Infiltration Characteristics and Their Prediction On a Toposequence at Nsukka, South-Eastern Nigeria.

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Abstract- ***Predicting infiltration characteristics and dynamics is crucial for efficient soil management and prevention of erosion. A research aimed at evaluating the infiltration characteristics and their predictability was conducted on three prominent soil series distributed across a toposequence at Nsukka (south-eastern Nigeria), during the year 2008. Soil physical properties along with infiltration runs were evaluated at the crest, mid slope and toe slope of the toposequence. Predictability of infiltration parameters was evaluated with the Philip's and Kostiakov's models. Also measured were the particle size distribution, organic matter concentration and the initial moisture content of the top-(0-20 cm) soil. Results revealed that Uvuru series has the highest bulk density (1.51 g cm^{-3}), organic matter concentration (4.71%) and initial moisture content (12.57%). More still, organic matter content, microporosity, bulk density, initial moisture content, coarse sand, silt and clay contents, all had influence on the infiltration characteristics of the soils. The sorptivity parameter (s) of the Philip's model showed the highest coefficient of variation (92%) while the soil dependent parameter showed the least coefficient of variation (3.03%). High correlation coefficient (0.99-1.00) was found in the predicted and observed soil properties. Based on our findings, it was concluded that Philip's and Kostiakov's models gave good prediction of infiltration characteristics of the soil of Nsukka, Nigeria.***

***Keywords:** cumulative infiltration, Sorptivity, transmissivity, toposequence, infiltration models.*

I. Introduction

Infiltration of water into soils is one of the most important hydrological processes occurring at the soil-atmosphere interphase (Mbagwu, 1995). The entry of water into the soil is controlled by infiltration characteristics of the soil in a particular location. Hence, information about infiltration characteristics of watershed /toposequence is a vital tool in planning about irrigation/drainage project, and in the determination of runoff potential for purposes of introducing conservation measures. Infiltration characteristics also gives one of the most important information required not just by the hydrologists for monitoring the recharge and pollution of ground water reservoir, but also by agronomists for guarding against drought, as well as by agricultural engineers for the planning and recommendations of soil-water conservation strategies.

In the recent past, many studies have been carried out on this important soil property in Nigeria by different researchers (Oshushanya, 2010; Salako, 2002; Wilkinson 1995; and Lal 1979). Most of their reports on water infiltration characteristics into tropical soils indicated generally high to excessive infiltration rates when compared with most temperate soils (Greenland and Lal, 1997). Some reasons given for these high infiltration rates of tropical soils include abundant earthworm activity for soils of western Nigeria (Lal 1979), low bulk density and stubble aggregates for undisturbed surface soils of southern Nigeria (Ghuman and Lal, 1986). Other reasons include lateral flow in response to biotic activity on the surface horizon (Lal, 1979; and Mbagwu, 1981), especially in the top (0-30 cm) of the soil (Obi and Akamigbo, 1981).

One important feature of infiltration of water into soils is that it slows down with time. Several efforts have been made to characterize and mathematically quantify infiltration phenomenon, through many attempts from physically-and- empirically derived equation which express infiltration as a function of time or of the total quantity of water infiltrated into the soil (Mbagwu, 1995). However, collection of infiltration data is a tedious exercise, hence the need for evaluation of the potential of some of these models in predicting infiltration characteristics of tropical watershed from physically and/or empirically derived equations, among which are those of Kostiakov's (1932) and Philip (1957) is paramount. The objectives of this study were to

1. assess Infiltration characteristics across a toposequence in south eastern Nigeria .
2. predict infiltration parameters using Philip's and Kostiakov's models.

II. Materials and Methods

Study Area and Data Collection

The experiment was conducted at the teaching and research farm of the University of Nigeria, Nsukka (latitude 06^o 52'N, longitude 07^{o}24'E and elevation of 400m above sea level). The location is within the forest-savanna transition vegetation zone. Ultisols make up about 90% and Entisol about 10% of the total area. The toposequence of the study area is characterized by Uvuru series at the crest (Entisol classified as Lithic Ustorthent), while Nkpologu and Nsukka series are at the mid slope and the toe slope position respectively (Ultisol classified as Typic Kandiustults) (Mbagwu, 1995). Soil physical properties and Infiltration runs were conducted from two data points at crest, middle slope and toe slope in the area. These were designated crest slope (UV_1 and UV_2), Middle slope (NKP_1 and NKP_2), and toe slope (NSK_1 and NSK_2). Soil physical properties (bulk density, particle size distribution, pore size geometry and organic matter) were evaluated with three undisturbed top-soil (0-20cm) samples collected within a distance of 1m to each infiltration site with core samplers and soil auger. The particle size was determined by the hydrometer method as described by Gee and Bauder (1986) Antecedent moisture content was determined gravimetrically after oven-drying the sample at 105.5^{0}C until constant weight.

θm = mass of water in the sample/mass of dry soil

Where θm= gravimetric moisture content

Bulk density was determined by core method. Total porosity was estimated from the bulk density values assuming a particle density of 2.65 g cm^{-3} as thus;

TP = (1-Bd/Pd) x 100/1

Where Tp= total porosity, Bd= bulk density, Pd= particle density

Soil organic carbon was also determined using the Nelson and summer's (1982) method. The organic matter content was obtained by multiplying values obtained for organic carbon by a factor of 1.724. Double-ring infiltrometer was used for the infiltration runs. Infiltration data obtained were fitted into Philip's and Kostiakov's infiltration models described in Hilel, 1998:

Philip's

$$I = At + St^{1/2} \quad - - - - \quad - - \{1\}$$

Where I = cumulative infiltration (cm)

S = soil water sorptivity, A = transmissivity and t = time elapsed, and

Kostiakov's

$$I = Kt^a \quad - - - - - - \quad - \text{-}\{2\}$$

Where I = cumulative infiltration (cm)

t = time elapsed (mins)

K and **a** are constants which represents initial rate of infiltration**,** and soil-dependent parameter (index of soil stability) whose value ranges from 0 and 1. Soil physical properties were correlated with infiltration parameters in order to unveil the dependent factor of infiltration in the soil.

III. RESULTS

Soil Characteristics

Generally, evaluated soils were high in clay content (25.04% - 37.04%) with a mean value of 30.04% and total sand with values ranging from 52 – 69 % (Table 1). Fine sand fractions dominated the total sand fractions of each location compared with the coarse sand fraction. The silt content of the soil was low (6.5% - 10.5%). The textural classes of the three evaluated soil series are Sandy-Clay loam.

The initial moisture content ranged from 8.78% for Nsukka series 1 (NSK_1) to 12.57% at Uvuru series 2 (UV_2) with a mean value of 10.22% (Table 2). Generally, the CV of the initial or antecedent moisture

Table 1: Particle size distribution of the soils

Location	Clay (%)	Silt (%)	Total sand (%)	Coarse Sand (%)	Fine sand (%)	Textual class
Nsk_1	25.04	6.56	69.40	24.60	43.80	SCL
Nkp_1	29.04	8.56	62.40	17.67	44.73	SCL
Uv_1	37.04	10.56	52.40	16.43	37.97	SC
Nsk_2	25.04	6.56	68.40	25.48	42.92	SCL
Nkp_2	29.40	8.56	62.40	15.90	46.50	SCL
Uv_2	35.04	8.56	56.40	17.70	42.70	SC
Mean	30.04	8.32	61.90	19.63	43.10	
CV%	16.70	18.30	10.70	21.70	6.67	

CV = Coefficient of variation, NSK_1 = Nsukka series 1, NKP_1 = Nkpologu series 1, UV_1 = Uvuru series 1, NSK_2 = Nsukka series 2, NKP_2 = Nkpologu series 2, UV_2 = Uvuru series 2, SC = Sandy clay, SCL = Sandy clay loam

Table 2; Initial soil moisture and organic matter contents of the soils.

Location	Gravimetric moisture content (%)	Organic carbon(%)	Organic matter (%)
Nsk_1	8.78	1.04	1.79
Nkp_1	9.02	1.08	1.87
Uv_1	12.54	2.68	4.63
Nsk_2	8.83	0.94	1.62
Nkp_2	9.60	1.46	2.52
Uv_2	12.57	2.73	4.71
Mean	10.22	1.66	2.86
SD	1.65	0.83	1.44
CV(%)	16.12	50.15	50.27

CV = Coefficient of variation, NSK_1 = Nsukka series 1, NKP_1 = Nkpologu series 1, UV_1 = Uvuru series 1, NSK_2 = Nsukka series 2, NKP_2 = Nkpologu series 2, UV_2 = Uvuru series 2, SD = standard deviation

content is low (16.12%). Hence, it cannot contribute to the variation in the infiltration characteristics among the sites studied. Organic matter content of the soils in the location studied ranged from 1.62 to 4.71%. The highest values were obtained for Uvuru series 2 while the least values were obtained for Nsukka series 2. Soil organic matter has profound influence on soil aggregate stability especially the water stable aggregate which affects the soil structure, and the movement or conduction of water through the soil pores. It can therefore, be an important source of variation in the infiltration characteristics of the soils studied. The bulk density ranged from1.23 gcm^{-3}(NSK_1) to 1.51 gcm^{-3} (UV_2) with a mean value of 1.394gcm^{-3} and a CV of 7.86% (Table 3). Both total porosity and macro porosity were high in all the studied sites with values ranging from 43.14 to 54.34% and from 37.20 to 46.18% respectively (Table 3). However,

Table 3; Bulk density and pore size distribution of the soils.

Locations	Mean bulk density (gcm^{-3})	Mean total porosity (%)	Mean macro-porosity (%)	Mean micro-porosity (%)
Nsk_1	1.23	54.340	46.180	8.162
Nkp_1	1.42	46.320	37.200	9.118
Uv_1	1.37	48.250	41.540	6.706
Nsk_2	1.37	49.850	44.250	5.600
Nkp_2	1.51	43.200	39.930	3.270
Uv_2	1.51	43.140	37.430	5.712
Mean	1.394	47.52	41.09	6.428
SD	0.58	3.91	3.70	2.07
CV %	7.86	8.23	9.013	32.26

CV = Coefficient of variation, NSK_1 = Nsukka series 1, NKP_1 = Nkpologu series 1, UV_1 = Uvuru series 1, NSK_2 = Nsukka series 2, NKP_2 = Nkpologu series 2, UV_2 = Uvuru series 2, SD = standard deviation

microporosity was generally low throughout the locations with its highest value (9.12%) recorded for NKP_1 and the least value (3.27%) for NKP_2. The highest time (55.08 mins) to reach equilibrium infiltration was recorded for Uvuru series 2 (Table 4). The cumulative infiltration rate was high ranging from 3.84 cm/mins at Uvuru series 2 to 85.22cm/mins at NSK_2.

Table 4: Time to reach equilibrium infiltration (teq) and cumulative equilibrium infiltration.

Locations	Time to reach equilibrium infiltration teq(mins)	Cummulative equilibrium infiltration I (cm/mins)
Nsk_1	31.94	24.30
Nkp_1	26.13	55.60
Uv_1	32.20	40.87
Nsk_2	35.44	85.22
Nkp_2	32.09	58.85
Uv_2	55.08	3.84

Nsk_1 = Nsukka series 1, NKP_1 = Nkpologu series 1, Uv_1 = Uvuru series 1, Nsk_2 = Nsukka series 2, Nkp_2 = Nkpologu series 2, Uv_2 = Uvuru series 2

IV. Predictions of Infiltration Characteristics

The transmissivity (A) value was highest (4.034) at NKP1 series 1 and lowest (0.259) at UV_2 with a CV of 68.10% which implies a high variability of this parameter along this toposequence (Table 5). Sorptivity (S) also varied throughout the sites as indicated by its high CV of 92% with UV_2 recording the least value (0.620) as against the highest value (13.981) recorded at NSK_2. The r^2-value for the regression analysis between values of cumulative infiltratrion predicted using Philip's model and those measured in the field generally showed high r^2-values in all the location studied (range from 0.998- to 1.000). The NKP_1 and UV_2 gave the highest r^2-values (1.000) from the regression analysis using Philip's model.

For the Kostiakov's model, the highest value of K (11.46) using Kostiakov model was obtained from NSK_2, followed by NKP_2 (6.19), while the least value (0.650) was obtained at UV_2 (Table 6). Also, the values of (***a***) varied from 0.732 for NSK_2 to 0.957 for NKP_1. The r^2-values for the regression analysis between values of cumulative infiltration predicted using this model and those measured in situ were high in all the locations studied ranging from 0.986 to 1.000. The high values of the r^2 obtained from each sites were an indication of good fit for these two models i.e. (Philip's and Kostiakov's models) were tested in this study , towards predicting the infiltration characteristics of the soils in each location (Table 5 and 6).The CV of K (90%) was high compared with the lower value of 3.03% obtained for the soil dependent parameter (***a***).

Table 5: Transmissivity (A) and Sorptivity (S) values using Philip's model $I = At + St^{1/2}$ (from regression analysis).

Location	Philip's Model	Transmissivity(A)	Sorptivity(S)	r^2-value
NSK_1	$I = 0.823t + 4.218t^{1/2}$	0.823	4.218	0.998
NKP_1	$I = 4.034t + 1.137t^{1/2}$	4.034	1.137	1.000
UV_1	$I = 2.094t + 5.103t^{1/2}$	2.094	5.103	0.999
NSK_2	$I = 1.933t + 13.981t^{1/2}$	1.933	13.981	0.999
NKP_2	$I = 2.578t + 6.543t^{1/2}$	2.578	6.543	0.999
UV_2	$I = 0.259t + 0.620t^{1/2}$	0.259	0.620	1.000
CV %		68.10	92.00	
X^2 = 0.18 (NS)				

CV = Coefficient of variation, NSK_1 = Nsukka series 1, NKP_1 = Nkpologu series 1,UV_1 = Uvuru series 1, NSK_2 = Nsukka series 2, NKP_2 = Nkpologu series 2, UV_2 =Uvuru series 2, **X^2 = Chi-square value; NS = Not significant at $p<0.05$**

Table 6: determination of K(initial rate of infiltration) and a (soil stability index) using kostiakov's model $I = Kt^a$

Location	Kostiakov's Model	K	a	r^2-value
Nsk_1	$I = 3.01t^{0.828}$	3.01	0.828	0.986
Nkp_1	$I = 4.86t^{0.957}$	4.86	0.957	1.000
Uv_1	$I = 4.98t^{0.860}$	4.98	0.860	0.998
Nsk_2	$I = 11.46t^{0.732}$	11.46	0.732	0.995
Nkp_2	$I = 6.19t^{0.861}$	6.19	0.861	0.997
Uv_2	$I = 0.650t^{0.838}$	0.650	0.838	1.000
CV %		70.00	3.03	
$X^{2=}$ 1.08 (NS)				

CV = Coefficient of variation, Nsk_1 = Nsukka series 1, NKP_1 = Nkpologu series 1, Uv_1 = Uvuru series 1, Nsk_2 = Nsukka series 2, Nkp_2 = Nkpologu series 2, Uv_2 = Uvuru series 2
X^2 = Chi-square value; NS = Not significant at $p < 0.05$

V. DISCUSSIONS

Variation in the infiltration rate may be attributed to the variation in the soil physical properties measured in the surface soil layers 0-20 cm depth. Such variation in textural separates contributes to the variation of the infiltration characteristics of the locations studied. For instance, the high clay content of the soils in the sites studied might have contributed to restricting or impeding water movement down the profile. This was most pronounced at UV_2 with the highest clay content and least cumulative infiltration. Similarly, the variations in total sand content of the soils also contributed to the variation in their infiltration characteristics. The sand layer especially the fine sand fraction retards the wetting front owing to lower unsaturated conductivity of the sand at equal matric suction resulting in decreased potential gradient and consequently, lower infiltration rate (Baver, 1976).Moreover, the soils at some sites especially at Uvuru series and Nkpologu series have high contents of stones and gravels within their profile, which created large channels that conducted water easily irrespective of their textural characteristics. The high initial moisture content of the location especially at the Uvuru series can be attributed to the high clay and organic matter content. Tobon *et al*. 2010 attributed the increased residual moisture content of volcanic soils to allophanic clays. Lal (1979) had shown that organic matter increases the moisture content and retention characteristics of soils.

The high bulk densities of the soils also influenced their infiltration characteristics. The infiltration rates were moderately high in all the sites except at UV_2 which showed the highest bulk density of $1.51gcm^{-3}$ and, consequently, a lower infiltration rate. However, the rate at which water was conducted at UV_1, which had already been altered by cultivation was rapid, in spite of its relatively high clay content and high bulk density. This illustrates the effects of land-use (cultivation) on the physical properties of soils such as creating more micro pores and macro pores for water absorption which enhanced infiltration. Though, infiltration rate generally increases with total porosity and macroporosity, these soil properties were relatively homogenous or more stable throughout in the present study, as evident in their low CV values of 8.23% and 9.013%, respectively. Therefore, they were not the major contributors to the variation in the infiltration characteristics of these soils. In support of this point, microporosity with a CV of 32.26% contributed to the variations in the infiltration characteristics of the soils studied.

The shortness in time to reach equilibrium infiltration can be attributed to the initially high moisture content of the soils as well as their structure and texture. Even though the cumulative infiltration rate observed in the location studied was moderately high, the infiltration capacity was low. This explains the short time interval to reach equilibrium infiltration.

The best fit for both models was obtained with data from Nkpologu series 1 (NKP1) and Uvuru series 2 (UV2) with both models. Although, the chi-square values were not significant ($p < 0.05$) for both models, Kostiakov's equation showed superior performance over the Philip's equation in predicting infiltration into the soils of the sites studied as the former gave higher chi-square value (1.08) than the latter (0.18). However, Oshunsanya (2010) reported the superior performance of Philip model over Kostiakov model in predicting infiltration into soils under different vetiver grass strips spacing in Ibadan.

VI. Conclusion

The soil properties determined or measured in the studied locations especially initial moisture content, organic matter content, bulk density, clay and fine sand content (texture), and micro porosity contributed immensely to the variation in the infiltration characteristics of the soils. The entry of water into the soil is necessarily affected among other factors by the infiltration characteristics of the soil. Both Philip's and Kostiakov's models have shown a good fit for predicting infiltration characteristics of the soils studied. Kostiakov's is preferred to Philip's in predicting infiltration into soils of the sites studied. Most of the sites except UV_2 showed high infiltration and cumulative infiltration rates but the capacity or the minimum rate of the soils to absorb water was small as evident in the small time required to attain equilibrium infiltration. Hence, the rate of water supply by rainfall and irrigation may likely exceed the soils limited rate of absorption within a shorter time and the excess may constitute runoff.

VII. Recommendations

Appropriate soil-water management should be devised for the soils. To achieve this, increased mulch and organic matter application is advocated in order to enhance the infiltration characteristics of soils in these locations. Also, planting of cover crops is also encouraged in order to reduce the effect of runoff or overland flows and associated erosion hazards. Irrigation water application rate should not exceed the soils limited rate of absorption i.e. should be such that would be at a rate lower than the infiltration capacity of the soils. Therefore, surface irrigation system such as border check (basin) or border strips at the valley bottom slope positions (Nkpologu series and Nsukka series) and overhead (sprinkler) irrigation system at the crest (Uvuru series) were suggested for the soils for efficient soil-water management.

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