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SOIL WATER CHARACTERISTICS OF TWO AGRO-ECOLOGICAL ZONES OF KATSINA STATE, NIGERIA: A COMPARISON STUDY BETWEEN THE SOILWAT MODEL AND LABORATORY TEST

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ABSTRACT

Soil water characteristics (SWC) is essential for studying water availability for plants, plant water stress, infiltration, water conductivity, drainage and irrigation scheduling. However, field determination of available soil water is often laborious and time consuming. In lieu of this, SOILWAT model can be used. The experiment covers two agro-ecological zones of Katsina State to compare results of SOILWAT model prediction of soil water characteristics and measured results of different soil depth of Katsina State. 84 soil samples were collected at depths 0 to 30 and 30 to 60 cm for top and subsoil respectively at 7 locations in the zones and reference points also recorded. The measured and predicted values of the SWC were compared using, mean bias of error, range and kriged form of interpolation map using GIS Software. The results of the predicted soil textural classes obtained from the SOILWAT model were similar to the measured textural classes for Sudan Savanna (SS) and Northern Guinea Savanna (NGS), however, the SS soils have more sand components than NGS.

Keywords: Water conductivity, Model prediction, Soil depth, GIS Software

INTRODUCTION

Soil water is defined as the infiltrated water shallow enough to be used by plants (Kern, 1995). Soil water characteristics are dependent on the soil water retention (water holding capacity) and soil water potential, which is necessary for studying water availability for plants, plant water stress, infiltration, drainage, irrigation scheduling, and water conductivity. Climate is important factor in which the water content of the soil depends. Recently, changes in climate affect agricultural lands, and as reported by Aliku and Oshunsanya (2016), irregularities in rainfall amount and distribution resulting from advent of climate change have led to a decline in available land for crop production. The distribution of water within the soil column is an indispensable factor in understanding the response of plants and soil water systems to the impacts of climate change (Walczak *et al.*, 2002).

The soil water characteristics (SWC) define the relationship between the soil suction and either the gravimetric water content, w, or the volumetric water content, Θ, or the degree of saturation, *S* (Vanapalli *et al*, 1999). Therefore, SWC relationship should have greater meaning if it is presented using a degree of saturation versus suction. The SWC is a conceptual and interpretative tool by which the behaviours of unsaturated soils can be understood.

The SWC and the saturated coefficient of permeability have been developed and used in predicting the relationship between suction and the coefficient of permeability (Brook and Corey, 1964; van Genuchten, 1980; Mualem, 1986; Fredlund and Xing, 1994). The constitutive equations for volume change, shear strength and flow through unsaturated soil are receiving general acceptance in geotechnical engineering applications (Fredlund and Raharjo, 1993). Because experimental studies on unsaturated soils are time consuming and costly, the relationship between the soil water characteristic and saturated soil properties are now developed to predict/model the engineering behaviour of unsaturated soils (Oyeogbe and Oluwasemire, 2013; Saxton and Rawls, 2006).

Thus, knowledge of SWC is paramount for making decisions in agricultural practices, such as irrigation and drainage. SOILWAT model developed by Saxtons and Willey (2006) was used to determine the soil water characteristics at saturated, field capacity, and wilting point; bulk density; and saturated hydraulic conductivity of sampled soils in two agro ecological zones of Katsina state. The predicted values were compared with the results obtained from direct observation in the laboratory to validate the model, if it can be adopted for agricultural practices in the locality; Igbadun et al (2011) proposed that before the adoption of any simulation model for use in any locality, it is important to first evaluate (observe) the model's ability to represent the state variables it intended to simulate for the locality.

MATERIALS AND METHODOLOGY

The study area, Katsina State, covering an area 23,938 sq. km., is located between latitudes $11^{0}08'$N and $13^{0}22'$N and longitudes $6^{0}52'$E and $9^{0}20'$E. The State is bounded by the Niger Republic to the north, Jigawa and Kano States to the east, Kaduna State to the South and Zamfara State to the West.

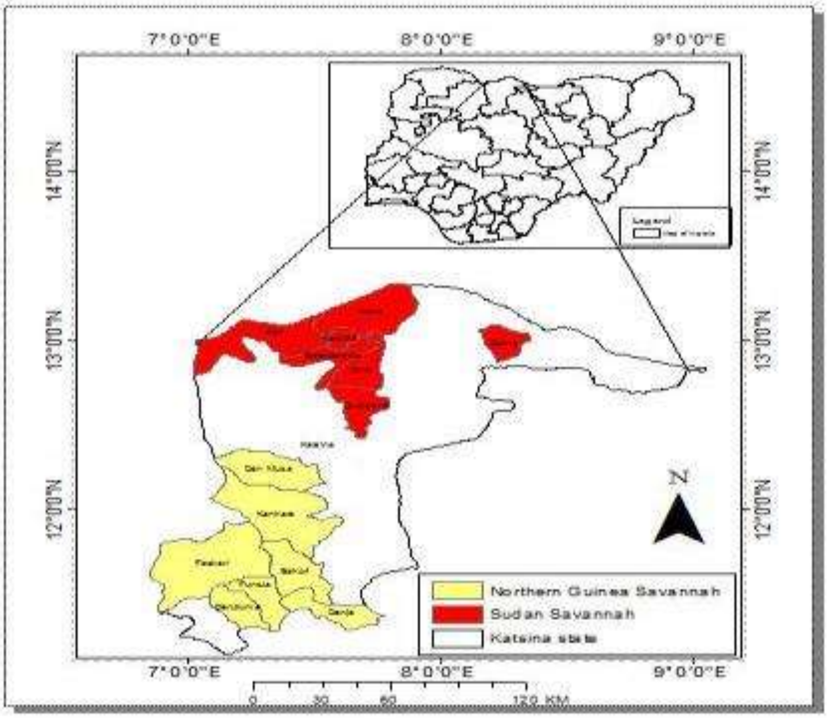


Fig. 1: Map of Katsina State. (ASTA laboratory, Bayero University, Kano)

Soil samples (composite) were collected undisturbed from Sudan Savanna and Northern Guinean Savanna of the State. Seven locations were randomly selected from each of the agro-ecological zones (Sudan Savanna and Northern Guinea Savanna).

In each field representing a location, the collection of the soil samples (Pleysier, 1995) was done in triplicates. The soil samples were collected with the aid of auger and core sampler, along the profiles at 0 – 30 cm (topsoil) and 30 – 60 cm (subsurface) of each profile respectively, following FAO guidelines (FAO, 2006).

Soil Analyses

On the field, Soil moisture meter was used for measuring the antecedent moisture content of the soil. The composite samples were analyzed in laboratories for particle size analysis, salinity, soil bulk density, organic matter content, saturated hydraulic conductivities and moisture characteristics at suction pressures 0 kPa (saturation point), 33 kPa (field capacity), and 1500kPa (wilting point) kPa . Electrical conductivity (salinity) was determined with a Conductivity meter. Organic carbon contents were determined by the Walkley-Black dichromate titration method (Nelson and Sommers, 1982). Particle size analysis was measured by the hydrometer method (Gee and Or, 2002) Bulk density was measured by the core method in which core samples were oven-dried at 105°C until a constant weight was achieved.

Comparison of the measured and predicted data

The comparison of the difference between predicted soil water characteristic parameters and measured values, was determined to find the Range (the difference between the lowest and highest value), the Mean Error of Bias (the difference between the mean of the predicted and measured values). ArcMap software was used for the kriging, while the values obtained represented the z-values and x and y represented the latitude and the longitude of the location. The latitudes and the longitudes of the locations were obtained using Google maps on Android.

RESULTS AND DISCUSSION

Soil Texture and Salinity of Different Depths of Study Area

The soil texture and salinity are presented in Table 1 showing the mean particle size distribution down the profile. The results from the laboratory analysis indicated the depth of 0 to 60 cm, the clay content increased from 7.76 to 9.67% in the Sudan Savanna (SS), and 22.29 to 38.71% in the Northern Guinean Savanna (NGS). However, the sand fraction decreased from 81.38 to 78.76% and 64.88 to 7.24% in the SS and NGS zones, respectively. The measured top soil from SS varied from sandy to loamy sand, while the predicted topsoil ranges from sand to sandy loam. The subsurface textures obtained from both the measured and predicted varied from sandy to sandy loam. The NGS contains higher clay particles than the SS zone. For the NGS zone, the predicted topsoil and subsurface textural class corresponds with the laboratory textural class, which are sandy loam and clay respectively. The average salinity level increased down the depth of the soil in the SS, while it decreases down the profile of NGS.

Table 1: Mean Values for Measured and Predicted Textural Classes.

Location	Depth (cm)	Salinity (dS/m)	Sand (%)	Silt (%)	Clay (%)	Measured Textural class	Predicted Textural class
SS	0 - 30	0.096	81.38	10.76	7.76	Sa – LoSa	Sa – SaLo
	30 - 60	0.203	78.76	10.43	9.67	Sa – SaLo	Sa – SaLo
NGS	0 – 30	0.272	46.76	30.24	22.29	Lo Sa	Sa – Cl
	30 - 60	0.06	23.29	37.90	38.71	Lo - Cl	SaLo – Cl

Note Sa: Sand; Lo Sa: Loamy sand; Sa Lo: Sandy loam; Cl: Clay

Comparison of Measured and Predicted Moisture Content at Saturation

Table 2 shows the comparison between the predicted and the measured moisture content at saturation. The mean error of bias between the SS profile is positive while the MEB of the NGS is negative, revealing that the average predicted value is lower than the measured value of soils in NGS.

The range of the measured MC at saturation is greater than the range of the predicted in all the profiles. The range of both the measured and predicted values of the NGS is higher than the range of SS soil. This is a result of lesser sandy texture in the soil of the NGS.

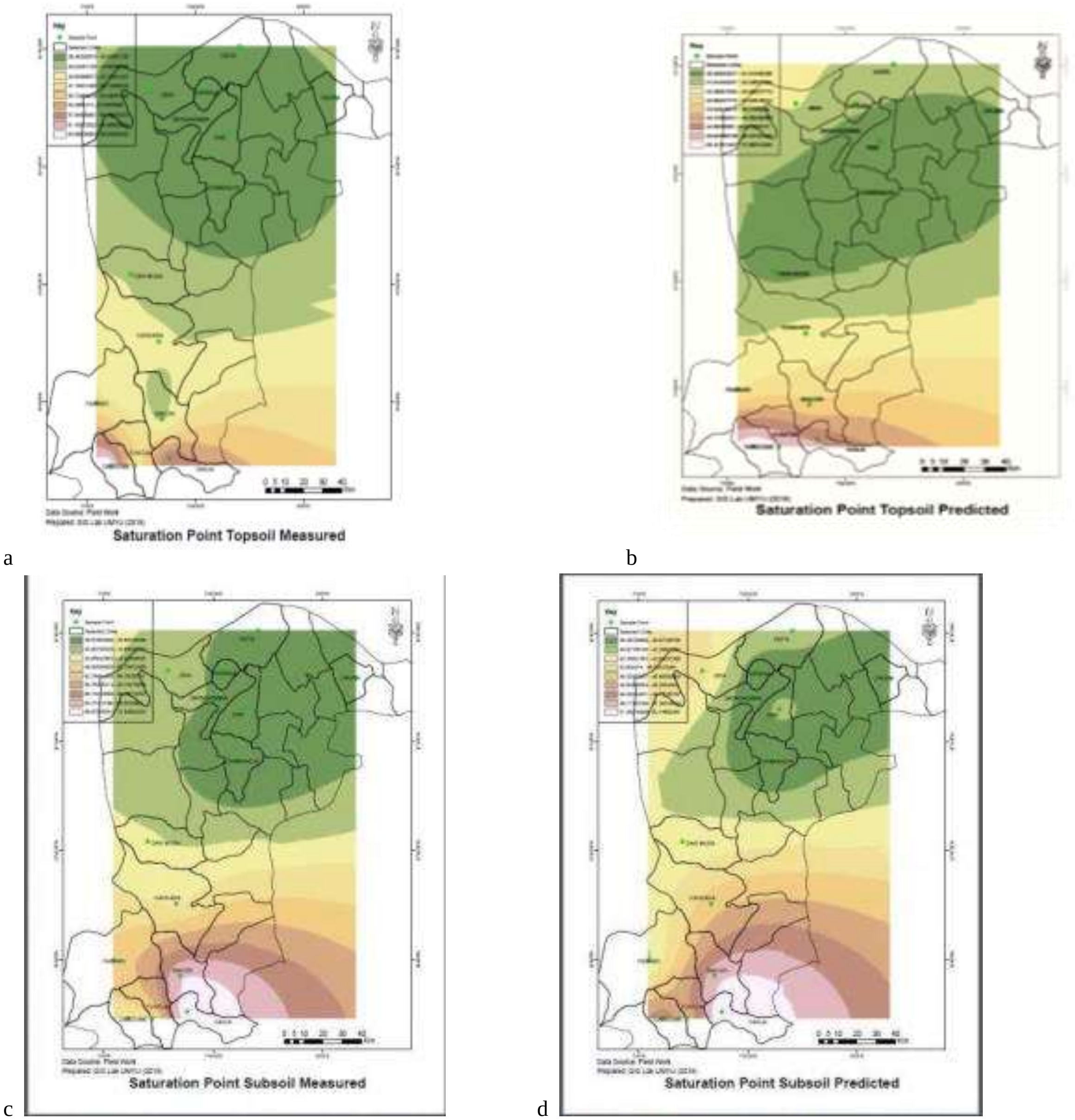
Table 2: Moisture Contents at Saturation (%Vol)

Location	depth (cm)	MSP	PSP	MEB	MR	PR
SS	0 - 30	38.14	41.54	3.41	34.2 to 40.1	39.9 to 44.2
	30 - 60	39.61	40.89	1.28	35.4 to 44.1	39.1 – 46.2
NGS	0 – 30	50.98	44.33	-6.65	42.1 to 71.3	40 to 53.5
	30 - 60	55.59	47.29	-8.63	41.9 to 78.2	38.2 to 53.3

Note: MSP- Measured Saturation point, PSP- Predicted Saturation point, MEB - Mean Error of Bias, MR – Measured range, PR- Predicted range.

Kriging comparison of saturation point

Figure 2 represents the kriging of the moisture content at saturated point. Comparison of the measured and predicted maps shows a noticeable variation in the topsoil of the SS zones in the latter. Kaita and Katsina fall in different category (higher) from the measured and Jibia falls into the next category. The NGS zone has more variation in the measured and predicted than the SS zone; each of the maps has more than 5 ranges variation.



Saturation Point Topsoil Measured

a

Saturation Point Topsoil Predicted

b

Saturation Point Subsoil Measured

c

Saturation Point Subsoil Predicted

d

Fig. 2: measured and predicted moisture content at saturation point

Comparison of the Measured and Predicted Moisture Content at Field Capacity

From table 3, the mean error of bias for the moisture content at field capacity are all negatives, this implies the average predicted values is less than the measured values by 2.02, 0.74, 2.2 and 4.53 for the SS top soil, SS sub soil, NGS top soil and NGS sub soil respectively. The range between the measured and the predicted values is higher in this parameter in the NGS than in the SS soils. This is an indication of higher clay content in the NGS soil.

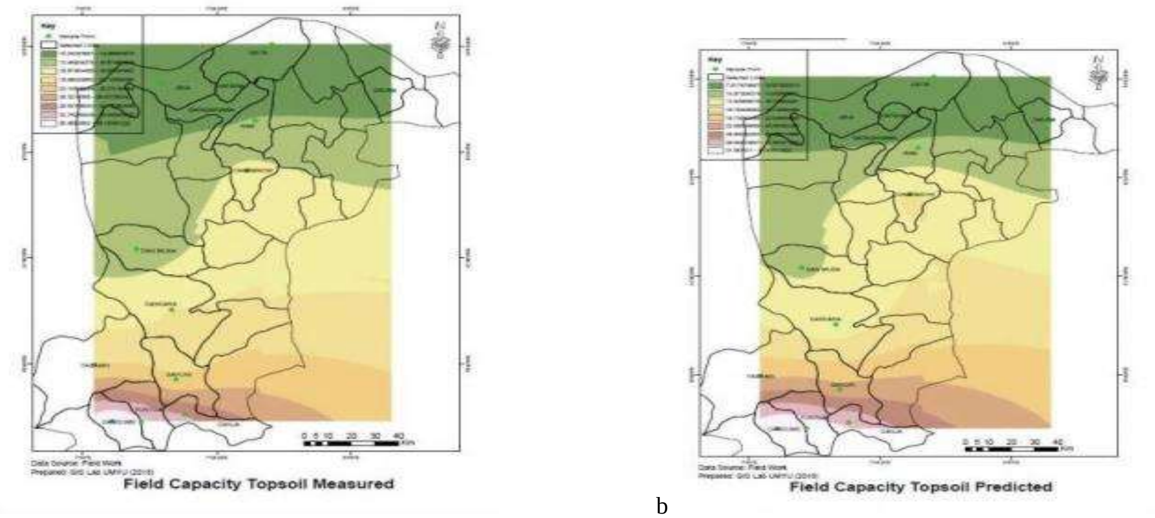
Table 3: Moisture Contents at Field Capacity (%Vol)

Location	depth (cm)	MFC	PFC	MEB	MR	PR
SS	0 – 30	12.60	10.58	-2.02	19.2 to 40.1	5.9 to 24.9
	30 – 60	13.12	12.39	-0.74	9.3 to 17.8	7.4 to 20.1
NGS	0 – 30	27.06	24.86	-2.2	11.9 to 45.3	8.5 to 45.3
	30 – 60	41.75	37.22	-4.53	24.7 to 57.1	21.5 to 45.3

Note: MFC- Measured Field Capacity, PFC- Predicted Field Capacity, MR – Measured range, PR- Predicted range.

Kriging comparison of field capacity

The maps (figure 3) of the top soil show measured and predicted of the SS zones have similar ranges. Kaita, Jibia, Katsina, Daura and Batagarawa have the same range in both maps; their range is the lowest in the State. The next range is Rimi which is higher than the previously mentioned axes in the zone. Charanchi has the highest in the maps (some locations in Charanchi were predicted to have higher ranges than in the measured). The top soil of NGS in both predicted and measured has more variation than in the SS zone. Dandume has the highest field capacity (measured and predicted) Dan Musa has the lowest field capacity in NGS zone.



a b

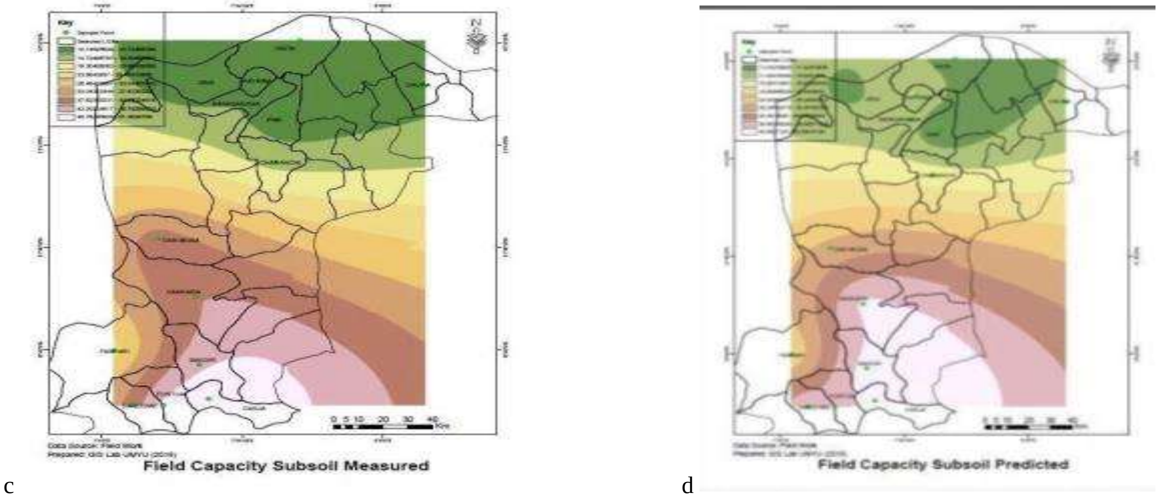


Fig. 3: kriging of measured and predicted moisture content at field capacity

Comparison of the Measured and Predicted Moisture Content at Wilting Point

From table 4 below, the top soil values indicate the average value of the measured wilting point (-0.38 and -1.78 for SS and NGS respectively) is more than the predicted value, while the average measured of subsoil (0.74 and 3.3 for SS and NGS respectively) are less than the measured values. The range of the NGS profiles (15.55 for measured and 13.77 for predicted in the top soil, and 19.97 for measured and 23.27 for the predicted in the sub soil) is higher than the SS profiles (5.06 for measured and 4.68 for predicted in the top soil, and 5.45 for measured and 6.2, for the predicted in the sub soil). This is a reflection of the higher range of the sand content (known for lack of water holding capacity) in the soil profiles of the SS. The values obtained in the wilting point for both the predicted and the measured is similar to the observation of Aliku and oshunsanya (2016), which, also, has higher wilting point in the subsoil than in the top soil.

Table 4: Moisture Contents at Wilting Point (%Vol)

Location	depth (cm)	MWP	PWP	MEB	MR	PR
SS	0 - 30	5.06	4.68	-0.38	2.50 to 9.30	2.00 to 8.70
	30 - 60	5.45	6.2	0.74	2.50 to 9.80	2.60 to 10.8
NGS	0 – 30	15.55	13.77	-1.78	4.10 to 32.10	4.00 to 33.30
	30 - 60	19.97	23.27	3.3	4.30 to 29.1	3.90 to 33.3

Note: MSP- Measured Wilting Point, PWP- Predicted Wilting Point, MR – Measured range, PR- Predicted range.

Kriging comparison of wilting point

In figure 4, comparing the wilting point at the top soil, the measured values of SS fall into the same range which is the lowest of record, but in the predicted, Charanchi axis falls out of the range (a higher value was predicted for it, which is out of range of the rest). This indicated that there is little variation in the measured map. The NGS zone has more variation than the SS zone with Dandume having the highest value for both the predicted and the measured values. The measured value for Dan Musa and Kankara has higher range than in the predicted, while the rest of the axes virtually fall in the same range both in the measure and the predicted.

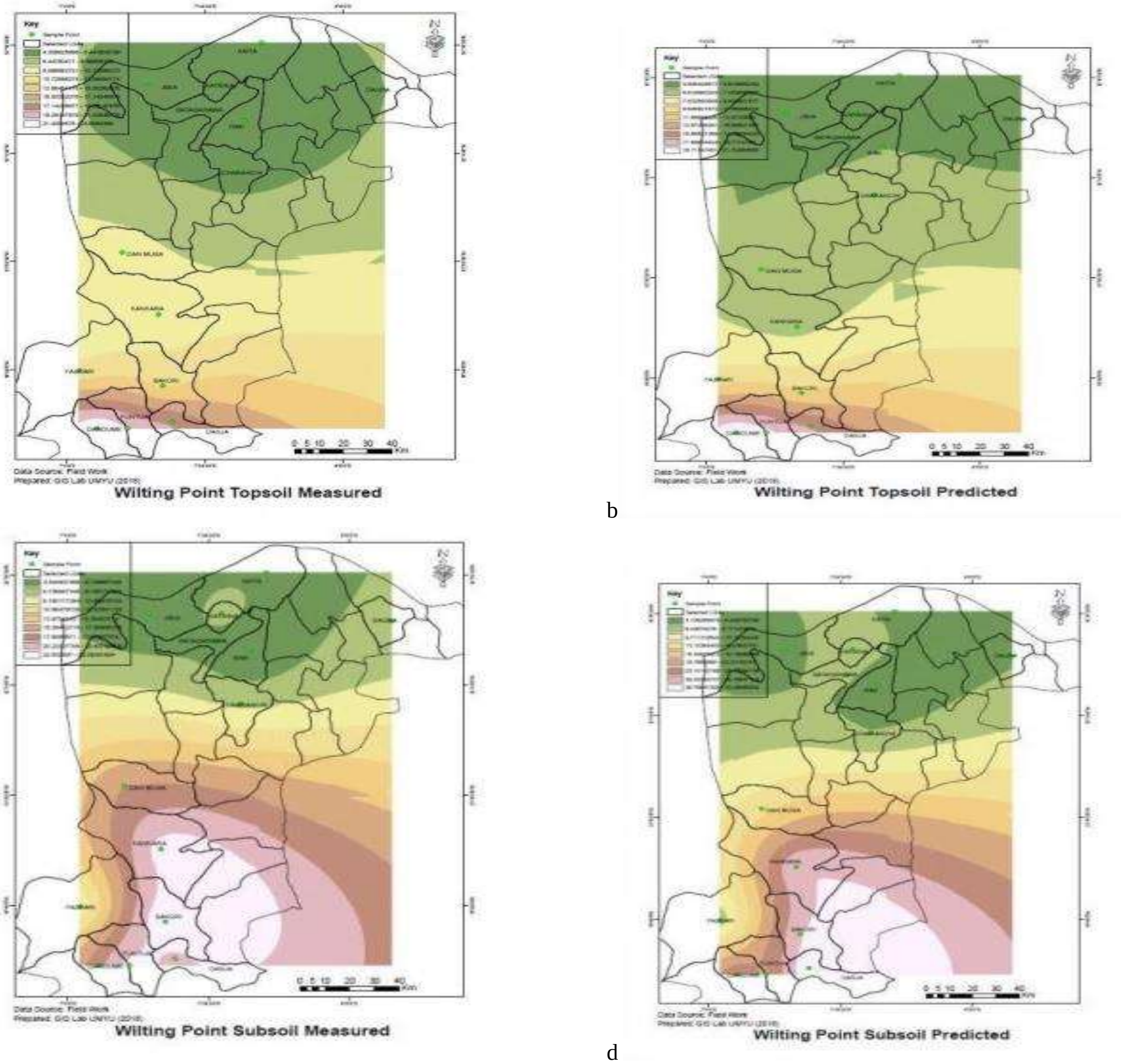


Fig. 4: kriging of measured and predicted moisture content at wilting point

Comparison of the Measured and Predicted Available Water Contents

Table 5 shows the comparison of the average available water at both the SS and NGS zones, and the mean error of bias. The MEB implies the average measured values to be less than the average measured of the soil available water contents of the zones. However, the MEB of the NGS zones (-0.004 and -0.08 for the top soil and sub soil) are lower than SS (-0.02 for both soil depth). The range is higher in the NGS measured values (0.17 and 0.25 for the top soil and sub soil respectively) compared to the predicted values (0.12 and 0.06 for the top and sub soil respectively).

Table 5: Soil Available Water (cm/cm)

Location	depth (cm)	MAW	PAW	MEB	MR	PR
SS	0 – 30	0.08	0.06	-0.02	0.03 to 0.15	0.04 to 0.16
	30 – 60	0.08	0.06	-0.02	0.04 to 0.13	0.03 to 0.12
NGS	0 – 30	0.114	0.11	-0.004	0.01-0.18	0.05 to 0.18
	30 – 60	0.22	0.12	-0.08	0.12 to 0.37	0.12 to 0.18

Note: MAW- Measured Available Water, PAW- Predicted Available Water, MR – Measured range, PR- Predicted range.

Kriging of the available water

The maps (Fig. 5a and 5b) represent the results of top soil of Katsina State after subjected to kriging. In these maps, it shows a high variation in the SS zones which is different from what has been measured in the previous parameters up to this point. Kaita has the lowest value in the SS measured and Charanchi has the highest available water in the zone. In the predicted map, Kaita, Jibia, Katsina, Batagarawa, Daura and Rimi has the same range with Charanchi having the highest range. In the NGS zone there are high variations in the zone, Funtua and Dandume have the highest range and Dan Musa has the lowest range. The predicted value of the sampled location of Kankara is low compared to the value obtained in the measured map.

In the subsoil maps, Kaita and Rimi have the same range for both the predicted and the measured. The variation in predicted is higher than the measured in the measured. Batagarawa, Katsina and Jibia fall into the same range and also in the predicted but in a lower range. Charanchi has the highest available water both in the predicted and the measured values, there is two range difference in the sample location of the axis. In the NGS zone, the highest range was recorded in Faskari axis, while Kankara has the lowest in both. There are variations in Dan Musa, Bakori, Funtua and Dandume axes. The variations have higher values in the predicted than in the measured.

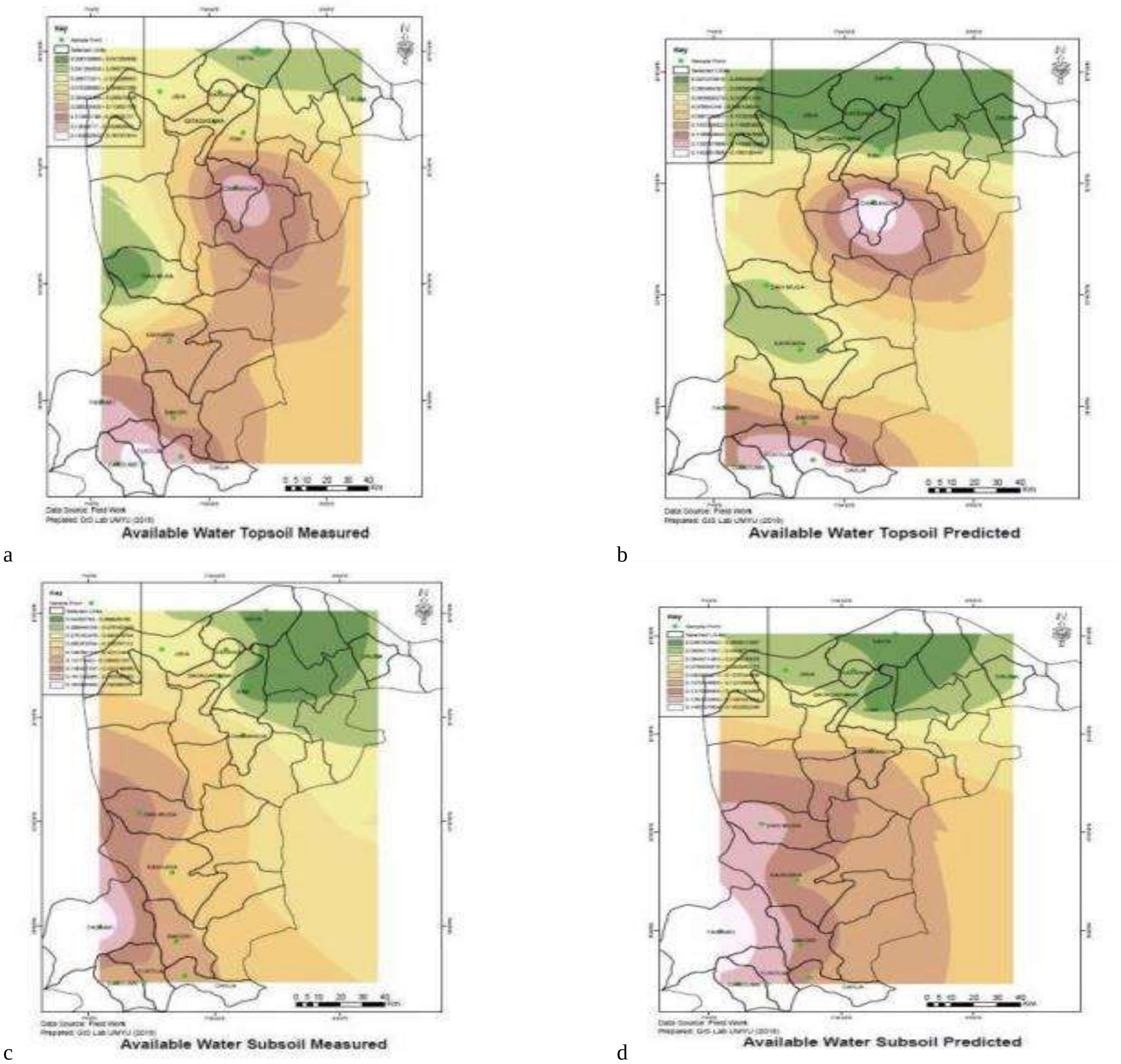


Fig. 5: kriging of measured and predicted available water

Comparison of the Measured and Predicted Saturated Hydraulic Conductivity

In table 6, the difference between the average saturated hydraulic conductivity of the predicted and the measured values, indicates the predicted values of the SS is greater (21.85 and 14.76 for top and sub soil respectively) than the measured while the predicted is less than the measured values in the NGS zones (-22.91 and -14.55 for top and sub soil respectively). The ranges of the values are high, for both the measured (36.45 - 101.27) and the predicted values (52.69 at the lowest and 106.67 at the highest). These results show high diversity between the measured and predicted results; this may be due to high soil density that strongly affects soil structures and large pore distribution of soils as reported by both Carman (2002); and Saxton and Rawls (2006)

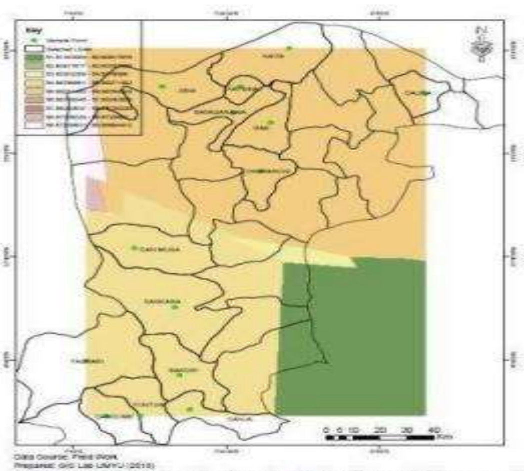
Table 6: Saturated Hydraulic Conductivity (mm/hr)

Location	Depth (cm)	MKsat	PKsat	MEB	MR	PR
SS	0 - 30	57.52	79.36	21.85	16.8 to 114.1	12.7 to 123.3
	30 - 60	46.47	61.24	14.76	3.6 to 108.7	19.39 to 111.2
NGS	0 – 30	5.66	30.75	-22.91	1.53 to 102.8	1.28 to 107.95
	30 - 60	20.18	5.63	-14.55	1.95 to 38.4	0.2 to 53.89

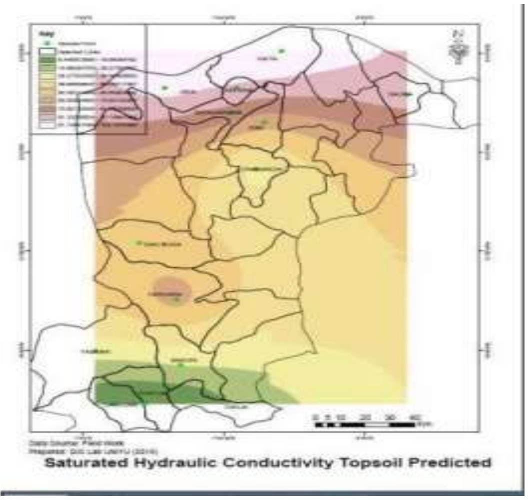
Note: MKsat- Measured Saturated Hydraulic Conductivity, PKsat - Predicted Saturated Hydraulic Conductivity MR – Measured range, PR- Predicted range.

Kriging of saturated hydraulic conductivity

In topsoil maps from figure 6, there is noticeable difference between the two when compared to each other. The measured values in the SS zone have only one range for all the sampled locations. While in the predicted, the variations are noticeable with Jibia and Kaita having the highest ranges of values. In the NGS zone for the top soil, the measured values also fall in the same range, which are lower than the SS zone. In the predicted topsoil for the NGS, there is variation in the axes, Dandume, Funtua and Danja fall in the same range which is the lowest in the State and Kankara has high Ksat for the sampled region of NGS.



a Saturated Hydraulic Conductivity Topsoil Measured



b Saturated Hydraulic Conductivity Topsoil Predicted

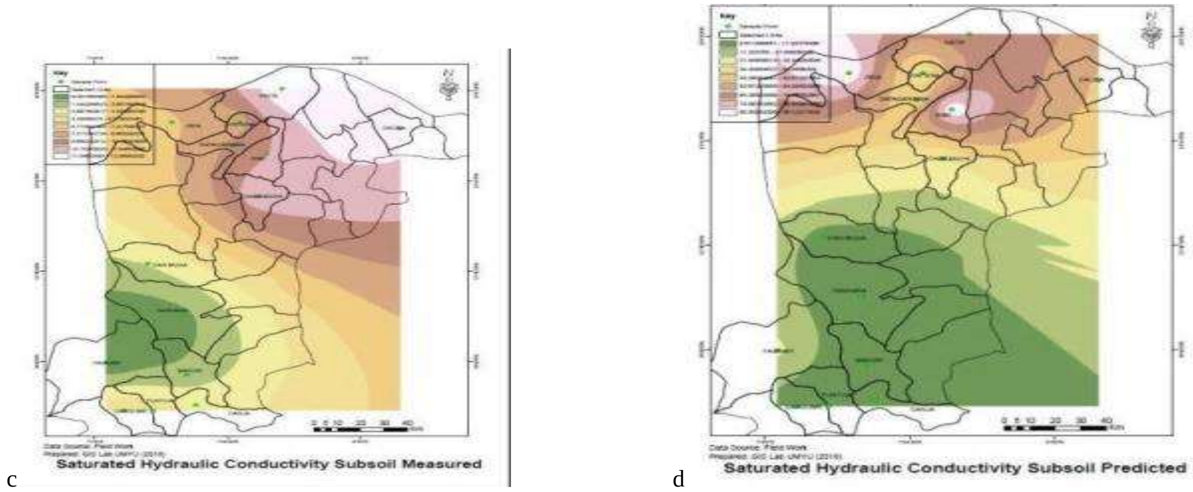


Fig 6: measured and predicted saturated hydraulic conductivity

Comparison of Measured and Predicted Bulk Density

In table 7, the MEB indicates the average predicted values of the entire zones to be greater than the average values of the measured. While the range of the range of the measured values (0.16 and 0.31 for the top and sub soil respectively) of the SS is higher than the range of the predicted 0.05 and 0.13 for the top and sub soil respectively, the range of the predicted values (0.36 and 0.4 for the top and sub soil respectively) is greater than the measured values (0.16 and 0.37 for the top and sub soil respectively) in the NGS zones.

Table 7: Bulk Density (g/cm^3)

Location	depth (cm)	MBD	PBD	MEB	MR	PR
SS	0 - 30	1.47	1.55	0.08	1.39 to 1.55	1.48 to 1.59
	30 - 60	1.49	1.57	0.079	1.26 to 1.57	1.43 to 1.61
NGS	0 – 30	1.43	1.48	0.05	1.38 to 1.54	1.23 to 1.59
	30 - 60	1.39	1.40	0.01	1.22 to 1.59	1.24 to 1.64

Note: MBD- Measured Bulk Density, PBD- Predicted Bulk Density, MR – Measured range, PR- Predicted range.

Kriging of bulk density

The top soil maps (figure 7) show a high variation in the measured values of the sampled locations of SS zone than in the predicted values. Daura and Kaita have the highest range of values in the predicted and Jibia has the lowest value for this zone. In the predicted however, Daura, Batagarawa, Rimi, and Charanchi sampled locations have the highest measured values for predicted, and Jibia has the lowest (similar to the measured). In NGS zone, Danja, Bakori, Funtua and Kankara have the lowest range for the measured values and Dan Musa along with Faskari has the lowest range for these axes. In the predicted map, Dan Musa has the highest while Dandume has the lowest, the rest of the sampled location in this zone falls in different range between these two.

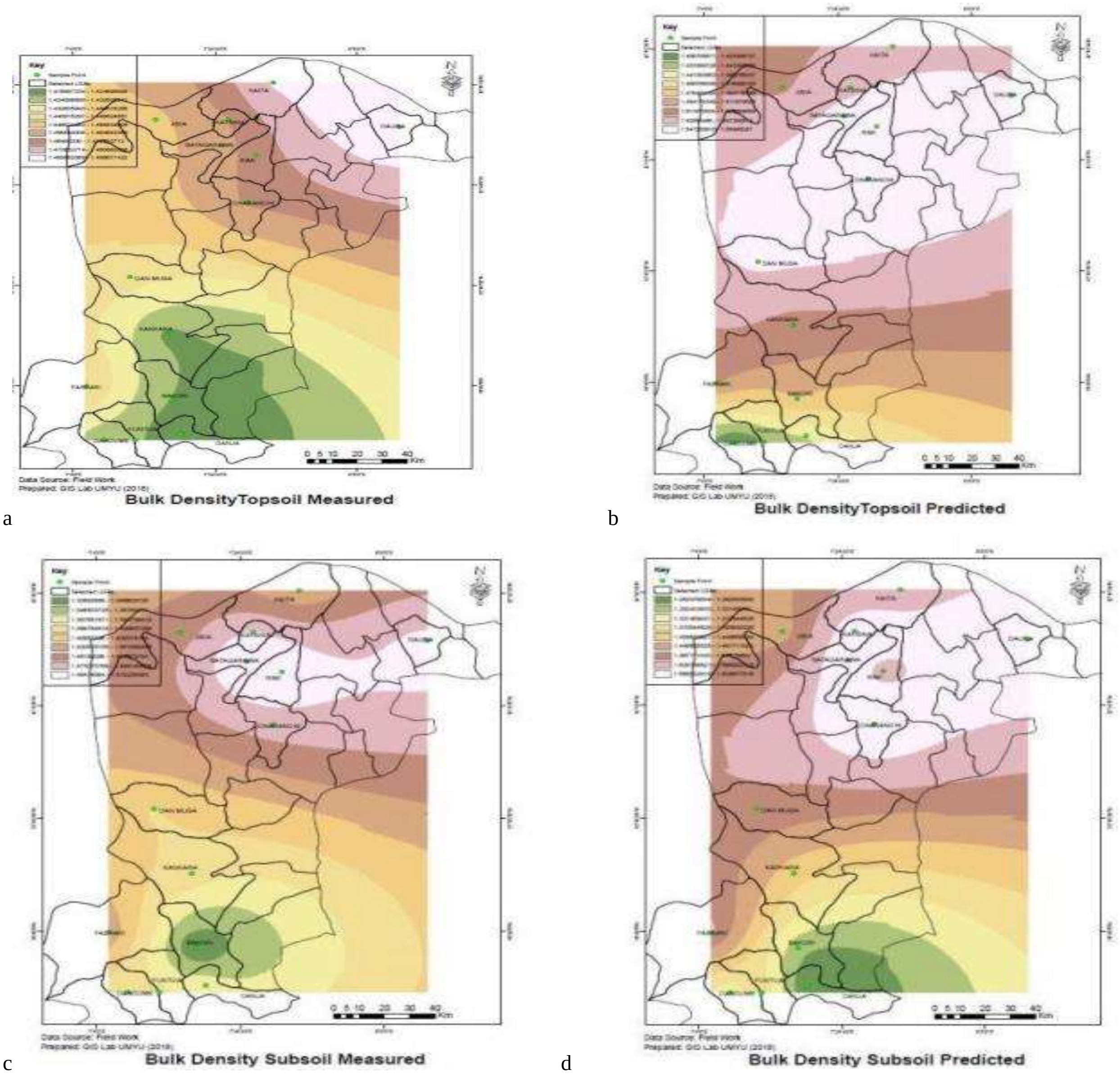


Fig.7: measured and predicted bulk density

CONCLUSION

Comparing the predicted and measured values, the model predicted textural classes that are similar to the measured classes in the Sudan Savanna and North Guinea Savanna Zones of Katsina State. The model accurately simulated the bulk density and the soil available water; moderately predicted the moisture content at field capacity, wilting point and saturation; but it did poorly for hydraulic conductivity. Kriging the values, measured and predicted, soil of similar location has water characteristic values similar to one another, which is visible through the little difference in range between the soils compared to those from different zone. This is similar to the conclusion of Sigua and Hudnall (2008), they used kriging to compare soil properties in their work; and they reported that soil with similar properties and environment are expected to behave similarly.

This research shows the model can be used to predict the soil water characteristics except for the hydraulic conductivity of these zones.

REFERENCES

Aliku, O. and Oshunsamya, O. S. (2016). Establishing relationship between measured and predicted 1 soil water characteristics using SOILWAT model in three agro-ecological zones of Nigeria Department of Agronomy, University of Ibadan, Nigeria. Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-165, 2016 Manuscript under review for journal Geosci. Model Dev. Published: 15 August 2016

Brooks, R. H., and Corey, A. T., (1964). Hydraulic Properties Of Porous Media. Hydrology Paper No. 3, Colorado State U., Fort Collins, Colorado.

FAO (2006). Guidelines for Soil Description (4th edition). FAO, Rome.

Fredlund, D. G., and Rahardjo, H. (1993). Soil Mechanics for Unsaturated Soils. John Wiley &Sons, New York, N. Y.

Fredlund, D.G. and Xing A. (1994) Equations for the soil-water characteristic curve. Canadian Geotechnical Journal 31, 521-532.

Gee, G.W. and Or, D. (2002). Particle Size Analysis. Methods of Soil Analysis. Part 4, 255-293.

Kern, J.S. (1995). Evaluation of soil water retention models based on basic soil physical properties. Soil Sci. Soc. Am. J., 5 Vanapalli, S. K., Fredlund, D.G. and Pufahl, D. E. (1999). The Influence of Soil Structure and Stress History on the Soil-Water Characteristics of a Compacted Till. Geotechnique Vol. 48, No. 2, pp. 143 – 159

Mualem, Y. (1986). Hydrraulic conductivity of unsaturated soils: prediction and formulas. In Methods of soils analysis. Part1. Physical and mineralogical methods 2nd 3dn, Agronomy (ed. A. klute), pp, 799-823, Madison, Wis: American Society of Agronomy.

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In: Page *et al* (eds) Methods of Soil Analysis. Part2. 2nd ed. Agron. monog. 9. ASA and SSSA, Madison, WI. Pp. 539-579.

Oyeogbe, A. I. and Oluwasemire, K. O. (2013). Evaluation of SOILWAT Model for Predicting Soil Water Characteristics in Southwestern Nigeria. International Journal of Soil Science, 8: 58-67.Bouma, J., 1989. Using soil survey data for quantitative land evaluation. Adv. Soil Sci., 9: 177-213.

Pleysier, J. L. (1995). Soil sampling and sample preparation. IITA research guide, No 2. Ibadan, Nigeria: IITA (p. 27)

Saxton, K. E. and Rawls, W. J. (2006). Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Sci. Soc. Am. J. 70:1569 – 1578.

Saxton, K. E. and Willey P. H. (2006). The SPAW Model for Agricultural Field and Pond Hydrologic Simulation. Chapter 17 in: *Mathematical Modeling of Watershed Hydrology,* V. P. singh abd D. frevert, (Ed.); CRC Press LLC.Sigua, C. G and Hudnall, W. H.(2008). Kriging analysis of soil properties. Journal of Soils and Sediments. 8.10.1007/s11368-008-0003-7

van Genuchten, M.Th. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J.44:892–898.

Vanapalli, S. K., Fredlund, D.G. and Pufahl, D. E. (1999). The Influence of Soil Structure and Stress History on the Soil-Water Characteristics of a Compacted Till. Geotechnique Vol. 48,No. 2, pp. 143 – 159

Walczak, T. R., Witkowska-Walczak, B. and Slawinski, C. (2002). Comparison of correlation models for the estimation of the water retention characteristics of soil. Int. Agrophys., 16: 79-82.9: 1134-1141.