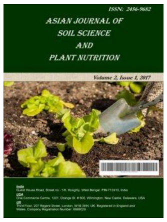

Asian Journal of Soil Science and Plant Nutrition

3(3): 1-5, 2018; Article no.AJSSPN.42878
ISSN: 2456-9682

Infiltration Models Validation in a Sandy Loam Soil in Zing, Taraba State

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Authors' contributions

This work was carried out in collaboration between all authors. Author HJP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SAG and ATG managed the analyses of the study. Author TWJ managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJSSPN/2018/42878
Editor(s):
(1) Dr. Tualar Simarmata, Professor, Department of Soil Sciences of Agriculture Faculty, University of Padjadjaran Bandung, Indonesia.
Reviewers:
(1) Gunnar Bengtsson, Sweden.
(2) Rebecca Yegon, University of Embu, Kenya.
(3) Mohamed Said Abdalla El Marazky, Agriculture Engineering Research Institute, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history/26192

Original Research Article

Received 22nd June 2018
Accepted 31st August 2018
Published 12th September 2018

ABSTRACT

Predicting the infiltration characteristics for soils is crucial for proper management and sustainable use of soil and water resources for prevention of soil erosion. The study was carried out to evaluate the infiltration models by measuring the field infiltration rate on sandy loam soils in Zing. Kostiakov, Modified – Kostiakov and Horton infiltration models were evaluated by comparing the measured and predicted infiltration rate of the soils. 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 and Kostiakov models with an RMSE (0.0372 and 0.0365) and the R^2 value of 0.999 and 0.998 respectively, closely predicted the measured infiltration rate, and can as well stimulate infiltration under the field conditions.

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Keywords: Infiltration models; infiltration; soil.

1. INTRODUCTION

Infiltration process is one of the most important components of the hydrological cycle Henry [1] 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 [2].

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 [3]. 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 providing an insight on the subsurface water movement and storage of water within a watershed [4]. Knowledge of soil infiltration characteristics is a required input in increasing irrigation water use efficiency, the design of irrigation systems, and decrease water and soil losses, all of which are crucial factors in agriculture [5]. Infiltration data is also an important parameter in field drainage applications [6]. 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 [4,7].

Several researchers were able to successfully compare and evaluate those available soil-infiltration models in different frameworks under field conditions [8,9,10,11,12]). Musa and Adeoye [13] reported Kostiakov's model to show good performance as compared to Philip's and Horton's models in their work to fit infiltration equations to the soil of the permanent site farm of the Federal University of Technology, Minna, in the Guinea savannah zone of Nigeria [3]. Mbagwu [14] in his study on moist tropical savannah soils reported that Philip's equation fails to predict measured infiltrations unless the assumptions of the model are met during the infiltration process. This study is carried out to validate the predictive accuracy of three infiltration models (Kostiakov, Modified Kostiakov, and Horton) on sandy loam soils of Zing Local government area of Taraba State, Nigeria and also to compare the infiltration rates estimated by the three infiltration models with those measured in the field.

2. MATERIALS AND METHODS

2.1 Location and Soil Properties

This study was conducted out at Tasompoh village in Zing Local Government Area of Taraba State which lies between latitude 8°45' and 9°10'N and longitudes 11°35' and 11°50'E located in the Savanna Zone of North Eastern Nigeria. The mean maximum and the minimum monthly temperature range between 35.06°C – 36.40°C and 20.16°C – 20.50°C respectively, while the mean monthly relative humidity and rainfall are 73.29% and 139mm respectively [15]. Selected soil physical properties of the study area are presented in Table 1. The 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 1.54 g/cm3 in the surface (0 – 15 cm) and 1.55 g/cm3 at the subsurface (15 – 30 cm), with porosity (42.20% and 41.50%) and moisture content of (4.42% and 4.89%) at the surface and subsurface respectively.

2.2 Field Measurements

Fifteen (15) infiltration runs were made during the experiment by ponding water in a double ring infiltrometer. The inner and outer diameters of the 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.

2.3 Infiltration Models

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

2.4 Kostiakov and Modified Kostiakov Equations

Kostiakov [16] and Lewis [17] both working independently offered a simple empirical equation based on curve fitting data relating infiltration to time as a power function which was presented as Equation (i) below

$$Z = kt^a \quad \text{(i)}$$

where, Z = cumulative infiltration in (cm/hr), t = time from start of infiltration in (min), k, a are constants which depend on the soil initial conditions.

Modified Kostiakov equation gave a better representation of the depth infiltrated over a long period of time which is presented as Equation (ii) below

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

Where, f_0 is the long-term steady infiltration rate in units of volume per unit length per unit time and width and other parameters (Z, k, t and a) are as explained in (i) above.

Equations (i) and (ii) representing Kostiakov and modified Kostiakov equations respectively are most preferred in surface irrigation application because of their ease and ability to appropriately fit most infiltration data.

2.5 Horton Equation

Horton [18] suggested an equation which he derived from the principles of work and energy presented as Equation (iii) below

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

where the steady-state infiltration rate is given as f, the infiltration rate at the time, t = 0 is given as f_0, infiltration decay factor as β, other parameters (Z and t) as previously defined in (i) above. The rate of decrease of infiltration rate (Z) to steady state infiltration (f) is determined by β. He attributed this fall/change largely to factors operating at the soil surface rather than to flow activities occurring within the soil.

Integrating Equation (iii) gives the cumulative infiltration of the Horton model and is expressed as Equation (iv) below

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

Values of the parameters of the three equations were estimated using regression module of the Instat statistical package. The parameters (k and a) for Kostiakov model ($Z = kt^a$), were found after subjecting the cumulative infiltration and time data to a non-linear regression analysis. The final infiltration rate, cumulative infiltration, and time data were also subjected to a non-linear regression analysis ($Z - ft = kt^a$) to determine parameters k and a for the modified Kostiakov model. Model parameters for Horton's equation were gotten by performing semi non-linear regression analysis on the infiltration rate and time data to determine parameters f_0 and β.

2.6 Statistical Analysis

The accuracy of the three models used for predicting the cumulative infiltration was weighed by comparing the observed values 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.

3. RESULTS AND DISCUSSION

Cumulative infiltration predicted by the models and the measured cumulative infiltration used for comparison are presented in Table 2. 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 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. 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 empirical models and was compared with the field measured cumulative infiltration. The values were plotted against each other and fitted with a linear equation with intercept taken as zero to confirm each prediction. Table 3 shows the slope of the fitted line and the coefficient of determination (R^2) for the three model. Differences between the predicted and the field measured values were checked by paired t-test and root mean square error (RMSE) and the values for these are presented in Table 3.

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 cumulative infiltration, it can, therefore, be concluded that the cumulative infiltration predicted by the models do not differ from the field measured cumulative infiltration since the observed difference are accounted for by the experimental error.

Table 3. 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

These results confirmed with those of [19], who test the applicability of six infiltration models on a fairly homogenous, coarse-textured soil and found Horton's model to give the most satisfactory result followed by Kostiakov model. Wudivira et al. [20] reported the 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 the difficulty of the iteration procedure to handle three parameters at the same time. The same reason was suspected to cause the observed result. However, a good performance of Horton model was observed by Abdulkadir et al. [21] using linear and non -linear least-squares regression procedures simultaneously. The results revealed that all three models provided a closely related fit to the numerical results, however, Horton's model varied most compared to the other two models with respect to the infiltration rate.

4. CONCLUSION

The study investigated the prediction accuracy of three infiltration models. Horton and Kostiakov models with an RMSE of (0.0372and 0.0365) and the R^2 value of 0.999 and 0.998 respectively, closely predicted the measured infiltration rate by providing good overall agreement with the field measured infiltration rates and can as well stimulate infiltration under the field conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26192