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Application of Three Soil Infiltration Models on A Irrigated Rice/Wheat at Bayara-Villge Bauchi-Nigeria

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ABSTRACT: Infiltration models are very important in designing and evaluating irrigation systems and determine irrigation schedules. The main objective of the research was to determine the application of three soil infiltration models on irrigated rice/wheat farm at Bayara-village-Bauchi. The infiltration models evaluated were Kostiakov, Philip, and Horton. The double infiltrometer was used. Moreover, each soil sample was tested in terms of the bulk density, specific gravity, porosity, soil moisture, and soil texture and average value was taken. Based on a relative grading scale, the performance of the infiltration models is ranked as Horton's > Kostiakov's > Philip model based on R^2/Standard error/decision factor respectively. The performance of Horton's model has been found to be better than the kostiakov's and Philip's model in most of the cases based on both the approaches of parameter estimation. This implied that the model could be used to simulate water infiltration during irrigation projects in the farms.

KEY WORDS: Infiltration, Double ring infiltrometer, infiltration models, statistical parameter, bulk density, particle density,

1.0 INTRODUCTION

The soil, located at the atmosphere-lithosphere interface plays an important role in determining the amount of precipitation that runs in off the lands and the amount that enters the soil for storage and future agricultural use. This characteristic behavior of soil varies considerably from place to place; hence the variabilities significantly affect farming activities.

Infiltration is the process which greatly influences the movement of irrigation water (especially rainfall) into surface runoff and subsurface flow and continues to occupy the attention of soil physicists, chemist and engineers. The rate of infiltration is the amount of water that goes into the soil per unit of time and determine the soil moisture availability for plants. To determine the crop water requirement in drylands and irrigation, it require information about soil infiltration characteristics.

Infiltration constitutes sole of water sources for optimum growth of vegetation and removes many contaminants of the water through physical, chemical and biological processes. As organic matter accumulates around the vegetation, the soil texture, soil crust,human or nature-induce disturbance becomes tighter, and infiltration rates decrease (Pingping *et al*., 2013) .

The infiltration rate can be determined by two general approaches (Reddy, 2008). One of these approaches analyses the observed rainfall hyetograph and the runoff hydrograph from a small plot or a natural watershed to estimate the infiltration rates. The other method uses infiltrometers (an instrument for measuring infiltration) which always gives information on average infiltration capacity at various basin. While the later gives actual infiltration rate curve, actual precision measurement of rainfall and runoff from the basin (Reddy, 2008). According to Renato et.al (2019) solutions to infiltration problems have been represented through analytical, numerical, conceptual and empirical mathematical formulations. Analytical solutions provide estimates of infiltration rate or cumulative infiltration as functions of time which depend on soil-water relation during the study time. Numerical simulations it deals with use of complex initial and boundary conditions. Conceptual models it balances the reduction of process complexity with a satisfactory representation of physical reality, obtaining simplified problem formulations while empirical infiltration models involve parameters fitted to the measured infiltration, but they have limited power as predictive tools because the same model cannot be used in different catchments (Renato *et.al* 2019).

In order for these models to be adopted by researchers, confidence in the model predictions needs to be demonstrated through adequate field verification, with agreement between measured values and those predicted by the simulation model (Ogbe *et al.*, 2008).

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was carried out at Bayara-village, Bauchi-Nigeria irrigated rice/wheat field which is located on latitude and longitude at an altitude of about 667m above lies within the northern Guinea Savannah bio-climatic zone with distinct wet and dry seasons. The wet season in the study area occurs between early May and early October, with a mean annual rainfall of about 1000 mm. The dry season occurs between middle of October and early May.

2.2 Methods

The double ring infiltrometer method was used for the infiltration test. The infiltrometer consisted of two concentric hollow rings was driven into the soil uniformly without any alteration of the edge of the infiltrameter and disturbing the soil, to the least depth of 15 cm rings, the outer ring of 60 cm diameter and 40 cm height, and the inner ring 20cm diameter and 40 cm height. The inner ring was hammered 15 cm into the soil and the outer ring was also hammered in the same manner with a plank to protect the surface of the ring from damage during hammering. The test was started by pouring water into the inner ring to an appropriate depth and at the same time, adding water to the space between the two rings to the same depth as quickly as possible. The water depth in the outer ring was kept the same during the observation period. The volume of water is maintained in inner compartment and the corresponding elapsed time was recorded. As the purpose of the outer ring is to suppress the lateral percolation of water from the inner ring, the water added to it need not be measured though water is added to it to maintain the same depth as the inner ring. Observations were continued till constant infiltration rate is observed. The time when the test began was recorded and the water level on the measuring rod was noted.

The determination of hydrometer method was used in the particle size described by (American Society for Testing Materials ASTM, 1985). Bulk density and porosity were determined as described by the equation 1 and 2 below. The saturated hydraulic conductivity (ک)0 measurements were made on the cores in the laboratory using the modified falling head permeameter method similar to that described by Bonsu and Lar yea (1989).

$f = \frac{e}{1+e}$--equation 1

$\rho_b = (1 - f)\rho_s$-- equation 2

Where

f = Porosity

e = void ratio

ρ_s = particle density

ρ_b = bulk density

3.0 RESULTS AND DISCUSSION

3.1 Soil Properties

Table 1. showed the results of the texture classification of the field predominantly clay loam, with sand, clay, and silt fractions of 51.52%, 21.48% and 48.48%, respectively. The average bulk density was 1.71 g/cm^3 with total porosity of 35% and void ratio of 54%. The average initial moisture content of the soil was 14.8%.

Table 1: Summary of initial soil physical and hydraulic properties

Soil property	Values
Moisture content	14.8
Bulk density (g/cm)	1.71
Particle density (g/cm)	2.67
Total porosity (%)	35
Void ratio (%)	54
Coefficient of permeability (cm/s)	$3.36x10^{-3}$
Hygroscopic water (%)	2.67
Sand (%)	51.52
Silt (%)	27
Clay (%)	21.48
Texture	Clay loam

3.2 Infiltration Curve

Figure 1 present the Infiltration curve. The field measurement of infiltration rate and estimation of infiltration rate (Horton, kostiakov's and Philip Model). Figure 1 indicate that Horton and Philip Model show similar asymptotic pattern with the observed values but the kostiakov's model differed most as compared to the other two models in terms of infiltration rate. Infiltration models were evaluated using single factor ANOVA. The bestfit model was selected on the basis of Coefficient of determination (R^2) and Decision Factor(η). Findings are summarized in Table 2 and 3.

The estimated average values of variances and sum of the observed values of infiltration rate and three models Kostiakov, Horton's and Philip is shown in Table 3. Results from Table 4 suggests that f-value (3.937964) was greater than f-critical (2.583667) and P-value (0.008104). According to Silva et al. (2015) classification of coefficient of determination (R^2), $0.00 \leq R^2 \leq 0.50$ unsatisfactory, $0.50 < R^2 \leq 1.00$ satisfactory. Table 4 showed the result of the correlation determination R^2 of the three infiltration models Kostiakov (0.7972), Horton's (1) and Philip (0.5708). Standard error and Decision Factor(η) was also shown to be Kostiakov (0.1592,0.66), Horton's (0.00.1.00) and Philip (0.2316,0.3392). From the three infiltration model and observed cumulative infiltration in the study area showed that, Horton's model is best and had the overall best performance with coefficient of determination R^2(1) and with standard error of 0.00 which indicate that the smaller the error the more precise the estimate of infiltration rate and the higher the decision factor the best matching for the observed valued of infiltration rate (Sunith et.al, 2018).This results of Horton's model agree with the early work done by Wang et.al (2017) and Ogbe et.al (2011). The value of standard error and decision factor are calculated using the equation 3 and equation 4 below:

$$Standard\ error = \sqrt{\frac{1-R^2}{n-2}}$$ --Equation 3

$$Decision\ factor(\eta) = Coeffiencient\ of\ determination(R^2) - Standard\ error$$ -Equation 4

Based on the results obtained from (Table 4) correlation of determination R^2, standard error and decision factor, Philip model values provided the lowest values and Hortom's model results obtained from the standard error and decision factor, indicating that infiltration rate was well-described by this model. Accordingly, the performance of the infiltration models is ranked as Horton's > Kostiakov's > Philip model based on R^2/Standard error/decision factor.

The correlation – coefficient ranging from r = -0.393 infitration rate and Kostiakov's model and r=0.906 infitration rate and Philip's model at ((≤0.05; Table 2).

The graphs between cumulative infiltration and time were plotted in figure 2.

Table2. Correlation coefficients for between the observed infiltration rate and infiltration models

	infitration rate (cm/hr)	*Kostiakov model*	*Horton's model*	*Philip model*
infitration rate (cm/hr)	1			
Kostiakov model	-0.393	1		
Horton's model	-0.613	0.893	1	
Philip model	0.906	-0.505	-0.756	1

Table 3: Statistical parameters

Infiltration Models	Correlation Coefficient(R)	Coefficient of determination (R^2)	Standard Error	Decision Factor(η)
Kostiakov's	-0.3935	0.7972	0.1592	0.66
Horton's	-0.6132	1	0.00	1
Philip	0.9057	0.5708	0.2316	0.3392

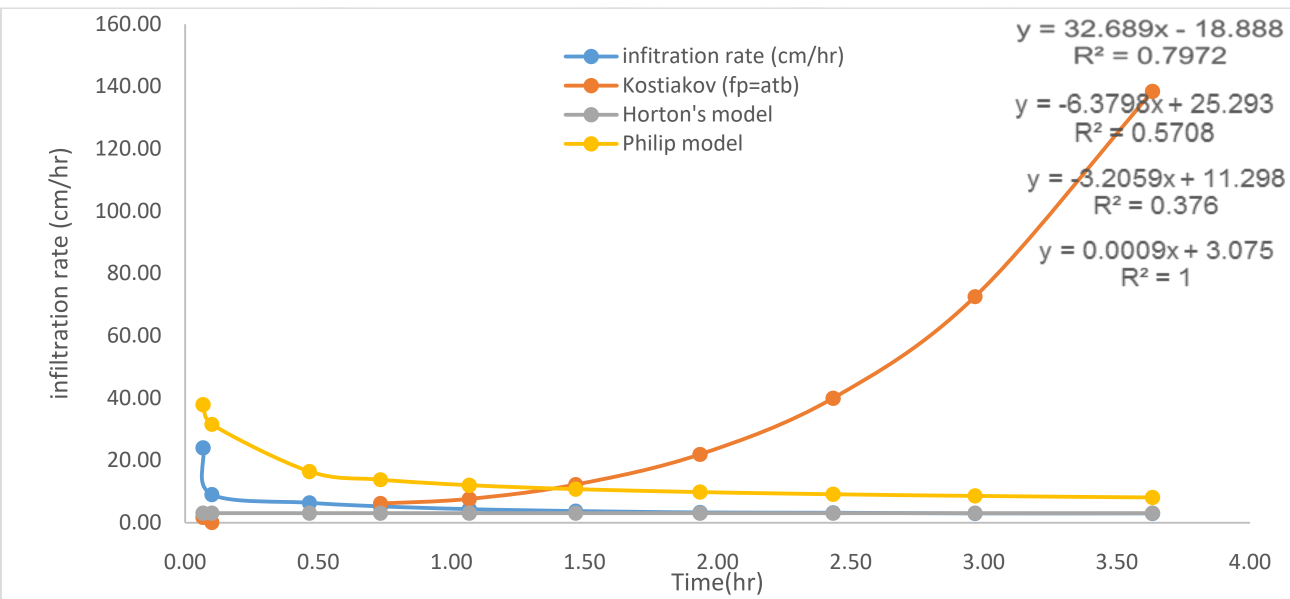

Fig 1. Infiltration rate model against elapsed time

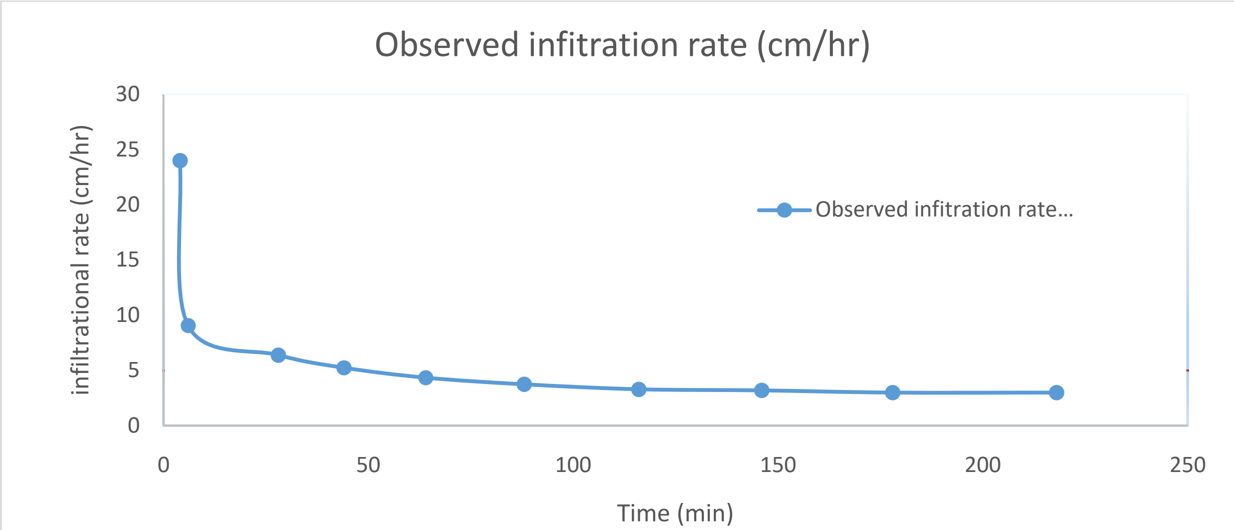

Figure 2: Graphs of observed infiltration rate against elapsed time

Table 4. Single Factor ANOVA

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Time in hour(hr)	10	14.86667	1.486667	1.513136
Infitration rate (cm/hr)	10	65.32	6.532	41.35913
Kostiakov (fp=atb)	9	300.73	33.41445	2088.106
Horton's model	10	30.76393	3.076393	1.33E-06
Philip model	10	158.0825	15.80825	107.8946

Table 5. ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6466.047	4	1616.512	3.937964	0.008104	2.583667
Within Groups	18061.75	44	410.4943			
Total	24527.8	48				

Conclusion

From the analysis of field infiltration rate with other infiltration models at Bayara-village in Bauchi-Nigeria following conclusions are arrived. The investigated models included a theory-based model, the Philip model, and empirical models: Considering the three infiltration models evaluated, the Horton's models gave best fit to the measured cumulative infiltration which was follow by Kostikov's model. Based on decision factor and standard error of the parameter, it was also found out that Horton's model is the best fit. This implied that the two infiltration (Horton's and kostiakov's model could be used to simulate water infiltration during irrigation projects in the Bayara-Village of Bauchi-Nigeria.

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