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HYDRAULIC SOIL DYNAMICS OF THE SPARSE CERRADO PHYSIOGNOMY IN CHAPADÃO DO DIAMANTE - SERRA DA CANASTRA (MG)

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Abstract

The Cerrado is characterized as an important Brazilian biome, forming strategic hydrographic basins within its territory that are significant both nationally and internationally. Despite its importance, the biome has been increasingly impacted by anthropogenic activities. In this context, this study aims to analyze and understand the physical-hydraulic characteristics of the soil in a sparse Cerrado physiognomy located in the Chapadão do Diamante (Serra da Canastra-MG), providing the necessary foundation for the assessment and development of future management strategies for similar areas. For field data prospecting, a rain simulator and a concentric ring infiltrometer were used. The results demonstrated a high infiltration capacity in the study area, with no significant surface runoff even under high-intensity precipitation (57.35 mm), revealing high values of basic infiltration velocity (BIV) at 626.56 mm/h. Overall, these values are associated with the dynamics of landscape elements, emphasizing the importance of biological processes, such as the role of vegetation and soil fauna, in modulating the soil's ability to retain, infiltrate, and store water.

Keywords: Water Infiltration; Rain Simulator; Concentric Ring Infiltrometer.

Resumo / Resumen

DINÂMICA HÍDRICA DO SOLO DE FITOFISIONOMIA DE CERRADO RALO DO CHAPADÃO DO DIAMANTE - SERRA DA CANASTRA (MG)

O cerrado caracteriza-se como importante bioma brasileiro, estruturando em seu interior bacias hidrográficas estratégicas tanto para o território nacional como internacional. Apesar de sua importância, o bioma vem sendo cada vez mais suprimido por atividades antrópicas. Neste sentido, este trabalho tem por objetivo analisar e compreender as características físico-hídricas do solo de uma fitofisionomia de Cerrado Ralo presente no Chapadão do diamante (Serra da Canastra-MG), gerando embasamento necessário para valoração e surgimento de futuras formas de manejo a áreas semelhantes. Para tal utilizou-se para prospecção de dados de campo um simulador de chuvas e um infiltrômetro de anéis concêntricos. Os resultados demostraram para área de estudos alta capacidade de infiltração, não exibindo volumes escoados superficialmente mesmo sob precipitações de alta intensidade (57,35mm), expondo altos valores de velocidade de infiltração básica (VIB) 626,56 mm/h. No geral, os valores estão associados a dinâmica dos elementos paisagísticos, destacando a relevância dos processos biológicos, como a ação da vegetação e da pedofauna na modulação da capacidade do solo em reter, infiltrar e armazenar a água.

Palavras-chave: Infiltração de Água; Simulador de Chuvas; Infiltrômetro de Anéis

DINÁMICA HÍDRICA DEL SUELO DE LA FITOFISONOMÍA DE CERRADO RALO EN CHAPADÃO DO DIAMANTE - SERRA DA CANASTRA (MG)

El cerrado se caracteriza como un importante bioma brasileño, estructurando en su interior cuencas hidrográficas estratégicas tanto para el territorio nacional como internacional. A pesar de su importancia, el bioma ha sido cada vez más afectado por actividades antropogénicas. En este sentido, este trabajo tiene como objetivo analizar y comprender las características físico-hídricas del suelo de una fitofisonomía de Cerrado Ralo presente en el Chapadão do Diamante (Serra da Canastra-MG), proporcionando la base necesaria para la valoración y el desarrollo de futuras formas de manejo en áreas similares. Para ello, se utilizó un simulador de lluvia y un infiltrómetro de anillos concéntricos para la prospección de datos de campo. Los resultados demostraron una alta capacidad de infiltración en el área de estudio, sin mostrar volúmenes significativos de escorrentía superficial incluso bajo precipitaciones de alta intensidad (57,35 mm), exponiendo valores elevados de velocidad de infiltración básica (VIB) de 626,56 mm/h. En general, estos valores están asociados a la dinámica de los elementos paisajísticos, destacando la relevancia de los procesos biológicos, como la acción de la vegetación y la pedofauna, en la modulación de la capacidad del suelo para retener, infiltrar y almacenar agua.

Palabras-clave: TInfiltración de Agua; Simulador de lluvia; Infiltrómetro de Anillos.

INTRODUCTION

The Cerrado is widely distributed throughout the national territory, consolidating itself as the second largest Brazilian biome, occupying around 24% of its extension (BOLFE et al., 2020). It is characterized by a complex and varied set of environments and vegetative communities, which together make up the phytophysiognomic mosaic of the biome, being considered the richest tropical savanna in the world in fauna and flora biodiversity. (RIBEIRO e WALTER, 1998; BOLFE et al., 2020; FERREIRA, 2023).

It is mostly distributed along the Brazilian Central Plateau, in regions with high altitudes compared to the surrounding areas, located in the central portion of the country (GOMES et al., 2004). In this sense, the geographic space occupied by the Cerrado biome plays an important role in the process of genesis and distribution of the country's water resources, consolidating itself as the area of origin of eight of the twelve largest and most important river basins in Brazil (LIMA, 2011; MARTELLI et al., 2023).

Despite its ecological importance and water security, the Cerrado is currently considered the biome with the highest current rate of devastation in Brazil (BOLSON and ARAÚJO, 2022), resulting from the process of occupation of its natural areas for the implementation of agricultural activities, which deforest and replace natural vegetation, systematizing extensive areas for agricultural planting and livestock farming (CONFESSOR, 2019; SANTOS and SANTOS, 2022).

In order to overcome this problem, it is necessary to develop research aimed at understanding how the natural landscapes of this environment function, providing the necessary subsidies to assimilate their importance, fostering the necessary bases for the development of more effective protective measures.

In this sense, the Serra da Canastra National Park houses different Cerrado phytophysiognomies within it, covering recharge zones and drainage headwaters of important river basins, such as the springs of the river basins São Francisco, Araguari, Santo Antônio, Bateias, Grande and Ribeirão Grande.

Due to its shape, geographical position and altitude, Serra da Canastra is configured as a drainage disperser, making it a watershed on the Brazilian platform, being the interfluve area of the São Francisco River hydrographic basins, which drains to the north, and Paraná, which drains to the south (SILVA et al., 2017; RODRIGUES et al., 2023).

Given its importance, this work aims to analyze and understand the physical and hydrological characteristics of Cerrado soils present in the Serra da Canastra National Park, more specifically of a Cerrado Ralo phytophysiognomy expressed in Chapadão do Diamante, producing a survey of primary data fieldwork involving the use of flood and sprinkler infiltrometers, in order to correlate the data collected with the landscape elements expressed in the area.

MATERIALS AND METHODS

In a previous study carried out in Chapadão do Diamante (Serra da Canastra-MG), Nazar and Rodrigues (2019a and 2019b) classified the region into different geocovers, subdivided according to the characteristics of the materials, topography and aerogammaspectometric data. Among the geocovers listed, the one classified as Sand-Clay-Ferruginous Materials or with Ferruginous Concretions stands out.

This class of geocover occupies 5.52% of the entire CHD area. It displays a layer of relatively deep materials, occurring predominantly in flattened reliefs or flat tops (interfluvial areas) coinciding with residual surfaces, which indicate long exposure to weathering processes in tropical climates (NAZAR, 2018).

They are characterized by areas with hydrogeomorphological conditions of relevance in the slopes of their occurrence, since they are located in the upper part of the slopes, exhibiting denser vegetation, deeper soils with a finer texture in relation to the surrounding areas (CONFESSOR, 2023) , consolidating itself as areas for capturing and redistributing precipitated water to downstream areas.

To better understand the physical and hydrological dynamics of these areas, experiments were carried out in the field on a slope positioned at a latitude of 20°14'6.76"S and longitude of 46°36'3.55"W involving two different models of infiltrometers, one being a Simulator of rain and a Concentric Ring Infiltrometer, where the tests were carried out in the period between rains in the region, with no interference from natural precipitation volumes.

The rainfall simulator used was built and calibrated for this study (CONFESSOR, 2023), which aimed to replicate high-intensity rainfall similar to those occurring in the experiment region. To this end, 46 years of precipitation data captured by the Vargem Bonita climatological station (2046013), located around the Serra da Canastra National Park, were analyzed.

Using the regression curve of the volumes of erosive rainfall in the region, an intensity of 57.4 mm/h was established, where the equipment uninterruptedly replicated 60-minute rainfall in three randomly chosen locations within the study area.

Using an erosion plot with dimensions of 70x100 cm, the data capture area was delimited, where the surface runoff volumes were collected every 5 minutes until the end of 60 minutes of simulation, totaling 12 samples per test.

Aiming to understand the maximum infiltration capacity of the soil, a semi-automatic concentric ring Infiltrometer with little variable load was used, which established a water column of 5 centimeters on the surface over the course of 3 hours of experimentation as seen in Figure 1 (CONFESSOR, 2023).

The infiltration values were captured in partial increments every 10 minutes until the end of the tests, totaling 18 samples. Using the equipment, three tests were carried out in the experiment area, with the collection points established randomly.

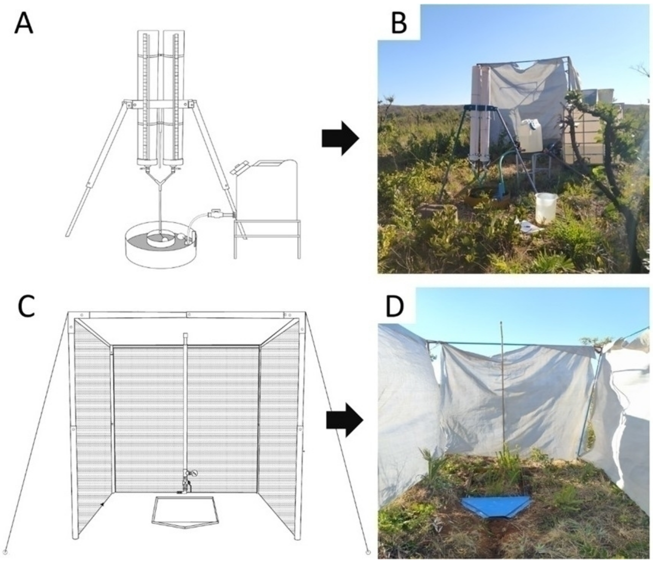


Figure 1 - Equipment used in the research. Semi-automatic concentric ring infiltrometer with little variable load (A and B); Rain simulator and wind protection (C and D). Source: The Authors.

The assessment of vegetation cover was conducted using the ENVI 4.2 software and employing the supervised classification technique. Images of the surface of the plots were captured at a height of 1 meter above the ground moments before the rain simulations. Subsequently, the images were processed to highlight the relationship between the exposed soil and that covered by vegetation (PINESE et al., 2008).

The soil in the area was classified by opening a profile, using the Brazilian soil classification system as a reference (SANTOS, 2018). To understand the physical characteristics of the soil (total density, particle density, granulometry and total porosity), samples were collected through a random choice of 4 points throughout the entire experiment area, being treated according to the manuals (EMBRAPA, 1997 and EMBRAPA, 2017).

At each point, undisturbed samples were taken from the surface (0-5 centimeters) to determine the soil's Total Density, Particle Density and Total Porosity. Deformed samples were also extracted from the subsurface at uniform intervals of 10 centimeters to a depth of 50 centimeters, necessary to understand the particle size characteristics.

The investigation of soil water loss through evaporation involved collecting three undisturbed samples from a depth of 0 to 5 centimeters using 100 cm3 volumetric rings. The samples were submerged in water for a period of 2 hours, with subsequent drainage and weighing after 1 hour. From that moment on, the samples were weighed every 24 hours over a period of six days (CONFESSOR, 2023). Water loss was monitored by the weight variation between the initial and subsequent samples.

RESULTS AND DISCUSSIONS

The slope where the study area is located is approximately 1 kilometer long, with an altitude range of approximately 80 meters. Throughout its area, it presents variations in slope, soil, microrelief and biological distribution, both vegetative and pedofauna, with seven different types of geocovers being classified between its top and bottom of the valley (Figure 2).

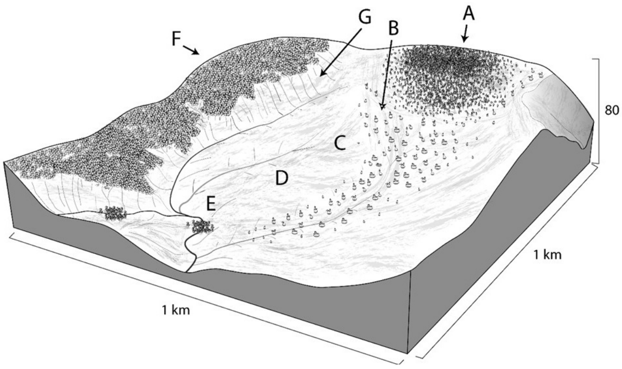


Figure 2 - Sketch of the study area located in Chapadão do Diamante – Serra da Canastra: Spatiality of research points. Sand-clay-ferruginous materials or materials with ferruginous concretions (A); Ferruginous bioturbation materials or with ferruginous concretions (murundus) (B); Gravel-sandy materials with an organic layer (C); Undifferentiated gravel-sandy materials (D); Organic materials (peatlands) associated with valley bottoms and wetlands (E); Rocky outcrops (F); Sandy gravel materials with blocky chaos (G). Source: Authors.

The geocover named Ferruginous sand-clay materials or with ferruginous concretions (FIGURE 2 A) occupies the top of the study slope, inserting itself into the watershed. It is distributed throughout an area characterized by smooth relief, with an average slope of less than 4.5%.

The vegetation of the site contrasts with the vegetation present in other geocovers (FIGURE 3), displaying a variety of species, with a wide distribution of woody plants, exposing twisted trees with an average height of 2.3 meters, interspersed abundantly with shrubs (average height 1.1 meters), herbaceous (average height of 0.5 meters in height) and grasses (average height of 0.5 meters in height), consolidating itself as a phytophysiognomy of Cerrado Ralo (RIBEIRO and WALTER, 1998).

The studies were conducted during the period between rains in the region, reflecting grasses with dry leaf and support structures. Despite this, the herbaceous, shrub and tree vegetation presented individuals with green leaves, and, in some cases, species exhibited flowering and fruits, indicating full vegetative vigor even in a period of the year characterized by rainfall water restriction.

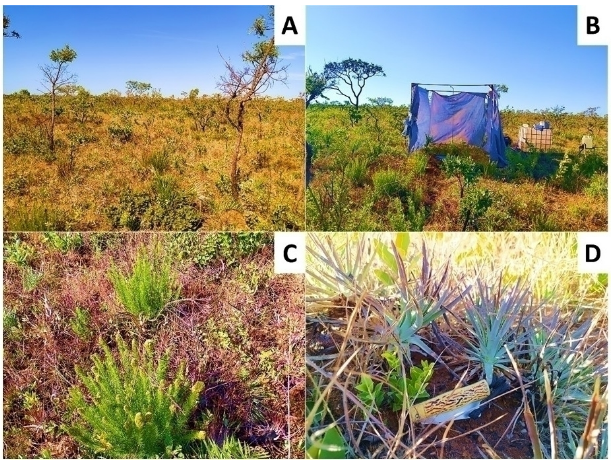


Figure 3 - Thin Cerrado vegetation present in the experiment area. Heterogeneity of plant species (A); experiment site (B); herbaceous and grass species covering the soil (C); Set of Bromeliaceae, grasses and herbaceous plants on the surface (D). Source: Authors (2023).

Through vegetative diversity and density, average values of 47.23% soil cover were found (FIGURE 4). These values refer to the forms of vegetative growth of plants, which exhibited different development habits, covering the soil in different strata, characterized by branches and leaves of arboreal plants at the top, shrubs at medium heights and grasses and herbs in the lower stratum.

These characteristics resulted in an abundant biomass, culminating in the production of a dense vegetative arrangement, with overlapping of leaf structural, reproductive and/or supporting parts, occurring within the plants themselves as well as between plants, generating reasonable soil coverage.

Despite being frequent, the lack of recent fires in the region allowed sufficient time for vegetative growth and propagation, in order to expose plants with preserved structural, leaf and reproductive parts in the area, and even some species exhibiting dry parts, still corroborated the increase in soil cover.

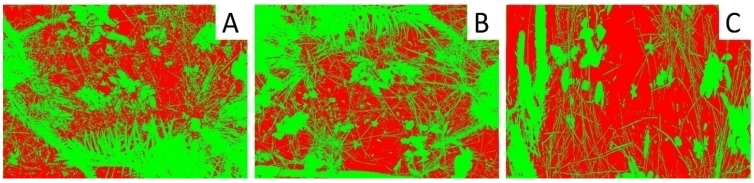


Figure 4 - Relationship between vegetation cover and soil exposed in the geocover Sand-clay-ferruginous materials or with ferruginous concretions. A- 50.04% exposed soil; B- 45.06% of exposed soil; C- 63.20% exposed soil. Source: Authors.

Classified as Typical to moderate Dystrophic Red-Yellow Oxisol, the soil at the experiment site, compared to the surrounding geocovers, was speckled, with no lithological substrate being found in prospectings 2 meters deep, being made up of fine material, composed almost entirely by particles with a diameter below 2 mm (> 99.5%), with a predominance of clays (FIGURE 5).

The granulometric curves demonstrated low variation in particle diameter along the vertical profile, which were classified by the uniformity coefficient between very uniform and moderately uniform, and by the curvature coefficient as poorly graded soil, given the predominance of particles of homogeneous caliber (FIGURE 5).

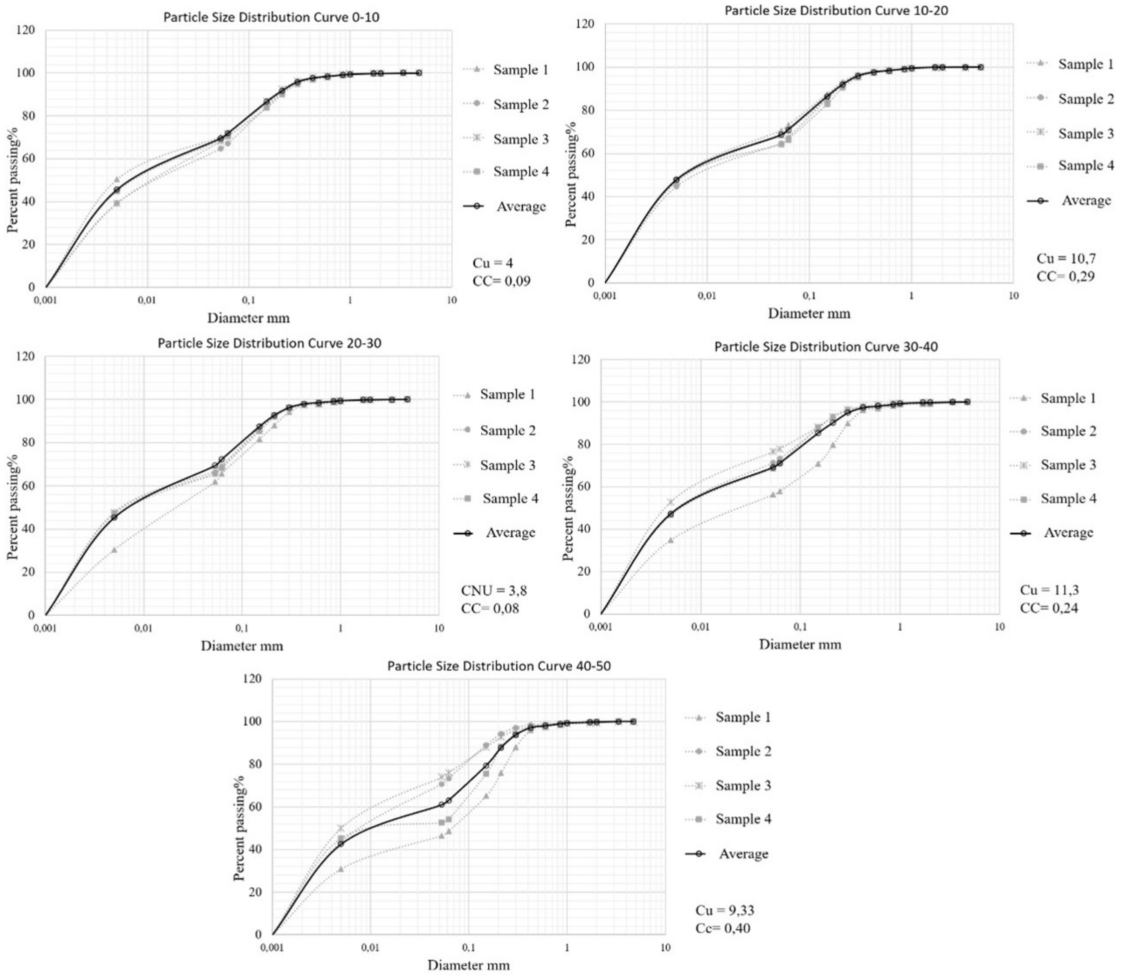


Figure 5 - Soil granulometric curves. *Cu-Uniformity Coefficient; *Cc-Coefficient of Curvature.
Source: Authors (2023).

The data produced by the ring infiltrometer revealed an initial peak infiltration speed of 931.2 mm/h for the local soil (FIGURE 6), stabilizing after 40 minutes of testing, starting to present a basic infiltration speed (VIB) average of 626.56 mm/h. Seeking to outline parameters for infiltration speeds, Bernardo et al. (2006) considered that a VIB above 30 mm/h is classified as very high, with values well above the reference parameters being found for the local soil (20.88 times higher).

In a study using the same parameters in a surrounding geocoverage, Confessor et al. (2024) found a VIB of 22.5 mm/h, a value 27.84 times smaller, indicating that the geo-environmental attributes of the location contributed to the formation of favorable conditions for water incorporation into the soil.

The variation in infiltration speed values between the beginning and end of the experiments was 33.47%, indicating that the environment has a high capacity for infiltration and percolation of water in the soil profile even when exposed for long periods to a water depth. 'constant water, presenting a correlation curve of R2 0.69 between the values found.

The experiments involving the rainfall simulator revealed constancy in the values of the runoff curve (R2 = 1), since, even when subjected to high-intensity rainfall (57.4 mm/h) the local soil did not exhibit volumes runoff over the surface, revealing its high capacity to absorb precipitated water (FIGURE 7).

No points of water pooling were observed throughout the tests, indicating that there were no favorable places for the accumulation of volumes on the surface, with a downward movement of all water in the soil profile.

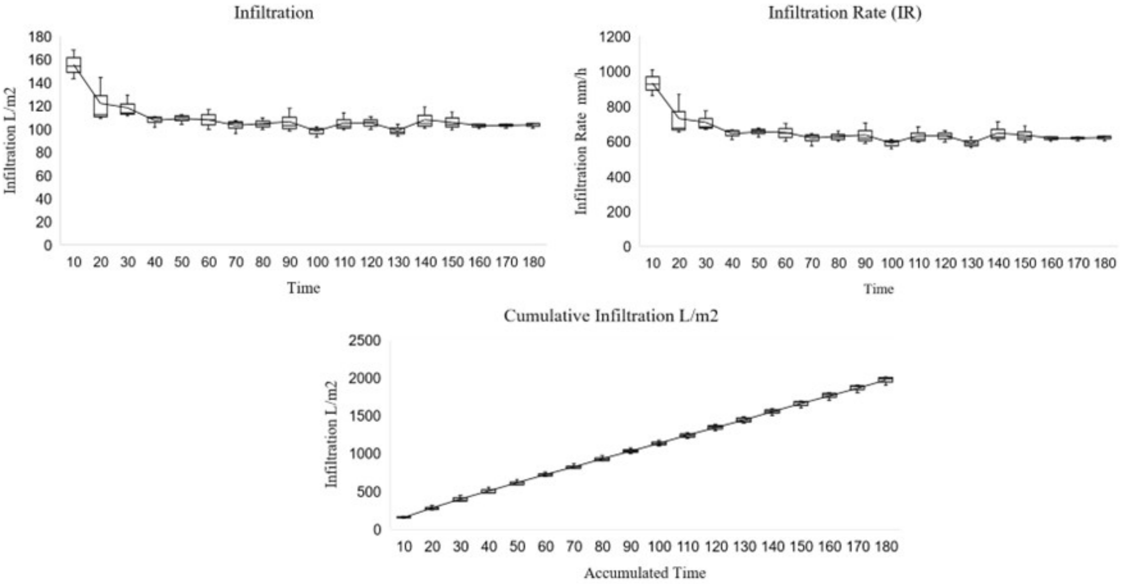


Figure 6 - Water infiltration using the Flood Infiltrometer method. Source: Authors (2023).

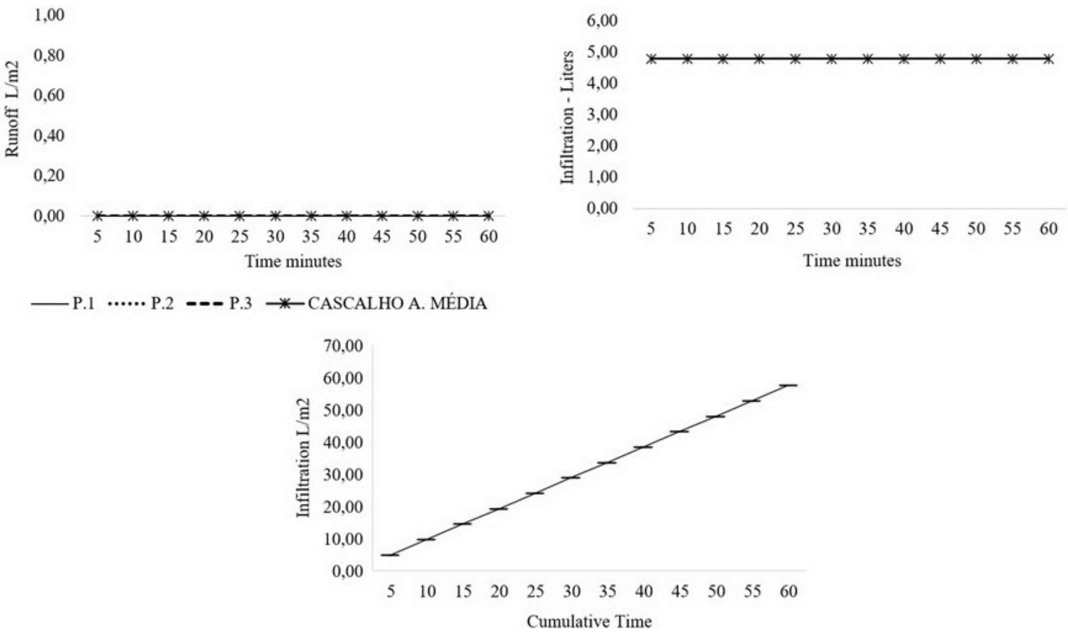


Figure 7 - Runoff and infiltration produced by the rainfall simulator. Source: Authors.

The rainfall simulator did not provide the volumes of water necessary for complete saturation of the soil to occur, so as not to allow knowledge of the volumes necessary for precipitation to promote the formation of surface water flows.

However, it is noteworthy that the local soil exhibited a basic infiltration speed well above the reference values, in order to present volumes that exceed the intensities of real precipitation, indicating the importance of using different investigation methods.

After saturation, the soil retained 0.56 ml/cm3 of water, with constant evaporation losses over time (R=0.98), with total losses of 0.44 ml/cm3 being observed over the six-day period. cm3, corresponding to 78.1% of all water retained in the soil (FIGURE 8).

The greatest losses were seen in the first 96 hours (82.8% of total volumes). Thus, the soil had a water retention capacity (WHC) of 0.12 ml/cm3 at the end of six days, that is, 21.9% of its total storage capacity.

The values found indicate that, after saturation, the soil in this environment presents a rapid restoration of its storage capacity, corroborating the retention of water from future precipitation, since the spaces necessary for the absorption of water volumes are released quickly, allowing the incorporation of new input values.

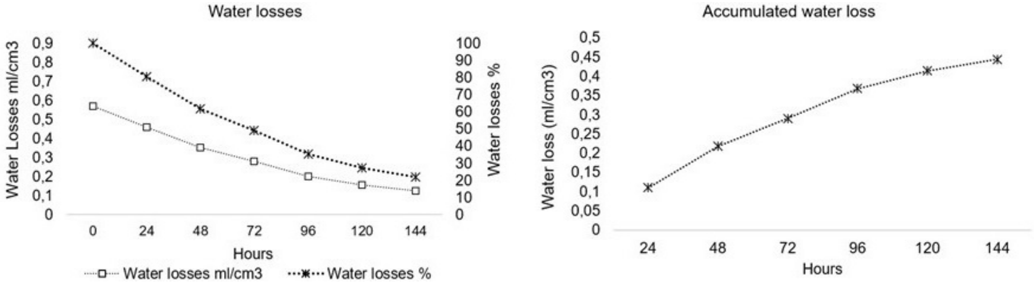


Figure 8 - Water losses through evaporation. Source: Authors (2023).

In general, the area exhibited a high capacity for incorporating water into the system, where the phytophysiognomy of the thin cerrado, composed of a varied set of plants, presented species with different forms and growth habits, which corroborated the protection of the soil surface against the action of the impacts of the drops. The heterogeneous composition of the vegetation also corroborated the occurrence of processes in the subsurface, visualized through a varied range of root systems, where different plants exposed different growth habits, depths and calibers of roots, generating a dense network of roots inside the soil. organic structures that extended from the surface to deeper horizons. When developing, roots move soil particles, helping to structure them, modifying density, contributing to an increase in porosity as well as water storage capacity, in order to increase the capacity and speed of infiltration (FIGURE 9) (LIBARDI, 1995; DIAS JUNIOR, 2000; ALVES et al., 2007, KLEIN et al., 2010;).

After entering senescence, over time the roots mineralize, generating empty spaces between soil particles, creating biopores that behave as preferential channels for water movement, contributing to increased hydraulic conductivity (FIGURE 9).

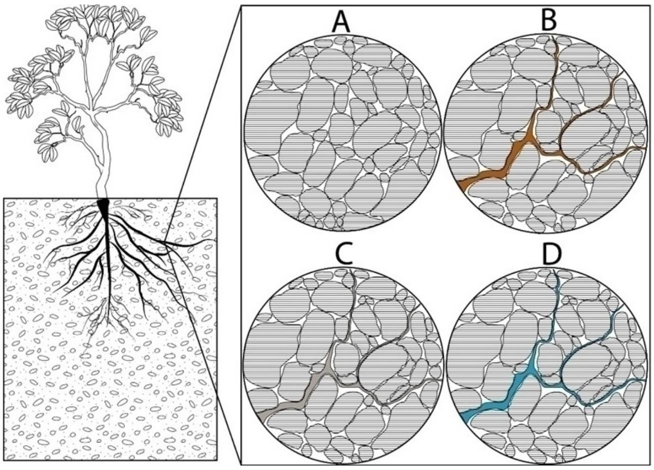


Figure 9 - Biopores in the soil generated by root growth dynamics: (A) Arrangement of soil mineral particles; (B) Rearrangement of soil mineral particles by root growth; (C) Root senescence; (D) Creation of biopores by roots and their filling by water. Source: Authors (2023).

It was also possible to observe the active presence of pedofauna at the site (FIGURE 10), composed of animals of different sizes that exhibited different forms of land use, consisting of arthropods (Termites), worms (Earthworms), larvae (Beetles), reptiles (Lizards), birds (Owl) and mammals (Armadillos).

When using environments below the surface, these animals imprint characteristics on the materials that modify the structural attributes of the soil, generating biopores through excavation, which vary in caliber, direction and extension.

Several armadillo burrows were found in abundance and scattered throughout the experiment area, with channels often exceeding 30 centimeters in diameter. Tunnels behave like large voids in the ground, capable of promoting not only the conduction of water, but also the storage of large volumes, favoring the processes of incorporating water into the profile.

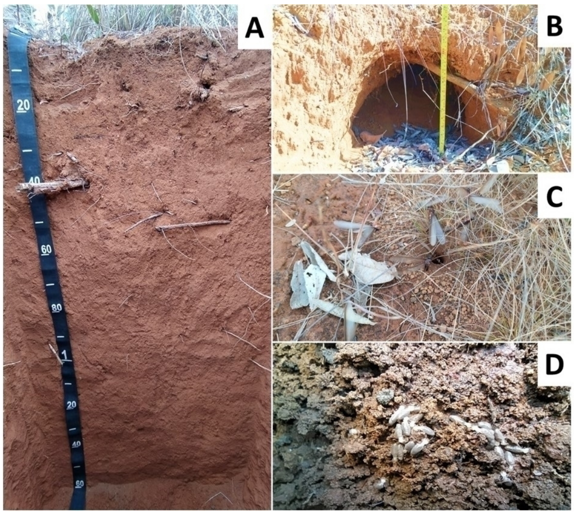


Figure 10 - Pedofauna action in the study area: (A) High density of biopores throughout the soil profile; (B) Armadillo den; (C) Winged termites emerging from a hole in the ground; (D) Termites found inside the soil. Source: Authors (2023).

The presence of termites was also verified, with a high concentration of active colonies at the site. In addition to the internal channels generated in the soil by the animals' activities, several holes on the surface were also observed throughout the experiment area, which were characterized as ducts responsible for connecting internal structures of the colonies to the soil surface.

These holes of variable diameter, often smaller than 5 centimeters, act as favorable paths for incorporating water into the soil, as they are characterized as tunnels that do not offer resistance to the movement of water, allowing the entry of volumes and the expulsion of air at the same time. present in the soil, contributing to the acceleration of infiltration processes.

Through digging habits, animals connect soil pores, generating an interconnected network of biopores and pores. This connection increases the water mobility capacity in the profile, since air and water movement paths are interconnected, producing environments suitable for infiltration and subsequent percolation of precipitated volumes (FIGURE 11).

In order to corroborate the biological action, the fine grain size of the soil, with a predominance of clay particles, contributed to the permanence of the biopores produced over time, since the colloids behave like cementing particles, increasing the longevity of the structures.

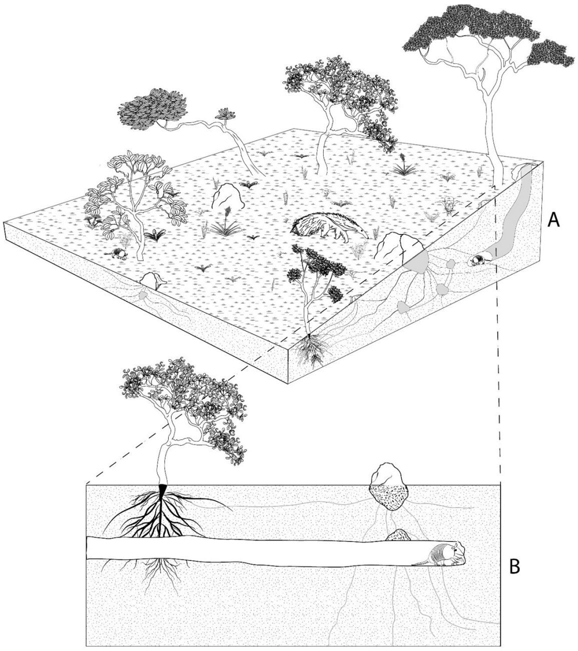
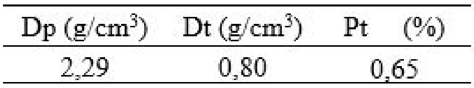


Figure 11 - Action of pedofauna in the soil profile. Creation of biopores by animals and vegetation A and B. Source: Authors (2023).

In this sense, the presence of heterogeneous vegetation, with varied abundance of pedofauna, combined with the depth and granulometric characteristics of the soil, produced a set of environmental conditions that culminated in the genesis of an environment with structured soil, with density values far below the limit critical value of 1.81g/cm3 (Dt) exposed by Reinert and Reichert (2006) (TABLE 1).



Dp (g/cm^3)	Dt (g/cm^3)	Pt (%)
2,29	0,80	0,65

Table 1 - Physical analysis of the soil; Dp- Particle density; Dt – Total density; Pt- Total Porosity. Source: Authors.

The sum of environmental characteristics reflected in the genesis of a hydrogeomorphologically dynamic environment, endowed with characteristics that allowed the acceleration of the incorporation of precipitated water into the soil, favoring the movement of infiltration, percolation and storage of water in the profile.

CONCLUSION

This study aimed to provide information on the physical-water dynamics of areas at the top of the Chapadão do Diamante (Serra da Canastra-MG), more specifically the geocover classified as sand-clay-ferruginous materials or with ferruginous concretions.

Using different field data prospecting methods (rainfall simulator and concentric ring infiltrometer), the study explored the soil's infiltration capacity, evaluated vegetation cover, analyzed soil composition and investigated water loss through evaporation.

The results indicated high water infiltration and percolation capacity in the soil, with values especially linked to the presence of a thin cerrado phytophysiognomy, which provided stratified soil vegetation cover. Vegetative diversity and density contributed to the protection of the soil surface against impacts from raindrops, reducing its surface in order to favor the incorporation of water into the soil.

In addition to the abundant presence of plant roots in the subsurface, the importance of the action of pedofauna (termites, earthworms, armadillos, etc.) in modifying the structural attributes of the soil is also highlighted. The active presence of these organisms produced the formation of biopores, characterized by preferential channels for the movement of water, interconnecting the pores and biopores already existing in the soil, in order to contribute to the increase of its hydraulic conductivity, favoring the infiltration and percolation of water. in the profile.

In summary, the results showed that the interaction between vegetation, pedofauna and soil characteristics contributed to the creation of a hydrogeomorphologically dynamic environment, with high water absorption and storage capacity, highlighting the relevance of biological processes, such as the action of pedofauna in modulating the soil's capacity to retain, infiltrate and store water.

In this sense, the importance of preserving natural areas of the Cerrado located in strategic regions, such as those at the top of slopes, is evident, as these locations have a high capacity for infiltration and retention of precipitated rainwater, even under high intensity events. Contributing to the storage of volumes and their subsequent disposal down the slope, becoming process regulatory areas.

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