

COMPARISON OF DIFFERENT INFILTRATION MODELS USING FIELD MEASURED INFILTRATION RATES OF A SANDY SOIL IN ZING LOCAL GOVERNMENT AREA OF TARABA STATE.

Abstract

Predicting the infiltration characteristics for soils is crucial for efficient management of soil and water resources and prevention of soil erosion. However, prediction of soil infiltration is a major problem due to its variability because proper selection of the technique used to determine the parameters of the models depend on the soil characteristics. A study was conducted to compare some infiltration models with observed field infiltration data. Three models including those of Kostiakov, Modified – Kostiakov and Horton were compared to determine which one most accurately predicted measured infiltration rate from the field. Parameters were developed from measured infiltration data and laboratory analyses of soil samples. Horton model with a RMSE of 0.0372 and R^2 value of 0.999 closely predicted the measured infiltration although the other models provided good overall agreement with the field measured cumulative infiltration depths.

Keywords: Infiltration models, Infiltration, Soil

Introduction

Infiltration process is one of the most important components of the hydrological cycle. The ability to quantify infiltration is of great importance in watershed management. Prediction of flooding, erosion and pollutant transport all depends on the rate of runoff which is directly affected by the rate of infiltration. Quantification of infiltration is also necessary to determine the availability of water for crop growth and to estimate the amount of additional water needed for irrigation (Zolfaghari *et al.*, 2012).

Infiltration is the term applied to the process of water entry into the soil generally by downward flow through all or part of the soil surface (Hilel, 1997). The rate of this process, relative to the rate of water supply, determines how much water will enter the root zone and how much, if any, will run off. Hence the rate of infiltration affects not only the water economy of terrestrial plants but also the amount of overland flow and its attendant dangers

of soil erosion and stream flooding. Where soil conditions, especially at the surface, limit the rate of infiltration, plants may be denied sufficient moisture while surface erosion increases. An understanding of infiltration and the factors that affect it is important not only in the determination of surface runoff, but also in understanding subsurface movement and storage of water within a watershed (Edoga and Odofin, 2011). Knowledge of the infiltration process as it is affected both by the soil's properties and transient conditions and by the mode of water supply is therefore a prerequisite for efficient soil and water management. It is key to soil and water conservation and irrigation management because it determines the amount of runoff over the soil surface during rainfalls or irrigations (Oku and Aiyelari, 2011).

Several studies have been conducted to establish models parameters, validate models or compare models efficiencies and applicability for different soil conditions. Musa and Adeoye (2010) in their study to adapt infiltration equations to the soil of the permanent site farm of the Federal University of Technology, Minna, in the Guinea savannah zone of Nigeria stated that Kostiakov's model showed a better performance over those of Philip's and Horton's models. Mbagwu (1997) reported that Philip's model would always fail to predict measured infiltrations when the assumptions of the model are not met during the infiltration process. However, the need for continuous in-depth and field specific-study of the applicability of infiltration equations cannot be over emphasized since models parameters and performance vary for different soils and with time. Oku and Aiyelari (2011) deduced that Philip's model was more suitable than Kostiakov's model from a study of the infiltration capacity of the soil (Inceptisols) of the humid rain forest in southern Nigeria using the two models. This study is carried out to determine the predictive accuracy of three infiltration models (Kostiakov, Modified Kostiakov and Horton) on soils of Zing Local government area of Taraba State, Nigeria to predict infiltration, estimate the models parameters and to compare the cumulative infiltration depths estimated by the models' with those measured in the field.

Materials and Methods

Study Area

The experiment was carried out at Tasompoh village in Zing Local Government Area of Taraba State which lies between latitude $8^{\circ} 45'$ and $9^{\circ} 10' N$ and longitudes $11^{\circ} 35'$ and $11^{\circ} 50' E$ located in the Savanna Zone of North Eastern Nigeria. The mean monthly maximum and minimum temperature range between $35.06^{\circ} C - 36.40^{\circ} C$ and $20.16^{\circ} C - 20.50^{\circ} C$ respectively, while the mean monthly relative humidity and rainfall are 74.67% and 168.90mm respectively.

Field Measurements

Fifteen (15) infiltration runs were made during the experiment by ponding water in a double ring infiltrometer. The diameters of the inner and outer rings were 30 cm and 60 cm, respectively. The outer cylinder was placed to a corresponding depth of 5 cm in the soil and the inner cylinder to a depth of 10 cm. Water was added first to the outer cylinder which acted as the buffer zone and immediately flows into the inner cylinder. The water depth in the inner cylinder was read at 1 minute intervals for the first 5 minutes and 5 minutes intervals for the next 30 minutes and 15 minutes intervals for the last 120 minutes.

Infiltration Models

Measured data from the field was compared with three models which include Kostiakov, modified Kostiakov and Horton's equation.

Kostiakov and Modified Kostiakov equations

Kostiakov (1932) and Lewis (1938) independently proposed a simple empirical infiltration equation based on curve fitting data. It relates infiltration to time as a power function as presented by Eq: (i)

$$Z = kta \quad (i)$$

where, Z = cumulative infiltration (cm/hr), t = time from start of infiltration (min), k , a = constant that depends on the soil and initial conditions. A better representation of the depth infiltrated over a long period of time is given by the modified Kostiakov equation expressed as

$$Z = kt^a + f_0t \quad (ii)$$

in which f_0 is the long term steady or basic infiltration rate in units of volume per unit length per unit time and width and other parameters as previously defined. The Kostiakov and modified Kostiakov tend to be the most preferred infiltration models used in surface irrigation application because of their simplicity, capability of fitting most infiltration data and probably because it is less restrictive as to the mode of water application than some other models.

Horton equation

Horton (1940) proposed an infiltration equation derived from work and energy principles as

$$z = f + (f_0 - f) e^{-\beta t} \quad (iii)$$

where, f is the steady state infiltration rate, f_0 is the infiltration rate at time, $t = 0$, β is the infiltration decay factor, other parameters as previously defined. The rate of decrease of infiltration rate (z) to steady state infiltration (f) is determined by β . Horton (1940) also attributed this decrease primarily to factors operating at the soil surface rather than to flow processes within the soil.

Integrating Eq: (iii) gives the cumulative infiltration of the Horton model and expressed as

$$Z = ft + (f_0 - f)\beta^{-1} (1 - e^{-\beta t}) \quad (iv)$$

Values of the parameters of the three models were estimated using regression module of the Instat statistical package. The parameters for Kostiakov model were estimated from the cumulative infiltration and time data which were subjected to a non-linear regression analysis ($z = kta$) to find the parameters k and a . Using the final infiltration rate, the cumulative infiltration and time data were subjected to a non-linear regression analysis ($z - ft = kta$) to determine parameters k and a for the modified Kostiakov model. Horton's model parameters were estimated by subjecting the infiltration rate and time data to a semi non-linear regression analysis $[(Z - f) = (f_0 - f) - \beta t]$ to determine parameters f_0 and β .

Statistical Analysis

The accuracy of the different equations for predicting the cumulative infiltration were evaluated by comparing the observed values of measurement on the field and the predicted values based on the fitted equation. The data were then subjected to a linear regression analysis and the t-paired test using the Instat Statistical Package.

Results and Discussion

Soil Properties

The result of analysis of soil physical properties of the study area is presented in table 1. The results showed that the texture of the field surface (0 - 15) cm and the sub-surface (15 - 30) cm depths for the study area were predominantly sandy, having sand fraction ranging from 72.8 – 78 %. The average bulk densities are 1.54g/cm³ and 1.55g/cm³ with average porosities of 42.20% and 41.50% at the 0 – 15cm and 15 – 30cm depth respectively. The average initial antecedent moisture contents are 4.42% and 4.89% at the surface and subsurface depths respectively.

Table 1: Soil Properties

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	BD (g/cm ³)	Porosity (%)	MC (%)
0 – 15	72.80	10.00	17.20	SL	1.54	42.20	4.42
15 – 30	78.00	11.20	10.80	SL	1.55	41.50	4.89

SL = Sandy loam

BD = Bulk Density

MC = Moisture Content

132 Table 2: Estimated model parameters for the study area

Model	Parameters	Values
Kostiakov	K	1.488
	A	0.783
Modified Kostiakov	K	1.703
	A	0.523
	F	0.344
Horton	f_c	21.00
	f_o	66.00
	B	-1.890

133

134 Tables 3 shows the models predicted cumulative infiltration for the study area and the
 135 measured cumulative infiltration used for comparison. The values predicted by the models
 136 closely agree with that measured from the field as seen in the tables. In the 10th and 90th
 137 minute, Horton model predicted values (9.3 and 48.9) that are similar to the observed value
 138 (9.4 and 49.3) respectively. Modified Kostiakov model predicted values that are lower than
 139 the value observed from the field in the 30th and 45th minute.

140

141 Table 3: Cumulative infiltration (cm) predicted by the models compared with measured
 142 values

Time (Min)	Measured	Kostiakov	Modified Kostiakov	Horton
5	5.2	5.4	5.9	5.4
10	9.4	8.9	9.0	9.3
20	16.0	14.6	14.9	16.8
30	20.3	19.2	18.6	21.4
45	29.1	27.6	26.8	30.1
60	35.0	33.9	32.5	37.7
90	49.3	48.3	47.9	48.9
120	55.7	57.2	56.8	58.3

143

Predictions were made using all the three models and the predicted cumulative infiltration were compared with the measured cumulative infiltration. The cumulative infiltration values predicted using the infiltration models and those measured were plotted against each other and fitted with a linear equation with zero intercept to verify the validity of each prediction. The slope of the line of best fit and its coefficient of determination (R^2) for each model is presented in Table 4. To check the discrepancies between the predicted and the measured values, paired t-test and Root Mean Square Error (RMSE) were used. Values of the t-test and RMSE for each model are also presented in Table 4.

The slope of the predicted and measured values showed that the models satisfactorily predicted the cumulative infiltration for all the strips with values ranging from 1.025 to 1.060 and the coefficient of determination values laid between 0.992 and 0.999, which are very high, and shows good predictability of the models.

Statistical results indicate that the three models used satisfactorily predicted the cumulative infiltration, given that the t-calculated values for all the models were less than the t-table value (2.131). Therefore, it can be concluded that the field measured cumulative infiltration do not differ from those predicted by the models since the observed difference can be accounted for by experimental error.

Table 4: Average values of the performance indices between the predicted and measured cumulative infiltration for the field.

	Kostiakov	Modified Kostiakov	Horton
R^2	0.998	0.992	0.999
Slope	1.042	1.060	1.025
t-test	-0.7730	-0.1581	-6.1566
RMSE	0.0365	0.0501	0.0372

The results agree with those of Al-Azawi (1985), who evaluated six infiltration models on a relatively homogenous, coarse-textured soil. He found that Horton's model gave the most satisfactory result; Kostiakov model gave a very good representation of the infiltration while modified Kostiakov, Green-Ampt, Philip and Holtan-Overton performed in that order respectively.

Hsu *et. al.* (2002) evaluated three models (Horton, Philip and Green-Ampt) for three soil types to assess the models based on Richard's equation. Results demonstrated that all three

equations provided similar fits to the numerical results, but the Horton model differed most as compared to the other two models in terms of infiltration rate.

Conclusion

The study investigated the prediction accuracy of three infiltration models. Horton's models gave the best fit to the measured cumulative infiltration. However, the other models provided good overall agreement with the field measured cumulative infiltration depths and are therefore capable of simulating infiltration under the field conditions encountered in the study.

Disclaimer: - This manuscript Title and Abstract was present in the conference.

Conference name: - Sustainable Management of Soil and Water Resources for Food Security, Climate Change Adaptation and Mitigation, At Ibadan, Oyo State Nigeria

Available link:

https://www.researchgate.net/publication/323945391_Comparison_of_Different_Infiltration_Models_Using_Field_Measured_Infiltration_Rates_of_A_Sandy_Soil_In_Zing_Local_Government_Area_of_Taraba_State

March 2018

References

- a. Al-Azawi, S. A. 1985. Experimental evaluation of infiltration models. Journal of Hydrology. 24(2): 77 – 88
- b. Horton, R. E. (1940). An approach towards a physical infiltration capacity. Soil Science Society of America Proceedings, Vol. 5, pp 399-417.
- c. Hsu, S. M., Ni, C. F. and Hung, P. F. 2002. Assessment of three infiltration formulas based on
 - a. model fitting on Richards equation. Journal of hydrologic Engineering. 7(5): 373 – 379
- d. Kostiakov, A. N. 1932. On the Dynamics of the Coefficient of Water Percolation in Soil and
 - a. on the Necessity of Studying it from the Dynamic Point of View for Purpose of Amelioration. Trans. 6th Comm. Int. Soil Science Society, Moscow, part A, 17
- e. Lewis, M. R. 1938. The rate of infiltration of water in irrigation practice. *Transactions of the American Geophysical Union* 18: 361-368.

- 213
- 214 f. Mbagwu, J. S. C.1997. Quasi-steady infiltration rates of highly permeable tropical
- 215 moist
- 216 a. savannah soils in relation to land use and pore size distribution. Soil
- 217 Technology
- 218 b. 11: 185 – 195
- 219 g. Musa, J. J. and Adeoye, P. A. 2010. Adaptability of infiltration equations to the soils
- 220 of the
- 221 a. Permanent Site Farm of the Federal University of Technology, Minna, in the
- 222 Guinea Savannah Zone of Nigeria. Au. Journal of Technology. 14(2): 147 –
- 223 155
- 224
- 225 h. Oku, E. and Aiyelari, A. 2011. Predictability of Philip and Kostiakov infiltration
- 226 model under
- 227 a. inceptisols in the Humid Forest Zone, Nigeria. Kasetsart Journal (Natural
- 228 Science), 45: 594 -602
- 229
- 230 i. Zolfaghari A. A. Mirzaee S. and M. Gorji 2012. Comparison of different models for
- 231 estimating
- 232 a. cumulative infiltration. International Journal of Soil Science. 12(1): 1 – 8