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Hydro-physical properties and organic carbon of a yellow oxysol under different uses

Welldy Gonçalves Teixeira[1], Isabel Dayane de Sousa Queiroz[2], Risely Ferraz Almeida[3]*, Fernanda Pereira Martins[4], Joseph Elias Rodrigues Mikhael[5] and Elias Nascentes Borges[6]

[1]Universidade Federal de Viçosa - UFV, Viçosa, MG, Brazil.
[2]Centro de Ensino Superior de São Gotardo, Professora. São Gotardo, MG, Brazil.
[3]Universidade Estadual Paulista "Júlio de Mesquita Filho"-UNESP, Jaboticabal, SP, Brazil.
[4]Universidade Federal de Uberlândia, Belo Horizonte, MG, Brazil.
[5]Louisiana State University, Baton Rouge, Louisiana, USA.
[6]Universidade Federal de Uberlândia, Uberlândia, MG, Brazil.

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Intensive soil use without a management plan based on its structures and limitations is the main cause of soil erosion and degradation. The physical properties changes of a studied agricultural area are evaluated by comparing with an area that did not suffer any modification caused by human activities, which is considered the ideal soil condition. This research evaluated the alterations in the hydro-physical properties and the organic carbon content of a Eutrophic Yellow Oxysol under different use and management systems in the Triângulo Mineiro, an important agriculture region in Brazil. The systems studied were, Cerrado with typical *stricto sensu* vegetation preserved for over 30 years; eucalyptus planted about 30 years ago, without fertilizer or cultivation since the implantation period; corn grown under the no tillage system intercropped with pasture; and *Brachiaria* sp. under no-tillage intercropped with corn, managed with cattle and annually fertilized with turkey litter. The soil bulk density, total porosity, size distribution of the pores, flocculation degree, geometric mean diameter, water infiltration and organic carbon were evaluated. The effects of land use and management system alterations on soil physical properties were similar at both depths, except the geometric mean diameter, which was higher in the surface layer. The eucalyptus and no-tillage systems with corn and pasture recovered the soil organic carbon contents as compared to the preserved Cerrado area, which was more significant in the surface layer. The soil with native Cerrado vegetation presented faster infiltration in relation to other systems followed by, in descending order, the areas planted with eucalyptus, pasture and corn. The infiltration rate and cumulative infiltration curves were similar to values obtained in the field.

Key words: Management systems, no-tillage, soil structure, water infiltration.

INTRODUCTION

Soil degradation is a serious environmental problem throughout the world, which may lead to a decline in soil quality with a continuing reduction of productivity. Inappropriate agricultural practices, among deforestation and other human activities, is an important driving force of soil degradation and the need to reduce the environmental impact of agricultural activities and to control soil degradation is one of the main aims of management systems.

Changes due to different management systems are evaluated by accessing chemical, physical and biological soil properties by comparing managed areas and areas under natural vegetation (Barros and Comerford, 2002). Studies by Tollnerm et al. (1990) and Broersma et al. (1995) showed that land use changes from natural and semi-natural vegetation to cultivated and grazed lands could affect soil bulk density, porosity and water storage, water infiltration, and water flow characteristics and surface runoff.

In Brazil, most of the central part is covered by seasonal savanna, known as “Cerrado”, in which Oxisols are the predominant soils in the region (46%). These soils are well drained, but strongly and deeply weathered and have natural poor fertility. Even presenting all these chemical constraints, the potential for arable land use and technological advances in soil and crop management in these vast areas have made the Cerrado the agricultural frontier of Brazil since the early 1970s, emphasizing its importance to the agriculture in the country.

In tropical soils, organic matter is one of the main properties responsible for the soil quality. Adequate levels of organic matter can minimize the impacts of agricultural practices and maintain the soil fertility. Thus, the adoption of conservation cropping systems, such as no-tillage, is fundamental to promote increased stocks of organic matter.

The water infiltration rate is another property that best reflects the soil quality and its structural stability. For Pott and de Maria (2003), the infiltration rate is one of the processes that best demonstrates the soil hydro-physical conditions due to the structural quality conditions such as the pore size distribution which is favorable to the root growth, aeration and soil water infiltration.

The studies on land use impacts have been focused mostly on soil physical and chemical properties, and few researches have investigated the effects on soil hydraulic properties. Soil hydraulic properties consist of soil water retention and hydraulic conductivity functions (Hussein and Warrick, 1995). These properties are influenced by several factors including soil texture, structure, bulk density and organic carbon. It is, therefore important to explore the effects of soil management systems on water infiltration capacity and its relationships with chemical and physical soil properties for a better understanding of the soil quality.

Thus, this study was conducted in the central region of Brazil named Triângulo Mineiro with the objective of evaluating alterations in hydro-physical properties and organic carbon content of an Oxysol under different uses and management systems.

MATERIALS AND METHODS

Characterization of the study area

The work was conducted on the Santa Terezinha farm, Uberaba, MG (19° 12' 11" S, 48° 11' 30" W at an altitude of 830 m). The climate is characterized as rainy tropical with a dry winter (Antunes, 1986). The original vegetation of the study area was the cerrado type (natural vegetation in Brazil).

Four areas were selected, the use of which can be characterized as: (a) Cerrado: vegetation typical of *stricto sensu* cerrado, without history of anthropic interference, preserved for more than 30 years. This area was chosen as a reference for comparison of the alteration of the evaluated characteristics; (b) Eucalyptus: Eucalyptus forested area, established for 30 years, without fertilization or cultivation since the implantation period; (c) Corn: Corn crop in no-tillage (NT), intercropped with pasture, according to the Santa Fé cultivation system - SSF; (Kluthcouski et al., 2000); (d) Pasture: area with *Brachiaria* sp. under NT, intercropped with maize, being managed with cattle and fertilized annually with turkey litter.

The physical and chemical characteristics of the soil, according to methods described in EMBRAPA (1997) are presented in Table 1. All these areas have the same soil type, which was classified as Eutrophic Yellow Oxysol, sandy loam texture, according to the Brazilian Soil Classification System (Santos et al., 2013).

Soil sample and variables analyzed

In June 2012, soil sample collections and the soil water infiltration rate measurements were carried out. During the assessments there was total absence of rain in the experimental area. In each area, four samples were taken in the 0 to 20 and 20 to 40 cm layers, in four points distributed at random. At each point, samples with disturbed structure were collected, placed in plastic bags, sieved at 4 mm and air-dried. These samples were used for particle size determination by the pipette method (Gee et al., 1986) and geometric mean diameter (GMD) by the method of Kemper and Chepil (1965).

Undisturbed soil samples were collected at the same locations mentioned above, using a Kopeck volumetric ring and Uland sampler. After collection, the samples were wrapped in screen fabric and sent to the laboratory for determination of bulk density (BD), macro- (Ma) and micro porosity (Mi) and total porosity (Pt) by the voltage table method, while the bulk density (BD), conducted by the volumetric ring method, was calculated as the ratio between the weight of dry sample in the oven and the ring volume (EMBRAPA, 1997).

For the organic carbon (OC) analyzes, single samples were collected at two depths and four points in each area, and after thoroughly mixing, they were air dried (ADFS) and analyzed as proposed by Yeomans and Bremner (1988).

The determination of the water-dispersible clay (WDC) was performed by the volumetric pipette method according to the

*Corresponding author. Email: rizely@gmail.com.

Table 1. Physical and chemical characteristics of a *Eutrophic Yellow Oxysol* under different use and management systems in the Fazenda Santa Terezinha, Uberaba, MG.

Systems	Sand	Silt	Clay	pH	P (mg dm^{-3})	Mg^{2+}	Ca^{2+}	K^{+}	Al^{3+}	H+Al
	g kg^{-1}					$cmol_c$ dm^{-3}				
					0-20 cm					
Cerrado	784	25.2	190.8	5.1	1.5	0.1	0.1	0.06	0.4	2.7
Eucalyptus	794.8	44.0	161.2	5.2	4.5	0.3	0.3	0.09	0.4	3.3
Pasture	780.4	54.8	164.8	6.1	37.5	0.2	1.5	0.07	0	1.6
Corn	674.2	29.8	296.0	5.5	82.4	0.4	2.0	0.09	0	2.4
					20-40 cm					
Cerrado	759.2	25.7	215.5	5.5	0.7	0.1	0.1	0.05	0.3	2.3
Eucalyptus	794.8	44.0	161.2	5.2	4.5	0.3	0.3	0.09	0.4	3.3
Pasture	785.3	41.0	173.7	6.0	4.2	0.1	0.8	0.07	0	1.6
Corn	698	32.0	270.0	5.5	17.4	0.3	1.1	0.05	0	2.4

pH in water, ratio 1:2.5. Ca^{2+} and Al^{3+}: extractor KCl 1 mol L^{-1}. H+Al: extractor Ca $(OAc)_2$ 0.5 mol L^{-1} pH 7.0. P and K: extractor Mehlich-1.

methodology described by EMBRAPA (2009), and with this result the flocculation degree (FD, %) of the clay fraction was calculated: x cylinders method described by Bernard et al. (2006) was used. After soil surface cleaning in each system used, the cylinders cylinders method described by Bernard et al. (2006) was used. After soil surface cleaning in each system used, the cylinders (external and internal) were fixed on the ground concentrically, to 15 cm deep. The infiltration was measured in the inner ring, with the aid of a graduated ruler, since the purpose of the outer ring was to prevent the infiltration from laterally proceeding into the soil. The water was added simultaneously in the two rings to a height of 9 cm of depth, allowing a maximum oscillation of 4 cm. Timing counting began when the water level reached a height of 7 cm and finished when it reached 5 cm. Constant infiltration was considered as when the value of the reading was repeated at least three times; at this point, the process was suspended, and it was considered that the infiltration rate had been reached.

With the results collected in the field, the cumulative infiltration (Z) and instantaneous infiltration rate (I) curves were obtained. A considerable number of readings were taken in the use system with eucalyptus (N=73) and cerrado (N=21), but in some systems used such as pasture (N=9) and corn (n=8), fewer readings were taken due to the rapid attainment of the constant infiltration rate.

To empirically estimate the water infiltration rate, the model proposed by Kostiakov in 1932 (Equation 1) was used, which describes well the water infiltration in short periods (Bernardo et al., 2006):

$$Z = kt^{a} \quad (1)$$

Where Z is the cumulative infiltration (mm), t is the infiltration time (min), k and a are two constants dependent on soil type. The parameters (k and a) of the Kostiakov equation were obtained by linear regression, as follows: Applying the logarithm of both terms of the equation, a straight line equation log I = log k + a log t is obtained, that is, the log I graphic as a function of log t, which is a straight line, a is the angular coefficient and log k, the linear coefficient. With this graphic device, I = *f*(t) we obtained, a very useful equation because with it I can be calculated for any time t.

The instantaneous infiltration rate (I) of water into soil (Equation 2) was obtained by deriving the cumulative infiltration versus time equation. Where I is the instantaneous infiltration rate (cm min^{-1}), t is the infiltration time (minutes), and k and a are two soil-type dependent constants.

$$I = k\,a\,t^{a-1} \quad (2)$$

Data processing and statistical analysis

The results were submitted for analysis of variance using a completely randomized design in a split plot design, with the treatments (use systems) considered as plots and soil layers as subplots. The means were compared by Tukey test at 0.05 of significance.

To verify the suitability of the estimated I and Z via the Kostiakov model compared with the values obtained in the field with the ring infiltrometer, hierarchical cluster analysis was used, by calculating the Euclidean distance between accesses. Among the algorithms, Ward was used to obtain similar access clusters, since in this method, the distance between the two groups is defined as the sum of squares between the two groups by all the variables. The results of the analysis were presented in graphical form (dendrogram) which aided in the identification of access groups (Hair et al., 2005).

RESULTS AND DISCUSSION

Analyzing the soil physical properties, the macroporosity (Ma), bulk density (Ds) and the flocculation degree (FD) differed according to systems use and management, without variation between depths, as shown in Table 2.

It can be seen that the two NT systems used, corn and pasture, presented lower Ma values (0.08 and 0.11 cm^3 cm^{-3}) as compared to cerrado vegetation and eucalyptus (0.19 cm^3 cm^{-3}) which may be due to the absence of tillage and the intense machine traffic (planting, treatments, harvesting) or animals in the pasture (trampling) that provide reduction of this parameter. The Mi and Pt did not differ between the systems evaluated, confirming the results of Melloni et al. (2008), who also found no differences in Mi between eucalyptus, pasture and cerrado systems.

Table 2. Macroporosity (Ma), microporosity (Mi), total porosity (Pt), bulk density (D_S),, flocculation degree (FD) and organic carbon (OC) in different land use and soil management systems and at two depths, evaluated on the Santa Terezinha farm, Uberaba, MG.

Systems	Ma	Mi	Pt	Ds	FD	OC
	$cm^3\ cm^{-3}$			$g\ cm^{-3}$	$g\ kg^{-1}$	
Cerrado	0.19^a	0.28^a	0.47^a	1.56^{ab}	319^{ab}	9.12^b
Eucalyptus	0.19^a	0.28^a	0.47^a	1.46^b	489^a	10.38^{ab}
Pasture	0.11^b	0.30^a	0.41^a	1.60^a	266^b	9.88^{ab}
Corn	0.10^b	0.31^a	0.41^a	1.55^{ab}	439^{ab}	13.12^a
Depths						
0-20 cm	0.13^a	0.29^a	0.42^a	1.54^a	391^a	13.19^a
20-40 cm	0.14^a	0.28^a	0.42^a	1.55^a	366^a	8.06^b

Averages followed by the same letter in column, between systems and depths, were not statistically different by the Tukey test ($p < 0.05$).

Regarding soil density, the values found in all the land uses (between 1.46 and 1.60 g cm^{-3}) are below the range classified by Reichert et al. (2003) for sandy loam soils, ranging from 1.70 to 1.80 g $cm^{-3.}$ Thus, the Ds values found in the present study in the four use systems are not considered harmful to plant development in sandy loam textured soils and therefore do not limit root growth of the species. In Arshad et al. (1996) study, the minimum density value for sandy soils above which there would be restricted to root development ranges from 1.70 to 1.75 g cm^{-3}.

The clay flocculation degree (FD) remained between 266 and 489 g kg^{-1} among soil use and management systems, without variation between depths. Eucalyptus had the highest clay FD in relation to other systems, while pasture had the lowest FD. These results may be related to chemical factors, such as the H+Al contents, which are the main flocculation agents in acid soils (Morelli and Ferreira, 1987). In this work, the H+Al contents were higher in the use system with eucalyptus, followed by corn, cerrado and pasture, in the two layers evaluated (Table 1), which suggests that most of the clay flocculation in the eucalyptus system is due to the aggregating effect of the H^+ and Al^{3+} cations. The exchangeable soil cations such as Ca^{2+} and Mg^{2+}, significantly influenced the aggregation process, but in acid soils, the effect of Ca^{2+} on aggregation is not as important because H^+ saturated soils flocculate more than Ca^{2+} saturated soils (Baver, 1952). Another important factor in the aggregation process refers to organic matter, which was significantly higher in the surface layer, as seen from the OC content (Table 2), which justifies the beneficial effect of organic matter on clay flocculation in areas with eucalyptus and corn.

Use systems and soil management significantly affected the OC, which varied from 9.12 to 13.12 g kg^{-1}. The area under maize grown in NT had the highest OC content, differing from the cerrado area, where the lowest levels were observed. The non-soil tillage combined with the contribution of grass residue, which is more lignified, on the surface in no-tillage, can lead to the slower residue decomposition, promoting the increase in soil organic matter stocks, as seen in the area under maize.

In the cerrado area, on the other hand, the diversity of plant species, notably higher than that of other systems evaluated, will result in litter deposits of organic substrates with varied composition. Moreover, there is greater diversity of organic compounds deposited in the rhizosphere, which favors the growth of different groups of microorganisms in the soil and may help stimulate its decomposition activity. Thus, the different soil conditions under cerrado vegetation make the existence of lower OC levels possible, given the mineralization of organic matter by a more intense activity of the microbial biomass. The areas under eucalyptus and pasture have similar behavior in relation to the OC content, with intermediate values for this characteristic.

The highest OC content occurred in the upper soil layer, where the residues were concentrated, presenting a reduction of 39% in the 20 - 40 cm layer, regardless of the system of use. Nevertheless, the OC levels are considered low, which may be related to the sandy loam soil texture (high sand content), which provides lower organic compound binding with mineral colloidal constituents and therefore less physical protection, facilitating their microbial decomposition (Bayer et al., 2000).

The aggregate stability, measured by the average aggregate geometric diameter (GMD) shows that in the surface layer, eucalyptus and pasture systems propitiated values similar to the Cerrado, with the exception of corn, which was less efficient with respect to aggregation (Table 3). In the subsurface layer, the soil use systems do not differ from each other, indicating similarity in soil structure of all the investigated areas. By presenting a higher diversity of plant species in various stages of growth, the occurrence of larger aggregates in the cerrado may have been influenced by the volume of

Table 3. Geometric mean diameter (GMD) in different land use and soil management systems and at two depths, measured on the Santa Terezinha farm, Uberaba, MG.

Systems	GMD (mm)	
	0-20 cm	20-40 cm
Cerrado	1.22^{aA}	0.92^{aB}
Eucalyptus	1.15^{abA}	0.75^{aB}
Pasture	1.10^{abA}	0.65^{aB}
Corn	0.72^{bA}	0.66^{aA}

Means followed by the same letter in the column, lowercase at the same depth and uppercase between depths, do not differ by the Tukey test (p <0.05).

roots, emphasizing the physical effect of the roots on the formation, maintenance and size of the aggregates.

High aggregate stability is related to lower soil density, which was found in this study for the use system with eucalyptus. In addition to the eucalyptus, the amount of organic waste produced may have been responsible for improving aggregate stability, contributing to protection from environmental agents and maintenance of carbon stocks in the system. In the pasture, a factor that may have contributed to the highest GMD values at 0-20 cm is the compaction caused by animal trampling, which makes the microaggregates unite into larger aggregates, through compressive forces, which increases the aggregate GMD.

For corn, the OC content was significantly higher in relation to other uses and did not present a relationship with the aggregate stability. The absence of correlation between the OC availability with GMD and the soil aggregate classes was also found by Almeida et al. (2014). However, in the soil there may also be more aggregate stability promoted by increased organic material accumulation (Beutler et al., 2001; Souza et al., 2008).

With regard to the depths, the highest GMD values were found in the surface layer, except for under corn, which showed similar values in the two layers. The organic matter is one of the principal soil particle aggregating agents, and therefore, in tropical soils, it is expected that part of the aggregate size variation, and in consequence, the aggregation rates, may be attributed to variation in the soil organic matter content. Thus, the higher soil aggregation in the 0 - 20 cm layer may be related to higher OC levels, while lower levels in the 20 - 40 cm layer may have contributed to the reduction the GMD of the systems evaluated.

The mean infiltration rate (I) and cumulative infiltration (Z) values for water into soil, obtained in field through the ring infiltrometer for the four system uses are shown in Figure 1. The soil with native cerrado vegetation had little variation in I during the evaluation time and had higher average in relation to other use systems followed by, in descending order, the areas planted with eucalyptus, pasture and corn. For Bono et al. (2012), removal of natural vegetation and the introduction, of either pasture or crops, leads to a consequent reduction of the basic water infiltration rate, confirming the findings of the present study.

At the start of the evaluation, the I in the cerrado was higher (320 cm h^{-1}) and decreased to a nearly constant value, stabilizing with about 245 cm h^{-1}. The area with eucalyptus showed the highest amplitude in relation to other areas, with I varying from 154 to15 cm h^{-1}. Corroborating with the results observed in this study, Araújo et al. (2007) evaluated the soil quality in the native cerrado area and in areas under different uses and found values of 204 and 185 cm h^{-1}, respectively, for native cerrado areas and pine forestation.

The higher I values, and thus of Z, observed in the cerrado are associated with increased Ma (Table 2) and larger aggregate size, which can be verified through their GMD (Table 3). Comparing the areas under NT, the corn showed lower I in relation to pasture, initially presenting 10 cm h^{-1} and stabilizing at 9 cm h^{-1}, while the pasture presented 36 cm h^{-1} at the start of the tests, reaching stabilization at 24 cm h^{-1}. The lowest water infiltration rate in the soil under NT is due to the soil structure degradation process (compression) caused by particle densification and the higher density in the surface layers (Pinheiro et al., 2009). Thus, the lower I values observed in soil cultivated with maize may be due to alterations introduced in the soil during the planting and harvesting processes, which caused increase in the Ds (Table 2), with consequent reduction of Ma and infiltration capacity, indicating greater physical degradation as compared to the soil cultivated with pasture.

The inverse of the I behavior can be observed in the Z of water in soil, which increased in all the land uses and reached the highest values in the area with eucalyptus, followed by savannah, pasture and corn.

I and Z curves estimated by the empirical model proposed by Kostiakov, using data observed in the field determinations, are shown in Figure 2. The values estimated by the equation and those from the field via double ring infiltrometer, were significantly and positively correlated for I (r = 0.94) and Z (R = 0.98). This similarity between the methods was also seen in the cluster analysis with the formation of distinct groups, respectively, for Z (Group 1) and I (Group 2) (Figure 3).

Conclusions

1. Alterations in the physical properties of the use and management system soils are similar at both depths, except the geometric mean diameter, which is greater in the surface layer. The eucalyptus system and no-tillage systems with corn and pasture recover the soil organic carbon contents ad compared to the preserved Cerrado area, which is more significant in the surface layer.
2. The soil with native cerrado vegetation presents a

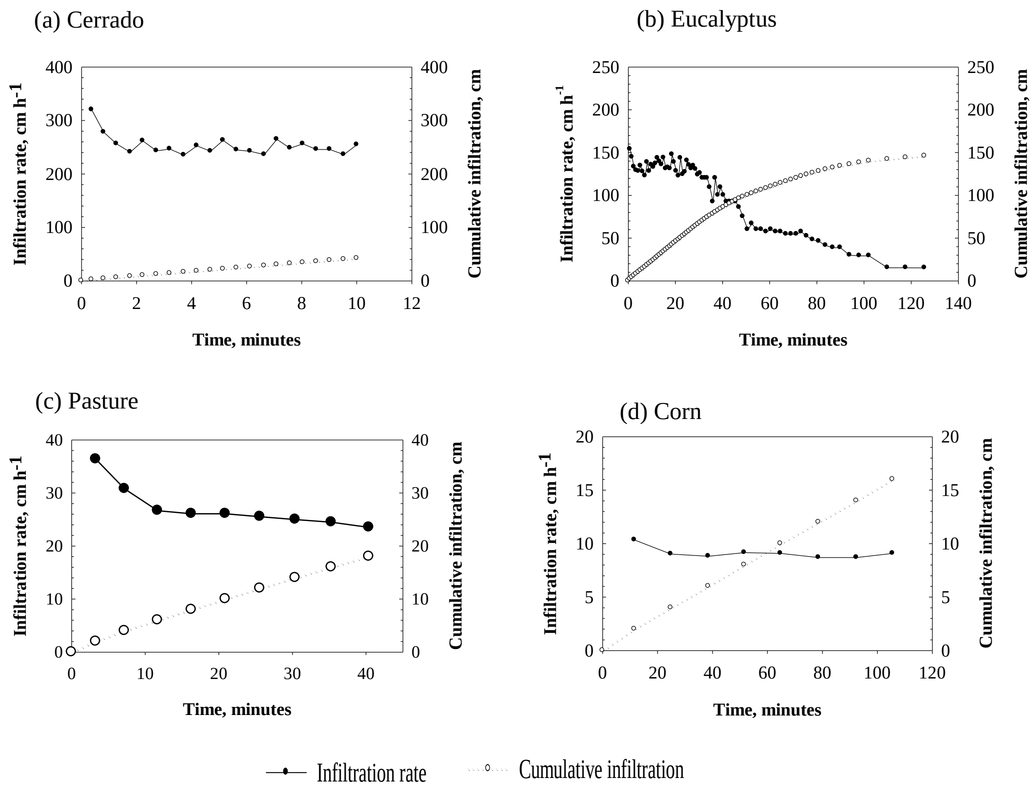

Figure 1. Field values obtained for infiltration rate and cumulative infiltration of water into soil in use systems: Cerrado (a), eucalyptus (b), pasture (c) and corn (d).

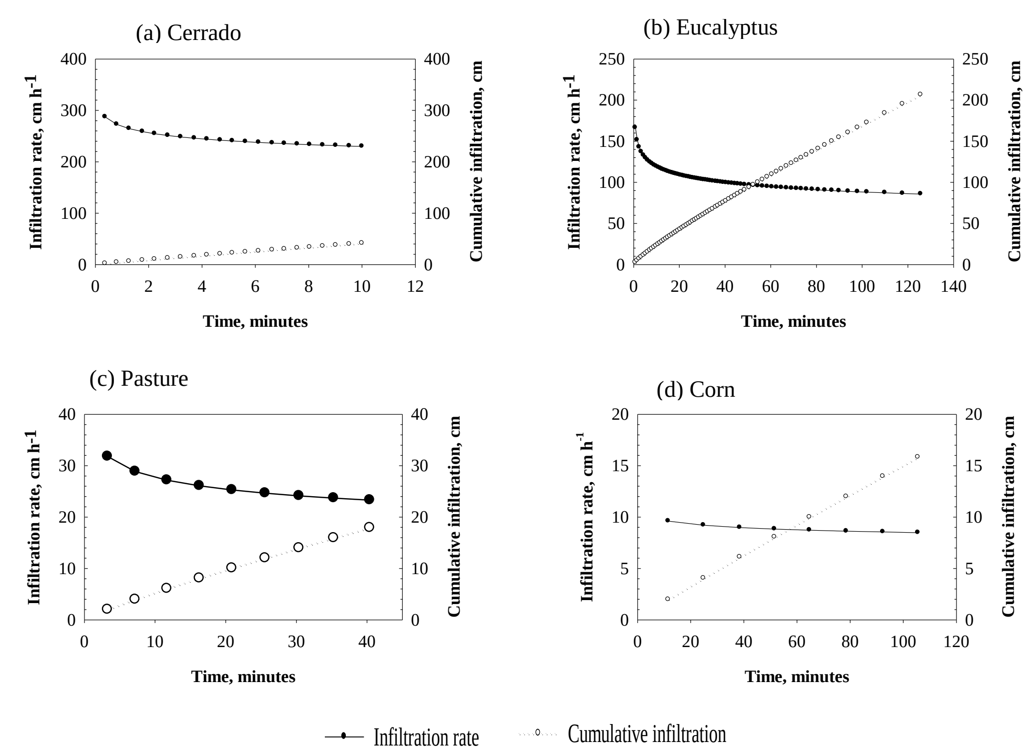

Figure 2. Kostiakov model estimated values of infiltration rate and cumulative infiltration of water into soil in use systems: Cerrado (a), eucalyptus (b), pasture (c) and corn (d).

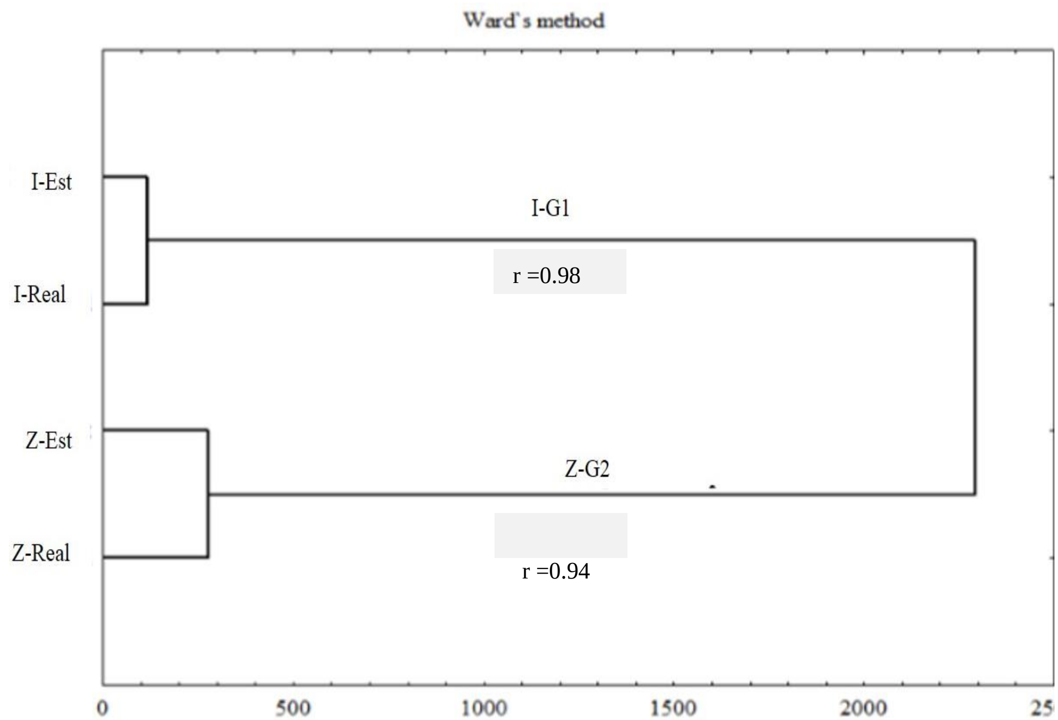

Figure 3. Cluster analysis represented by a dendrogram for the variables: infiltration rate (I) and cumulative infiltration (Z), under real (real) and estimated (Est) conditions. In the graph, r represents the Pearson correlation coefficient ($p < 0.05$).

higher infiltration rate in relation to other systems, followed by, in descending order, the areas planted with eucalyptus, pasture and corn.

3. The infiltration rate and cumulative infiltration curves, estimated by the empirical model proposed by Kostiakov, are similar to values obtained in the field.

Conflict of Interests

The authors have not declared any conflict of interests.

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