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Performance of Green Ampt's Model for Simulating Water Infiltration into Soils

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***Abstract* – The performance of GreenAmpt's soil water infiltration model was evaluated and reported in this paper. The study was carried out in Samaru, Zaria. A field size of 200 m2 (20 m by 10 m) under continuous cultivation was cleared. The field was ploughed to a depth of 20 cm. Soil samples were taken from three strips for soils physical property determination; infiltration runs were made using the double ring infiltrometer from six points on each strip. Statistical analyses of the models' performance showed that the coefficient of determination (R2) between the models simulated and field measured cumulative infiltration ranged from 0.917 to 0.997. The value of the modelling efficiency (E) index ranged from 0.469 to -11.085 while the Mean Absolute Error (MAE) ranged from 1.178 to 20.499. The values of the coefficient of residual mass CRM ranged from -1.317 to 0.331.GreenAmpt's model can be used for several field and weather conditions, it has the advantage of being a purely physically based model.**

***Keywords*– GreenAmpt, Simulation, Infiltration, Water infiltration, Simulation models, Infiltration models.**

I. INTRODUCTION

Infiltration characteristics of soils can be quantified by direct measurement on the field and/or when field infiltration data are fitted mathematically to infiltration models (Oku and Aiyelari, 2011). Lili et al., (2008) reviewed the commonly used direct methods for measuring soil infiltration which include: single ring and double ring infiltrometers, mariotte-double ring infiltrometer, disc permeameter, rainfall simulator, runoff-on-ponding, runoff-on-out and linear source methods, the results obtained from field infiltration test and soil analysis are used for infiltration modelling. 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 (Hillel, 1998; Skaggs and Khaleel, 1982).

All infiltration models make use of some factors in their characterization. However, the physically based equations like GreenAmpt's rely more heavily on the soil hydraulic and physical properties occurring within the profile, such as saturated hydraulic conductivity, soil moisture gradient, and suction at the wetting front. Empirical models rely more on parameters that are determined by curve fitting or estimated by other means and, thus, may better reflect the effect of differences in surface conditions than the physical models, as long as parameters are calibrated separately for those different conditions. Additionally, sometimes approximate physically based models are used as empirical models with parameters determined in a similar manner. The assumptions, form and intent of each equation need to be considered in deciding which equation to use for a particular application (Ellen, 2006). Infiltration models exist in a number of collections and they have been employed in many field conditions and soil types (Abubakar and Abdullahi, 2012).

Adequate water resource management is essential for stable and efficient crop production especially under irrigated agriculture (Annabi, et al., 2007). Hence, efforts are being directed towards water management and conservation activities such as irrigation and control of flood and erosion. Realistic planning of these water management activities requires sufficient information on the rate at which different soils take up water under different conditions. Data on rates of infiltration of water into soils can be used to supplement other soil information which could assist soil scientists, engineers, hydrologists and others to deal more effectively with a wide spectrum of water resource management and conservation problems (Adeoye, et al., 2011). Infiltration is critical because it supports life on land on our planet. The rate of water infiltration into the soil is one of the important parameters in design and performance evaluation of irrigation and drainage projects, hydrological studies, soil pools of fish farming, and other soil and water conservation practices. The arid and semi-arid regions of Nigeria have short length of rainfall, which is a major limiting factor in crop production with great implication of water availability for cultivation of crops (Adeoye, et al., 2011).

The knowledge of final steady infiltration rate of soil is important for irrigation water efficiency, designing desirable irrigation systems, and loss of water. Thus, infiltration rate is an important factor in sustainable agriculture, effective watershed management, surface runoff, and retaining water and soil resources (Ellen, 2006). Infiltration characteristics of a given soil are part of the dominant variables influencing irrigation. The total irrigation time or intake opportunity time will have to be estimated from the soil intake rate (Ayeni and Adetunji, 2010). In addition, the amount of water applied in a border or furrow irrigation upon which advance and recession expression have been determined will have to be estimated from infiltration expression using the contact time. In sprinkler irrigation, the water application rate must not exceed the soil intake rate and similarly stream sizes for border and furrow systems are governed by the soil infiltration rate. Therefore, the role played by infiltration in irrigation and the hydrologic cycle in general is an exceedingly important one that requires study using GreenAmpt's model (Annabi, et al., 2007). GreenAmpt's model was named after two researchers Green and Ampt. They expressed it as:

(Green and Ampt, 1911) ------- [1]

Where:

ψ = soil suction head at the sharp wetting front (cm);
ΔΘ = the change in water content (θs - θi) (g/g);
θs = final moisture content or saturation moisture content(g/g);
θi = initial moisture content before water infiltration (g/g);
ks = saturated Hydraulic conductivity (cm/hr);

When integrated, cumulative infiltration becomes:

(Green and Ampt, 1911) ------- [2]

Green and Ampt's (GA) model is a physically based or approximate model that directly applies Darcy's law. The original equation was derived for infiltration from a ponded surface into a deep homogeneous soil with uniform initial water content. The GA model has been found to apply best to infiltration into uniform, initially dry, coarse textured soils which exhibit a sharply defined wetting front as depicted in Figure 1 (Hillel, 1970). This pattern is often called a piston displacement profile or plug flow. The transmission zone is a region of nearly constant water content above the wetting front, which lengthens as infiltration proceeds. The wetting front is characterized by a constant matric suction, regardless of time or position and is a plane of separation between the uniformly wetted infiltrated zone and the as-yet totally un-infiltrated zone (Hillel, 1998). These assumptions simplify the flow equation so that it can be solved. Green and Ampt (1911) recommended that soil physical properties should be measured in the field, so that undisturbed field conditions are reflected in the resulting values.

Figure 1: Illustration shows uniform water entry assumption, transmission zone, and sharply defined wetting front (Adapted from Ellen, 2006).

Where: θr = Residual water content of very dry soil, θe = Effective porosity, ῃ = Porosity, ho = Depth of water ponding on surface and L = Wetted depth

II. MATERIALS AND METHODS

1. Study Area

The study was carried out at the Department of Agricultural Engineering experimental field, Samaru, Zaria, Nigeria. Zaria is located on latitude 11o 11'N and longitude 07o 38'E, at an altitude of about 667m above mean sea level. Zaria 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 (Yusuf and Mohammed, 2011).

2. Determination of Soil Properties

Six soil samples were collected from each strip at depths of 0 – 15 cm and 15 – 30 cm using Core Samplers of 5 cm diameter and 6 cm height to collect soil samples after Ploughing and harrowing had been done. The soil analysis was carried out in the Soil Physics and Nitrogen Laboratory of the Department of Soil Science, Ahmadu Bello University, following standard procedures for the determination of textural class analysis, gravimetric moisture content, volumetric moisture content, soil pH, hydraulic conductivity, bulk density, porosity, organic matter content and electrical conductivity (EC), some sample were also packed into polythene bags from the two depths stated above for soil particle size analysis determination.

3. Estimation of Model's Parameters

The parameters for the GA equations (Equation 1 and 2) were obtained as follows: ΔΘ was obtained by taking the difference between the initial and final moisture content; suction at the wetting front also known as the matric potential was obtained with the formula by Rawls, (1992):

. --------- [3]

Where: C is % clay content
S is % sand content
Ø is Porosity

The cumulative infiltration was first calculated by the method of iteration (trial and error) since the value I appears in both the right hand and left hand side of the equation, a suitable assumed value of I was substituted into the equation until the right hand side and the left hand side became the same values, same procedure was done for the time elapsed.

The value of I was substituted to get the infiltration rate.

4. Model Validation

In order to prove the performance of the model and its parameters, the model was validated by comparing their simulated data with field measured data. The validation of the models was done using: RMSE (root mean square error), R2 (coefficient of determination), CRM (coefficient of residual mass), MAE (Mean absolute error) and Nash-Suctlife efficiency index. RMSE and MAE criteria are more related to precision; their values decreases with increasing precision (Mahdian and Gallichand 1995). R2 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).

III. RESULTS AND DISCUSSION

1. Soil Properties

The averages of the result of analysis of soil physical properties of the study area are presented in Table 1. The results showed that the texture of the field surface (0 - 15) cm and the sub-surface (15 - 30) cm depths for the three sampled strips were predominantly sandy clay loam according to the United States Department of Agriculture (USDA) classification, having sand fraction ranging from 43 – 66 %, silt ranging from 11 – 20 % and clay 15 – 29 %.

Table –I: Average soil physical characteristics of the strips

Strip%FC %PWP %AW B.D (g/cm3) M.C (g/g)Ks (cm/hr)EC (dS/m) % O.M
PH

Strip	%FC	%PWP	%AW	B.D (g/cm^3)	M.C (g/g)	K_s (cm/hr)	EC (dS/m)	% O.M	PH
1	28.53	7.44	21.10	1.53	0.06	7.37	0.40	2.71	6.55
2	28.10	6.58	21.52	1.21	0.12	5.92	0.40	2.93	6.48
3	24.92	6.03	18.88	1.81	0.05	4.58	0.28	2.54	6.17

*BD = Bulk density; MC =Moisture content; Ks= Saturated Hydraulic Conductivity; EC = Electrical conductivity; OM = Organic matter content; FC = field capacity; PWP = permanent wilting point; AW = Available water.

Table –II: Average initial and final moisture content for the strips

	Strip 1	Strip 2	Strip 3
Initial MC(?i)	21.75	30.12	12.06
Final MC(?s)	44.07	44.74	43.42
?? = ?s - ?i	22.33	14.63	31.36

2. Model's Parameter Evaluation

The parameters for Green-Ampt's model calculated from Pedotransfer functions using suction head at the wetting front, change in moisture content are tabulated as follows.

Table –III: Green-Ampt's equation parameters and modelled equations.

StripParameter values or estimated constant Modelled equations

Strip	Parameter values or estimated constant			Modelled equations
	k_s	??	?	
1	7.37	0.278	102.70	
2	5.92	0.133	97.36	
3	4.58	0.314	101.57	

3. Simulation of Cumulative Infiltration using the Estimated Parameters

The values of the parameters estimated shown in Tables 3 were then incorporated into the respective models equation and simulation of cumulative infiltration was made for each of the strips, the predicted cumulative infiltration were compared with the measured cumulative infiltration.

4. Model Validation

Table 4 also shows the statistical indices of the comparison between the model simulated and observed cumulative infiltration.

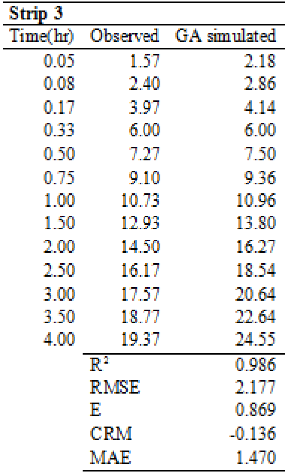
Table IV: Observed and Model predicted cumulative infiltration of strip one

Strip 1		
Time(hr)	Observed	GA simulated
0.05	2.52	2.38
0.08	3.99	3.13
0.17	6.53	4.52
0.33	8.30	6.55
0.50	10.63	8.16
0.75	13.80	10.19
1.00	16.72	11.99
1.50	19.54	15.05
2.00	22.69	17.79
2.50	25.02	20.25
3.00	26.79	22.55
3.50	28.34	24.73
4.00	29.48	26.82
	R^2	0.984
	RMSE	3.446
	E	0.862
	CRM	0.188
	MAE	3.095

Table -V: VObserved and Model predicted cumulative infiltration of strip two

Strip 2		
Time(hr)	Observed	GA simulated
0.05	2.37	2.17
0.08	3.73	2.94
0.17	5.46	4.15
0.33	7.27	6.00
0.50	9.32	7.50
0.75	11.48	9.38
1.00	13.64	11.00
1.50	15.71	13.85
2.00	17.69	16.39
2.50	19.37	18.70
3.00	21.20	20.87
3.50	22.64	22.90
4.00	23.67	24.87
	R^2	0.985
	RMSE	1.412
	E	0.963
	CRM	0.074
	MAE	1.211

Table -VI: Observed and Model predicted cumulative infiltration of strip three



Strip 3		
Time(hr)	Observed	GA simulated
0.05	1.57	2.18
0.08	2.40	2.86
0.17	3.97	4.14
0.33	6.00	6.00
0.50	7.27	7.50
0.75	9.10	9.36
1.00	10.73	10.96
1.50	12.93	13.80
2.00	14.50	16.27
2.50	16.17	18.54
3.00	17.57	20.64
3.50	18.77	22.64
4.00	19.37	24.55
	R^2	0.986
	RMSE	2.177
	E	0.869
	CRM	-0.136
	MAE	1.470

The coefficients of determination (R2) between the field-measured and model simulated data were very high (> 0.90) which implied that the model was able to simulate water infiltration in the study area adequately. The result of the coefficient of determination (R2) ranged from 0.917 to 0.997 which are all close to unity and an indication of close agreement between the measured and predicted data for the infiltration models. The values of E (Nash-Sutcliffe's modelling efficiency) ranged from -11.085 to 0.988 for the entire study area. For the entire study area the MAE which has an inference closely related to RMSE ranged from 1.470 to 3.095. The coefficient of residual mass (CRM) ranged from -1.136 to 0.881.

IV. CONCLUSIONS

There is a high level of correlation between the simulated and the measured infiltration model, this was observed in the high R2 value obtained from the analyses. This model could be used to estimate the infiltration rate of any soil at a time, t, if the physical properties of the soil is known, all other factors remaining constant. The parameters of the model 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.

REFERENCES

[1]. Abubakar and Abdullahi, 2012). Influence of Rice Husk on Bulk Density of Fadama Soils. Nigerian institute of Agricultural Engineering Conference Proceedings Volume 33, 156 – 159.

[2]. Adeoye, P. A., Adebayo, S. E. and Musa, J. J. (2011). Growth and Yield Response of Cowpea (Vigna unguiculata) to Poultry and Cattle Manure as Amendments on Sandy Loam Soil Plot. Agricultural Journal, 6(5): 218-221.

[3]. Annabi, M. S., Houot, C., and Poitrenaud, Y. L. (2007). Soil aggregate stability improvement with urban composts of different maturities. Soil Science Society of America Journal. 71, 413-423.

[4]. Ayeni, L. S. and Adetunji, M. T. (2010). Integrated Application of Poultry Manure and Mineral Fertilizer on Soil Chemical Properties, Nutrient Uptake, Yield and growth components of maize Nature and science journal., 2010: 8(10) 60-67

[5]. Ellen, T. (2006). Comparison of infiltration equations and their field validation by rainfall simulation. M.Sc. Thesis Submitted to the Faculty of the Graduate School of The University of Maryland.

[6]. Green, W. H. and Ampt, G. (1911). Studies of Soil Physics. Part 1. The flow of air and water through soils. Journal of Agricultural Science 4: 1-24.

[7]. Hillel, D. (1970) "Soil and Water: Physical Principals and Processes. Academic Press, New York, NY.

[8]. Hillel, D. (1998). Environmental Soil Physics. Academic Press. San Diego, CA.

[9]. Hillel, D. and W. R. Gardner. (1970). Transient infiltration into crust topped profiles. Journal of Soil Science 109: 69-76.

[10]. Lili, M., Bralts, V. F., Yinghua, P., Han, L. and Tingwu L. (2008). Methods for measuring soil infiltration. State of the art, Int. J.Agric&Biol Eng. 1(1), 22-30.

[11]. Mahdian, M. H. and Gallichand, J. (1995). Validation of the SUBTOR model for simulating soil water content. Transaction of the ASAE Vol 38(2):513 – 520.

[12]. Nash, J. E. and Sutcliffe, J. V. (1970), River flow forecasting through conceptual models part I — A discussion of principles, Journal of Hydrology, 10 (3), 282–290.

[13]. Oku, E. and Aiyelari, A. (2011). Predictability of Philip and Kostiakov infiltration model under inceptisols in the Humid Forest Zone, Nigeria. Kasetsart Journal (Natural Science), 45: 594 -602.

[14]. Rawls, W. J., Ahuja, L. R. Brakensiek, D. L., Shirmohammadi, A. (1992). Infiltration and soil water movement. In Handbook of Hydrology. McGraw-Hill, Inc.

[15]. Skaggs, R. W., and Khaleel, R. (1982) Chapter 4: Infiltration. In Hydrologic modelling of Small Watersheds. St Joseph, Mich.: ASAE.

[16]. Soil Survey Division Staff (1993). Soil survey manual. Chapter 3, selected chemical properties. Soil Conservation Service U.S. Department of Agriculture Handbook 18.Retrieved 2011-03-12.

[17]. Steel, R. G. D. and Torrie, J. H. (1960). Principles and Procedures of Statistics with Special Reference to the Biological Sciences. McGraw Hill. 3rd Edition

[18]. United States Department of Agriculture (USDA) (1993). Soil survey manual. www.nps.ars.usda.gov/menu.htm.

[19]. Yusuf, Y. O. and Mohammed, N. A. (2011). An Assessment of Spatial Distribution of Rainfall Amount in Zaria, Kaduna State. 52nd Conference of the Association of Nigerian Geographers Usman Danfodio University, Sokoto, Nigeria from 14th - 17th February, 2011