PERFORMANCE EVALUATIONOF A SOIL WATER CHARACTERISTICS MODEL FOR THE THREE MAJOR SOIL TYPES INNIGER STATE, NIGERIA

BY

MURANA, Musiliu Oyetayo
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ABSTRACT

Soil water characteristics are critical hydraulic properties governing soil water availability and movement in soils. Sustainable soil water conservation would not be possible without accurate knowledge of these hydraulic properties. Study of soil properties such as field capacity (FC), permanent wilting point (PWP) and hydraulic conductivity (Ks) play important roles in soil moisture retention. These parameters can be measured directly; their measurement is difficult and expensive. Thus, Saxton and RawlSoil Water Characteristics-Hydraulic Properties Calculator (SWC-HPC) model provided another alternative for estimating soil parameters from more readily available soil data. In this study, 180 soil samples were collected from three different sites locating at Minna (Ferruginous tropical soil), Badeggi (Hydromorphic soil) and Mokwa (Ferrosol) which represent the major soil types in Niger State. Laboratory values of soil water characteristics were obtained from thenineprofile pits dug at (2m x 1m x 1.5m).One bulk sample and three undisturbed soil core samples were taken at a depth of 20cm progressively down the profile to a depth of 100cm. Soil samples were analysed for percentage sand, clay, and silt, as well as organic matter, salinity and compaction which were the independent variables in the model while wilting point, field capacity, saturation point, hydraulic conductivity, bulk density and plant available moisture content were the dependent variables.The model out puts were statistically compared with observed parameters from laboratory tests using the root mean square error (RMSE), coefficient of variation (CV), modelling efficiency (EF), coefficient of residual mass (CRM) and chi-square. The model accurately predicted the observed bulk densities of the soil tested, satisfactorily simulated soil moisture content at permanent wilting point and moderately simulated plant available water. The model however poorly predicted the saturated hydraulic conductivity and soil moisture content at field capacity of the soil tested. The SWC-HPC may therefore be used only to simulate soil bulk densities; moisture status at permanent wilting point and plant available water values in the three study locations of Niger State.

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ABBREVIATIONS

Bdo-	Observed bulk density (g/cm^3)
Bdp-	Predicted bulk density (g/cm^3)
Om-	Organic matter (g/kg)
FCo-	Observed field capacity (%Vol)
FCp-	Predicted field capacity (%Vol)
PWPo-	Observed permanent wilting point (%Vol)
PWPp-	Predicted permanent wilting point(%Vol)
PAWo-	Observed plant available water (cm/cm)
PAWp-	Predicted plant available water (cm/cm)
Ko-	Observed saturated hydraulic conductivity mm/hr)
Kp-	Predicted saturated hydraulicconductivity (mm/hr)
X^2-	$[(O-E)^2/E]$
CL-	Clay loam
SL-	Silty clay
C-	Clay
S C L	Sandy clay loam
L-	Loam
SL-	Sandy loam
S-	Sand
Si-	Silt
C-	Clay
Pd-	Pit depth (cm)
O	Observed laboratory values

E	Estimated model values
FC	Field capacity
SP	Saturation point
P	Predicted

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Nigeria, a country located between latitudes 4^0 to 14^0N and longitude 2^0 to 14^0 E with a total area of 923,768 km^2 (Food And Agriculture Organization., 2006) contains six ecological zones, ranging from mangrove swamps belt and tropical forests along the coast to open woodland and savannah on the low plateau which extends through much of the central parts of the country to semi arid plains in the north and high lands to the east (United States Department of Agriculture, 2006). These ecological zones can be divided further into various sub-zones according to FAO findings. The major sub-zones in Nigeria are fresh water swamps, forest, lowland rainforest, mangrove forest, motene savannah, Guinea savannah, Jos Plateau, Derived savannah and Sahel savannah (FAO, 2006). The savannah zone of Nigeria cuts across the west, east and northern part of the country and covers an area of about 700,000 km^2(FAO, 2006).

The whole of the savannah covers about three-quarters of Nigeria's total land area. The soils are characterized by low activity clay with kaolinite and sesquioxides (FeOH) forming 80-90% of clay fraction (Moberge and Esu; 1991) and highly weathered with soil types ranging from loamy sand to sandy loamy in the top. The greater amount of kaolinite and sesquioxides leads to lower cation exchange capacity (CEC) of the soils (Enwezor, Udo, Ayotade, Adepelu, and Chude; 1990). Soils in the moist guinea savannah are characterized by coarse textured surface soil with low activity kaolinitic clay; high base status, low effective cation-exchange capacity, deficiencies of N,P,K,S and Zn which are high sub-capacity to soil compaction and erosion, because the soil does not have stable structures (Tian, Kang, Akjobundu and mimanyoung, 2005). The surface soil in the Guinea savannah is generally sandy, this accounts for high runoff at the top soil with low water holding capacity hence soil water can be lost to evaporation (Salako, Ghuman, and Lal, 1995).

Soils in the moist Guinea savannah have their origin from igneous and sedimentary rocks, these rocks account for the presence of recent alluvium, Nupe Sandstone and Basement Complex (Reconnaissance Soil Survey of Nigeria (1990) Soils like Alfisols, Ultisols, Oxisols, Entisols, Inceptisols and Vertisols are soil types usually found in the moist Guinea savannah zone, (Salako *et al.,* 1995, Tian *et al*., 2005; FAO 2006). These soils are usually seen at the surface as dark brown or dark yellowish brown, sandy loam and moderate fine texture. (Reconnaissance Soil Survey of Nigeria, 1990).

In Nigeria, bush fire, deforestation, increasing intensity of cultivation (Senjobi, Adeokun, Dada and Ogunkunle, 2007), tillage related practices (Lal, 1986; Khurshid, Iqbal, Arif and Nawaz, 2006), low input agriculture, accelerated erosion (Fahnestock, Lal and Hall, 1995) and construction work are summarized as causes of land degradation.

Based on the above, for agricultural activities in the zone to increase in terms of production of crops, irrigation practices and use of machinery, the soil water characteristics must be studied alongside other soil properties, hence the need for evaluation and model validation.

Soil-water characteristics refer to the relationship between soil and the moisture content present in it. This relationship is commonly represented with curve, referred to as soil-water characteristics curve (SWCC); and it shows the moisture contents of the soil at different suctions. The moisture content defines the amount of water contained within the soil pores. In soil science, the term volumetric water content, O, is commonly used for moisture content, while in geotechnical engineering practice, the term gravimetric water content, w, which is the ratio of the mass of water to the mass of solid, is used. Another terms commonly used to indicate the percentage of void that are filled with water is degree of saturation, S. the suction, also referred to as soil water potential, is related to the pressure that will be exerted to remove mixture from the soil. It may be express either as matric suction (also known as capillary pressure) or total suction (matric suction plus osmotic suction). Soil suction may range from zero kilo-Pascal (kPa) for moisture content as saturation (when all soil pores are filled with water) to about 1,000,000 kPa at zero moisture content (all soil pores are filled with air) (Fredlund, and Xing, 1994).

In Agriculture, the soil moisture content between two points on the SWCC is of great importance to crop growth and development. These points are air entry point and residual moisture content point. The air entry point on the SWCC (i.e. the bubbling pressure point) is the matric suction where air start to enter the large pores in the soil (Fredlund and Xing, 1994). The moisture content at this point is commonly referred to as the field capacity (FC). The residual moisture content point on the SWCC is the moisture content where a lager suction (=1,500 kPa) is required to remove water from the soil. The moisture content at this point is known as permanent wilting point (PWP). The moisture content of the soil between the FC and PWP is referred to as available water (AW). This is the water available for plant to take up for its metabolic activities. Information on the AW of soils are required in planning irrigation scheduling for crops, design of irrigation systems, drainage systems and other soil and water management strategies(Igbadun, Oyebode, and Mohammed, 2011).

Soil moisture is fundamental in several disciplines of the environmental sciences. Unsaturated soil behaviour such as shear strengths volume change, diffusivity and adsorption are related to the soil water characteristics (Fredhund and Rahardjo, 1993). Soil water characteristics contain important information regarding the amount of water contained in the pores at a given soil suction and the pore size distribution corresponding to the stress state in the soil (Fredlund, Wilson, and Fredlund, 2002).

Accurate estimates of soil moisture content are necessary for meteorological, hydrological, climatological, ecological and agricultural research and operations. The largest spatial and temporal variability of soil moisture caused by heterogeneity of soil texture, topography, vegetation and climate in the natural environment makes it difficult to measure and so dynamic models have been used as an alternative in many applications. However, the results obtained by dynamic modelling depend heavily on the quality of the input data used (Abbott and Refsgaard, 1996).

The accuracy of soil water estimation is important in order to improve weather, climate and hydrological models. For example, Rown-tree and Bolton (1983) showed that small error in the soil moisture initialization could lead to large error in weather forecasts. Also, Moberg and Jones (2004) demonstrated that unrealistically high day time maximum temperature were simulated as a result of excessive drying out of soil.

In agriculture, knowledge of soil moisture patterns allows more efficient planning of irrigation scheduling and better crop yield forecasting. Knowledge of spatial and temporal evolution of soil moisture would be beneficial for precision agriculture which is based on the concept of soil specific management within a field according to specific site conditions in order to maximize population and minimize environmental damage (Vrindts, Reynier, Darius, Baendemaeker, Gilot, Sadaoni, Frankinet, Hanquet and Destain, 2003.). For mechanized farming, it is important to know the strength of the soil which depends partly on its moisture content. Soil moisture conditions could serve as a warning for subsequent flooding or drought if the soil has become too saturated or too dry (Richter and Semenov, 2005).

1.2 Statement of Problem.

Over the years, soil-water characteristics are determined through laboratory procedures carried out on collected soil samples. These procedures are cumbersome, time and energy consuming and expensive. In addition, the capability for soil water characteristics determination is generally lacking in Nigeria as only few laboratories have the required equipment such as tension table, pressure membrane apparatus and permeameter. Soil texture, on the other hand, is routinely determined in most soil laboratories in Nigeria. Thus, estimating soil water characteristics from soil texture will save time, energy and cost.

1.3 Project Justification

Estimating soil water characteristics from readily available physical parameters has been a long-term goal of soil physicists and engineers. This is because of the difficulties associated with the determination of the soil water characteristics. For instance, their determination usually involves soil sampling and laboratory work which are time consuming and laborious. In addition, the capability for their determination is generally lacking in Nigeria as only few laboratories have the required equipment such as tension table, pressure membrane apparatus and permeameter. Soil texture, on the other hand, is routinely determined in most soil laboratories in Nigeria.

1.4 Significance of study

The purpose of this project is to test the accuracy level of the Hydraulic Properties Calculator (HPC) model for predicting soil water characteristics in Niger State.

If this research shows that the program is applicable to the soil at the sampling sites located at Minna (Ferruginous tropical soil), Badeggi (Hydromorphic soil) and Mokwa (Ferrosol), which represent the three major soil types in Niger State, it can then be used for predicting the soil water characteristics of these soils and other similar soils in Niger State and by extension in Nigeria from their texture instead of separately determining the soil characteristics. However, a thorough evaluation of the model must be carried out before its widespread adoption in Niger State and beyond. The Hydraulic Properties Calculator (HPC) model (Saxton and Willey, 2006) to be evaluated is a graphic computer program used for estimating the water retention and water transmission characteristics of soil profile layers. Using soil texture modified by additional soil variables of organic matter, salinity, gravel and compaction, the program has the ability to predict soil water characteristics, namely wilting point, field capacity, bulk density, saturation capacity, plant available water and saturated hydraulic conductivity as output variables.

1.5 Scope and Limitation of the Study

The choice of the area of study for the research will cover Minna (Ferruginous tropical soil), Badeggi (Hydromorphic soil) and Mokwa (Ferrosol) locations in Niger State, Nigeria.

The results presented in the thesis were statistical average of many samples and therefore only an approximation of any specific soil layer status. The study is limited to one year duration between the month of June 2011 to July 2012.

1.6 Aim and Objectives.

The aim of the study is to establish the predictability and reliability of the model, and hence, its use in determining water characteristics of soils in Niger State. The specific objectives of the study were to:

1. Use SWC-HPC model to stimulate the soil water characteristics of soils in the locations under study.
2. To compare the model output parameters with those obtained from the laboratory test values for the same soils.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil Water Properties and Effect on Agricultural Practices.

Soil properties can be chemical, biological, and physical. The physical properties of soil are the properties that determine the soil water characteristics which are broadly classified into three groups namely;

(a) Soil texture
(b) Soil water properties and
(c) The soil strength properties

These three properties are relevant to agriculture and are important for farmstead construction works. The soil texture and soil water properties are however, the ones greatly influenced by the farmers. Physical properties are of two classes which are static and dynamic.

Static properties are those which are fixed for a given soil and which do not involve the rate of movement of water and this includes;

1. Saturated moisture content
2. Field capacity
3. Wilting point
4. Capillary rise

5. Drainable porosity
6. Atterbert’s limit

The dynamic properties involve rate of water movement and some of these varies with time. These are infiltration, seepage and dynamic conductivity (Btiatta and Michael, 1995)

2.2 Soil Texture

The soil contains three major mineral constituents namely; sand, silt, and clay. Besides these three major constituents, a certain volume of soil contains air, water and salt either dissolved in water or in a free crystalline form or adsorbed to the surface of the soil particles and decomposed or undecomposed organic matter. Hence soil can be seen as porous substance comprising various proportions of above minerals. Soil texture described in terms such as sand, sandy loam, silt, silty loam and clay loam and clay relate to the relative proportions of sand, silt and clay in the soil. These influence the aggregate stability, permeability to air, water drainage characteristics, water holding capacity, and nutrient status of the soil. Coarse sandy soil show little aggregation, but have relatively large spaces between the particles, giving free movement of air and water, but a low water holding capacity (Btiatta and Michael, 1995).Fine sandy soil forms aggregates which slake easily on wetting to form a rather impervious surface cap, and thus they may be somewhat poorly drained and difficult to manage. Soils with much silt also form unstable aggregates and as the pores between the fine particles are narrow, they have a high water holding capacity, but tend to suffer from colloidal particles and narrow pores, and are rather impermeable to air and water and do not drain freely. Hence the rate of water movement through a soil varies inversely with the finesse of the soil texture (Marshal and Holmes, 1988).

On the field the texture of a soil can be determined by feel method and mechanical analysis data in conjunction with the textural triangle while in the laboratory, method such as hydrometer, pipette or other methods can be employed (Mohammed, 2006).

2.3 Saturated Hydraulic Conductivity

Darcy's law of hydraulic conductivity or permeability as one of the most important measurement in the physics of water flow through soil implies the rate at which water flows through soil.

It varies with factors such as soil porosity, pore size and water temperature. Flow rate approaches hydraulic conductivity after a long time when the soil has wetted to depth and the hydraulic gradient is simply gravitational, unity when expressed as hydraulic head per unit height change (Marshal and Holmes, 1988).

Shingo Iwata, Tashio Tabuchi, Benno, Warken, Tin corvalis and Oregon (1995), stated that Darcy's law of saturated hydraulic conductivity measures two purposes;

- The comparison of hydraulic conductivity rate of different soil horizons, particularly as a guide to water movement and a possible drainage problem within soil profiles, and
- As a basis for infield drainage design.

Darcy's saturated flow equation states that

$$v = \frac{Q}{A} \equiv K \frac{(\theta_{2-}\theta_1)}{L_{12}} \qquad 2.1$$

Where,

V = velocity (m/s),

Q = discharge (m^3/s) and A =area (m^2)

K =saturated hydraulic conductivity constant

θ_1 =initial moisture content (cm^3)

θ_2 = final moisture content (cm^3)

L = length (m)

Hydraulic conductivity may be saturated or unsaturated depending on the water content of the soil, if the soil is homogenous and isotropic hydraulic conductivity is uniform and has no dependence upon the direction of water flow. The hydraulic conductivity of a saturated soil of stable structure is constant because the whole of the pore space is always water filled; by contrast the hydraulic conductivity of an unsaturated soil is likely to change continuously in response to the change of matrix potential, the gradient of which is a part of the gradient of the hydraulic potential and those changes imply changing water content. It is also likely that water content changes with time. In soils with abrupt horizon, change corresponds to changes in the hydraulic conductivity value, can have serious effect on the movement of irrigation or drainage water within the profile (Landon, 1991).

2.4 Moisture Content (θ)

Soil moisture content is the ratio of mass of water in soil sample to the mass of oven dry sample. In the field, it varies usually between wilting point and saturation. A percentage of this water is utilized by the plants, a percentage is held within the soil pores, a percentage is evaporated and a percentage may go down as deep percolation, mainly it is the soil texture that determines the various components of disposition of the moisture of the soil. Moisture content of the soil is needed mostly to determine the capacity of the soil to retain available irrigation water and design of drainage because all growing plants require continuous water (Btiatta and Michael, 1995).

Gardner, Bell, Cooper, Dean, Gardner, and Hodnett, M. (1991), states that soil moisture content is the water that may be evaporated from soil by heating to 100^0C and 110^0C until there be no further weight loss. On the field, moisture content can be estimated by measurement and calibration in term of water content by electrical conductivity or thermal conductivity of soil itself or by buried porous absorbers through Mechanical resistance to probe penetration and gamma ray attenuation (Marshal and Holmes; 1988).

Other methods of estimating moisture content include:

1. Gravimetric method

2. Tensometer method

3. Neutron probe
4. Pressure membrane and pressure plate
5. Appearance and feel of soil

Gravimetric method can be mathematically stated as

i. Mass wetness $\boldsymbol{\omega}$ (g/g)

$\boldsymbol{\omega} = M_w/M_s$ 2.2

Where,

M_w = mass of water (g)

M_s = mass of dry soil particles (g)

b. Volume wetness θ(cm^3/cm^3)

$\theta = \frac{M_w}{M_s}$ 2.3

Where,

Vw = Volume of water (cm^3)

Vt = Volume of soil (cm^3)

a. Mass wetness (ω) and volume wetness (θ)

$\theta = \omega \times \rho_b$ 2.4

Where,

θ = Volume wetness (cm^3 /cm^3)

ρ_b = Bulk density (g/cm^3)

ω = Mass wetness (g/g)

2.4.1 Saturation capacity (Øsat)

Saturation capacity is the mass of water in a completely saturated soil sample which implies that all soil pores are filled with water. At the field saturation occurs when soil remains water logged for a long time or the soil lies below the water table. Saturation capacity on the field is more difficult to carry out; hence soil sample is required to be taken in can to be saturated in the laboratory after which it can be oven dried. In coarser soil where water is held loosely, the chances of error when transferring from field to laboratory are more than finer soil in which the water is held with a greater force (Btiatta and Michael, 1995).

2.4.2 Field Capacity Moisture Content (θ_{fc})

The remaining mass percent of water in an initially saturated soil after it has been subjected to a pressure of 1/3 atm. For a long enough time till no more water comes out of the soil (Marshal and Holmes, 1988).

Luthin J.N (1973) subjected hanging column apparatus or Hein’s apparatus in determining field capacity in the laboratory while Btiatta and Michael (1995) subjected its determination by taking undisturbed soil sample from the field after 24 hours, for a light soil or 48 hours, for heavy soil, of heavy rain or irrigation and determine it moisture content by oven drying method.

In this case, field capacity moisture content is that part of soil which is held within soil pores after the free water drains out of the soil under the action of gravity. Using this method, the evaporation loss in 24 or 48 hours as the case may be is to add to the mass of moisture determined by oven drying method. It's the water used consumptively by plants while gravitational water is draining from the soil. A soil will come to field capacity more quickly when an active crop is growing than when there are no roots removing water from soil. Field capacity is used in determination of water available in the soil for plant and for estimating the volume of water remained in the soil.

Egharevba (2002) gives its mathematical expression as

$$\text{Field Capacity} = \frac{Net\ weight\ (f.c) - Oven\ dry\ weight}{Oven\ dry\ weight} \times 100 \qquad 2.5$$

He further stated that field capacity is lower in light soil than heavy soil, ranging roughly between five and thirty percent.

2.4.3 Wilting Point Moisture Content (θw)

Btiatta and Michael (1995) expressed wilting point as a mass percentage of water in the moist soil after it has been subjected to a pressure of 15 atmosphere for long enough period till no further water drains out of the sample.

Glenn, Schwab, Delmar, Fangmeier, William Elliot, and Richard. K.Frevert. (1993).brings about permanent wilting point or the wilting coefficient (PWP) or simply wilting point (WP) which is the soil moisture content when plant wilt permanently, which occurs at lower end of available moisture range, also confirmed by Egarevba, (2002), hence plant wilt when it is no longer able to extract sufficient moisture from the soil to meet its water needs. Thus it then undergoes temporary wilt in hot windy day.

Wilting point is estimated as hydraulic tension of 1500kPa (15 bar) and dependent only on the texture and unaffected by salinity or gravel (Saxton, Rawls, Romberger, and Papendick, 1986) but in the laboratory the pressure plate apparatus is used in the determination of wilting point (Btiatta and Michael, 1995). Wilting point is important on the onset of monsoon when much of the incoming rainfall is held in the soil rather than floating out as runoff.

2.5 Available Water (θ_a)

It is the moisture percentage between field capacity and wilting point, it is important for irrigation decision (Btiatta and Michael, 1995). The more there is depletion in the available water the more will be the runoff. In standard theoretical approach, this must be considered in estimating the excess water for drainage design; the concept is highly useful to work out excess water, if any is needed to be drained due to rainfall on a particular day when water budgeting computation are performed (Btiatta and Michael, 1995) .Agvise laboratory (2006) make a mathematically expression for plant available water to be the difference between the field capacity and the wilting point that is, plant available water = field capacity – wilting point.

$$PAW = Fc - WP \qquad 2.6$$

2.5.1 Bulk Density (ρ_b)

It represents the compartment of the soil particles and pea arrangements; hence it is an indicator of both infiltration and internal trainability. It implies that when soil undergoes compaction its bulk density increases (Btiatta and Michael, 1995).

This density is of the bulk soil in its natural state including both the particles and pore space (Michael A. M., 1999). Bulk density can be dry bulk density or wet bulk density, the wet density, the wet density of bulk soil is the mass of soil including any water present in the soil per unit volume.

It is expressed as;

$$\rho_w = \frac{MT}{VT} \qquad 2.7$$

Where M_T = Total mass of soil (g)

V_T =Total volume of the soil (cm^3)

ρ_w = Wet bulk density (g/cm^3)

The dry bulk density is the mass of oven dry soil per unit volume of moisture and it is soil expressed as,

$$\rho_d = M_S/V_T \qquad 2.8$$

where V_T = total volume of soil

ρ_d = dry bulk density (g/cm^3)

M_S = total mass of soil (g)

The relationship between wet bulk density, dry bulk density and moisture content are:

$$\rho_d = \frac{110\ (\rho w)}{100 + W} \qquad 2.9$$

Where ρ_d = dry bulk density

ρ_w = wet bulk density

W = moisture content of soil

2.5.2 Soil Permeability

The permeability of soil is the velocity of flow caused by a unit gradient; it is the movement of air and water through the soil. It is influenced by the soil gradient and this point to the difference between permeability and infiltration, hence the flow through the soil in any direction mostly influenced by the physical properties of soil such as soil texture, structure, change in soil temperature and organic matter (Vaughn, Hanse, Orson, Israelsen, Glen and Stringham ,1988).

Landon (1991) expressed soil permeability as the ability of the soil to allow air and water to move through it. Site with high permeable soil absorb more rainfall, produces less runoff, are less susceptible to erosion and support plant growth more successfully.

2.6 Effect of Compaction on Soil Water

Compaction is the compression of soil due to the expulsion of air from the voids and may be brought about by rolling or tamping (Smith, Coughlan, Yule, Laryea, Srivastava, Thomas, and Cogle, 1992). Soil compaction increases soil density and this increased density, often has obvious effect on the profiles hydraulic performance, particularly with respect to water conductivity as pores within soil becomes compacted smaller or closed. In the other hand if soils have been tilled, it often increased soil porosity and lower densities established, although this is often a somewhat temporary condition as the soil re-compact under additional tillage and rainfall.

Coarse soil has an increasing soil density effect, but this also will impact on the water holding capacity and conductivity rates. Soil compaction most significantly affect the wetter portions of unsaturated hydraulic conductivity relationship since water moves through the larger, more affected pores. Though there is likely some effect on matrix potentials at the dryer range and more determined by the soil particles and small aggregates (Saxton and Willey, 2006)).

The empirical adjustment procedure using very general compaction quantification of loosely, normal, dense, hard and sever, was provided since there are minimal literature data available relating soil density to conductivity, “the normal” density would be that estimated by hydrologic saturation values from the original data set to define the potential air porosity, assuming a mineral density of 2.65 (g/cm^3) and adjusting for percent organic matter reduction (Rawls, Brakensiek and Saxton, 1982).

2.7 Effect of Organic Matter on Soil Water

Organic matter is known as relatively rapid decomposition of fresh organic material such as plant and animal litter added to well-aerated, moist, tropical soil with resulting releases of some nutrient and the formation of partially stable soil aggregates. In other sense, the term organic matter means plant residue or other organic material that are applied to the surface of soil such as mulch, this reduces erosion by reducing the impact of raindrops and by absorbing water and reducing runoff. It provides more hospitable environment for the plant establishment and eventually decomposes to improve structure and the fertility of the soil (Landon, 1991).

It consists of colloidal particles which are known as humus and contains nitrogen, phosphorus and sulphur that were present in the original plant residues. The humus absorbs exchangeable cat ions (Na^+, K^+, Ca^{2+}, $Mg2^+$) hence providing moisture at a longer time to plant. Thus binding the soil and particles together, because of its colloidal nature, humus absorbs water, thus increasing the water-holding capacity of the soil and its permeability. The structure of the soil is also improved by the humus (Webster and Wilson, 1980).

The ability of organic matter to hold water and transmits soil water has been studied over the years with different result, but in recent years some useful trends have been incorporated in soil water hydrological model (Saxton *et al*., 1986).The data of original relationships in estimating soil water characteristics had shown a generally low organic matter content averaging only 0.66%, this has resulted from collection of much depth of many soil profiles, and only a small portion of sample found near the horizon surface will be expected to have high organic matter. The analysis of the data shows little effect of organic matter on soil water holding characteristics, it is logical to make adjustment of the texture derived values particularly for those horizons near the soil surface. Note this adjustment is not expected to be applied beyond the organic matter content of typical mineral-dominated agricultural soil, thus certainly not for soil that would generally be classified as highly organic or “peat”, (Saxton *et al*., 1986).Soils with organic matter are less prone to erosion and more fertile than soil without organic matter.

2.8 Effects of Salinity on Soil Water

Soil salinity represents a condition in which the soluble salt content of the soil reaches a level harmful to crops through the reduced osmotic potential of the soil solution and the toxicity of specific ions like chloride, sulphate, carbonates and bicarbonates of calcium, magnesium, sodium and potassium.

This soluble salt may be from those present in the original soil profile or transported to the profile by irrigation water containing an unusual high concentrations. Salinity becomes a problem when enough salts are accumulated in the root zone to negatively affect plant growth, excess salt in the root zone hinder plant root from drawing water from surrounding soil, this lower the amount of water available to the plant, regardless of the amount of water in the root zone. The presence of salt in the water makes plants to exert more energy extracting water from the soil. Hence excess salinity in soil water can decrease plant available water and cause plant stress.

Salinity has effect on soil physical properties. In the soil water, salinity can affect soil physical properties by causing fine particle to bind together into aggregates beneficial in term of soil aeration, root penetration and root growth. Although increasing soil solution, salinity will have a positive effect on soil aggregation and stabilization, at high levels salinity can have negative and potentially lethal effects on plant. Thus salinity cannot be increased to maintain soil structure without considering potential impacts on plant health.

2.8.1 Effect of Gravel on Soil Water

The effect of gravel within the soil is to decrease the amount of soil matrix. It is believed that the soil matrix completely surrounds the gravel particles, and that the gravel particles do not contribute to soil water retention or hydraulic conductivity. The net effect of soil with gravel compared to that containing only the matrix soil will be to decrease the plant available water and hydraulic conductivity and increase the bulk density an amount proportionate to the volume occupied.

2.9 Soil Water Characteristic Model

The importance of AW and SWCC in the science and engineering of soil and water conservation has encouraged the continuous search for quick and easier means of quantifying their parameters. Studied have shown that soil-water characteristics (soil water retention and hydraulic conductivity) is very much related to soil physical properties, which include soil particle size distribution, bulk density, porosity, organic matter contents, among others (Salter and Williams, 1965; Gupta and Larson, 1979; Rawls et al, 1982; Williams, Ahuja and Naney,1992; Fredlund and Rahardjo, 1993; Rawls, Gimenez and Grossman. 1998).

Concerted efforts had been made by soil scientist to develop predictive relationship between soil water characteristics and physical properties of soils. Such relationship referred to as Pedrotransfer functions (PTF) (Bouman and van Lanen, 1987; Tietje and Tapkenhinrichs, 1993; Bell and van Keulen 1995) are predictive functions of soil properties that are readily available, easily routinely, or cheaply measured.

The PTFs and their solution are now been employed in designing computer programmes for rapid and on the desk prediction of SWCC. Among such computer simulation models include SOILPAR (Acuits and Donatelli, 2003), ROSETTA (Schapp, Leij, and Genuchten, 2001), and the Soil Water Characteristics-Hydraulic Properties Calculator (SWC-HPC) (Saxton and Willey, 2006).

Other methods that provided similar results, but with limited versatility are (Willians *et al*., 1992, Rawls *et al*., 1982; Stolte, Freijer, Bouten,. Dirksen, Halbertsma, van Dam, van den Berg, Veerman, and Wosten, 1994). Also pedrotransfer functions (Pachepsky and Rawls, 2005) are an example of modern equations that cannot be readily applied because of the input requirement that goes beyond that customarily available for hydraulic analysis.

An update of Saxton *et al*., 1986 model was carried out by Saxton and Rawls with new equation derived from a large USDA soil database using only commonly available variables of soil texture and OM, incorporate the improved conductivity equation of Rawls *et al* (1992) and combine these with effect of bulk density, gravel and salinity to provide a broadly applicable predictive system. Many early trials were sufficiently successful with limited data sets to suggest that there were significant underlying relationship between soil water characteristic and parameters such as soil texture (Gupta and Larson 1979, Rawls *et al*., 1982; Gijsman, Jagtap and Jones, 2002). More recent studies have evaluated additional variables and relationships (Vereecken, Maes, Feyen and Darius, 1989; Van Genuchten and Leiji 1992, Pachepsky and Rawls 2005).

All these methods involve multiples soil descriptors, some of which are often not available for practical applications. Most were derived by statistical correlation, but more recent analyses have explored neural network analysis (Schapp *et al*., 2001) or field descriptions and pedotransfer functions (Grossman, Harms, Seybold, and Herrick, 2001; Rawls and Pachepsky, 2002).

A comprehensive comparison of different approaches reported by Gijsman, Jagtap, and Jones, (2002) showed that the method of Saxton *et al*. (1986) was the best…." Thus an enhancement of the Saxton *et al*, (1986) method is an appropriate extension to improve the field application of soil water characteristic estimates with improved data basis and supplemented by recently derived relationships of conductivity and including appropriate local adjustments for OM, density, gravel and salinity.

2.9.1 The Soil Water Characteristics-Hydraulic Properties Calculator model

The Soil Water Characteristics-Hydraulic Properties Calculator (SWC – HPC) model is a graphic computer program developed by Saxton and Willy (2006). It is used for estimation of hydrologic water holding and transmission characteristics of an agricultural soil horizon. The SWC – HPC is a component of the Soil-Plant-Water-Atmosphere (SPAW) hydrologic model (Saxton and Willey, 2006). However, it is also an independent program with its input and output variables. The major input variable required to run the SWC –HPC is particle size distribution, specifically percent sand and clay. Other input variables which are optional but are required to refine the output of the model and increase its predictability, are organic matter, salinity, gravel and degree of compaction. The input values are entered by using the slider bars for each variable. The output variables of the SWC-HPC include percent volumetric moisture content at wilting point, field capacity and saturation. Other outputs of the model include available water (AW), saturated hydraulic conductivity, bulk density and textural class of the soil. The results are dynamically displayed in text boxes and on a moisture-tension and moisture-conductivity graph as the input are varied. This provides a rapid and visual display of the estimated water holding and transmission characteristics over a broad range of variables. According to Saxton and Rawls (2006), the soil water characteristic equations used in the development of SWC-HPC model are valid within a range of soil texture of approximately 0-60% clay content and 0-95% sand content, bulk density of between 1.0 and 1.8 g/cm^3 and organic matter content not greater than 8%. The development of SWC-HPC and the relevant equations are given in detail by Saxton and Willey (2006) and Saxton *et al*. (1986).

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CHAPTER THREE

3.0. RESEARCH METHODOLOGY

3.1. Site description

The study was carried out in 2011/2012 on three different sites in Niger state as shown in (Fig.3.1) below. The site locations are Minna (Ferruginous tropical soil), at longitude 6^0 N and latitude 7^0E, Badeggi (Hydromorphic soil) at longitude 8^0N and latitude 9^0E and Mokwa (Ferrosol) at longitude 7^0 N and latitude 8^0E.

Figure 3.1.Niger State Map showing Study Site Locations (Oche, 2012)

The area of study falls in the circle of southern zone of moist Guinea Savannah located in the middle of the country is the most extensive ecological zone in Nigeria, covering near halve of the country. Guinea Savannah zone has a Unimodal rainfall distribution with the average annual temperature and rainfall of 27.8 ^{0}C and 1051.7 mm respectively. The zone is characterized by low rainfall with the length of wet season that ranges from 150 to 200 days, and long dry period, which normally begin in April/ May and at peak in August (Halilu Adamu, 2004).

The study location has a gentle slope to upper slope of 1 to 2%, which helps in drainage of the field. The soils of the study area are classified as the three major soil types in Niger State according to Nigeria: Physical Setting- Niger State (WWW. Onlinenigeria.com/nigeriadv.asp).

3.2 Data Collection and Soil Sample Analyses

3.2.1 Field study: After recognisances survey studying location was selected. Three soil profile pits of dimension 2 m x 1m x 1.5 m were dug on each of the three selected soil units. Sixty soil samples were collected from each location within the latitudes $6^{0}$to 9^{0}N and longitudes 6^{0} to 10^{0}E totalling one hundred and eighty samples altogether from the three sites.

3.2.2 The Primary Data Sources

The collection of soil samples from the location sites were carried out by the use of hoe, knife, core rings, steel tape and mallet from the profile pit and taken to the laboratory where various speculated test were been carried out. At each site, three rectangular pits of dimension 2 m x 1m x 1.5 m at 200 m away from each other, were dug with the aid of shovel, digger, and hoes, alongside a steel rule and measuring tape, three soil core samples and one bulk sample each were taken progressively at depth of 20 cm downward to a depth of 100cm.The soil core samples were used for determining bulk density, field capacity, permanent wilting point, saturation capacity and saturated hydraulic capacity. And the bulk samples taken were also used for particle size analysis and organic matter content determination. The soil compaction samples were equally taken on the soil surface with pocket penetrometer. After the test had been conducted the statistical analysis of the data was carried out using excel package. In order to evaluate the models Chi-Square Distribution was used to compare laboratory values with the predicted values.

3.3 Parameters Determined in the Laboratory

These parameters are divided into two variables which are;

Independent variables

Dependent variables

Independent Variables

The independent soil parameters/variables include:

i. Sand (%wt),
ii. Clay (%wt),
iii. Silt (%wt), and
iv. Organic matter (%wt)

Dependent Variables

The dependent soil parameters/variables include:

(i) Wilting point (%vol)

(ii) Field capacity (%vol)

(iii) Saturation (%vol)

(iv) Available water (%vol)

(v) Saturated hydraulic conductivity (cm/hr), and

(vi) Bulk density (g/cm^3

3.3.1 Determination of Bulk Density

Undisturbed core samples of 5cm diameter and 5cm height were weighed and oven dried for 24 hours at 105^{0}C temperature (Sinai, Zaslavsky, and Golany, 1981). Dry bulk density is the ratio of the mass of the oven- dried soil to its volume. It is usually expressed as gram per centimetre cube (g/cm^3).The soil within each core was extruded and empty core weighed in order to obtain the weight of oven-dried soil. Bulk density was calculated, using the following;

$$\rho_b = Ms/ v_b \qquad 3.1$$

where, ρ_b is the soil bulk density, Ms is the mass of oven-dried soil (g) and V_b is the bulk volume of the soil (cm^3).

The bulk volume (V_b) was computed as:

$$V_b = \pi r^2 h. \tag{3.2}$$

Where, r and h are the radius and height of the core, respectively

The bulk density was computed using the expression:

$$\text{Bulk density, } \rho_b = \frac{X3 - X1}{Volume\ of\ Soil\ (cm3)} \tag{3.3}$$

where,

X1 = Weight of empty cylinder

X2 = Weight of wet soil + cylinder

X3 = Weight of oven-dry soil +cylinder

The volume of soil = volume of the cylinder determined from the known diameter and length of the cylinder.

3.3.2 Soil Moisture Determination

The soil moisture content was determined from the expression:

$$\text{Moisture content } (\emptyset v) = \frac{X2 - X3\ (\rho d)}{X3 - X1} \tag{3.4}$$

3.3.3 Soil Water Retention Characteristic Determination

Matric potential-water content [h (α)] of the undisturbed soil cores, otherwise referred to as soil water characteristics were determined with a combination of tension table and pressure plate extractors (Khite, 1998). The pressure plate which is porous in nature was soaked overnight in water to bring it to saturation. The saturated undisturbed soil samples that were saturated over night were placed on the ceramic plate and were inserted in the pressure chamber. The undisturbed soil samples in the core ring were then subjected to suctions equivalent to 0.1, 0.3, 1.0, 5, 10, and 15 bars in the pressure plate extractor. Soil moisture content at 0 bar (saturation capacity) 0.3 bar (field capacity), and 15.0 bars (Wilting point) were measured with a combination of tension table and pressure plate apparatus.

The available water content was determined from the following expression:

$$\text{Available water (AW)} = FC - PWP\ (cm^3) \qquad 3.5$$

3.3.4 Particle Size Analysis

Bouyoucos hydrometer method was used to quantitatively determine physical proportions of three sizes of primary soil particles as determined by their setting rate in an aqueous solution using hydrometer.

50g of oven dry soil which had been passed through a 2 mm sieve and transferred to a mix shaker bottle, 100 ml of distilled water and 50 ml of 5.0% sodium hexametaphosphate solution which serve as a dispersing agent were added. The mixtures were shaking for 30 minutes and then placed on the shaker for 2 hrs which the content was transferred quantitatively without losing any particle into the sedimentation cylinder up to 1 litre marked with distilled water. The soil samples were disturbed with the aid of plunge for proper suspension with a thermometer. The hydrometer reading was taken by immersing the hydrometer into the samples mixture, until the hydrometer is floating, with the aid of stop clock when it is stable. The first reading on the hydrometer is taken at 40 s after the cylinder is set down, the hydrometer was removed and record temperature of suspension with a thermometer. At this time the percentage silt and clay in suspension was read and recorded. The suspension was further allowed to settle for two hours, the reading without disturbance was taken to measure the percentage of clay in suspension.

The %Silt, %Clay, %Sand as well as %Silt of clay was determined from the following expressions:

$$\%\ \text{Silt + Clay} = \frac{(S1-B1)+\left((ST1-20\ 0C \times 0.36)\right)}{50} \times 100 \qquad 3.6$$

$$\%\ \text{Clay} = \frac{(S2-B2)+\left((ST2-20\ 0C \times 0.36)\right)}{50} \times 100 \qquad 3.7$$

%Sand = 100 - %Silt + Clay 3.8

%Silt = %Silt + Clay - %Clay 3.9

where,

S1 = Sample Hydrometer Reading at 40 secs

ST1= Sample Thermometer Reading at 40 secs

S2 = Sample Hydrometer Reading at 2 hrs

ST2 = Sample Thermometer Reading at2 hrs

B1 = Blank Hydrometer Reading at 40secs

BT1 = Blank Thermometer Reading at 40 secs

BT2 = Blank Hydrometer Reading at 2hrs

BT2 = Blank Thermometer Reading at 2hrs

Temperature Correction

For every 1^0C above 20^0C, add 0.36 to the hydrometer reading and for every 1^0C below 20^0C subtract 0.36 from the hydrometer reading.

3.4 Compaction Measurement

A direct-reading pocket penetrometer was used for the measurement of soil compaction at 5 cm depth. Average value of five reading was taken at each layer for each soil profile.

3.5 Saturated Hydraulic Conductivity Determination

Falling Head Method was used to determine the hydraulic conductivity by using the I C W laboratory permeameter (Eiji Kelkamp Agrisearch No. 09 02). The equipment operates on the principle that water is caused to flow through a saturated soil column by the pressure difference on both sides of a well saturated soil sample.

The caps from the ring were removed and the samples were saturated over night in a basin of water. The container containing the sample was then inserted into the permeameter after establishing a constant head. Depending on the ease with which water flows through the sample, the time at which a conveniently chosen volume is attained in the burette is taken using a stop watch. The height of water inside the ring holder and outside was measured and the saturated hydraulic conductivity (Ks) was calculated from the formula;

$$Ks = \frac{V.\ L}{AT(\Delta H)} \qquad 3.10$$

Where, V = volume of water collected (cm^3)

L = Length of soil column (cm)

A = Cross sectional area of the sample (equivalent to area of core ring) (cm^2)

T = Time in seconds

ΔH = Hydraulic head difference (cm)

3.6 Organic Matter Determination

Walkley Black approached was used in determining organic matter. This involved weighing of 1g of 0.5 mm sieved soil into 500 mm conical flask in duplicate. Potassium hepta-oxo dichromate iv ($K_2Cr_2O_2$) of 10 ml solution was accurately pipette into each flask and swirl to gently disperse the soil. 20 ml of concentrated tetra- oxo sulphate vi acid (H_2SO4) using automatic pipette was directly streamed into the suspension immediately. The flask was again gently swirled until soil and reagent mix, then it were again vigorously swirled for one minute. The beaker was again rotated and allowed to stand on a sheet of asbestos for about 30 minutes, 100 ml 0f distilled water was added after standing for 30 minutes, 3-5 drops of barium diphenylamine indicator was added. 0.7 ml ferrous sulphate solution was used to titrate till end point was reached, which is greenish cast end point and it then changes to dark green, at this point ,ferrous sulphate was added drop by drop until the colour changes sharply from blue to red and reflected right against a white background.

A blank titration in the same manner was made without soil samples to standardize the dichromate. The results were calculated as follows;

$$\%O.C = \frac{[(A-B)*0.3N]}{W} \qquad 3.11$$

Where A = blank titre value

B = sample titre value

0.3 = carbon conversion factor

W = original weight of soil

N = normality of $FeSO_4$

%O.C = %organic carbon

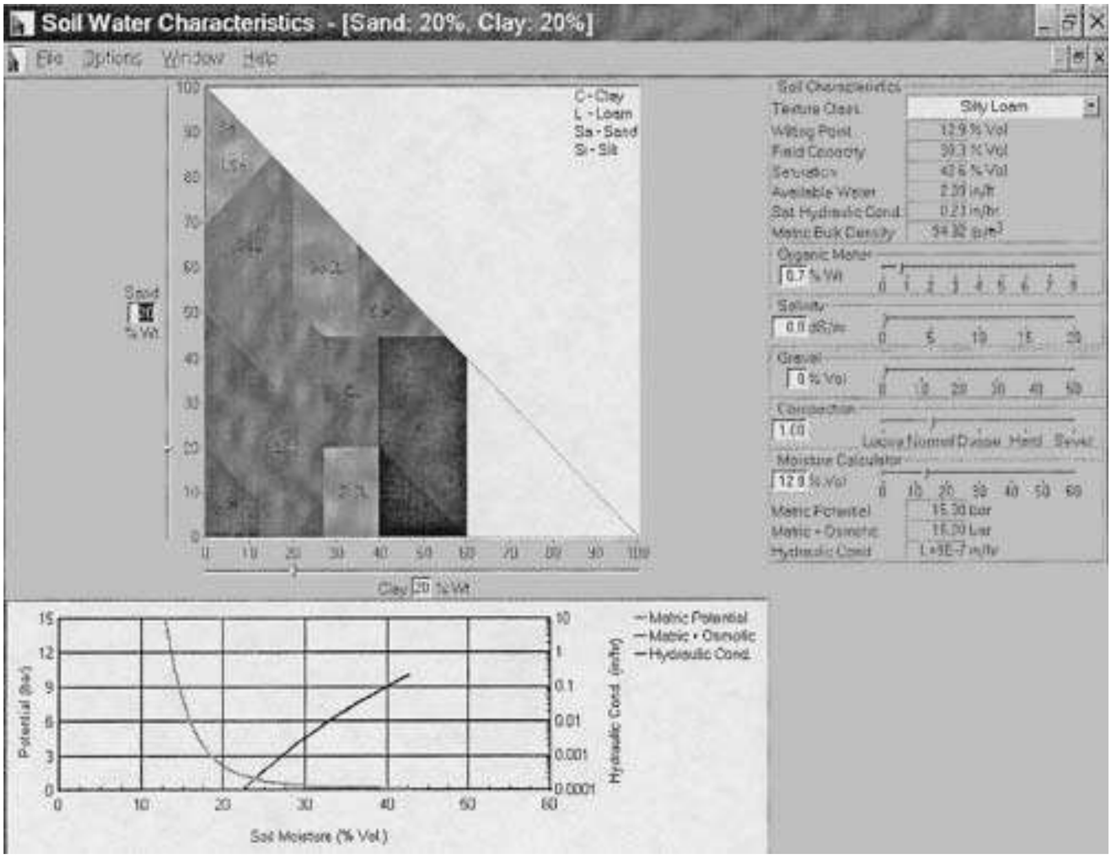
$\%O.M = \%\, O.C * 1.729$

Where %O.M= %organic matter

3.7. The Soil Water Characteristics-Hydraulic Properties Calculator model

The graphical computer program is the HPC used in estimating the hydrologic water holding and transmission characteristics of an agricultural soil profile layer using soil water physical characteristic such as soil texture, organic matter, salinity, gravel and density. And if soil texture and any one of the above are input, it gives the values of other likely values corresponding to the experimental data tested in both the field and laboratory.

Sand, Clay, Silt and organic matter and salinity are the independent variable input into the hydrologic model and the slider bars on the ruler are adjusted for OM, salinity, gravel, and density. The results are dynamically displayed in text boxes and on a moisture-tension and moisture-conductivity graph as the input are varied. This provides a rapid and visual display of the estimated water holding and transmission characteristics over a broad range of variables (fig.3.2).



Soil Water Characteristics - [Sand: 20%, Clay: 20%]

Soil Characteristics
Texture Class: Silty Loam
Wilting Point: 12.9 % Vol
Field Capacity: 30.3 % Vol
Saturation: 42.6 % Vol
Available Water: 2.10 in/ft
Sat Hydraulic Cond: 0.23 in/hr
Matric Bulk Density: 94.32 lb/ft³
Organic Matter: 0.7 % Wt
Salinity: 0.0 dS/m
Gravel: 0 % Vol
Compaction: 1.00
Moisture Calculator: 12.9 % Vol
Matric Potential: 15.30 bar
Matric + Osmotic: 15.30 bar
Hydraulic Cond: 1.49E-7 in/hr
Clay: 20 % Wt

Fig. 3.2 Graphical input screen for the soil water characteristic model (Saxton *et al*, 2006).

3.8 Simulation procedure

The predictability of the SWC-HPC model was tested by inputting the percent clay, percent sand, and organic matter content (for values = 0.1) of each soil sample into the model. The soil salinity and weight of gravel were set at zero while the degree of compaction was set at normal. (The soil samples were not analyzed for salinity and degree of compaction and no gravels were detected in the profile pits). Table 1 shows the particle size distribution data inputted into the model. The model outputs considered in this study include moisture contents at saturation, FC, PWP, saturated hydraulic conductivity, and bulk density. The table 1 below shows the particle size distribution of soil samples used as input data into the model.

Table 3.1: Particle size distribution of soil samples, used as input data into the model

Soil sample No	**Sand %**	**Clay %**	**Silt %**	**Textural Ciass**
1	82	12	6	LoamySand
2	68	15	17	SandyLoam
3	70	19	11	Sandy Loam
4	70	10	20	Sandy Loam
5	66	9	25	Sandy Loam
6	76	12	12	Sandy Loam
7	62	15	23	Sandy Loam
8	70	16	14	Sandy Loam
9	62	14	24	Sandy Loam
10	68	9	23	Sandy Loam
11	80	14	6	Sandy Loam
12	78	14	8	Sandy Loam
13	74	15	1	Sandy Loam
14	68	19	13	Sandy Loam
15	62	14	24	Sandy Loam
16	64	15	21	Loam
17	65	16.2	18.8	Loam
18	51.8	18.2	30	Loam
19	66.8	16.2	17	Sandy Loam
20	89	10	1	Loamy Sand
21	72.8	12.2	15	Sandy Loam
22	76.8	11.2	12	Sandy Loam
23	80.8	9.2	10	Loamy Sand
24	58.8	16.2	25	Loam
25	51.8	24.2	24	Loam
26	74.8	13.2	12	Sandy Loam
27	81.8	12.2	6	Sandy Loam
28	83.8	10.2	6	Sandy Loam
29	81.8	11.2	7	Sandy Loam
30	72.8	14.2	13	Sandy Loam
31	82	10	8	Loamy Sand
32	75	18	7	Sandy Loam
33	71	23	6	S C L
34	83	9	8	Loamy Sand
35	83	9	8	Loamy Sand
36	76	13	11	Sandy Loam
37	83	12	5	Loamy Sand
38	81	12	7	Sandy Loam
39	66	20	14	S C L /S L
40	83	9	8	Loamy Sand
41	81	10	9	Sandy Loam
42	67	22	11	S C L
43	65	24	11	S C L
44	71	20	9	S C L /S L
45	67	19	14	Loam

3.9 Model evaluation procedure

Chi- square analysis was used for site by site comparison between predicted values and the laboratory measured values. However the combined analysis for comparison between the model predicted values and the laboratory measured values was carried out using statistical indices like the root mean square error (RMSE), coefficient of variation (CV), modelling efficiency (EF) and coefficient of residual mass (CRM). These statistical indices were selected to adequately evaluate the model performance. The RMSE, CV, EF, and CRM were given as (Mahdian and Gallichard, 1995; Krause, Boyle and Base, 2005; Antonopoulos, 1997; Igbadun et al., 2011).

$$\text{RMSE} = \left[\frac{1}{n} = \sum_{i=1}^{n}(p_i - o_i)^2\right]^{0.5} \qquad 3.12$$

$$\text{CV} = (100) \times \frac{\left[\frac{1}{n} \sum_{i=1}^{n}(p_i - o_i)^2\right]^{0.5}}{o_m} \qquad 3.13$$

$$\text{EF} = 1 - \frac{\sum_{i=1}^{n}(o_i - p_i)^2}{\sum_{i=1}^{n}(o_i - o_m)^2} \qquad 3.14$$

$$\text{CRM} = \frac{\sum_{i=1}^{n} o_i - \sum_{i=1}^{n} p_i}{\sum_{i=1}^{n} o_i} \qquad 3.15$$

Where, Pi is model predicted values, Oi is observed values, Om is mean of observed values, and ′n′ is number of data. The RMSE is a measure of precision while the CV (expressed in %) is a measure of variability between predicted and observed data. The RMSE should tend towards zero as the measure of precision between the predicted and observed value increases. The CV for a model aims to describe the model fit in terms of the relative sizes of the squared residuals and outcome values. The higher the CV, the greater the dispersion in the variable. The lower the CV, the smaller the residuals relative to the predicted value, and is suggestive of a good model fit. The modelling efficiency (EF) also referred to as the coefficient of Nash-Sutcliffe (Nash and Sutcliffe, 1970), is a measure of fit between predicted and measured data. It is similar to the coefficient of determination (R^2).Nash-Sutcliffe efficiencies can range from -8 to 1. An efficiency of 1 ($E = 1$) correspond to the perfect match of predicted to the observed data. An efficiency of 0 ($E=0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-8 < E < 0$) occurs when the residual variance (described by the numerator in Eq.3), is larger than the data variance (described by the denominator), and it implies that the observed mean is a better predicator than the model.

Essentially, the closer the model efficiency is to 1, the more accurate the model is (Nash and Sutcliffe, 1970). The coefficient of residual mass (CRM) is an indicator of the tendency of the model to either over or under predict measured values. A positive value of CRM indicates a tendency of underestimation while a negative value indicates a tendency of overestimation (Antonopoulos, 1997).

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1 Particle Size and Textural Class

The results of particle size distribution showing the percentage distribution of Sand, Silt and clay in the three sites are presented in Tables 4.1, 4.2 and 4.3 below. Close assessment of the three sites shows no significant difference in the sand and clay percentage in the three sites but significant variation in the silt percentage most especially in (Badeggi). The silt percentage is very low compared to the rest. The laboratory measured and model predicted textural class conforms in (Minna) and (Mokwa) at 60% level while (Badeggi) was about 40% agreement as shown in Tables 4.1, 4.2 and 4.3. Badeggi has the highest percentage of sand and silt that is 89% and 25% respectively. While it was observed that Mokwa, have the highest percentage of clay and the least value of silt which are 29% and 5% respectively. This may not be unconnected with nature of the soil.

Table 4.1: Particle Size and Textural Class Analysis Result

Estimated and Predicted Water characteristics Value for textural classes at different organic matter values (Minna)

Sample NO	%Sand	% Silt	%Clay	Organic Matter (g/kg)	Textural Class $_{O}$	Textural Class $_{\%}$	Wilt Pt (%Vol)$_{O}$	Wilt Pt (%Vol)$_{\%}$	Field Cap (%Vol)$_{O}$	Field Cap (%Vol)$_{\%}$	Saturation (%Vol)$_{O}$	Saturation (%Vol)$_{\%}$	PAW (cm/cm)$_{O}$	PAW (cm/cm)$_{P}$	Bulk Density (g/cm^{3})$_{O}$	Bulk Density (g/cm^{3})$_{P}$
1	82	6	12	5.2	Loamy Sand	LoamySand	16.28	11.7	20.72	19.2	32.56	49.6	0.04	0.08	1.48	1.34
2	68	17	15	6.9	Sandy Loam	SandyLoam	13.32	14.7	19.24	26	32.56	54.2	0.06	0.11	1.48	1.21
3	70	11	19	6.04	Sandy Loam	Sandy Loam	23.12	16	27.2	26.2	31.28	50	0.04	0.1	1.36	1.32
4	70	20	10	5.17	Sandy Loam	Sandy Loam	33.44	10.6	38	20.8	41.04	51.7	0.05	0.1	1.52	1.28
5	66	25	9	2.59	Loam	Sandy Loam	21.14	7.6	30.2	17.3	39.26	45.3	0.09	0.1	1.51	1.45
6	76	12	12	14.23	Sandy Loam	Sandy Loam	23.52	14.3	27.93	24.9	33.81	57.1	0.04	0.11	1.47	1.14
7	62	23	15	11.21	Loam	Sandy Loam	16.5	15.4	24.75	28.8	29.7	58.2	0.08	0.13	1.65	1.11
8	70	14	16	5.17	Sandy Loam	Sandy Loam	22.1	13.7	25.5	23.6	27.2	49.5	0.03	0.1	1.7	1.34
9	62	24	14	4.31	Loam	Sandy Loam	19.08	11.9	23.85	23.1	31.8	49.1	0.05	0.11	1.59	1.35
10	68	23	9	3.02	Sandy Loam	Sandy Loam	24.96	8	29.64	17.5	42.12	46.5	0.05	0.1	1.56	1.42
11	80	6	14	4.74	Sandy Loam	Sandy Loam	10.85	12.3	13.95	20	29.45	47.9	0.03	0.08	1.55	1.38
12	78	8	14	6.47	Sandy Loam	Sandy Loam	15.4	14	20.02	23.1	30.8	52.1	0.05	0.09	1.54	1.27
13	74	1	15	3.45	Sandy Loam	Sandy Loam	18.84	11.8	21.98	20	31.4	45.7	0.03	0.08	1.57	1.44
14	68	13	19	5.17	Sandy Loam	Sandy Loam	21.84	15.3	24.96	25.5	34.32	48.9	0.03	0.1	1.56	1.36
15	62	24	14	2.59	Loam	Sandy Loam	18.72	10.4	25.92	20.7	34.56	44.8	0.07	0.1	1.44	1.46

O: Laboratory Observed values P: Model Predicted values.

Table 4.2 : Particle Size and Textural Class Analysis Result

Estimated and Predicted Water characteristics Value for textural classes at different organic matter values (Badeggi)

Sample NO	%Sand	% Silt	%Clay	Organic Matter(g/kg)	Textural Class $_{O}$	Textural Class $_{\%}$	Wilt Pt $(\%Vol)_{O}$	Wilt Pt $(\%Vol)_{\%}$	Field Cap $(\%Vol)_{O}$	Field Cap $(\%Vol)_{P}$	Saturation $(\%Vol)_{O}$	Saturation $(\%Vol)_{\%}$	PAW $(cm/cm)_{O}$	PAW $(cm/cm)_{\%}$	Bulk Density $(g/cm^3)_{O}$	Bulk Density $(g/cm^3)_{p}$	K-Value $(mm/hr)_{O}$	K-Value $(mm/hr)_{\%}$
1	64	21	15	1.5	Loam	Sandy Loam	15.51	10.1	22.56	19.4	52.17	41.9	0.07	0.09	1.41	1.54	18	28.42
2	65	18.8	16.2	1.4	Loam	Sandy Loam	14.42	10.6	25.56	19.5	52.54	41.5	0.11	0.09	1.42	1.55	15	26.01
3	51.8	30	18.2	0.7	Loam	Sandy Loam	12.9	11.3	25.8	22.4	52.89	40.3	0.13	0.11	1.29	1.58	50.4	15.02
4	66.8	17	16.2	0.6	Sandy Loam	Sandy Loam	10.92	9.9	17.16	18.1	48.36	39.7	0.06	0.08	1.56	1.6	4.8	24.59
5	89	1	10	0.3	Loamy Sand	Loamy Sand	7.15	5	11.44	9.2	45.76	40.4	0.04	0.04	1.43	1.58	1.8	70.55
6	72.8	15	12.2	1.2	Sandy Loam	Sandy Loam	6.9	8	11.04	15.4	45.56	41.3	0.04	0.07	1.38	1.56	43.8	42.3
7	76.8	12	11.2	0.7	Sandy Loam	Sandy Loam	8.1	6.9	10.8	13.3	48.6	40.4	0.03	0.06	1.35	1.58	15	47.87
8	80.8	10	9.2	1	Loamy Sand	Loamy Sand	10.36	5.9	13.32	11.8	35.52	41.5	0.03	0.06	1.48	1.55	13.8	63.12
9	58.8	25	16.2	0.7	Loam	Sandy Loam	19.08	10.1	23.85	19.9	33.39	40	0.05	0.1	1.59	Jan-00	14.4	20.92
10	51.8	24	24.2	1.5	Loam	SandyClay .L	28.08	15.3	31.2	26.5	39	42.3	0.03	0.11	1.56	1.53	24	10
11	74.8	12	13.2	1.4	Sandy Loam	Sandy Loam	14.7	8.7	17.64	15.8	36.75	41.5	0.03	0.07	1.47	1.55	52.2	40.66
12	81.8	6	12.2	1.4	Sandy Loam	Loamy Sand	8.64	8.1	11.52	13.8	40.32	41.7	0.03	0.06	1.44	1.55	38.4	50.05
13	83.8	6	10.2	0.4	Sandy Loam	Loamy Sand	7.45	5.8	8.94	10.8	38.74	40	0.01	0.05	1.49	1.59	26.4	58.75
14	81.8	7	11.2	0.3	Sandy Loam	Loamy Sand	7.75	6.4	10.85	11.7	38.75	39.6	0.03	0.05	1.55	1.6	54	51.4
15	72.8	13	14.2	0.3	Sandy Loam	Sandy Loam	10.14	8.4	27.04	15.3	47.32	39.1	0.17	0.07	1.69	1.61	57.6	32.48

O: Laboratory Observed values P: Model Predicted values

Table 4.3: Particle Size and Textural Class Analysis Result

Estimated and Predicted Water characteristics Value for textural classes at different organic matter values (Mokwa)

Sample NO	%Sand	% Silt	% Ciay	Organic Matter (g/kg)	Textural Class $_O$	Textural Class $_\%$	Wilt Pt (%Vol)$_O$	Wilt Pt (%Vol)$_\%$	Field Cap (%Vol)$_O$	Field Cap (%Vol)$_\%$	Saturation (%Vol)$_O$	Saturation (%Vol)$_\%$	PAW (cm/cm)$_O$	PAW (cm/cm)$_\%$	Bulk Density (g/cm^3)$_O$	Bulk Density (g/cm^3)$_\%$	K-Value (mm/hr)$_O$	K-Value (mm/hr)$_\%$
1	82	8	10	3.86	Loamy Sand	Loamy Sand	12.48	9.4	14.04	16.4	43.68	47.7	0.02	0.07	1.5	1.39	58.5	70.33
2	75	7	18	2.13	Sandy Loam	Sandy Loam	8.4	12.3	10.8	19.6	36	42.2	0.02	0.07	1.2	1.53	22.92	26.6
3	71	6	23	2.3	S C L	S C L	7.68	15.3	10.24	23.5	37.12	42.1	0.03	0.08	1.28	1.54	38.7	14.93
4	83	8	9	5.08	Loamy Sand	Loamy Sand	13.41	10.1	16.39	17.4	46.19	50.7	0.03	0.07	1.49	1.31	22.26	83.38
5	83	8	9	2.62	Loamy Sand	Loamy Sand	19.76	7.5	22.8	13.6	44.08	45	0.03	0.06	1.52	1.46	67.68	71.62
6	76	11	13	3.12	Sandy Loam	Sandy Loam	9.96	10.3	11.62	17.9	38.18	45.2	0.02	0.08	1.66	1.45	7.92	47.32
7	83	5	12	2.62	Loamy Sand	Loamy Sand	11.97	9.2	13.68	15.3	39.33	44.1	0.02	0.06	1.71	1.48	77.52	54.54
8	81	7	12	1.48	Sandy Loam	Sandy Loam	15.3	8.2	18.7	14.2	37.4	41.9	0.03	0.06	1.7	1.54	62.34	49.62
9	66	14	20	2.3	S C L /S L	Sandy Loam	19.68	13.6	21.32	22.7	39.36	42.9	0.02	0.09	1.64	1.51	37.44	19.87
10	83	8	9	3.12	Loamy Sand	Loamy Sand	23.38	8	26.72	14.3	41.75	46.1	0.03	0.06	1.67	1.43	9.42	73.74
11	81	9	10	2.95	Sandy Loam	Loamy Sand	8.46	8.5	9.87	15.1	43.71	45.6	0.01	0.07	1.41	1.44	49.02	65.36
12	67	11	22	2.62	S C L	S C L	10.26	15	11.97	24	41.04	43.2	0.02	0.09	1.71	1.51	12	16.7
13	65	11	24	2.95	S C L	S C L	19.47	16.4	21.24	25.9	37.17	43.9	0.02	0.1	1.77	1.49	73.2	13.7
14	71	9	20	3.44	S C L /S L	Sandy Loam	22.1	14.5	23.8	23.1	39.1	44.6	0.02	0.09	1.7	1.47	45.12	22.96
15	67	14	9	2.79	Loam	Sandy Loam	29.2	7.8	33.58	17.4	39.42	45.9	0.04	0.1	1.46	1.43	21.18	58.28

O: Observed values P: Predicted values

4.2 Predicted versus observed soil moisture contents at field capacity, wilting point and plant available water.

Figure 4.1 shows the predicted and observed soil moisture content at field capacity. The predicted data ranged from 9.2% to 28.8% with a mean value of 19.21%, while the observed data ranged from 8.94% to 38.0% with a mean value of 20.21%. The mean error of bias between the predicted and observed values was 44.52%. The figures 4.2 and 4.3 show the predicted and observed volumetric moisture content at permanent wilting point (PWP) and plant available water (PAW), respectively. The predicted moisture content at PWP ranged from 5.0% to 16.0%, with a mean value of 10.76%, while the observed data ranged from 6.9% to 33.44% and a mean value of 15.84. The mean error of bias between the predicted and observed moisture content at PWP was 65.02%. The predicted moisture content at PAW ranged from 0.05% to 0.11% with a mean value of 0.08%, while the observed data ranged from 0.01% to 0.11%, with a mean value of 0.04%. The mean error of bias between the predicted and observed moisture content at PAW was 0.003%.

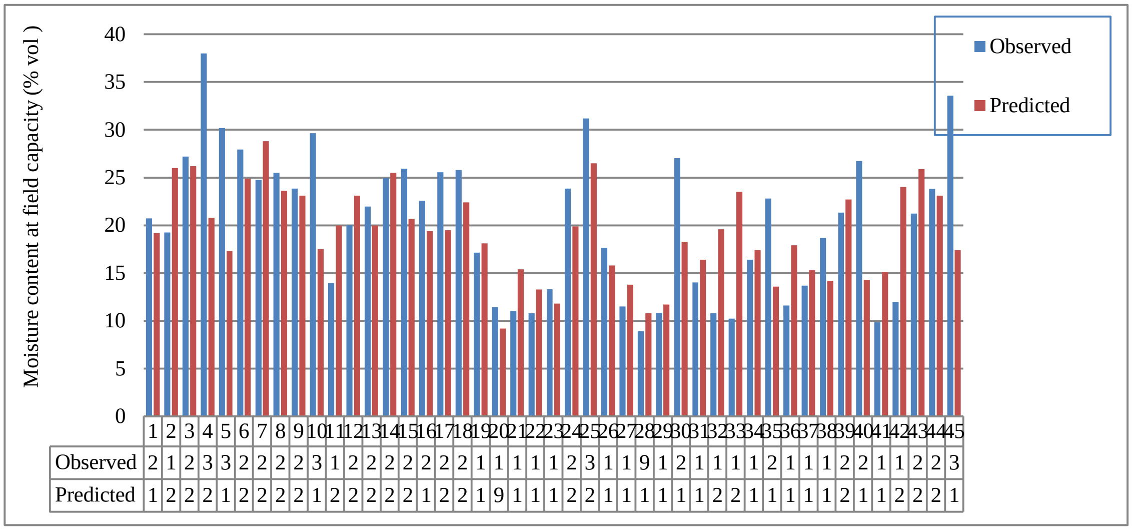


Figure 4. 1: Comparison of predicted and observed volumetric soil moisture content at field capacity

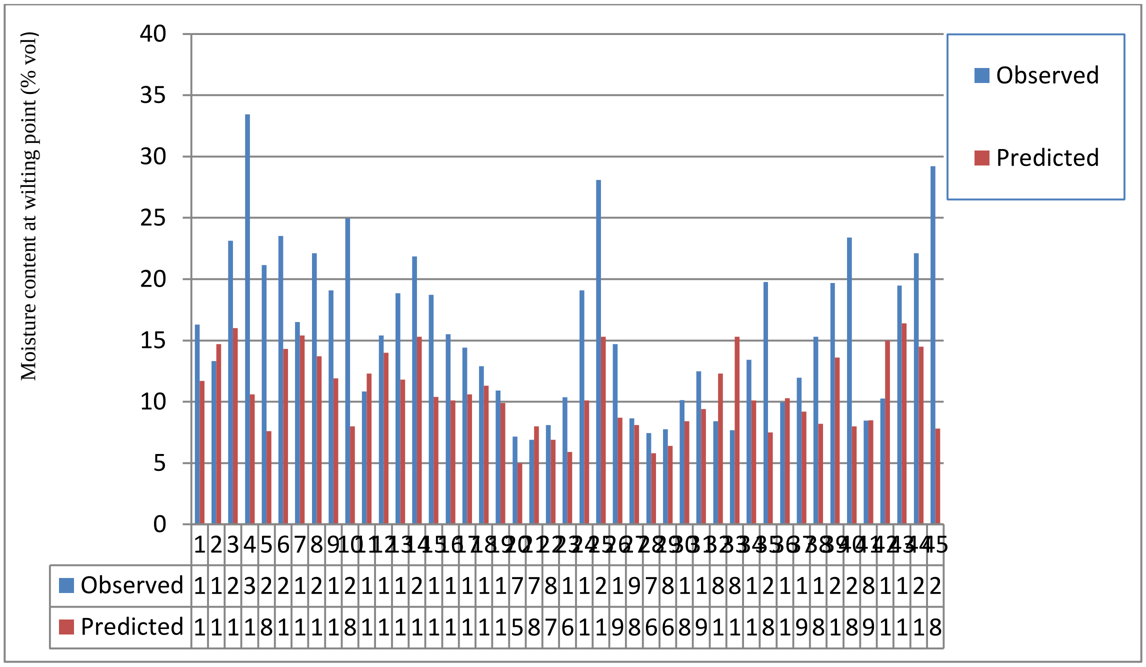


Figure 4.2: Comparison of predicted and observed volumetric soil moisture content at wilting point

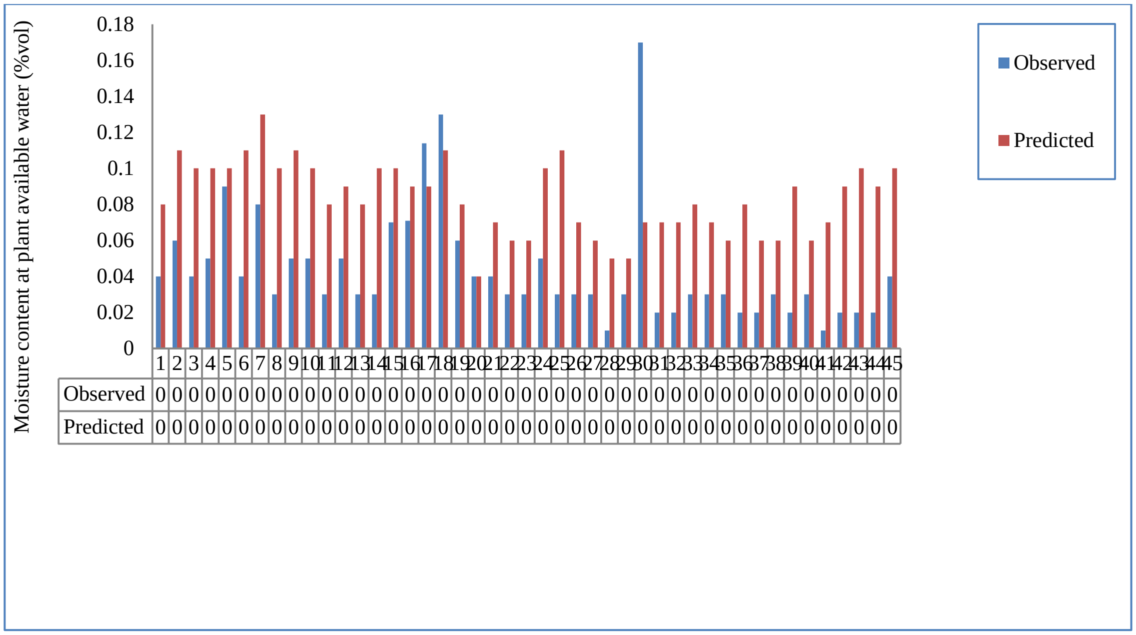


Figure 4.3: Comparison of predicted and observed soil moisture content at plant available water

Table 4.4: shows the statistical indices of the comparison between the model predicted and laboratory observed values of soil moisture status at field capacity, permanent wilting point and plant available water. The root mean square errors (RMSE) of the FC and PAW data were lower than that of PAW, being 0.05%, 6.67% and 8.06%, respectively. RMSE should tend towards zero as the measure of precision between the predicted and measured data increases. The results imply that the degree of precision of the model predictions of moisture contents at permanent wilting point were less than that of field capacity and plant available water. The coefficient of variability (CV) of the predicted and observed moisture contents at field capacity, wilting point and plant available water were higher based on 7Wilding (1985) classification. Wilding (1985) classified coefficient of variability of soil parameters of: < 15% as low, 15 < CV < 30% as moderate, and > 30 % as high. The results indicate that the predicted moisture contents at FC, PWP and PAW were highly dispersed

from observed data. The modelling efficiency which is a measure of the degree of fit or closeness of the predicted data to the observed values showed that FC data had higher degree of fit than PWP and PAW, being 0.17, -0.52 and -1.61, respectively. However, the coefficient of residual mass (CRM) revealed that the model under predicted moisture contents at field capacity and permanent wilting point by 0.05 (i.e., 5%) and 0.32 (i.e. 32%) respectively, while it over- predicted moisture content at plant available water by 0.91 (i.e. 91%). The results imply that the SWC- HPC model satisfactorily predicted soil moisture status of the fields studied at field capacity and could not predict soil moisture status of the fields studied at PWP and PAW.

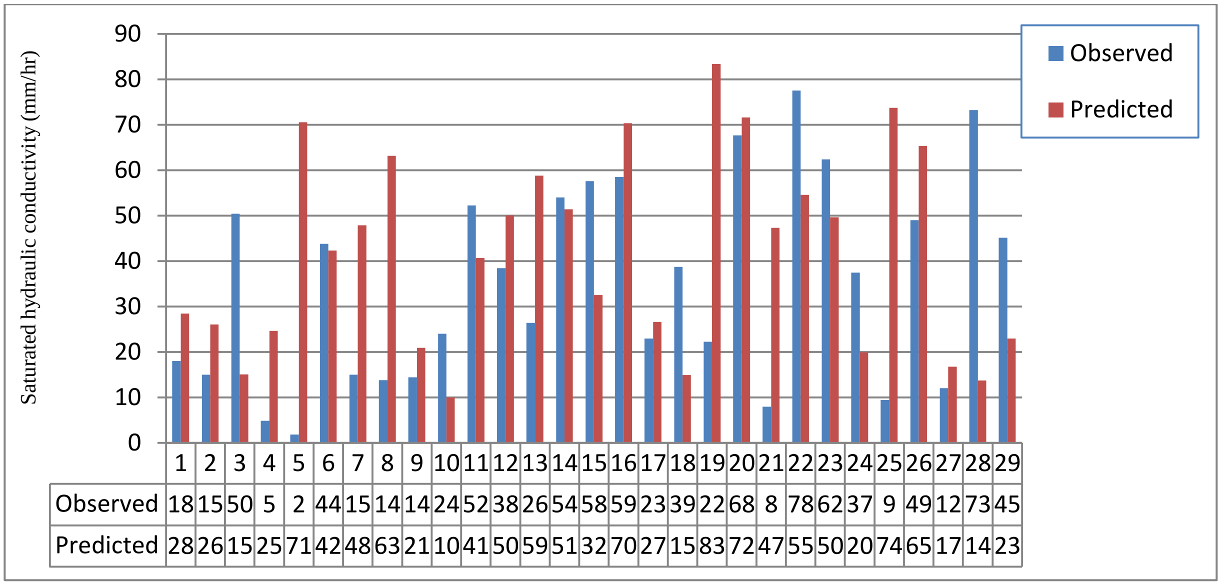
Table 4.4: Statistical indices of the comparison of predicted and observed soil moisture status at field capacity, wilting point and plant available water

Statistical indices	Field capacity	Wilting point	Plant available water
RMSE	6.67	8.06	0.05
CV (%)	33.02	50.91	115.38
EF	0.17	-0.52	-1.61
CRM	0.05	0.32	-0.91

4.3 Predicted versus observed saturated hydraulic conductivity and bulk density

Figures 4.4 and 4.5 show the predicted and observed values of saturated hydraulic conductivity and soil bulk density, respectively. The predicted saturated hydraulic conductivity ranged from 10 to 83.38 mm/hr with a mean value of 41.82 mm/hr, while the observed data ranged from 1.8 to 77.52 mm/hr with a mean value of 34.95 mm/hr. The mean error of bias between the predicted and observed data was 926.16 mm/hr. The model's predicted bulk density values ranged from 1.11 to 1.59 g/cm^3 with a mean value of 1.46 g/cm^3, while the observed data ranged from 1.2 to 1.77 g/cm^3 with a mean value of 1.52 g/cm$^{3.}$ The mean error of bias between the predicted and observed moisture bulk density was 0.04 g/cm^3.

Table 4.5 shows further statistical indices of the comparison between predicted and observed values of saturated hydraulic conductivity and bulk density. The level of precision between predicted and observed values of saturated hydraulic conductivity was very low; the CV was 99.13% and the modelling efficiency was less than zero (- 1.01). Modelling efficiency of the observed data is a better predictor than the model. This implies that the SWC – HPC model poorly predicted the saturated hydraulic conductivity of the field studied. However, the model was found to accurately predict the soil bulk densities.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Observed	18	15	50	5	2	44	15	14	14	24	52	38	26	54	58	59	23	39	22	68	8	78	62	37	9	49	12	73	45
Predicted	28	26	15	25	71	42	48	63	21	10	41	50	59	51	32	70	27	15	83	72	47	55	50	20	74	65	17	14	23

Figure4. 4: Comparison of predicted and laboratory observed hydraulic conductivity

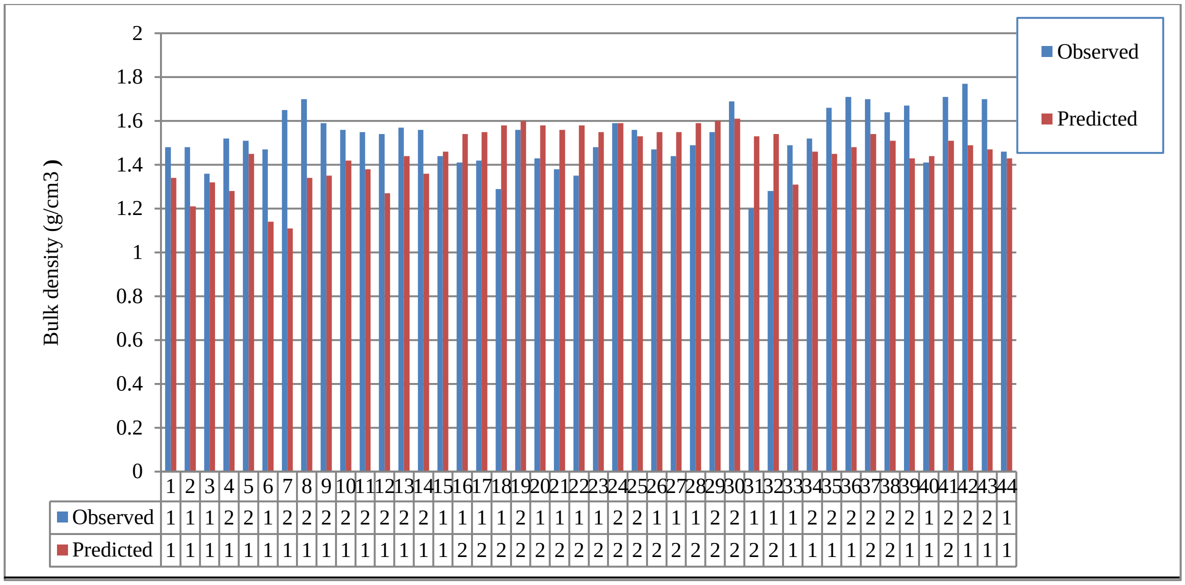


Figure 4.5: Comparison of predicted and laboratory observed soil bulk density

The RMSE was 0.20, while the level of dispersion between predicted and observed data measured by the CV was 13.04%. The modelling efficiency was very low (EF = -1.48) and the magnitude of over-prediction indicated by the CRM was more than 1%.

Table 4.5: Statistical indices of the comparison of predicted and observed saturated hydraulic conductivity and bulk density.

Statistical indices	Saturated hydraulic conductivity	Bulk density
RMSE	30.43	0.20
CV (%)	99.13	13.04
EF	-1.01	-1.48
CRM	-0.20	0.04

4.4 Site by site Analysis of Bulk Density and Water Retention Characteristics

The chi-square results of site by site analysis were as shown in Appendix A. The chi-square obtained results of bulk density for the three sites; Minna, Badeggi and Mokwa show no significant variation with tabular chi-square value at 5% level of probability distribution

(Tables 1a to 3a). The chi-square obtained results for the Permanent Wilting Point (PWP) in the three sites show a significant variation with tabular chi-square value at 5% level of probability distribution (Tables 7a to 9a). But Plant Available Water results for the three sites show no significant variation (Tables 10a to 12a). The obtained chi-square results for field capacity in Minna and Mokwa equally show a significant variation with chi-square tabular value (Tables 4a & 6a). On the other hand the field capacity result of Badeggi shows no significant variation (Table 5a) which may be linked to the nature of the soil. The soil has the highest percentage of clay.

4.5 Site by Site chi-square Analysis for Saturated Capacity

The site by site chi-square obtained result of saturated hydraulic conductivity shows a significant variation from tabular chi-square value at 5% level of probability distribution as shown in Appendix B (Tables 1b & 2b). This shows that the model cannot be used to predict saturated hydraulic conductivity in the area under study as shown in Appendix B (Tables 1b & 2b).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The performance of Soil Water Characteristics-Hydraulic Properties Calculator (SWC – HPC) model in predicting soil water characteristics from particle size distribution was evaluated for soils in Minna, Badeggi and Mokwa, Niger State, Nigeria. The model was found to accurately simulate bulk densities and plant available water of the soil tested, moderately simulated soil moisture content at field capacity, permanent wilting point and poorly simulated saturated hydraulic conductivity. These levels of performances may be improved upon if information on the salinity and degree of compaction of the soil of the study locations are available.

5.2 Recommendations

Based on the analyses of the application of this model to the research area,

1. There should be further research on the model calibration.
2. The model can be used for predicting bulk density and plant available water based on the outcome of this research work.
3. Since the model does not predict for values of clay above 60%, the model should be adjusted to account for this, so as to enable it to be used in an area with higher clay percentage.
4. With series of researches, another model should be developed using the various Soil types in Niger State and considering the climatic factors.

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APPENDIXES A: Site by Site Chi-Square Result for Bulk Density

Table 1a: Chi- square test for bulk density (Minna)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	**Bd_o (g/cm^3)**	**Bd_p (g/cm^3)**	**$(O\text{-}E)^2/E$**
82	12	6	5.2	1.48	1.34	0.015
68	15	17	6.9	1.48	1.21	0.060
70	19	11	6.04	1.36	1.32	0.001
70	10	20	5.17	1.52	1.28	0.045
66	9	25	2.59	1.51	1.45	0.002
76	12	12	14.23	1.47	1.14	0.096
62	15	23	11.21	1.65	1.11	0.263
70	16	14	5.17	1.7	1.34	0.097
62	14	24	4.31	1.59	1.35	0.043
68	9	23	3.02	1.56	1.42	0.014
80	14	6	4.74	1.55	1.38	0.021
78	14	8	6.47	1.54	1.27	0.057
74	15	1	3.45	1.57	1.44	0.012
68	19	13	5.17	1.56	1.36	0.029
62	14	24	2.59	1.44	1.46	0.000
					X^2 =	**0.755**

Bd= laboratory obtained bulk density, Bdp= Model predicted bulk density, Om= Organic matter.

Table 2a: Chi- square test for bulk density (Badeggi)

Sand %	Clay %	Silt %	O_m (g/kg)	Bd_0 (g/cm^3)	Bd_p (g/cm^3)	$(O\text{-}E)^2/E$
64	15	21	1.5	1.41	1.54	0.011
65	16.2	18.8	1.4	1.42	1.55	0.011
51.8	18.2	30	0.7	1.29	1.58	0.053
66.8	16.2	17	0.6	1.56	1.6	0.001
89	10	1	0.3	1.43	1.58	0.014
72.8	12.2	15	1.2	1.38	1.56	0.021
76.8	11.2	12	0.7	1.35	1.58	0.033
80.8	9.2	10	1	1.48	1.55	0.003

58.8	16.2	25	0.7	1.59	1.59	0.000
51.8	24.2	24	1.5	1.56	1.53	0.001
74.8	13.2	12	1.4	1.47	1.55	0.004
81.8	12.2	6	1.4	1.44	1.55	0.008
83.8	10.2	6	0.4	1.49	1.59	0.006
81.8	11.2	7	0.3	1.55	1.6	0.002
72.8	14.2	13	0.3	1.69	1.61	0.004
					X^2 =	0.172

Bd= laboratory obtained bulk density, Bdp= Model predicted bulk density, Om= Organic matter.

Table 3a: Chi- square test for bulk density (Mokwa)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	**Bd_0 (g/cm^3)**	**Bd_p (g/cm^3)**	$(O-E)^2/E$
75	18	7	2.13	1.2	1.53	0.071
71	23	6	2.3	1.28	1.54	0.044
83	9	8	5.08	1.49	1.31	0.025
83	9	8	2.62	1.52	1.46	0.002
76	13	11	3.12	1.66	1.45	0.030
83	12	5	2.62	1.71	1.48	0.036
81	12	7	1.48	1.7	1.54	0.017
66	20	14	2.3	1.64	1.51	0.011
83	9	8	3.12	1.67	1.43	0.040
81	10	9	2.95	1.41	1.44	0.001
67	22	11	2.62	1.71	1.51	0.026
65	24	11	2.95	1.77	1.49	0.053
71	20	9	3.44	1.7	1.47	0.036
67	19	14	2.79	1.46	1.43	0.001
					X^2 =	**0.414**

Bd= laboratory observed bulk density, Bdp= Model predicted bulk density, Om= Organic matter.

Table 4a: Chi-Square Test for Field Capacity (Minna).

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	FC_o (% vol)	FC_p (% vol)	**$(O-E)^2/E$**
82	12	6	5.2	20.72	19.2	0.120
68	15	17	6.9	19.24	26	1.758
70	19	11	6.04	27.2	26.2	0.038
70	10	20	5.17	38	20.8	14.223
66	9	25	2.59	30.2	17.3	9.619
76	12	12	14.23	27.93	24.9	0.369
62	15	23	11.21	24.75	28.8	0.570
70	16	14	5.17	25.5	23.6	0.153
62	14	24	4.31	23.85	23.1	0.024
68	9	23	3.02	29.64	17.5	8.422
80	14	6	4.74	13.95	20	1.830
78	14	8	6.47	20.02	23.1	0.411
74	15	1	3.45	21.98	20	0.196
68	19	13	5.17	24.96	25.5	0.011
62	14	24	2.59	25.92	20.7	1.316
					X^2 =	**39.060**

Df = 14 $P_{.05}$ = 23.68

FC_0 = Laboratory observed values, Fcp = Model estimated values.

Table 5a: Chi-Square Test for Field Capacity (Badeggi).

and %	**Clay %**	**Silt %**	**O_m (g/kg)**	FC_o (%vol)	FC_p (%vol)	$(O-E)^2/E$
64	15	21	1.5	22.56	19.4	0.515
65	16.2	18.8	1.4	25.56	19.5	1.883
51.8	18.2	30	0.7	25.8	22.4	0.516
66.8	16.2	17	0.6	17.16	18.1	0.049

89	10	1	0.3	11.44	9.2	0.545
72.8	12.2	15	1.2	11.04	15.4	1.234
76.8	11.2	12	0.7	10.8	13.3	0.470
80.8	9.2	10	1	13.32	11.8	0.196
58.8	16.2	25	0.7	23.85	19.9	0.784
51.8	24.2	24	1.5	31.2	26.5	0.834
74.8	13.2	12	1.4	17.64	15.8	0.214
81.8	12.2	6	1.4	11.52	13.8	0.377
83.8	10.2	6	0.4	8.94	10.8	0.320
81.8	11.2	7	0.3	10.85	11.7	0.062
72.8	14.2	13	0.3	27.04	18.3	4.174
					X^2 =	**12.173**

Df = 14 $P_{.05}$ = 23.68 FC_0 = Laboratory observed values, Fcp = Model estimated values.

Table 6a: Chi-Square Test for Field Capacity (Mokwa).

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	FC_o (%vol)	FC_p (%vol)	$(O-E)^2/E$
82	10	8	3.86	14.04	16.4	0.340
75	18	7	2.13	10.8	19.6	3.951
71	23	6	2.3	10.24	23.5	7.482
83	9	8	5.08	16.39	17.4	0.059
83	9	8	2.62	22.8	13.6	6.224
76	13	11	3.12	11.62	17.9	2.203
83	12	5	2.62	13.68	15.3	0.172
81	12	7	1.48	18.7	14.2	1.426
66	20	14	2.3	21.32	22.7	0.084
83	9	8	3.12	26.72	14.3	10.787
81	10	9	2.95	9.87	15.1	1.811
67	22	11	2.62	11.97	24	6.030
65	24	11	2.95	21.24	25.9	0.838
71	20	9	3.44	23.8	23.1	0.021
67	19	14	2.79	33.58	17.4	15.046
				266.77	280.4	
					X^2 =	**56.473**

Df = 14 $P_{.05}$ = 23.68

FC_0 = Laboratory observed values, Fcp = Model estimated values.

Table 7a: Chi-Square Test for Permanent Wilting Point (Minna)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	PWP_o (% vol)	PWP_p (% vol)	**$(O-E)^2/E$**
82	12	6	5.2	16.28	11.7	1.793
68	15	17	6.9	13.32	14.7	0.130
70	19	11	6.04	23.12	16	3.168
70	10	20	5.17	33.44	10.6	49.214

66	9	25	2.59	21.14	7.6	24.123
76	12	12	14.23	23.52	14.3	5.945
62	15	23	11.21	16.5	15.4	0.079
70	16	14	5.17	22.1	13.7	5.150
62	14	24	4.31	19.08	11.9	4.332
68	9	23	3.02	24.96	8	35.955
80	14	6	4.74	10.85	12.3	0.171
78	14	8	6.47	15.4	14	0.140
74	15	1	3.45	18.84	11.8	4.200
68	19	13	5.17	21.84	15.3	2.796
62	14	24	2.59	18.72	10.4	6.656
					X^2 =	**143.851**

Df = 14 $P_{.05}$ = 23.68

PWPo = Laboratory observed values, PWPp = Model estimated values.

Table8a: Chi-Square Test for Permanent Wilting Point (Badeggi)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	PWP_o (%vol)	PWP_p (%vol)	$(O-E)^2/E$
64	15	21	1.5	15.51	10.1	2.898
65	16.2	18.8	1.4	14.42	10.6	1.377
51.8	18.2	30	0.7	12.9	11.3	0.227
66.8	16.2	17	0.6	10.92	9.9	0.105
89	10	1	0.3	7.15	5	0.925
72.8	12.2	15	1.2	6.9	8	0.151
76.8	11.2	12	0.7	8.1	6.9	0.209
80.8	9.2	10	1	10.36	5.9	3.371
58.8	16.2	25	0.7	19.08	10.1	7.984
51.8	24.2	24	1.5	28.08	15.3	10.675
74.8	13.2	12	1.4	14.7	8.7	4.138
81.8	12.2	6	1.4	8.64	8.1	0.036
83.8	10.2	6	0.4	7.45	5.8	0.469
81.8	11.2	7	0.3	7.75	6.4	0.285
72.8	14.2	13	0.3	10.14	8.4	0.360
					X^2 =	**33.210**

Df = 14 $P_{.05}$ = 23.68

PWPo = Laboratory observed values, PWPp = Model estimated values.

Table 9a: Chi-Square Test for Permanent Wilting Point (Mokwa)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	PWP_o (%vol)	PWP_p (%vol)	**$(O-E)^2/E$**
82	10	8	3.86	12.48	9.4	1.009
75	18	7	2.13	8.4	12.3	1.237
71	23	6	2.3	7.68	15.3	3.795
83	9	8	5.08	13.41	10.1	1.085

83	9	8	2.62	19.76	7.5	20.041
76	13	11	3.12	9.96	10.3	0.011
83	12	5	2.62	11.97	9.2	0.834
81	12	7	1.48	15.3	8.2	6.148
66	20	14	2.3	19.68	13.6	2.718
83	9	8	3.12	23.38	8	29.568
81	10	9	2.95	8.46	8.5	0.000
67	22	11	2.62	10.26	15	1.498
65	24	11	2.95	19.47	16.4	0.575
71	20	9	3.44	22.1	14.5	3.983
67	19	14	2.79	29.2	7.8	58.713
					X^2 =	**131.215**

Df = 14 $P_{.05}$ = 23.68

PWPo = Laboratory observed values, PWPp = Model estimated values.

Table 10a: Chi- Square Test for Plant Available Water (Minna).

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	PWP_o (% vol)	PWP_p (% vol)	**$(O-E)^2/E$**
82	12	6	5.2	16.28	11.7	1.793
68	15	17	6.9	13.32	14.7	0.130
70	19	11	6.04	23.12	16	3.168
70	10	20	5.17	33.44	10.6	49.214
66	9	25	2.59	21.14	7.6	24.123
76	12	12	14.23	23.52	14.3	5.945
62	15	23	11.21	16.5	15.4	0.079
70	16	14	5.17	22.1	13.7	5.150
62	14	24	4.31	19.08	11.9	4.332
68	9	23	3.02	24.96	8	35.955
80	14	6	4.74	10.85	12.3	0.171
78	14	8	6.47	15.4	14	0.140
74	15	1	3.45	18.84	11.8	4.200
68	19	13	5.17	21.84	15.3	2.796
62	14	24	2.59	18.72	10.4	6.656
					X^2 =	**143.851**

$P_{.05}$ = 23.68 Df = 14

PAWo = Laboratory observed plant available water, PAWp = Model estimated plant available water

Table 11a: Chi- Square Test for Plant Available Water (Badeggi).

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	AW_A (g/100g)	AW_B (g/100g)	$(O-E)^2/E$
64	15	21	1.5	0.071	0.09	0.004
65	16.2	18.8	1.4	0.114	0.09	0.006
51.8	18.2	30	0.7	0.13	0.11	0.004

66.8	16.2	17	0.6	0.06	0.08	0.005
89	10	1	0.3	0.04	0.04	0.000
72.8	12.2	15	1.2	0.04	0.07	0.013
76.8	11.2	12	0.7	0.03	0.06	0.015
80.8	9.2	10	1	0.03	0.06	0.015
58.8	16.2	25	0.7	0.05	0.1	0.025
51.8	24.2	24	1.5	0.03	0.11	0.058
74.8	13.2	12	1.4	0.03	0.07	0.023
81.8	12.2	6	1.4	0.03	0.06	0.015
83.8	10.2	6	0.4	0.01	0.05	0.032
81.8	11.2	7	0.3	0.03	0.05	0.008
72.8	14.2	13	0.3	0.17	0.07	0.143
					X^2 =	**0.366**

$P_{.05}$ = 23.68 Df = 14

PAWo = Laboratory observed plant available water, PAWp = Model estimated plant available

Table 12a: Chi- Square Test for Plant Available Water (Mokwa).

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	PWP_o (%vol)	PWP_p (%vol)	**$(O-E)^2/E$**
82	10	8	3.86	12.48	9.4	1.009
75	18	7	2.13	8.4	12.3	1.237
71	23	6	2.3	7.68	15.3	3.795
83	9	8	5.08	13.41	10.1	1.085
83	9	8	2.62	19.76	7.5	20.041
76	13	11	3.12	9.96	10.3	0.011
83	12	5	2.62	11.97	9.2	0.834
81	12	7	1.48	15.3	8.2	6.148
66	20	14	2.3	19.68	13.6	2.718
83	9	8	3.12	23.38	8	29.568
81	10	9	2.95	8.46	8.5	0.000
67	22	11	2.62	10.26	15	1.498
65	24	11	2.95	19.47	16.4	0.575
71	20	9	3.44	22.1	14.5	3.983
67	19	14	2.79	29.2	7.8	58.713
					X^2 =	**131.215**

$P_{.05}$ = 23.68 Df = 14

PAWo = Laboratory observed plant available water, PAWp = Model estimated plant available

APPENDIX B: Site by Site Chi-Square Result for Saturated Hydraulic Conductivity

Table 1b: Chi-Square Test for Saturated Hydraulic Conductivity (Badeggi)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	K_O (mm/hr)	K_P(mm/hr)	$(O-E)^2/E$
64	15	21	1.5	18	28.42	3.820
65	16.2	18.8	1.4	15	26.01	4.661
51.8	18.2	30	0.7	50.4	15.02	83.339
66.8	16.2	17	0.6	4.8	24.59	15.927
89	10	1	0.3	1.8	70.55	66.996
72.8	12.2	15	1.2	43.8	42.3	0.053
76.8	11.2	12	0.7	15	47.87	22.570
80.8	9.2	10	1	13.8	63.12	38.537
58.8	16.2	25	0.7	14.4	20.92	2.032
51.8	24.2	24	1.5	24	10	19.600
74.8	13.2	12	1.4	52.2	40.66	3.275
81.8	12.2	6	1.4	38.4	50.05	2.712
83.8	10.2	6	0.4	26.4	58.75	17.813
81.8	11.2	7	0.3	54	51.4	0.132
72.8	14.2	13	0.3	57.6	32.48	19.428
					X^2 =	**300.894**

Df = 14 $P_{.05}$ = 23.68

Ko= Laboratory observed values, Kp = Model estimated values

Table 2b: Chi-Square Test for Saturated Hydraulic Conductivity (Mokwa)

Sand %	**Clay %**	**Silt %**	**O_m (g/kg)**	K_O (mm/hr)	K_P(mm/hr)	**$(O\text{-}E)^2/E$**
82	10	8	3.86	58.5	70.33	1.990
75	18	7	2.13	22.92	26.6	0.509
71	23	6	2.3	38.7	14.93	37.844
83	9	8	5.08	22.26	83.38	44.803
83	9	8	2.62	67.68	71.62	0.217
76	13	11	3.12	7.92	47.32	32.806
83	12	5	2.62	77.52	54.54	9.682
81	12	7	1.48	62.34	49.62	3.261
66	20	14	2.3	37.44	19.87	15.536
83	9	8	3.12	9.42	73.74	56.103
81	10	9	2.95	49.02	65.36	4.085
67	22	11	2.62	12	16.7	1.323
65	24	11	2.95	73.2	13.7	258.412
71	20	9	3.44	45.12	22.96	21.388
					X^2 =	**511.576**

Df = 14 $P_{.05}$ = 23.68

Ko= Laboratory observed values, Kp = Model estimated values

APPENDIX C

Glossary-Soil Water Characteristics

Hydraulic Conductivity: the capability of water to move within the soil matrix driven by matrix and gravitational potential, (cm/s: mm/hr).

Bulk Density(BD);the total air dry soil mass divided by the total volume,(g/cm^3).Estimated as the 1-SAT(%v air space) time particle density of 2.65 times fraction soil matrix plus 2.65 times gravel fraction.

Field Capacity (FC): the water content (%v) of the soil matrix approximating the water content of a saturated soil that has been allowed to freely drain. Estimated as a hydraulic tension of 33kPa (33Bar) and dependent only on the soil texture and un- affected by salinity or gravel.

Plant Available Water (PAW): the quantity of water (in/ft-c/m) that a plant is able to extract from a soil at field capacity, calculated as FC (%v) minus (%v) times a depth of soil.

Saturation (SAT): the saturation moisture content of the soil matrix such that the entire soil porosity is water filled, (%v), and dependent only on the soil texture and unaffected by salinity or gravel.

Texture: the dispersed soil fraction of soil particle diameters in category of clay (<2um), silt (2-50um) and sand (50-2000um) as denoted by US Department of Agriculture.

Wilting Point (WP): the water content, (%v) below which plant is generally unable to extract water from the soil. Estimate as a hydraulic tension of 1500kPa (15Bar) and dependent only on the soil texture and unaffected by salinity or gravel.

Tension (soil water potential): matrix potential of soil water held within the interstices of particles by capillary forces, dependent upon soil texture and moisture content.

Gravel: soil particles (%w) larger than coarse sand (>2000um; 2mm) which do not hold soil water by matrix tension and do not conduct water movement.

Salinity: chemicals dissolved within the soil water, often salt, which add an osmotic pressure to the matrix potential for the purpose of plant water abstraction across root membrane by osmosis. It measured as electrical conductivity of a saturated soil water solution (mmhos/cm; ds/m).

Appendix D

Statistical Analysis

Applying the X^{2} {chi – square} textile. $X^{2} = \sum \{(O-E)^{2} /E\}$

O = observation value = Laboratory determined value

E = Expected value = Model predicted valued

V = degree of freedom

= level of significant (5%) = < 0.05

15 was choosing representing the total number of samples from each site.

From the X^{2} table (Appendix A) at 5% probability.

V = 14, a critical value of 23.68 was determined hence $X^{2} = 23.68$

General Hypothesis

H_o : the two experimental data are independent, there is no statistically significant different between the laboratory measured data and the model predicted of independent variables.

H_1 = the two experimental data are not independent, there is statistically significant difference between laboratory measured data and model predicted.

{1} Bulk Density

Site 1: Minna

Decision

X^2 Bd = $\sum \{(O-E)^2/E\}$ = 0.75475 = 0.755

$0.755 < 23.68$

H_o = is accepted

H_1 = rejected.

Interpretation

There is no statistically significant different between the laboratory measured bulk density and model predicted bulk density.

Site 2: Badeggi

Decision

X^2 Bd = $\sum \{(O-E)^2/E\} = 0.1721$

$0.1721 < 23.68$

H_o = is accepted

H_1 = is rejected

Interpretation

There is no statistical significant difference between the laboratory measured bulk density and model predicted bulk density.

Site 3: Mokwa

Decision

X^2 Bd = $\sum \{(O-E)^2/E\} = 0.4137$

$0.4137 < 23.68$

H_o = is accepted

H_1 = is rejected

Interpretation

There is no statistical significant difference between the laboratory measured bulk density and model predicted bulk density.

{2} Field capacity

Site 1: Minna

Decision

X^2 (Fc) = $\sum \{(O-E)^2/E\}$ = 39.06

39.06 >23.68

H_o = is accepted

H_1 = is rejected

Interpretation

There is significant difference between the laboratory mearured field capacity and model predicted field capacity.

Site 2: Badeggi

Decision

X^2 (Fc) = $\sum\{(O-E)^2/E\}$ = 12.173

12.173 <23.68

H_o = is rejected

H_1 = is accepted

Interpretation

There is no significant deference between the laboratory measure field capacity and model predicted field capacity.

Site 3: Mokwa

Decision

X^2 (Fc) = $\sum\{(O-E)^2/E\}$ = 56.47

56.47 >23.68

H_o = is rejected

H_1 = is accepted

Interpretation

There is significant difference between the laboratory measure and field capacity and model predicted field capacity.

{3} Permanent Wilting Point

Site1: Minna

Decision

$X^2 = (Pwp) = \sum\{(O-E)^2/E\} = 143.85$

$143.85 > 23.68$

H_o = is rejected

H_1 = is accepted

Interpretation

There is significant difference between the laboratory measured (pwp) and model predicted (PWP)

Site2: Badeggi

Decision

$X^2 = (pwp) = \sum\{(O-E)^2/E\} = 33.210$

$33.21 > 23.68$

H_o = is rejected

H_1 = is accepted

Interpretation

There is significant difference between the laboratory measured (pwp) and model predicted (PWP)

Site 3: Mokwa

Decision

X^2= (pwp) = $\sum\{(O-E)^2/E\}$ = 131.21

131.21 >23.68

H_o = is rejected

H_1 = is accepted

There is significant difference between the laboratory measured (pwp) and model predicted (PWP)

{4} Plant available water

Site1: Minna

Decision

X^2= (pwp) = $\sum\{(O\text{-}E)^2/E\}$ = 0.413509

0.4135 <23.68

H_o = is rejected

H_1 = is accepted

Interpretation

There is no statistical significant different between the laboratory measure (PAW) and model predicted (PAW).

Site2: Badeggi

Decision

X^2= (PAW) = $\{(O\text{-}E)^2/E\}$ = 0.3658

0.3658 <23.68

H_o = is accepted

H_1 = is rejected

Interpretation

There is no statistical significant different between the laboratory measured (PAN) and model predicted (PAN)

Site 3: Mokwa

Decision

X^2= (PAN) = {(O-E)^2/E} = 0.5570

0.5570 <23.68

H_o = is accepted

H_1 = is rejected

Interpretation

There is no statistical significant deferent between the laboratory measured (PAN) and model predicted (PAN).

{5} Standard hydraulic capacity (Ks)

Site 2: Badeggi

Decision

X^2= (Ks) = {(O-E)^2/E} = 300.90

300.90 >23.68

H_o = is accepted

H_1 = is rejected

Interpretation

There is statistical significant different between the laboratory measured (Ks) and model predicted (Ks)

Site 3: Mokwa

Decision

X^2= (Ks) = $\{(O-E)^2/E\}$ = 511.58

511.58 >23.68

H_o = is accepted

H_1 = is rejected

Interpretation

There is statistical significant different between the laboratory measured (Ks) and model predicted (Ks)