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WATER INFILTRATION RATE IN DISTROFERRIC RED LATOSOL UNDER DIFFERENT CROPPING SYSTEMS

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ABSTRACT

This study aimed to evaluate the water infiltration, hydraulic conductivity and hydraulic diffusivity in distroferric Red Latosol under different conditions of agricultural and livestock use. The different conditions of agricultural use and soil livestock are as follows: Cultivation of sugarcane, Annual crops, Crop-Livestock-Forest Integration Systems and Permanent Cerrado. Water infiltration in the soil was determined "*in situ*" by the method of cylinder infiltrometers and empirically through models Kostiakov, Kostiakov-Lewis and Horton. By means of infiltration of water in the soil, the hydraulic conductivity of the saturated soil and the hydraulic diffusivity of the soil were determined. In the evaluation, the following statistical indices were also used: Residual mass coefficient, adjustment coefficient and efficiency. Most hydraulic conductivity, hydraulic diffusivity and infiltration occurred in the then Cerrado area in descending order by the Sugarcane area, the Crop-livestock-forest integration systems and annual crops.

Keywords: compaction; physical attributes; anthropic interference.

VELOCIDADE DE INFILTRAÇÃO DE ÁGUA EM LATOSSOLO VERMELHO DISTROFÉRRICO SOB DIFERENTES SISTEMAS DE CULTIVO

RESUMO

Objetivou-se avaliar a infiltração de água, a condutividade hidráulica e a difusividade hidráulica em Latossolo Vermelho distroférrico sob diferentes condições de utilização agrícola e pecuária. As diferentes condições de utilização agrícola e pecuária do solo, foram as seguintes: Cultivo de cana-de-açúcar, Culturas anuais, Sistema Integração Lavoura, Pecuária e Floresta, e a Área de Cerrado permanente. A infiltração de água no solo foi determinada "*in situ*" através do método do infiltrômetro de anel e empiricamente por meio de modelos de Kostiakov, de Kostiakov-Lewis e de Horton; a partir da infiltração de água no solo foi determinada a condutividade

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hidráulica do solo saturado e a difusividade hidráulica do solo. Na avaliação, foram também utilizados os seguintes índices estatísticos: coeficiente de massa residual, coeficiente de ajuste e eficiência. A maior condutividade hidráulica, difusividade hidráulica e infiltração ocorreu na área de cerrado seguida em ordem decrescente pela área de cana-de-açúcar, o sistema integração lavoura, pecuária e floresta e culturas anuais.

Palavras-chave: compactação; atributos físicos; interferência antrópica.

INTRODUCTION

Infiltration is the process in which the water passes through the ground surface at the beginning value is high, however this decreases with time to become linear when the soil enters the saturation state, called the steady infiltration rate (SIR), their knowledge and relationship with the characteristics and soil properties is extremely important for the efficient management of irrigation blade to be applied, development of irrigation projects and observation of changes due to the introduction of agricultural crops (RIQUELME et al., 2012; VILARINHO et al., 2013).

According and Gonçalves and Moraes (2012) understanding the water infiltration and aggregation of ground particles modified by cultural practices are critical in predicting the flow of water and solutes in the soil. The depth study and knowledge of the physico-hydric properties of the soil are considered important for the management of agricultural areas (JOSEPH et al., 2012).

This infiltration process, however, is influenced by several factors, especially the physical properties of soil and its existing water (moisture), volume of rainfall or irrigation, organic matter, spatial variability of the land (topography), vegetation cover, root system, biological activity, surface roughness, soil aggregation (soil density and particle), management system and porosity (SOBRINHO et al., 2003; PANACHUKI et al., 2006).

Changes in soil density and total soil porosity can vary considerably, depending on the texture, the levels of soil organic matter and frequency of cultivation (MARCOLIN and KLEIN, 2011). Different crops and soil managements can modify their physical properties, so over time the original structure tends to change. As a result of this event, there may be changes in the soil water infiltration rate, the hydraulic conductivity, surface runoff and water storage and distribution in the soil profile (PANACHUKI et al., 2006.; SILVA, 2007).

The intensity with which some variables affect the infiltration process still is not clear, moreover because of the nature of the processes, environmental characteristics, the method used to determine and type and soil management, infiltration rate has large variability (SOUZA NETTO et al., 2013).

This study aimed to evaluate the water infiltration, hydraulic conductivity and hydraulic diffusivity in distroferric Red Latosol under different conditions of agricultural and livestock use.

MATERIAL AND METHODS

The study was conducted in areas located at the Federal Institute Goiano - Campus Rio Verde, GO, situated at latitude 17°48'28"S and longitude 50°53'57"W, mean altitude of 720 m undulated relief (6% slope). The climate is classified as Köppen and Geiger (1928) as Aw (tropical), with rain in the months from October to May, and dry from June to September.

The average annual temperature is 20-35°C and precipitation ranging from 1500 to 1800 mm annually. The predominant soil of the study area is classified as distroferric Red Latosol of medium texture (EMBRAPA, 2006).

The different conditions of agricultural use and soil livestock, are as follows: Cultivation of sugarcane: area was cultivated with sugarcane for a year. The initial tillage area for crop implantation consisted of harrowing, mechanical distribution of limes and subsequent harrowing in order to incorporate limes in the soil. Finally, a leveling was done in the growing area. For the construction of the planting furrows, we used the subsoil and subsequent removal of soil forming the planting site. Annual crops: the area was used annually during the harvest for 20 years. During this period, the cultivation was carried out only with conventional tillage, constituting basically superficial harrowing. The main crops used are soybeans and mays. Crop-Livestock-Forest Integration Systems (CLFI): the area was cultivated for three years in intercropping system with maize and pasture grass, integration with eucalyptus in different bands. The mays planting was carried out with Santa Fé system, and after the mays harvest, the entry is allowed in cattle grazing area. Permanent Cerrado (Cerrado): the area is in permanent reserve area, the Cerrado biome, never subjected to anthropic use.

To determine the physical properties of soil samples were collected in the layers 0.0-0.2 and 0.2-0.4 m, with deformed and non deformed structure. Samples with undisturbed structure were subjected to the following determinations: Soil density (Sd), microporosity (MI), total porosity (TP), macroporosity (MA), calculated as the difference between total porosity and microporosity, as shown in Table 1.

Water infiltration tests were performed on the soil in each of the study sites. The methodology used was the double-ring cylinder infiltrometer (BERNARDO, 1989), consisting of an outer ring with diameter of 0.20 m and 0.40 m high and an inner ring with 0.10 m in diameter and 0.40 m high. The rings were inserted in the soil to a depth of about 0.20 m with a ruler attached to the edge of the inner ring, designed to touch the ground surface to measure the water slide. The time of each reading were 0, 1, 2, 5, 10, 15, and 30 minutes starting from zero time, and repeats every 30 min until the total duration of each test 210 min.

Tests were conducted until the infiltration rate observed in the inner ring becomes approximately constant with time. The infiltration rate is considered constant when the read value of the water level in the inner cylinder has been repeated at least three times. Water infiltration in the soil was determined "*in situ*" by the method of cylinder infiltrometers and empirically through models Kostiakov (KOSTIAKOV, 1932), Kostiakov-Lewis (KOSTIAKOV, 1932; LEWIS, 1937) and Horton (HORTON, 1940) according to equations 1, 2 and 3:

$$V = V_i \cdot t^b \quad (1)$$

Table 1. Soil physical properties under sugarcane cultivation, annual crops (soybeans and mays), crop-livestock-forest integration systems (mays and signal grass in integration with eucalyptus) and area of permanent reserve, the Cerrado biome, Rio Verde - GO.

Área[1]	Layer	Sd	Pd	TP	MA	MI
	m	g cm^{-3}		%	m^3 m^{-3}	
Sugarcane	0.0 – 0.2	1.02	2.68	0.62	0.12	0.50
	0.2 – 0.4	0.97	2.80	0.65	0.10	0.55
Cerrado	0.0 – 0.2	1.13	2.68	0.58	0.14	0.44
	0.2 – 0.4	1.19	2.67	0.55	0.13	0.42
Annual Crops	0.0 – 0.2	1.22	2.72	0.55	0.19	0.36
	0.2 – 0.4	1.29	2.60	0.50	0.13	0.37
CLFI	0.0 – 0.2	1.19	2.62	0.54	0.09	0.46
	0.2 – 0.4	1.25	2.56	0.51	0.18	0.33

[1]CLFI: Crop-livestock-forest integration systems; Sd: Soil density; Pd: particle density; TP: total porosity, microporosity (MI) and macroporosity (MA).

$$V = V_i \cdot t^b + V_f \cdot t \quad (2)$$

$$V = V_i + \left(V_i - V_f\right)^{-K_f \cdot t} \quad (3)$$

on what: V - water infiltration rate into the soil, cm h^{-1}; V_i - initial infiltration rate, cm h^{-1}; V_f - final infiltration rate, cm h^{-1}; B and K_f - proportionality constant dependent on soil type and intensity of precipitation.

To evaluate the performance of the infiltration values obtained in the field and the values calculated from the empirical models Kostiakov, Horton and Kostiakov-Lewis for infiltration tests, comparative analyzes of the results were made statistically by the determination coefficient (R^2).

The quality of fit of the models was evaluated by nonlinear regression between the estimated values and the average values observed in the different conditions of soil and agricultural use livestock, along with the respective coefficients of determination. In the evaluation, the following statistical indices were also used: Residual mass coefficient (RMC), adjustment coefficient (AC) and efficiency (EF) (SOBRINHO et al., 2003), according to equations 4, 5 and 6:

$$RMC = \frac{\left(\sum_{i=1}^{n} X_i - \sum_{i=1}^{n} P_i\right)}{\sum_{i=1}^{n} X_i} \quad (4)$$

$$AC = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{\sum_{i=1}^{n}\left(P_i - \bar{X}\right)^2} \quad (5)$$

$$EF = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{\sum_{i=1}^{n}\left(X_i - \bar{P}\right)^2} \times \frac{1}{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2} \quad (6)$$

Descriptive analysis was performed for comparison of water infiltration rate in areas of soil. To determine the empirical equations that best have adapted the conditions of areas with different types of land use, RMC, AC and EF parameters were used. The hydraulic conductivity of saturated soil (Ks) was determined by the equation 7 (BERNARDO et al., 2006):

$$K_S = \frac{Q \times L}{A\left(L + h\right)} \quad (7)$$

on what: Ks - saturated hydraulic conductivity of the soil (cm h^{-1}); L - ring depth buried (cm); Q - percolated flow through the sample (cm^3 h^{-1}); A - cross section of the sample (cm^2); h - hydraulic load (cm).

The soil hydraulic diffusivity was determined by Klute (1965) and Pauletto et al. (1988), according to equation 8:

$$D(\theta) = K(\theta)\frac{\partial h}{\partial \theta} \quad (8)$$

The setting of the parameters of the equations of hydraulic conductivity and soil hydraulic diffusivity was performed using the RETC application version 6.02 (van GENUCHTEN et al., 2009).

RESULTS AND DISCUSSION

Table 2 checked the values of steady infiltration rate (SIR), empirical models and statistical indices for the different areas studied. The SIR area cultivated with sugarcane was the one closest to the SIR permanent reserve area, the Cerrado biome presenting high values in relation to other areas. The cerrado SIR was 56.2, 84.8 and 93.1% higher than in the area with sugarcane, Integration crop, livestock and forest and annual crops, respectively (Table 2). Vilarinho et al. (2013), to determine the infiltration rate in distroferric Red Latosol under native Cerrado vegetation, found a stable infiltration rate of magnitude of 36 cm h^{-1}. Leite et al. (2015) found that the increased presence of pores in the native forest favored greater water infiltration rate in soil.

In areas of Cerrado and sugarcane were checked larger SIR the same manner

Table 2. Steady infiltration rate (SIR), the infiltration rate equations, coefficients of determination (R^2) of empirical models and statistical indices for areas with different conditions of agricultural use.

Area[1]	SIR (mm h^{-1})	Model	Equation	R^2 (%)	RMC	AC	EF
Cana	220.9	Kostiakov	$IS = 639.49\ T^{-0,493}$	99	0.77	0.32	$2.89\ 10^{-6}$
		Kostiakov-Lewis	$IS = 153.01\ T^{-0,479}$	99	6.19	5.69	$5.09\ 10^{-5}$
		Horton	$IS = 1097,5\ T^{-0,6}$	92	0.29	0.20	$1.83\ 10^{-6}$
C. Anuais	34.9	Kostiakov	$IS = 111.26\ T^{-0,327}$	99	0.69	3.29	$4.12\ 10^{-6}$
		Kostiakov-Lewis	$IS = 40.787\ T^{-0,396}$	99	4.38	61.5	1.61
		Horton	$IS = 147.76\ T^{-0,396}$	94	0.49	$7.7\ 10^{-5}$	$2.02\ 10^{-6}$
CLFI	76.8	Kostiakov	$IS = 322.53\ T^{-0,495}$	99	0.73	2.49	$5.24\ 10^{-6}$
		Kostiakov-Lewis	$IS = 117.85\ T^{-0,567}$	99	4.39	31.4	$6.61\ 10^{-5}$
		Horton	$IS = 555.47\ T^{-0,602}$	92	0.27	1.45	$3.05\ 10^{-6}$
Cerrado	504.3	Kostiakov	$IS = 2022\ T^{-0,823}$	99	1.44	1.37	$2.46\ 10^{-7}$
		Kostiakov-Lewis	$IS = 1486.8\ T^{-0,531}$	99	1.16	1.62	$2.91\ 10^{-7}$
		Horton	$IS = 6142.9\ T^{-0,968}$	87	0.23	0.64	$1.14\ 10^{-7}$

[1]CLFI: Crop-livestock-forest integration systems; RMC: Residual mass coefficient; AC: Adjustment coefficient; EF: Efficiency.

in these areas were also observed the larger particles density values, total porosity and microporosity, and soil density values (Table 1). José et al. (2012) found the interference density, total porosity, macroporosity and microporosity in water infiltration. management systems such as tillage, conventional tillage modify the porosity and distribution of the different formats of soil pores, hence water infiltration into the soil is influenced by these changes in porosity caused by management practices (GONÇALVES and MORAES, 2012).

According to the classification of SIR proposed by Klute (1965), the areas with Sugarcane, Annual crops, CLFI and Cerrado, are classified as high, medium, medium and high, respectively.

The lowest values of the SIR in the fields of CLFI and Annual crops can be explained by changing the physical structure of the soil, which occurred due to livestock and the succession soybean/mays (for 20 years), which favored the formation of a more compacted layer of soil. Souza et al. (2004) state that this causes significant change in total soil macroporosity, density and water infiltration rate.

Heid et al. (2009) evaluated an distroferric Red Latosol under different agricultural uses, with no-tillage and conventional tillage in area native Cerrado, he noted that the aggregate stability has been modified over the years of agricultural use, thus influencing the retention and storage of water.

The models Kostiakov and R^2 Kostiakov-Lewis showed over 99% indicating that at most 1% of the infiltration rate variations are not explained by variation in time; already Horton model did not show the same adjustment, with R^2 ranging between 87 and 94%, thus demonstrating deviations of up to 13% (Table 2). Santos et al. (2015) found R^2 greater than 80% from the equations set for models Kostiakov and Kostiakov-Lewis and values obtained by cylinder infiltrometers, and the model Kostiakov-Lewis describes water infiltration process soil very realistic manner, while Kostiakov model diverges from the results obtained by assaying the end.

The residual mass coefficient (RMC) used as the equation Kostiakov, Kostiakov-Lewis and Horton, showed values of 0.91, 4 and 0.32, respectively. The greater the RMC was observed when it was used the model of Lewis Kostiakov-in area sugarcane cultivation, while the lower RMC was observed when model was used in Cerrado Horton area. For these RMC values can be seen that the model of Horton showed a better match than the models Kostiakov and Kostiakov-Lewis, but in general all the models showed some level of overestimation of infiltration rate in different conditions of use agricultural and soil livestock. Pertussatti et al. (2015) found RMC values near zero for models Kostiakov-Lewis, Horton and Philip however the model Kostiakov-Lewis was the one that obtained the best fit in distrophic Purple Latosol, Dusky Red Latosol and Quartzarenic Neosol

The adjustment coefficient (AC) medium were 1.87, 25.1 and 0.76 for models Kostiakov, Kostiakov- Lewis and Horton, respectively. The biggest AC was verified when we used the model Kostiakov-Lewis in the area of annual crops, in this same area was also checked the lowest AC, however for the model of Horton. Efficiency (FE) models Kostiakov, Kostiakov-Lewis and Horton, generally had values below 6.61 10^{-5}, except for the model Kostiakov-Lewis in the area with annual crops that had the highest value, this being 1.6.

Gomes Filho et al. (2014) observed that the Adjustment Coefficient (<1.8) was, as a rule, better in Horton´s equation, and that the efficiency index (EF) was the same in equations of Kostiakov, Kostiakov-Lewis and Horton, with lower values than 0.000799.

In Figure 1, we can observe the curve infiltration rate (IR) as a function of time, which showed R^2 84, 40, 82 and 73% in areas of Sugarcane, Annual crops, shut and Crop-livestock-forest integration systems, respectively, thus it can be seen major shifts in the area of Annual crops, where it was the lowest coefficient of determination. The highest infiltration rate over time was observed in the Cerrado area, due to improved soil physical conditions, followed by the area with Sugarcane,

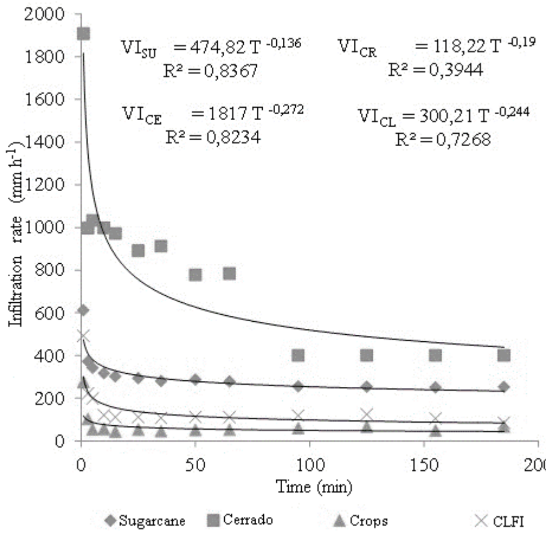

Figure 1. Water infiltration rate in the soil as a function of time in areas with different land uses.

Crop-livestock-forest integration systems and Annual crops.

According Santos and Pereira (2013) as texture both soil structure are important for the movement of water along the profile, since they determine the amount and arrangement of the pores. Thus, changes in pore size distribution due to handling agricultural use, can reduce or increase the SIR, as shown in Table 2, or even the infiltration rate (Figure 1).

These results corroborate those found by Zwirtes et al. (2011), that working on a typic ferric aluminum Red Latosol observed that the soil of the native forest has a higher infiltration rate (IR) compared to that suffered human action and that the infiltration rate is lower in soil that has grazing bovine. Just as for SIR, the IS also suffers the same influence over the structural changes of the soil, due to the different types of management systems adopted. The change in pore size is one of the properties that affects these two variables for influencing the soil water holding capacity.

Leite et al. (2015) observed that water infiltration in the soil was influenced by management systems (alley cropping, conventional cultivation of beans and no-tillage) that showed degradation of the physical attributes evidenced by soil density values.

The non-soil disturbance for a long period of time Red Latosol, tends to increase the microporosity (CÁSSARO et al. 2011), the same trend of increased microporosity can be seen in Table 1, this may cause reduction in IS and SIR. Figure 2 shows the infiltration rate for the equations of Kostiakov, Kostiakov-Lewis, Horton and obtained by the field method of concentric rings for the areas with Sugarcane cultivation, Crop-livestock-forest integration systems, Annual crops and Cerrado. Of these empirical models obtained in the Horton all areas slightly higher infiltration rate values, while Kostiakov-Lewis these values were lower. Horton values are closer to those obtained field, but this tends to overestimate the infiltration rate at the initial time in relation to field method, while the model Kostiakov at the same time tends to underestimate these values.

Oliveira (2015) noted that the model Kostiakov underestimated the infiltration rate at the beginning of the process in eutrophic Red Nitosol and Quartzarenic Neosol except Haplic Cambisol where the model overestimated the initial infiltration rate, also found that the model of Horton this same soil can estimate the value of the initial infiltration rate, but this makes the model does not well represent the process curve: understates the beginning of infiltration and overestimates the end.

In areas with growing Sugarcane, Crop-livestock-forest integration systems, Annual crops and Cerrado, empirical models generally behaved similarly. The model has Horton values closest to the infiltration rate

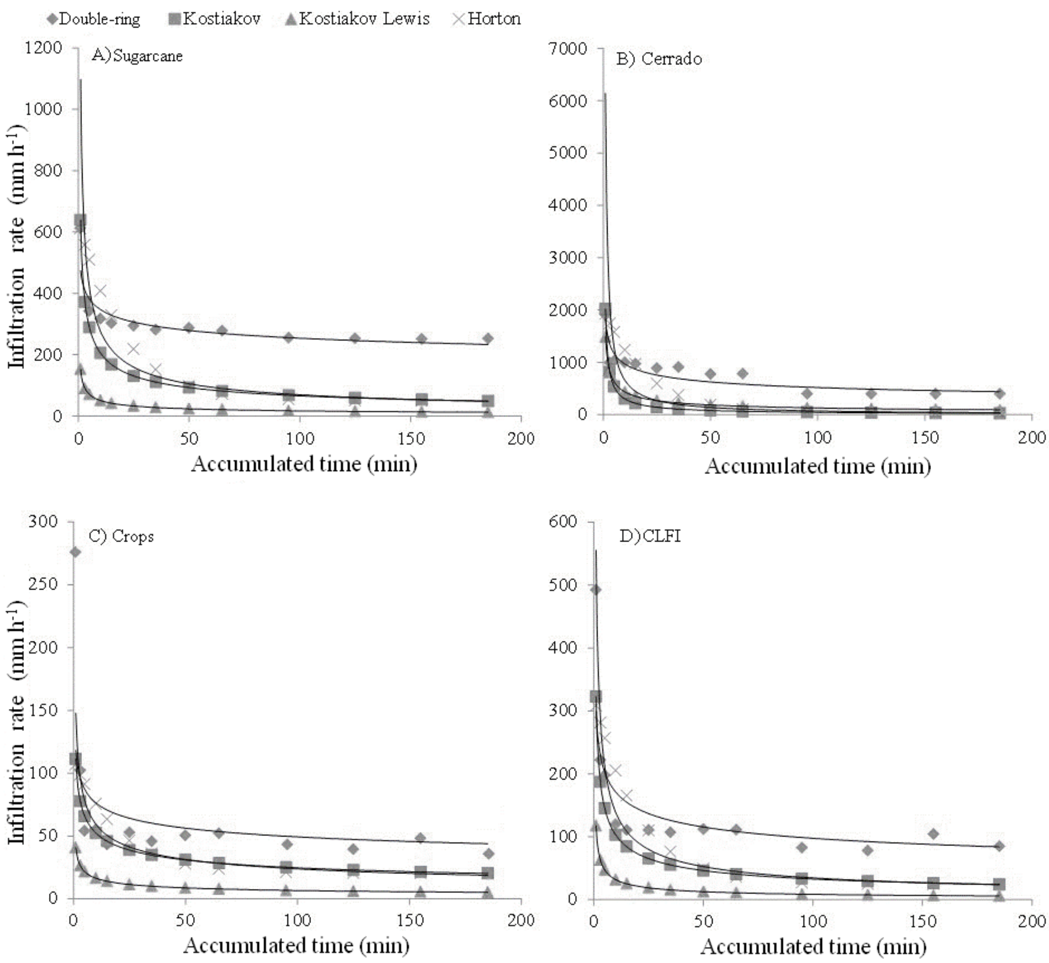

Figure 2. Water infiltration rate in the soil obtained in the field by the cylinder infiltrometer method and data estimated by Kostiakov equations Kostiakov-Lewis and Horton areas with different land uses.

obtained in the field by the method cylinder infiltrometers next to the 50 min, but after that time their values up to the equal Kostiakov model (Figure 2). Rodrigues (2013) found that the model of Horton despite having the lowest R^2, showed the basic infiltration rate similar to the value obtained in the field with double-ring cylinder infiltrometer of reduced dimensions.

In Cerrado biome in Red Latosol, the empirical model of Horton has shown a lot of times comparative to Kostiakov (Figure 2), however as seen in Table 2, the model of Horton proved best to estimate the IS and SIR. Alves Sobrinho et al. (2003) studied the infiltration of water in a Red Latosol under conventional and no tillage system, also noted that the Horton equation was the most suitable to estimate the water infiltration rate in the soil. The comparison of these empirical models with the data obtained in the field, allows you to check which model fits best or is more applicable to local conditions.

The hydraulic conductivity in the areas of Cerrado, Sugarcane, Annual crops and Crop-livestock-forest integration systems were pretty much the same until the water content of 0.5 $cm^3\ cm^{-3}$, from this point the hydraulic conductivity was similar only between areas with Cerrado and Sugarcane, while for areas with Annual crops and Crop-livestock-forest integration systems, the conductivity values were close to the water content of 0.6 $cm^3\ cm^{-3}$, from which the hydraulic conductivity was higher in the area of Crop-livestock-forest integration systems (Figure 3). Silva Junior et al. (2013) observed that the infiltration tests to determine the hydraulic conductivity carried out in distroferric Red Latosol, water volumetric content varied between 0.31 and 0.54 $m^3\ m^{-3}$ for the layer of 0-0.20 m and 0.29 and 0.61 $m^3\ m^{-3}$ to layer 0.20 to 0.60 m.

The hydraulic conductivity of saturated soil of the Cerrado area was approximately 82.7, 91.7 and 53.3% higher than the Ks checked in the area of Crop-livestock-forest integration systems, annual crops and

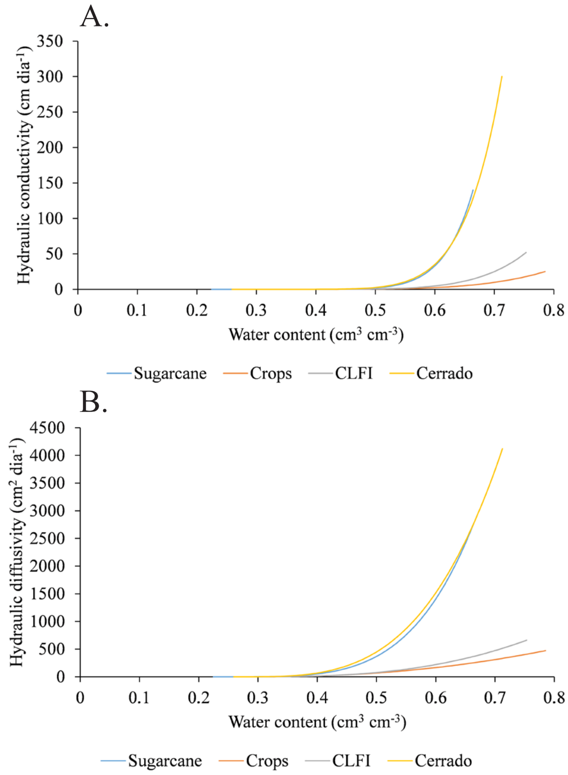

Figure 3. Conductivity hydraulic (A) and hydraulic diffusivity (B) depending on the water content in soil for areas Sugarcane, Annual crops, CLFI and Cerrado.

Sugarcane, respectively (Figure 3A). The larger Ks values are verified, generally where there is a greater degree of structure, which may be modified by aggregation processes of the particles and formation of macropores, which are dependent on other soil conditions in addition to those adopted cultural practices (UYEDA, 2009).

The hydraulic diffusivity in the areas of Cerrado, Sugarcane, Annual crops and Crop-livestock-forest integration systems were similar to the water content of 0.4 $cm^3\ cm^{-3}$, which is a figure slightly lower than that in the hydraulic conductivity. For areas with Annual crops and Crop-livestock-forest integration systems, the hydraulic diffusivity values were close to the water content of 0.6 $cm^3\ cm^{-3}$, which is similar to behavior observed in hydraulic conductivity for these same areas. The no-tillage and conventional tillage systems affect the water physicochemical properties of the soil, including parameters such as diffusivity and hydraulic conductivity of the soil saturated and unsaturated, influencing its holding capacity and water availability (SILVA et al., 2012).

The hydraulic diffusivity of the Cerrado area was approximately 84, 88 and 33% greater than the diffusivity observed in the area of Crop-livestock-forest integration systems, Annual crops and Sugarcane, respectively (Figure 3B). Cunha et al. (2015) found that the initial hydraulic diffusivity in no-tillage system was 16% higher than the diffusivity of conventional tillage system.

Note, therefore, that the area of Cerrado has the highest conductivity values and saturated hydraulic diffusivity compared with other areas studied, followed by Sugarcane, which demonstrates the importance of maintaining the physical structure of the soil. According to Conceição et al. (2014) the knowledge of these two variables, provides the foundation necessary to forecast water absorption by plants.

CONCLUSIONS

Most hydraulic conductivity, hydraulic diffusivity and infiltration occurred in the then Cerrado area in descending order by the Sugarcane area, the Crop-livestock-forest integration systems and annual crops.

The low values of the steady infiltration rate in the fields of annual crops and Crop-Livestock-Forest Integration Systems are mainly by changing the physical structure of the soil. Horton equation that was more suited, while the other tended to underestimate the steady infiltration rate obtained by cylinder infiltrometer method. The different conditions of agricultural and livestock use in distroferric Red Latosol, has great effect on the infiltration rate, hydraulic conductivity and soil hydraulic diffusivity.

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