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Analysis of Infiltration Rate in Kalinga State University (KSU) using Mathematical Models

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***Abstract*— *The study determined the soil infiltration rate of crop production area of Kalinga State University, Tabuk City, Kalinga. Field testing at three different locations of the production area was performed using double ring infiltrometer having a diameter of 24 in and 12 in for the outer ring and inner ring respectively. The soil was characterize as clayey. Three infiltration models: Hortons, Kostiakov and Philips were used to simulate infiltration rates and compared with actual field measurements. Result showed that the infiltration rate models in KSU were $i = 239.5t^{0.072}$, $i = S383.7t^{-\frac{1}{2}} - 137.5tandi = 0.9525t + 51.58(1 - e^{1.3423t})$ for Philips, Lewis Kostiakov and Hortons. Across models, statistical analysis showed that, the model and observed values having an NSE of 0.59, 0.63 and 0.73 for Philip, Lewis Kostiakov and Hortons models. It demonstrated that the models generated is in agreement with the actual field experiments and can be used for characterizing soil infiltration rate.*

***Keywords*— infiltration rate, crop production, infiltrometer, mathematical models, Kalinga State University.**

I. INTRODUCTION

Infiltration is the passage of water into the soil surface. In general, infiltration has a high initial rate that diminishes with time. The infiltration rate varies from very low to very high due to changes in the soil characteristics within a field. The rate depends on soil type, water, biological, cultural practices and topography. Infiltration rate varies from very low to very high due to changes

In agricultural production, infiltration plays a very important role particularly in plants growth and development. On the other hand, the criteria for quality irrigation design and operations such as water use efficiency and uniformity of water distribution also needs infiltration rate data.

Infiltration is of particular interest to hydrologists, soil and water conservationist, farmers and water resources engineers. It is a key to successful irrigation and water conservation in rainfed agriculture. It is also an important hydrologic process that must be considered in drainage and flood control work. Also, effective water management and conservation require data on infiltration rates.

In the university**,** it has been observed that water supply has become insufficient for the institution particularly during dry days. The scarcity of water supply is attributed to the increase of water requirements of the university due to its increasing population, livestock and crop production. With the same quantity of water supply and conventional water use and management of the institution, the likelihood of problem on water scarcity will become more serious. Problem on water supply can be minimized if not totally solved through the adoption of water saving technologies both in agricultural and non - agricultural sectors.

In crop production, determining when to irrigate and how much water to apply in rapidly changing systems of soils is a strategy for an efficient utilization and management of this natural resource. The efficient water use, infiltration rate of soil is very important parameter that must be considered and studied. Meek et al. (1992) Settling and trafficking of a soil after tillage causes rapid changes in the soil physical condition until a new equilibrium is reached. In the soil studied, a Wasco (coarse-loamy, mixed, nonacid, thermic Typic Torriorthent) sandy loam, soil compaction reduces infiltration rates, which under grower conditions could result in inadequate infiltration of irrigation water to supply crop requirements. They also found out that Tillage between crops increased the infiltration rate during the first part of the season in trafficked soils but decreased or had no effect on non traffic ked soil. Alfalfa (*Medicago sativa* L.) increased the infiltration rate fourfold during a 2-yr period in a heavily compacted soil. Likewise, an increase in bulk density from 1.6 to 1.8 Mg m^{-3} decreased infiltration rate 54% in the field. Hydraulic conductivity of undisturbed cores was at least seven times larger than that measured in columns of disturbed soil (same bulk density). This difference is believed to be the result of natural channels in the undisturbed soil that are destroyed when the soil is disturbed.

On the other hand, the researchers revealed that under controlled traffic, when surface seal is not a problem, tillage will not be necessary to obtain adequate infiltration rates except in the wheel paths. Kironchi *et al*. (1992) revealed that effective water management and conservation require data on infiltration rate in different soils.Yimer *et al* (2008) Infiltration capacity is an important variable for understanding and predicting a range of soil processes. Giiertz *et al*. (2005) found out that Land use is a key parameter in the hydrologic cycle and reduced activity of the macrofauna the infiltration capacity is significantly lower in cultivated soils than in savannah and forest.Shukla et al (2003) Soil structural and water transmission properties, as influenced by land use and soil management, affect the coefficients of infiltration predictive models.Wood *et al* (1987) found that factors such as soil texture, soil organic matter, *soil* bulk density, plant cover*, biomass production, time to runoff and time to ponding were important and of all the variables studied, total* ground cover *was considered to be the most important single variable influencing infiltration and sediment production.ACerdà (1997) found out that under simulated rainfall it was found that the soils* with lower infiltration rates have greater seasonal infiltration changes.

Many researchers recognize the importance of characterizing soil infiltration rate. Soil infiltration rate determination is considered tedious. The data which is a result of the simulation provide additional knowledge and empirical evidence as a basis in water management and conservation planning, used for designing an efficient irrigation and drainage systems, and flood control works.

Thus, the study simulated and analyzed the infiltration rate of KSU using mathematical models. Specifically, it: a) assesses the infiltration rate of the agricultural production area of the university; b) simulates the infiltration rate using Mathematical models; and, c) analyzes the different infiltration rate models in terms of their predictive power, and strength of relationship between the observed and the model output.

II. METHODOLOGY

Location of the Study

The site of the study is situated at the crop production area of Kalinga State University, Bulanao, Campus.

Site characterization

Soil physical properties such as soil texture, porosity, bulk density, willbe characterized. Other factors that affects the infiltration rate like cultural practices and topography will also be determined.

Infiltration Measurement

The method to be used in measuring the infiltration rate of the crop production laboratory area of KSU is the double ring infiltrometer. The open-ended cylinders made of G.I. sheets are carefully embedded into the soil. A constant head will be maintained inside the inner ring where measurement is being made. To minimize errors due to lateral flow of water from the soil below the inner ring, the buffer zone in between the inner and outer rings is also kept flooded at about the same depth as that maintained in the inner ring. Water entering into the soil surface over sets of time interval will be recorded. The experiment will be continuously observed until such time that the amount of water entering into the surface over time will become constant.

Simulation Method

Simulation will be performed using the Lewis-Kostiakov, Hortons and Philip models:

a. **Lewis-Kostiakov equation**: Kostiakov and Lewis proposed the empiricalequation $i = ct^{\alpha}$, where: c and α are constants.

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The steps in performing the simulation of infiltration rate using Lewis-Kostiakov equation were the following:

i. The cumulative form of the equation will be plotted as straight line on log-log paper.

ii. Determine the logarithmicvalues of the cumulative infiltration rate.

iii. The logarithmic values of the cumulative infiltration rate will be plotted versus the cumulative infiltration time.

iv. From the best fitting straight line, choose two points (f_1, t_1) and (f_2, t_2) and get the value of c and α.

v. Simulate the infiltration rate

b. **The Hortons equation** is express as $f=fc+(fo-fc)e^{-kt}$. The equation contains three parameters such as initial infiltration rate (fo), final infiltration rate (fc) and soil factor (k) that have to be evaluated experimentally. The sequence of steps for evaluating fc, fo and k are as follows:

i. Determine fc directly from the result of actual infiltration test

ii. The infiltration rate data obtained from actual infiltration rate will be plotted on arithmetic cross section paper and draw the curve connecting most or all data points.

iii. From the curve select two points with the pair of values (f_1, t_1) and (f_2, t_2).

iv. Set two equations using the pair of coordinates

$f_1=fc+(fo-fc)e^{-kt_1}$

$f_2=fc+(fo-fc)e^{-kt_2}$

Transposing

$f_o - fc = (f_1-fc)e^{-kt_1} = (f_2-fc)e^{-kt_2}$

v. Assume various values of k and plot the two curves of (fo-fc) vs k. The point of intersection gives the value of k.

vi. Simulation will be performed using theobtained values of the constants.

c. **Philip Equation**: The model is given by the expression $f=\frac{S}{2}t^{-1/2}+$ a, where S and A are constants. S is a measure of capillary uptake while A is index of the gravitational term.

To perform the simulation of infiltration using the Philip equation, the following steps will be done:

i. Plot the infiltration rate versus time as in Hortons equation.

ii. Select two points (f_1, t_1) and (f_2, t_2).

iii. Set the two equations corresponding to these points as follows:

$$f1=\frac{S}{2}t1^{-1/2}$$

$$f2=\frac{S}{2}t2^{-1/2}$$

iv. Solve for S and substitute the value of S into either of the two equations to determine A.

v. Perform simulation of infiltration rate

Statistical analysis

The different infiltration rate models will be analyzed as to their strength of relationship, predictive power and difference between the observed infiltration rate and model output. This will be done by using the following statistical tools;

a. Root Mean Square Ratio (RSR). The RSR will be used to assess the predictive performance of the model. The formula uses to determine RMSE is given by the equation:

$$RSR=\frac{RMSE}{Sd}$$

in which

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Xobs.i-Xmodel,i)^2}{n}}$$

where:

RSR = Root Mean Square Ratio

RMSE = Root Mean Square Error

$X_{obs\ i}$ = the observed infiltration rate values

$X_{model\ i}$ = the modelled infiltration rate values at time/place

b. Pearson correlation coefficient (r). Correlation often measured as a correlation coefficient indicates the strength and direction of a linear relationship between the simulated and observed infiltration rate and calculated as;

$$r = \frac{\sum_{i=1}^{n}(Xi - Xmean).(Yi - Ymean)}{\sqrt{\sum_{i=1}^{n}(Xi - Xmean)^2 . \sum_{i=1}^{n}(Yi - Ymean)^2}}$$

c. Nash-Sutcliffe coefficient (NSE). The Nash-Sutcliff model efficiency coefficient E is commonly used to assess the predictive power and quantitatively describe the accuracy of the model output. The formula used to determine NSE is given by the equation;

$$\text{NSE} = 1- \frac{\sum_{i=1}^{n}(Xobs,i - Xmodel)^2}{\sum_{i=1}^{n}(Xobs,i - X\ mean\ of\ observed\ data)^2}$$

where:

$X_{obs\ i}$= theobserve values of infiltration rate

X_{modeli} = the observe is modeled values of infiltration rate at time/place

III. RESULT AND DISCUSSION

Site Characterization

The textural classification of the KSU crop production laboratory area is clayey with pH of 6.7 which is nearly neutral. The Bulk density is 1.4 and porosity 47%. The soil moisture during the conduct of the experiment is under Field Capacity.

Model Calibration

The infiltration models were calibrated using the infiltration data gathered from the use double ring infiltrometer method. Results of model calibration are shown in Table 1.

Table 1. Constant value of the models from model calibration

INFILTRATION MODELS	CUMULATIVE INFILTRATION RATE (i mm/hr)	CONSTANT
Philips	$i = St^{-\frac{1}{2}} - At$	S = 383.7 A = 137.5
Lewis Kostiakov	$i = Ct^{\alpha}$	C=239.5 α = 0.072
Hortons	$i = fct + \frac{fo - fc}{k}(1 - e^{-kt})$	fo=70.1887 fc = 0.9525 k = 1.342

Model Validation

The infiltration models were then validated using the observed data. Regardless of the infiltration model, there is a satisfactory agreement between simulated and observed values with NSE of 0.59, 0.63 and 0.73 for Philip, Lewis Kostiakov and Hortons models respectively. The results of model validation are shown in Table 2.

Table 2. Value of the statistical parameters

INFILTRATION MODELS	MODEL VALIDATION			
	NSE	RMSE	RSR	R^2
Philips	0.59	0.8	0.63	0.78
Lewis Kostiakov	0.63	0.79	0.59	0.71
Hortons	0.73	0.81	0.60	0.65

Model Simulation

Results of the simulation of cumulative infiltration rate is shown in Table 3. Figure 4, shows that cumulative infiltration rate of Hortons, Lewis and Philip's almost match the cumulative infiltration rates of the observed data. This indicates that the model simulation is in agreement to the observed data. Hence, these equations can possibly use for estimating infiltration capacity in the observation site.

Table 3. Simulation of cumulative infiltration rate

TIME (min)	CUMULATIVE INFILTRATION RATE (i in mm/hr)			
	Observed	Hortons	Lewis	Philip's
9	106.68	57.56556	208.9141076	127.9859
15	157.48	108.3682	216.7409028	157.4825
23	186.06	151.1582	223.5150195	184.8669
34	199.91	184.9902	229.8946101	210.9392
52	208.38	208.1093	237.0361301	238.0646
79	219.66	221.3321	244.2819949	259.2786
87	229.19	232.5826	245.9844725	262.7045
112	250.53	239.4908	250.4990049	267.6233
133	257.78	244.2032	253.6177384	267.6233
157	260.96	247.3783	256.6652553	267.6233
185	263.68	249.5345	259.7159799	267.6233
242	266.35	250.8323	264.7872162	267.6233
275	268.66	251.9525	267.2355685	267.6233
317	272.29	252.9718	269.9843399	267.6233
405	274.89	253.934	274.7888263	267.6233
490	277.58	254.888	278.5841638	267.6233
760	278.42	255.8405	287.5284916	267.6233
920	279.38	256.793	291.5110562	267.6233

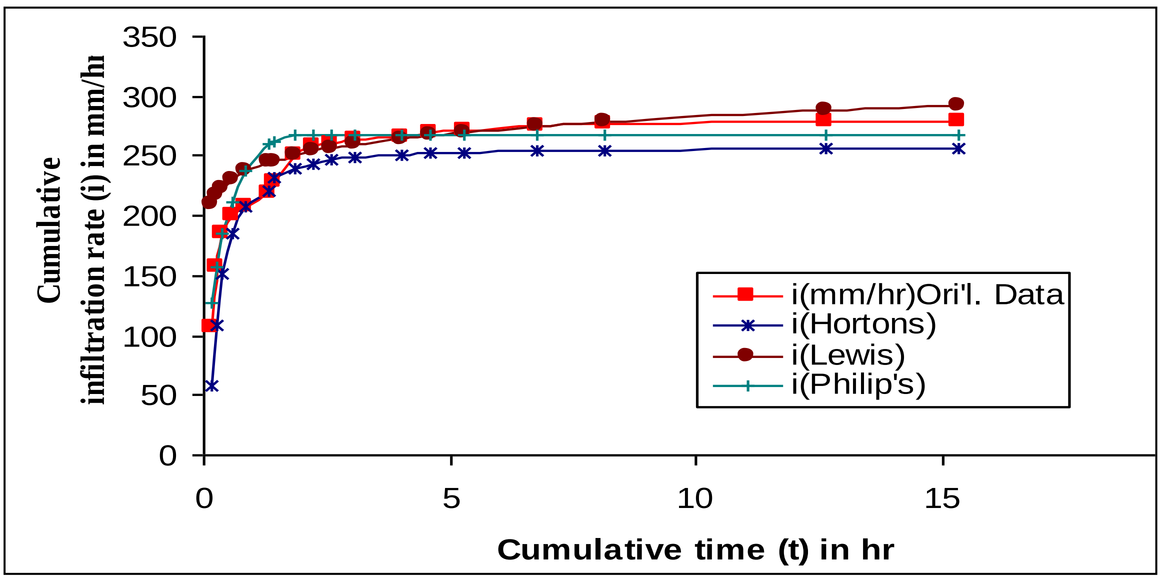

Fig.1: Simulated Cumulative infiltration rate of the three infiltration models

IV. CONCLUSIONS AND RECOMMENDATIONS

A double ring infiltrometer with a diameter of 24" and 12" for outer and inner ring respectively was used in the soil infiltration test. Three mathematical models such as Hortons, Kostiakov and Philips were used in the study. The infiltration models were $i = 239.5t^{0.072}$, $i = S383.7t^{-\frac{1}{2}} - 137.5t$ and $i = 0.9525t + 51.58(1 - e^{1.3423t})$ for Philips, Lewis Kostiakov and Hortons. Statistical analyses showed that, there is a satisfactory agreement between simulated and observed values across models . with NSE of 0.59, 0.63 and 0.73 for Philip, Lewis Kostiakov and Hortons models. Overall, of the three models, Horton model gave the best fit to the observed data.

The three infiltration models proved to be applicable in performing simulations of soil infiltration rate that can be used for planning and designing irrigation methods and scheduling.

RECOMMENDATIONS

There should be a further research to clarify impacts of other land uses on infiltration rate; simulation and analysis of infiltration rate under other soil classification; and further study on the reactions of cultural practices on soil infiltration.

REFERENCES

[1] JAMES C.WOOD*M. KARLWOOD*JOHN M.TROMBLE† Important Factors Influencing Infiltration and Sediment Production on Arid Lands in New Mexico. Journal of Arid Environments. Volume 12, Issue 2, March 1987, Pages 111-118.

[2] ACERDA. 1997. Seasonal changes of the infiltration rates in a Mediterranean scrubland on limestone.Hydrology Volume, 1 November 1997, Pages 209-225.

[3] SHUKLA, M. K.[1]; LAL, R.[1]; UNKEFER, P.[2] Experimental Evaluation of Infiltration Models for Different Land Use and Soil Management Systems. Soil Science: March 2003 - Volume 168 - Issue 3 - p 178-191S. GIERTS

[4] GIERTS S. JUNGER B. DIEKKRUGER B. (2005). Assessing the effects of land use change on soil physical properties and hydrological processes in the sub-humid tropical environment of West Africa PhysicsVolume 30, Issues 8–10, 2005, Pages 485-496.

[5] F. YIMER , I. MESSING S. LEDIN A. ABDELKADIR. (2008). Effects of different land use types on infiltration capacity in a catchment in the highlands of Ethiopia. British Society of Soil Science

[6] G. KIRONCHI, S.M. KINYAL AND J.P. MBUVI (1992). Effect of Soils, Vegetation and Land use on Infiltration in a Tropical Semi-Arid Catch .JournalEast African Agricultural and Forestry Journal Volume 57, 1992 - Issue 3-4

[7] BURL MEEK, LUCY GRAHAM AND TERRY DONOVAN · (1982). Long-term Effects of Manure on Soil Nitrogen, Phosphorus, Potassium, Sodium, Organic Matter, and Water Infiltration Rate[1]Soil Science Society of America Journal . 46 No. 5, p. 1014-1019