

Performance of Selected Water Infiltration Models in Sandy Clay Loam Soil in Samaru Zaria

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Abstract

The performance of selected water infiltration models were evaluated and reported herein. Ten (10) water infiltration models consisting of five (5) empirical (Philip (PH), Kostiakov (KT), Modified Kostiakov (MK), Kostiakov-Lewis (KL) and Natural resources conservation service(NRCS)), three (3) physically based (Green-Ampt (GA), Smith-Parlange (SP), Talsma-Parlange (TP)) and two (2) semi empirical (Swartzendruber (SW) and Horton (HT)), were evaluated for sandy clay loam soil. The aim was to study the ability of the models in accurately predicted measured cumulative infiltration. The study was carried out at the Agricultural Engineering experimental plot at Samaru, Zaria. The soil was predominantly Sandy clay loam. The results showed that the coefficient of determination (r^2) between the models simulated and field measured cumulative infiltration ranged from 0.905 to 0.998.

Index terms— water infiltration, empirical models, sandy clay loam, samaru zaria.

1 I. Introduction

Infiltration is the process of water movement from the ground surface into the soil and is an important component in the hydrological cycle (Haghaibi et. al., 2011).

Adequate water resource management is essential for stable and efficient agriculture. Hence, efforts are being directed towards water management and conservation activities such as irrigation and control of flood and erosion. Realistic planning of these water management activities requires sufficient information on the rate at which different soils take up water under different conditions. Data on rates of infiltration of water into soils can be used to supplement other soil information which could assist soil scientists, engineers, hydrologists and others to deal more effectively with a wide spectrum of water resource management and conservation problems (Ajayi, 2015; Mishra et al., 2003).

Infiltration characteristics of soils can be quantified by direct measurement on the field and/or when field infiltration data are fitted mathematically to infiltration models (Oku and Aiyelari, 2011). Lili et al., (2008) reviewed the commonly used direct methods for measuring soil infiltration which include: single ring and double ring infiltrometers, mariotte-double ring infiltrometer, disc permeameter, rainfall simulator, runoff-on-ponding, runoff-on-out and linear source methods, the results obtained from field infiltration test and soil analysis are used for infiltration modeling.

Infiltration modeling approaches are often separated into three categories: physically based, approximate/semi-empirical (analytical), and empirical models. The physically based approaches use parameters that can be obtained from soil water properties and do not require measured infiltration data. The evaluation of semi-empirical/analytical models are purely mathematical or graphical, it is called semiempirical because their evaluation process involves the use of the asymptomatic or steady state infiltration capacity unlike the physically based models that depends strictly on soil water characteristics. Empirical models tend to be less restricted by assumptions of soil surface and soil profile conditions, but more restricted by the conditions for which they were evaluated, since their parameters are determined based on actual fieldmeasured infiltration data (Hillel, 1998; Skaggs and Khaleel, 1982).

45 Researchers have condensed soil infiltration characteristics into a number of simple mathematical models
 46 (Ajayi, 2015), confidence in the model predictions needs to be demonstrated through adequate field verification,
 47 with agreement between measured values and those predicted by the simulation model (Ogbeet al., 2008).

48 The aim of this paper is to assess the performance of ten (10) widely adaptable infiltration models for Sandy
 49 Clay loam soil. The selected models are: Philip (1957), Kostiaikov (1937), Horton (1940), Modified Kostiaikov
 50 (1978), Kostiaikov-Lewis (1982), Green-Ampt (1911), Swartzendruber (1972), Smith-Parlange (1978), Talsma-
 51 Parlange (1972) and Natural resources conservation service (NRCS 1989) models. The specific objectives are
 52 to estimate the models parameters and to compare the cumulative infiltration (Swartzendruber (SW) and
 53 Horton (HT)), were evaluated for sandy clay loam soil. The aim was to study the ability of the models in
 54 accurately predicted measured cumulative infiltration. The study was carried out at the Agricultural Engineering
 55 experimental plot at Samaru, Zaria. The soil was predominantly Sandy clay loam. The results showed that the
 56 coefficient of determination (r^2) between the models simulated and field measured cumulative infiltration ranged
 57 from 0.905 to 0.998. The value of the modeling efficiency (E) ranged from 0.623 to -7.145 while the. The Modified
 58 Kostiaikov's model had the overall best performance, Green-Ampts model had the best performance amongst the
 59 physically based models and the modified Kostiaikov's and Swartzendruber's model had the best performances in
 60 the empirical and semi-empirical group respectively.

61 depths estimated by the models with those measured in the field.

62 2 II. Materials and Methods

63 The study was carried out at the Department of Agricultural Engineering experimental field, Samaru, Zaria,
 64 Nigeria. Zaria is located on latitude 11 o 11'N and longitude 07 o 38'E, at an altitude of about 668 m above
 65 sea level. The portion of the field used was 200m long by 50m wide. Six points was chosen and soil samples
 66 were collected at 0-15 cm and 15-30 cm depths for soil analysis. Infiltration measurement was carried out using
 67 a double ring infiltrometer. The infiltrometer was driven into the soil to a depth of 15cm and a measuring
 68 tape was fixed inside the inner cylinder from where readings were taken. Readings were then taken at intervals
 69 to determine the amount of water infiltrated during the time interval with an average infiltration head of 5cm
 70 maintained. The infiltration rate and the cumulative infiltration were then calculated. The soil texture of the site
 71 was determined by mechanical analysis method. The United States Department of Agriculture (USDA) Textural
 72 Classification Triangle was used to classify the soil based on the results obtained from the analysis. Where: I
 73 = cumulative infiltration (cm), i = infiltration rate, t= time from the start of infiltration (hr), and a, a_1 , a_2
 74, a_3 , and k, k_1 , k_2 are empirical parameters that need to be estimated. ψ = soil suction head at the sharp
 75 wetting front (cm); $\Delta \theta$ = the change in water content ($\theta_s - \theta_i$) (g/g); θ_s = final moisture content or saturation
 76 moisture content (g/g); θ_i = initial moisture content before water infiltration (g/g); k_s = saturated Hydraulic
 77 conductivity (cm/hr); b = rectifying factor, S (cm/hr $^{1/2}$) = Sorptivity, A (cm/hr) = Transmittivity, f_0 = initial
 78 infiltration rate; f_c = steady state infiltration rate; k= Horton's decay constant specific to the soil, $c = 0.6985$
 79 according to NRCS, c and d are Swartzendruber's empirical constants, C_0 = Soil's Transmittivity (cm 2 /hr).

80 3 b) Estimation of model parameters and model validation

81 The averages of the cumulative infiltration depth 'I' and the cumulative infiltration time 't' were used in the
 82 estimation of the models' parameters. Each model was first transformed into its linear equivalent in which 'I'
 83 and 't' are the dependent and independent variables, respectively, and the coefficients of the linear functions are
 84 the model parameters to be estimated, the physically based models and analytical models were also evaluated
 85 following standard procedures.

86 The values of the parameters estimated were then incorporated into the respective models and the capability
 87 of each model to simulate cumulative infiltration depth for each strip was evaluated by comparing the models
 88 simulated data with field-measured data. The field-measured data used for the

89 4 III. Results and Discussion

90 Tables 4 and 5 below shows the models' simulated cumulative infiltration depth. The coefficients of determination
 91 (r^2) between the field-measured and model simulated data were very high (> 0.90) which implies that the ten
 92 models were able to simulate water infiltration in the study area adequately. The values of E (Nash-Sutcliffe's
 93 modeling efficiency) ranged from -7.145 to 0.978 for the entire study area, Kostiaikov's model with the value of
 94 0.978 gave the closest agreement between observed and predicted values while Horton and Swartzendruber's model
 95 showed the poorest agreement with values of -7.145 and 0.623, respectively. The physically based models also
 96 showed good performance, and this shows their reliability in field application. To further check the discrepancies
 97 between the predicted and the measured values, Root Mean Square Error (RMSE) was used.

98 The result of the RMSE shows that Kostiaikov and Modified Kostiaikov's model had the least error in comparing
 99 the predicted values with field measured values followed by Philip's model. The semi-empirical models which are
 100 Swartzendruber and Horton's model were poor in their prediction this may be due to the fact that their parameters
 101 lack a consistent physical interpretation and also the process involved in the evaluation of the parameters might
 102 be very sensitive to approximation errors and errors due to parallax while determining the initial and steady state
 103 infiltration rates from the graph as inputs for the prediction of cumulative infiltration. Philips model performed

104 better than Kostiakov, this is contrary to the work by Igbadun and Idris (2007), who observed that classical
 105 Kostiakov (1932) model, fitted experimental data better than Philip (1957) model for a hydromorphic soil at
 106 Samaru, Nigeria.

107 The result of this study agrees with the findings of Al-Azawi (1985), who evaluated six infiltration models
 108 on a relatively homogenous, coarse-textured soil. He found that Philip's model gave a very good representation
 109 of the infiltration while Kostiakov, modified Kostiakov, Green-Ampt, and Holtan-Overtton performed in that
 110 order respectively. Berndtsson (1987) studied the application of Infiltration Equation to a Catchment with Large
 111 Spatial Variability in Infiltration" compared two commonly used infiltration equations on a heavy calcareous
 112 clay soil. The result showed that the Horton equation displayed a slightly better fit to observed infiltration as
 113 compared with Philip's equation. Hsu et al., (2002) evaluated three models (Horton, Philip and Green-Ampt) for
 114 three soil types to assess the models based on Richard's equation. Result demonstrated that all three equations
 115 provided similar fits to the numerical results, but the Horton model differed most as compared to the other two
 116 models in terms of infiltration rate.

117 For the purpose of this study empirical, semiempirical and physically based models were used, Modified
 118 Kostiakov, Swartzendruber and Green-Ampt's model had best performance in their respective groups using the
 119 RMSE indices. ??bagwu (1993) recommended the modified Kostiakov equation for routine modeling of the
 120 infiltration process on soils with rapid water intake rates. The Kostiakov and modified Kostiakov equations tend
 121 to be the preferred models used for irrigation infiltration, probably because it is less restrictive as to the mode
 122 of water application than some other models.

123 5 IV. Conclusions

124 The parameters and prediction accuracy of ten infiltration models was carefully studied, among the ten infiltration
 125 models studied, Modified Kostiakov model and Philip's model performed better in their ability to predict
 126 cumulative infiltration, although the other models provided good overall agreement with the field measured
 127 cumulative infiltration depths and are therefore capable of simulating infiltration under the field conditions in
 128 this study, Horton's model performed well initially at 20 minutes after the test began, however it over-predicted
 129 cumulative infiltration after this time. Consequently, the application of these equations under verified field
 130 conditions leads to the determination of the appropriate infiltration characteristics for the equations that would
 optimize infiltration simulation, irrigation performance and minimize water wastage. ¹

2

Strip	Average soil physical characteristics of the strips						
	B.D(g/cm ³)	M.C(g/g)	K _s (cm/hr)	%Clay	%Silt	%Sand	
CM		1.53	0.06	7.37	23.2	17.8	59.0
PM		1.21	0.12	5.92	24.0	20.0	56.0
CT		1.81	0.05	4.58	26.0	14.0	60.0

[Note: *BD = Bulk density; MC =Moisture content; K_s = Saturated Hydraulic Conductivity; C = % Clay ;S_i
 = % Silt; S_a = % Sand; a) Infiltration Models Studied]

Figure 1: Table 2 :

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1

Year	Volume	S/N Model	Name	Cumulative Infiltration equation	Fitting parameters
2016	1	Kostiakov(1932)		$?? = ????$	k
10	2	Green-Ampt(1911)		$?? = ????$	a, I
I	3	Modified		$?? = ????$	k_1
ue IV	4	Kostiakov (1978)		$?? = ????$	S
Version	5	Philip(1957)		$?? = ????$	k, f
()	6	Horton (1940)		$?? = ????$	A, C
S/N Model	7	Kostiakov-		$?? = ????$	k_2
Name	8	Lewis (1982)		$?? = ????$	a, b, S
Cumulative Infiltration equation	9	NRCS Model		$?? = ????$	c, d
Fitting parameters	10	Talsma & Parlange (1972)		$?? = ????$	k, s
		Swartzendruber (1972)		$?? = ????$	k, s
		Smith & Parlange (1978)		$?? = ????$	k, s

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Figure 2: Table 1 :

3

Time (min)	Strip A	Strip B	Strip C	Strip D	Strip E	Strip F
3	1.80	1.60	1.80	1.40	1.30	2.00
5	3.30	2.60	2.50	2.30	1.90	3.00
10	3.80	3.60	3.00	4.00	3.40	4.50
20	4.80	6.10	4.20	5.60	5.40	7.00
30	6.30	7.60	5.90	6.90	6.40	8.50
45	7.90	9.10	7.20	8.70	8.10	10.50
60	8.90	12.10	8.20	9.70	9.90	12.60
90	10.40	14.60	10.40	12.20	12.00	14.60
120	12.40	16.10	11.80	14.30	13.10	16.10
150	13.90	17.70	14.40	15.80	14.60	18.10
180	15.30	19.50	15.50	17.10	16.50	19.10
210	16.30	20.50	16.40	18.10	17.90	20.30
240	16.80	20.90	17.20	18.40	18.90	20.80

Figure 3: Table 3 :

4

Model

Figure 4: Table 4 :

5

Time(hr)	Obs	KT	MK	KL	HT	PH	NRCS	GA	TP	SW	SP
0.05	1.57	1.90	2.02	1.91	1.92	1.98	2.01	2.18	2.42	0.39	1.75
0.08	2.40	2.49	2.50	1.87	3.15	2.56	2.50	2.86	3.13	0.59	2.27
0.17	3.97	3.60	3.44	2.02	6.04	3.65	3.46	4.14	4.46	1.06	3.20
0.33	6.00	5.20	4.90	2.58	11.14	5.21	4.93	6.00	6.37	1.94	4.70
0.50	7.27	6.44	6.10	3.25	15.46	6.42	6.14	7.50	7.87	2.78	5.85
0.75	9.10	7.99	7.64	4.30	20.77	7.93	7.68	9.36	9.72	4.03	7.25
1.00	10.73	9.30	9.00	5.39	25.02	9.22	9.04	10.96	11.32	5.25	8.50
1.50	12.93	11.53	11.39	7.60	31.31	11.43	11.40	13.80	14.05	7.67	10.7
2.00	14.50	13.43	13.49	9.84	35.80	13.33	13.48	16.27	16.41	10.06	12.71
2.50	16.17	15.12	15.40	12.09	39.28	15.03	15.37	18.54	18.53	12.43	14.49
3.00	17.57	16.65	17.17	14.36	42.22	16.60	17.11	20.64	20.49	14.79	16.15
3.50	18.77	18.07	18.84	16.62	44.85	18.05	18.75	22.64	22.32	17.14	17.73
4.00	19.37	19.39	20.42	18.89	47.31	19.43	20.29	24.55	24.05	19.49	19.24
R 2		0.993	0.983	0.905	0.917	0.991	0.984	0.986	0.990	0.931	0.985
RMSE	0.894	1.017	3.568	17.172	0.946	0.995	2.177	2.079	3.693	1.416	
E		0.978	0.971	0.648	-7.145	0.975	0.973	0.869	0.881	0.623	0.945

Figure 5: Table 5 :

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5 IV. CONCLUSIONS

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