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CHANGES IN INFILTRATION UNDER DIFFERENT VEGETATIONS COVERAGES IN SOILS OF THE SEMIARID PERNAMBUCANO BRAZIL

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ABSTRACT

Anthropic actions such as the removal of native vegetation cause the soil infiltration processes to be modified in the semiarid region. The objective of this research was to evaluate the infiltration capacity of the soil in different vegetation coverings in the semiarid region of Pernambuco, Brazil. The evaluation of the different infiltration capacities were carried out using concentric cylinder infiltrometer in three treatments: T1 - without vegetation cover, T2 - soil covered with litter, T3 - soil covered with native vegetation of caatinga and the estimates with the models of Horton and Kostiakov. Among the treatments studied, the soil covered by native vegetation of semi-shrubby caatinga, showed the highest infiltration capacity and basic infiltration speed. The substitution of native vegetation reflected in significant differences between treatments, soil without cover and soil with litter, both with the soil class Neossolos Flúvicos. Among the models analyzed, Horton's showed the best adjustment of the estimated values regarding the infiltration rate.

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INTRODUCTION

Water erosion is considered one of the main processes of environmental degradation strongly linked to climate change that has been affecting large areas on a global scale. It is estimated that approximately 35% (about 50 million km^2) of the earth's surface are affected by arid and semi-arid climatic conditions defined by water scarcity and characterized by seasonal climatic extremes with unpredictable rain patterns (Ferreira *et al*., 2016). Water scarcity in arid and semiarid regions has led to unique physiological and behavioral adaptations in many species of plants and animals. Variation regimes both in climate, topography, geology, soil type and quality, burning regimes, and the influence of human management were important factors in driving the diversity of dryland species, forming a mix of habit contrasts, which determined the distribution of living organisms (Sinclair Marinho *et al*., 2016).The northeastern semiarid is among the most variable and unpredictable environments in the world, where rainfall is low and poorly distributed with high interannual climate variability (Nunes *et al*, 2015). During the year there is a negative annual water balance and frequent long periods of drought; however, the occurrence of major floods is not uncommon (Salvatierra *et al*., 2017). The vegetation cover influences the infiltration process and consequently the erosion process, acting in the reduction of the volume of water that reaches the soil, through the interception, changing the distribution of the size of the raindrops, thus affecting the kinetic energy of the rain (Rossato *et al*., 2017). The water infiltrated in the soil determines the water balance in the root zone of the crops, being an essential factor for the planning of rainfed agriculture and, mainly for irrigated agriculture. Knowledge of the infiltration process is also of fundamental importance for the management and conservation of soil and water, as it determines the occurrence of runoff, responsible for undesirable processes such as erosion and flooding (LIANG *et al*., 2009). Therefore, studies that evaluate soil infiltration rates and the factors that affect this process in areas of high erosive potential and that suffer from water scarcity, as in the case of the semiarid region of Pernambuco, are fundamental. In this context, the objective of this research was to evaluate the infiltration capacity of the soil in different vegetation coverings in the semiarid region of Pernambuco, Brazil.

MATERIALS AND METHODS

The field experiments were carried out on the Cedro farm, which has approximately 200 ha of area, close to the Exu stream, which forms one of the microbasins belonging to the Pajeú hydrographic basin (Figure 1). An area is located at the coordinates of 7º58'58.55"south and longitude of 38º25'51.36"west and bordering geographically, in the north, with the State of Paraíba, in the south, with the municipality of Floresta, in the east with the municipalities of Calumbi, Betânia and Santa Cruz da Baixa Verde, and in the west, with the municipalities of São José do Belmonte, Mirandiba and Carnaubeira.
The climate is characterized by the great abnormality of the pluviometric precipitations, through the cold fronts, in the cyclonic vortexes of superior air (CVSA) and in the Intertropical Convergence Zone (ICZ), the rainy season from January to April and the months of greatest drought from July to October. Given these conditions, the months of March and September 2017 were selected to conduct the experiments (ASSIS *et al*., 2013). Experiments were conducted under three conditions of soil cover. Treatment 1 – Uncovered vegetation soil, suffers intense traffic from animals, which use the water from the stream for watering; Treatment 2 – soil covered with litter, there was a predominant presence of Algaroba *Prosopis juliflora* (Sw) DC.

An invasive exotic species widely used in the caatinga as wood producing firewood, forage and other uses; Treatment 3 – soil covered by native vegetation semi-shrubland such as Jurema Preta, *Mimosa tenuiflora* (Wild) Poir., Canafistula, *Peltophorum dubium* (Spreng)Taub., Anjico, *Anadenanthera colubina* (Vell) Brenan., Juazeiro, *Ziziphus joazeiro* Mart., Quince, *Croton blanchetiamus* Baill., Mandacaru, *Cereus jamacaru* DC., Quipá, *Tacinga quipa* (F. A. C. Weber) N. P. Taylor & Stuppy ., Catingueira, *Poincianella pyramidalis* (Tul.) L. P. Queiroz., Aroeira, *Myracroduon urundeuva* (Allemão); Paw-of-cow *Bauhinia cheilantha* (Bong) Steud. The soil of treatments were classified as Neossolo Flúvico, according Santos *et al*. (2018). Undisturbed soil samples were collected at depths 0-0.10m 0.10-0.30m and 0.30-0.60m, aiming at the physical characterization of the soil and quantification of organic matter. The samples collected in the field were conditioned and transported to the Soil Physics Laboratory for attribute analysis. The samples was reserved for the analysis of soil density (Ds) by the paraffined lump method, a methodology used to adapt better to stony or very dry soils, which limit the use of cylinders in the collection of samples. The TFSA samples were obtained from de-capping, which were homogenized, air-dried and passed through a 2.00 mm sieve. Clay dispersed in water (ADA) were determined, and the indices of flocculation (IF) and dispersion (ID) were calculated, based on the relationship between the contents of total clay and clay dispersed in water, EMBRAPA (2011).The density of the soil (Ds) was obtained using the paraffined clod method EMBRAPA (2011).Total porosity being calculated by EMBRAPA (2011). To determine the infiltration capacity, concentric steel rings consisting of an external cylinder 0.40m in diameter and 0.30m high and an internal cylinder with 0.20m internal diameter and 0.30m high were used. They were evenly driven into the ground, with taps on the edges starting with the outer cylinder, then driving the inner cylinder. With the results of the water layer accumulated in the soil (I), the Kostiakov Eq. (1) equation was applied.

$$I = Kt^{\propto} \qquad (1)$$

Where: I = accumulated infiltration (cm); t = time interval (min); K and α = empirical constants. Since the linear regression method can only be applied to linear equations, initially the infiltration equation, which is an exponential equation, must be transformed into a linear equation. For this, the logarithmic operations corresponding to the infiltration Eq. (2) are applied:

$$\mathrm{logl} = \mathrm{logK} + \propto \mathrm{logT} \qquad (2)$$

This equation corresponds to the equation of the line of type Y = A + B X, where: Y = log I; A = log K; B = α; X = log T. In the linear regression method, the values of A and B are determined by the following expressions:

$$B = \frac{\Sigma \mathrm{xy} - \frac{\Sigma \mathrm{X}\ \Sigma \mathrm{Y}}{\mathrm{N}}}{\Sigma \mathrm{X}^2 - \frac{(\Sigma x)^2}{\mathrm{N}}}$$

$$A = \overline{\mathrm{Y}} - \mathrm{B}\overline{\mathrm{X}}$$

Thus, to arrive at the instantaneous infiltration speed equation, the infiltration equation as a function of time is derived Eq. (3):

$$VI = \frac{d\,I}{d\,T} = \propto K\,T^{\propto - 1} \qquad (3)$$

Horton in 1940verified that the variation of the infiltration rate in relation to time (dI / dT) is proportional to the difference between the instantaneous infiltration rate and the stable infiltration rate. Developing the empirical Eq. 4 for infiltration rate as:

$$ft = f_c + (f_0 - fc).e^{-k.t} \qquad (4)$$

Since the decay rate k can be estimated by:

$$k = (f_0 - f_c)/FC$$

Where:f_t= Infiltration rate over time (mm / min); f_0= Minimum infiltration rate (mm / min); f_c= Initial infiltration rate (mm / min); k = exponential constant; t = mean time of the interval (min). The efficiency coefficient (E) adapted byLegates and Mccabe (1999), the square root of the average error (RQEM), the absolute maximum error (EMA) and the determination coefficient (R^2) were applied using the Horton and Kostiakov in the three coverage conditions in both the dry and rainy periods.

RESULTS AND DISCUSSION

The granulometry, although little subject to alterations caused by the soil cover, provides knowledge of the proportions of particles by size, being indispensable for understanding the nature and physical-hydric behavior of the soil, as it significantly influences the properties of the soil that change easily with its Leite *et al*. (2018). The granulometries are quite diverse in treatments, along the soil profile, due to the diversity and forms of deposition of the original material (Table 1). Laboratory analysis of the textural composition pointed to the predominance of sandy loam texture. Consequently, in sandy loam soil there is a predominance of sand particles, more sandy soils have greater macroporosity, macropores are formed between aggregates and are important for favoring water infiltration, allowing drainage, influencing soil aeration and exchanges gas Leite *et al*. (2018). In the case of the treatments 1 and 2, there was a predominance of fine and very fine fractions of sand, as treatment 3 presented, in addition to a greater concentration of the coarser particles of sand than the other two treatments, it also differed due to its higher proportions of sand, between the medium and fine fractions.

uncovered soil area is also responsible for the high percentage (27.5%) of organic matter in the topsoil, when compared to areas covered by vegetation that obtained much lower values (7.5%). This differentiated value is due to the deposition of animal feces. When comparing the values of the less superficial layers, we have a drastic reduction of 25% of the organic matter content in uncovered soil, while in the litter and caatinga areas the percentage decreased by only 2.5%. Pedrosa *et al.* (2017), explain that the microbial biomass present in the soil, in addition to being responsible for the labile reserve and nutrient cycling, decomposition of organic matter and energy flow, is sensitive to changes that occur in the soil, so the soil is discovered to have lost its natural vegetation cover and being more vulnerable to degradation has less microbial biomass activity, making most of the organic matter not assimilated into the soil.

Table 1. Physical characterization of the soil in the three treatments

Depth ----m----	Sand	Silt	Clay		Bulk Density ----g cm^{-3}---	Clay dispersed in water --------g kg^{-1}--------	Texture
	---------------- g kg^{-1} -------------------						
	Treatment 1						
0.00 – 0.10	589.50	258.50	152.00		2.72	16.32	sandy loam
0.10 – 0.30	567.00	257.50	175.50		2.74	20.50	sandy loam
0.30 – 0.60	523.50	249.50	227.00		2.70	26.78	sandy loam
	Treatment 2						
0.00 – 0.10	508.50	293.50	198.00		2.65	22.66	sandy loam
0.10 – 0.30	507.30	300.20	192.50		2.70	24.72	sandy loam
0.30 – 0.60	558.80	254.80	186.40		2.74	24.43	sandy loam
	Treatment 3						
0.00 – 0.10	695.00	158.20	146.80		2.76	12.12	sandy loam
0.10 – 0.30	693.70	155.80	150.50		2.72	14.14	sandy loam
0.30 – 0.60	716.80	141.80	144.40		2.79	12.24	sandy loam

Table 2. Statistical indexes of efficiency of the employed models of Kostiakov and Horton for the soils studied in the conditions of rainy and dry weather Period Treatments Models

Period	Treatments	Models	Model evaluation			
			E	*RQEM*	*EMA*	*R*^{2}
	Uncovered Soil	Kostiakov	0,6369	0,3322	0,8873	0,5724
		Horton	0,6371	0,1898	0,73	0,7219
	Litter	Kostiakov	0,7975	0,159	0,529	0,5877
		Horton	0,8415	0,1823	0,49	0,6214
Rainy	Caatinga	Kostiakov	0,2196	0,3623	0,5983	0,6621
		Horton	0,7006	0,3622	0,99	0,8357
	Uncovered Soil	Kostiakov	0,5695	0,4203	1,2024	0,5699
		Horton	0,3553	0,1207	0,51	0,6878
	Litter	Kostiakov	0,6412	0,3254	0,6542	0,5707
Dry		Horton	0,4808	0,1513	0,73	0,5469
	Caatinga	Kostiakov	0,1107	0,4093	0,7194	0,75
		Horton	0,6546	0,488	2,02	0,6291

This higher concentration of sand in the soil composition reflects the values obtained in the particle density, varying between 2.65 to 2.79 g cm^{-3} (Table 1). The soil density analyzed in treatments 1,2 and 3 showed characteristic values of sandy soils, varying from 1.38 to 1.66 g cm^{-3}. Being the highest densities found in the treatment, bare soil, consequently also the lowest percentages of total porosity, this area suffers intense traffic of animals that added to the lack of vegetal cover of the soil makes this soil more exposed to the effects of compaction by trampling. As noted by Montero-bagatella *et al.* (2017) this reduction in porous space, with increased soil density, translated into soil compaction, promotes degradation of the structure of this soil. With the increase in compaction and / or densification, the infiltration of water into the soil is greatly reduced, promoting a marked runoff of water and a greater possibility of dragging soil and nutrients. In soils in the semi-arid region, this condition in the long term contributes to the irreversible degradation of soil and vegetation, generating areas susceptible to the desertification process Souza, Menezes and Cámara (2015). On the other hand, animal traffic in the

The maintenance of vegetation cover is also important for mitigating the impacts of raindrops and slowing the speed of runoff, increasing the infiltration of water into the soil. Its efficiency in reducing soil losses due to erosion can be attributed mainly to the protection of the soil surface, preventing the direct impact of raindrops on the surface, reducing soil disaggregation Frota and Nappo (2012). The determination of the accumulated infiltration was obtained through tests carried out in the field in the conditions of rainy and dry weather for the three treatments of soil cover, uncovered soil, litter and caatinga.

From these data it can be seen those treatments 1 and 2 resulted in lower values of accumulated infiltration, resulting in 18.84 and 33.32 cm infiltrated in uncovered soil and in soil covered with litter respectively, already the area covered by the average accumulated value of caatinga reached 76.54 cm of infiltration in rainy weather conditions (Figure 3).

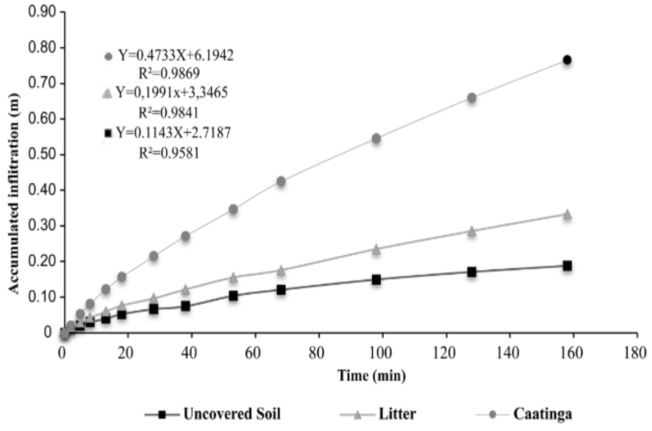

Figure 1. Accumulated infiltration as a function of Time in the areas of Caatinga, Soil with Litter and Uncovered Soil for the rainy season

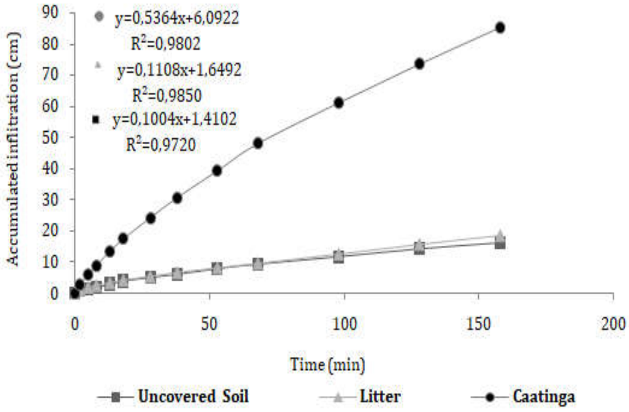

Figure 2. Accumulated infiltration as a function of Time in the areas of Caatinga, Soil with Litter and Uncovered Soil for the dry period

The trend was maintained in the dry period (Figure 4) where the soil covered by caatinga showed the highest mean value of infiltration 0.85 m while the treatments with litter and uncovered soil obtained close values 0.18 and 0.16 cm respectively. Comparing the three treatments in the two weather conditions (rainy and dry), the lowest accumulated infiltration values were observed in treatment 1, soil without vegetation cover. Despite having a higher percentage of organic matter in its surface layer, the same soil showed low porosity and high soil density, influencing low infiltration. A similar result, with less infiltration in an area of uncovered soil compared to areas covered by litter and caatinga, was found by Silva *et al*. (2015) in the Pernambuco semiarid region, studying the infiltration of water in the soil through simulated rain. The curves obtained in Figure 5, show the infiltration process measured in the field and estimated by the empirical models of Kostiakov and Horton, the infiltration process starts with high infiltration rates that decrease exponentially with time, approaching a constant value, usually called the basic infiltration speed (VIB). The initial rate of infiltration is higher, at the beginning of the test because it is relatively dry, therefore having a higher potential gradient. After a period of time the potential gradient decreases and the infiltration rate decreases.

The highest infiltration capacity was obtained by the soil covered by native vegetation, caatinga, in treatment 3. The average infiltration rate measured in the area reached the value of 1.44 cm min^{-1} in the dry period and 1.06 cm min^{-1} in rainy season. In treatment 2, soil covered with litter with a predominance of mesquite, the infiltration capacity was 0.86 cm min^{-1} in rainy weather, in dry weather the speed of the infiltrated water increased to 0.57 cm min^{-1}. And the lowest infiltration capacity was observed in the treatment of uncovered soil (0.52 cm min^{-1}) in the rainy season, reducing it to 0.35 cm min^{-1} in the dry season. Bustamante *et al*. (2019) also observed a higher capacity of infiltration of the soil in an area of native forest in relation to soils under different uses and agricultural management practices.

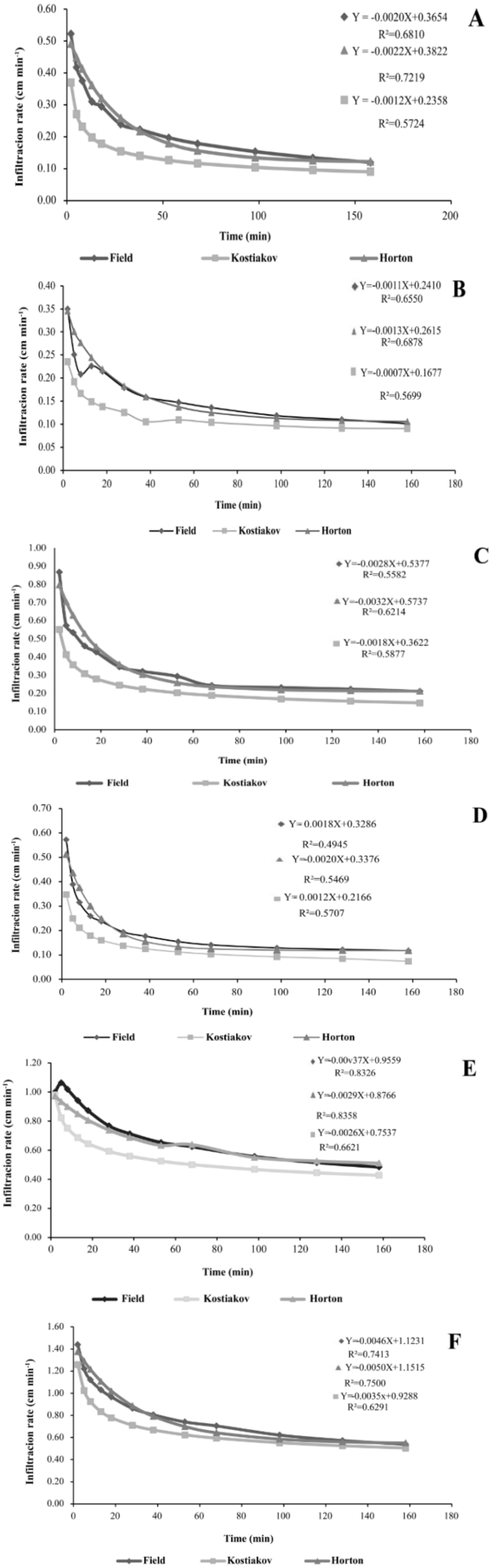

Figure 3. Infiltration rate measured in the field and estimated by the Horton and Kostiakov models. A- soil discovered in the rainy season; B- soil discovered in the dry period; C- soil covered by litter in the rainy season; D- soil covered by litter in the dry season; E- soil covered by Caatinga in the rainy season; F- soil covered by Caatinga in the dry period

The values of the statistical indices (E, R^2, RQEM and EMA) referring to the performance of the kostiakov and Horton models in relation to the soil infiltration rate for the three treatments are listed in (Table 4). The values obtained from these indexes suggest that, in general, the two models presented an estimate coherent with the data observed in the field, with high values of E and R2. However, the Horton model performed better, showing the highest values of E (0.8415) and R^2 (0.8357), in addition to a better fit to the estimated infiltration rate curves compared to those observed in the field. These results corroborate those found in studies with sandy loam soils, such as the one carried out by Dalri *et al*. (2018). According to Legates and Mccabe (1999) the Horton model obtained a better precision fit with the observed data when compared to the values estimated by the modified Kostiakov equation. Dalri *et al*. (2018), also proved better performance of the Horton model compared to the Kostiakov models. Therefore, the model proposed by Horton can be indicated as the most adequate to estimate the rate of soil infiltration for the three treatments studied here, bare soil, soil covered with litter and soil covered by caatinga belonging to the classe of Neossolo Fluvico in the Pernambuco semiarid region.

CONCLUSION

The absence of vegetation covers together with the trampling of animals verified in the area of uncovered soil, resulted in a higher soil density, less total porosity and generating soil compaction. This was reflected in the infiltration process, with this treatment showing less infiltration capacity among the three studied. The soils with soil covered with litter and soil covered semi-shrubby caatinga, performed higher infiltration rates. Regarding the empirical models used, Horton and Kostiakov, both can be applied to estimate the rates of water infiltration in the soils and in the studied treatment conditions, presenting values close to those measured in the field. Between the two models, Horton presented a better precision fit between the estimated data and the data obtained using the concentric cylinder infiltrometer.

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