WATER INFILTRATION MODELLING OF SANDY CLAY LOAM SOIL UNDERDIFFERENT SOIL CONDITIONS USING SWARTZENDRUBER'S MODEL

[1]Ajayi A. S., [2]Ehiomogue P.,Alfa M. I., [3]Eriakha E. C.

[1]Department of Agricultural Engineering, Michael Okpara University, Umudike, Abia State
[2]Department of Civil Engineering, University of Jos, Plateau State
[3]Department of Agricultural and Bio-Environmental Engineering Technology, Auchi Polytechnic Auchi, Edo State

ABSTRACT

The performance of Swartzendruber's infiltration models was carried out herein. A field under continuous cultivation was cleared and divided into 2 strips; each strip was divided into six (6) points for infiltration measurement. The average of the result of three strips was used for the models parameters estimation, and the average of the remaining three was used to validate the models. Statistical analyses of the models' performance showed that the coefficient of determination (R^2) between the models simulated and field measured cumulative infiltration is 0.931 for tilled strip and 0.844 for untilled strip, this indicates an overall close agreement. The model obtained for the study area is: $I = 4.57t + 41.20[1 - \exp(-0.018t^{0.5})]$ for tilled strip and $I = 2.20t + 2.05[1 - \exp(-0.355t^{0.5})]$ for untilled strip. This can be used subsequently to simulate infiltration rate for soils of same texture.

Keywords: Modelling, Swartzendruber, Infiltration, Infiltration model, Sandy Clay Loam

INTRODUCTION

Infiltration is defined as the entry of water into the soil through its surface (Michael, 1978). It is a property of the soil and differs from deep percolation which is the downward movement of soil water beyond the reach of plant roots. Infiltration rate is defined as the rate of water entry into the soil through its surface (Yonts*et al.,* 2003).In watershed modeling, a major hindrance to predicting surface runoff is the uncertainty in characterizing soil infiltration. The difficulty of predicting infiltration is mainly due to the variation of infiltration–related soil physical properties from site to site in the field. Direct infiltration measurement is laborious, tiresome, time consuming and could be expensive particularly where water is limiting. A method to predict infiltration is therefore desirable and is possible through some simple time dependent infiltration models (Arab *et al.,* 2014).

Over a century ago, numerous analytical and semi-empirical models for one-dimensional horizontal and vertical infiltration through homogeneous soil with specific simplified initial conditions have been developed. Some of these models include those of: Green and Ampt (1911), Kostiakov (1932); Horton, (1940); Philip, (1957a); Swartzendruber (1972) amongst others. Most vertical infiltration models assume that the rainfall applied at the surface can infiltrate for a long period of time (that is, the groundwater table is very deep or soil has low hydraulic conductivity). Early expressions of infiltration rate (such as, Green and Ampt (1911) were later discussed within the more general framework of flow in unsaturated porous media (such as, Philip, 1957; Mein and Larson, 1973; Morel-Seytoux and Khanji,1974).

Infiltration modelling approaches are often separated into three categories: physically based, approximate/semi-empirical (analytical), and empirical models. The physically based approaches use parameters that can be obtained from soil water properties and do not require measured infiltration data. The evaluations of semi-empirical/analytical models are purely mathematical or graphical.

Infiltration models exist in a number of collections, empirical models are the most used models in field works and modelling because of their simplicity and accuracy, little attention has been given to analytical models like that of Swartzendruber, the aim of this paper is to model water infiltration in tilled and untilled sandy clay loam soil of Samaru Zaria using Swartzendruber's model and also to determine the performance of the model in simulating water infiltration under the stated conditions.

Swartzendruber's Infiltration Model (1972)

This infiltration model was derived exactly from a quasi-solution of the governing differential flow equation. On the basis of least squares fitting, the new model in three-parameter dimensionless form is:

$$I = f_c t + \frac{c}{d}[1 - \exp(-dt^{0.5})] \quad [1]$$

Where: c and d are empirical constants and f_c is the final or basic infiltration rate.

In order to get the infiltration rate (i), Equation 1 is differentiated with respect to time to give:

$$i = f_c + \frac{c}{2} * \left(\frac{e^{-d\sqrt{t}}}{\sqrt{t}}\right) \quad [2]$$

MATERIALS AND METHODS

Data Collection and Analysis

Secondary cumulative infiltration data collected from the field under continues cultivation, the land area under study was divided into two strips, one tilled using a mould board plough and disc harrow and the other strip was left untilled, each strip was divided into six points at the experimental plot of the Department of Agricultural Engineering, Ahmadu Bello University was taken from Ajayi (2015), the average of three points was used for parameter estimation and the average of the remaining three was used for model validation as shown in Table 1.

Table 1: Average cumulative infiltration for model's parameter estimation and model validation for tilled and untilled strip

Time(hr)	Average Cumulative Infiltration For Tilled strip		Average Cumulative Infiltration For Untilled strip	
	Parameter Estimation	Model Validation	Parameter Estimation	Model Validation
0.05	1.73	1.57	1.10	1.20
0.08	2.80	2.40	1.80	1.90
0.17	3.47	3.97	3.30	2.60
0.33	5.03	6.00	3.60	3.40
0.50	6.60	7.27	4.60	4.30
0.75	8.07	9.10	5.30	5.10
1.00	9.73	10.73	7.10	5.80
1.50	11.80	12.93	7.50	7.00
2.00	13.43	14.50	8.00	7.40
2.50	15.33	16.17	8.20	7.70
3.00	16.77	17.57	8.50	8.20

3.50	17.73	18.77	8.70	8.40
4.00	18.30	19.37	9.00	8.70

Source: Ajayi, 2015

Estimation of Model Parameters

In order to assess the performance of the model in predicting the cumulative infiltration, the parameters of model was first determined. The parameters are: f_c, c and d, the value of f_c obtained from the field measured cumulative infiltration was substituted directly with the field measured I and t into Eq. (1), equations containing two variables c and d were obtained depending on the time interval. Thirteen equations were obtained in all, the first seven were added to make one equation and the remaining six were also added according to a method suggested by Michael (1978) for solving analytical equations, two equations were obtained afterwards, solving them simultaneously gave the values of c and $d$as shown in Table 2, these parameters were substituted into Eqs. (1) and (2) to get the cumulative infiltration and infiltration rate.

Table 2: Swartzendruber's Equation parameters and modelled equations

Strip	Parameter values			Modelled Equations
	c	d	f_c	
Tilled	*0.758*	*0.018*	*4.570*	$I = 4.57t + 42.11[1 - \exp(-0.018t^{0.5})]$
Untilled	*0.728*	*0.355*	*2.200*	$I = 2.20t + 2.05[1 - \exp(-0.355t^{0.5})]$

Model Validation

The validation of the models was performed using: RMSE (root mean square error), R^2 (coefficient of determination) and Nash-Suctlife efficiency index. RMSE value decreases with increasing precision (Mahdian and Gallichand, 1995). R^2 provides a measure of how well observed outcomes are replicated by the model (Steel and Torrie, 1960), it ranges from 0 to 1. The Nash–Sutcliffe efficiencies range from $-\infty$ to 1. An efficiency of 1 corresponds to a perfect match between predicted data and the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, the closer the model efficiency is to 1; the more accurate the model is (Nash and Sutcliffe, 1970).

Their respective equations are shown as Equations. 3, 4 and 5:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - \tilde{O})^2}{\sum_{i=1}^{n}(P_i - \tilde{O})^2} \text{Eq. 3}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \text{ Eq. 4}$$

$$E = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \tilde{O})^2}\right] \text{Eq. 5}$$

Where: P_i = predicted values, $\tilde{O}$ = mean of the observed data, O_i = observed values, n = number of samples.

RESULTS AND DISCUSSION

Simulation of Cumulative Infiltration using the Estimated Parameters

The values of the parameters estimated as shown in Tables 2 above were then incorporated into the mathematical model and simulation of cumulative infiltration was made and the predicted cumulative infiltration were compared with the field measured cumulative infiltration. The field-measured data used for the comparison were those that were not previously used in determining the parameters of the models.

Model Validation

Tables 3 shows the statistical indices of the comparison between the model's simulated and observed infiltration for this study.

Table 3: Observed and Model predicted cumulative infiltration for Control

Time(hr)	Average cumulative Infiltration Formodel Validation(cm)	Predicted Cumulative Infiltration (cm)	Average cumulative Infiltration Formodel validation(cm)	Predicted Cumulative Infiltration (cm)
0.05	1.57	0.39	1.20	0.27
0.08	2.40	0.59	1.90	0.38
0.17	3.97	1.06	2.60	0.64
0.33	6.00	1.94	3.40	1.11
0.50	7.27	2.78	4.30	1.56
0.75	9.10	4.03	5.10	2.19

1.00	10.73	5.25	5.80	2.81
1.50	12.93	7.67	7.00	4.02
2.00	14.50	10.06	7.40	5.21
2.50	16.17	12.43	7.70	6.38
3.00	17.57	14.79	8.20	7.54
3.50	18.77	17.14	8.40	8.70
4.00	19.37	19.49	8.70	9.84
	R^2	0.931		0.844
	RMSE	3.693		2.290
	E	0.623		0.215

The coefficients of determination (R^2) between the field-measured and model simulated data is high (> 0.80) which implied that Swartzendruber's models was able to simulate water infiltration in the study area adequately and also an indication of close agreement between the measured and predicted data for each of the infiltration models. Table 3 shows the *R* square values from the statistical analysis from which it could be observed that the model performed better in the tilled strip than the untilled with the values of 0.931 and 0.844 respectively.

The value of E (Nash-Sutcliffe's modelling efficiency) 0.623 for tilled strip and 0.215 for untilled strip, this means the model also performed better in the tilled strip than the untilled, to further check the discrepancy between the observed and the predicted values, the RMSE was used with values of 3.693 and 2.290 for tilled and untilled respectively. This shows that the model can be used for simulating cumulative infiltration anywhere under the same soil texture.

CONCLUSION

The need for continuous and in-depth study on the applicability and accuracy of infiltration equations cannot be exhausted since equation parameters and performance vary for different soils and climate. The parameters studied herein are particularly applicable to sandy clay loam soils. They should be used for predicting water infiltration to other soils with caution. The model provided good overall agreement with the field measured cumulative infiltration depths and are therefore capable of simulating infiltration under the field conditions in this study.

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