Evaluation of Water Infiltration Equations on Fadama Soils of Jos – North, Plateau State, Nigeria

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Abstract
The main purpose of this study is to obtain water infiltration parameters of the Fadama Soils on the Jos Plateau. Estimation of water infiltration on a soil is a major constraint due to its variability depending on local soil characteristics. This could be used in simulating infiltration for the Fadama soils when designing agricultural projects. Field measurement of infiltration were made using the double ring infiltrometer at the three locations (Rizek, Kerker and Shen – du) on the Jos Plateau. Readings were taken at intervals of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 65,70, 75, 80, 85, 90, 95, 100,105, 110, 115 and 120minutes. A set of field measured cumulative infiltration depths were used for the estimation of the model parameters for the five models, while the other set was used in simulating the infiltration equations. At Rizek, Horton and NCRS model performed better (0.997) followed by Philip's model (0.973) while Kostiakov and modified Kostiakov's model have the least value of 0.923 each. Philip's model has the best fit (1.00) followed by the NCRS's model (0.999) at Kerker while the Kostiakov and modifiedKostiakov'smodel had 0.997 each and Horton with the least value (0.986). At Shen – du, Kostiakov and modified Kostiakov performed better (0.997), then, Horton with (0.986), NCRS has 0.993 with Philip's model having the least value (0.991).The study indicate that Kostiakov, Philip, Horton, NCRS and Modified Kostiakov's models were capable of simulating infiltration for the Fadama soils (Rizek, Kerker and Shen – du) on the Jos, Plateau.
Keywords: Infiltration Equations, Fadama Soils, Kostiakov Equation, Infiltartion Models

INTRODUCTION

Infiltration refers to water moving into soil from rainfall or irrigation and is the first stage of water movement in the soil. Infiltration starts as soon as the first drop of rainfall touches the ground surface and continues even after precipitation ceases until the soil is filled to field capacity. It is of great importance in any irrigation plan. For any runoff problem to be solved, it is important to know the infiltration rate, the soil water content after infiltration and the adaptability of some of the infiltration equations to these soils.

Infiltration rate is the process of water movement from the ground surface into the soil. The actual rate at which water enters into the soil at any given time is termed as the infiltration rate (Haghiabi et al., 2011). This rate describes the capacity of a soil to absorb water. Infiltration is linked with surface runoff and groundwater recharge (Uloma et al., 2013). It is also used in modeling, irrigation design and many natural and man-made processes (Igbadun and Idris, 2007). It is also used in the determination of saturated hydraulic conductivity of soil layers (Raoof et al., 2011; Vieira and Ngailo, 2011). Infiltration rate describes the capacity of a soil to absorb water. Its characteristics are key variables in hydrologic analysis and modeling. It is also used in agriculture. Substantial reduction in time and cost of field measurement of infiltration can be achieved by using infiltration models.

There exist ample studies for the evaluation of infiltration models either for the purpose of establishment of model parameters validating models and applicability for different soil conditions (Mudiare and Adewumi, 2000; Usman *et al.*, 2011; Stanley, 2015). For example, Igbadun and Idris (2007) investigated the capacity of Kostiakov's, Kostiakov – Lewis' and modified Kostiakov infiltration models to describe water infiltration into a hydromorphic soil of the flood plain in Zango, Zaria, Nigeria. Oku and Aiyelari (2011) opined that Philip's model was more suitable than Kostiakov's model from a study of the infiltration rate of the soil of the humid forest in southern Nigeria. Moroke *et al.* (2008) and Parlange (1973) stated that the values of the estimated parameters obtained by different models are soil-dependent and site-specific. In addition, they noted that complicated conditions and regional soil variations affect the estimated values. Mbagwu (1995) recommended that empirical models be used to describe infiltration process.

There is no comprehensive and documented infiltration data on the soils of these areas which could serve as a bench mark in assisting the local farmers. It is therefore, the objective of the study to evaluate water infiltration using some time dependent infiltration equations and to determine which of these equations best fits the Fadama soils these three locations on the Jos, Plateau, and also, to propose the water infiltration equations which could be used in simulating infiltration for these soils when designing irrigation projects, soil water management and water resource conservation practices, thereby saving time and cost of field measurement.

MATERIALS AND METHODS

The Study Area

The Jos Plateau covers about 9,400km^2 of the complex in central Nigeria. Its average elevation is about 1,250 meters above mean sea level, with average elevation of Jos town about 1,150 metres and the highest peak some 20km eastwards from Jos - Shere Hill, rising to 1777m. Jos Plateau is bounded on the north and west by the Kaduna plains by the Bauchi plains (on average 700m) and on the south by the Benue plains (about 300m). The distance north to south is approximately 130km, while from west to east is almost the same -120km.Olowolafe*et al*. (2004) reported that the Jos Plateau is located in the central part of Nigeria between latitudes 8°30' and longitudes 8°20' and 9°30'E with a surface area of about 9,400km. It has an average elevation of about 1,250m above sea level and stands at a height of about 600m above the surrounding plains.

Field Measurement

Field infiltration measurements were carried out on the Jos Plateau in Rizek, Kerker and Shen – du villages. Soil samples were collected from adjacent areas of the marked spots at incremental depth to determine the metric bulk density, field capacity, saturated hydraulic conductivities, permanent wilting point, saturation and available water. According to Marshall and Holmes (1988), bulk density increases with the degree of compaction which may be due to the effect of cultivation practices and/or rainfall events on the top soil. A high bulk density would affect infiltration rates (Brady, 1984). It has been noted that bulk density decrease is closely associated with an increase in infiltration capacity. Ahmed and Duru (1985) in John and Peter (2010) found a strong correlation between bulk density and infiltration rate of soil tested in Samaru, Kaduna State of Nigeria.

A double ring infiltrometer was used for the infiltration measurement. The rings were then driven into the ground by hammering a wooden bar placed diametrically on the rings to prevent any blowout effects around the bottoms of the rings. The water level was obtained within the inner ring as the water in the outer ring was kept approximately the same level as that in the inner ring to avoid lateral flow. Repeated readings were taken at 5minutes up to 120minutes intervals with the use of stop watch and measuring tape in all the locations. The infiltration rate and the cumulative infiltration were then calculated.

Infiltration Models Evaluation

Kostiakov Equation

Kostiakov's (1932) infiltration models are derived using the data observed either in the field or laboratory. This model proposes a simple empirical infiltration equation based on curve fitting from field data. The functional relationship between infiltration, I, and time, t, is given by the equation;

$I = kt^a$ ……………………………………………………. (1)

I = cumulative infiltration (cm)

t = time from the start of infiltration (hr)

"k" and "a" are empirical constants that needs to be estimated

To determine the parameters k and a, the logs of both sides of Eq. (1) were taken. The slope of this graph gives the value of a while logk gives the intercept. The value of k was obtained from the anti-logk.

When Eq. (1) is differentiated, the infiltration rate i (cmhr^{-1}) will be obtained as:

$I = akt^{a-1}$ ………………………………………………… (2)

Modified Kostiakov's Equation

Kostiakov's (1932) infiltration equation was modified by adding a better representation of the depth infiltrated over a long period of time, and is given by;

$I = kt^a + b$ ……………………………………………….. (3)

Where b is the rectifying factor, which depends on the soil's initial condition.

Philip's Equation (1957)

The mathematical and physical analysis of the infiltration process developed by Philip (1957) separated the process into two components which are that caused by a sorptivity factors and that influenced by gravity. The Philip`s model takes the form of a power series but in practice an adequate description is given by the two-parameter equation.

$i = St^{1/2} + At$ ………………………………………………. (4)

where

S= sorptivity (cm/hr$^{1/2}$) and

A = transivity or permeability coefficient (cmhr^{-1})

The constant values of A and S may be determined by plotting a graph of di/dt against $t^{-1/2}$.

Horton's Equation (1940)
This model is one of the best known models in hydrology. He recognized that infiltration capacity (I_o) decreases with time until it approaches a minimum constant rate (I_c) which according to him, the decrease in infiltration is attributed primarily due to factors operating at the soil surface rather than the flow within the soil (Xu, 2003).
The Horton's infiltration equation is given by;

$$I = I_c + (I_o - I_c)e^{-kt} \quad \ldots\ldots (5)$$

Thus, the cumulative infiltration becomes the integral of Eq. (5) and is given by;

$$I = I_c t + \frac{I_o - I_c}{k}[1 - e^{-kt}] \quad \ldots\ldots (6)$$

where
k= the decay constant specific to the soil and other factors
I= the infiltration rate

Natural Resources Conservation Service (NRCS)
Experts of United States Department of Agriculture, Natural Resources and Conservation Services found that when the Kostiakov's (1932) infiltration model equation is used after a long time, the value of infiltration rate becomes zero and this differs greatly from actual field result. The NRCS model was modified from Kostiakov's model as reported by Cuenca (1989) in Oiganji et al. (2015).
The NRCS mode is given by;

$$I = kt^a + C \quad \ldots\ldots (7)$$

$$i = kat^{a-1} \quad \ldots\ldots (8)$$

where C = 0.6985 (Cuenca, 1989)

Model Validation
Model validation is carried out by comparing their simulated data with the field measured data. Out of the four infiltration tests from each location, the average of two tests was used to estimate the model's parameters and the average of the remaining two tests were used to validate the models in order to check their predictability.

The validation of the modes was done using Coefficient of Determination (R^2), Eq. (9), and Root Mean Square Error (RMSE), Eq. (10). The R^2 provides a measure of how well observed outcomes are replicated by the model (Steel and Torrie, 1960). It ranges from 0 – 1.

$$R^2 = \frac{\Sigma^n_{i=1}(xi - \overline{x})}{\Sigma^n_{i=1}(yi - \overline{y})} \quad \ldots\ldots (9)$$

$$RMSE = \sqrt{\frac{\Sigma^n_{i=1}(xi - y)^2}{N}} \quad \ldots\ldots (10)$$

Where;
$\overline{y}$= predicted values,
$\overline{x}$=mean of observed value,
x=observed value,
N=number of samples

RESULTS AND DISCUSSIONS

Table 1: Hydraulic properties of Different Locations of Fadama Soils on the Jos Plateau

Fadama Soils	Soil Depth (cm)	Metric Bulk Density (2/cm^3)	Saturated Hydraulic Conductivity (cm/hr)	Filed Capacity (vol.%)	Wilting point (vol.%)	Saturation (vol. %)	Available water (cm/cm)
Rizek							
Ap	0-20	1.32	0.56	37.2	21.1	50.0	0.16
A	20-33	1.22	0.20	44.6	33.6	54.1	0.11
B_1	33-60	1.24	0.25	42.9	30.5	53.3	0.12
B_2	60-98	1.26	0.20	42.9	30.6	52.4	0.12
B_C	98-152	1.25	0.23	42.9	30.5	52.4	0.12
C_1	152-173	1.36	0.36	37.5	2.3	48.8	0.14
C_2	173-200	1.38	0.31	37.4	24.0	48.0	0.13
Average		**1.29**	**0.30**	**40.77**	**27.66**	**51.29**	**0.13**
Kerker							
Ap	0-24	1.32	0.56	37.2	21.1	50.0	0.16
A	24-35	1.22	0.20	44.6	33.6	54.1	0.11
B_1	35-53	1.24	0.25	42.9	30.5	53.3	0.12
B_2	53-66	1.22	0.20	44.6	33.6	54.1	0.11
B_3	66-107	1.23	0.31	42.9	30.4	53.7	0.13
Average		**1.25**	**0.30**	**42.44**	**29.84**	**53.04**	**0.13**
Shen-du							
Ap	0-27	1.29	0.13	43.2	31.3	51.2	0.12
E	27-83	1.31	0.15	42.1	29.7	50.5	0.12
Bt_1	50-83	1.30	0.15	42.1	29.7	50.9	0.12
Bt_2	83-108	1.30	0.13	42.9	30.8	50.7	0.12
C	108-200	1.28	0.10	43.9	32.3	51.4	0.12

Model Parameter Evaluation

The average infiltration parameters of the five infiltration equations (Kostiakov, 1932; Philip, 1957; Horton, 1940; NRCS, 1940; and Modified Kostiakov, 1932) considered in this study for the three locations are reported as follows:

Table 2: Kostiakov's Estimated Constant and Modeled Equations

Location	Estimated constant		modeled equation
	k	a	
Rizek	0.759	2.326	$I = 0.759t^{1.326}$
Kerker	1.260	1.227	$I = 1.260t^{0.227}$
Shen – du	1.260	1.200	$I = 1.260t^{0.2}$

Table 3: Modified Kostiakov's Estimated Constant and Modeled Equations

Location	Estimated constant			modeled equation
	k	a	b	
Rizek	0.759	2.326	0.72	$I = 0.759t^{1.326} +b$
Kerker	1.260	1.227	0.30	$I = 1.260t^{0.227} +b$
Shen – du	1.260	1.200	- 0.008	$I = 1.260t^{0.2} +b$

Table 4: Philip's estimated constants and modeled equations

Location	Estimated constant		modeled equation
	S	A	
Rizek	3.12	2.40	$I = 3.12\sqrt{t} + 2.40t$
Kerker	4.50	0.50	$I = 4.50\sqrt{t} + 0.5t$
Shen – du	5.02	1.00	$I = 5.02\sqrt{t} + 1.0t$

Table 5: Horton's estimated constants and modeled equations

Location	Estimated constant			modeled equation
	k	Io	Ic	
Rizek	0.321	21.65	10.20	$I = 10.20t + \frac{11.45}{0.321}[t - e^{0.321}]$
Kerker	0.718	24.50	8.0	$I = 8.00t + \frac{16.50}{0.718}[t - e^{0.718}]$
Shen – du	-0.615	26.50	8.10	$I = 8.10t + \frac{18.4}{0.615}[t - e^{-0.615}]$

Table 6: NRCS estimated parameters and modeled equation

Location	Estimated constant			modeled equation
	k	a	c	
Rizek	0.35	1.20	0.6985	$I = 0.35t^{0.2} + 0.6985$
Kerker	0.96	0.87	0.6985	$I = 0.96t^{-0.13} + 0.6985$
Shen – du	0.88	0.69	0.6985	$I = 0.88t^{-0.31} + 0.6985$

Simulation of Cumulative Infiltration Using the Estimated Parameters

The values of the estimated parameters depicted in table 2 – 6 were then incorporated into the respective model's equation and calculation of cumulative infiltration was made for each of the three locations using all the five models. The predicted cumulative infiltrations were compared with the measured cumulative infiltration. The field measured data used for the comparison were those that were not previously used in determining the parameters of the models.

Table 7: Observed and Model Predicted Cumulative Infiltration for Rizek

Observed (cm)	Kostiakov (cm)	Philip (cm)	Horton (cm)	NRCS (cm)	Modified kostiakov (cm)
3.37	0.06	2.58	6.96	0.79	0.78
1.42	0.15	3.41	10.40	0.85	0.87
1.21	0.30	4.16	13.76	0.91	1.02
0.83	0.49	4.83	16.84	0.98	1.21
1.28	0.76	5.52	20.04	1.05	1.48
0.44	1.09	6.18	23.16	1.12	1.81
0.89	1.47	6.79	26.03	1.19	2.19
0.45	1.95	7.42	29.02	1.27	2.67
0.63	2.50	8.04	31.94	1.35	3.22
0.92	3.10	8.61	34.63	1.42	3.82
0.28	3.81	9.21	37.44	1.50	4.53
0.93	4.60	9.80	40.19	1.59	5.32
0.47	5.43	10.35	42.73	1.66	6.15
0.48	6.40	10.93	45.38	1.75	7.12
0.48	7.45	11.51	47.98	1.84	8.17
0.48	8.53	12.04	50.39	1.92	9.25
0.48	9.77	12.60	52.91	2.01	10.49
0.48	11.11	13.16	55.38	2.10	11.83
0.47	12.46	13.69	57.68	2.18	13.18
0.49	13.99	14.24	60.08	2.27	14.71
0.48	15.62	14.79	62.45	2.36	16.34
0.50	17.25	15.30	64.66	2.45	17.97
0.52	19.08	15.84	66.96	2.55	19.80
R^2	0.923	0.973	0.997	0.997	0.923
RMSE	8.35	9.84	42.41	1.33	8.85

Table 8: Observed and Model Predicted Cumulative Infiltration for Kerker

Observed (cm)	Kostiakov (cm)	Philip (cm)	Horton (cm)	NRCS (cm)	Modified kostiakov (cm)
2.64	0.32	5.24	7.49	1.06	0.62
1.50	0.54	5.32	10.93	1.22	0.84
1.61	0.77	5.41	14.14	1.38	1.07
1.66	1.00	5.49	16.96	1.51	1.30
1.28	1.26	5.57	19.77	1.66	1.56
1.32	1.53	5.66	22.42	1.80	1.83
1.16	1.79	5.74	24.78	1.93	2.09
1.08	2.07	5.82	27.15	2.06	2.37
1.37	2.36	5.91	29.41	2.20	2.66
0.92	2.64	5.99	31.44	2.32	2.94
0.92	2.95	6.07	33.51	2.45	3.25
0.93	3.26	6.16	35.50	2.58	3.56
0.93	3.56	6.24	37.31	2.70	3.86
0.93	3.88	6.32	39.16	2.83	4.18
0.93	4.20	6.41	40.96	2.95	4.50
0.93	4.52	6.49	42.61	3.07	4.82
0.96	4.85	6.57	44.31	3.20	5.15
0.95	5.19	6.66	45.98	3.32	5.49
0.97	5.51	6.74	47.52	3.43	5.81
0.49	5.86	6.82	49.12	3.55	6.16
0.48	6.21	6.91	50.69	3.67	6.51
0.50	6.55	6.99	52.15	3.79	6.85
0.52	6.90	7.07	53.68	3.91	7.20
R^2	0.997	1.00	0.986	0.999	0.997
RMSE	3.32	5.16	35.56	1.94	3.54

Table 9: Observed and Model Predicted Cumulative Infiltration for Shen – du

Observed (cm)	Kostiakov (cm)	Philip (cm)	Horton (cm)	NRCS (cm)	Modified kostiakov (cm)
2.67	0.33	3.21	8.17	1.11	0.33
1.80	0.55	4.05	11.97	1.24	0.54
1.41	0.78	4.78	15.53	1.37	0.77
1.59	1.01	5.40	18.68	1.47	1.00
1.40	1.26	6.02	21.84	1.58	1.25
1.30	1.52	6.60	24.83	1.68	1.51
1.70	1.77	7.12	27.49	1.77	1.77
1.10	2.05	7.65	30.18	1.86	2.04
1.20	2.33	8.16	32.73	1.95	2.32
1.10	2.60	8.62	35.03	2.03	2.59
1.30	2.89	9.10	37.37	2.12	2.89
1.00	3.19	9.56	39.62	2.20	3.18
1.60	3.48	9.99	41.65	2.28	3.47
1.00	3.78	10.44	43.74	2.35	3.78
1.00	4.09	10.87	45.75	2.43	4.09
1.00	4.39	11.27	47.59	2.50	4.38
1.00	4.71	11.69	49.49	2.58	4.70
1.00	5.03	12.11	51.34	2.65	5.02
1.00	5.34	12.49	53.03	2.72	5.33
1.00	5.67	12.89	54.79	2.79	5.66
1.00	6.00	13.29	56.51	2.86	5.99
1.00	6.31	13.65	58.10	2.92	6.30
1.00	6.65	14.04	59.76	2.99	6.64
R^2	0.997	0.991	0.986	0.993	0.997
RMSE	3.01	8.71	39.52	1.25	3.00

The coefficients of determination (R^2) between the field-measured data and the modeled simulated data were very high (> 0.90) for Kostiakov, Philip, Horton, NCRS and modified Kostiakov's models. This result implies that the models were able to simulate water infiltration adequately in the study area. Considering the performances of the individual models at the study sites, the results indicates that Horton and NCRS's models provides the best fit with the respective values of 0.997 each, Philip's model had 0.973 while Kostiakov and modified Kostiakov's model had a value of 0.923 each for Rizek.

At Kerker, Philip's model shows a perfect fit (1.00), NRCS had 0.999, Horton had 0.986 while Kostiakov and modified Kostiakov had each 0.997. The R^2 value for Shen – du indicate that Kostiakov and modified Kostiakov shows highest (0.997 each), NCRS had 0.993, Philip had 0.991 and Horton had the least with 0.991.

In order to check the discrepancies between the measured and the predicted values, Root Mean Square Error (RMSE) was used. The result from the RMSE values obtained is shown in table 10. The performance of the models was ranked in descending order of accuracy showing their numerical values.

Table 10: RMSE Ranking

Model	Rizek RMSE Value	Rank	Kerker RMSE Value	Rank	Shen – du RMSE Value	Rank
Kostiakov	8.35	4	3.32	4	3.01	3
Philip	9.84	2	5.16	2	8.71	2
Horton	42.41	1	35.56	1	39.52	1
NCRS	1.33	5	1.94	5	1.25	5
Modified Kostiakov	8.85	3	3.54	3	3.00	4

1 = least, 5 = best

The RMSE value from table 10 shows that the NCRS's model rank the highest in all the three locations followed by Kostiakov's then Philip's model. Horton's model had the least error in comparing predicted and measured data. The predictions of NCRS model was close to that of Kostiakovthis may be due to the similarities in their equations but differ by a rectifying factor (b) to modified Kostiakov's model.

This result is similar to those of Eze (2000) and Ahmed (1982) who used similar models for the soil of Minna, Niger State and Samaru in Zaria, Kaduna State, respectively. Al-Azwi (1985) evaluated six infiltration models on a relatively homogenous, coarse-textured soil and found out that Philip's model gave a very good representation of the infiltration while Kostiakov, Green-Ampt and Holtan-Overton performed in that order respectively.

CONCLUSION

Simulated data were evaluated by comparing them with the field data and they showed close agreement with each other, indicating that Kostiakov, Philip, Horton, NCRS and modified Kostiakov's models were capable of simulating infiltration for the Fadama soils (Rizek, Kerker and Shen – du) on the Jos, Plateau.

References

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

Al-Azwi, S.A (1985).Experimental Evaluation of Infiltration models.Journal of Hydrology. 24(2):77-88

Brady, N.C. (1984). The nature and properties of Soils.9th ed., Macmillan, New York, NY, USA.

Cuenca, R. H. (1989): Irrigation System Design – An Engineering Approach. Prentice-Hall, Inc., Englewood Cliffs, NJ. pp552

Eze, P.C. (2000). Infiltration Rates of Soils as Influenced by Land Use management in the Nigeria Guinea Savannah. Unpublished M.Sc. Thesis, Soil Science Department, Federal University of Technology, Minna, Nigeria.

Haghiabi, A. H., Abel-Koupai, M. Heidarpour, and J. M. Habili, (2011):A New Method for Estimating the Parameters of Kostiakov and Modified Kostiakov Infiltration Equations, World Applied Journal, vol. 15, no. 1, pp. 129–135.

Igbadun, H. and Idris, U. (2007): "Performance Evaluation of Infiltration Models in a Hydromorphic Soil," Nig. J. Soil &Env. Res, vol. 7, pp. 53–59.

John, J. J. and Peter, A. A. (2010): Adaptability of Infiltration Equations to the Soils of the Permanent Site Farm of Federal University of Technology, Minna, in the Guinea Savannah Zone of Nigeria. Department of Agricultural Engineering, Federal Universlty of Technology, Minna, Nigeria.

Kostiakov, A. N. (1932): The Dynamics of Coefficeints of Water Percolation in Soils and the Necessity for Studying it from a Dynamic Point of View for Purpose of Amelioration. Transaction Congress International Society for Soil Science, 6th Moscow, Russia, Part A:17 – 21 .

Marshal, T.J.; and Holmes, J.W. (1988).Soil physics.2nd ed., John Wiley, New York, NY, USA.

Mbagwu, J.S.C. (1995) Testing the Goodness of Fit of Infiltration Models for Highly Permeable Soils under

Different Tropical Soil Management System. Soil and Tillage Research, 34, 199-205.

Moroke, T.S., Dikinya, O. and Patrick, C. (2008) Comparative Assessment of Water Infiltration of Soils under different Tillage System in Eastern Botswana. Physics and Chemistry of the Earth, 34, 316-323. http://dx.doi.org/10.1016/j.pce.2008.08.002

Mudaire, O .J. and Adewumi, J. K. (2000): Estimation of Infiltration from Field Measured SorptivityValues. Nigeria Journal of Soil Science Research, 1, 1 -3, http://dx.doi.org/10.1016/j.agwat.2006.04.09

Oiganji, E., Henry, U.I., Stanley, A.A. and Njese, I.M (2015): Evaluation of Water Infiltration Equations on a Sandy Loam Soil of Jos-North, Plateau State, Nigeria.

Oku, E. and Aiyeri, A. (2011): Predictability of Philip and Kostiakov Infiltration Model underInceptisols in the Humid Forest Zone, Nigeria. Kasetsart Journal (Natural Science), 45.594-602.

Olowolafe, E.A., Adepetu, A.A., Dung, J. E. and Osagbemi, M.O. (2004).Effect of Application of Different Levels of Nitrogen and Phosphorus Fertilizer on Upland Rice Yield on the Jos plateau. Nigeria. Journal of environment Sciences 6:39-45.

Parlange, J.R. (1973): Note on Infiltration Advance Front form Forder Irrigation. Water Resources Research, 9, 1075- 1078.

Philip, J. R. (1957): The Theory of Infiltration: The Infiltration Equation and its Solution, Soil Science. 83, 345 – 357.

Raoof, M., A. A. Nazemi, S. M. Sadraddini, and A. Pilpayeh, (2011): Measuring and Estimating Saturated and Unsaturated Hydraulic Conductivity in Steady and Transient States in Sloping Lands, World Applied Sciences Journal, vol. 12, no. 1, pp. 2023

S. A. Vieira and J. A. Ngailo, (2011): Characterizing the Spatial Variability of Soil Hydraulic Properties of a Poorly Drained Soil, World Applied Sciences Journal, vol. 12, no. 6, pp. 732–741.

Stanley, A. A. (2015): Performance of Selected Water Infiltration Models in Organic – Amended Soils. Unpublish MSc. Thesis Submitted to the Postgraduate School Ahmadu Bello University, Department of Agricultural Engineering.

Uloma, A. R., C. T. Onyekachi, E. K. Torti, and U. Amos,(2013): Infiltration Characteristics of Soils of Some Selected Schools in Aba, Nigeria, Archives of Applied Science Research, vol. 5, no. 3, pp. 11–15.

Usman, H., H. Yakubu and I. J. Tekwa (2011): An Infiltration Model Development and Evaluation for Pitcher Irrigation System. Agriculture and Biological Journal of North America. Online: 2151 – 7525, doi: 10:525/abjna.2011.2.6.880.886