

INFILTRATION MODELS VALIDATION IN A SANDY LOAM SOIL IN ZING, TARABA STATE**Abstract**

Predicting the infiltration characteristics for soils is crucial for proper management and sustainable use of soil and water resources and prevention of soil erosion. This study was carried out to validate some infiltration models with observed field infiltration data in the loamy sand soils of Zing under local conditions. Kostiakov, Modified – Kostiakov and Horton infiltration models were used to compare the measured and predicted cumulative infiltration rate of the soils of the study area. Fifteen infiltration runs were made by ponding water into double ring infiltrometer which was used to carry out the measurements. 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 even though, the other models also provided good prediction in line with the field measured cumulative infiltration.

Keywords: Infiltration models, Infiltration, Soil

Introduction

Infiltration process is one of the most important components of the hydrological cycle. 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 [1].

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 [2]. 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 [3]. Knowledge of soil infiltration characteristics is a required input in increasing irrigation water use efficiency, design of irrigation systems, and decrease water and soil losses, all of which are crucial factors in agriculture [4]. Infiltration data is also an important parameter in field drainage applications [5]. 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 [6].

Several researchers were able to successfully compare and evaluate those available soil-infiltration models in different frameworks under field conditions ([7], [8], [9], [10] and [11]). Musa and Adeoye [12] reported Kostiakov's model as one with better performance compare to Philip's and Horton's models 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. Mbagwu [13] observed 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 (Ogbe *et al.*, 2011). Oku and Aiyelari [6] in their study on infiltration capacity of the soils of the humid rain forest in southern Nigeria reported Philip's model to be more suitable than Kostiakov's model in predicting the infiltration rate of the study area. This study is carried out to validate the predictive accuracy of three infiltration models (Kostiakov, Modified kostiakov and Horton) on loamy sand soils of Zing Local government area of Taraba State, Nigeria and also to compare the cumulative infiltration depths estimated by the three infiltration 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 [14] and [15] independently proposed a simple empirical infiltration equation based on curve fitting data. It relates infiltration to time as a power function as presented by Equation (i)

$$Z = kt^a \quad (i)$$

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 [16] 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 [16] also attributed this decrease primarily to factors operating at the soil surface rather than to flow processes within the soil.

Integrating Equation (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 ($Z = kt^a$) 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 ($Z - f_t = kt^a$) 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

Table 1 below shows the results of the analysis of soil physical properties of the study area. From the results, sand particle dominates the surface and sub-surface soil of the area ranging from 72.8 – 78%, hence the sandy loam texture. Bulk densities ranging from 1.54g/cm³ in the surface (0 – 15cm) and 1.55g/cm³ at the sub surface (15 – 30cm), with porosity (42.20% and 41.50%) and moisture content of (4.42% and 4.89%) at the surface and subsurface 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

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_0	66.00
	B	-1.890

Models predicted cumulative infiltration for the study area and the measured cumulative infiltration used for comparison are shown in Table 3. The models predicted values that closely agree with those measured from the field. In the 10th and 90th minute, Horton model predicted values (9.3 and 48.9) that are similar to the observed value (9.4 and 49.3) respectively. Modified Kostiakov model predicted values that are lower than the value observed from the field in the 30th and 45th minute.

Table 3: Cumulative infiltration predicted by the models field measured 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

Predictions were made using all the three models and the predicted cumulative infiltration were compared with the field measured cumulative infiltration. The values are plotted against each other and fitted with a linear equation taken intercept as zero to validate each prediction. Table 4 below shows the slope of the fitted line and the coefficient of determination (R^2) for each model. Paired t-test and root mean square error (RMSE) was used to check the

differences between the predicted and the field measured values and the values are shown in Table 4.

The slope of the predicted and measured values confirmed 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.

The t-calculated values for all the models were less than the t-table value (2.131) indicating that the models have satisfactorily predicted the commulative infiltration, it can therefore be concluded that the cumulative infiltration predicted by the models do no differ from the field measured cumulative infiltration since the observed difference are accounted for by the experimental error.

Table 4: Performance indices between the predicted and measured cumulative infiltration for the field.

	Kostiakov	Modified Kostiakov	Horton
R²	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

These results confirmed with those of [17], who evaluated six infiltration models on a relatively homogenous, coarse-textured soil and found Horton's model to give the most satisfactory result; followed by Kostiakov model, Kostiakov, Green-Ampt, Philip and Holtan-Overton. Wudivira et al. [19] reported failure of Horton equation in the measurement of infiltration rates of soils using non-linear least square regression when comparing three infiltration models in Samaru and attributed the apparent failure of the Horton equation to difficulty of the iteration procedure to handle three parameters at the same time. Same reason was suspected to cause the observed result. However, a good performance of Horton model was observed by [20] using linear and non-linear least-squares regression procedures simultaneously. 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 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. 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.

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