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Analysis of Soil Water Characteristic and Water Stress Estimates using the Soil-Plant-Air-Water (SPAW) Model

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ABSTRACT

This study presents the status of selected soil sites in north central Nigeria. Hydrologic analyses often involve the evaluation of soil water infiltration, hydraulic conductivity, water storage, and plant-water relationship. The results revealed that soil depths of 0-15 cm had higher soil-water release rates than the fine-textured soil at 15-30 cm depth. Sandy loam and sandy clay loam were the major soil textures found in the selected sites. The highest moisture content of the soil was 20.22% at 15-30 cm depth whereas the lowest moisture content of 15.8% and bulk density of 1.80 were obtained at 15-30 cm. The model for predicting water content for wilting point using some physical properties of the soil ranged between 13.70% and 22.40% whereas at field capacity water content ranged between 24% to 30.10%. The result shows that there was no significant effect of the predicted soil parameter using both the Levene's Test for Equality of variance and T-test for equality of means. There was a no significant effect of the moisture content and bulk density at ($P \leq 0.05$), which indicate that the predicted data ~~was~~ were adequate and revealed the true characteristics of the site location. It was therefore concluded that the study area is suitable for irrigation practice and that the SPAW model can be adopted for use provided some conditions such as the initial moisture content of the study area is considered.

Keywords: Saturation, soil, water, hydraulic, water

INTRODUCTION

Nigeria has a wide diversity of soil under different ecological conditions and with different levels of fertility. The different soils are a function of prevailing climatic condition, vegetative cover, and topography of the area among others (Karamesouti et al., 2015; Ochoa et al., 2016). The major soil types in Nigeria, according to FAO soil taxonomy legends are fluvisols, regosols, gleysols, acrisols, ferrasols, alisols, lixisols, cambisols, luvisols, nitosols, arenosols and vertisols. These soil types vary in their potential for agricultural use. None of these soils was rated as class 1 with high productivity by the FAO. Nigerian soils can be classified into groups made up of four (climatic) zones that are soil associations.

Soil moisture plays a critical role in land surface processes and hydrological cycles. It does not only participate in soil hydrological processes but also influences vegetation growth and even modifies weather processes and local climate (Song et al., 2017). Field capacity (FC) and saturated hydraulic conductivity (Ks) are two key soil hydraulic properties that jointly affect soil water storage, transmission and distribution (Gómez-Paccard et al., 2015; Pan et al., 2017; Chen et al., 2018). Knowledge of how Field capacity and hydraulic conductivity vary and of their influencing factors is essential for a better understanding of soil hydrological processes.

Field capacity and hydraulic conductivity are also key parameters in most hydrological, climate and land surface models (Garrigues et al., 2015; Leung et al., 2015; Montzka et al., 2017). Therefore, understanding the effects of vegetation changes on field capacity and hydraulic conductivity is necessary for model parameterization and reducing the uncertainty of simulations (Pan et al., 2017). Soil hydraulic properties are highly heterogeneous both spatially and temporally and could respond swiftly to external changes and disturbances (Pradhan and Indu, 2019). Field capacity and Ks are mainly influenced by vegetation, soil (Zongping et al., 2016), topography (Perkins et al., 2018), climate and human activities (Naganna et al., 2017). In recent years, vegetation degradation has been widespread because of natural environmental changes and anthropogenic influences. Efforts have been devoted to revealing the effects of vegetation degradation on soil hydraulic properties across scales and ecosystem types (Lozano-Baez et al., 2019). For forest, Srivastava et al., (2018) and Kim et al., (2018) analysed the variations in Ks along gradients of disturbance and confirmed the increasing trend of hydraulic conductivity with forestation processes. Dada et al., (2019) investigated the effect of cattle treading on soil physical and hydraulic properties in Abeokuta, Southwest Nigeria.

This study is aimed at the analysing Soil-Water Characteristic and water stress Estimates in selected agricultural area in Gidan Kwano area of North central Nigeria and to evaluate the soil physical attributes using SPAW model.

MATERIALS AND METHODS

Study Area

Gidan Kwano in Bosso Local Government area of Niger state is located within the North Central part of Nigeria in Niger State, 12 km from the state capital, Minna along Minna-Bida express road. Gidan Kwano lies between Latitudes 9°31'N and Longitudes 6°26'E with an estimated land mass of about eighteen thousand nine hundred hectares (10,000 ha). The site is bounded Northwards by the Western rail line from Lagos to the northern part of the country and the eastern side by the Minna – Bida Road and to the North – West by the Dagga hill and river Dagga (Musa, et al., 2011). Table 1 presents the coordinates of the various locations where the soil samples were collected from the research farm of the Federal University of Technology, Minna, Nigeria. The soil samples were collected at two level of 0-15 cm and 15-30 cm for each location. This is based on the finding of Afolabi et al., (2014).

Table 1: the coordinate of the study sites

Locations	Latitude (North)	Longitude (East)
Plot 1	9^{O}31'1"	6^{O}27'30"
Plot 2	9^{O}30'45"	6^{O}27'02"
Plot 3	9^{O}31'10"	6^{O}27'24"
Plot 4	9^{O}31'50"	6^{O}27'09"
Plot 5	9^{O}31'43"	6^{O}27'37"
Plot 6	9^{O}31'35"	6^{O}27'40"

Soil physical properties

Soil Texture

The hydrometer method was employed to determine the particle size distribution of the various soil samples collected and soil textural classification carried according to Elfaki *et al*. (2016).

Bulk density

Soil bulk densities were determined using the method described by Fullhart et al., (2018). Soil samples were collected using the soil core sampler at depths 0-15 cm and 15-30cm for each of the study location. The core sampler used had a ring cylinder with a height of 5.1cm and diameter of 5cm. The soil extending beyond each end of the sample holder was trimmed to ensure soil is contained in exactly the volume of the sampler holder. The soil core where wrapped in polyethylene, placed in wooden box and transported to the laboratory for analysis. This is in accordance with the works of Haselbach et al., (2017). The soil samples were transferred to a container, place in an oven at 105^{o} C, and dried to constant weight. The weight of soil was recorded and bulk density was calculated from the relationship in equation 1 and the relationship is in line with the study conducted by Musa et al. (2011).

$$\rho_b = {M_t}/{V_t} \text{ ----------(1)}$$

Where M_t is the total oven-dry mass of the soil (kg) and V_t is the volume of the soil V_t (m^3).

Statistical analysis

The results obtained from the field and those determined using the SPAW model were statistically compared using SPSS 20.0 version (2020) at a significance level of ≤ 0.05 were at various depths. The mean and standard deviation for the various samples collected were also determined. ANOVA test was carried out to check if there be any significance between the points.

RESULTS

The results of soil textural classifications, available water/moisture content and bulk density obtained from different plot of the study areas and the modelled data are presented in Tables 1. The sand content of the soils was relatively high, while the silt and clay contents were observed to be low. The Mean, Standard deviation and the Standard error mean of all the properties considered for this study are presented Table 3. The plot data at different soil depth of 0-15cm and 15-30cm were analysed to investigate the rate of deviation between the observed and the modelled data for the different plots.

Table 1: Textural classification of soils for the modelled and observed data

Plots	Sand (%)	Slit (%)	Clay (%)	Textural Classification	Available Water (cm/cm)		Bulk density (g/cm^3)	
					Observed	model	Observed	model
1	57	11	32	sandy clay loam	18.55	0.09	1.64	1.44
	56	8	36	sandy clay	18.50	0.09	1.57	1.45
2	61	10	29	sandy clay loam	16.90	0.09	1.39	1.44
	59	10	31	sandy clay loam	16.44	0.09	1.52	1.44
3	58	20	22	sandy clay loam	18.12	0.10	1.47	1.49
	51	14	35	sandy clay	15.18	0.10	1.40	1.40
4	48	11	41	sandy clay	16.02	0.10	1.48	1.37
	53	12	35	sandy clay	14.76	0.10	1.46	1.41
5	60	14	26	sandy clay loam	17.70	0.09	1.50	1.48
	62	13	25	sandy clay loam	20.22	0.09	1.38	1.49
6	56	16	28	sandy clay loam	17.70	0.10	1.52	1.46
	50	14	36	sandy clay	18.12	0.10	1.46	1.38

Table 2: Statistical variation between the modelled and observed data

Parameter	Sand (%)		Silt (%)		Clay (%)		Bulk Density (g/cm^3)		Observed Available water/Moisture Content (cm/cm)		Modelled Available water/Moisture Content (cm/cm)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
N	6	6	6	6	6	6	6	6	6	6	6	6
Mean Value	56.67	55.17	13.67	11.83	29.67	33.00	1.50	1.47	17.50	17.20	0.10	0.10
Standard Deviation	4.63	4.71	3.83	2.40	6.47	4.34	0.08	0.07	0.91	2.11	0.01	0.01
Standard Error Mean Value	1.89	1.92	1.56	0.98	2.64	1.77	0.03	0.03	0.37	0.86	0.00	0.00

Where N is the number of sampled plots

DISCUSSION

The Physical properties of percent soil constituents obtained at various depths from the field were also used to determine the hydraulic properties of the samples using the SPAW model. The obtained data from the field showed that there exist a low silt/clay soil ratio which suggest that the area under study have not been put into effective agricultural practice thus a low degree of erosion activities. This result negates the works of Afolabi et al., (2014) which carried out a similar study within the permanent site irrigation farm of the Federal University of Technology, Minna. Most of the soil samples in the depth region of 0 -15 cm shows that they are mainly sandy clay in nature while those in the depth region of 15-30 cm and sandy clay loam soils. It is observed that there is a relationship between the upper and lower layers of the soils. These findings are similar to the works of Musa et al., (2014). The highest values sand, silt and clay content where observed in plots 5 at a depth of 15-30 cm, plot 6 at a depth level of 0-15 cm, and at plot 1 at a depth of 15-30 cm respectively while the lowest values of sand, silt and clay were observed at plot 6 at a depth of 15-30 cm, plot 1 at a depth of 15-30 cm, and plot 3 at a depth of 0-15 cm respectively. The textural classification of the of the soil of the study area indicated that the most common type of soil is the sandy clay loam which are easily detached but hard to transport (Bonilla and Johnson, 2012; Mirzaee et al., 2017). This therefore reveals that the actual percentage of sand in any soil sample determines to a great extent the saturated hydraulic conductivity of that particular soil (Afolabi et al, 2014). Thus, there are some level of variation in the percent sand, silt, and clay content of the various soil samples collected which is similar to the works of Okon et al., (2017) and Deb et al., (2019) for the differences in physicochemical properties of soils under oil palm plantations of different ages in Ohaji/Egbema, Imo State and Variability of soil physicochemical properties at different agroecological zones of Himalayan region: Sikkim, India respectively.

The mean values of sand, silt and clay at depths 0-15 cm were 56.67%, 13.67% and 29.67% while at 15-30 cm depth the values are 55.17%, 11.83%, and 33.00% respectively. The standard deviation observed between the relationship of the actual field data for soil depth of 0-15 cm are 4.63, 3.83 and 6.47 while for soils at depth of 15-30 cm are 4.71, 2.40 and 4.34 respectively. it is observed that the upper most soil had a higher deviation compared to those at the lower end of the soils which is similar to the findings of Shuman et al., (2010) in which they studied the measurement Scheduling for Soil Moisture Sensing: from physical models to optimal control. The standard error mean value for the various soil samples at depth 0-15cm for sand, silt and clay are 1.89, 1.56 and 2.64 respectively while for depth of 15-30 cm were 1.92, 0.98, and 1.77 respectively.

Available soil water/moisture content is the amount of water required by plants from the date of planting to the date of harvest (Musa et al., 2020). Thus, it is an important control on hydrologic function, as it governs vertical fluxes from and to the atmosphere, groundwater recharge, and lateral fluxes through the soil (Hernández et al., 2018). Soil water characteristics is dependent on the relationship between the soil and amount of water available for plant use which is a determinant factor for the establishment of an irrigation command area (Kunah et al., 2019). It is also an excellent metric of hydrologic model performance, as it integrates temporal variation in precipitation and evaporation and is responsive to topography and soil physical properties governing fluxes of water (Nasta et al., 2018). The laboratory results obtained for the various soil samples within the study area indicates that the available soil water/moisture content determined where relatively high when compared with that obtained from the model. The field result had a maximum and minimum values of 20.22 and 14.76 cm/cm while the modelled result was between 0.09 and 0.10 cm/cm. This difference observed is linked to the high moisture holding capacity of clay which was found to be common at this soil depth and also the model used here is generalized which is not site specific. The observed values are within the firm work of Musa et al., (2014) which studied the effect of Water Stress on the Yield of Selected Vegetable Crops in the Southern Guinea Savannah Ecological Zone of Nigeria. The mean values for the observed available water/moisture content for soil depth of 0-15 cm was 17.50 cm/cm while for soil depth of 15-30 cm was 17.20 cm/cm. it is observed that there is a good relationship of water transmission between the various depths considered. The modelled available water/moisture content for depth of 0-15 and 15-30 cm was o.10 respectively. the standard deviation for the observed and modelled available water/moisture content for the soil depths of 0-15 and 15-30 cm were 0.91 and 0.01 respectively while for soil depths of 15-30 cm was 2.11 and 0.1 respectively. The standard mean error values for the available water/moisture content for soil depths of 0-15 cm and 15-30 cm was 0.37, 0.00, 0.86 and 0.00 respectively.

The values of the soil bulk density observed in the study area where observed to be highest at 1.64 for plot 1 and lowest at 1.38 for plot 6 for soil depths of 0-15 cm and 15-30 cm respectively while that of the modelled values ranged between 1.37 and 1.49 g/cm^3. The obtained results from the field were found to be similar to the studies conducted by Musa and Egharevba (2009), Musa et al., (2011) and Afolabi et al., (2014) for the soils of the same study area. The reason for the high bulk density in plot 1 could be linked to the high percentage of silt and clay content and the possible proximity of underlaying rocks to the soil surface.

The field and predicted data using laboratory and SPAW methods were also subjected to independent sample t-test to examine if there are similarity between the sample depth and the site location using Levene's Test for Equality of Variances at significant level of =1 and t-test for Equality of Means (2-tailed ≤ 0.05). The result shows that there is no significant effect on the soil parameter predicted when considering both the Levene’s Test for Equality of variance and T-test for equality of means which indicate that the predicted data was adequate and revealed the true status of the study location. Analysis of variance (ANOVA) also show no statistical significant on the effect within the group of parameter on the soil sample.

CONCLUSION

This study showed that some soil physical properties such as texture, organic matter, and bulk density are most important parameters used in determining predicted the hydrological data using SPAW model. Light textured soil (0-15cm) depth were observed to have a higher soil- water characteristics rates than the heavier textured soils (15-30 cm) depth which is due to the large conducting pores in sandy soil. Sandy loam and sandy clay loam were major soil texture found in the selected sites. The organic matter at depths of 0-15 cm and 15-30 cm were high compared to other available researches conducted for soils of the same area. It was discovered that the soil- water characteristics rates of the tested soil at different plot was not significant ($P \leq 0.05$). This soil-water characteristic capacity can become stable over a long period. Based on the end data obtained from the soil- water characteristics rates, classification of the various soils shows high level of accuracy of the SPAW model using independent t-test and Analysis of variance statistical analysis judgment to validate adequacy of the model on soil sample of the Gidan Kwano Area, Minna was made conceivable.

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