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Estimation of Soil Water Infiltration of Different Landuses on an Ultisol in the Humid Rainforest Zone of Southern Nigeria

Orji, O. A. and Nwachukwu S.U
Department of Crop/Soil Science, Rivers State University
P. M. B. 5080, Port Harcourt Nigeria

Abstract
Field infiltration assessment of soils are no doubt a very labour intensive and time-consuming exercise, but with the use of an infiltration model, estimation and prediction of soil infiltration capacity are made easier. Estimation of soil infiltration capacity and evaluation of Philip model capacity to simulate infiltration of three landuses namely Artificial Forest (AF), Coconut Plantation (CC) and Arable Crop Cultivated Land (CL) were carried out in an ultisol in a humid rainforest zone of Rivers State in Southern Nigeria. Field infiltration was carried out in three replicates for each landuse using the double ring infiltrometer. Some physical properties were also determined. The mean values were fitted into the Philip model to derive model simulate equation for cumulative infiltration. The bulk density, total porosity, mean weight diameter of aggregates and saturated hydraulic conductivity values were better enhanced with the CC landuse, with better structure resulting from minimal tillage, when compared with those of AF and CL . There were significant differences in the initial and steady state infiltration rates (4.8 and 2.8cm/5mins) and cumulative infiltration (4.65cm) of the CC when compared with those of AF and CL. The result showed relatively close relationship exist between the field measured and Philip model estimated infiltration. The model equation for the three landuses were $0.067t^{1/2}+0.096t$ ($R^2=0.69$), $0.155t^{1/2}+0.449t$ ($R^2=0.88$) *and* $0.096t^{1/2}+0.086t$ ($R^2=0.94$) *for AF, CC and CL landuse respectively.*

Key words: *infiltration rates, field and model estimated infiltration*

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I. Introduction

An adequate amount of water must infiltrate into the soil for optimum crop production (Armer, 2011, USDA, 2019).Soil infiltration expresses the soil's ability to allow water movement into and through the soil profile Smith (2017). It allows the soil to temporarily store water, making it available for uptake by plants and soil organisms.

Infiltration rates are a measure of how fast water enters the soil and are typically expressed in inches per hour. This usually decreases as the soil moisture content increases (Bachmann et al. 2003). Infiltration capacity however, is the maximum rate of infiltration. For initial in-field assessments, however, it is more practical to express infiltration time in the number of minutes it takes soil to absorb each inch of water applied to the soil surface. Water entering too slowly may lead to ponding on level fields, erosion from surface runoff on sloping fields, or inadequate moisture for crop production. Porous soils allow water to infiltrate and recharge ground-water aquifers and sustain base flow in streams. An infiltration rate that is too high can lead to nitrate-nitrogen or pesticide leaching, if they are not managed correctly.

Infiltration is affected by crop and land management practices that affect surface crushing, compaction and soil organic matter (Bharati, et al, 2002, Moroke, et. al. 2009, Basche and DeLonge, 2019). Management measures, such as residue management, cover crops can improve infiltration.

The Philip's two term model is a truncated power series solution developed by Philip (1957a, 1957b and 1969). During the initial stages of infiltration, the first term of the model equation (sorptivity) dominates the process. Sorptivity is a function of the soil's suction which is important for knowing soil hydraulic properties. The parameter is defined as physical quantity that shows the capacity of a porous medium for capillary uptake and release of water into the soil. This parameter can be estimated by defining the relationship between soil hydraulic and other available measured properties, which can be used to estimate hydraulic parameter Abubakr, (2012).

Knowledge of soil infiltrability is necessary for proper soil management and conservation practice for crop production. This is because of great importance in understanding and managing hydrological processes, crop water supply, irrigation, and soil erosion, which in turn provides information necessary to determine runoff, infiltration and recharge of a particular soil. However, field measurements of soil water infiltration is both labourious and time consuming. An assessment of suitable models to achieve this soil management practice is therefore desired.

II. Materials and Methods

Estimation of soil infiltration capacity and evaluation of Philip model capacity to simulate infiltration of three landuses namely a six year old Artificial Forest (AF), over 15 year old Coconut Plantation (CC) and yearly Arable Crop Cultivated Land (CL) were carried out in an ultisol in a humid rainforest zone of Rivers State in Southern Nigeria. A double ring infiltrometer with a height of 60cm and internal diameters of 30 and 60cm for the inner and outer rings respectively, was used to measure both the infiltration rate and cumulative infiltration of the soils at across different landuses studied (Bouwer, 1986). The inner ring was first driven into the ground, then the outer ring was placed centrically around the inner ring before it is driven into the soil; as described by Adinudu *et. al*., (2013). The two was driven into the soil ground to a depth of about 10cm. 2cm of sand layer was spread at the bottom of the inner ring to minimize soil surface disturbance when pouring water into the ring compartments. To ensure vertical flow in the inner ring, the outer ring was kept at a 25cm constant head of water, throughout the measurement period. Infiltration of water into the soil was taken with the use of a transparent meter rule, every 5 minutes for the first 30minutes and subsequently every 10minutes for another 40minutes. This gave a total of 70minutes for each point of measurement.

Bulk and cylindrical core samples were collected for the same depth of infiltration measurement, and used to determine some physical properties of the soils of the various landuses. They include the soil texture, mean aggregate size, bulk density, total porosity, field capacity moisture content and the saturated hydraulic conductivity of the soils using the constant head permeameter by methods described by Orji and Ikechi, 2018.

Philips Infitration Model

For cumulative infiltration, the general form of the Philip's model is expressed in powers of the square-root of time as:

$I = St^{1/2} + At$ ………………………………………………………. Equation (1)

Where

I = is the cumulative infiltration**,**

S = is the Sorptivity, t is the time of infiltration and

A = is a parameter with dimension of the saturated hydraulic conductivity and is equal to transmissivity.

The rate of infiltration is determined by differentiating (eqn) 1, as shown below

$dI/dt = {}^{1}/_{2}\, St^{1/2} + A$ ……………………………………..Equation (2)

Where

A (Transmissivity factor) = intercept

S (Sorptivity factor) = slope

The constants 'A' and 'S' were determined by plotting cumulative infiltration (I) against $t^{1/2}$ as given in eqn. (2). The values of the estimated constants were incorporated into the model equation to simulate cumulative infiltration depth for each landuse. The capability of the model to stimulate cumulative infiltration was evaluated by comparing the field data with the model's simulated data using analysis of variance at $P \leq 0.05$

III. Results and Discussion

Table 1: Some Physical Properties of the Soils of the Experimental Site

Properties	Artificial forest	Coconut plantation	Cultivated land
Bulk density (gcm^{-3})	1.57	1.54	1.62
Total porosity (%)	38.6	39.8	36.7
Volumetric moisture content (cm^3cm^{-3})	0.17	0.21	0.21
Saturated hydraulic conductivity ($cm\ sec^{-1}$)	8.4×10^{-3}	2.4×10^{-2}	1.3×10^{-2}
Mean weight diameter (mm)	2.66	2.76	2.62
%Sand	83.4	85.4	79.4
%Silt	3.7	3.7	4.3
%clay	12.9	10.9	16.2
Textural class	Loamy sand	Loamy sand	Sandy loam

The soil of the three landuse were generally sandy loam to loamy sand. The mean weight diameter of the soil aggregates at the plough layer was 2.62 to 2.76mm. The bulk density values were 1.54, 1.57 and 1.62gcm^{-3} for coconut plantation (CC), artificial forest (AF), and arable crop cultivated land (CL) respectively. The total porosity followed the same trend, ranging between 36.7 to 39.8%. The saturated hydraulic conductivities was highest for CC at 2.4 x 10^{-2}cmsec^{-1} and 1.3 x 10^{-2}cmsec^{-1} for CL and 8.4 x 10^{-3}cmsec^{-1} for AF.

Infiltration Rates

The field measured infiltration rate is as shown on Fig.1. Infiltration rates were generally high across the three land uses. The initial infiltration values were 4.8, 2.2 and 1.8cm/5mins for, CC, CL and AF respectively. The final infiltration rates at the end of one hour was 2.8, 1.0 and 0.8cm/5mins for the same landuses. The soils having high sand contents may have contributed to this; as sandy soils have large macropores that enhance faster infiltration rates. Results showed that the infiltration rate for CC was significantly different from that of AF and CL. This was consistent with the saturated hydraulic conductivity values, sand contents bulk density and total porosity values of CC when compared with that of AF and CL (Table 1). The CC landuse with minimal tillage and grass cover may have contributed to better structures than the cultivated and artificially planted forest landuses. This is similar with findings of Bharati et al. 2002.

Generally, infiltration rates decreased as time progressed. The initial infiltration rates were 3.6, 9.6 and 4.4 cm min^{-1} for AF, CC and CL respectively and decreased to 0.8, 2.8 and 1.0 cm min^{-1} at final infiltration of 1 hour. As more water replaces the air in the soil pores, the rate of water movement into the soil gets slower and gradually reaches a steady state rate.

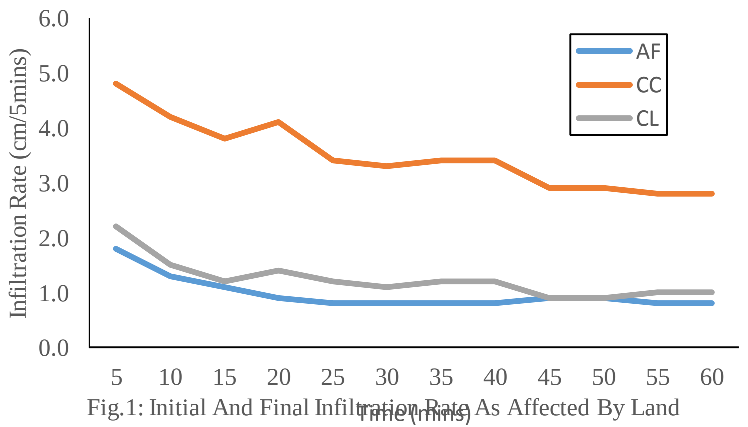

Fig.1: Initial And Final Infiltration Rate As Affected By Land Use

Cumulative Infiltration

The cumulative infiltration as affected by landuses is as shown on Fig. 2. The field measured cumulative infiltration values, after one hour, for CC were significantly higher (46.5cm) when compared with AF and CVL of 14.2 and 16.3cm respectively. The Philips model simulated cumulative infiltration followed the same trend with value 32.7cm, 7.3 and 6.8cm for CC, AF and CL respectively.

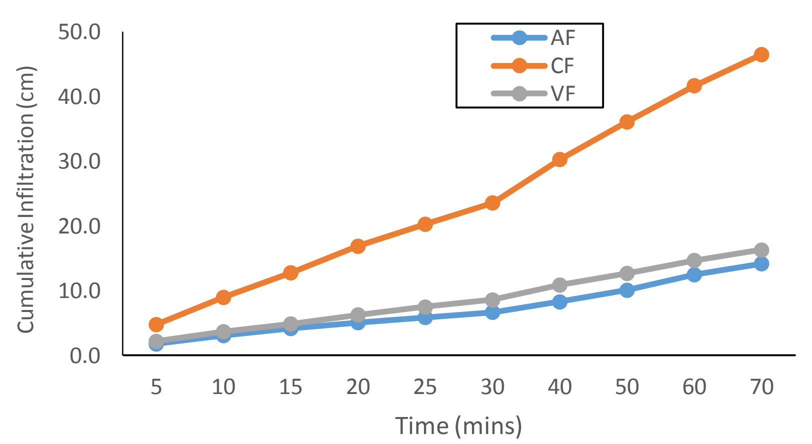

Fig. 2: Field Measured Cumulative Infiltration

Results showed that the field measured cumulative infiltration values were generally higher than the Philip model simulated cumulative infiltration; across the three landuses (Fig.3). These were however, not statistically different.

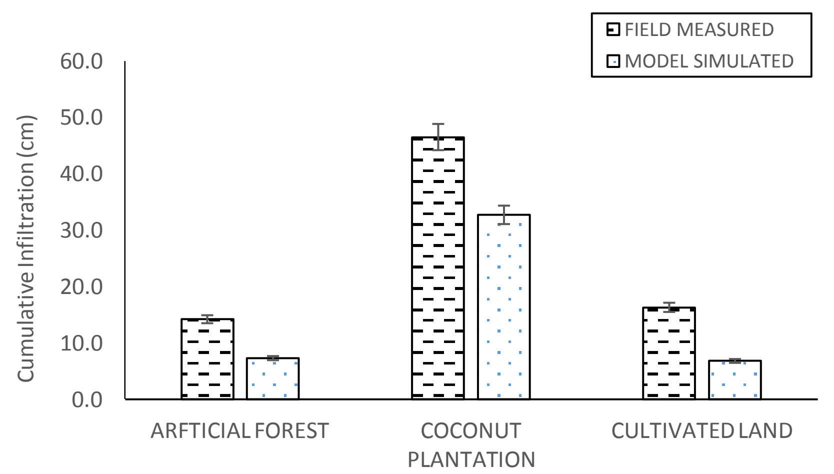

Fig.3: Field and Model Simulated Cumulative Infiltration

The Philip model equation for the three landuses is shown on Table 2. The coefficient of dependability (R^2) values were 0.69, 0.88 and 0.94 for AF, CC and CC. respectively. Results sowed that the Philips model equation showed that the cumulative infiltration was relatively closer to the field measured cumulative infiltration. This was followed by the CC and AF landuses. There were no significant differences between the field measured and Philip model estimated cumulative infiltration. This suggests that a relatively close relationship exists between the field measured and model estimated cumulative infiltration.

The values for transmisivity 'A' ranged from 0.086 to 0.449, while that of the sorptivity 'S' ranged from 0.067 to 0.155. This corroborate the findings of Igbadun et al 2007 which evaluated the performance of infiltration models for the soils of Zaria, Kaduna State, and obtained transmissivity values ranging from 0.078 - 0.155.

Table 2: Philip Model Estimated Soil Parameters and Equation for the Various Landuse

Landuse	**Sorptivity (S)**	**Transmissivity (A)**	**$I=St^{1/2}+At$**	**R^2**
Artificial Forest	0.067	0.096	$0.067t^{1/2}+0.096t$	0.691
Coconut	0.155	0.449	$0.155t^{1/2}+0.449t$	0.884
Cultivated	0.096	0.086	$0.096t^{1/2}+0.086t$	0.943

IV. Conclusion

This study evaluated the infiltration parameters as affected by three different land uses on the same soil type. Physical properties of the soils like bulk density, total porosity, mean weight aggregate and saturated hydraulic conductivity were better enhanced in the coconut plantation landuse; indicating better structure with minimal soil tillage. This also enhanced initial and steady state infiltration rates and cumulative infiltration in this landuse, when compared with the regularly cultivated landuse and the artificial forest landuse.

The Philip model simulated cumulative infiltration values were lower than the field measured values, although the differences were not significant. The model equation for the three landuses were $0.067t^{1/2}+0.096t$ ($R^2=0.69$), $0.155t^{1/2}+0.449t$ ($R^2=0.88$) and $0.096t^{1/2}+0.086t$ ($R^2=0.94$) for AF, CC and CL landuse respectively.

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