Nigerian Journal of Soil Science
journal homepage:www.soilsjournalnigeria.com

Evaluation of Infiltration Models in Soils of Two Land Use Systems in Calabar, Nigeria

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ARTICLE INFO

Article history:
Received: 28th June, 2018
Received in revised form :30th July, 2018
Accepted: 2nd August, 2018
Available online: 1st December, 2018

Keywords:
Infiltration Models
land use,
goodness of fit

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https://doi.org/10.36265/njss.2018.280210
ISSN-1597-4488 ©publishingrealtime.
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ABSTRACT

Recently, the importance of the infiltration process in agriculture and the environment has resulted in an upsurge of interest by soil and water scientists to model the process for quantitative application. A study was conducted on the University of Calabar Teaching and Research Farm, Calabar to evaluate the effect of oil palm (OP) and arable farm (AF) land use systems on the Green-Ampt (GA), Philip (P), Kostiakov (K), Horton (H) and Mezencev (MZ) infiltration models, as well as the applicability or efficiency of the models to predict infiltration into the soils. Infiltration data were obtained with double ring infiltrometer, and the parameters of the models were obtained through curve-fitting. Model accuracy was evaluated with the Willmott's index of agreement (W), chi-square (X^2), coefficient of determination (R^2), root mean square error (RMSE) and mean error (ME) test statistics. The results showed that soil under oil palm had measured cumulative infiltration and infiltration rate of 72.81 cm and 14.10cm/hr while arable farm had 74.76 cm and 12.92 cm/hr, respectively. The cumulative infiltration predicted by Philip and Kostiakov models were very close to the field data for OP and AF. Horton and Mezencev models underestimated the infiltration process because their ME values were negative while Green–Ampt, Kostiakov, and Philip overestimated the infiltration process as they had positive ME values. In terms of accuracy and applicability, the order of performance was P>K>MZ>GA>H. Therefore, the Philip and Kostiakov models could be used to predict infiltration into the soils, but that the Philip model was superior to the Kostiakov model for the University of Calabar Teaching and Research Farm and similar soils in other ecologies.

1. Introduction

Soils of the humid tropics are fragile, i.e., extremely sensitive to degradative processes (structural decline) and low resilience, i.e., ability to recover after an agricultural perturbation (Lal, 1997), and are prone to flooding and erosion due to the torrential and high intensity rains (Udosen, 2017), and inappropriate land use and soil mismanagement. However, the prediction of flooding, pollutant transport, and erosion depend on the runoff rate which is directly affected by the infiltration rate (Ogban *et al.,* 2012). Infiltration is a major component of the hydrological cycle, i.e., the dynamics of water between the earth and the atmosphere, because it determines the fraction of the irrigation or rainwater that enters the soil and is stored, and the amount that runs off and responsible for soil erosion (Pla, 2007; Oku and Aiyelari, 2011).

Infiltration is the entry of water into the soil (Hillel, 1971) under a downward hydraulic gradient influenced by capillary and gravitational forces, with capillary forces predominating at the initial stages of the infiltration process and gravitational forces at large times (Hillel, 1998), as well as provide information about relevant hydraulic and structural soil properties. However, the limiting factor in soil's water uptake, and thus control of flooding and erosion, is soil infiltrability or infiltration capacity, the maximum rate at which it can accept the flux of water entering through its surface (Hillel, 1998). Quantifying soil infiltrability in relation to soil properties and land use is necessary for efficient irrigation planning, hydrologic analysis and modelling, and soil and watershed management (Hillel, 1971; Azuka *et al.,* 2013).

Infiltration is affected by the inherent properties of the soil such as soil texture and soil structure, which in turn affect the pore space and matric and gravitational forces, and initial moisture condition, the rainfall pattern, and land use and soil management practices (Hillel, 1998). Water infiltration into soils is highly sensitive to land use and soil management, which can alter the nature and properties of the soil surface resulting in the alteration of the hydrological balance and the infiltration characteristics of the soil. Also, soil hydraulic properties such as water retention capacity, saturated hydraulic conductivity, infiltration rate, sorptivity, and transmissivity are affected differently by land use practices, due to the accompanying changes in soil's intrinsic properties. Selby (1972), reported that the conversion of land from forest to pasture resulted in significant changes in the infiltration characteristics of the soil surface layer in central North Island, New Zealand because the open structure of the forest soil had been destroyed by grazing. In Angra, India, Agnihotri, and Yadav (2002), reported infiltration rates that were greater in the forested land than in farmland. Moreover, in Ndola, Tanzania, Saiko, and Zonn (2003), obtained higher infiltration rates in the fallowed land than in cultivated land.

In South-western Nigeria, Wilkinson and Aina (1976), reported higher infiltration rates into two tropical-forest soils under bush fallow (natural regrowth) compared to arable cropland where soil structural integrity had been compromised. Also, Amusan *et al.* (2005), found that soil texture and infiltration rate declined due to changes in vegetation and soil structural characteristics in South-western, Nigeria. Similar research results have been reported in South-eastern Nigeria. For instance, Antigha and Essien (2007) and Osuji *et al.* (2010), reported highly significant ($p = 0.01$) infiltration rates in the bush fallow land than in arable cropland. Eze *et al.* (2011), observed that the infiltration rate of a sandy soil under forest was higher than under sparse vegetation and bare cultivation. Ogban (2017), reported significantly ($p \le 0.05$) high infiltration rates in soil under oil palm compared to fallow and cultivated soil, and in the trend: OP>FL>CC. Differences between FL and CC were not significant. Generally, low infiltration characteristics were recorded in CC than in FL and OP and indicated the degradative effect that cultivation may have on soil properties. Osuji *et al.* (2010), reported significant relationships between steady infiltration rates and soil organic matter, bulk density, and total porosity. Shukla *et al.* (2003), Bormann and Klassen (2008) and Haghighi *et al*. (2010) attributed changes in infiltration rates to soil hydraulic properties, porosity, soil organic matter, and bulk density and different land use practices.

Infiltration characteristics can mostly be evaluated under either ponded or rainfall conditions or predicted using infiltration models (Haverkamp *et al*., 1988; Majaliwa and Tenywa, 1998). Several studies have been conducted to quantify the infiltration process (Green and Ampt, 1911; Kostiakov, 1932; Horton, 1940; Philip, 1957a; Talsma and Parlange, 1972; Rao *et al*., 2006), as well as evaluate infiltration models either for the purpose of validation to establish the model parameters or comparison of model efficiencies and applicability for different soil conditions (Ahmed, 1982; Bach *et al*., 1986; Davidoff and Salim, 1986; Obiechefu, 1991; Topaloglu, 1999; Wudduvira *et al.,* 2001; Igbadun and Idris, 2007; Egbai *et al*., 2011) because the models are strongly subjected to soil spatial variability (Dashtaki *et al.,* 2009). Al-Azawi (1985), reported that a lack of knowledge of the model parameters for different soils and locations makes the use of these models difficult. Infiltration model parameters could be determined when field infiltration data are fitted mathematically to infiltration models.

The University of Calabar Teaching and Research Farm is located on the tertiary coastal plain sands parent material in Southern, Nigeria. The area receives rainfall in excess of 3000 mm annually, occurring during the rainy season, but much of the rainwater is lost through Hortonian flows, with the attendant risk of frequent extensive flooding and severe soil erosion. In the dry season, the crop growing area is fallowed because of water deficit, making it the single most important and critical factor of crop production on the farm and the entire southern ecology, where inappropriate land use and soil mismanagement are common features of agriculture. Consequently, large-scale increases in crop production require an irrigation scheme whose critical factor is soil water status and which is a function of the infiltration capacity of the soil. While infiltration models have been well discussed in the literature (Hopmans *et al.,* 2007), and some studies conducted on the test site (Amalu and Antigha, 1999; Ukata *et al.,* 2015), their practical application to the University of Calabar Teaching and Research Farm has not been studied. This study was carried out to evaluate some of the commonly used infiltration models to select an appropriate model/s as a basis to improve the management of the soil and its productive capacity for increases in crop yield.

1.1 Infiltration Models

Five infiltration models were examined to evaluate their parameters (Table 1). Rawls *et al.* (1993) and Mishra *et al.* (1999), classified the infiltration models as empirical, semi-empirical and physically based models. Mishra *et al.* (1999), outlined the basis of the infiltration models and stated that (i) the physically based models rely on the law of conservation of mass and the Darcy law, (ii) the semi-empirical models employ simple forms of the continuity equation, and (iii) the empirical models do not directly use any of the above equations because they are based on data derived from either field or laboratory experiments. Moreover, in the physically based or mechanistic models, a solution is found for the water flow equation to derive an expression for the infiltration rate, which is then interpreted physically. In contrast, the empirical approach consists of first finding a mathematical function whose shape as a function of time marches the observed features of the infiltration rate and then attempting a physical explanation of the process. However, the physically based models are often used as empirical models, i.e., applied to field-measured data and their parameters determined by curve-fitting. Consequently, they lose the physical significance of the parameters because their basic assumptions are violated (Haverkamp *et al.,* 1988)

1.1.1 Empirical Models

Kostiakov (1932), found a functional relationship between cumulative infiltration, I, and time, t, thus:

$$I = ct^{\alpha} \tag{1}$$

where, I = cumulative infiltration (cm), t = elapsed time (min), c and α are constants (fitting parameters) that depend on soil and initial conditions, with $c > 0$ and $0 < \alpha < 1$. That is, the parameters in Equation (1), though not theoretically-based, however, vary with the soil physical properties. Equation (1) tends to be the most preferred infiltration model in surface irrigation application because of its simplicity, capability of fitting most infiltration data, and probably because it is less restrictive as to the mode of water application. However, to use Equation (1), a logarithmic transformation is necessary to obtain the expression:

$$LogI = Logc + \alpha Logt \tag{2}$$

A plot of log I versus log t produces a straight line with the slope as α while the intercept on the log$I$ axis gives the value of logc. The value of c can be obtained from the *anti-logc*. i.e.

$$c = 10^{\log c} \tag{3}$$

Mezencev (1948), also called the modified Kostiakov (1932) model to overcome the limitation of infinite infiltration rate at relatively large times. Mezencev's cumulative infiltration and infiltration rate are expressed as:

$$I = i_c t + \alpha t^{\beta} \tag{4}$$

$$i = i_c + \alpha \beta t^{\beta - 1} \tag{5}$$

where, α (α >0) and β (0< β < 1) are constants, i_c = final infiltration rate (cm/hr), i = infiltration rate (cm/hr). Either plotting β can obtain the value of α and $\log(I - i_c\ t)$ β with logt or through linear regression analysis. The slope of the regression analysis corresponds to *β*, and the intercept represents *α*.

1.1.2 Semi-empirical Models

Horton (1940), proposed a three-parameter semi-empirical infiltration equation derived from work and energy principles as:

$$i = i_c + (i_o - i_c)e^{-kt} \tag{6}$$

where, i = infiltration rate at time, t, (cm/hr), i_o = initial infiltration rate (cm/hr) at $t = 0$, i_c = final infiltration rate (cm/hr), k = infiltration decay coefficient in dimension of time, t, (t^{-1}). Equation (6) is derived from the simple assumption that the reduction in the infiltration capacity during rain is directly proportional to the rate of infiltration and is applicable only when the effective rainfall intensity is greater than i_c (Linsley *et al.,* 1975). The parameters in the Horton model can be determined by plotting $ln(i-i_c)$ against time, t, to get the best fit line through the plotted points. The intercept on the ordinate represents $ln(i_o-i_c)$ while the Horton decay coefficient represents the slope. The rate of decrease of infiltration rate, i, to steady-state infiltration , i_c, is determined by k. Equation (6) indicates that if the rainfall intensity, for instance, exceeds the infiltration capacity of the soil, infiltration tends to decrease exponentially. Horton infiltration model has an advantage over Kostiakov by having finite infiltration rate when the time is zero.

1.1.3 Physically-based Models

Green–Ampt (1911), developed an infiltration model by applying Darcy's law to the wetted zone in the soil based on the existence of a distinct wetting front, with infiltration rate as:

$$i = K_s\left[1 + \frac{S_t}{I}\right] \tag{7}$$

and the cumulative infiltration as:

$$I = K_s t + S_t \ln\left(1 + \frac{I}{S_t}\right) \tag{8}$$

Where, S_t = storage suction factor, K_s = saturated hydraulic conductivity. Other parameters are as defined above. The parameters K_S and S_t were calculated using linear regression analysis of i against $1/I$. The slope and intercept are represented by $K_S S_f$ and K_S respectively.

Philip (1957a, 1969) developed a time-series to solve the Richards equation for vertical and horizontal infiltration. He proposed a simple equation for the cumulative infiltration and showed that horizontal infiltration is given as:

$$I = St^{1/2} \tag{9}$$

where, I = cumulative infiltration (cm), S = sorptivity (cm/ $t^{1/2}$). For vertical infiltration, Philip (1957a) solution of the Richards equation was of the form of *physically-based* converging infinite series in powers of $t^{1/2}$, which described cumulative infiltration, *I*, as a function of time, *t*, as:

$$I = St^{1/2} + A_1 t^{2/2} + A_2 t^{3/2} + A_3 t^{4/2} + \ldots \tag{10}$$

where, A_1, A_2 A_3 ... are transmissivity parameters.

Philip (1957b) further showed that a truncated form of Equation 10 with just two fitting parameters is sufficient for all practical purposes to describe the time dependence of cumulative infiltration thus:

$$I = St^{1/2} + A_1 t \tag{11}$$

and the infiltration rate as:

$$\frac{dI}{dt} = i = 1/2\, St^{-1/2} + A_1 \tag{12}$$

i = infiltration rate (cm/hr), A = transmissivity (cm/hr), t = time (hr), while *I* and *S* are as defined in Equation (9).

Philip model parameters were determined by least square regression analysis method following the procedure outlined in Minasny and MacBrtney (2000) and Isong *et al.* (2017).

2. Materials and Methods

2.1 Study area: The study was conducted in the 16-ha oil palm plantation (Latitudes $4^0 56'$ and $4^0 59'$ N and Longitudes $8^0 20'$ and $8^0 21'$ E) and in the 4-ha arable farm (Latitude $4^0 27'$ and $5^0 32'$ N and Longitude $7^0 15'$ and $9^0 28'$ E), both in the University of Calabar Teaching and Research Farm.

This area has a hot, humid tropical climate with two distinct seasons; the rainy season which lasts from April to October and dry season which spans from November to March. Total annual rainfall in the area far exceeds 2600 mm. The mean annual temperature ranges from 23°C and 31°C, while relative humidity averaged 84 %.

The farm is located on an undulating topography, underlain by the tertiary coastal plain sands parent material, usually referred to as the *acid sands*. The soils are coarse-textured, relatively homogenous and profoundly permeable and are classified as Kandiudults or Acrisols (Akpan-Idiok *et al.,* 2012). Some physical properties of the soils are shown in Table 2. The arable land is seasonally cultivated to maize, watermelon, fluted pumpkin, cassava yam, etc.

2.2 Infiltration measurement

Water infiltration was measured at eight points on each land use systems with the double ring infiltrometer (Reynolds *et al.*, 2002). The infiltrometer consisted of outer and inner rings measuring 50 and 30 cm in diameter, respectively, and a height of 30 cm. A metal bar was placed on the rings and driven concentrically with a hammer into the soil to a depth of 10 cm. Each infiltration run was allowed a time duration of 180 minutes (3 hours). The average of the measurements was taken and subsequently used in the computation of the infiltration parameters.

2.3 Statistical analysis

2.3.1 Estimation of infiltration model parameters: In the field study, the parameters of each model (Table 1) were unknown. Also, Horton model represented an exponential decay curve while Kostiakov and Mezencev were power functions. Field observed data were fitted to the exponential decay curve and the power function curves by a dynamic curve fitting tool using non-linear regression with the aid of the SigmaPlot 12.5 statistical package, to obtain their respective model parameters. The parameters in Philip and Green-Ampt models were estimated from least square regression analysis following the procedure outlined in Al-Azawi (1985), Minasny and MacBrtney (2000), Vandervarere *et al.* (2000) and Isong *et al.* (2017).

2.3.2 Evaluation of infiltration model performance: The statistical goodness of fit indices in Table 2 alongside with t -test were used in evaluating the performance of models in this study.

Table 1: Infiltration Models evaluated

Name of equation	Expression		Parameters to estimate	Meaning of symbols	References
	Cumulative infiltration	Infiltration rate			
Green-Ampt* (GA)	$I = K_s t + S_t \ln\left(1+\frac{I}{S_t}\right)$	$i = K_s\left(1+\frac{S_t}{I}\right)$	K_s, S_t	K_s= saturated hydraulic conductivity (cm/min) S_t = storage suction factor	Green-Ampt (1911)
Kostiakov*** (K)	$I = ct^{\alpha}$	$i = c\alpha t^{\alpha-1}$	c, α	t = time (min) α = an index of structural stability c = a measure of the initial rate of infiltration	Kostiakov (1932)
Horton** (H)	$I = i_c t + \frac{(i_o - i_c)}{k}\left(1-e^{-kt}\right)$	$i = i_c + (i_o - i_c)e^{-kt}$	k, i_o, i_c	i_o = initial infiltration rate, cm/min i_c = final infiltration rate, cm/min k = rate constant in dimension of time (min^{-1})	Horton (1940)
Mezencev*** (MZ)	$I = i_c t + \alpha t^{\beta}$	$i = i_c + \alpha\beta t^{\beta-1}$	α, β	i_c = final infiltration rate (cm/min) β = constant α = constant	Mezencev (1948)
Philip* (PH)	$I = St^{1/2} + At$	$i = \frac{S}{2}t^{-1/2} + A$	S, A	S = sorptivity ($cmmin^{-0.5}$) A = transmissivity (cm/min)	Philip (1957)

Note: i = Infiltration rate (cm/min); I = Cumulative infiltration (cm); t = Time from beginning of infiltration (min); * = physically based model; ** = semi-empirical model; *** = empirical model

Table 2: Physical Properties of the Soil of the Study sites

Land use	Sand	Silt	Clay	Texture	MC (cm^3/cm^3)	Ks (cm/h)
	←	$g\ kg^{-1}$	→			
OP	839	147	14	Loamy Sand	0.15	51.06
AF	832	148	20	Loamy Sand	0.19	38.01

OP = oil palm; AF = arable farm; MC = moisture content; K_s = saturated hydraulic conductivity

Table 3: Statistical Goodness of fit

The goodness of fit indices	Abbrev.	Expression	Range of Variability	Optimal Value	References
Willmott's index of agreement	W	$W = 1 - \frac{\sum_{i=1}^{n}\left[I_p - I_o\right]^2}{\sum_{i=1}^{n}\left[\lvert I_p - \bar{I}_o\rvert + \lvert I_o - \bar{I}_o\rvert\right]^2}$	0 to 1	1	Willmott (1981); Willmott *et al.* (1985)
Coefficient of determination	R^2	$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(I_o - I_p\right)^2}{\sum_{I=1}^{n}\left(I_o - \bar{I}_o\right)^2}$	0 to 1	1	Van Liew *et al.* (2003)
Chi-square goodness of the fit test statistic	X^2	$X^2_{cal} = \sum \frac{(I_o - I_p)^2}{I_p}$	-	-	Oku and Aiyelari (2011)
Mean error	ME	$ME = \frac{1}{n}\sum_{i=1}^{n}\left(I_p - I_o\right)$	$-\infty$ to $+\infty$	0	Duan *et al.* (2010)
Root mean square Error	RMSE	$RMSE = \left(\frac{\sum (I_p - I_o)^2}{n}\right)^{1/2}$	0 to $+\infty$	0	Duan *et al.* (2010)

$\bar{I}_p$ = mean of the predicted data; I_o = observed cumulative infiltration; I_p = predicted cumulative infiltration; $\bar{I}_p$ = mean of the predicted data; n = number of cumulative infiltration measurement

3. Results and Discussion

3.1 Effect of OP and AF on infiltration rate and cumulative infiltration

Infiltration rate, the flux passing through the surface and flowing into the soil profile (Hillel, 1971), was orders of magnitude initially higher than the saturated hydraulic conductivity, *Ks*, but consistently declined gradually with increase in time of infiltration to a constant value after about 120 min in OP and AF (Figure 1). The observed trend of decreasing infiltration rate within the time-scale of this study agrees with theory (Reynolds *et al.,* 2002) that the flux-density of water per unit area decreases monotonically to approach the equilibrium or final soil infiltrability or *Ks* (Hillel, 1971; Kutilek and Nielsen, 2015). Soil infiltrability and its variation with time are known to be dependent on the initial wetness and suction, as well as the texture, structure, and uniformity of the profile (Hillel, 1971).

The high initial infiltration rate (OP = 78.6 cm/h; AF = 79.82 cm/h) was attributed to the generally low soil moisture content (Table 3) and therefore large suction head and the coarseness of soil texture which favoured gravity-driven infiltration (Baver *et al.*, 1972; Reynolds *et al.,* 2002).
The gradual decrease in infiltrability in OP and AF with time was attributed to changes in soil surface conditions,

i.e., compaction of the soil surface by raindrop action, aggregate breakdown, slaking and sealing of pores, and to a decreasing matric potential gradient as the wetting front penetrated deeper into the soil profile. Radcliffe and Rasmussen (2000), reported that entrapped air also contributes to a decreasing initially high infiltration rate. Linsley *et al.* (1975), stated that the decreasing rate of infiltration with the time of water application was due to the continuous diversion of gravity water into capillary-pore spaces by capillary forces, thus, diminishing the quantity of gravity water passing successively lower horizons leading to increased resistance to gravity flow in the surface horizons.

The initial infiltration rate, i_o, was significantly different ($p<0.05$) between OP and AF (Table 3), which was similar to reports by Wilkinson and Aina (1976), Osuji *et al.* (2010) and Eze *et al.* (2011), that soils under oil palm forest maintained open soil structure associated with increased biological activities, e.g., surface cover of plant materials, dead roots that create pores in addition to textural pores, etc with high infiltration rate, compared to the arable land where cultivation results primarily in a change in soil structure through aggregate breakdown, colloidal dispersion and clogging of the soil pores and lower infiltration rate. Thus, the effect of soil use on infiltration rate masked the homogeneity in the soil as demonstrated by a similarity in soil texture and agrees with reports by Lal and van Doren (1990) that water infiltration is highly sensitive to soil use and management.

The final infiltration rate, i_f, was similar between OP and AL (Table 4) but higher in the former than in the latter. The i_f is at a maximum i_o at the onset and approaches a low, constant rate i_f as the soil profile becomes saturated, controlled by subsoil permeability. The slightly higher i_f in OP than AL points to the fact that cultivated soils usually experience degradation of soil structure and structure-moderated soil properties, e.g., bulk density, total porosity, and pore-size distribution, and hydraulic conductivity in the soil surface zone , which can be accentuated where bare cultivation is the rule. Such degradation is generally typical in low resilient soils; soils with low ability to recover after a perturbation (Lal, 1993), and under traditional soil use systems in the humid tropics with weak or non-existent soil surface management , affecting water intake. Burch *et al.* (1987), reported that agricultural soils, particularly seasonally bare soils, exhibit lower infiltration capacities, and less macroporosity than do forest soils. The similarity in i_f indicated that soil texture and other unidentified factors were probably more important than the land use systems (Lal and van Doren, 1990). Generally, soil texture exerts the most remarkable effect on the infiltration rate when the water supply is not limiting, and it determines the duration of time to i_f whether infiltration is gravity-driven (common in coarse-textured soil) or capillarity-driven (common in fine-textured soil). Indeed, the time to i_f of about 120 min in OP and AF (Figure 1) may probably be of no effect since the rainfall rate will always exceed the i_f on the farm.

The entry of water into the soil vadose zone is controlled by capillarity and gravity forces and soil properties, governed by the Richards equation (Richards, 1931), whose solution requires that the soil moisture content and hydraulic conductivity be defined as functions of pressure head . Generally, however, during a high intensity rainfall event as is common in the study area, the infiltration capacity or i_f, decreases over time as the soil moisture content increases, and in the limiting case if the soil becomes saturated, the infiltration capacity becomes constant and monotonically approaches the *Ks* (Rawls *et al.,* 1992). The i_f was 14.10±3.01 cm/h in OP and 12.92±3.94 cm/h in AF. These results were orders of magnitude lower than the laboratory measured *Ks* (Table 2); the high *Ks* could be attributed to field and laboratory errors and, therefore, the assumption that at significant times i_f is equal to *Ks* could not hold. For a given soil, the effects of the inherent characteristics such as profile heterogeneity in texture and pore-size distribution are reflected in the *Ks*, the resistance that the soil matrix offers to the flow of fluids. Thus, the comparison of *Ks* and i_f indicated that the latter is limiting under the usually high amount and intensity rains in the area. The data of i_f and *Ks* also demonstrated that infiltration excess or Hortonian overland flow may readily occur in the area but may be delayed in OP with high i_f than in AF with low i_f, provided that rainfall rate not exceed the infiltration rate. However, the effect of the difference in i_f between OP and AL may be short-lived under the rainstorms common in the area.

Table 4: t-test of cumulative infiltration, initial and final infiltration rates

	Mean ± sd				
	OP	**AF**	**Mean difference**	**t- test**	**Sig.(2-tail)**
CI	35.23±21.25	36.70±22.35	-1.47	-4.09	0.001***
i_o	34.27±16.19	35.59±16.39	-1.33	-2.62	0.02*
i_c	14.10±3.01	12.92±3.94	1.18	0.556	0.596

* = significant level at 5%**;** *** = significant level at 0.01%; sd = standard deviation; CI = cumulative infiltration; OP = oil palm; AF = arable farm

Cumulative infiltration, the time integral of the flux of water into the soil, was not significantly different between OP and AF (Figure 2). The figure shows that the cumulative depths of water were close at the early stages of the infiltration process but diverged slightly after 40 minutes and maintained the non-significant difference and curvilinear trend to the end of the three-hour infiltration duration in both OP and AF. The average cumulative infiltration was 72.81 cm in OP and 74.76 cm in AF. The curvilinear pattern exhibited by the cumulative depth of water infiltrated was thus in agreement with the theory of infiltration (Reynolds *et al.,* 2002). The high cumulative infiltration recorded in this study might be due to an infinitely deep, homogeneous and permeable soil profile (high Ks) and therefore, water storage depth (Table 2) which ordinarily is advantageous against runoff generation if only the water application rate (rainfall or irrigation) would not exceed the soil infiltrability.

3.2 Effect of OP and AF on Model Predicted Parameters

Green-Ampt parameters: The parameters K_s (saturated hydraulic conductivity) and S_t (suction storage factor or capillarity), respectively averaged 0.342 cm/min and 0.377 cm/min, and 15.56 and 12.56 in OP and AF (Table 5). The high values of S_t depict the high initial infiltration rate in both land use systems. However, the highly significant ($p<0.01$) S_t in OP than in AF pointed to the effect of forest cover on soil structure, in particular, soil pore-space and water intake.

Philip parameters: The sorptivity, *S*, in Philip model averaged 3.82 cm/min$^{0.5}$ in OP and 4.03 cm/min$^{0.5}$ in AF, indicating that sorptivity forces associated with capillarity were initially high. Sorptivity is a measure of the soil's ability to absorb water (Philip, 1957a) and is dependent on initial water content (Philip, 1957b; Chong and Green, 1979). Transmissivity, *A*, a gravity factor that governs the final infiltration rate, was similar in both OP and AF, averaging 0.133 cm/min and 0.136 cm/min, respectively. The estimated values were generally low and orders of magnitude less than i_f, and several orders of magnitude less than *Ks*, indicating that Philip's parameter probably underestimated the i_f and *Ks* of the soil. Duan *et al.* (2011), reported that the estimated value of the Philip *A* should be close to the measured final infiltration rate; however, the values were not identical, and Dashtaki *et al.* (2009), attributed the discrepancy to the fact that these parameters are inherently empirical. Similarly, Philip (1957a), noted that the equality between *A* and *Ks* did not exist; rather, parameter *A* varies from one-third to two-third Ks. It could also be because the cumulative time of three hours was not sufficiently long enough for *A* to equal *Ks* in the study area.

Horton parameters: The parameters in the infiltration model showed that i_o was 1.310 cm/min in OP and 1.330 cm/min in AF, while i_c averaged 0.190 cm/min in OP and 0.156 cm/min in AF. Similar to Philip's *A*, Horton's i_c was also orders of magnitude less than measured i_c. Similarly, *k* averaged -0.0549 in OP and -0.0490 in AF**.** In the Horton's model, k, as a decaying factor, reflects the changes in the slope of the infiltration curve; large k indicates that the infiltration rate decreases faster (Zhao and Wu, 2004). Except for the steepness in the initial portion of the infiltration curve (Figure 1) (Al-Azawi, 1985), the k predicted showed that the decrease in the infiltration rate was slow in both land use systems. The infiltration equations obtained for OP and AF were $i = 11.4 + 67.2e^{-0.0549t}$ and $i = 9.36 + 70.46e^{-0.049t}$ respectively.

Kostiakov parameters: The Kostiakov model parameter *c* averaged 1.959 in OP and 1.913 in AF, while the parameter α had a mean of 0.712 in OP and 0.713 in AF. The infiltration equations obtained for OP and AF are $I = 1.959t^{0.721}$ and $I = 1.913t^{0.735}$ respectively. The average values of the time exponent of Kostiakov's model, α, the index of sorptivity reflecting the rate of declining infiltration capacity, and that the steeper it is, the steeper the slope and the greater the rate of decline of infiltration. Results indicated that α was positive and consistently less than one ($0<\alpha< 1$), indicating reasonably high sorptivity which was in accordance with the theory of infiltration ($0<\alpha< 1$) (Kostiakov, 1932). Hartly (1992), observed that in homogeneous soils the α is mostly higher than 0.5. In a similar study, Al-Azawi (1985) and Oku and Aiyelari (2011), reported α values that were larger than 0.5. Similarly, c, Kostiakov's initial infiltration rate, was confident and consistently higher than zero. Large values of *c* indicate large initial infiltration (Naeth *et al.,* 1991) rate as well as differences between the initial and steady infiltration rates (Liu and Kang, 1997). Hence, both values of α and c were high in the two land use systems.

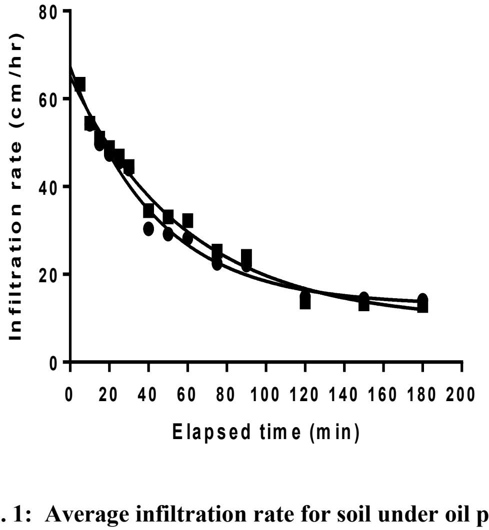

Fig. 1: Average infiltration rate for soil under oil palm and arable farm
Note: OP = Oil palm soil; AF = Arable farm soil

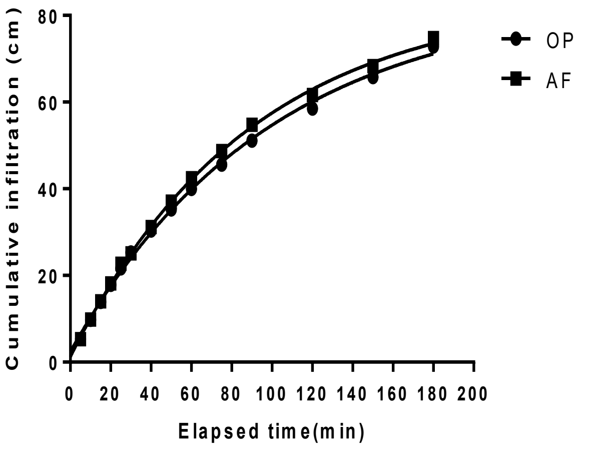

Fig. 2: Average cumulative infiltration for soil under oil palm and arable farm
Note: OP = oil palm soil; AF = Arable farm

Table 5: The Estimated Fitting Parameters of the Models

Models	Green-Ampt		Philip		Horton			Kostiakov		Mezencev		
	k_s (cm/min)	S_t	S (cm/min$^{0.5}$)	A (cm/min)	i_c (cm/min)	i_o (cm/min)	k	c	α	i_c (cm/min)	α	β
OP-1	0.084	16.738	1.122	0.108	0.175	1.020	-0.139	0.992	0.672	0.160	1.832	0.253
OP-2	0.613	14.279	6.630	0.134	0.117	1.679	-0.0150	2.823	0.740	0.287	3.062	0.628
OP-3	0.451	13.243	5.181	0.0941	0.161	1.392	-0.0194	2.387	0.719	0.233	2.685	0.591
OP-4	0.275	10.898	2.201	0.212	0.320	0.977	-0.0523	1.389	0.751	0.260	1.659	0.515
OP-5	0.206	16.111	2.081	0.185	0.298	1.230	-0.0858	1.533	0.706	0.253	2.213	0.400
OP-6	0.321	15.859	3.450	0.170	0.250	1.523	-0.0761	1.907	0.728	0.250	2.193	0.558
OP-7	0.134	22.888	2.620	0.050	0.151	0.888	-0.0382	1.661	0.646	0.157	2.312	0.421
OP-8	0.655	14.516	7.256	0.114	0.049	1.770	-0.0138	2.976	0.741	0.280	3.198	0.640
Mean	0.342	15.566	3.82	0.133	0.190	1.310	-0.0549	1.959	0.721	0.235	2.394	0.501
sd±	0.212	3.491	0.802	0.018	0.0925	0.334	0.0436	0.707	0.037	0.050	0.549	0.134
AF-1	0.458	15.087	5.653	0.076	0.116	1.439	-0.0175	2.576	0.712	0.210	2.831	0.607
AF-2	0.104	7.894	1.377	0.049	0.102	0.501	-0.0396	0.845	0.682	0.103	1.167	0.439
AF-3	0.386	7.699	2.464	0.276	0.270	1.409	-0.091	1.340	0.801	0.277	1.331	0.640
AF-4	0.101	9.830	1.197	0.083	0.142	0.613	-0.0678	0.868	0.688	0.133	1.358	0.358
AF-5	0.544	11.798	5.839	0.115	0.0425	1.436	-0.0133	2.405	0.747	0.230	2.553	0.650
AF-6	0.582	15.420	6.774	0.102	0.0601	1.646	-0.0144	2.866	0.733	0.256	3.097	0.631
AF-7	0.373	18.016	3.896	0.218	0.280	1.850	-0.082	2.138	0.734	0.280	2.388	0.579
AF-8	0.464	14.710	5.018	0.166	0.230	1.749	-0.071	2.265	0.747	0.230	2.388	0.646
Mean	0.377	12.557	4.027	0.136	0.156	1.330	-0.049	1.913	0.731	0.215	2.139	0.569
sd±	0.183	3.824	2.136	0.078	0.0931	0.504	0.032	0.786	0.0378	0.0649	0.746	0.109
Overall Max	0.655	22.888	7.56	0.276	0.320	1.850	-0.0133	2.976	0.801	0.287	3.198	0.646
Overall Min	0.084	7.699	1.122	0.049	0.0425	0.501	-0.139	0.845	0.646	0.103	1.167	0.253
Overall mean	0.359	14.062	3.922	0.134	0.173	1.320	-0.0523	1.936	0.722	0.225	2.267	0.535
Overall sd±	0.193	3.864	2.132	0.064	0.0914	0.413	0.0371	0.722	0.0372	0.057	0.647	0.123
t-test	-0.305^{NS}	3.340**	-0.167^{NS}	-0.053^{NS}	0.6^{NS}	-0.094^{NS}	-0.216^{NS}	0.107^{NS}	-0.876^{NS}	0.572^{NS}	0.693^{NS}	6.534***

OP = oil palm farm; AF = arable farm; sd = standard deviation; model parameters are as defined in Table 1.

** = Significant level at 5%; *** = Significant level at 1%; NS = Non-significant; OPS = Soil under oil palm farm; AFS = Soil under arable farm; SD = standard deviation; model parameters are as defined in Table 1.

Note: t-test compare between OP and AF on each fitting parameters

Mezencev parameters: The Mezencev model constant i_c, the basic infiltration rate after 3 hours, had a mean value of 0.235 in OP and 0.215 cm/min in AF. The α averaged 2.394 in OP and 2.139 in AF, while the β averaged 0.501 in OP and 0.569 in AF. The average values of the time exponent of Mezencev model were positive and consistently less than one, which agreed with the theory of infiltration (Mishra *et al.,* 2003). Rawls (1993), reported that at theoretically large times, laboratory measured *Ks* should be equal to the observed i_c. However, the results of this study defied this assumption, because *Ks* was higher than i_c.

3.3 Effect of OP and AF on Model Validation

Paired t-test analysis (Table 6) of the predictive ability of the models showed significant ($p<0.05$) differences between the measured and Green-Ampt (GA), Horton (H), and Mezencev (MZ) modelled cumulative infiltration in OP; the Philip (P) and Kostiakov (K) estimated *I* was not different from the observed value. The analysis indicated that GA, P, and K, however, underestimated *I*, while H and MZ overestimated the *I.* Similarly, paired t-test analysis showed that H and MZ predicted *I* was significantly ($p<0.05$) different from the measured *I*, while that estimated by GA, P, and K was similar to the observed *I* in AF (Table 7). Also, GA and P under-estimated *I*, H and MZ over-estimated *I*, while K accurately estimated it.

In Figure 3, all models initially accurately predicted *I*, that is, there was a negligible difference between the predicted, and the observed *I* within the first 40 minutes of infiltration in OP, but thereafter, GA, H, and MZ deviated significantly, and either underestimated or overestimated *I*. The results indicate that P and K models could be relied upon to predict *I* in OP. Similar to OP in Figure 3, Figure 4 showed that all models initially, accurately predicted *I* up to the 50th minute, beyond which H and MZ deviated significantly ($p> 0.05$) from the field-measured *I*, indicating that P, K, and GA could be used to estimate I in both OP and AF.

3.4 Selection of best-fit infiltration model

The infiltration models were subjected to the goodness of fit criteria in Table 3, which resulted in the best-fit indices in Table 7. Generally, the models' W and R^2 indices were >0.90 in both OP, and AF land uses. However, the P and K were closer to unity and accounted for almost all the variability in the data as well as provided a very good fit for the data than GA, H, and MZ in OP and AF. Wuddivira and Abdulkadir (2000) have obtained similar results in the northern Guinea savanna of Nigeria. The X^2 goodness of fit, used to express the amount of disparity between the predicted and observed values, showed that K model had the least value followed by P at the 0.05 level of significance in soils of OP and AF; there was a wide disparity between measured and predicted *I* by GA, H, and MZ at the same level of significance. Thus, K and P could be used to predict *I* in soils under the land use systems. The RMSE, the index of the correspondence between measured and predicted *I*, was least under P followed by K, and thus corresponded better to measured *I* than GA, H, and MZ which overestimated *I* in OP and AF. The ME index, to indicate whether a model under- or over-estimates measured values, was similar in pattern to RSME for all tested models. In this study, P and K models systematically under-estimated *I*, the cumulative infiltration, while GA, H, and MZ over-estimated cumulative infiltration. In terms of the best fit model, the order of performance was P>K>MZ>GA>H.

3.5 Model ranking according to the goodness of fit

The ranking of models (Tables 8 & 9) based on the goodness of fit criteria, W, R^2, RMSE, ME and X^2 showed that for W and R^2, the overall model rank for both OP and AF was P>K>MZ>GA>H. Similarly, the ranking for RMSE, ME and X^2 goodness of fit criteria was K>P>MZ>GA>H. The summary of the model rankings (Table 10) indicated that P, Philip's model had the lowest final ranking, closely followed by K, Kostiakov's model while H, Horton's model ranked the highest. This implied that Philip and Kostiakov models were more efficient in predicting the cumulative infiltration, followed by Mezencev and Green–Ampt, and Horton model with the least predictive power for estimating cumulative infiltration in OP and AF. The results showed that P was superior to K and the other models in predicting cumulative infiltration in the study area. Although Azuka *et al.* (2013) and Arab *et al.* (2011) reported that Kostiakov's model was superior to Philip's equation in predicting infiltration into soils of differing land uses, other studies conducted in various locations in Nigeria (Oshunsanya, 2010; Oku and Aiyelari, 2011; Ogban *et al.,* 2012) have reported the superiority of the Philip model over the Kostiakov's model in predicting infiltration into soils under different land use systems.

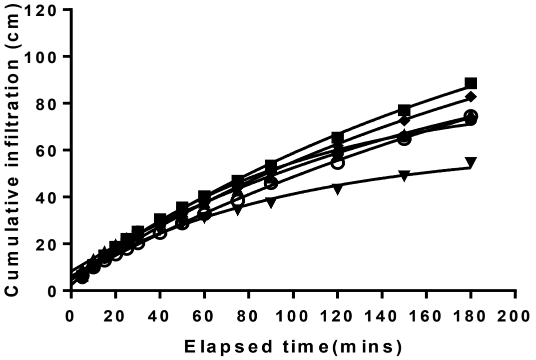

Figure 3: Measured and model predicted cumulative infiltration in OP.
Note: M = Field measured curve; GA = Green–Ampt; P = Philip curve; H = Horton; K = Kostiakov curve; MZ = Mezencev

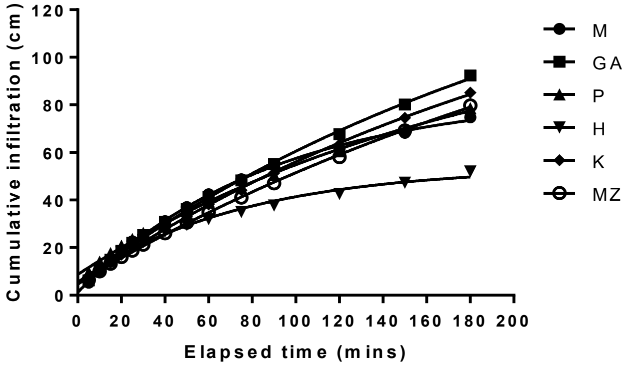

Fig. 4: Measured and predicted cumulative infiltration in AF.
Note: M = Field measured curve; GA = Green–Ampt; P = Philip curve; H = Horton; K = Kostiakov curve;
MZ = Mezencev.

Table 6: Effect of OP and AF on measured and predicted cumulative infiltration (cm) depth

	(OP)						(AF)					
	M	Model predicted					M	Model predicted				
Time (min)		GA	P	H	K	MZ		GA	P	H	K	MZ
5	5.28	6.26	9.21	5.85	6.25	6.54	5.28	6.24	9.68	5.99	6.20	6.42
10	9.79	11.02	13.41	10.52	10.30	9.94	9.81	10.94	14.09	10.84	10.30	10.08
15	13.93	15.08	16.79	14.29	13.80	12.82	14.06	14.98	17.64	14.81	13.85	13.21
20	17.86	18.74	19.74	17.39	16.99	15.44	18.14	18.65	20.73	18.09	17.09	16.06
25	21.66	22.12	22.43	19.98	19.95	17.88	22.68	22.03	23.54	20.82	20.12	18.73
30	25.33	25.30	24.91	22.17	22.75	20.21	25.13	25.21	26.14	23.13	22.99	21.26
40	30.39	30.53	29.48	25.73	28.00	24.60	31.15	30.81	30.91	26.82	28.37	26.05
50	35.25	35.52	33.66	28.58	32.88	28.74	37.03	36.12	35.28	29.69	33.39	30.56
60	39.95	40.31	37.57	31.04	37.50	32.72	42.40	41.23	39.35	32.05	38.15	34.88
75	45.58	46.95	43.06	34.31	44.05	38.45	48.73	48.28	45.07	35.05	44.19	41.08
90	51.10	53.42	48.21	37.35	50.24	45.96	54.75	55.14	50.44	37.74	51.32	47.03
120	58.53	65.33	57.81	43.17	61.82	54.55	61.61	67.68	60.43	42.61	63.33	58.04
150	65.76	77.04	66.74	48.89	72.61	64.72	68.27	80.17	69.72	47.34	74.55	69.27
180	72.81	88.59	75.19	54.59	82.81	74.59	74.76	92.35	78.51	52.04	85.18	79.76
t-test		-2.38^{*}	-0.57^{NS}	3.84^{**}	-0.48^{NS}	3.99^{**}		-1.73^{NS}	-0.69^{NS}	3.55^{**}	0.3^{NS}	2.85^{*}

Note: M = field measured cumulative infiltration; GA= Green-Ampt; P = Philip; H = Horton; K = Kostiakov; MZ = Mezencev.
A negative t-test value indicates a higher cumulative infiltration was recorded for model predicted data than field data and positive value is otherwise; ** = significant at 1%; * = significant at 5%

Table 7: Infiltration Models and Goodness of fit indices

Location	Model	Cumulative infiltration equation	W	R^2	X^2	RMSE	ME
OPS	GA	$I = 0.342t + 15.566\ln(1 + \mathrm{I}/15.566)$	0.985	0.926	5.746	5.572	3.071
	P	$I = 3.82t^{0.5} + 0.133$	0.997	0.988	4.025	2.267	0.355
	H	$I = 0.190t + 20.40\left(1 - e^{-0.0549t}\right)$	0.943	0.830	31.809	8.435	-7.097
	K	$I = 1.959t^{0.721}$	0.993	0.968	3.292	3.681	0.480
	MZ	$I = 0.235t + 2.394t^{0.541}$	0.988	0.953	9.498	4.430	-3.290
AFS	GA	$I = 0.377t + 12.557\ln\left(1 + I/12.557\right)$	0.984	0.924	6.082	5.942	2.574
	P	$I = 4.027t^{0.5} + 0.136$	0.995	0.981	5.645	2.938	0.552
	H	$I = 0.156t + 23.96\left(1 - e^{-0.049t}\right)$	0.890	0.695	47.066	11.896	-8.341
	K	$I = 1.913t^{0.731}$	0.992	0.964	4.441	4.104	-0.341
	MZ	$I = 0.215 + 2.139t^{0.569}$	0.988	0.951	9.300	4.768	-2.955
Average	GA	$I = 0.359t + 14.062\ln(1 + \mathrm{I}/14.062)$	0.985	0.925	5.914	5.757	3.088
	P	$I = 4.514t^{0.5} + 0.147$	0.996	0.985	4.835	2.603	0.454
	H	$I = 0.173t + 21.93\left(1 - e^{-0.0523t}\right)$	0.916	0.763	39.437	10.165	-7.719
	K	$I = 1.936t^{0.722}$	0.993	0.966	3.866	3.893	0.07
	MZ	$I = 0.225 + 2.267t^{0.535}$	0.988	0.952	9.399	4.599	-3.122

Table 8: The W and R^2 ranking for the infiltration models

	GA		P		H		K		MZ	
Models Rank	**W**	**R^2**	**W**	**R^2**	**W**	**R^2**	**W**	**R^2**	**W**	**R^2**
OP	4	4	1	1	5	5	2	2	3	3
AF	4	4	1	1	5	5	2	2	3	3
Overall model rank	4	4	1	1	5	5	2	2	3	3

R^2 = coefficient of determination; W = Willmott's index of agreement; OP = oil palm; AF = arable farm

Table 9: The RMSE, X^2 and MS ranking for the infiltration models

	GA			P			H			K			M		
Models Rank	**RMSE**	**X^2**	**ME**	**RMSE**	**X^2**	**ME**	**RMSE**	**X^2**	**ME**	**RMSE**	**X^2**	**ME**	**RMSE**	**X^2**	**ME**
OP	4	3	3	1	2	1	5	5	5	2	1	2	3	4	4
AF	4	3	3	1	2	2	5	5	5	2	1	1	3	4	4
Overall model rank	4	3	3	1	2	2	5	5	5	2	1	1	3	4	4

RMSE = root mean square error; ME = the mean error; X^2 = chi-square; OPS = Soil under oil palm farm; AFS = Soil under arable farm

Table 10: Final infiltration model ranking

Models	GA	P	H	K	MZ
scores	18	7	25	8	17
Final ranking	4	1	5	2	3

4. Conclusion

A study was conducted to evaluate the effect of oil palm and arable land uses on the Green-Ampt (GA), Philip (P), Kostiakov (K), Horton (H) and Mezencev (MZ) infiltration models, as well as the applicability or efficiency of the models to predict infiltration into the soils on the University of Calabar Teaching and Research Farm. The results showed a consistent trend in the performance of the Philip's and Kostiakov's models in estimating the cumulative infiltration under the two land use system, compared to the other models. Also, Philip's model was superior to the Kostiakov's model in predicting infiltration in this study and is therefore recommended for the soils of the farm and similar soils elsewhere. It is also recommended that the rate of water application to the oil palm and arable farm soils should be less than or equal to the infiltration capacities of 14.1 cm/hr and 12.92 cm/hr, respectively, in other to avoid ponding and runoff or erosion on the farm.

References

Agnihotri, R. and Yadav, R. (2002). Evaluation of infiltration capacity of Ustifluvent soils susceptible to gully erosion. *J Hydr. Sci*. 37:399-406.

Ahmed, A. (1982). Infiltration rates and related parameters for some selected Samaru soils. M. Sc. Dissertation. Department of Agric. Engr., Ahmadu Bello University, Zaria, Nigeria.

Akpan–Idiok, A. U., Ofem, K. I. and Chilekezi, C. (2012). Characterization and classification of soils formed on coastal plain sands in South-eastern Nigeria. p. 57– 63. *Proc. 30th Annual Conference Soil Sci. Soc. Nig.* 12 – 16th March, University of Nigeria, Nsukka.

Al-Azawi, S. A. (1985). Experimental evaluation of infiltration models. *J. Hydr.* 24(2): 77-88.

Amalu, U. C. and Antigha, N. R. B. (1999). Physical properties and moisture retention characteristics of some coastal plain soil in Calabar, South-eastern Nigeria. *Soil Sci.* 7: 153-158.

Amusan, B., Ball, E. and Anderson, G. (2005). Changes in characteristics of a degraded soil under fallow in Southwestern Nigeria. *J Agric. Engr*. 4:12-17.

Antigha, N. R. B. and Essien, I. E. (2007). The Relationship between Infiltration rate and Hydraulic Conductivity of some soils in Akpabuyo Local Government Area of Cross River State, Nigeria. *Global J. Pure.Applied Sci.* 6:2.

Arab, A. I., Mudiare, O. J., Oyebode, M. A. and Idris, U. D. (2011). Performance evaluation of selected infiltration equations for irrigated (FADAMA) soils in Southern Kaduna Plain, Nigeria. *Basic Research Journal of Soil and Environmental,* 2(4): 1- 18.

Azuka, C.V., Mbagwu, J. S. C. and Oyerinde, G. T. (2013). Infiltration characteristics and their prediction on a toposequence at Nsukka, South-eastern Nigeria. *Int. J. Sci. Adv. Tech.* 3(6): 1-7.

Bach, L. B., Wierenga, P. J. and Ward, T. J. (1986). Estimation of the Philip infiltration parameters from rainfall simulation data. *Soil Sci. Soc. Am. J.* 50:1319-1323.

Baver, L. D., Gardner, W. H. and Gardner, W. R. (1972). *Soil Physics*. Wiley Eastern Ltd., New Delhi. 498p.

Bormann, H., Klassen, K. (2008). Seasonal and land use dependent variability of soil hydraulic and soil hydrological properties of two Northern German soils. *Geoderma*145:295-302.

Burch, G. J., Bath, R. K., Moore, I. D. and O'Loughlin, E. M. (1987). Comparative hydrological behaviour of forested and cleared catchments in Southeastern Australia. *J. Hydr.* 90:19-42.

Chong, S. K., and Green, R. E. (1979). Application of field measured sorptivity for simplified infiltration prediction. P. 4-80, 88-96. *In: Proc. Hydr. Trans. Modelling Symp. Publ. Am. Soc. Agric. Engr.* New Orleans, LA.

Dashtaki, S. G., Homaee, M., Mahdian, M. H. and Kouchakzadeh, M. (2009). Site-dependence performance of infiltration models. *Water Res. Manag*. 23:2777–2790.

Davidoff, B. and Salim, H. M. (1986). Goodness of fit for eight water infiltration models. *Soil Sci. Soc. Am. J.* 50:759-764.

Duan, R., Fedler, C. B. and Borrelli, J. (2010). Field evaluation of infiltration models in lawn soils. *Irrig. Sci.* 29: 379-389.

Egbai, O. O., Uquetan, U. I., Ewa, E. E., Ndik, E. J.and Okeke, O. F. (2011). Infiltration rate assessment of coastal plain soils for sustainable crop production in Calabar, *Nig. J. Sustainable Dev.* 4(4): 222-229.

Eze, E. B., Eni, D. I. and Oko, C. (2011). Evaluation of the infiltration capacity of soils in Akpabuyo, Cross River State, Nigeria. *J Geog and Geol*. 3(1):189-199.

Green, W. H., and Ampt, G. A. (1911). Studies on Soil Physics 1: The flow of air and water through soils. *J. Agric. Sci*. 4: 1-24.

Haghighi, F., Gorji, M., Shorafa, M., Sarmadian, F., Mohammadi, M. H. (2010). Evaluation of some infiltration models and hydraulic parameters. *Spanish J. Agric. Res.* 8 (1): 210-217.

Haverkamp, R., Kutilek, M., Parlange, J. Y., Rendon, L. and Krejca, M. (1988). Infiltration under ponded conditions: Infiltration equations tested for parameter time-dependence and predictive uses. *Soil Sci.* 145: 317-329.

Hillel, D. (1971). *Soil and Water: Physical Principles and Processes*. Academic Press, New York. 288p.

Hillel, D. (1998). *Environmental Soil Physics* (1st ed). Academic Press, New York.

Hopmans, J. W., Parlange, J. Y. and Assouline, S. (2007). Infiltration. p. 7 (1–18). *In:* Delleur, J. W. (ed.) *The Handbook of Groundwater Engineering,* 2nd ed. CRS, Florida.

Horton, R. E. (1940). An approach toward a physical interpretation of infiltration capacity. *Soil Sci. Soc. Am. Proc.* 5: 399-417.

Igbadun, H. E. and Idris, U. D. (2007). Performance evaluation of infiltration models in a hydromorphic soil. *Nig. J. Soil Envir. Res*. 7: 53–59.

Isong, I. A., Ogban, P. I., Antigha, N. R. B. and Okon-Inyang, P. B. (2017). Evaluation of methods for determining sorptivity and transmissivity parameters in Philip two-term infiltration model. *Nig. J. Soil Environ. Res.* 15: 41-52 .

Kostiakov, A. N. (1932). On the dynamics of the coefficient of water percolation in soils and on the necessity for studying it from a dynamic point of view for the purpose of amelioration. Trans. Int. Congr. *Soil Sci*. 1932(A):17-21.

Kutílek M., Nielsen D.R. (2015). Soil Regulates Circulation of Water on the Planet Earth. *In* Soil. Springer, Dordrecht

Lal, R. (1993). Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil Till. Res*. 27: 1-8.

Lal, R. (1997). Degradation and resilience of soils. *Phil. Trans. R.* Soc. Lond. B 352: 997-1010.

Lal, R., and Vandoren, D.M.Jr., (1990). Influence of 25 years of continuous corn production by three tillage methods on water infiltration for two soils in Ohio. *Soil Till. Res.* 16(1): 71-84.

Linsley, R. K., Kohler, M. A. and Paulhus, J. L. H. (1975). *Hydrology for Engineers* (2nd ed). McGraw-Hill: New York. 482p.

Liu, X, Z, and Kang, S. Z. (1997). On soil infiltration distribution of small watershed in gullied region of loess plateau. *J. Jilin For. Univ.* 13(4): 203-208.

Majaliwa-Mwanjalolo, J. G. and Tenywa, M. M. (1998). Infiltration characteristics of soils of Kyetume ridge, Kabanyolo, Uganda. MUARIK Bull. 1:57-65.

Mezencev, V. J. (1948). Theory of formation of the surface runoff. *Meteorolgia I Gidrologia*, 3*,* 33-40.

Minasny, B. and McBratney, A. B. (2000). Estimation of sorptivity from disc-permeameter measurements. *Geoderma* 95:305-324.

Mirzaee, S., Zolfaghari, A. A., Gorji, M., Dyck, M. and Dashtaki, S. G. (2013). Evaluation of infiltration models with different numbers of fitting parameters in different soil texture classes. *Arch. Agron. Soil Sci.* 60 (5), 681-693.

Mishra, S. K, Kumar, S. R. and Singh, V. P. (1999). Calibration of a general infiltration model. *J. Hydr. Proc*. 13: 1691–1718.

Obiechefu, G. C. (1991). Evaluation of infiltration equations for Nsukka soils. *The Nig. Agric. J.* 26:27-42.

Ogban, P. I. (2017). Effect of Land Use on Infiltration Characteristics of Soils in Northern Akwa Ibom State, South-eastern Nigeria. *Nig. J. Soil Envir. Res.* 15: 117-127.

Ogban, P. I., Obi, J. C., Anwanane, N. B., Edet, R. U. and Okon, N. E. (2012). Testing the goodness of fit of infiltration models for soils formed on Coastal Plain Sands in Akwa Ibom State, Southeastern Nigeria. *Nig. J. Soil Sci*. 22(1):134-140.

Oku, E. and Aiyelari, A. (2011). Predictability of Philip and Kostiakov infiltration model under inceptisols in the Humid Forest Zone, Nigeria. *Kasetsart J. (Natural Science)* 45: 594 -602.

Osuji, G. E., Okon, M. A., Chukwuma, M. C. and Nwarie, I. I. (2010). Infiltration Characteristics of Soils under Selected Land Use Practices in Owerri, Southeastern Nigeria. *World J. Agric Sci.* 6(3):322-326.

Philip, J. R. (1957a). The theory of infiltration 1: The infiltration equation and its solution. *Soil Sci.* 83: 345–357.

Philip, J. R. (1957b). The theory of infiltration 4: Sorptivity and algebraic infiltration equations. *Soil Sci*. 84: 257-264.

Philip, J. R. (1969). The theory of infiltration. *Adv. Hydrosci.* 5: 215-296.

Pla, S. (2007). Infiltration. Paper presented at College on Soil Physics. In: *Abdus Salam International Centre for Theoretical Physics.* Trieste, Italy. October 22 – November 9, 2007.

Radcliffe, D. E, and Rasmussen, T. C. (2000). Soil water movement. In: Sumner, M. E. (ed.) *Handbook of Soil Science.* The University of Georgia.

Rao, M. D., Raghuwanshi, N. S. and Singh, R. (2006). Development of a physically based infiltration model for irrigated soils. *Agric. Water Manag*. 85:165-174.

Rawls, W. J., Ahuja, L. R Brakensiek, D. L. and Shirmohammadi, A. (1993). Infiltration and soil water movement. Chapter 5. In Maidment, D. R. (ed.) *Handbook of Hydrology*. McGraw-Hill, Inc. USA.

Reynolds, W. D., Elrick, D. E. and Youngs, E. G. (2002). Ring or cylinder infiltrometer (vadose zone). Pp.818-843. In:

Methods of Soil Analysis. Part 4: Physical Methods. Soil Sci. Soc. Am. Book Series: 5. Madison, Wisconsin, USA.

Richards, L. A. (1931). Capillary conduction of liquids through porous mediums. *Physics* 1: 318–333.

Saiko, T.A. and Zonn, I, S. (2003). Land use and management impacts on structure and infiltration characteristics of Ohio soil. *Science* 169:167-177.

Selby, M. J. (1972). The relationship between land use and erosion in the central North Island, New Zealand. *New Zealand J. Hydr*. 26:175-184.

Shukla, M. K., Lal, R., Owens, L. B. and Unkefer, P. (2003). Land use and management impacts on structure and infiltration characteristics in the North Appalachian region of Ohio. *Soil Sci*. 168(3):167-177.

SigmaPlot 12.5 (2013). Systat Software, Inc., San Jose California USA, *www.systatsoftware.com*

Talsma, T. and Parlange, J. Y. (1972). One-dimensional vertical infiltration. *Aus. J. Soil Res.* 10:143-150.

Topaloglu, F. (1999). Comparing tillage technique by infiltration model. *Trop. J. Agric. For*.23:609-614.

Udosen, C. (2017). *Rainfall Trends in a Humid Tropical Environment*. AniHap Resources, Uyo. 244p.

Ukata, S. U., Akintoye, O. A., Digha, O. N., Alade, A. and Asiyanbi, A. (2015). The transformation of Kostiakov infiltration equation on the infiltration rate of forest land cover in Biase, Cross River State, Nigeria. *J. Environ. Sci., Tox. Food Techn*. 9(3), 47-50.

Van Liew, M. W., J. G. Arnold, & J. D. Garbrecht. (2003). Hydrologic simulation on agricultural watersheds: Choosing between two models. *Transaction. ASAE,* 46(6): 1539-1551.

Vandervaere, J. P., Vauclin, M. and Elrick, D. E. (2000). Transient flow from tension infiltrometers: Four methods to determine sorptivity and conductivity. *Soil Sci. Soc. Am. J.,* 64:1272– 1284.

Wilkinson, G.E. and Aina, P. O. (1976). Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping. *Geoderma* 15(1): 51-59.

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., O'Donnell, J. & Rowe, C. M. (1985). Statistics for the evaluation and comparison of models. *J. Geophy Res.* 90 (C5): 8995–9005.

Willmott, C.J. (1981). On the validation of model. *Physical Geog.* 2:184–194.

Wuddivira, H. N. and Abdulkadir, A. (2000). Determination of infiltration characteristics of a Typic Haplustalf in Samaru, northern Guinea savanna, Nigeria. p. 99- 101. In: Babalola O. (ed) *Proc. 26th Annual Conf. Soil Sci. Soc. Nig.* 30th October – 3rd November. Ibadan, Nigeria.

Wuddivira, H. N., Abdulkadir, A. and Tamu, J. (2001). Prediction of infiltration characteristics of an *Alfisol* in the Northern Guinea savanna of Nigeria. *Nig. J. Soil Res.* 2:1-5.

Zhao, X. N., and Wu, F. Q. (2004). Developments and reviews of soil infiltration research. *J. of Northwest For . Univ*. 19(1): 42-45.