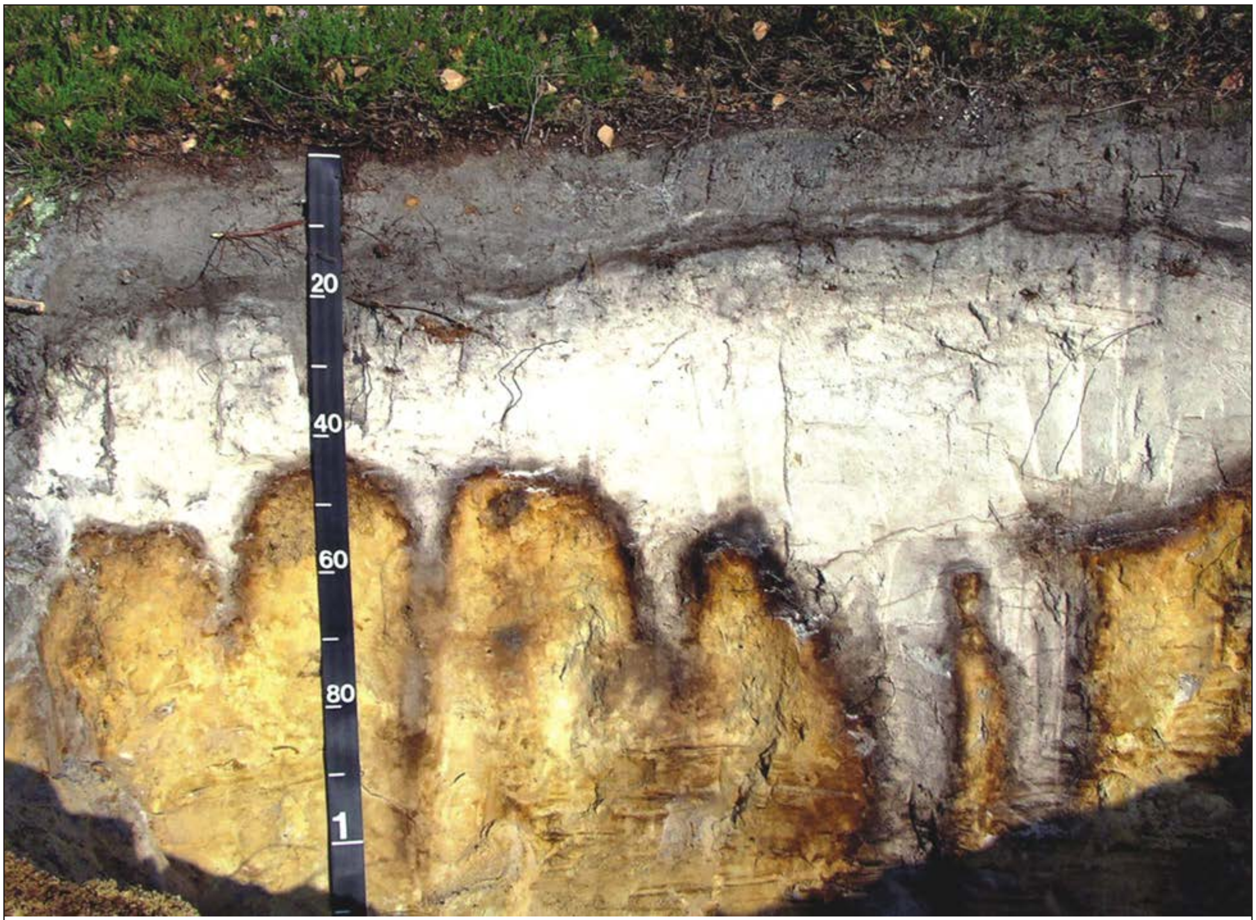

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Evaluation of SOILWAT Model for Predicting Soil Water Characteristics in Southwestern Nigeria

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ABSTRACT

Investigations of soil water potential and its variability with soil characteristics are necessary for studying water availability for plants, plant water stress, infiltration, irrigation scheduling, drainage and water conductivity. However, measurements of soil water characteristics are difficult, costly and time consuming. A modified version of the SOILWAT model (2006) of the soil water characteristics was adapted to 50 (replicated thrice) soil samples collected at depths 0-60 cm from upper, middle and lower slopes in 12 dug profile pits in 5 states of Southwestern Nigeria. Samples were assessed for their physical, hydrological and chemical parameters in the laboratory and compared with the simulated values obtained with the SOILWAT model. Coefficient of determination (R^2) as a goodness-of-fit index of agreement and the Root Mean Square Error (RMSE) were computed. The soils textural class varied from Sand, Sandy loam, Loamy sand and Sandy clay loam. There was good agreement between the measured and simulated bulk density for Sandy loam texture class ($R^2 = 0.722$; RMSE = 0.476), saturated moisture content ($R^2 = 0.544$; RMSE = 30.135), field capacity ($R^2 = 0.770$; RMSE = 86.877) and available water content ($R^2 = 0.547$; RMSE = 0.940) at $p<0.05$ probability level. However, a poor fit was observed for saturated hydraulic conductivity and permanent wilting point. SOILWAT had a fairly good prediction of bulk density for a Sand texture class ($R^2 = 0.460$, $p<0.05$, RMSE = 0.476) but a poor fit for saturated hydraulic conductivity, saturated moisture content, field capacity, permanent wilting point and available water content. However, it had the smallest RMSE when compared to the other texture class.

Key words: Goodness-of-fit, measurement, simulation modelling, SOILWAT model, soil water

INTRODUCTION

Soil water is defined as the infiltrated water shallow enough to be used by plants (Kern, 1995). Soil water characteristics is dependent on the soil water retention B soil water potential, which is necessary for studying water availability for plants, plant water stress, infiltration, irrigation scheduling, drainage and water conductivity. The distribution of water within the soil column will be an indispensable factor in understanding the response of plants and soil water systems to the impacts of climate change (Walczak *et al*., 2002).

Measurement and analyses of the soil water characteristics are difficult, costly and time consuming. Hence, the use of expensive special equipment becomes necesssary. Several research studies over last three decades has formulated models, which enables its determination on the basis of measured soil physical and chemical properties, which serves as inputs (Rajkai and Varallyay, 1989; Williams *et al.*, 1992; Saxton and Rawls, 2006).

These models are referred to as pedotransfer functions (PTFs) (Bouma, 1989). Soil water modelling is defined as the dynamic simulation of hydrologic processes by numerical integration of individual processes with the aid of computer (Saxton *et al.*, 1986). A better understanding of agricultural water management and hydrological analyses to a form a reliable predictive soil water characteristics system will be dependent upon simulation modelling (Saxton and Rawls, 2006).

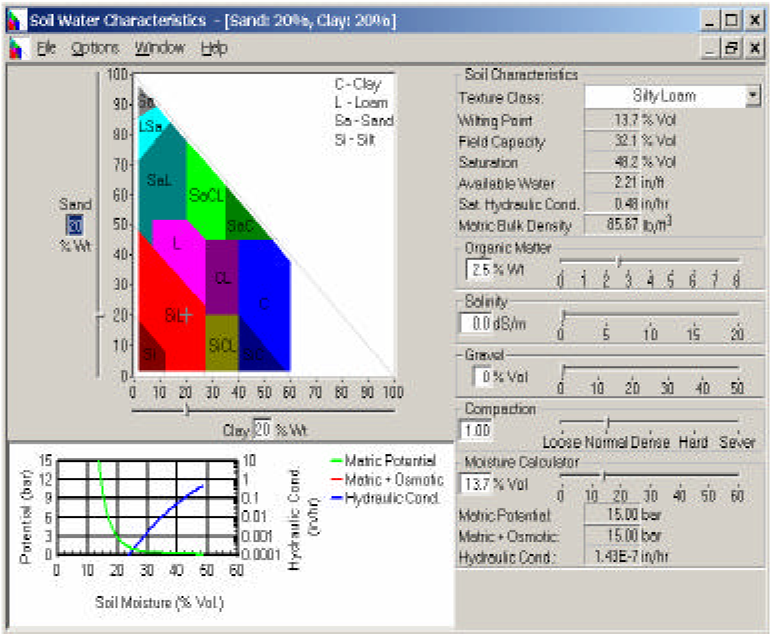
The Soil and Water Assessment tool (SOILWAT) is a modelling software package to analyse water, soil, agriculture and nutrient interactions at catchment modelling. This is a technology used to construct a relatively transparent surrogate (substitute) for the real soil water, then combined into a more comprehensive results and analysed by statistics which can be manipulated with far greater ease than the complex original (Saxton and Rawls, 2006).

Soil water retention as a function of sand and clay textures and organic matter is described by a set of generalised equations (Rawles and Brakensiek, 1982; Rawls *et al.*, 1982; Saxton *et al.*, 1986; Saxton and Rawls, 2006). Gijsman *et al.* (2002) reported an extensive review of eight modern estimating methods applicable to hydrologic and agronomic analyses. They observed significant discrepancy among the methods due to the regional data basis or methods of analyses thus creating doubt on the value of lab-measured water retention data for crop models. They concluded that an analysis with asset of field-measured data showed that the method of Saxton *et al.* (1986) performed the best. Thus, an enhancement of the Saxton and Rawls (2006) method is an appropriate extension to improve the field applications of soil water characteristic estimates with improved data basis and supplemented by recently derived relationships of conductivity and including appropriate local adjustments for organic matter, density, gravel and salinity.

A soil-water (SOILWAT) model capable of simulating soil hydrological properties of soil texture will help scientist in providing crucial data set for better understanding of our soils for better management. These data are also critical requirements in crop simulation models for decision making aimed at obtaining optimum results. Xue *et al.* (1996) compared soil moisture observations with modeling results, he reported that the soil hydraulic parameters have a profound impact on the model simulations. The objective of this study was to compare the prediction made by SOILWAT model with the measured soil parameters and evaluate the general applicability and prediction accuracy of SOILWAT model for the predominant soil types in the derived savannah of Southwestern Nigeria.

MATERIALS AND METHODS

Soil and water assessment tool (SOILWAT model): Soil water characteristics hydraulic properties calculator developed by Keith Saxton in cooperation with Department of Biological Systems Engineering Washington State University. The soil water characteristics equations are valid within a range of soil textures approximately 0-60% clay content and 0-95% sand content. Adjustments to the solutions have been added to include the effects of bulk density, gravel and salinity (Tanji, 1990). A programmed texture triangle as an input screen (Fig. 1) provides a ready solution to the equations and values for the layer definitions of the soil profile. This methodology is incorporated in the model and is also available as a stand-alone program.



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

Sand 20 % Wt

Clay 20 % Wt

Soil Characteristics

Texture Class:	Silty Loam
Wilting Point	13.7 % Vol
Field Capacity	32.1 % Vol
Saturation	48.2 % Vol
Available Water	2.21 in/ft
Sat. Hydraulic Cond.	0.48 in/hr
Matric Bulk Density	85.67 lb/ft^3

Organic Matter 2.5 % Wt

Salinity 0.0 dS/m

Gravel 0 % Vol

Compaction 1.00

Moisture Calculator 13.7 % Vol

Matric Potential	15.00 bar
Matric + Osmotic:	15.00 bar
Hydraulic Cond.:	1.43E-7 in/hr

Fig. 1: Graphical input screen for the soil water characteristic model

Soil sample strategy: Undisturbed samples (50) were collected in triplicates (150) using a 98.17 cm^3 core sampler at depths of 0-60 cm from twelve dug mini profiles pits of 45×45 cm at the surface and 80 cm deep. Topographic landscapes at upper, middle and lower slopes in grassland and farmland vegetations in 5 states (Lagos: Iweka Series, Ogun: Alagba Series, Oyo: Iwo and Apomu Series, Osun: Itagunmodi Series, Ondo: Owo Series in South-Western Nigeria; Guinea Savannah zone classified as an Alfisols (USDA) order. The soils are indicated as Typic Tropoquent (Smyth and Montgomery, 1962) or Euteric Gleysol (FAO, 1983) and Ferric luvisol and Oxic Rhodustalf (FAO, 1988). Coordinates and elevation above sea level of the sites were obtained (Fig. 2).

Determination of soil solid and liquid phase of soil water potential-soil water content characteristics were performed on soil samples using standard procedures (USDA/SCS, 1982). Measurement of particle size distribution, bulk densities, gravimetric moisture content, hydraulic conductivities, lower and upper limit of soil potentials. Chemical analyses of organic carbon content were also determined. Soil gravel content was separated and weighed.

Soil properties: The physical and chemical properties measured are presented in Table 1. The data presented were of soil properties values ranging from the least to the highest values obtained for each soil characteristics.

Experimental setup and textural class: Particle size analyses of the soils obtained from the experimental sites indicates a sand, loamy sand, sandy loam and sandy clay loam textural classes. This variation in textures was used as the basis for grouping the soils and subsequently, for easy computation of the data sets for verification by the model; since the texture predominately determines the water holding characteristics of most agricultural soils reported by Saxton *et al.* (1986). A greater number of the sampled soils were of loamy sand texture with sandy loam, sandy clay loam and sand textural classes in that order as depicted in Table 2.

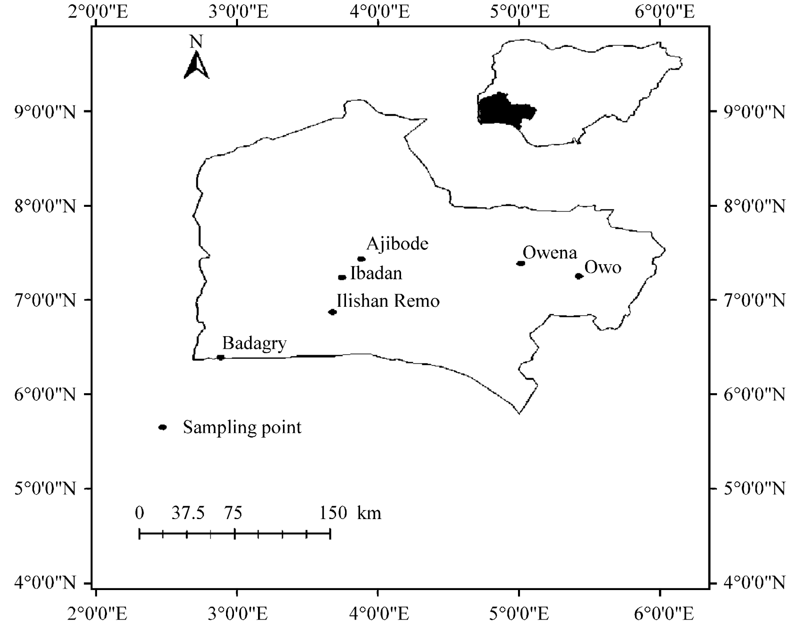


Fig. 2: Map showing the sampled locations (Dept. of Geography, University of Ibadan, Nigeria)

Table 1: Range of values of soil properties

Soil characteristics	Values
Bulk density (Mg m^{-3})	0.98-1.74
Organic carbon (%)	0.52-3.62
Saturated hydraulic conductivity (cm h^{-1})	1.89-97.78
Gravel content (% w)	0.10-81.20
Sand (g kg^{-1})	660-920
Clay (g kg^{-1})	60-310
Silt (g kg^{-1})	10-130

Table 2: Textural classes and their mean particle contents

		Particle content (%)		
Textural class (USDA)	No.	Sand	Silt	Clay
Sand	7	90.51 ±0.99	2.63±0.98	6.86 ±1.07
Loamy sand	25	85.22 ±2.26	4.78 ±2.28	10.00 ±1.28
Sandy loam	10	77.46 ±3.73	7.72 ±3.80	4.82 ±2.95
Sandy clay loam	8	72.97 ±3.69	2.75 ±0.87	24.28 ±3.64

Values are Mean±SD. USDA: United State Department of Agriculture

Statistical analysis: For comparison of the difference between predicted soil water characteristic parameters and observed values, coefficient of determination (R^2) as a goodness-of-fit index of agreement and the Root Mean Square Error (RMSE) were computed. Willmott (1981) described RMSE as 'among the best overall measures of model performance', of which RMSE is more sensitive to extreme values due to its exponentiation; it therefore can be considered as a high estimate of the actual average error. The index of agreement is a standardized measure (scale 0-1) of the degree to which a model's predictions are error free. y_i denotes the measured value, $\hat{y}_i$-the predicted value, $\bar{Y}$-the average of the measured value and N is the total number of observations:

$$R^2 = 1 - \frac{\sum_{1}^{N}(y_i - \hat{y}_i)^2}{\sum_{1}^{N}(y_i - \overline{Y}_i)^2}$$

$$RMSE = \sqrt{\frac{\sum_{1}^{N}(y_i - \hat{y}_i)^2}{N}}$$

RESULTS AND DISCUSSION

Correlation between measured vs. simulated soil water characteristics: A comparison is presented between measured and simulated water content for the 50 soil samples using the Saxton and Rawls (2006) model. The statistical results are presented in Table 3. Amongst the four

Table 3: Linear regression of the texture class as related to the soil water characteristics

	Linear regression	
Texture class	R^2	RMSE
Bulk density		
S	0.460*	0.476
LSa	0.033ns	1.46
SaL	0.722*	0.476
SCL	0.049ns	0.411
Ks		
S	0.000ns	33.248
LSa	0.025ns	166.16
SaL	0.135ns	78.486
SCL	0.000ns	104.685
Sat.MC		
S	0.259ns	23.51
LS	0.191ns	31.46
SaL	0.544*	30.135
SCL	0.228ns	41.194
FC		
S	0.167ns	58.811
LSa	0.181ns	116.108
SaL	0.770*	86.877
SCL	0.157ns	81.323
PWP		
S	0.339*	8.426
LSa	0.178ns	16.626
SaL	0.361*	9.729
SCL	0.413*	10.791
AWC		
S	0.115ns	0.632
LSa	0.084ns	1.345
SaL	0.547*	0.94
SCL	0.255ns	0.906

R^2: Coefficient of determination, RMSE: Root mean square, Ks: Saturated hydraulic conductivity, Sat.MC: Saturated moisture content, FC: Field capacity, PWP: Permanent wilting point, S: Sand, Lsa: Loamy sand, SaL: Sandy loam, SaCL: Sandy clay loam, ns: Non significant, *Significant at 5% probability level textural classes, the SOILWAT provided a superior estimation of all the soil water characteristics for the sandy loam than for sand, loamy sand and sandy clay loam soils. A better fit for bulk density and field capacity between the simulated and measured soil water characteristics relationships was observed in sandy loam texture as depicted in Fig. 3.

The SOILWAT model produced a fairly good prediction of bulk density for sand soil with a R^2 of 0.460 and RMSE of 0.411. The results showed a lower RMSE for sand soil which ranged from 0.411 to 54.81 when compared to sandy loam which had the better prediction (higher R^2) of all the textural class with RMSE values, which ranged from 0.476 to 86.877 as presented in Table 3.

Bulk density: When compared with the measured data, SOILWAT significantly simulated Bulk Density (BD) for Sandy loam ($R^2 = 0.722$, $p<0.05$; RMSE of 0.476 and regression equation given as; $Y = 0.754x+0.451$) as presented in Table 3. The relationship between the simulated and measured values showed that 72.2% of the fluctuation in the measured values was explained by the model; which indicated a good prediction as shown in Fig. 3. For sandy soil, SOILWAT had a fairly good simulation ($R^2 = 0.460$, $p<0.05$; RMSE of 0.411). While, for Loamy sand and Sandy clay loam soils, it had a poor-fit. The concentration of the sand soil in one site i.e., non-uniformity of the distribution of sand texture class amongst the sites may be one among other factors responsible for the fairly good-fit between measured and simulated data since the variation in the textural class amongst the sites was defeated. Gijsman *et al.* (2002) reported that the SOILWAT, though, performed best among other models compared in his studies, but this does not apply to all soils. For very sandy soils, no method performed well. The high amount of coarse-size particles in the sandy soils is possibly the reason for the fairly good-fit by the model (Fredlund *et al.*, 2002; Hwang and Powers, 2003).

Saturated hydraulic conductivity: Loamy sand and Sandy loam soils had a low R5 and a negative regression equations (R5 = 0.025, $y = -0.023x+6.939$, RMSE = 166.16 and R5 = 0.135, $y = -0.148x+8.532$, RMSE = 78.486, respectively) when simulated with the model as presented in Table 3. For Sand and Sandy clay loam, it had no correlation (R^2 of 0.000 and RMSEs of 33.25 and 104.69, respectively). Since sample environment (confinement and overburden) are not represented in laboratory procedures, laboratory data may not always agree with field data. The disagreement appears more pronounced at high water contents (Arya and Dierolf, 1992).

Saturated moisture content: The model had a fairly good-fit for sandy loam with R^2 of 0.544; RMSE of 30.460. While, sand, sandy clay loam and loamy sand had a poor-fit (R^2 of 0.259, 0.228 and 0.191, respectively) as depicted in Table 3.

Field capacity: SOILWAT predicted field capacity significantly for Sandy loam soil ($R^2 = 0.770$, $p<0.05$; RMSE of 86.877). This indicted that 77% of the variation in the measured values is explained by the model as indicted by the relationship the between simulated and measured values and thus represented a good-fit (Fig. 3). But it had a poor-fit for Loamy sand ($R^2 = 0.181$), sandy clay loam ($R^2 = 0.157$) and $R^2 = 0.167$ for sand soil which also presented a negative regression as showed in Table 3. Tomasella and Hodnett (1998) reported that, in many cases, the textures of many tropical soils, particularly oxisols such as those of Brazilian Amazonia, are outside the range of validity of these PTFs. As a result, the water retention estimations may also be significantly in error or they may fail totally, for example by indicating a water content at field capacity that is

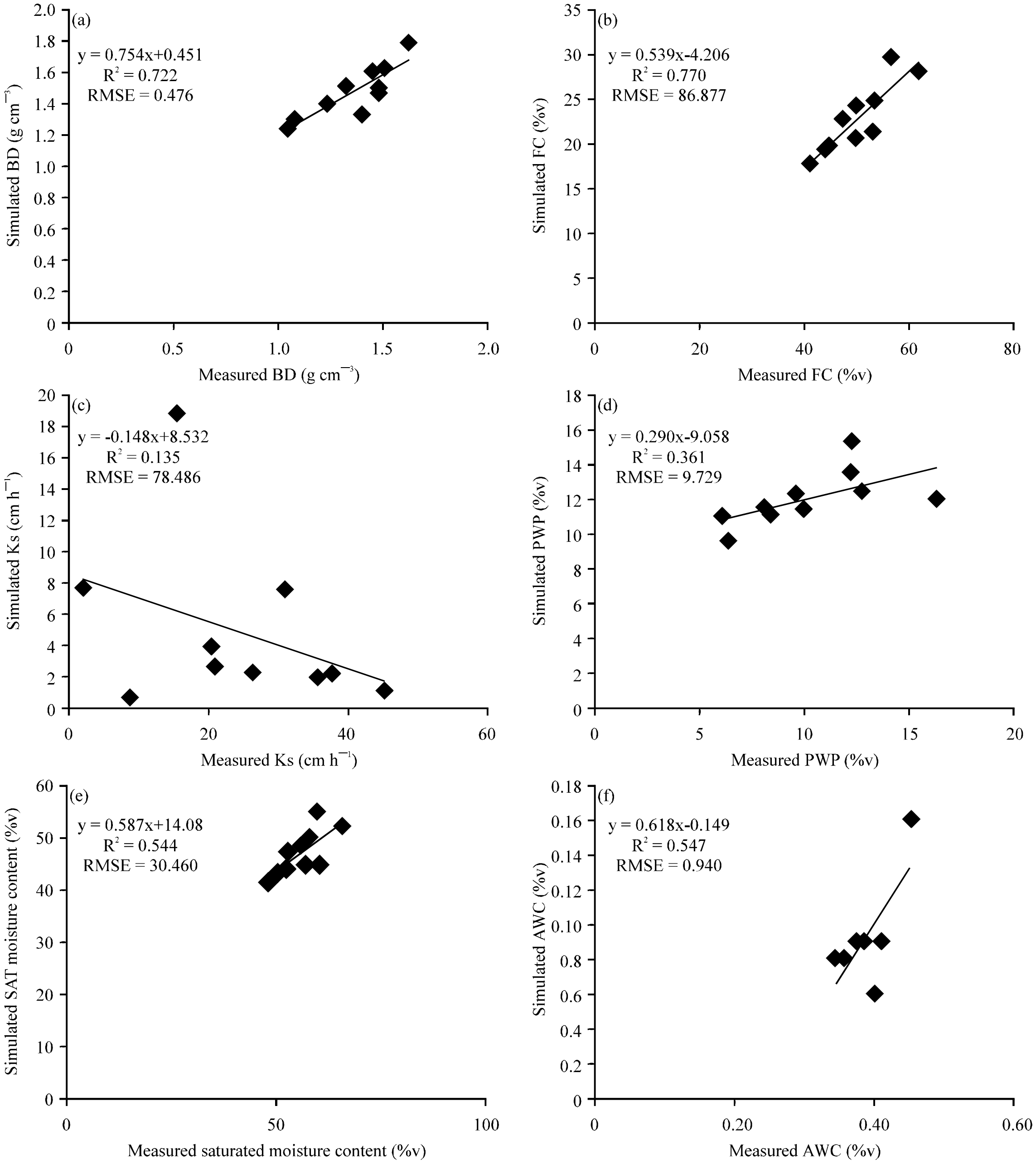


Fig. 3(a-f): Relationship between simulated vs. measured soil water characteristics of Sandy loam soil, (a) Bulk density, (b) Field capacity, (c) Saturated hydraulic conductivity, (d) Permanent wilting point, (e) Saturated moisture content and (f) Available water content

higher than at saturation. This occurs using the PTF of Mishra *et al.* (1989) for oxisols from Nigeria and Brazil with clay contents of 52 and 85%, respectively. The predicted moisture retention curve often falls to zero volumetric water content before the experimental data are complementary desaturated (Fredlund *et al.*, 1997).

Permanent wilting point: A poor-fit with SOILWAT was achieved in all the texture classes (Table 3). Nagpal and De Vries (1976) and Arya and Dierolf (1992) reported that laboratory data may not always agree with field data, probably as a result of sample size as observed in the laboratory measurements. The results of the study showed that the model had a poor-fit for the soil types at low soil water content. However, Arya and Dierolf (1992) reported that the disagreement appears more pronounced at high water contents.

Available water content: Sandy loam recorded a fairly good-fit when simulated (R^2 of 0.547 with RMSE of 0.940). A poor-fit of the model was observed for sandy clay loam, loamy sand and sand texture classes. Comparison of the measured to the simulated values shows a wide variation in the textural classes analysed as presented in Table 3.

Validation of the SOILWAT goodness-of-fit for soil water characteristics: For the 50 samples, the soil water characteristics were predicted using SOILWAT (Saxton and Rawls, 2006) model and the goodness-of-fit measurement obtained from the R^2 value. SOILWAT was found to provide a reasonable estimate of the soil water characteristics for sandy loam soils. There appears to be greater difficulty in estimating the soil water characteristics for loamy sand soils, sandy clay loam soils and sand soils.

It has been previously noted that it is particularly difficult to estimate the soil water characteristics from particle-size distribution for some texture class. The general soil categories include: (i) soils that have high amount of coarse-size particles, mixed with few fines and (ii) soils that have high amount of clay size particles (Fredlund *et al.*, 2002; Hwang and Powers, 2003). The same trend was found to be true for the experimental/sampled soils. Sampling error or bias in field sampling e.g., sample size, presence of roots and gravel particles which serves as obstacle in obtaining undisturbed samples. The model had a tolerable range of 0-60% for gravel content.

CONCLUSION

The SOILWAT model resulted in higher coefficient of determination for Sandy loam soil which expresses the goodness-of-fit between the simulated and measured values. However, the poor-fit measurement of the model for sand, loamy sand and sandy clay loam might be as a result of the sensitivity of the model in terms of location or site-specific and the high gravel content of the sampled soils which made up this textural class. The SOILWAT model has a tolerable range of 0-60%. The ability of SOILWAT to simulate soil water characteristics for sandy loam soil demonstrates the potential of the model when properly initialised and field measurement accurately taken. SOILWAT has shown the potential of serving as tool that would enable decision makers to explore the future of sustainable agriculture, even in developing countries where soil water extraction apparatus have become a limitation in determining soil water availability. Despite the optimistic position of system modelling, realisation of the full potential depends considerably on availability and quality of inputs for running the model, taken into consideration location or site-specific information in developing the model.

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