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RESEARCH ARTICLE

SOIL INFILTRATION RATE AT THE RESEARCH AREA IN EASTERN SAMAR STATE UNIVERSITY SALCEDO CAMPUS

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ABSTRACT

This study was conducted at ESSU Salcedo Research Area, Salcedo Eastern Samar using fabricated double ring infiltrometers to estimate the range of infiltration rates. Four (4) treatments were replicated three (3) times on a 0.12 hectare located at the southeast part of the Research Area. A total of twelve (12) samples were used. RCBD was used as the experimental design with slope as gradient. Result of the study revealed that the initial infiltration rate values ranges from 128.32 cm/hr to 167.96 cm/hr with a mean of 147.32 cm/hr, while the final rate ranges from 20.78 cm/hr to 28.15 cm/hr with a mean of 23.55 cm/hr. The mean proportionally to factor (β) was -0.036 per minute. The results were based on the initial soil moisture content ranging from 33.99% to 36.70% with a mean of 35%. Using nonlinear regression analysis, it was found out that Horton's model yielded a coefficient of determination (R2) of about 83.9%. This means that 83.9% were explained by time factor while the remaining 16.1% were explained by other factors not included in the study. It can be implied that Horton's model was applicable to clay loam soil to predict the initial and final infiltration rate and valid at the given initial moisture content. Thus, it is suggested that further study using other models of infiltration be conducted in summer when the soil is relatively dry. Longer duration of time for infiltration study be used to determine a more accurate prediction of infiltration of water into the soil.

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INTRODUCTION

Infiltration is the vertical entry of water into a soil surface. It is the sole source of soil moisture to sustain the growth of vegetation and of the groundwater supply of wells, springs and streams (Scwab *et al.,* 1993). The ability to quantify infiltration is of great importance in watershed management. Prediction of flooding, erosion and pollutant transport all depend on the rate of runoff which is directly affected by the rate of infiltration. Quantification of infiltration is necessary to estimate the amount of additional water needed for irrigation (Turner, 2006). Two figures are of interest – the initial intake rate (usually in the first hour) and the equilibrium or basic infiltration rate at which the constant rate that develops after several hours. Water applied to the soil surface through rainfall and irrigation events subsequently enters the sol through the process of infiltration. If the supply rate of water to the soil surface is greater than the soils ability to allow the water to enter, excess water will either accumulate on the soil surface of become runoff. Infiltrability is a term generally used in the disciplines of soil physics and hydrology to define the maximum rate at which rain or irrigation rates can be absorbed by a soil under a given condition. Indirectly, infiltrability determines how much of the water will flow over the ground surface into streams or rivers, and how much will enter the soil, and thus assist as in providing an estimate of water available for download percolation through drainage, or return to the atmosphere by the process of evapo-transpiration (US EPA, 1998). Infiltration rate can be measured by observing the fall of water within the two concentric cylinders driven vertically into the soil surface layer. The use of a double cylinder (or double ring) with measurement confined the inner ring, minimizes error due to non-vertical flow at the edge of the cylinder. Infiltration models can be simulated using the following models: Kostiakov's model, Horton model, Holtan's model and Philip's two-term model.

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Objectives of the Study

This study was made to determine the infiltration capacity of the soil at ESSU Salcedo Research Area. Specifically, it aimed to determine:

- The constant infiltration rate as time approaches infinity (fc).
- The infiltration rate at the onset of infiltration (fo).

- The positive constant or proportionally factor for a given soil at initial condition (β).

REVIEW OF RELATED LITERATURE AND STUDIES

Infiltration Measurement

Field techniques of infiltration measurements used surface areas occupying only a small fraction of the area of hydrological interest. The analysis of measurement data should recognize the three-dimensional nature of the flow from the finite source areas in the test in order to give results appropriate to a surface area of infinite extent (Young, 1991). One of the measurements is with the use of Infiltrometer Ring. During this test the soil region is wetted in the shape of the bulb with lateral flow taking place outwards from the wetted region, especially at early times, in addition to the vertical flow of water down the soil profile. It is observed that infiltration into a uniform soil becomes constant at an early stage of the test, long before the lateral movement becomes negligible. A double ring infiltrometer is commonly used in the field. Hence, the outer ring serves as a control so that water in the inner cylinder only infiltrates vertically. The drop in water level is measured with time and the best results are obtained when the soil moisture is at field capacity.

Mathematical Modeling

This has become an important methodology in support of the planning and decision making process. Soil infiltration models provide an analytical framework for obtaining and understanding the mechanism and controls of the surface and ground water flow. Results from soil water infiltration models can be used to simulate the fate and transport of containments by other models (US EPA, 1998). Infiltration modeling approaches are often separated into three categories: physically based, approximate and empirical models (Turner, 2006). The physical based models are based on simplified solutions to the Richard's equation which describe water flow in soils in terms of the hydraulic conductivity and the soil water pressure as a function of soil water content, for specified boundary conditions. Approximate models apply the physical principles governing infiltration for simplified boundary and initials conditions. It is based on the assumptions of uniform movement of water from the surface down through deep homogeneous soil with a well-defined wetting front; assumptions that are more valid for sandy soils that for clay soils (Haverkamp *et al.,* 1987 as cited by Turner 2006). On the other hand, empirical models tend to be less restricted by assumptions of soil surface and soil profile conditions, but more restricted by the conditions for which they were calibrated, since their parameters are determined based on actual field-measured infiltration data (Hillel, 1998; Skaggs and Khaleelll, 1982 as cited by Turner, 2006).

Horton's Model

The Horton model of infiltration is one of the best known models in hydrology. Horton recognized that infiltration capacity (fp) decreased with time until it approached a minimum constant rate (fc). Horton's equation has been widely used because it generally provides a good fit to data (Turner, 2006). Horton's equation had advantages over the Kostiakov's equation. First, at t equals 0, the infiltration capacity is not infinite but takes on the finite value fo. Also as t approaches infinity, the infiltration capacity approaches a nonzero constant minimum value of fc (Horton, 1940; Hillel, 1998 as cited by Turner 2006). Although the Horton's equation is empirical in that β, fc and fo must be calculated from experimental data, rather than the measured in the laboratory, it does reflect the laws and basic equation of soil physics (Chow *et al.,* 1998 as cited by Turner 2006). A limitation for this model is that is applicable only when rainfall intensity exceeds the minimum constant infiltration (Rawis *et al*., 1993 as cited by Turner, 2006).

Studies on Soil Infiltration Rate

A study of Hammecker *et al.* (2005) on "Water Infiltration in Saline Sandy Soil", showed that hydraulic conductivity was significantly lower with distilled water when compared with saline water. Despite having low clay content (approximately 4%), this sandy soils were very responsive to sodicity. The study of Shanley and Diamond (1998) on the "Infiltration Rate Assessments of Some Major Soils" revealed that infiltration capacity was reasonably stable between years but there was a significant difference between seasons. Capacities in summer were about 3-5 times the winter values. Except on the poorly drained soil, the infiltration capacity exceeded or equated the five year return rainfall rate indicating a very small risk of overload flow in summer. In winter, the capacities at three sites, including freely drained sites, were less than 2.5 mm per hour indicating a significant general risk in winter.

The study of Folly which is focused on the "Soil Surface Roughness and Infiltration in the Savanna Ecosystem and Its Importance on Erosion" showed that the four different types of soil type (Leptisols, Pinthosol, Vertisol, and Luvisol or Lixisol) in Savanna ecosystem are relatively low and in line with findings on soils in the Sahelian zone. It shows also that the soil type influence infiltration whereas roughness and depression storage are related to soil management or crops. Management using a hoe as opposed to bullock ploughing seemed most effective regarding increasing roughness or depression storage. In general, roughness has little impact when it comes to reducing runoff during high intensity rainfall unless conservation measures are being used. Micro topographical characteristics combined with the relatively low infiltration rates in the ecosystem therefore cause erosion. The study of Sabusap (1999) on "Infiltration Rate Study of Selected Soil types in ViSCA" was made to estimate the range of cumulative and rate of infiltration and to determine which of well-known infiltration models is applicable for predicting cumulative and rate of water infiltration under dry soil conditions in ViSCA. Results of the study revealed that loamy sand soil has higher cumulative infiltration with a mean of about 34 cm, followed by loam soil with 19.2 cm and the sandy clay loam soil with 16.3 cm. It was also found out that Kostiakov's model has the higher coefficient of determination (R^2), followed closely by Horton's and Philip's models.

MATERIALS AND METHODS

Research Design

A Randomized Complete Block Design (RCBD) with four (4) treatments and three (3) replications was used in the study. Replications were made rectangular and the lengths were oriented perpendicular to the direction of the gradient. Treatments were made by subdividing each replication into four equal sizes. Replications were chosen using slope as gradient. The allocation of treatments to units within blocks was chosen randomly.

Site Preparation

The experimental area was pre-determined and surveyed prior to the conduct of the study. An area that was free from any obstruction such as stones and debris was selected. Cleaning of area was done by cutting grasses to near soil level. The experimental site was divided into three (3) blocks consisting of four (4) treatments in each block. A measuring tape was used to determine the required distance of 40 meters by 30 meters. Also, drums and containers were brought to the area for water storage.

Infiltrometer Installation

The study used four locally fabricated double ring infiltrometer devices. The inner and outer cylinders were 30 cm and 60 cm in diameter, respectively. During each experiment, the four cylinders were installed with care to minimize soil disturbances. Before driving it to the soil, it was marked to its desired depth and a wooden plank was placed on top of each cylinder to prevent damage on the edges of the cylinder prior to hammering. The cylinders were driven into the soil about 15 cm depth. The infiltrometer were leveled using a level vial.

Data Gathering

The net matting was placed on each cylinder before filling with water. This prevented surface sealing. During the test, water was poured on the inner cylinder until it reaches its maximum depth that the cylinder could hold but would not exceed spilling. At the same time, water was added on the outer cylinder with the same depth. This prevented seepage (the lateral spread of water) from the inner cylinder. The time was recorded when the tests began. The water level on the measuring rod was also calibrated and recorded. The rate of fall or drop on the water level in the inner cylinder was measured at 1, 5, 10, 15, 30, 45 and 60 minutes and at 30 minutes interval thereafter (Diamond and Shanley, 1998). Refilling was done when the water level was not sufficient to read the next reading interval. This process was done throughout the entire experiment. The data gathered was tabulated, computed and analyzed.

Initial Soil Moisture Content Determination

Fresh soil samples were collected from each treatment site and were weighed to get the fresh weight of the soil. The soil samples were oven dried for at least 24 hours or until the dried samples weights become constant with time. The recorded fresh (M_t) and dry weight (M_s) were used to determine the soil moisture content P_w (dry-weight basis) at the time of infiltration measurements.

$$P_w = \frac{[M_f - M_s]}{M_s} \times 100$$

The initial soil moisture content was determined to relate it with the initial rate of infiltration. Moisture content affected initial infiltration rate.

Parameter Estimation

The parameter of Horton's model f_c, f_o and β were evaluated from observed infiltration data. The equation was transformed into simple linear regression form. A simple linear regression analysis of the equation was useful in determining parameters in Horton's equation. The value of f_c was subtracted on both sides of the Horton's equation, forming a new equation.

$$f - f_c = (f_o - f_c)\, e^{-\beta t}$$

And taking the natural log of each side gives the following equation;

$$\log (f - f_c) = (f_o - f_c) - \beta t (\log e)$$

The Horton's equation forms a linear form y=mx + b. A simple linear regression analysis of the equation was useful in determining parameters in Horton's equation, hence f_c and f_o could be directly determine in infiltration data. The natural log of the resulting values of $f - f_c$ was plotted as a function of time ($\log f - f_c$ vs. t) to determine β. The parameter β was the slope of a line.

Data Analysis

Linear regression analysis was used in the study. The parameters (f_o, f_c, and β) and coefficient of determination (R^2) were determined on Horton's equation.

RESULTS AND DISCUSSION

Infiltration Rate

Table 1 shows the average results of the parameters among treatments. This was to show the initial moisture content, initial and final infiltration rate, the proportionately factor and the coefficient of determination (R^2). Time factor was considered as treatments wherein there were variations on infiltration rate with respect to time. This is due to the fact that weather condition is unpredictable that may cause differences between infiltration rates. Initial moisture content ranges from 33.99% to 36.70% with a mean value of almost 35%. This means that the soil at the experimental area had a moisture content of 35% at the time of the study. This shows that moisture content varies depending on time, for example, during summer, moisture content will be much lower because the soil is relatively dry and capable of storing additional water both in and on the soil. This will further reduce the risk of overland flow (Diamond and Shanley, 1998). The reason for the differences in the moisture content was probably due to the presence of vegetation. Among other factors, variations in initial moisture content could cause variation in the initial rate (Linsley *et al.,* 1992; Young and Warkentin, 1966 as cited by Sabusap, 1999).

The result shows that the area had a corresponding initial infiltration rate of 147.32 cm/hr, final infiltration rate of 23.55 cm/hr and positive constant of 0.036 per minute. The resulting Horton's equation was $Fp = 23.55 + 123.77 \exp^{-0.036t}$, where Fp is the infiltration capacity of ESSU Salcedo Research Area in cm/hr and t is the time of water application in minutes. Furthermore, the resulting infiltration capacity of ESSU Salcedo Research Area was tabulated in table 2. The result obtained was not the same from what Thompson and Troeh (1978) cited since infiltration rate is dependent on different factors. This could be attributed to soil factors including the type of soil, vegetation, soil additives including fertilizers, soil management practices and initial moisture content.

Table 1. Average Parameters, Coefficient of Determination, Horton's Equation and Time Lapse among Treatments

Treatments	Moisture Content %	Parameters			Coefficient of Determination R^2	Horton's Equation	Time Lapse
		Initial Infiltration rate, f_o, cm/hr	Final Infiltration rate, f_c, cm/hr	Positive Constant, β, min^{-1}			
1	34.48	128.32	22.33	-0.033	0.85	$22.33+105.99^{e-0.033t}$	310
2	36.70	167.96	23.19	-0.036	0.89	$23.19+144.77^{e-0.036t}$	290
3	34.49	163.51	28.15	-0.044	0.85	$28.15+135.35^{e-0.044t}$	245
4	33.99	132.52	20.78	-0.036	0.87	$20.78+111.74^{e-0.036t}$	325

Table 2. Final Result of the Parameters, Coefficient of Determination and Horton's Equation

Moisture Content %	Parameters			Coefficient of Determination R^2	Horton's Equation
	Initial Infiltration rate, f_o, cm/hr	Final Infiltration rate, f_c, cm/hr	Positive Constant, β, min^{-1}		
35	147.32	23.55	-0.036	0.839	$23.55+123.77^{e-0.036t}$

Time Trend of Infiltration

Table 3 shows the compound infiltration capacity of the area using the derived Horton's equation with respect to time. It indicates that infiltration had dropped considerably to about 86% (126.93 cm/hr) from its average initial value of 147.32 cm/hr in 5 minutes and this dropped further to about 26% (37.82 cm/hr) at the end of 60 minutes and would still dropped to about 16% (23.55 cm/hr) at the end of 300 minutes. The trend of infiltration rates for the area indicates that infiltration rate would still decrease further with time until it reaches a steady value. The rate was expected to continue to drop as long as the moisture content in the soil profile was less than that of saturation point. A steady value also called the minimum or constant infiltration rate was attained as the soil profile becomes saturated (Cuevas, 1984 as cited by Sabusap, 1999).
Based on the result, the initial infiltration rate is high due to the fact that the soil is unsaturated at the onset of infiltration until it reaches the minimum constant infiltration rate at 300 minutes. This means that after 5 hours, if there is a continuous rain and its rate exceeds the constant infiltration rate, there is a possibly that surface runoff will happen. And if this will continue for several hours, it will lead to flooding.

Fitting of Horton's Infiltration Model

Results show that the derived Horton's equation had a higher coefficient of determination of almost 84%. The higher the value of R^2, the greater the degree of statistical relation in the observations. It is also interpreted as the proportion or percentage of the total variation in the dependent variable which can be explained by the independent variable (Sabusap, 1999). Therefore, 84% of the total variation in the infiltration rate was explained by the time factor. The remaining percentage (16%) could be explained by other factors affecting infiltration rate not included in the study. This also shows that the result is reliable because it had a higher coefficient of determination and that Horton' mode could be used to predict the rate of infiltration of the soil in the Research Area.

Conclusions and Recommendations

Based on the results of the study, the following conclusions were drawn: The derived equation from Horton's model yields an accurate prediction of the rate of infiltration and yield reliable result for the parameters (f_c, f_o, β). The Horton's equation can be used to determine the following parameters: the constant infiltration rate as time approaches infinity (f_o), the infiltration rate at the onset of infiltration (f_o), and the positive constant or proportionality factor of a given soil at initial condition (β). The derived equation from Horton's equation is reliable. It has a high coefficient of determination (R^2). This can be used to predict the initial and final infiltration rate of the soil in ESSU Salcedo Research Area. It is therefore recommended that longer duration of time for infiltration study be used to determine a more accurate prediction of infiltration of water into the soil. Similar study be conducted during summer season where the soil is relatively dry. Lastly, other models such as Kostiakov's, Holtan's, Green-Ampt model and others be used to determine the constant infiltration rate as time approaches infinity, the infiltration rate at the onset of infiltration and the positive constant or proportionately factor of a given soil at initial condition (β).

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