MODELLING SOIL WATER RETENTION OF SOUTHWESTERN NIGERIA AS RELATED TO TEXTURE

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ABSTRACT: (9 pt)

Knowledge of the soil water retention is indispensable. Modern simulation and analyses of hydrologic processes relies heavily on appropriate descriptions of the soil water holding and transmission characteristics of the soil profile to form a comprehensive predictive system of soil water characteristics for agricultural water management and hydrologic analyses.

This paper analyses the soil-water (SOILWAT) model capable of simulating soil hydrological properties from soil texture necessary for providing crucial data set for better understanding of soils for better management.

Sampled soils were of Loamy sand, Sandy loam, Sandy clay loam and Sandy textural classes obtained from derived savannah zone of southwestern Nigeria. A total of 150 core samples were collected from different layers of dug profile pits of 1m depth.

Coefficient of determination (R^2) as a goodness-of-fit index of agreement and the root mean square error (r.m.s.e) were computed. The model had a good agreement between the measured and simulated for Sandy loam texture classes. R^2 = 0.79; R^2 = 0.62; R^2 = 0.76; R^2 = 0.55 and R^2 = 0.56 at $P<0.05$ probability level for bulk density, saturated moisture content, field capacity, available water and permanent wilting point respectively. However, a poor fit was observed for saturated hydraulic conductivity (R^2=0.13).

SOILWAT had a fairly good prediction for sand and sandy clay loam texture class for bulk density 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 r.m.s.e when compared to the other texture class.

1. INTRODUCTION

Texture predominately determines the water holding characteristics of most agricultural soils (Saxton *et al.* 1986). The determination of soil water potential-soil water content characteristics is both time and labour consuming and also requires the use of expensive special equipment. This is the reason that intensive work has been done for over decades on the formulation of algorithms - models, which enable soil water retention to be determined on the basis of other soil physical properties routinely measured in laboratories (Rajkai and Varallyay, 1989; Williams *et al.,* 1992).

The following soil properties are most frequently taken into consideration for the estimation of soil water retention curves: particle size distribution, organic matter content and bulk density (Rawls and Brakiensiek, 1982a; Rajkai and Varallyay, 1989). In some instances particle size distribution (PSD) is considered as the only parameter (Ahuja et al., 1985; Haverkamp and Parlange, 1986). Additionally, soil structure and the mineralogical composition of clays are used (Williams *et al*., 1992). For estimation of the water retention curve, the particular measured values of water characteristics are sometimes used, i.e., water content under complete saturation, water content at chosen soil water potential values and the amount of water available for plants (Rawls and Brakensiek, 1982a).

These models are referred to as pedotransfer functions (PTFs) (Bouma, 1989). A dynamic simulation of hydrologic processes with the aid of a computer, which is used to construct a relatively transparent surrogate (substitute) for the real soil water and then combined into a more comprehensive result and analyze by statistics or time series; thus can be manipulated with far greater ease than the complex original.

Modern simulation and analyses of hydrologic processes relies heavily on appropriate descriptions of the soil water holding and transmission characteristics of the soil profile to form a comprehensive predictive system of soil water characteristics for agricultural water management and hydrologic analyses. This paper analyses the soil-water (SOILWAT) model capable of simulating soil hydrological properties by comparing the measured values with the simulated.

2. MATERIALS AND METHODS

2.1 Soil and Water Assessment Tool (SOILWAT)

The Soil and Water Assessment tool (SOILWAT) is a modelling software package to analyse water, soil, agriculture and nutrient interactions at catchment modelling. The technique is a set of generalised equations which describes soil tension and conductivity relationships versus moisture content as a function of sand and clay textures and organic matter (Rawls *et al.,* 1982b; Saxton *et al.,* 1986; Saxton and Rawls, 2006).

2.2. Field Sampling

Undisturbed samples were collected in triplicates using cores samplers dug from profile pit cut across the locations sampled. Samples were taken at depths of 0-100cm. Coordinates and elevation above sea level was obtained.

2.2.1. Laboratory Analyses

Measurement of physical and chemical analyses was determined following standard procedures. Soil gravel content was separated and weighed.

2.3. Statistical Analyses

For comparison of the difference between predicted soil water characteristic parameters and observed values, coefficient of determination as a goodness-of-fit index of agreement and the root mean square error (RMSE) were computed. The index of agreement is a standardized measure (scale 0-1) of the degree to which a model's predictions are error free.

3. RESULTS AND DISCUSSION

3.1. Soil Properties

The data presented were of soil properties (physical and chemical) values ranging from the least to the highest values obtained for each soil characteristics (Table 1.).

3.1.1. Texture

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 texture predominately determines the water holding characteristics of most agricultural soils reported by Saxton *et al.* 1986.

3.2. Mean values of Soil Water Characteristics based on Textural class

3.2.1. Bulk density

Sand had the highest bulk density (Bd) values (1.48 mgm^{-3}) as shown in Table 2. The lowest Bd was recorded in Sandy clay loam had (1.35 mgm^{-3}) followed by loamy Sandy loam (1.36 mgm^{-3}) and Sand (1.41 mgm^{-3}). The high organic matter present in these textures increased aggregation of the particles thereby reducing the space occupied by the soil solid and invariably increased water holding capacity of these soils. The mechanical stress caused by the weight of overburden soil as a result of compaction of the increasing clay fraction may have caused an increased in the bulk density of sandy clay loam as summarised by Sonja *et al.,* 2005. It seems logical to expect that this stress would affect soil bulk density. Despite this, results show that depth is not a strong predicator of bulk density.

3.2.2. Organic matter

Result from Table 2 showed sand clay loam had the highest mean organic matter content (OM) (2.36%). Increased OM content produces a soil with increasing water holding capacity and conductivity largely as a result of its influence on soil aggregation and associated pore space distribution and also because of its hydrophilic character and its influence on soil structure. There was no change or actually an increased in plant available water holding capacity with changes in soil organic matter. This may be due to changes in water retention at both field capacity (FC) and permanent wilting point (PWP) and changes in Bd as summarised by (Bauer and Black, 1992). The high organic matter influenced the bulk density value of the soils.

3.2.3. Gravel

The highest mean gravel content was recorded in loamy sand (18.98 %w) and in sand (13.40 %w). Soils that form these two texture class had a significant amount of gravel within their 10-30cm depth. It is rational to assume that the net effect of soil with gravel compared to that containing only the matrix soil will be to decrease the available water content (AWC) and saturated hydraulic conductivity (Ks). Thus, the high gravel content in sand soil increased the Ks and a decrease in AWC (0.33 $cmcm^{-1}$) which had an influence on the high Bd of the soil. This may be as a result of the large pores created within the soil matrix by the gravel particles, and that the gravel particles do not contribute to soil water retention or hydraulic conductivity.

3.2.4. Saturated hydraulic conductivity

Generally, Sand soil has a preponderance of macropores. Thus, has the ability to transmit water easily when compared to the other texture class. Results from Table 2 showed a higher Ks mean value for sand soil (38.8$cmhr^{-1}$) when compared to the other textures. This may be due to a wide variability reflective of the presence of macropore channels e.g gravel particles, roots and others (Mohanty *et al*., 1994), difficulties in obtaining representative undisturbed cores samples (Arya *et al*., 1992), and the sample size which the constant head permeameter did not address (Pedro, 2007) for laboratory measured Ks.

3.2.5. Saturation moisture content

Also refer to as maximum water holding capacity of the soil such that the entire soil porosity is water filled, which is dependent on the soil texture. Soils of sandy clay loam texture held greater AWC (58.9 %v) than the other textures. This may be due to preponderance of micropores, capillarity and pores size distribution. Hence, it is strongly affected by the soil's structure (Hillel, 1998). The greater the clay content, in general, the greater the water retention at any particular suction.

3.2.6. Field capacity

FC designates water content at -33Kpa. The amount of water retained at -33Kpa is lowest in sand soil (39.2 %v) due to the preponderance of larger pores when compared to the pores sizes of loamy sand, sandy loam and sandy clay loam. Increasing suction is thus associated with decreasing soil wetness. A gradual increase in suction will result in emptying of progressively smaller pores as presented in the result. Hence, at lower suction the amount of water retained is greatly influenced by structure and less by texture as shown by the results.

3.2.7. Permanent wilting point

The water retention at higher suction (-1500Kpa) represents PWP. Sandy clay loam (11.9 %v) retains more water than the other texture class. This is due to the preponderance of narrow pores present. In Sandy soils, most of the pores are relatively large, and once these pores are emptied, only small amount of water (6.0 %v) is present as seen in the Table 2. At higher suction, water retention is influenced more by the soil's texture and specific surface and less by structure. In soils with clay, more of the water is absorbed so increasing the matrix suction causes a more gradual decrease in wetness.

3.2.8 Available water content

Water content available for plant use expressed in depth of water per depth of soil shows sandy soil with less amount of AWC (0.33 cmcm-^{1}) compared to the other textures as presented in Table 2. Generally, sandy loam and sandy clay loam have higher amount of plant available water than loamy sand and sand texture class due to the preponderance of micropores which retain water at higher suction. The amount of AWC measured for sandy loam, sandy clay loam, loamy sand and sand were within the range when compared to the average estimates of AWC for this same textural class (Cassel *et al*., 2005).

3.3. Relationship between Measured vs. Simulated Soil Water Characteristics based on Textural class

A comparison is presented between measured and simulated water content using the model. The data are presented in Table 3 and graphical presented in Fig. 2. Amongst the four 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 with a higher coefficient of determination ranging from 0.79 to 0.13. The SOILWAT model produced a fairly good prediction for sand soil.

3.4. Verification of SOILWAT Goodness-of-fit for Soil Water Characteristics

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

The same trend was found to be true for the experimental/sampled soils. Sampling error e.g. sample size, method and equipment employed 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.

4. CONCLUSION

The ability of SOILWAT to simulate soil water characteristics for Sandy loam soil and sand textures demonstrates the potential of the model when properly initialized 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, since most of tropical soils are of these textural classes and mostly in developing countries where soil water extraction apparatus have become a limitation in determining soil water availability.

Despite the optimistic position of system modelling, realization 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.

Table 1. Range of Soil Properties value

Soil characteristics	Values
Sand (%)	64-87
Clay (%)	8-26
Silt (%)	3-18
Bulk density (mgm^{-3})	1.38-1.68
Hydraulic conductivity ($cmhr^{-1}$)	2.45-79.00
Organic carbon (%)	0.25-2.55
Gravel content(%w)	0.15-71.0

Table 2. Mean Values of Soil Properties based on Textural class

Texture Class	OM	Gv	BD	Ks	Sat	FC	PWP	AWC
	%	%w	mgm^{-3}	$cmhr^{-1}$	% v	% v	% v	$cmcm^{-1}$
S	1.73	13.40	1.48	38.81	44.40	39.20	6.00	0.33
Lsa	2.13	18.98	1.41	31.58	48.16	42.88	7.20	0.36
SaL	2.24	9.43	1.36	24.31	55.74	50.10	10.2	0.40
Sa CL	2.36	1.40	1.35	25.60	58.88	51.90	11.9	0.40

Table 3. Mean values of Measured and Simulated Soil Water Characteristics

Texture Class	Msd. BD	Sim. BD	Msd. Ks	Sim. Ks	Msd. Sat	Sim. Sat	Msd. FC	Sim. FC	Msd PWP	Sim. PWP	Msd. AWC	Sim. AWC
	mgm^3		cm/hr		% v		% v		% v		cm/cm	
Sa	1.48	1.57	18.81	13.28	44.40	44.49	39.52	40.21	6.04	8.67	0.33	0.30
LSa	1.41	1.61	31.58	6.20	48.16	44.50	42.88	40.25	7.15	9.79	0.36	0.39
SaL	1.36	1.48	24.31	4.93	55.74	46.85	50.08	52.80	10.15	12.01	0.40	0.30
Sa CL	1.35	1.40	25.60	0.79	58.88	47.44	51.88	54.08	11.88	15.39	0.40	0.49

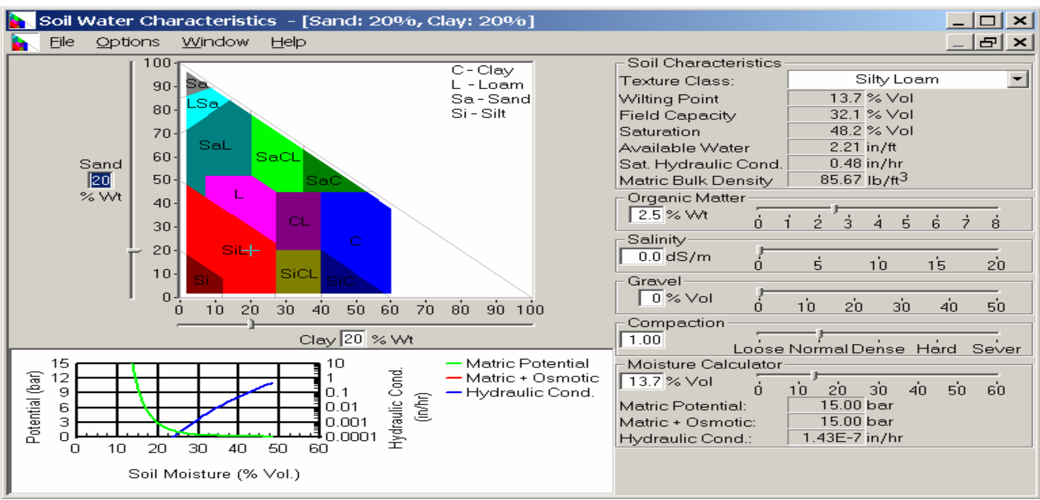

Fig.1. Graphical input screen for the Soil Water Characteristic Model

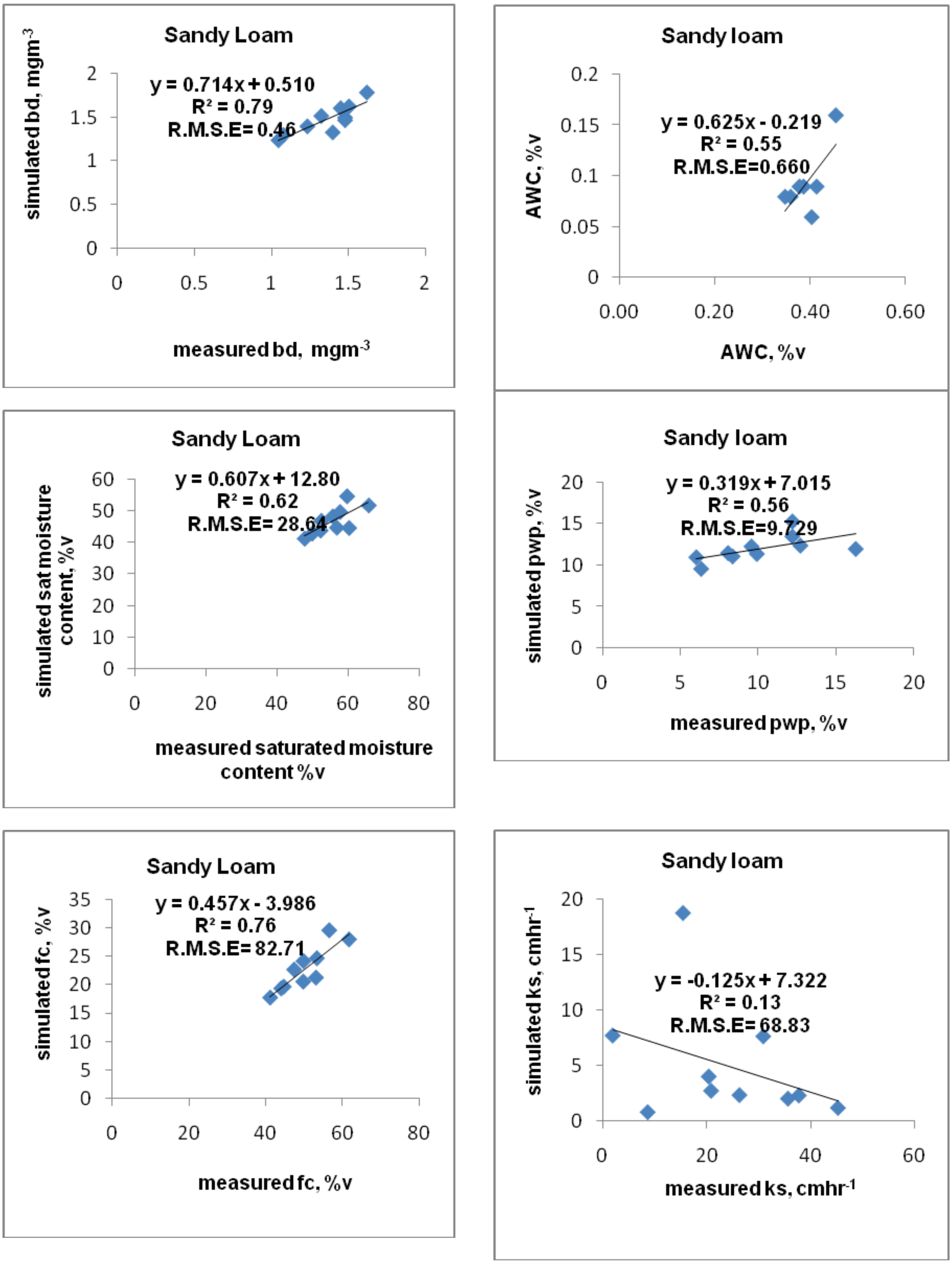

Fig. 2. Relationship between Measured and Simulated Soil Water Characteristics for Sandy loam Soil.

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