Adjustment of the infiltration curve by different empirical models

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Abstract

The estimation of some hydro-physical properties of soil through the use of empirical models is an excellent alternative for reducing the time and cost of laboratory tests, especially for quick and precise application of those values in agricultural projects. The aim of this study is to estimate the speed of infiltration of water into the soil by means of empirical models proposed by Horton, Kostiakov and Kostiakov-Lewis and comparing the results with data obtained in the field through the ring infiltrometer. The research was conducted in sandy soil texture of the experimental area of the State Enterprise for Agricultural Research - EMEPA, located in Lagoa Seca, PB. A total of 65 tests of infiltration through the ring infiltrometer were performed along the experimental area. The models of Horton, Kostiakov and Kostiakov-Lewis, were fitted to data obtained in the field with the ring infiltrometer. Among the models tested, the one proposed by Horton had the best performance. However, the prognostic models of Horton, Kostiakov and Kostiakov-Lewis were almost similar.

Key words: soil water movement, infiltrometer, nonlinear regression.

Introduction

The infiltration of water in soil is a dynamic process of vertical penetration through the soil surface. The knowledge of the water rate infiltration in soil is of fundamental importance to define techniques for soil conservation, planning and scale irrigation and drainage systems, and assist in the composition of a real picture of water retention and aeration in the soil. The knowledge of this variable is essential for developing a project for irrigation in order to obtain higher yield of crops. The determination of infiltration has been widely studied and there is a general opinion on what is the best method for their determination.

Among the physical properties of soil, the rate of water infiltration in soil is one of the most important when studying phenomena that are related to the movement of water, among these the infiltration and redistribution (CARVALLO, 2000; REICHARDT and TIMM, 2004). The rate of infiltration of the soil must be quantified by simple methods and capable to represent properly, the natural conditions where the soil is ?. Accordingly, it is necessary to adopt methods and models whose determinations are based on equal conditions to those observed in the field. Since the rate of infiltration is affected by initial moisture content, conditions of the soil surface, saturated hydraulic conductivity, distribution of size and volume of pores, presence of laminated horizons, distance between the source of supply of water and the wetting front, texture and type of clay.

This work aims to study and evaluate empirical models for predicting the speed of infiltration of water into the soil and compare the results with data obtained in the field through the ring infiltrometer. It also aims to verify whether the mathematical models evaluated in this work is really viable to estimate the speed of infiltration of water into the soil.

Material and methods

Location of the study and analysis of data

The experiment was conducted at the experimental area of the State Agricultural Research Company - EMEPA, located in Lagoa Seca, State of Paraíba. Presenting the geographical coordinates, 07 º 13 ‘S, 35 ˚ 52’ W and average altitude of 335 m, the climate, according to the classification of Köppen, is the type Aw’i. (tropical humid with the dry spring to early summer), the average annual temperature is 23.3 º C and annual average precipitation of 764.3 mm, with rainy season extending from October to March, December to February being the most rainy period and the most dry, June to August. The average relative humidity is 82.7%, as a result the land area is classified as a Argissolo Vermelho Eutrófico abrúptico (EMBRAPA, 1990).

The area chosen for the experimental study about irrigation has an area of 5074 m2, the experimental unit with 1.386 m2 which was divided into 4 subunits. In the center of each of these subunits a mesh (grid) sample was made, on which is demarcated equidistant sampling points, a total number of 65 places. In each of these points tests of infiltration were performed over a period of 160 minutes.

At each point of measurement it was also performed size analysis on samples collected at soil depths of 0 to 20, 20 - 40 cm. The fractions of clay and silt were determined by sedimentation after dispersion with sodium hexametaphosphate, using the pipette method (Loveland and Whalley, 1991). According to Embrapa (1999), it is a Neosolo Reolitico. The soil density was determined using the volumetric ring method (EMBRAPA, 1999) (Table 1)

To determine "in situ" the speed of infiltration of water in soil, it was carried out infiltration tests with the ring infiltrometer (15 cm diameter) on the soil surface in 65 points regularly distributed in the four experimental subunits.

Theoretical development

The rate of infiltration of the soil was empirically estimated by the models proposed by Kostiokov (1932), Horton (1940) and Kostiakov-Lewis. The empirical models that describe the evolution of the rate of infiltration according to the time of infiltration, were, respectively, as follows:

Model of Horton;

$$V = V_o + (V_o - V_f)\exp(-K_f t)$$

Model of Kostiakov;

$$V = V_o t^b$$

Model of Kostiakov-Lewis;

$$V = V_o t^b + V_f t$$

In these equations, V (cm h-1) the rate of infiltration of water into the soil in time t (h) after the water accumulation on the soil surface are presented; Vo and Vf (cm h1) are respectively the velocities of initial and final infiltration; b and Kf are constants of proportionality which depends on the soil type and intensity of precipitation. The Kf, Vo and Vf values can be obtained experimentally, and Vf simply the asymptote of the graph of V versus t infiltration, Kf the slope of the line graph (V - Vf) versus t, and Vo-Vf of the orderly intercept, when t = 0.

The Kostiakov model is an empirical equation where the two parameters Ki and b are determined from simultaneous reading, according Philip (1957) its application is limited to a very long time of infiltration. The Horton model (1940) is not based on any physical theory, which according to Philip (1957) is relatively inadequate to represent a very rapid decrease in the rate of infiltration, but for long time, it represents better the infiltration if compared with the Kostiakov model. According Libardi (1995) the Horton model (1940) has great advantage of explaining the law of infiltration by the fact that the model is based on physical theory of flow in porous media, which is described by the equation of Darcy-Buckinham.

Evaluation of performance

To evaluate the performance between the values of the rate of infiltration of water in the soil determined by the ring infiltrometer and with the values estimated by the empirical models of Kostiakov, Horton and Kostiakov-Lewis for the 65 tests of infiltration, it was used the graphic method of line 1:1 (MONTGOMERY and RUNGER, 2003) and the standard error of estimate (SE) for each model, which measures the dispersion between the values observed and estimated by the proposed models by the following formulas (BUSSAB and MORETTIN, 2004).

Results and discussion

The soil of the area under study presents very sandy surface layer (0-20 cm), and a gradual increase in the levels of silt and clay in depth from 20 to 40 cm, but this increase did not alter the textural classification of soil in their depths. As the Brazilian System of Soil Classification (EMBRAPA, 1999), it was observed that the soil of the experimental area presents franco-arenosa texture in the depths under study, with the following composition: from 0-20 cm: sand, 75.27 g kg-1, silt; 8.08 g kg-1 and clay, 16.65 g kg-1, 20-40 cm: sand, 72.24 g kg-1, silt, 10.10 g kg-1 and clay, 17.66 g kg-1.

The average rate of infiltration and infiltration of water accumulated in the soil for 65 points in the experimental area of the State Enterprise for Agricultural Research - EMEPA, obtained in the field through the ring infiltrometer can be seen in Figure 1. It may be noted that early in the process of infiltration rate was relatively fast (39.61 cm h-1), and decreases to a value approximately constant, called the steady state infiltration rate, stabilizing at the time of 160 min (0.71 cm h-1). The opposite behavior of infiltration rate can be seen with the infiltration of water accumulated in the soil.

Commonly refers to the steady state infiltration rate (Vb) of a soil as that is the moment when the curve slope (asymptotic horizontal) is equal to -0.01 cm h-1 (PREVEDELO, 1996). The average basic infiltration rate (0.71 cm h-1), representing the whole area under study was obtained by reference to the equation curve of the average rate of infiltration of water into the soil. According to Bernardo (2002), the steady state infiltration rate is important when you wish to flood an area, it must provide the water at high rates, and higher than the basic infiltration so that the water drips on the ground and wet the plot. In furrow irrigation, for example, for that the water reaches the end of the furrow, without infiltrating too much in the early groove, the water at high rate is needed.

According to Bernardo (2002), soils that have values Vb greater than 3 cm h-1are soils of Vb very high, values between 1.5 and 3 cm h-1, soils of high Vb; values between 0.5 and 1.5 cm h-1, medium Vb; values below 0.024 cm h-1, low Vb. Comparing the values of Vb found with the classes of Vb proposed by this author, it appears that the soils of the experimental area of the State Enterprise for Agricultural Research - EMEPA have average Vb, which was expected, according to the classes and the density of soil present, which facilitates the process of infiltration of water.

The average values of infiltration rate estimated by the model versus the values obtained in the field through ring infiltrometer (Figure 2) were plotted to check the suitability of estimating

Figure 1. Average values of infiltration rate and accumulated infiltration measured in the field obtained in the field, Campina Grande (PB), 2005

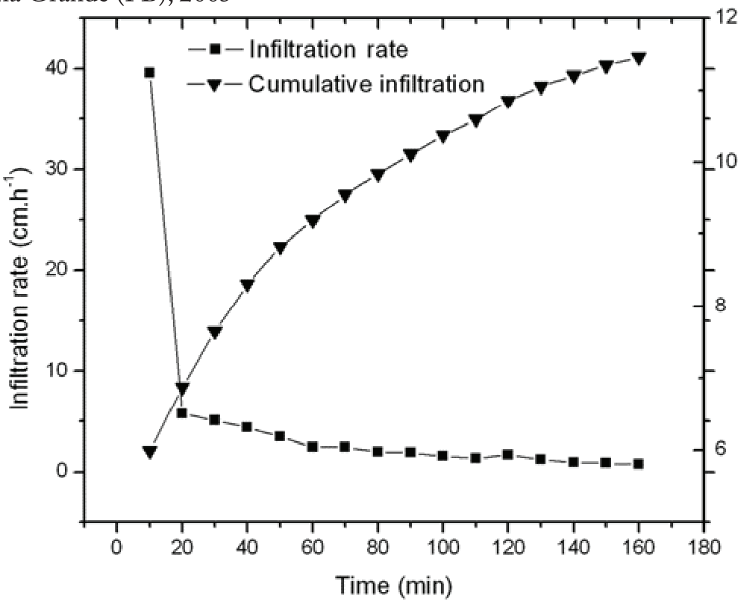
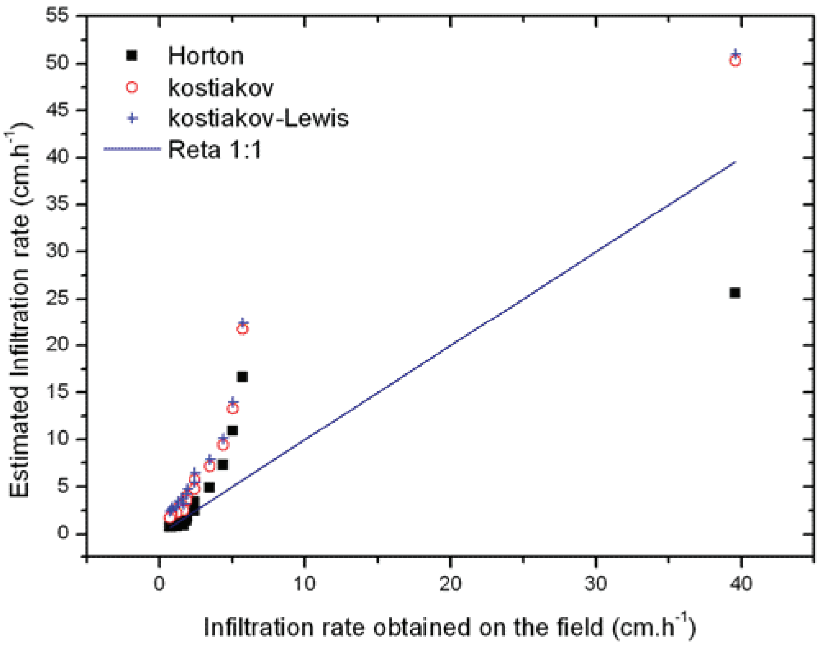


Figure 2. Average infiltration rate estimated by empirical models: Horton, Kostiakov and Kostiakov-Lewis, versus to those measured in field, Campina Grande (PB), 2005



the rate of infiltration through the models presented in this paper, as a criterion for evaluating the ability to estimate these models, the method adopted is the chart 1:1 line that indicates the estimated values are close to those observed in the field.

Estimates obtained by the model proposed by Horton had more satisfactory results among the models tested, due to the fact the data is better distribute around the ideal 1:1 line. Horton's model tends to overestimate low values at the beginning of infiltration and underestimate it for high values of (35 to 45 cm h-1), but with good approximation (Figure 2). When comparing the models Kostiakov and Kostiakov-Lewis among them, there is similar performance in calculating the rate of infiltration, as shown in Figure 2. It also can be observed that the models Kostiakov and Lewis-Kostiakov tend to overestimate low values at the beginning of infiltration. The explanation for the improved performance of the model proposed by Horton is the

Table 1. Statistics summary of soil density (SD) and available water (AW) in the three depths, Campina Grande-PB, 2005.

Statistical Parameters	Soil Density (g cm^{-3})		Available water (cm^3 cm^{-3})	
	Depth (cm)			
	0-20	20-40	0-20	20-40
Average	1,525	1,478	9,40	9,60
Coefficient of variation	6,40	7,300	20,20	19,70
Standard Deviation	0,098	0,108	1,90	1,90
Maximum Value	1,721	1,734	13,60	13,20
Lower Value	1,247	1,261	5,30	4,70
Total Magnitude	0,474	0,473	8,3	8,50

incorporation of the coefficient of Kf, the type of soil used (franco arenoso) and its simplicity.

The values of parameters and standard error of estimate (ES) for each model is presented in Table 1, in percentage; it can be observed that the lower the value of the standard error of estimation the better it fits on the empirical model to actual conditions .Therefore, the empirical model proposed by Horton (1964) was more efficient to estimate the infiltration rate of water into the ground because it presents the smallest standard error of estimate (104.87%), followed by the models of Kostiakov-Lewis and Kostiakov, that had similar performance (Table 2).

The three empirical models proposed varied very little between them, however the estimated infiltration rate had been very different (higher values) of the values observed in the early days of the initial process of infiltration (10 to 40 minutes), not providing appropriate equations to estimate the early infiltration rate of water into the ground, as can be seen in Figure 3.

The average values of ES (%) recorded for each proposed model, also indicate a moderate proportion of data variance of infiltration rate, it is probably due to errors in the estimation procedures

Figure 3. Average values of infiltration rate estimated by empirical models: Horton, Kostiakov and Kostiakov-Lewis, Campina Grande (PB), 2005.

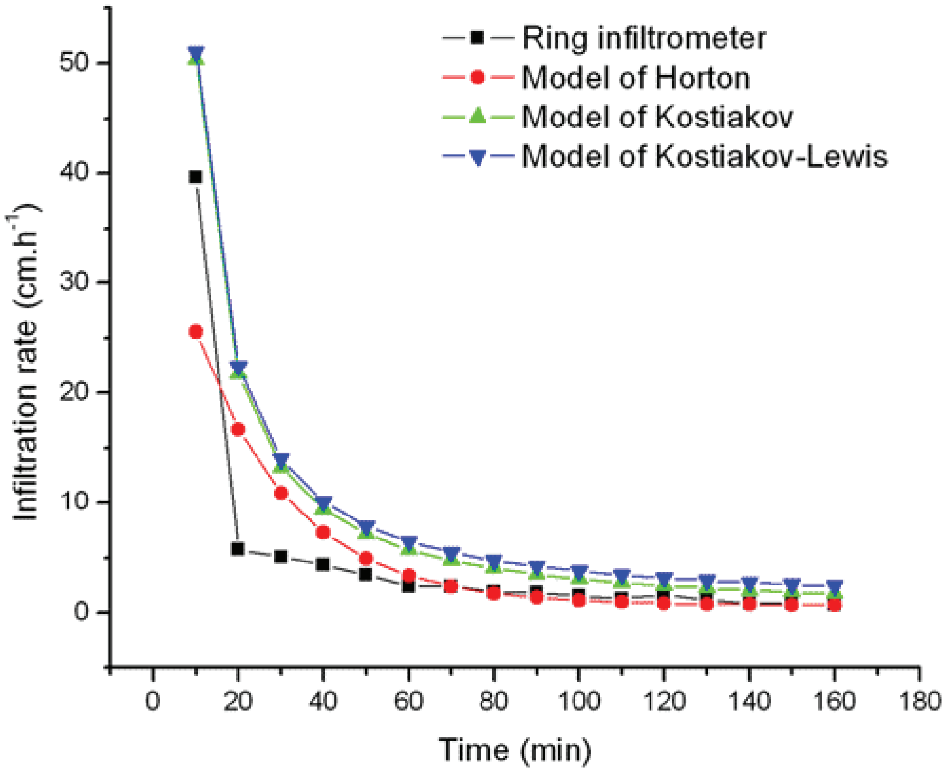


Table 2. Values of parameters and standard error of estimation of empirical models of Kostiakov, Horton and Kostiakov-Lewis (averages of 65 tests performed in field), Campina Grande (PB), 2005.

Models	Empirical Models				
	V_8	V_f	K_f	b	ES(%)
Horton (HT)	39,61	0,70	2,677	-----	104,83
Kostiakov (K)	39,61	-----	-----	1,212	124,48
Kostiakov-Lewis (KL)	39,61	0,70	-----	1,212	135,47

of the parameters of the models, but also due to possible outlies or unusual data. Also for the data of infiltration rate measured directly in the field, the average value of ES indicates a moderated proportion of variance in the data, which the likely explanation is due to the large heterogeneity of the hydro-physical properties of the soil, such as texture, density and soil moisture, hydraulic conductivity, etc.

Conclusions

The model of Horton presented the best results in estimating the infiltration rate of water into the soil when compared with results obtained in the field through the ring infiltrometer. The three models tested provided results statistically equivalent, as evidenced by the similarities of the values of the standard error of estimate. Adjustment Of The Infiltration Curve By Different Empirical Models.

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