic bag. Sieving was repeated as above using the next sieves (0.25 mm, 0.05 mm and <0.05 mm) by pouring the soil and water that passed through the 2-mm sieve in the 0.25-mm sieve and shaken. Aggregates retained in the sieves (0.25 mm, 0.05 mm and <0.05 mm) and those that passed through it (i.e. up to <0.05 mm) were collected, air dried, weighed and then corrected for sand and the proportional weight of soil aggregate was calculated from equation given by:

$$\frac{weight\ of\ soil\ retained\ \ in\ sieve - its\ percentage\ \ sand\ \ content}{weight\ of\ bulk\ \ soil\ taken - its\ percentage\ \ sand\ \ content}$$

(3.10)

Mean weight diameter (MWD) of aggregates separated by dry and wet sievingmethods were calculated by summing the product of mean diameter of aggregates and proportion of soil in each aggregate-size class (Kemper and Rosenau, 1986) as given in equation 3.12 and results were used to define the stability of the soil aggregates.

$$\text{MWD} = \quad = \sum_{i=1}^{n} \text{Xi Wi} \quad (3.11)$$

Where X_i = proportional by weight of sand free aggregate

W_i = mean diameter of proceeding and preceding sieve

3.4.5 Determination of particle size distribution in soil aggregate fractions

The hydrometer method (Gee and Bauder, 1986) was used in determining particle size distribution of the aggregate fractions > 2mm, > 0.25mm and > 0.05mm and the percentage of clay, silt and sand was determined using the formula:

$$\%\ \text{clay} = \frac{corected\ \ 2\ hours\ hydrometerreadingx\ \ \ 100}{weig\ htofsoiltaken} \quad (3.12)$$

$$\%\ \text{silt} = \frac{corected\ \ 40\ secondsreading}{weig\ htofsoiltaken}\ \text{x}\ 100 - \%\ \text{clay} \quad (3.13)$$

$$\%\ \text{sand} = 100 – (\%\ \text{silt} + \%\ \text{clay}) \quad (3.14)$$

Corrected reading = (actual reading – blank reading) + 0.36T

where,

T = room temperature minus 20^{o}C.

3.4.6 Determination of soil organic carbon in aggregate fractionations and bulk soil

Soil organic carbon content was determined both in bulk soil and in the various aggregate fractions separated during the wet sieving by the dichromate oxidation method (Nelson and Sommers 1982). One gram of each of the aggregate fractions and bulk soil was weighed into 250ml conical flasks, then 5ml of potassium dichromate ($K_2Cr_2O_7$) was added followed by a rapid addition of 10ml of concentrated sulphuric acid (H_2S0_4) to each flask. The mixture was swirled and allowed to stand and cool for

30 minutes on a laboratory bench, after which 100ml of distilled water was added. Two to three drops of 0-phenathrolein ferrous complex indicators were added and the suspension in each flask was titrated with ferrous ammonium sulphate $(Fe(NH_4)_2SO_4)_2$ to a red end point. A blank of the reagent was also run and the percentage organic carbon was calculated using the formula:

$$\% \text{ organic carbon} = \frac{(blanktitre - actualtitre\ )x\ 0.3xMxF}{weig\ htofsoiltaken}$$

(3.15)

where,

M = molar concentration of NH_4FeSO_4

F = correction factor, 1.33

3.4.7 Determination of soil pH

Soil pH was determined with a pH meter from the 2 mm sieve soils, both in water and 0.01M Calcium chloride solution at a soil to solution ratio 1:2.5 (Rhoades, 1982). The pH was read on equilibration with a glass electrode on a Pye-Unicam model 290mk pH meter.

3.4.8 Determination of moisture retention of soils

Moist core soil samples collected for determination of bulk density were covered at both ends and taken immediately to the laboratory and weighed. The samples were then oven-dried for at least 24 hours at 105 to 110°C and then weighed. The soil moisture content was then determined by the following formula:

$$\text{Soil moisture retention} = \frac{SoilmoistWeig\ \ ht - ovendryweig\ \ ht}{ovendryweig\ \ ht} \qquad (3.16)$$

Soil moisture retention at different suctions were determined from the soil core samples using the pressure plate apparatus. Suction points of 0 bars (Maximum retention capacity), 0.1 bars, 0.3 bars (field capacity), 0.5 bars, 1.0 bar 5 bars, 10 bars and 15 bars (permanent wilting point) were used to extract water from the soils. Data generated were used to determine water retained at each suction and plotted as a pF curve for the soils in each plot.

3.4.9 Determination of saturated hydraulic conductivity

Saturated hydraulic conductivity (Ks) was determined by the constant head permeameter method of (Black *et al.*, 1965). The disturbed core samples representing each plot was covered at one end, with a piece of muslin cloth held in place with the aid of rubber bands and allowed to stand overnight in water to ensure complete saturation. These saturated samples were then arranged in a constant head permeameter, velocity of flow and changes in hydraulic heads were determined. Saturated hydraulic conductivity was calculated using Darcy's equation given by:

$$K = \frac{VL}{At\Delta H} \tag{3.17}$$

Where:

K = saturated hydraulic conductivity; cm/min

V = Volume of soil; cm

t = time; minutes

A = Area; cm

L = Length of soil core; cm

ΔH = change in hydraulic head; cm.

3.5 Development of Pedotransfer Functions

Simple linear regression of the variables was run in order to predict the hydraulic properties of the study plots. The hydraulic properties were predicted as response or dependent variables Y by a linear function of soil physical properties as regressors or independent variable X.

$$Y = \beta_0 + \beta_1 X \qquad (3.18)$$

The variable Y (FC, PWP and AWHC) is the response or dependent variable in this equation, and β_0 and β_1 are the unknown parameters to be estimated. The variable X (mean weight diameter, large macro aggregates, small macro aggregates, soil texture and soil organic carbon) is the regressor or independent variable.

3.6 Data Analysis

Data collected in this study was subjected to statistical analysis of variances as described by Snedecor and Cochran (1967). Using the SAS computer package (SAS, 2009), the differences among the treatment means were evaluated using Duncan's multiple range test; DMRT (Duncan, 1995). The magnitude and type of relationship between soil properties of the treatments was assessed through simple correlation and regression analysis. Linear and nonlinear expressions otherwise called pedo-transfer functions (PTFs) were generated for estimating soil hydraulic properties from easily measured soil properties obtained in this study.

CHAPTER FOUR

4.0 RESULT AND DISCUSSIONS

4.1. Particle Size Distribution

Results of the particle size distribution and soil organic carbon measurement are presented in Table 4.1. Average values of percentage clay, silt and sand shows that the soils are sandy loam/sandy clay loam in texture in all the plots investigated (0-15 cm), with the clay content increasing with depth while sand and silt content reduced with depth. This observation is in accordance with the findings of Jones and Wild's (1975) characteristics for most savanna soils. The increase in clay content with depth was often associated with illuvial deposition from the surface to subsoil (Ogunwole *et al.*, 2001). Generally, the effect of the treatments on particle size distribution was highly significant ($p<0.01$) on all the particle sizes except on clay content (Table 4.1). Highest sand content was observed in dung + potassium(DK) (58.36%) and dung (D) (56.03%) plots followed by dung + nitrogen (DN), nitrogen+phosphorus+potassium(NPK) and dung+phosphorus (DP) with lowest content in dung+nitrogen+phosphorus+potassium (DNPK) (42.36%). Similarly, higher silt contents were found in plots previously treated withdung+nitrogen+phosphorus+potassium(DNPK) (50.32%) than the other treatments. The latter might be as a result of the effect of mechanical implement disturbance and the grazing of animals as well as abrasion effect with time thereby reducing sand fraction to silt (Okai, 1995).The general low clay content of all the treatments may probably be due to losses associated with frequent cultivation from the past histories of these plots (Ogunwole and Ogunleye, 2004).The implication of having more sand content in almost all the plots than any other fraction is that such plots are expected to have an exponential increase in permeability with an increase in particle size as reported by Abdulkadir (2000). It is also expected that such plots permit rapid infiltration because of their higher permeability and effective porosity as observed in Table 4.1.This expectation is in conformity with the findings of Babaji (1982). Jones and Wild (1975) classified most of the clay found in savanna soils as low activity clay with low water holding capacity, low to moderate CEC and low nitrogen content thus implying low fertility status of such soils. Crop production is not profitable without soil nutrition hence the use of soil conditioners and amendments (Lawal and Girei, 2013).

There was no significant difference on the effect of soil depth, and the interaction of soil depth and the treatment on the particle size distribution of all the plots investigated (Table 4.1).

4.2. Total Organic Carbon (TOC)

No significant treatments effect on soil organic carbon content was recorded (Table 4.1). However, plots treated with N, DNPK and DP recorded higher values relative to the other plots. Plots treated with sole K and no organic amendment had the least values of TOC. The high organic C levels observed in these plots (K and control) might be as a result of increased soil fertility and moisture retention from dung addition which resulted in increased weed growth and ground cover. Accumulated plant biomass probably contributed to the high TOC content over the years from plant and litter deposition from long fallow that the plots are subjected to (Lawal and Girei, 2013). Agbenin and Goladi (1997) also recorded high organic matter content with addition of farmyard manure as organic nutrient inputs.

Though no significant effect of soil depth was observed on the total organic carbon content of all plots, large values were observed on the surface soils than sub soils, which may be attributed to accumulation of plant litter on surface soil (Singh and Ghoshal, 2011).

Table 4. 1: Effect of farmyard manure and mineral fertilizer on soil particle size distribution and soil organic carbon

	SILT	CLAY	SAND	TOC	FRACTIONATE OC		
DEPTH		%			0.25mm	0.05mm	<0.05mm Silt +

					UPOC	IPOC	Clay
1	40.99	6.49	52.16	1.1	0.51	0.64^{a}	1.09
2	41.72	6.79	50.86	0.98	0.45	0.51^{b}	0.89
SE ±	0.783	0.219	1.087	0.081	0.034	0.034	0.054
	NS	NS	NS	NS	NS	**	NS
Trt							
CONTROL	43.32^{ab}	6.65^{abc}	50.02^{dc}	0.97	0.37	0.51	0.94
D	34.49^{d}	6.32^{abc}	59.19^{a}	1.05	0.32	0.71	1.13
DK	32.66^{d}	5.65^{bc}	61.36^{a}	1.03	0.38	0.67	0.98
DN	32.32^{d}	5.32^{c}	59.02^{ab}	0.83	0.49	0.58	1.06
DNPK	46.66^{a}	7.32^{a}	46.02^{d}	1.24	0.5	0.43	0.85
DP	38.24^{dc}	5.82^{abc}	55.94^{ab}	1.23	0.53	0.58	1.14
K	35.83^{dc}	6.99^{ab}	57.19^{abc}	0.75	0.48	0.56	0.9
N	42.33^{ab}	7.32^{a}	50.32^{dc}	1.29	0.64	0.53	1.01
NPK	32.32^{d}	6.99^{ab}	60.02^{ab}	0.99	0.58	0.57	0.1
P	39.67^{bc}	7.49^{a}	52.68^{bcd}	1.03	0.5	0.6	0.91
SE ±	1.751	0.489	2.431	0.181	0.076	0.075	0.121
	**	*	**	NS	NS	NS	NS
DEPTH*TRT	NS	NS	NS	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; TOC=Total organic carbon; UPOC= unprotected particulate organic carbon; IPOC= intra particulate organic carbon.

A substantial increase in organic matter levels on surface soils of grassland ecosystems was also observed by Esu (1999) because of the presence of plant litter.

The high availability of organic carbon as a result of additions of fertilizer in the form of organic manure or mineral or both, is viewed to improve soil fertility because of their potential in modifying soil physical condition by improving water holding capacity, aeration, drainage, friability and ability to provide energy for microbial activity (Goladi and Agbenin, 1997).

4.3. Fractionate Organic Carbon

Table 4.1 shows no significant difference of the treatments on unprotected particulate organic carbon (UPOC; 0.25mm fractionate OC), Intra aggregate particulate organic carbon (IPOC) (0.05mm fractionate OC) and Silt +Clay fractionate OC. However, plots treated with N and NPK recorded the highest value while plots with D and no amendment recorded the least mean of UPOC. The organic carbon here (UPOC) is prone to accessibility to microbes and loss by erosion resulting from tillage operations (Angers *et al.*, 1993) and thus, may not be readily available at the end of the season when the sampling was carried out thus the non-significant difference observed between the treatments (Lawal and Girei, 2013). Intra particulate organic carbon (IPOC) fractionate recorded high mean organic carbon in dung treated plots such as D followed by DK, although DNPK recorded the least IPOC value. The organic carbon in IPOC can only be lost during cultivation as it has become stable over the fallow periods. The high value recorded in plot treated with D and DK may be attributed to manure addition which promoted stability of macro aggregates (Farrage *et al.*, 2003). In the Silt + Clay fraction, organic carbon content was high in plots treated with DP and D only, while NPK plot recorded the least value. Organic carbon in silt + clay fractions are resistant to decomposition (Paul *et al.*, 2001), therefore suitable for the formation of stable organic mineral complexes involved in the formation of macroaggregate. Aoyoma (1999) reported that this fractionate organic carbon may form smaller but long lasting improvement in aggregate stability.

The effect of soil depth on fractionate organic carbon was highly significant ($p<0.01$) for only IPOC (0.05mm) fractionate (Table 4.1) in which 0-15cm depth had the highest mean value of intra particulate organic carbon. Soil organic carbons in the other fractions were not significantly affected by soil depth. The high values of IPOC observed in the surface soil may be due to the high content of organic matter resulting from the deposition of plant litter that remained undisturbed over the fallow period (Lawal and Girei, 2013).This is in line with the findings of Esu (1999). This depicts the role of organic matter in the formation of microaggregates.

Generally, decrease in organic carbon was observed with increase in the aggregate size class (Tables 4.1 and 4.2).This either suggest that enmeshing action of root probably play a greater role in aggregation than aggregate-associated organic matter or the action of microbial biomass during the fallow periods (Sainju *et al*., 2003). Probably, tillage and amount and placement of plant biomass in the soil may have influenced the relationship between soil aggregation and soil organic carbon content found in the study area.

4.4. Fractionate particle size distribution.

The influence of farm yard manure and mineral fertilizer on fractionate particle size distribution was significantly observed for silt ($p<0.01$) and sand ($p<0.05$) in 0.05mm fraction, and silt ($p<0.05$) and sand ($p<0.01$) of <0.05mm fraction (Table 4.2). No significant difference was observed for the other fractions. Generally an increase in sand content was observed with increase in the fractionate size thus indicating the presence of large aggregates formed by either the organic matter present or through microaggregation of the fine particles (Sainju *et al*., 2003). However the clay content was found to be increasing with decrease in the fractionate size. This depicts the possibility of increased proportion of macroaggregates in the soils (Franzluebbars *et al*., 2000).The significant effect observed in the micro aggregates also confirm the presence of microaggregation in the soil. This also shows that aggregation within the fractionates occur as a result of microaggregation.

Table 4. 2: Effect of farmyard manure and mineral fertilizer on soil fractionate particle size distributions. (g)

	0.25mm			0.05mm			<0.05mm		
					(g)				
DEPTH	**PSDST**	**PSDC**	**PSDSN**	**PSDST**	**PSDC**	**PSDSN**	**PSDST**	**PSDC**	**PSDSN**
1	18.9	9.79	70.55	45.43	10.03	44.55	49.49	12.76	37.75
2	15.71	9.13	75.16	46.79	10.63	42.08	54.96	14.36	30.92
SE ±	2.137	0.331	2.333	0.814	0.473	1.18	3.069	0.745	3.433
SL	NS	NS	NS	NS	NS	NS	NS	NS	NS
Trt									
CONTROL	17.09	0.74	71.15	48.43^{ab}	10.43	41.15^{bc}	63.09^{ab}	15.76	22.32^{c}
D	20.09	11.59	66.81	43.76^{b}	11.76	44.48^{abc}	56.43^{abcd}	18.09	25.48^{bc}
DK	18.09	9.43	72.48	45.76^{b}	10.09	44.15^{abc}	41.43^{bcd}	10.76	47.81^{ab}
DN	18.83	8.63	72.54	43.76^{b}	8.76	47.48^{ab}	34.76^{d}	11.76	53.48^{a}
DNPK	10.76	7.76	81.48	48.43^{ab}	8.09	43.48^{abc}	66.76^{a}	14.09	19.15^{c}
DP	24.09	9.43	66.48	48.26^{ab}	10.43	38.81^{bc}	40.43^{cd}	12.76	46.81^{ab}
K	19.09	9.09	71.81	44.43^{b}	10.43	45.15^{abc}	39.43^{cd}	13.09	47.48^{ab}
N	20.76	10.76	68.48	52.09^{a}	10.43	37.48^{c}	66.43^{a}	14.43	19.15^{c}
NPK	12.43	9.76	77.81	37.76^{c}	11.43	50.81^{a}	52.09^{abcd}	12.43	35.48^{abc}
P	11.76	8.76	79.48	48.43^{ab}	11.43	40.15^{bc}	61.43^{abc}	12.43	26.15^{bc}
SE ±	4.778	0.74	5.22	1.82	1.057	2.639	6.863	1.666	7.677
SL	NS	NS	NS	**	NS	*	*	NS	**
DEPTH*Trt	NS	NS	NS	NS	NS	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; PSDST= particle size distribution in silt; PSDC= particle size distribution in clay; PSDSN= particle size distribution in sand; SL=significant level.

No significant effect was observed on the effect of depth on the fractionate particle size distribution. Though small aggregation may likely be evident in the subsurface due to increased cohesive tension of clay and silt particles to form relatively large aggregate compared to sand particles. This is because sand content in the whole soil and aggregates decreased or silt and clay content increased with increased soil depth (Table 4.2)

4.5. Bulk Density

Soil bulk density of all the plots observed ranges from 1.84 to 1.34 gcm^{-3}.All the plots were significantly different in the value. Plots previously treated with N, NPK and D recorded low bulk density values with respect to other plots while plots with DNPK, P and DK showed high values of bulk density (Table 4.3).Sommerfeldt and Chang (1986); Ogunwole and Ogunleye (2005) reported higher surface bulk density with increased manure application. Ogunwole and Ogunleye(2004) concluded that long term application of farmyard manure alone or in combination with other mineral fertilizers would increase surface soil bulk density of a land under intensive cultivation (Ogunwole and Ogunleye, 2004). This, if not managed, may lead to depletion of surface soil nutrients resulting from increased runoff and erosion as a result of poor infiltration capacity. Land use during fallow such as grazing coupled with the tramping of animalsis also suspected to cause tightening of soils and decrease in the volume of soil pores over time (Zhou *et al*., 2007). The implication of this is that for sandy loam texture, soil bulk density greater than 1.60 g cm^{-3} is already tending toward compaction which will hinder root penetration (Ogunwole and Ogunleye, 2005). Adeoye (1983) also found that bulk density greater than 1.62 g cm^{-3} had significant effect on root growth in the Northern Guinea savanna.

Table 4. 3: Influence of farmyard manure and mineral fertilizer and Depth on soil bulk density, pH , and saturated hydraulic conductivity.

		BD $(g\ cm^{-3})$	$pH_{(water)}$	$pH_{(CaCl)}$	Ksat $(cm\ hr^{-1})$
DEPTH	1	1.57	7.09	6.10	0.059
	2	1.62	7.08	5.95	0.066
	SE ±	0.045	0.029	0.057	0.008
	SL	NS	NS	NS	NS
TREATMENT	CONTROL	1.57^{abc}	7.15^{ab}	6.12^{a}	0.056
	D	$1.62a^{bc}$	7.07^{abc}	6.12^{ab}	0.069
	DK	1.71^{ab}	7.2^{a}	6.08^{a}	0.053
	DN	1.63^{abc}	6.97^{bc}	5.6^{ab}	0.069
	DNPK	1.84^{a}	6.92^{c}	5.93^{ab}	0.053
	DP	1.41^{bc}	7.12^{abc}	5.95^{a}	0.047
	K	1.66^{abc}	7.15^{ab}	6.2^{a}	0.085
	N	1.34^{c}	7.1^{abc}	6.28^{a}	0.081
	NPK	1.42^{bc}	7.05^{abc}	6.07^{a}	0.052
	P	1.74^{ab}	7.13^{ab}	5.93^{ab}	0.062
	SE ±	0.099	0.064	0.127	0.018
	SL	*	*	*	NS
	DEPTH*Trt	**	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; D=dung; N=nitrogen; P=phosphorus, K=potassium; BD=Bulk density; pH=soil reaction; Ksat=saturated hydraulic conductivity, SE=standard error of means; SL=significant level; *, **=significant at 5% and 1% level of probability, respectively.

Another possible reason for the lowest bulk density values in plots treated with inorganic fertilizer with respect to other plots may be associated with better growth and establishment of plant root in the soil thereby loosening the soil coupled with the presence of higher sand content than any other soil particle. Rich source of energy for microbial activity might also be another factor of loosening the soil.

Bulk density of studied plots was not significantly affected by soil depth, although it was observed to be increasing with depth (Table 4.3). A probable reason for this might be associated to the presence of more clay either due to illuviation or compaction from use of heavy machinery or grazing.

4.6. Soil reaction (pH)

The reaction of the soil (pH) to applied fertilizers was significant ($p<0.05$) even at fallow. Plots treated with DK, P and K recorded the highest pH_{H2O} values, while DN plots recorded the least mean pH_{H2O} value.Generally, soils treated with organic fertilizer singly, or in combination with the inorganic fertilizer are expected to have near neutral pH relative to treatments under single inorganic fertilizer application. Batche and Heathcote (1969) reported increase in pH values with increase in organic manure addition. Almost all plant required nutrient will be available within the pH values observed in the study area. The pH_{CaCl} values in plots treated with N and K which are statistically similar ($p > 0.05$) to Control while DK and NPK plots recorded highest pH values. Lowest pH_{CaCl} values were observed in P, DNPK and D than in other treatments.

No significant effect of depth variation was observed on soil reaction. However, soil pH was found to decrease with depth (Table 4.3) probably indicating leaching of the nutrients from the surface downward with time (Okai, 1995) or uptake of basic cations by crops (when plots were under cultivation), thus, inducing acidic environment with depth (Sanchez and Miller, 1986).

4.7 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_s) values of the plots studied ranges from 0.047 to 0.085 cm/hr. The DNPK, DK and DP plots were statistically higher than the other treatments (Table 4. 3). This finding is in slight conformity with the results obtained by Ogunwole and Ogunleye (2005) and Abdulkadir and Habu (2013) which showed that plots treated with the combination of organic and inorganic fertilizer had better conductivities than those treated with straight fertilizers only. Availability of more water conducting pores from the presence of residues and root channels in these plots (Table 4.1) may be the likely reasons for the high Ks values observed (DNPK, DK and DP) (Brady and Weil, 1999). A substantial increase in Ks due to increase in organic manure as observed by Shirani *et al*. (2002) may also account for values obtained in this study. The low conductivity value observed in the other treatments; particularly the single fertilizer rate, might be due to degradation of soil structural stability due to grazing and tramping of animals during periods of fallow thereby increasing availability of micropores at the expense of macropores.

Saturated hydraulic conductivity was found to decrease with increase in soil depth (Table 4.3).This might be due to increased bulk density with depth as observed by Ohu *et al*. (1989). Another possible reason also is the increase in clay content with depth, where clay particles will clog conducting pores and decrease saturated hydraulic conductivity (Okai, 1995).

4.8. Aggregate Stability of Selected DNPK plots

4.8.1. Water stable aggregate and wet mean weight diameter

No significant effect of soil depth was observed on water-stable aggregate in this study (Table 4.4). However, stability of macro aggregate (>0.5mm) was found to decrease with depth.This result confirms the findings of Abdulkadir and Habu (2013) that reported decrease in stability of water stable macroaggregates with depth.

Influence of treatments on stability of water stable aggregates was highly significant ($p<0.01$) as observed from the values obtained (Table 4.4). For the small macroaggregates (>0.5mm), N, control and DK plots had the most stable aggregates. The influence of divalent cations accompanying mineral fertilizer in the stability of macroaggregates in these study plots was reported by Ogunwole (2008).Increase in water stable aggregates with application of mineral fertilizer N was also observed by N'Dayegamiye *et al*. (2010).The lowest proportion of small macroaggregate was observed in NPK which is statistically similar to DNPK and P. However Hades *et al*. (1990) reported an improvement in the stability of macro aggregates with application of phosphorus fertilizer. DNPK and Control plots recorded highest water stable microaggregates (0.05mm)than other treatments (Table 4.4).This might not be unconnected with the influence of calcium present in the mineral fertilizer in the formation of clay-polyvalent cation –organic matter complexes which exerts a stabilizing effect on the level of microaggregation (Clough and Skjemstad, 2000).

Wet mean weight diameter (MWDD) of the plots studied was not significantly affected by combination of farm yard manure and mineral fertilizer application over a long period of time (Table 4.5). However plots receiving N, DN and no fertilization obtained high wet MWD than other treatments with the DNPK plot having the least value (Table 4.5).Ogunwole (2008) reported high wet MWD in DP plot. Hades *et al*. (1990) observed that nitrogen and zero fertilizer application affect and stabilize the sizes of larger structural units. Soil depth and the interaction effect between depth and treatment showed no significance on the wet MWD in the study plots (Table 4.5).A reason for the low wet MWD recorded in some of the plots may be associated with degradation of large macro aggregates fraction in the dry soil when being immersed in water (Unger, 1997), a situation consistent with natural wetting by intense rain. Presence of large quantities of ion present as a result of complimentary application of manure and inorganic fertilizer could also de-stabilize the soil by dispersing larger soil aggregates (Ogunwole, 2008).

Generally, additions of organic material in the form of either farmyard manure or through the decomposition of plant residue over long periods of time play a significant role in the stability of aggregates in water or wind. This improves the soils capability for withstanding water erosion (Ogunwole, 2008).

Table 4. 4: Effect of farmyard manure and mineral fertilizer on wet mean weight diameter (mm) and soil water stable aggregate fractions (g)from different sieve diameters

		MWDW	0.5mm	0.25mm	0.05mm	<0.05mm
DEPTH	1	0.32	3.76	69.18	78.34	42.75
	2	0.32	3.34	65.59	80.17	45.53
	SE ±	0.011	0.493	1.377	1.478	1.685
	SL	NS	NS	NS	NS	NS
TREATMENT	CONTROL	0.34	8.40^{a}	58.79^{cd}	78.96^{a}	53.81^{a}
	D	0.30	4.75^{b}	69.72b	83.98^{bcd}	41.53^{bcd}
	DK	0.33	5.19^{ab}	82.42^{a}	77.65^{b}	34.75^{d}
	DN	0.34	3.92^{b}	83.09^{a}	74.54^{b}	38.44^{cd}
	DNPK	0.26	4.33^{b}	48.01^{e}	92.96^{a}	54.71^{a}
	DP	0.32	5.22^{b}	67.00^{bc}	84.32^{ab}	42.45^{abcd}
	K	0.30	2.82^{b}	79.04^{a}	77.47^{b}	40.67^{abcd}
	N	0.34	9.48^{a}	56.58^{de}	80.23^{b}	53.73^{ab}
	NPK	0.33	2.12^{b}	74.16^{ab}	76.31^{b}	47.41^{abc}
	P	0.33	3.39^{b}	69.20^{b}	79.32^{b}	48.09^{abc}
	SE ±	0.024	1.101	3.080	3.306	3.768
	SL	NS	**	*******	*****	**
	DEPTH*Trt	NS	NS	**NS**	**NS**	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; MWDW=wet mean weight diameter; SE=standard error of means ;SL=significant level.

4.9. Dry stable aggregate and dry mean weight diameter

Distribution of large macro aggregates (>2mm), macroaggregates (>0.025mm) and microaggregates (>0.05mm) fractions were significantly affected ($p<0.05$mm) along the study depth (Table 4.5) while the small macroaggregate (>0.5mm) and the silt+clay (<0.05mm) fractions were not significantly affected by the depth. Stability of aggregates increased with depth except for microaggregate, a scenario that can be attributed to the strong effect of clay as a cementing agent. This finding is in line with the findings of Guber *et al*. (2005) and implies that minimum use of heavy machinery in the field is required to avoid further degradation of the stable aggregates as well as the formation of hard pan in the subsurface soil.

Among treatments, stability of macro aggregates were significantly affected ($p< 0.05$). However micro aggregates and silt+clay fractions were not influenced by fertilizer application (Table 4.5). High proportions of large and small macro aggregates were recorded in DNPK, N, control and NPK and DK plots, respectively. This might be attributed to the addition of organic matter in form of farmyard manure or accumulation of litter material resulting from death of grasses during fallow periods or the influence of well established symmetrical roots in enmeshment of particles as a result of adequate nutrients (Reubens *et al.*, 2010). Availability of N and NPK in the plots might have stimulated activities of fungi and other microbes that play important roles in binding of particles together through secretion of binding agents (Haynes and Francis,1993). Chances of reducing amounts of macroaggregate(0.25mm-2mm) from these plots cannot be ruled out because long term cultivation may likely reduce aggregation (Tisdall and Oades, 1982). The non-significant influence of different fertilization regimes on soil microaggregates and silt+clay fractions further suggests that fertilizer application significantly affected formation of the macroaggregates in these plots (Shehu, 2013).

The treatment was found to play a significant role on drymean weight diameter (MWDW) and have on stability of soils. Higher proportions of dry stable aggregates were recorded in plots previously treated with N and DNPK while DN plots recorded the least value (Table 4.4).

The high dry MWD recorded in the fertilizer and dung-treated plots might be as a result of increasedamounts of organic materials from organic manure additions as reported by Ogunwole (2008). Another possible reason for the high value may be associated with the high amounts of divalent cations which accompany integrated applications of manure and inorganic fertilizer.The implication of this is that, plots with highest mean value of dry MWD will have better stable aggregates that can withstand wind erosion than other treatments, while those with low mean values may be most prone to wind erosion due to low dry stable aggregates. One probable reason for reduction in MWD with fertilization compared with that of control under the long term trial, may be due to disruptive forces that resulted from long term cultivation and incorporation of fertilizer (Ogunwole *et al*., 2008).

Significant effect of soil depth on dry MWD of the study plots was recordedwith 15-30cm depth recording the highest mean value. This is probably due to cementing effect of clay particle which increased with depth, and played an important role in the formation of micro aggregates. The interaction effect ofsoil depth and treatments on dry MWD was not significant even at 5% level of probability.

Table 4. 5: Effect of farmyard manure and mineral fertilizer on dry mean weight diameter (mm) and dry soil aggregate fractions (g)from different sieve diameters

DEPTH	MWDD	2mm	0.5mm	0.25mm	0.05mm	<0.05mm
1	0.97^{b}	27.54^{b}	59.40	26.30^{a}	77.83^{a}	7.96
2	1.13^{a}	38.382^{a}	58.72	26.30^{a}	69.775^{b}	6.46
SE ±	0.051	2.288	0.879	0.546	2.575	0.829
SL	*	*	NS	*	*	NS
Trt						
CONTROL	1.18^{ab}	42.4^{ab}	54.18^{d}	19.4^{e}	75.95	7.42
D	1.17^{ab}	39.28^{abc}	60.77^{abc}	24.25^{cd}	68.82	6.07
DK	1.11^{abc}	24.88^{cd}	62.58^{ab}	28.88^{ab}	75.75	7.12
DN	0.77^{c}	25.84^{cd}	61.58^{abc}	30.15^{ab}	76.01	6.34
DNPK	1.248^{a}	50.77^{a}	58.37^{bcd}	17.65^{e}	66.45	6.15
DP	0.96^{abc}	28.42^{bcd}	55.68^{cd}	25.5^{bc}	77.97	11.43
K	0.85^{bc}	24.03^{d}	58.93^{bcd}	31.22^{ab}	74.33	9.93
N	1.26^{a}	43.18^{ab}	56.92^{bcd}	20.88^{de}	72.07	6.33
NPK	1.01^{abc}	27.97^{bcd}	66.17^{a}	30.9^{a}	68.42	5.43
P	0.95^{abc}	27.83^{bcd}	55.42^{cd}	25.37^{bc}	82.27	8.85
SE ±	0.115	5.115	1.965	1.220	5.758	1.853
SL	*	*	*	***	NS	NS
DEPTH*Trt	NS	NS	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; MWDD=dry mean weight diameter; SE=standard error of means; SL=significant level.

4.10 Soil moisture characteristics of the study plots

There was a significant difference between the soil depth in moisture retention capacity at different suction points (Table 4.6). A decrease in moisture content was observed with decrease in depth at all suction points depicting the strong role played by organic matter in holding large quantity of water than soil pore spaces. Significant influence of the treatment on soil moisture retention capacity was only observed atsuction points 0.1bar (Table 4.6). At all the suction points, DNPK was found to have higher moisture content than the other treatments. It was observed that plots treated with both combination of organic and inorganic fertilizer were having high moisture content than those treated with single fertilizer. An increase in moisture retention with addition of organic manure as observed in this study was reported by Lal and Shukla (2004), Alliaume *et al.* (2010); and they linked this observation to the presence of good aggregate stability resulting from high organic carbon content of the soil due to the application of organic manure. Shehu (2013) also reported a positive improvement in soil moisture retention, especially at high tension with the presence of organic matter in soils. Addition of dung and accumulation of organic matter from decomposition of grasses and their roots in control plot was viewed to increase the soil moisture retention capacity from 0.3bars to 15bars.A similar finding was reported by Zhang *et al.* (2006) and Abdulkadir and Habu (2013).

Generally, a decrease in soil moisture retention was observed with increase in suction throughout the study (Table 4.6).

More available plant water was observed in DN,DNPK and Control plot. This may be related to the positive improvement in soil moisture retention, especially at high suction with the presence of organic matter in such plots. Interaction between the treatments and

Table 4. 6: Effect of farmyard manure and mineral fertilizer on soil moisture retention

	0bar	0.1bar	0.3bar	1bar	5bar	10bar	15bar	AWHC
DEPTH			(cm^3/cm^3).					
1	0.50^{a}	0.39^{a}	0.35^{a}	0.31^{a}	0.27^{a}	0.27^{a}	0.25^{a}	0.10
2	0.41^{b}	0.34^{b}	0.29^{b}	0.28^{b}	0.23^{b}	0.21^{b}	0.19^{b}	0.10
SE ±	0.01	0.01	0.011	0.01	0.009	0.01	0.01	0.009
SL	**	**	**	*	**	**	*	NS
Trt								
CONTROL	0.39^{b}	0.36	0.31	0.31	0.22	0.20	0.20	0.11
D	0.42^{b}	0.32	0.31	0.29	0.23	0.23	0.23	0.08
DK	0.51^{ab}	0.41	0.34	0.32	0.29	0.29	0.27	0.09
DN	0.46^{b}	0.37	0.33	0.28	0.23	0.21	0.18	0.15
DNPK	0.66^{a}	0.52	0.40	0.39	0.33	0.28	0.26	0.15
DP	0.42^{ab}	0.31	0.25	0.24	0.23	0.21	0.21	0.04
K	0.38^{b}	0.32	0.30	0.30	0.25	0.23	0.22	0.08
N	0.36^{b}	0.28	0.24	0.23	0.20	0.19	0.19	0.05
NPK	0.37^{b}	0.31	0.27	0.26	0.21	0.20	0.20	0.07
P	0.54^{ab}	0.47	0.42	0.40	0.33	0.31	0.31	0.12
SE ±	0.023	0.023	0.024	0.023	0.021	0.022	0.021	0.02
SL	*	NS	NS	NS	NS	NS	NS	NS
DEPTH*Trt	NS	NS	NS	NS	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; AWHC= available water holding capacity; SE=standard error of means; SL=significant level.

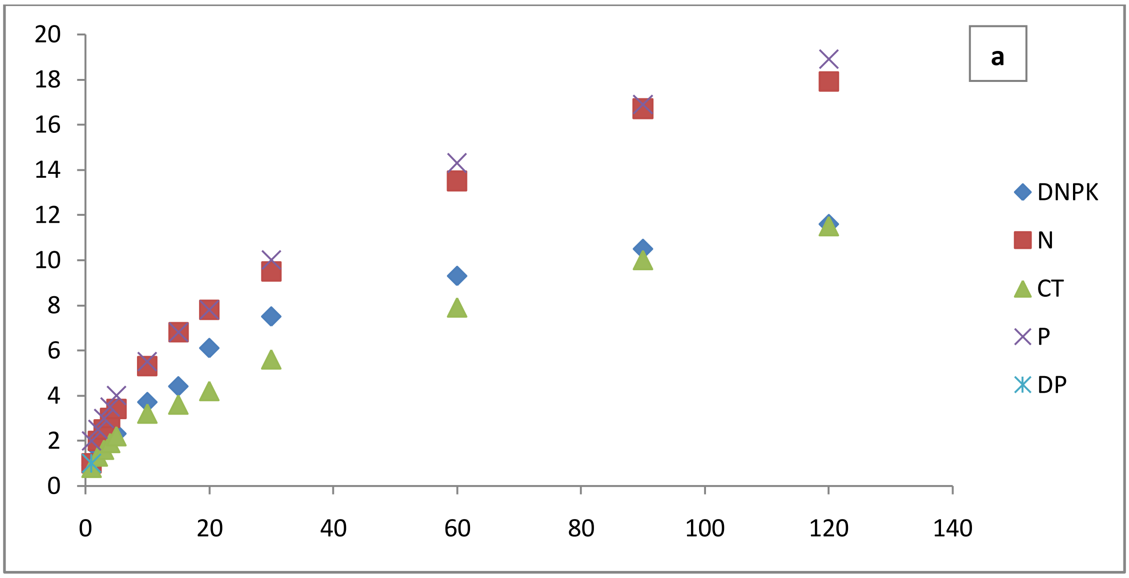
depth did not yield any significant effect on soil moisture retention capacity of the study plots (Table 4.6).

4.11. Infiltration

Considering the plot of cumulative infiltration versus time of all the treatments, the results reveal an initialrapid increase in infiltration that stabilizes with time. (Figure 4.1a and 4.1b). Soil inherent heterogeneity in all the plots have played a role in the results obtained in this study. Variability in cumulative infiltration for some treatments were higher than others. Such variability was more pronounce for DK, P and N plots as shown in Figure 4.1b. Results also indicate that for the early stages of infiltration, cumulative infiltration between the treatments were not different even in the control plot. This finding indicate that for a given quantity of applied irrigation or rainfall water, larger proportion will infiltrate into the soil for DK, P and N plots than all other treatments plots. Also less runoff will be observed in such plots.

The same trend as observed in the plot of cumulative infiltration versus time as reported above was observed for the plot of infiltration rate against time, only that the infiltration rate progressively decreases with time for all the treatment plots (Figure 4.2a and 4.2b).

High infiltration rate observed in the DK,P and N treated plotsmight be due to the presence of dry stable aggregate and low bulk density since soil hydraulic properties positively correlates with dry large macroaggregates, dry mean weight diameter and bulk density (Table 4.13). Shehu (2013) and Schnug and Haneklaus (2002), reported relationships between the improved soil mechanical stability and increased infiltration rates. High infiltration rate, good tilth and adequate aeration for plant growth is generally known to be improved by well aggregated soils with large pores whose continued presence depends on the stability of soil aggregates (Kemper and Rosenau, 1986). Low infiltration values recorded despite the addition of organic manures in someplots might be connected with low mean weight diameter and presence of few large macroaggregates as observed in Table 4.3. High bulk densities observed in the dung plots relative to other plots (Table 4.3) might be as a result of spatial variability of soil properties within the field (Cambardella *et al.*, 1994) could be another reason for the low infiltration rate observed in the study.



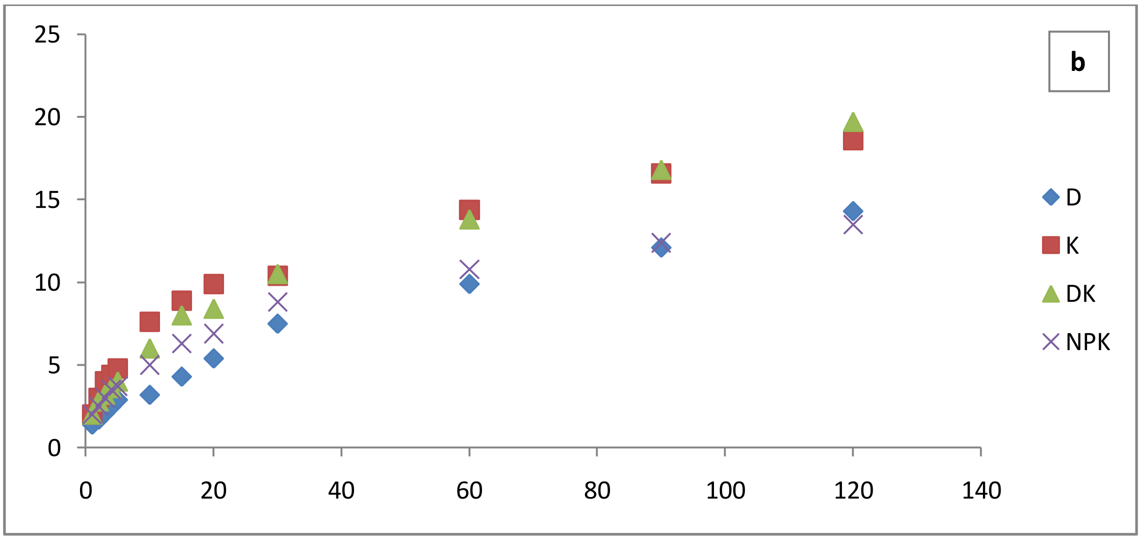
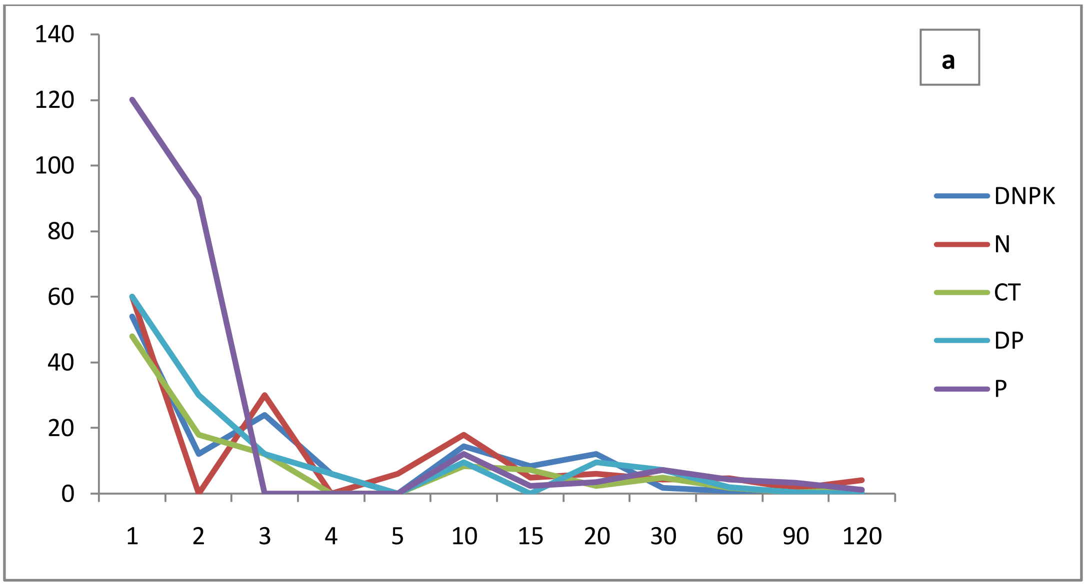


Figure 4. 1Cumulative infiltration versus time for all the treatments.The different colours and symbol refer to the different treatments. D= dung; N= nitrogen; P= phosphorus; K= potassium and CT= control.



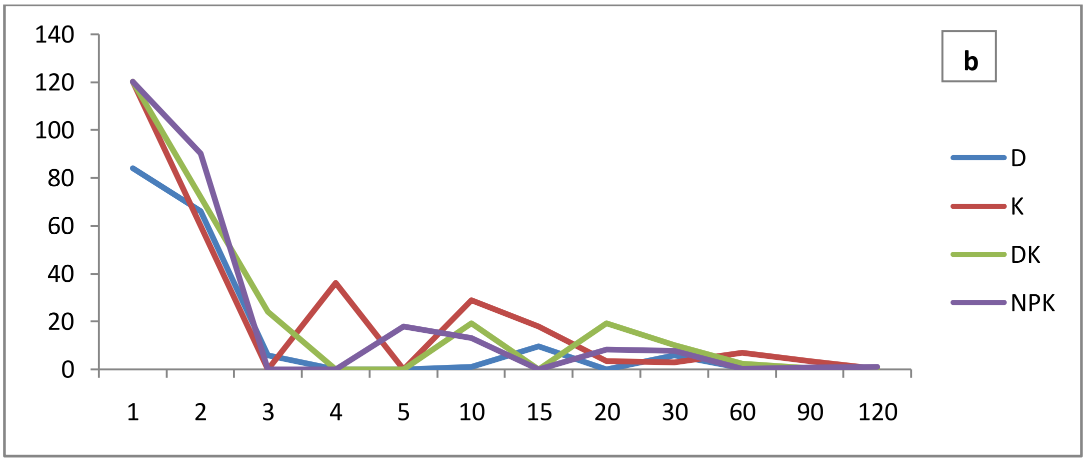


Figure 4. 2a and b: Infiltration rate versus time for all the treatments.The different colours and symbol refer to the different treatments.

4.12. Infiltration models

4.12.1. Kostiakov's Model

All the linear curve fittings used to estimate the parameters of the Kostiakov infiltration equation yielded coefficients of determination (r^2) close to unity (Tables 4.7).This was further established when fitting parameters were used directly in the Kostiakov model which yielded calculated model values with average means r^2 values of 0.9956 for all points (Table 4.7). This confirms the close relationship between observed and predicted infiltration rates. It also confirms the applicability of Kostiakov equation in estimating infiltration parameters therefore predicting cumulative infiltration of similar soils in Guinea savanna soils of Nigeria.

Linear regression plots of observed versus predicted cumulative infiltration of all plots gave regression lines with slopes closed to unity (Tables 4.8).

Earlier studies of two infiltration models by Shehu (2013) showed superiority of Kostiakov over Philip’s equation. However, Abdulkadir *et al.* (2011) reported that earlier comparative studies on two infiltration models in Samaru, using non-linear least square initially and later linear least-square regression, reveals the superiority of Philip’s equation over the Kostiakov’s equation.

Table 4. 7: Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Kostiakov’s infiltration model.

Trt	n	B	R^2	Equation
CT	-0.685	1.5241	0.961	I=1.5241*t^0.685
DNPK	-0.709	1.0093	0.977	I=1.0093*t^0.709
DP	-0.748	1.1885	0.996	I=1.1885*t^0.748
P	-0.579	1.2883	0.995	I=1.2883*t^0.579
NPK	-0.715	1.9272	0.998	I=1.9272*t^0.715
K	-0.658	1.5346	0.987	I=1.5346*t^0.658
DK	-0.634	1.7458	0.997	I=2.7458*t^0.634
N	-0.759	1.2794	0.989	I=1.2794*t^0.759
D	-0.634	1.7378	0.997	I=1.7378*t^0.634
DN	-0.828	1.0864	0.998	I=1.0864*t^0.828
Mean			0.9895	

†Trt treatment, B and n are Kostiakov fitting parameters, r^2 coefficient of determination

Table 4. 8: Linear regression coefficients and relationships between measured and predicted cumulative infiltration (mm) after 90 minfrom Kostiakov's infiltration model.

Trt	Regression Equation	R^2
CT	Y=1.0688X-0.621	0.9840
DN	Y=1.0545X-0.630	0.9970
DNPK	Y=1.1085X-0.578	0.9928
DP	Y=1.4468X-0.303	0.9968
P	Y=0.951X-0.278	0.9971
NPK	Y=3.7932X-0.329	0.9977
D	Y=1.0124X-0.122	0.9992
K	Y=1.0615X-0.546	0.9947
DK	Y=0.9977X+0.191	0.9984
N	Y=1.0635X-0.587	0.9979
Mean		0.9956

†Y is the measured infiltration rate while X is the predicted infiltration

4.12.2.Philip’s equation

Very good r^2 values were recorded when obtaining fitting parameters A and S (Table 4.9).This indicate the goodness of fit of the infiltration data into Philip’s model. However, for all plots studied, A value was only negative in NPK treated plot. (Table 4.9). Such negative value suggest that at some time during infiltration cumulative amount reached a maximum and decreased thereafter as infiltration continued (Davidoff and Selim, 1986). This is not true in the actual infiltration process, and negative A valuehas no physical significance. However, in many infiltration studies, A values have been reported as negative (Taylor andAshcroft 1972; Cook *et al.*, 1982; Fahad *et al.*, 1982).

However, the superiority of Philips model over Green and Ampt’s and linearized Philip’s model was reported by Swatzendruber and Youngs (1974) in their studies of three physically-based infiltration models. This is not the case here. The ability of the Philip’s equation together with other equations to simulate the long-term infiltration rates of surface reclaimed mine soil relatively well was reported by Cook *et al.* (1982).

Table 4.9: Fitting parameters and fitting equations of selected DNPK experimental plots

Trt	S	A	R^2	Equation
CT	1.194	0.166	0.557	I=1.194*t^0.5+0.166*t
DN	1.00	0.387	0.958	I=1.00*t^0.5+0.387*t
DNPK	1.138	0.137	0.726	I=1.138*t^0.5+0.137*t
DP	0.835	0.185	0.928	I=0.835*t^0.5+0.185*t
P	1.30	0.063	0.885	I=1.30*t^0.5+0.063*t
NPK	54.04	-5.257	0.654	I=54.04*t^0.5-5.257*t
K	1.69	0.144	0.737	I=1.69*t^0.5+0.144*t
DK	1.784	0.157	0.939	I=1.784*t^0.5+0.157*t
N	1.373	0.276	0.901	I=1.373*t^0.5+0.27*t
D	1.833	0.143	0.876	I=1.833*t^0.5+0.143*t

in Samaru from Philip's infiltration model.

† S and A; Philip's fitting parameters; Trt= treatment, R^2=coefficient of determination

Table 4. 10: Linear regression coefficients and relationships between measured and predicted cumulative Infiltration (mm) after 90 min from Philip's infiltration Model

Trt	Regression Equation	R^2
CT	$Y = 1.043X - 0.288$	0.989
DN	$Y = 0.975X + 0.187$	0.984
DNPK	$Y = 0.977X + 0.153$	0.995
DP	$Y = 1.038X - 0.265$	0.987
P	$Y = 1.063X - 0.559$	0.987
NPK	$Y = 0.992X+0.627$	0.981
D	$Y=1.0298X -0.347$	0.996
K	$Y=1.0827X-1.485$	0.954
DK	$Y=1.0084-0.1315$	0.999
N	$Y=1.0115X-0.081$	0.996
Mean		0.986

†Y is the measured infiltration rate while X is the predicted infiltration.

4.12.3. Horton’s equation

A wide variation was observed when calculated infiltration rate was compared with field measured result using Horton’s equation for this study. The same observation was made when infiltration measurements were repeated in 2014 on the same plots in order to validate the former observation of fitting Horton’s model. Wudivira *et al*. (2001) reported failure of Horton equation in the measurement of infiltration rates of soils using non-linear least square regression when comparing three infiltration models in Samaru and attributed the apparent failure of the Horton equation to difficulty of the iteration procedure to handle three parameters at the same time. However,an impressive performance of Horton’s model was observed by Abdulkadir *et al*. (2011) using linear and non-linear least-squares regression procedures simultaneously. Also, an overall best performance ofthe three- parameter Horton model in Ohio was observed by Shukla *et al*. (2003). Berndtsson (1987) reported a better fit of Horton’s model over Philips infiltration models for semi-arid soils in northern Tunisia. Ghorbani Dashtaki *et al.*(2009) reported a better performance for Horton model than Kostiakov and Philip models. However, such was not the case in this study.

4.13 Goodness of Fit of Infiltration Models

For model verification and goodness of fit, the three models were used to describe the experimental data for each replication as well as pooled data for each treatment. All models except Horton provided good overall agreements with the experimental/measurement data.

Infiltration parameters for all the replications were obtained from linear and non-linear regression for the three models are given in Tables 4.7 and 4.9. For each treatment, the r^2values obtained were higher for Kostiakov's model than for Philip’s.

If one considers r^2 as a measure of the goodness of fit of a model, we may therefore conclude that for any one treatment, Kostiakov's model provided better fit with experimental data over Philip's and Horton's models.

The relations between measured and modelled infiltration rates, as calculated from the different

models, are shown in Tables 4.8 and 4.10. The results indicate a very good relationship between the Kostiakov's model and measuredcumulative infiltration. Philip's model provided slight deviations from experimental data (Table 4.10). Such deviations were consistent for all treatments and occurred at early and advanced stages of infiltration.

4.14. Predicting soil hydraulic properties using pedotransfer functions

Running a stepwise regression using SAS computer package that uses soil hydraulic properties(field capacity, permanent wilting point and available water holding capacity) as the response variables (Dependent variables) and the soil physical properties(mean weight diameter, large macro aggregates, small macro aggregates, soil texture and soil organic carbon) as regressors (Independent variable) generated relationships that predict soil hydraulic properties of the study plots (Table 4.11).The model used the criteria of 0.15 significant level of probability in regressing the variables. Only those variables that met the criteria were left in the model. For field capacity (FC) and available water holding capacity (AWHC), only bulk density (BD) and sand fraction were left as dependent variables, the equations and parameters estimates are given in Table 4.11.

Table 4. 11: Parameter estimate of the hydraulic properties using a stepwise linear regression

Parameter	Step	Variable left	equation	Df	Pr > F	R2
FC	1	BD	Y=0.06235+0.08511*BD	1	0.0241	0.4904
	2	SAND	Y=0.14255-0.00131*SD	1	0.1814	0.6124
		BD	Y=0.14255+0.07701*SD	1	0.0332	
AWHC	1	BD	Y=0.06116+0.07539*BD	1	0.0618	0.3705

† FC Field capacity, AWHC Available water holding capacity, BD Bulk density, SD Sand, DF Degree of freedom, r^2 Coefficient of determination.

Table 4.12 contains the estimates of β_0 and β_1 as obtained from the SAS computer package in the form of intercept and slope, respectively, from regression of dependent variables as a function of independent variable. The table also contains the coefficient of variability (r) and coefficient of determination (r^2).The probability values obtained from the simple linear regression analysis of the soil hydraulic functions and soil physical properties shows related good relationship amongst many of the variables. From the parameters estimates, the linear fitting models for FC, PWP and AWHC were given in Table 4.12.

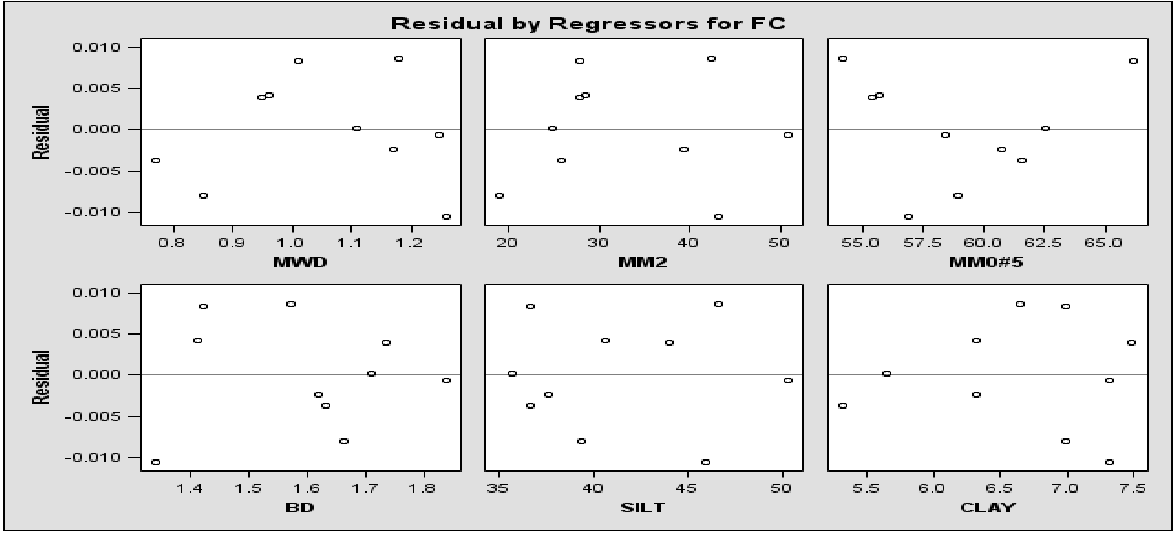
Table 4. 12: Relationship between water retention characteristics (dependent) and selected parameters (independent)

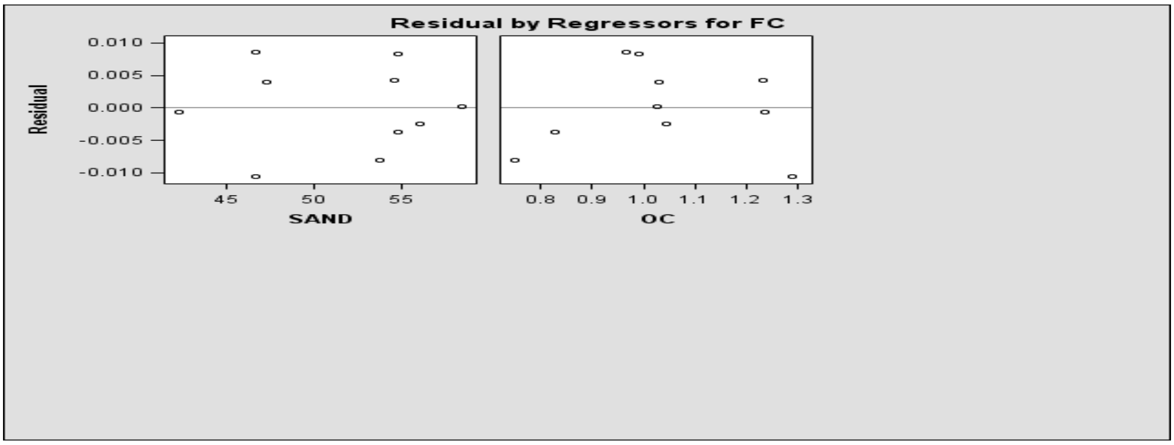
Variables				
Dependent (Y)	Independent (X)	Equation	r^2	r
FC	MWD	Y=1.395 + 0.0301*MWD	0.8887	0.9427
FC	LMA	Y=1.39546 - 0.0005*LMA	0.8887	0.9427
FC	SMA	Y=1.39546 - 0.0033*SMA	0.8887	0.9427
FC	BD	Y=1.39546 + 0.1001*BD	0.8887	0.9427
FC	ST	Y=1.39546 - 0.0143*ST	0.8887	0.9427
FC	CL	Y=1.39546 - 0.0016*CL	0.8887	0.9427
FC	SD	Y=1.39546 - 0.0125*SD	0.8887	0.9427
FC	OC	Y=1.39546 + 0.0652*OC	0.8887	0.9427
PWP	MWD	Y=0.848 + 0.0964*MWD	0.9185	0.9584
PWP	LMA	Y=0.84818 - 0.0020*LMA	0.9185	0.9584
PWP	SMA	Y=0.84818 - 0.0042*SMA	0.9185	0.9584
PWP	BD	Y=0.84818 + 0.0744*BD	0.9185	0.9584
PWP	ST	Y=0.84818 - 0.0108*ST	0.9185	0.9584
PWP	CL	Y=0.84818 + 0.0115*CL	0.9185	0.9584
PWP	SD	Y=0.84818 - 0.0068*SD	0.9185	0.9584
PWP	OC	Y=0.84818 + 0.1040*OC	0.9185	0.9584
AWHC	MWD	Y=0.879 - 0.0131*MWD	0.9717	0.9857
AWHC	LMA	Y=0.879 + 0.0007LMA	0.9717	0.9857
AWHC	SMA	Y=0.879 - 0.0003*SMA	0.9717	0.9857
AWHC	BD	Y=0.879 + 0.0351*BD	0.9717	0.9857
AWHC	ST	Y=0.879 - 0.0063*ST	0.9717	0.9857
AWHC	CL	Y=0.879 - 0.0175*CL	0.9717	0.9857
AWHC	SD	Y=0.879 - 0.0087*SD	0.9717	0.9857
AWHC	OC	Y=0.879 - 0.040*OC	0.9717	0.9857

†FC=field capacity, PWP=permanent wilting point, AWHC=available water holding capacity, MWD=mean weight diameter, LMA=large macroaggregate, SMA=smallmacro aggregate, BD=bulk density,ST=silt, CL=clay, SD=sand, OC=organic carbon r correlation coefficient, r^2 coefficient of determination

A plot of the residuals versus the regressors (Figure 4.3) indicates non-constant variance in all the data. The plot of residuals versus the predicted values for all the diagnostics indicates a slight trend in the residuals; they appear to increase slightly as the predicted values increase. Since these residuals have no apparent trend, the analysis is considered to be acceptable (SAS user's guide).

Figure 4. 3:Plot of residuals vs regressors for field capacity.





FC,field capacity; BD,bulk density; OC,organic carbon and MWD,mean weight diameter

4.15. Temporal variability of soil properties as influenced by long-term application of DNPK

This work synthesized results of some soil properties from earlier studies on the long-term DNPK experiments at Samaru, Nigeria. Data on soil properties collected from these plots were obtained from Batche and Heathcote (1969), Agbenin and Goladi (1998), Ogunwole and Ogunleye (2004 and 2005), Raji and Ogunwole (2006), Abdulkadir and Habu (2013) and Mohammed *et al.*, (2013). Regrettably, most of the earlier work before the year 2000 focused on soil chemical fertility, thus a huge gap exists for data on physical soil properties.

4.15.1. Soil organic carbon data from DNPK plots (1959 - 2008)

Data for soil organic carbon documented between 1959 and 2008 from earlier studies are presented in Figure 4.4 and 4.5.Trend shows initial low organic carbon prior to any farming activity for dung plots. However, the trends across all treatments show a fluctuating (inconsistence) increase and decline in organic carbon level between the year 1959 and 2008. A slight constant state was observed in 2008, though still higher when compared to values observed in 2002 in most cases. This trend is similar for four treatments, at all levels, over the years.

Results show that dung was the main treatment that consistently increased soil organic carbon (SOC), up to the highest rate of application. This is reflected by the highest value of organic carbon observed with the highest level of dung applied (i.e D2) (Figure 4.4).

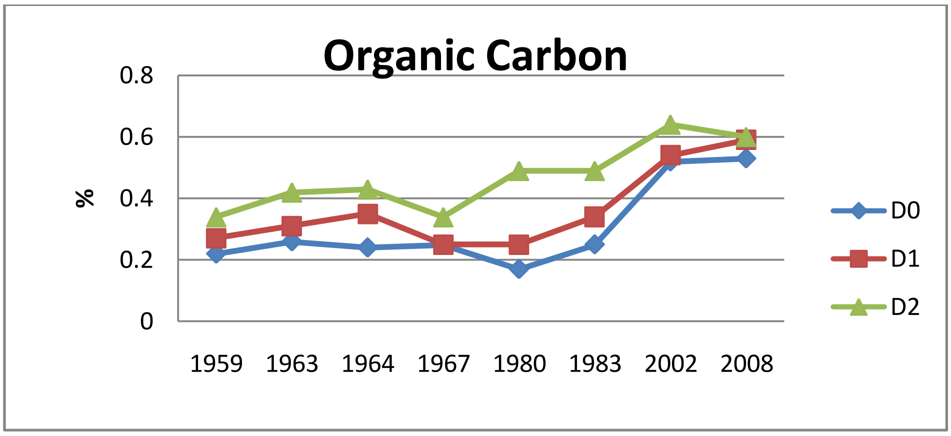


Figure 4. 4: Trends of organic carbon levels under three levels (0,1,2) of dung application rate in dung (D) plots between 1959-2008.

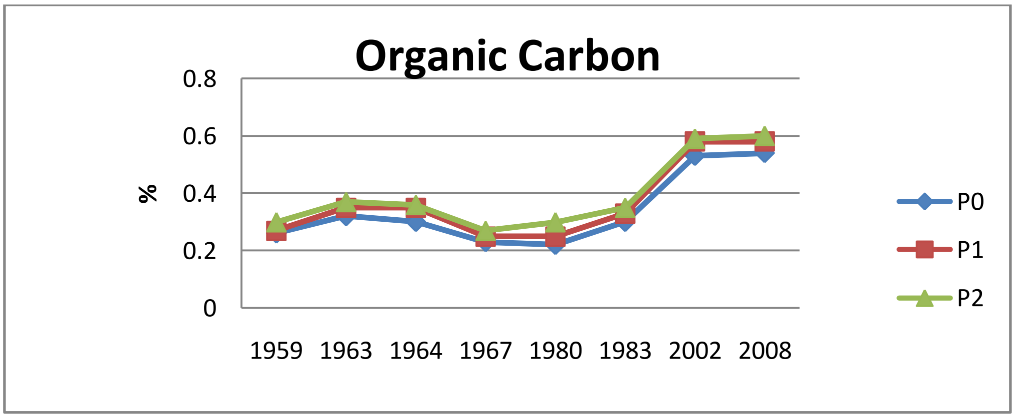


Figure 4. 5: Trends of organic carbon levels under three levels (0,1,2) of phosphorus (P) application rates in P-plots between 1959-2008.

Comparatively higher values of organic carbon and total nitrogen were observed in 2002 .This could be attributed to the fact that the field was fallowed for five years. Research reports have shown varied role that fallow played in carbon sequestration in soil. Raji and Ogunwole (2006) reported low organic carbon content during cultivation periods of DNPK field. They attributed their findings to the highly degraded nature of the soils as a result of annual harvesting of organic matter from these plots while under continuous cultivation. The non-perturbation of soil during the fallow period could also have reduced activities of soil microbes. It is also likely that during fallow periods, water-stable aggregates kept organic matter out of reach of microbes thus impeded decomposition (Hassink, 1997; Hoogmond, 1999). Conant *et al*. (2001) reported that marginal lands in United States under fallow have potential to sequester about 50 g C m^{-2} yr^{-1}.

By 1983, when the experiment was 34 years old, Amapu (1984) found that about 32.63 and 65.5 tonnes C ha^{-1} had been added from 2.5 and 5 tonnes dung ha^{-1}. Thus, equivalent of 13 and 11.6% of carbon supplied in Farm yard manure FYM had been retained in the soil as organic matter. This also translates into the mineralization of 87 and 88.4% of the manure applied. These values indicate that quite reasonable amounts of organic material are retained in the soil each year. Diels *et al*. (2002) used ROTHC model and estimated that the experiment had built up 1 tonne C ha^{-1} after 20 years of existence. In another study, Agbenin and Goladi (1997) found that after 45 years of continuous application, the dung-treated plots had carbon contents that are at approximately the same level as that of the ‘native’ site. Area-based changes calculated in relation to the ‘native’ site were not significant numerically, further corroborating findings that FYM was effective in mitigating carbon losses. The study by Agbenin and Goladi (1997) also showed that, while inorganic fertilizers in combination with dung not only arrested carborn loss, they also increased N and P in relation to the ‘native’ site.

With respect to phosphorus treated plots, organic carbon was found to be increasing significantly with increase in level of phosphorus fertilizer all over the years observed (Figure 4.4).This has been attributed, in part, to production of greater root residues from high crop yields on P-treated plots. The observation is also credited to the fact that phosphate fertilizers allow relatively more carbon to be converted into humus by ‘locking’ fertilizer phosphate in organic form, and creation of humic carboxylic acids (Russell, 1973).

The trend of organic carbon content of the study plots with respect to nitrogen and potassium fertilizers treated plots were found to be increasing slightly but not significantly with increase in their levels (Appendixes xv and xvi). A similar finding was observed by Drinkwater *et al.* (1998) in which slightly lower values of 2.2 t C ha^{-1} were obtained in Pennsylvania in 15 years of using chemical nitrogenous fertilizer.

Raji and Ogunwole (2006) also concluded that application of manure over a long period of time resulted in sequestration of more soil organic carbon than application of NPK fertilizer alone did in DNPK trial. The latter authors recorded 68% or 3.55 t C ha^{-1} increment after 45 years of continuous manure application which they attributed to the ability of organic manure in promoting the formation and stabilization of macro aggregate and particulate organic carbon.

4.15.2. Soil Reaction (pH) data from DNPK plots from 1959 to 2008

An initial decrease in soil pH was observed with increasein level of N fertilizer for the first few years observed (Figure 4.5).However, sligt rise in pH was observed which later stabilizes and then begins to decline. The application of nitrogen fertilizers indicates acidifying effects on soils, which is caused by hydrolysis of salt and by acid production during nitrification, leading to leaching of soil bases accompanied by low pH buffering capacity of the soil (Mohammed *et al.*, 2013)

However, mean values for soil pH, across treatment levels (Appendix xvii), showed an inconsistent trend in pH with different levels of dung for all the years. The observed increase has been linked to the production of $CaCO_3$ during decomposition of organic residues in dung or production of soil humic substances that can form complexes with aluminium and manganese ions (Batche and Heathcote, 1969). Effects of phosphorus fertilizer were similar to those of dung (Appendix xviii). Potassium (K) treatment did not seem to have any appreciable effect on soil reaction (Appendix xix).

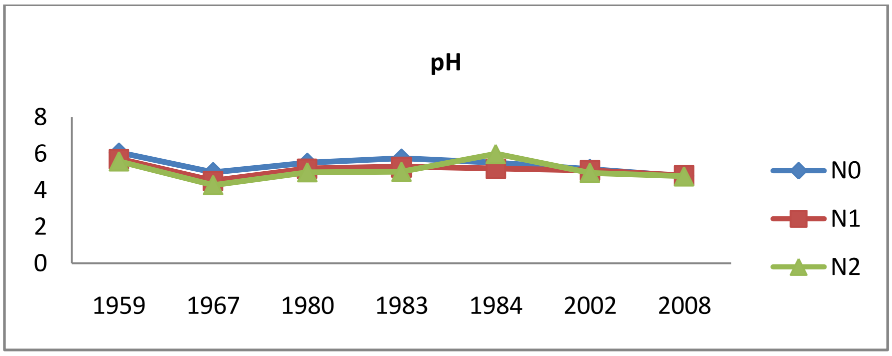


Figure 4. 6: Trends of soil pH under three levels of nitrogen (N) application rate in N plots between 1959-2008.

4.15.3. Data from selected soil physical properties from DNPK plots (1997 - 2013)

Data collected on soil physical properties were for average mean weight diameter, bulk density and saturated hydraulic conductivity and are presented in Figure 4.7.All average values recorded for bulk density were slightly above average values reported by Goladi (1997) as 1.51 mm gm^{-3},although slight but none significant differences were observed across the years (Figure 4.7).This slight differences were attributed to the effect of cultivation on bulk density of savanna soil which is usually short-lived because bulk density quickly returns to its original state at the end of a growing season (Goladi, 1997). A similar reasoning was highlighted by Raji and Ogunwole (2006).

The stability of the macroaggregate was observed to be decreasing across the years (Figure 4.7). This might be attributed to absence of farming activities during the fallow period, since application of fertilizer (organic or inorganic) is believed to have an indirect role in macroaggregate stability because of the role they play in biomass accumulation and root exudation that serve as binding agent (Tisdall and Oades, 1982; Beare *et al*., 1994).Accumulation of biomass from the bushes growing during the fallow periods is small compared with the accumulation during farming activities, thus having less impact on stability of soil macroaggregates. Low microbial activity might have reduced macro stability. Another reason for the reduced stability of macro aggregate may be attributed to the long-term application of NPK fertilizer as reported by Nyiraneza *et al*. (2009). However, an improvement of macro stability was noticed in 2008 when the field was cultivated which was attributed to the role of roots in the enmeshment of particles together.

Saturated hydraulic conductivity was found to be decreasing during the fallow periods, although an increase was observed when the field was cultivated in 2008 (Figure 4.7). A possible reason for the observed increase may be associated with the soil's structural arrangement of the surface or as a result of improvement in macro aggregate stability, both influenced by the management practices adopted in the field (Ogunwole and Ogunleye, 2005).The influence of pore sizes and geometry on soil hydraulic properties is also suspected to play a positive role on the increase observed as reported by Brady and Weil (1999) and Ahuja *et al*. (1998). Observed decrease during the fallow period was connected to degradation of structural stability of the soil that resulted in tightening of the soil and decrease in the volume of soil pores over time (Zhou *et al*., 2007).

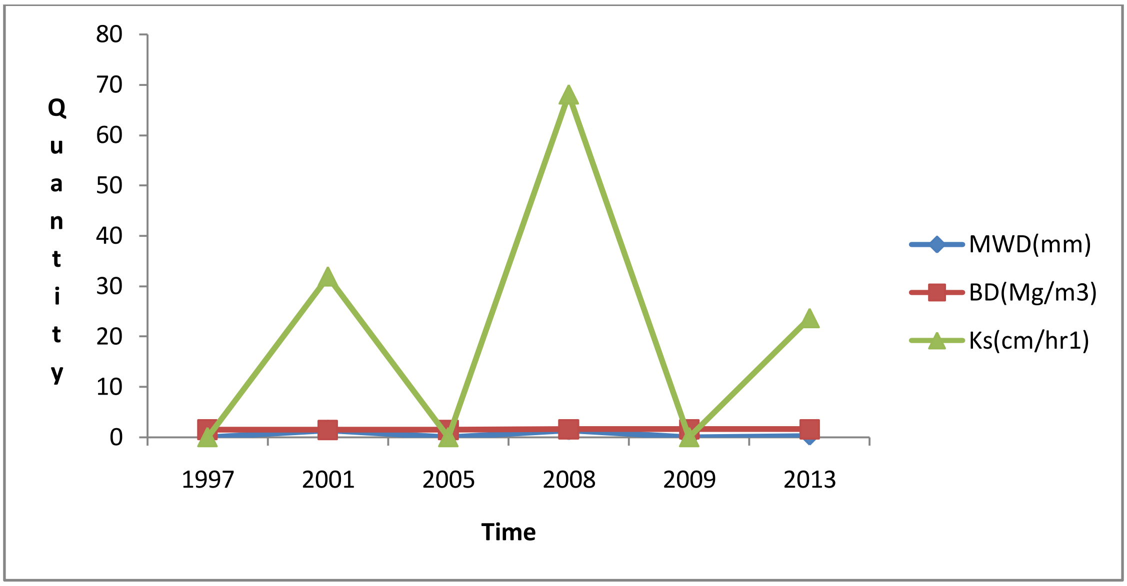


Figure 4. 7: Trend of some selected soil physical properties of the DNPK plot in Samaru between 1997 to 2013.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

The study was conducted with the aim of assessing infiltration characteristics and temporal variability of soil properties as influenced by long-term fertilizer trial. In order to achieve this aim, ten plots with histories of fertilizer treatments that is, a combination of farm yard manure (Dung) and NPK fertilizer or single applications were selected for this study. The study was carried out in two phases; field and laboratory for determination of soil properties. Soil samples were collected from two depths (0-15 cm and 15- 30 cm).Data collected were analyzed with SAS computer package to test for significant difference of mean values at 1 and 5% probability levels. Means with significant difference were separated using Duncan multiple range test computer package. Bivariate and multivariate where applicable correlation, linear and non-linear least square regression analysis were used to establish relationships among soil properties to obtain simple relational expressions. Field infiltration data was fitted into three infiltration models that is, Kostiakov's, Philip's and Horton's model.

Results show that soil texture of the study area is dominated by sandy loam or sandy clay loam. The results also show that different treatments imposed in these plots had significant influences ($p<0.05$) on percentage sand and silt, soil aggregate fractionate, soil bulk density, soil pH, soil infiltration rate, soil moisture retention capacity and water aggregate stability. However, the percentage soil organic carbon, soil fractionate organic carbon, saturated hydraulic conductivity and dry aggregate stability were not affected by these treatments.

On the influence of soil depth on the studied plots, water aggregate stability and soil moisture retention capacity were significantly affected. In contrast, dry aggregate stability, particle size distribution, fractionate organic carbon, fractionate particle size distribution, bulk density, soil pH and saturated hydraulic conductivity were not significantly affected by soil depth.

Infiltration model evaluation showed that Kostiakov's model with mean value for coefficient of determination (r^2) close to unity (0.9955) was a more accurate predictor of infiltration over Philip's (0.983) and Horton's model. The data obtained were not perfectly fitted into Horton's model.

Correlation and regression analysis showed that water retention at field capacity and permanent wilting point and plant available water were positively associated with dry aggregate stability, large macro aggregate, bulk density, sand, silt, clay and soil organic carbon.

Temporal variability result of the studied plots reveals that fertilizer treatments adopted increased soil organic carbon and raised soil pH level in the long term trial. Soil physical properties such as macroaggregate stability and saturated hydraulic conductivity were found to be decreasing over the years under natural fallow. Bulk density remained almost constant under fallow but increases with cultivation of the plots.

5.2. Conclusion

The complimentary application of the organic and mineral fertilizers to agricultural soils has been shown to have excellent potentials ofsequestering organic carbon and maintain or improve soil quality indicators such as infiltration rate, bulk density, aggregate stability, soil moisture retention capacity, soil organic carbon content, soil structure and soil texture. The impact of the management practices adopted was clearly observed in the improvement of these soil properties over a long period of cultivation which is reflected at fallow period. Lower soil bulk density and pH levels, higher level of soil aggregation and lower susceptibility to wind and water erosion were observed on the entire plot studied. The results obtained from these soils under different fertilization as a result of natural fallow when compared with data from earlier studies suggest the sustainability of integrated nutrient management in improving soil quality in the long-term in agricultural production systems.Overall, the Kostiakov’s model gave the best representation of the infiltration rate-time relationship for all the selected plots studied.

5.3 Recommendations

Recommendations from this study are:

More work on soil physical properties on other treatments in the DNPK trial field is needed to fill the gaps that existed in the present work.

The sustainability of the trial field is crucial to enable it stand among peers such as Rothhamstead trial field of London and P60 Groß Kreutz of Germany.

The field should be properly fenced to prevent trespassing by grazing animals in order to maintain the condition of the field during times of fallow and cultivation depending on the research purposes.

The use of other methods such as tension disk infiltrometer and pedotransfer function should be explored to replace the traditional and labourious method with the double ring infiltrometer in assessing fieldsoil hydraulic properties.

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APPENDICES

Appendix i

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Kostiakov's infiltration model.(Replicate 1, 2013)

Trt	n	B	R^2	Equation
CT	-0.619	1.0990	0.99	I=1.0990*t^0.619
DNPK	-0.637	1.0889	0.985	I=1.0889*t^0.637
DP	-0.748	1.6827	0.976	I=1.6827*t^0.748
P	-0.730	1.1180	0.984	I=1.1180*t^0.730
NPK	-0.634	1.0765	0.960	I=1.0765*t^0.634
K	-0.856	1.1091	0.970	I=1.1091*t^0.856
DK	-0.599	2.1827	0.992	I=2.1827*t^0.599
N	-0.595	1.0965	0.992	I=1.0965*t^0.595
D	-0.557	1.81134	0.99	I=1.8113*t^0.557
DN	-1.676	1.4588	0.984	I=1.4588*t^1.676

†Trt= treatment, I= Cumulative infiltration, B and n are Kostiakov fitting parameters, r^2 =coefficient of determination

Appendix ii

Linear regression coefficients and relationships between measured and predicted Cumulative infiltration (mm)after 90 min from Kostiakov's infiltration model.(Replicate 1,year 2013)

Trt	Regression Equation	R^2
CT	Y=1.2829X-0.3611	0.9948
DN	Y=198.18X-753.17	0.9299
DNPK	Y=1.0813X+0.556	0.9893
DP	Y=2.8535X-0.325	0.9914
P	Y=1.5624X-1.071	0.9923
NPK	Y=0.8159X+1.123	0.9648
D	Y=1.0344X-0.327	0.9956
K	Y=1.1866X-2.5395	0.9558
DK	Y=0.991X+0.118	0.998
N	Y=1.0015X+0.0021	0.9947
Mean		0.9806

†Y is the measured cumulative infiltration while X is the predicted cumulative infiltration

Appendix iii

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Kostiakov's infiltration model(Replicate 1, year 2014)

Trt	n	B	R^2	Equation
CT	-0.560	1.3842	0.996	I=1.3842*t^0.560
DNPK	-0.481	1.2012	0.978	I=1.2012*t^0.481
DP	-0.441	0.9270	0.992	I=0.9270*t^0.441
P	-0.532	1.5646	0.998	I=1.5646*t^0.532
NPK	-0.380	2.1533	0.998	I=2.1533*t^0.380
K	-0.497	1.5297	0.996	I=1.5297*t^0.497
DK	-0.480	1.5307	0.993	I=1.5307*t^0.480
N	-0.555	1.2417	0.993	I=1.2417*t^0.555
D	-0.505	1.0102	0.996	I=1.0102*t^0.505
DN				

†Trt treatment, I Cumulative infiltration, B and n are Kostiakov fitting parameters, r^2 coefficient of determination

Appendix iv

Linear regression coefficients and relationships between measured and predicted cumulative infiltration (mm) after 90 min from Kostiakov' infiltration model(Replicate 1, year 2014)

Trt	Regression Equation	R^2
DNPK	Y=1.1153X-0.499	0.9693
N	Y=1.0615X-0.346	0.9834
CT	Y=0.9792X+0.115	0.9959
P	Y=0.9656X+0.227	0.9969
DP	Y=0.931X+0.202	0.9928
D	Y=0.957X+0.166	0.9947
K	Y=1.0062X-0.0457	0.9889
DK	Y=1.0468X-0.259	0.9786
NPK	Y=0.8706X+0.752	0.9703
Mean		0.9856

†Y is the measured cumulative infiltration while X is the predicted infiltration

Appendix v

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Kostiakov's infiltration model(Replicate2, year 2014)

Trt	n	B	R^2	Equation
CT	-0.544	0.8706	0.997	I=0.8706*t^0.544
DNPK	-0.536	1.0328	0.985	I=1.0328*t^0.536
DP	-0.520	0.9931	0.992	I=0.9931*t^0.520
P	-4916	1.8239	0.997	I=1.8239*t^4916
NPK	-0.416	1.9498	0.996	I=1.9498*t^0.416
K	-0.454	2.3126	0.984	I=2.3126*t^0.454
DK	-0.485	1.9467	0.996	I=1.9467*t^0.485
N	-0.581	1.2764	0.988	I=1.2764*t^0.581
D	-0.502	1.2331	0.987	I=1.2331*t^0.987
DN				

†Trt treatment, I Cumulative infiltration, B and n are Kostiakov fitting parameters, r^2 coefficient of determination

Appendix vi

Linear regression coefficients and relationships between measured and predicted cumulative infiltration (mm) after 90 min from Kostiakov' infiltration model(Replicate2, year 2014)

Trt	Regression Equation	R^2
DNPK	Y=1.0828X-0.365	0.9710
N	Y=1.1033X-0.623	0.9890
CT	Y=1.0087X-0.029	0.9989
P		
DP	Y=0.9674X+0.131	0.9973
D	Y=0.9434X+0.249	0.9935
K	Y=1.0822X-0.6318	0.9864
DK	Y=1.0125X-0.096	0.9971
NPK	Y=1.0249X-0.151	0.9928
Mean		0.9907

†Y is the measured cumulative infiltration while X is the predicted infiltration

Appendix vii

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Philip's infiltration model (Replicate 1, year 2013)

Trt	S	A	R^2	Equation
CT	1.194	0.166	0.557	I=1.194*t^0.5+0.166*t
DN	1.00	0.387	0.958	I=1.00*t^0.5+0.387*t
DNPK	1.138	0.137	0.726	I=1.138*t^0.5+0.137*t
DP	0.835	0.185	0.928	I=0.835*t^0.5+0.185*t
P	1.30	0.063	0.885	I=1.30*t^0.5+0.063*t
NPK	54.04	-5.257	0.654	I=54.04*t^0.5-5.257*t
K	1.69	0.144	0.737	I=1.69*t^0.5+0.144*t
DK	1.784	0.157	0.939	I=1.784*t^0.5+0.157*t
N	1.373	0.276	0.901	I=1.373*t^0.5+0.27*t
D	1.833	0.143	0.876	I=1.833*t^0.5+0.143*t

†I, cumulative infiltration; S and A; Philip's fitting parameters; Trt= treatment, r^2=coefficient of determination

Appendix viii

Linear regression coefficients and relationships between measured and predicted cumulativeinfiltration (mm) after 90 minPhilip's infiltration model(Replicate 1, year 2013)

Trt	Regression Equation	R^2
CT	Y = 1.043X - 0.288	0.989
DN	Y = 0.975X + 0.187	0.984
DNPK	Y = 0.977X + 0.153	0.995
DP	Y = 1.038X - 0.265	0.987
P	Y = 1.063X - 0.559	0.987
NPK	Y = 0.992X+0.6273	0.981
D	Y=1.0298X -0.3469	0.996
K	Y=1.0827X-1.4848	0.954
DK	Y=1.0084-0.1315	0.999
N	Y=1.0115X-0.0813	0.996

Y is the measured infiltration rate while X is the predicted infiltration

Appendix ix

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Philip's infiltration model (Replicate 1, year 2014)

Trt	S	A	R^2	Equations
CT	1.2398	-0.0197	0.2483	I=1.2398*t^0.5-0.0197*t
DN	1.4032	0.0471	0.7924	I=1.4032*t^0.5+0.0471*t
DNPK	1.2398	-0.0197	0.2573	I=1.2398*t^0.5-0.019*t
DP	0.08872	-0.0184	0.4313	I=0.08872*t^0.5-0.0184*t
P	1.5704	0.0278	0.7537	I=1.5704*t^0.5+0.0278*t
NPK	1.9825	-0.0783	0.5564	I=1.9825*t^0.5-0.0783*t
K	1.5318	0.0023	0.0097	I=1.5318*t^0.5+0.0023*t
DK	1.5399	-0.0180	0.3793	I=1.5399*t^0.5-0.0180*t
N	1.3077	0.0274	0.3164	I=1.3077*t^0.5+0.0274*t
D	1.0016	0.0052	0.110	I=1.0016*t^0.5+0.0052*t
Mean				

†I,=cumulative infiltration; S and A; Philip's fitting parameters; Trt= treatment, r^2=coefficient of determination

Appendix x

Linear regression coefficients and relationships between measured and predicted Cumulative infiltration (mm) from Philip's infiltration Model(Replicate 1, year 2014)

Trt	Regression Equation	R^2
DNPK	Y=1.0495X-0.2442	0.9810
N	Y=1.042X-0.2797	0.9800
CT	Y=1.0085X-0.065	0.9934
P	Y=0.9905X+0.076	0.9981
DP	Y=0.1745X+0.4387	0.8955
D	Y=0.9784X+0.1011	0.9952
K	Y=1.0395X-0.1288	0.9883
DK	Y=1.0176X-0.1124	0.9842
NPK	Y=0.8334X+1.0814	0.9155
Mean		

Y is the measured infiltration rate while X is the predicted infiltration

Appendix xi

Fitting parameters and fitting equations of selected DNPK experimental plots in Samaru from Philip’s infiltration model (Replicate2, year 2014)

Trt	S	A	R^2	Equations
CT	-38.0260	32.676	0.7608	I=-38.0260*t^0.5+32.676*t
DNPK	38.5140	-31.355	0.2483	I=38.5140*t^0.5-31.355*t
DP	56.0870	-56.483	0.4170	I=56.0870*t^0.5-56.483*t
P	-110.23	89.329	0.7189	I=-110.23*t^0.5+89.329*t
NPK	34.088	-22.539	0.6970	I=34.088*t^0.5-22.539*t
K	36.852	-24.139	0.0283	I=36.852*t^0.5-24.139*t
DK	108.80	-84.365	0.4448	I=108.80*t^0.5-84.365*t
N	-14.987	40.270	0.3310	I=-14.987*t^0.5+40.270*t
D	-44.759	49.678	0.0914	I=-44.759*t^0.5+49.678*t

†I, cumulative infiltration; S and A; Philip’s fitting parameters; Trt= treatment, r^2=coefficient of determination

Appendix xii

Linear regression coefficients and relationships between measured and predicted Cumulative infiltration (mm) from Philip's infiltration Model(Replicate2, year 2014)

Trt	Regression Equation	R^2
DNPK	Y=306.91X+683.77	0.8735
N	Y=260X-753.95	0.9223
CT	Y=353.11X-651.06	0.9591
P	Y=580.99X-2072.7	0.941
DP	Y=579.28X+1121.8	0.9698
D	Y=437.37X-1007.9	0.957
K	Y=162.56X+738.23	0.8854
DK	Y=546.62X+2100.9	0.9355
NPK	Y=210.04X+739.43	0.8914
Mean		

Y is the measured infiltration rate while X is the predicted infiltration

Appendix xiii

Mean soil Carbon contents (g kg^{-1}) over the Years.

Treatment and level	1959	1963	1964	1967	1980	1983	2002	2008
D 0	2.20	2.60	2.40	1.50	1.70	1.50	5.20	5.30
1	2.70	3.05	3.50	3.40	2.50	3.40	5.40	5.90
2	3.40	4.20	4.30	3.40	4.90	4.90	6.40	6.00
LSD	***	***	***	ns	ns	ns	ns	
N 0	2.70	3.30	3.10	2.40	2.40	3.30	5.50	6.20
1	2.80	3.40	3.60	2.40	2.30	3.10	5.20	5.70
2	2.80	3.60	3.40	2.60	2.90	2.90	5.80	5.40
LSD	ns	ns	ns	ns	ns	ns	ns	
P 0	2.60	3.20	3.00	2.30	2.20	3.00	5.30	5.40
1	2.70	3.50	3.50	2.50	2.50	3.30	5.80	5.80
2	3.00	3.70	3.60	2.70	3.00	3.50	5.90	6.00
LSD	***	ns	*	**	ns	ns	ns	
K 0	2.90	3.60	3.60	2.60	2.40	3.20	5.60	5.60
1	2.70	3.30	3.30	2.50	2.30	3.30	5.90	5.90
2	2.60	3.50	3.20	2.40	2.90	3.40	5.50	5.50

Sources: Jones (1971); Amapu (1984); DNPK Experiment log books, IAR Samaru.

Appendix xiv

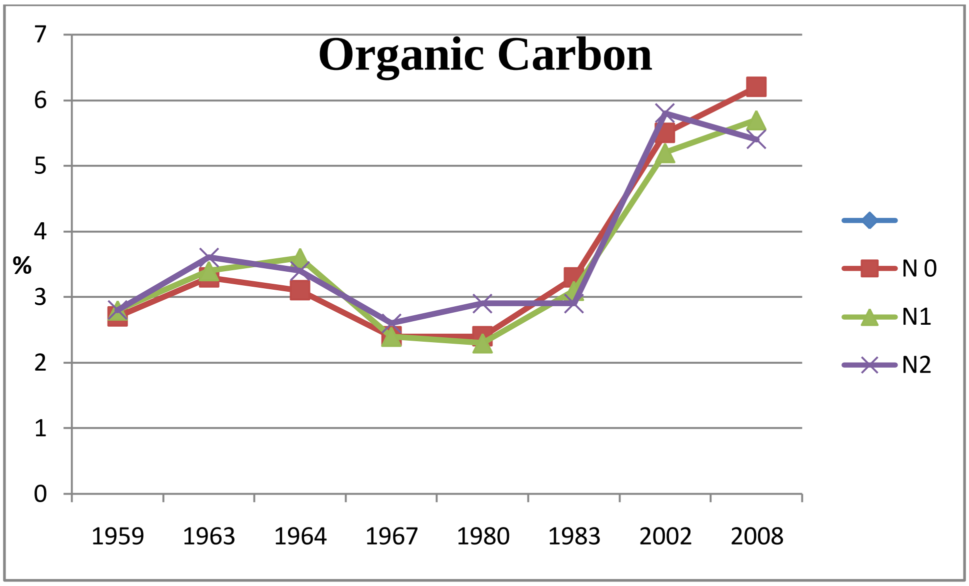
Soil pH values Recorded for the years

Treatment	1959	1967	1980	2002	2008
D 0	5.60	4.26	4.89	4.99	4.47
1	5.81	4.65	5.22	5.08	4.79
2	5.92	4.90	5.45	5.15	4.80
N 0	6.05	5.02	5.50	5.16	4.77
1	5.70	4.52	5.17	5.09	4.81
2	5.58	4.28	4.98	4.98	4.75
P 0	5.80	4.47	5.14	5.11	4.70
1	5.69	4.61	5.22	4.97	4.80
2	5.85	4.73	5.22	4.97	4.88
K 0	5.72	4.59	5.08	5.05	4.78
1	5.18	4.56	5.19	5.12	4.79
2	5.80	4.66	5.18	5.06	4.77

aqueous suspension (1:2.5 0.01M $CaCl_2$) 1NKCl (1:2.50.01M $CaCl_2$) (1:2.5 0.01M $CaCl_2$)

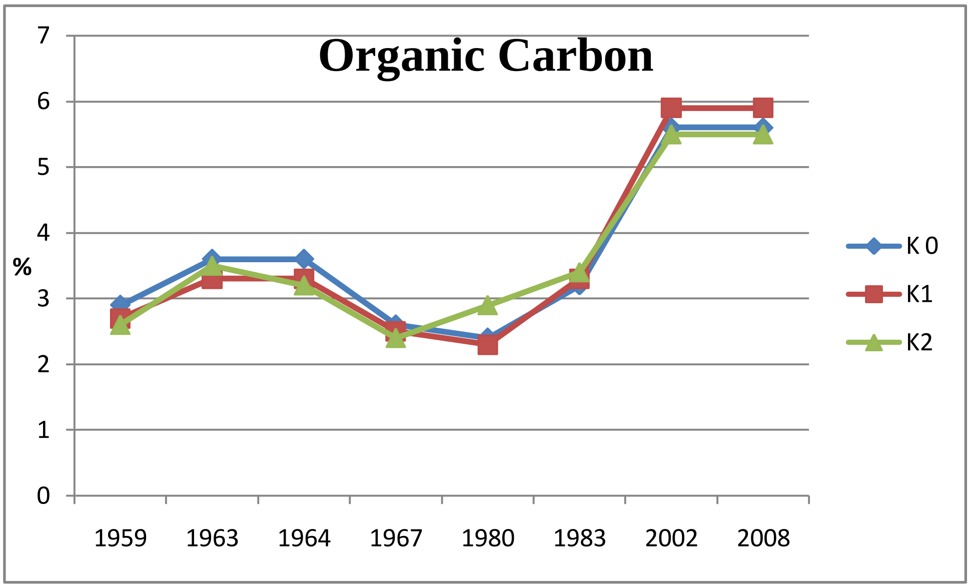
Sources: Jones (1971); Amapu (1984); DNPK Experiment log books, IAR Samaru.

Appendix xv



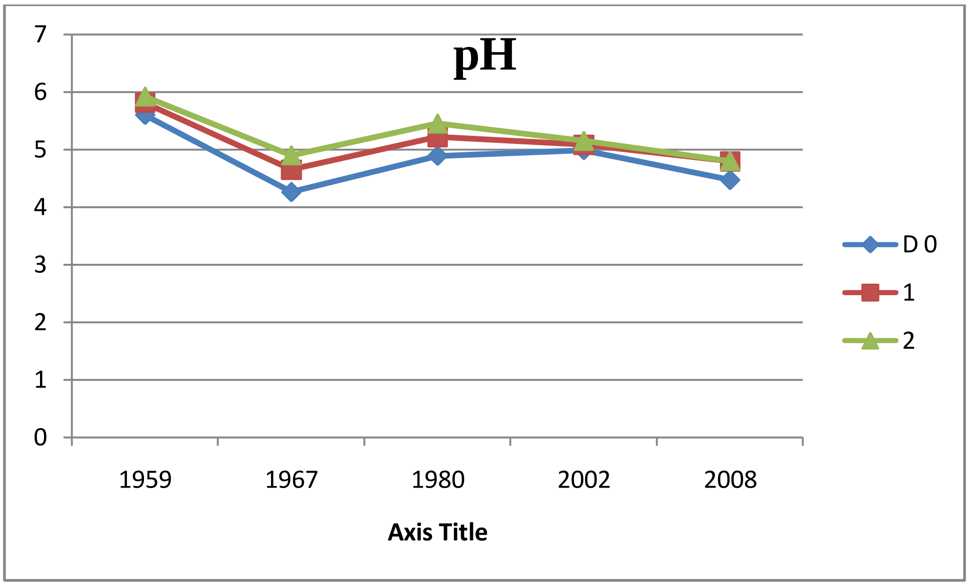
Trends of organic carbon levels under three levels (0,1,2) of Nitrogen application rate in D- plots between 1959-2008.

Appendix xvi



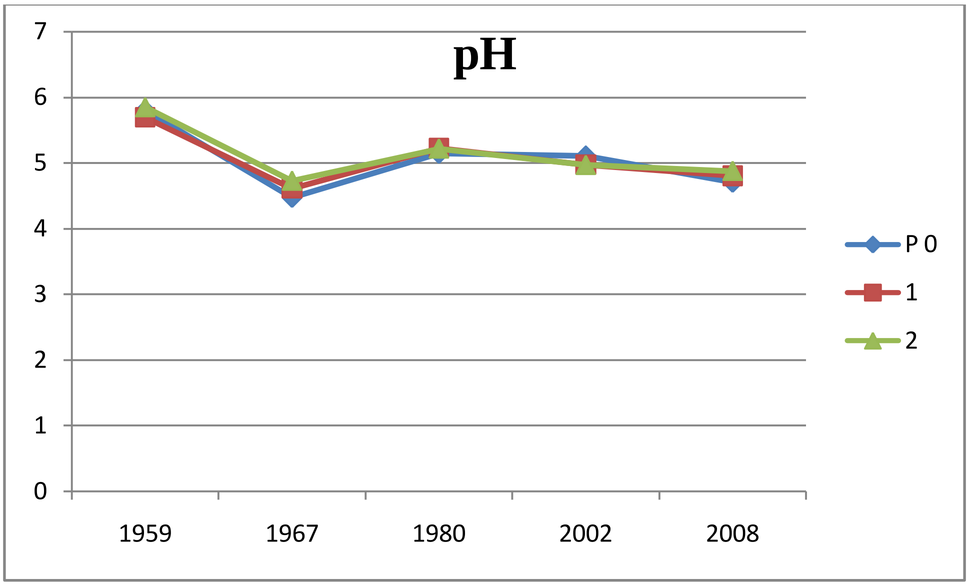
Trends of organic carbon levels under three levels (0,1,2) of K application rate in D - plots between 1959-2008.

Appendix xvii



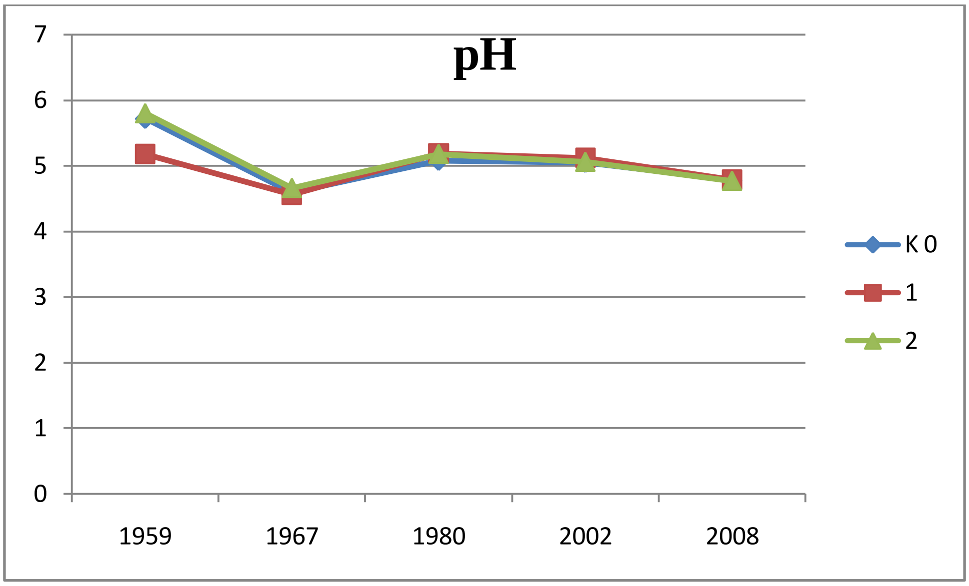
Trends of soil pH under three levels of dung (D) application rate inDungplotsbetween 1959-2008.

Appendix xviii



Trends of soil pH under three levels of phosphorus (P) application rate in P plotsbetween 1959-2008.

Appendix xix



Trends of soil pH under three levels of potassium (K) application rate between 1959-2008.