

Use of Kostiakov's Infiltration Model on Michael Okpara University of Agriculture, Umudike Soils, Southeastern, Nigeria

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Abstract

The main purpose of this study is to obtain the water infiltration parameters of the soils of Michael Okpara University of Agriculture, Umudike. This could be used in simulating infiltration for these soils when designing irrigation projects, thereby saving time and cost of field measurement. Field measurements of infiltration were first made using a double ring infiltrometer. The test lasted for 180 mins in each location. Infiltration values ranged from 0.03 cm/min to 0.1 cm/min. The highest value was obtained in the Forest Block. Kostiakov's infiltration model was then applied on the field data in order to determine the soils' infiltration parameters and equations. The model empirical constants or parameters obtained were "m" and "n". For "m" the values were: 0.53 for the soil of Forest Block, 0.42 for Poultry block, 0.50 for P.G. block, 0.41 for the soils of Staff School and Guest House. The corresponding "n" values were: 1.37, 1.12, 0.37, 1.79, and 1.38. Infiltration equations: $0.41t^{1.38}$, $0.41t^{1.79}$, $0.42t^{1.12}$, and $0.53t^{1.37}$ were determined for the locations. These were used to simulate data which were evaluated by comparing them with the field data. The two data sets showed closed relationships. This implied that the model could be used to simulate water infiltration during irrigation projects in the farms of Michael Okpara University of Agriculture, Umudike.

Keywords

Kostiakov, Model Parameters, Infiltration, Soil, Water, Irrigation

1. Introduction

Water infiltration into the soil is a very important issue in soil water management and water resource conserva-

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tive practices. 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. [1] These models can be used in designing and optimizing irrigation projects. [2] evaluated the Parlange's model for four soil units, ranging from sandy loam to loam soils and found that the model was adequate in predicting cater infiltration to a reasonable level of accuracy. [3] studied the performance of four different models in a hydromorphic soil of Zango plain, Zaria Nigeria and found that [4] [5] models provided best fit with experimental data for the soil. [6] evaluated the infiltration rates of soils under four land uses in north-eastern Mexico while [7]-[9] 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. [10] recommended that empirical models be used to describe infiltration process.

1.1. Literature

Infiltration models can be generally classified into three groups: physically based models, semi-empirical models and empirical models [11]. Empirical models are derived from data observed in the field or in the laboratory. The models of Kostiakov's, Huggin, Monke Modified Kostiakov, etc. fall in category of empirical models. Some of the available empirical models have been quite popular and frequently used in various water resource applications all over the world, owing to their simplicity yielding reasonable and satisfactory results in most applications. For example, the wide-spread application of the Kostiakov (KT) and Modified Kostiakov (MKT) models in irrigation engineering are very important based on its field applicability.

1.2. Kostiakov's Equation

This model suggested a formula which assumes that at time $t = 0$, the infiltration rate is infinite and at $t = \infty$, the rate approaches zero [12]. This equation is given by:

$$I = Mt^n \quad (1)$$

where

I = Cumulative infiltration rate

n = index of soil structural stability

M = A measure of initial rate of initial rate of infiltration and structural condition of the soil

R = Time elapsed

Taking the logs of both sides gives:

$$\log I = \log M + n \log t \quad (2)$$

A plot of $\log I$ against $\log t$ gives a straight line whose slope gives the value of n , while the intercept gives the value of $\log M$. To determine the values that best fit the equation, the values of I were calculated by substituting the values of antilogs of $\log M$ and n in Equation (1) for each value obtained at any time t . " M " and " n " depends on soil type, vegetative cover, soil characteristics, moisture condition, rainfall intensity and soil surface conditions.

1.3. Objective

It is the objective of this study to obtain the water infiltration parameters of the soils of Michael Okpara University of Agriculture, Umudike, which would become an input in soil water management and water resource conservative practices in this area. Also to propose the water infiltration equations which could be used in simulating infiltration for these soils when designing irrigation projects, thereby saving time and cost of field measurement.

2. Materials and Method

Field measurements of infiltration were first made using a double ring infiltrometer in five different locations namely Staff School, Guest House, Forest, Poultry and the P.G. Hostel all located at Michael Okpara University of Agriculture, Umudike.

Measurement

The infiltration capacities of Umudike soils obtained are given below.

3. Discussions

Table 1 shows the field measured cumulative infiltration depths and the infiltration rates for each location. The infiltration rate for the soil of Staff School block was 0.10 cm/min while its cumulative infiltration depth was 17.8 cm after 180 mins. The soils of P.G. and Guest House blocks have infiltration rates of 0.03 cm/min with cumulative infiltration depth of 13.0 cm and 4.6 cm respectively. These were influenced by the texture, moisture content and vegetation cover of these soils.

Table 2 shows the values of the estimated parameters. “m” values ranged from 0.37 - 1.79. The infiltration equations obtained for the soils were: $0.41t^{1.38}$, $0.41t^{1.79}$, $0.50t^{0.37}$, $0.42t^{1.12}$ and $0.53t^{1.37}$. This confirmed the fact that the values of the estimated parameters are soil dependent and site specific as noted by [13]-[15].

Table 3 shows the physical properties of the soils, the textures of the soils and sandy loam and sandy clay loam. The bulk density ranged from 1.4 - 1.7 g/cm³. The Organic Matter content and porosity of the soils are relatively high, ranging from 1.6 - 3.4 and from 34% - 46% respectively. The PH of the soils indicated acidity while the total nitrogen highest value was 0.19.

Table 4 presents the predicted cumulative infiltration. These were compared with field data. The cumulative infiltration showed a negligible difference between the field and the simulated data. **Figure 1** and **Figure 2** represent the infiltration curves for the field and simulated data respectively. **Figure 3** and **Figure 4** compared the simulated and field infiltration curves for the soil of Guest House block and for the soil of Staff School block. These curves were closely related, indicating that the predicted Kostiakov’s equations used in simulating infiltration for the soils gave infiltration values with no significant variations from the field data. This shows that Kostiakov’s model can be used in this area. This result is similar to those obtained by [16] in the evaluation of some infiltration models and hydraulic parameters. [17] used same model for soil of Minna, Niger State in soil grouping of the Federal university of Technology, Minna, Nigeria. He obtained the following parameters: $M = 1.069$, $n = 0.821$ for cultivated soils and $M = 0.741$, $n = 0.760$ for the fallowed soils of the same location. [18] in the evaluation of soil infiltration model coefficients obtained the infiltration equation: $I = 1.0947T^{0.66}$ for Kostiakov’s model.

Table 1. Field measurement of Infiltration rate (TR) and Cumulative Infiltration (CI) of Umudike Soils.

Time (mins)	Staff School		Guest House		PG Hostel		Forest Block	
	I.R. (cm/min)	C.I. (cm)	I.R. (cm/min)	C.I. (cm)	I.R. (cm/min)	W.I. (cm)	I.R. (cm/min)	C.I. (cm)
5	0.80	4.0	0.60	3.0	0.16	0.8	0.80	4.0
10	0.48	4.8	0.36	3.6	0.12	1.2	0.48	4.8
15	0.37	5.6	0.28	4.2	0.09	1.4	0.38	5.8
20	0.30	6.0	0.25	4.6	0.08	1.6	0.34	6.8
30	0.23	6.8	0.17	5.0	0.07	2.0	0.25	7.4
40	0.19	7.6	0.16	6.2	0.06	2.4	0.22	8.6
50	0.17	8.4	0.14	6.8	0.06	2.8	0.19	9.6
60	0.15	9.2	0.12	7.2	0.05	3.0	0.18	10.6
75	0.14	10.4	0.11	8.4	0.05	3.4	0.17	13/0
90	0.13	11.6	0.10	8.8	0.04	3.8	0.17	15.0
120	0.11	13.0	0.09	10.2	0.03	4.0	0.16	18.8
150	0.10	15.4	0.07	10.6	0.03	4.4	0.16	24.4
180	0.10	0.10	0.07	13.0	0.03	4.6	0.16	24.4

Table 2. Soil parameters and equations.

Simulated Kostiakov's Soil Infiltration Parameters for the Locations					
S/N	Location	M	N	Kostiakov's Equations	R ²
1	Forest	0.53	1.37	$0.53t^{1.37}$	0.965
2	Poultry	0.42	1.12	$0.42t^{1.12}$	0.942
3	P.G. Hostel	0.50	0.37	$0.50t^{0.37}$	0.916
4	Staff School	0.41	0.79	$0.41t^{1.79}$	0.941
5	Guest House	0.41	1.38	$0.41t^{1.38}$	0.967

Table 3. Physical properties of the soils of the locations.

S/N	LOCATION	SAND %	SILT %	CLAY %	TEXT URE	B.D. (g/cm ³)	P.D. (g/cm ³)	PH	ORG. MAT. (%)	T.N.	PORO. %
1	P.G. Hostel	69.6	14	16.4	SL	1.7	2.57	5.7	2.0	0.16	34
2	Forest Block	62.6	18	17.4	SCL	1.4	2.57	5.7	2.4	0.19	46
3	Staff School	64.6	18	17.4	SL	1.8	2.57	5.7	2.0	0.16	39
4	Guest House	65.6	16	18.4	SL	1.6	2.56	5.6	1.6	0.12	38
5	Poultry	57.6	20	21.4	SCL	1.6	2.57	6.2	3.4	0.19	38

B.D. = Bulk density; T.N. = Total Nitrogen; P.D. = Particle; ORG. MAT. = Organic Matter; Poro. = Porosity.

Table 4. Simulated data compared with field data.

Time (cm)	Staff School		Guest House		Forest		Poultry		P.G. Hostel	
	Simulated Data (cm)	Field Data (cm)	Simulated Data (cm)	FIELD data (cm)	Simulated Data (cm)	Field Data (cm)	Simulated Data (cm)	Field Data (cm)	Simulated Data (cm)	Field Data (cm)
5	3.4	4.0	2.7	3.0	3.2	4	2.2	2.6	0.5	0.8
10	4.6	4.8	3.5	3.6	4.6	4.8	2.9	3.0	1.2	1.2
15	5.4	5.6	4.2	4.2	5.7	5.8	3.5	3.4	1.4	1.4
20	6.1	6.0	4.7	4.6	6.7	6.8	3.9	3.8	1.6	1.6
25	6.7	6.4	5.1	5.0	7.5	7.0	4.3	4.0	1.9	1.8
30	7.2	6.8	5.6	5.0	8.3	7.4	4.7	4.2	2.0	2.0
40	8.1	7.6	6.2	6.2	9.7	8.6	5.3	5.0	2.3	2.4
50	8.9	8.4	6.9	6.8	10.9	9.6	5.8	5.2	2.6	2.8
60	9.6	9.2	7.4	7.2	11.9	10.6	6.3	6.6	2.8	3.0
75	10.5	10.4	8.1	8.4	13.5	13.0	6.8	7.6	3.2	3.4
90	11.3	11.6	8.7	8.8	14.9	15.0	7.4	8.0	3.5	3.8
120	12.7	13.0	9.8	10.2	17.3	18.8	8.4	8.4	3.5	4.0
150	14.0	15.4	10.8	10.6	19.5	24.4	9.1	9.4	4.5	4.4

4. Conclusions

The objective of this study was to use Kostiakov's model to obtain the water infiltration parameters and equations of the soils of Michael Okpara University of Agriculture, Umudike, which could be used in simulating infiltration for these soils when designing irrigation projects, thereby saving time and cost of field measurement. Simulated infiltration could also serve an input in soil water management and water resource conservative practices in the area.

Field measurements of infiltration were first made using a double ring infiltrometer in five different locations at Michael Okpara University of Agriculture, Umudike. Infiltration rate ranged from 4.6 cm/min to 24.4 cm/mm. Kostiakov's infiltration model was then applied on the field data to determine the soil's infiltration model coef-

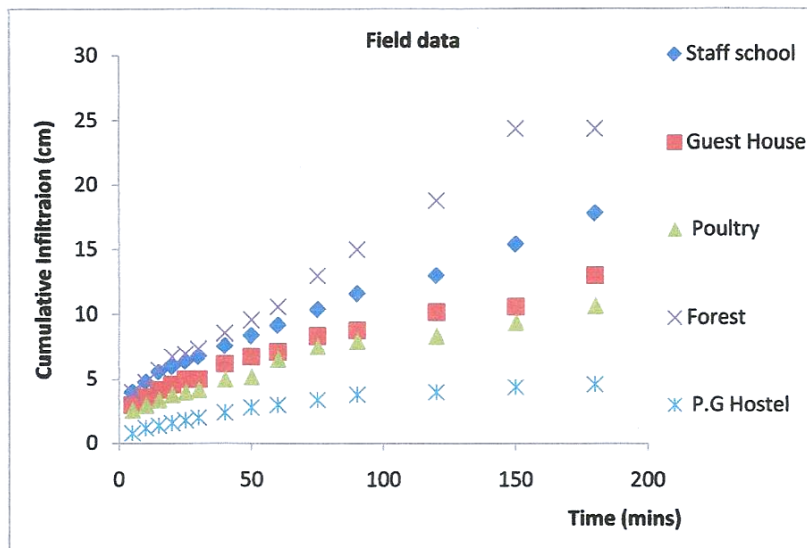


Figure 1. Infiltration of the field data.

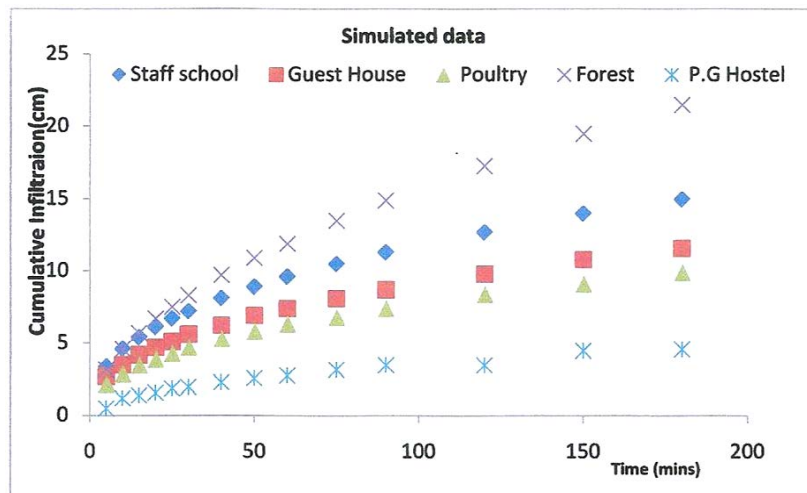


Figure 2. Infiltration curves of the simulated data.

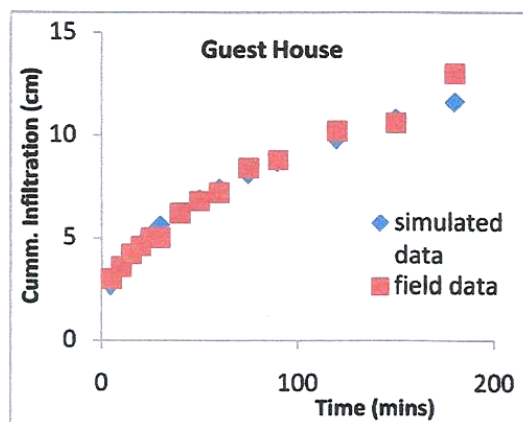


Figure 3. Simulated and field infiltration curves for the soil of Guest House block.

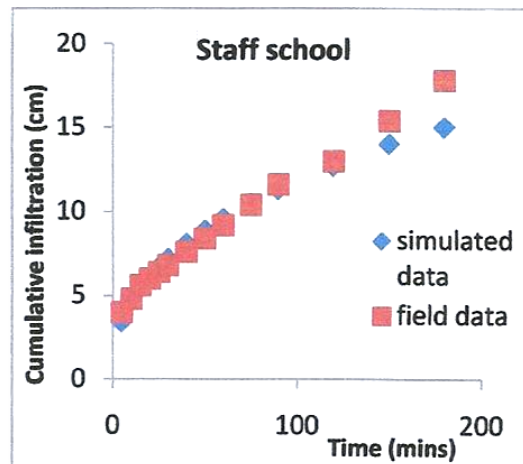


Figure 4. Simulated and field infiltration curves for the soil of Staff School block.

ficients. The coefficients obtained for “m” were: 0.53 for P.G. block 0.41 for the soils of Staff School and Guest House. The corresponding “n” values ranged from 0.37 - 1.79. Infiltration equations obtained for the soil were $0.41t^{1.38}$, $0.41t^{1.79}$, $0.50t^{0.37}$, $0.42t^{1.12}$ and $0.53t^{1.37}$. Simulated data were evaluated by comparing them with the field data and they showed a close agreement with each other, indicating that Kostiakov’s infiltration model was capable of simulating infiltration for the soils of Michael Okpara University of Agriculture, Umudike.

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