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Papers

An Assessment of Water and Soil Losses in Pastures of The Brazilian Savanna Using Simulated Rainfall

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Keywords
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Abstract

Pastures occupy a large part of Brazilian national territory, being of heterogeneous characteristics and varying in climate, fertility, and management. Water erosion, generated by the action of rainfall, is a principal source of soil depletion. These soils exhibit distinct behaviors spatially and temporally. Therefore, this research aims to evaluate the water and soil losses in a pasture of the Cerrado region during two periods of the year (winter and summer) with the aim of understanding the hydro-geomorphological dynamic of the pastures in question. A rainfall simulator was calibrated at 64.34 mm/h, to replicate similar intensities to those of the study region, for 30 minutes (32.17 mm) over four erosion plots. Overall, the plots presented low water and sediment losses, with the largest runoff volumes in the summer and the highest erosion rates in winter. These results are connected to seasonal climate variations expressed in the region, which are reflected in the plant growth habits, generating alterations in the structural quality of the pastures. It follows that the return of the rainy season (winter-summer transition) represents a critical phase for the triggering of the erosive process.

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INTRODUCTION

Brazil is a world leader in cattle rearing, having a large herd for the production of meat and dairy products (USDA, 2018), most of the animals being reared on pasture in extensive farming (ARAUJO et al., 2017).

To provide support to this activity, large areas of the national territory are used in the form of pastures, which are inserted in areas that vary in size, climate, and management. Therefore, the extension and quality of the pastures are distributed heterogeneously, presenting singularities that vary within each property and between properties (CARVALHO et. al., 2006). The adoption of more assertive measures in the use of pastures may contribute to better use of such areas, protecting environmental resources and generating the possibility of increased production without the need to incorporate new areas.

Besides assisting in increased availability of food, correct management contributes to improved soil protection from the action of rainfall, since hydric erosion is one of the main contributing factors to the depletion of soils in the tropical climate (BERTONI; LOMBARD NETO, 2017), reducing its productive capacity and consequently negatively affecting its use.

Beyond breakdown and dragging of soil particles, the erosion also carry microorganisms, organic material, and mineral elements, decreasing fertility and leading to losses at the deposition sites, such as eutrophication and the silting up of water bodies (IZIDORIO et al., 2005; MARTINS FILHO et al., 2009; SOUSA et al., 2012).

Similarly to the pastures, the climate conditions also present variations between regions, showing distinct volumes of water input, which differ both spatially and temporally (CONFESSOR, 2021; DI PIAZZA et al., 2011; SAMPAIO et al., 2007). This makes it important to know the dynamic between the pastures and the rainfall arising from the local climate conditions, enabling an understanding of the processes involved to support more assertive management techniques for the protection of the soils.

Therefore, this study aimed to evaluate the water and soil losses in a pasture environment in the Cerrado region, using a rainfall simulator with the capacity to replicate high-intensity rainfall, with similar characteristics to that which occurs in the Cerrado climate. Simulations were carried out in two periods of the year (winter and summer), with the aim of understanding how the landscape changes imposed by seasonal variation can interfere in this dynamic.

MATERIALS AND METHODS

The experiments were carried out in an area of pasture on the Fazenda Experimental do Campus Glória (Experimental Farm of the Glória Campus), belonging to the Universidade Federal de Uberlândia (Federal University of Uberlândia) (UFU), in the municipality of Uberlândia-MG. The chosen area is of approximately 5 hectares (ha), subdivided into 5 pickets of approximately 1 hectare each, used for the rotation of the cattle herd and sporadically for a smaller number of horses.

The experiments were conducted in two distinct periods of the year, there being a test phase in the summer (rainy season) and another in the winter (between rains), so as to understand how the variation in the rainfall regime can generate changes in the pastures and how soil and water losses are affected at a time of frequent rains as well as at the beginning of their return.

A rainfall simulator was chosen as the equipment allows personalization of the rainfall intensity without the need to wait for the occurrence of natural events. Rainfalls of homogenous intensity were replicated in the two test periods, enabling comparison between the experiments conducted, and the procedures can be followed in more details in Confessor et al. (2022).

A mobile rainfall simulator was developed for this, being fixed in the field directly above the pasture. The equipment is 4.6 meters high and 5 meters long (Figure 1) and was calibrated to replicate rainfalls similar to those occurring in the region of Uberlândia – MG (Cerrado climate) (CONFESSOR et al., 2022; CARVALHO et al., 2020; CONFESSOR, 2019; CONFESSOR; RODRIGUES, 2018), whereby high-intensity events were adopted, as they present greater potential for the generation of losses in the environment.

Figure 1 - Rainfall simulator on Cerrado pasture. Experiments were carried out during the rainy period (summer).

Source: The authors (2019).

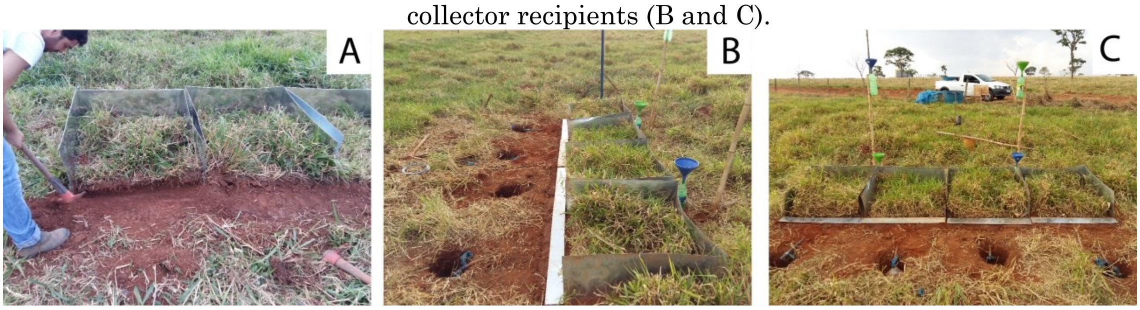
In summary, for the two test phases, the equipment replicated rainfalls of 32.17 mm, for an uninterrupted period of 30 minutes (an intensity of 64.34 mm/h). To guarantee similar humidity conditions between the test phases, pre-watering of the area was carried out 24 hours before the experiments, with a simulation of 32.17 mm for a period of 30 minutes being adopted.

To carry out the experiments, a randomized design was used to choose the test areas, with the simulator being inserted in representative areas of local conditions. To avoid counting any previous intervention, it was decided not to use the same points for the two test phases.

The volumes of water and eroded soil were accompanied through the use of four plots, each of $1m^2$, fixed in the soil below the simulator, one beside the other (CONFESSOR, 2019). The plots have the function of capturing and conducting the surface flows to a pooling gutter, enabling measurement of the volumes.

The fixation of the plots obeyed the direction of the slope (Figure 2), which had a gradient of 10% for the two phases. After installation of the plots, soil cavities were opened to house the collector recipients (Figure 2 B), being placed close to the gutters (Figure 2 C), enabling knowledge of the beginning of surface runoff (initial abstraction) and minimizing the lag between production and reading, this stage being accompanied through the use of a stopwatch.

Figure 2 - Erosion plots placed in a pasture environment. Leveling of the land for the fixation of the pooling gutters (A); installed erosion parcels and cavities in the soil for the accommodation of collector recipients (B and C).



Source: The authors (2019).

The collected volumes were measured at intervals of 5 minutes until completing 30 minutes of simulation, totaling 6 samples per plot. In each collection, the samples were homogenized and an aliquot of up to 300 ml was extracted for each plot, this being subsequently filtered in the laboratory (SILVA, 2021) to enable quantification of the sediments carried by the flow.

Analysis of the plant coverage on the plots was carried out using ENVI 4.0 software, using the supervised classification of images, which were extracted moments before the simulations through the use of a photographic camera, being subsequently treated so as to show the relationship between exposed soil and soil covered with vegetation (PINESE JUNIOR. et al., 2008).

The physical analyses of the soil were conducted at the Laboratório de Geomorfologia e Erosão de Solos (LAGES – UFU; Laboratory of Geomorphology and Soil Erosion), respecting the internal operating procedures - POP (SANTOS; RODRIGUES, 2019), in addition to the procedures in the Manual Técnico de Análise de solos (Technical Manual of Soil Analysis) (EMBRAPA, 1997).

RESULTS AND DISCUSSION

The pasture and its composition

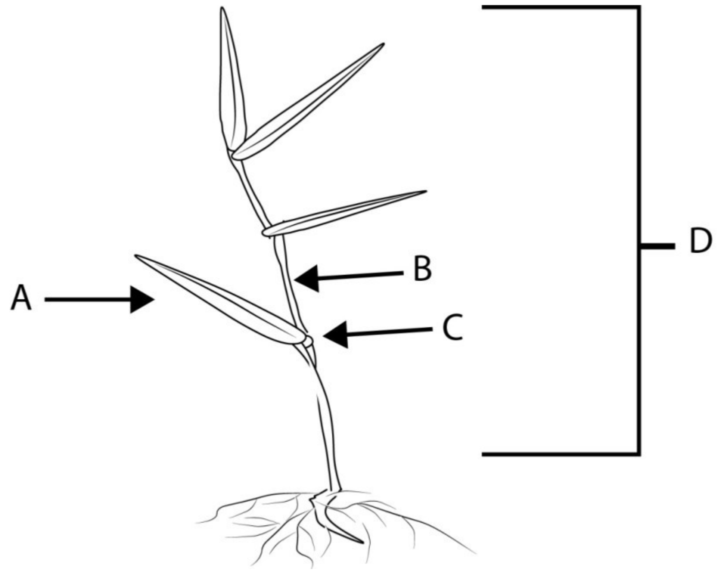
In Brazil, approximately 180 million hectares are used for the cultivation of pasture (MARTUSCELLO et al., 2009), with around 85% of this area being occupied by plants from the family *Gramineae* of the genus *Brachiaria* (FONSECA et al., 2006). The plants from this genus are found mainly in tropical regions and cover approximately 80 species (MONTEIRO et al., 1974), 8 of which are considered native to Brazil (SENDULSKY, 1977).

Their broad distribution is a reflection of their natural characteristics, presenting linear growth almost throughout the year, with a large production of dry material. These plants are adapted to various soil types, with no significant limitations concerning diseases (SEIFFERT, 1984), making them broadly used as a basis for livestock production.

They are perennial plants of cluster development and once established they may present cespitose growth habits (in which new shoots or stalks appear in clusters, generally forming a clump) or decumbent growth (after elevation, the plant hangs over the soil, where it spreads), exposing intense vegetative densification (BOGDAN, 1977).

Its structural morphology varies with each species, some of which are common constituents among grasses. In general, brachiaria have narrow, elongated leaves (Figure 3 A), fixed on a thin, cylindrical reed (Figure 3 B) through a sheath (Figure 3 C), thus characterizing the tiller (Figure 3 D).

Figure 3 – Main constituent parts of brachiaria. Narrow, elongated leaves (A); Reed (B); Sheath (C); The union of the parts constitutes the Tiller (D), this being the basic structure of brachiaria.

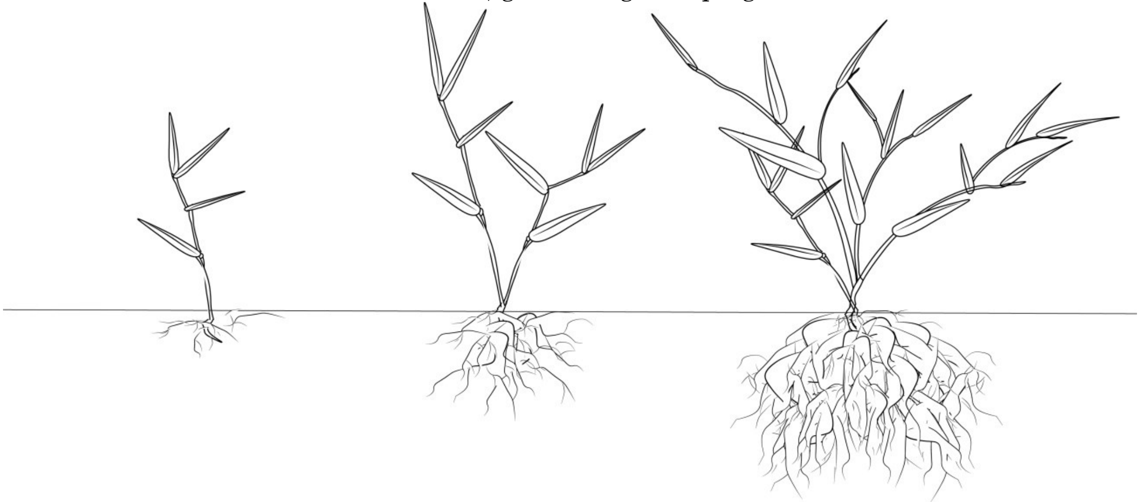


Source: The authors (2019).

Therefore, a set of different tillers in the same plant is characterized as a clump, the pastures being constituted by clusters of clumps (SANTOS et al., 2011) (Figure 4), that are variably distributed over the surface.

The rapidly established fasciculated root system acts close to the surface and at depth, its great density contributing to soil structuring processes, approximating particles and forming aggregates (BRANDÃO; SILVA, 2012).

Figure 4 - Brachiaria plant growth, aerial and root system development, with the increase of new tillers, generating clumping.



Source: The authors (2019).

There are various factors that interfere in the quality and structure of pastures. Over time, plants pass through phases that are characterized by investments in aerial or subterranean, vegetative or reproductive structures (CARVALHO et al., 2001). Therefore, the vegetative stages of the plants directly reflect the quality of their composition.

Thus, the different individuals that make up the pasture have distinct proportions of leaves, reeds, inflorescences, and dead material in the structural profile of the plants. A single pasture can have plants of different heights (SANTOS et al., 2011), be it due to conditions imposed by the soil (fertility, moisture, compaction), or to external variables such as insolation, predation, diseases, or animal defoliation, which also occurs selectively, given that different animals can present consumption preferences, attacking preferred structural parts such as leaves rather than reeds (CARVALHO et al., 2001).

The type of management also interferes in the quality of pastures, whether through the adoption of conservationist practices, the establishment of a certain quantity of animals, or the use of fertilization (ALVES, 2008). Usually, well-managed pastures have a minimum height of 20 centimeters (KICHEL N.; KICHEL G., 2001), given that up to this point there is removal through animal consumption predominantly of the plant leaves, which preserves the other structures and accelerates pasture recovery.

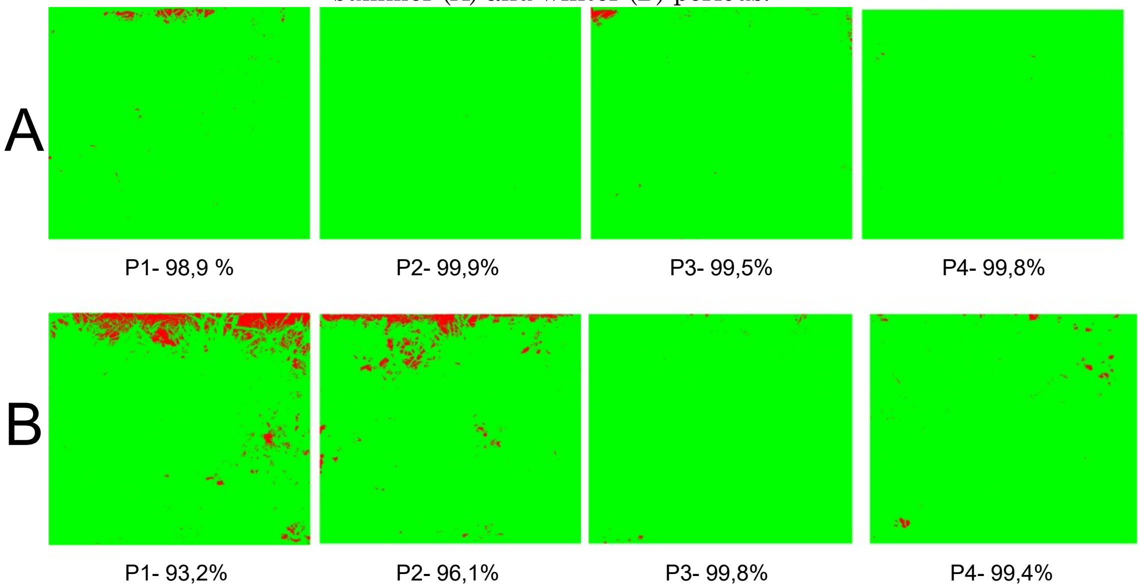
Therefore, pastures have quality and abundance variables in time and space (REAGAIN; SCHWARTZ, 1995), showing great complexity in the standardization of areas due to the number of processes capable of influencing their conditions, whether of establishment, propagation, growth, or management (CARVALHO et al., 2001).

Therefore, it is necessary to carry out an analysis of certain conditions of each pasture to guarantee an environment conducive to the maintenance of its quality and reflected in more appropriate mechanisms for soil conservation, which, in turn, is reflected in the quality of the pastures.

Characteristics of the experimental area

The pasture used to carry out the experiments demonstrated good conditions in both test periods, with soil coverage values close to totality, with a mean of 99.5 % for the rainy period and 97.12 % for the period between the rains, with respective mean plant heights of 30 and 20 centimeters (Figure 5).

Figure 5 –Assisted image treatment using ENVI software. Vegetation cover (CV) of plots for the summer (A) and winter (B) periods.



Source: The Authors (2019).

Although there was little variation in the soil coverage, there was a large change in the vegetative conditions of the plants (Figure 6). The greater availability of water during the rainy period provided favorable conditions for vegetative propagation, whereby the plants are green and with vegetative structures in full growth.

In contrast, in the period between the rains, the lower water availability led to considerable alterations in the plants' structures, limiting physiological processes and reducing leaf growth, leading to an abundance of dry leaves along the plant profiles (Figure 6 A).

Figure 6 – Alterations in the landscape promoted by changes in rainfall volumes and seasonal variations. Dry winter (A); Rainy summer (B).

Source: The authors (2019).

The soil in the experimental area had a clayey texture, and, according to the density samples, was compacted in both experimental periods (Table 1), with values above the critical level of 1.7 g cm^{-3} stipulated by Reinert and Reichert (2006) for this textural class.

Table 1 – Physical analyses of the soil in the pasture environment.

Sand (%)	Clay (%)	Silt (%)	Classification	Pd	Sd (s)	Sd (w)
34	61	5	Clayey	2.65	2.37	2.40

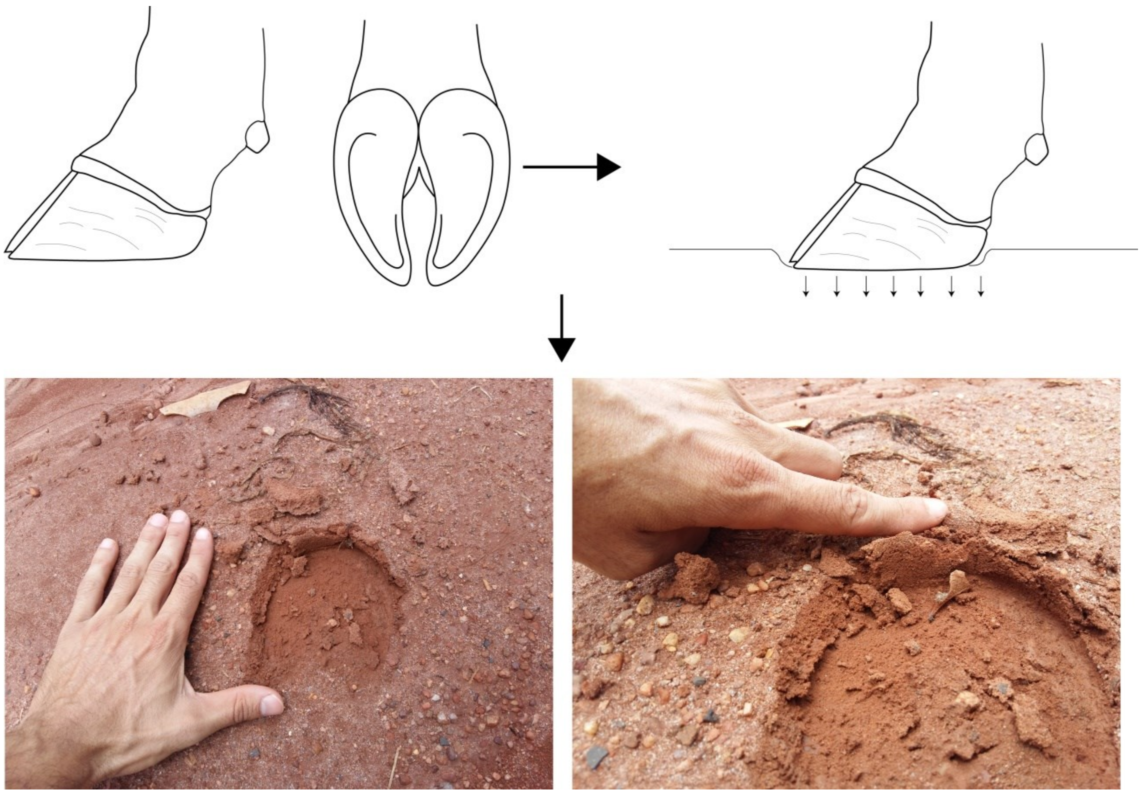
Quality of soil used for pasture. (Pd. – Particle density; Sd. – Soil density; (s) summer, and (w) winter. Source: The authors (2019).

Soil compaction is linked to the use of the area, which was used, without interruption, as pasture for a period of 15 years. Management measures aimed at improving the physical conditions of the soil were not adopted during this period of time.

Compaction was shown to result from the transit of animals in the area. The number and weights of the animals in the pasture were variable, being closely related to age, breed and management. The disposition of the animal's' weight on the soil occurs through a few support points, having contact with the surface in a reduced area of land (four legs), leading to great levels of concentrated pressure on the soil particles (MORAES; LUSTOSA, 1997) (Figure 7).

The constant action of trampling over time generates thickening of the surface particles and the consequent formation of a thin layer of compacted soil, inducing the formation of a thin layer of compacted soil (VZZOTTO et al., 2000).

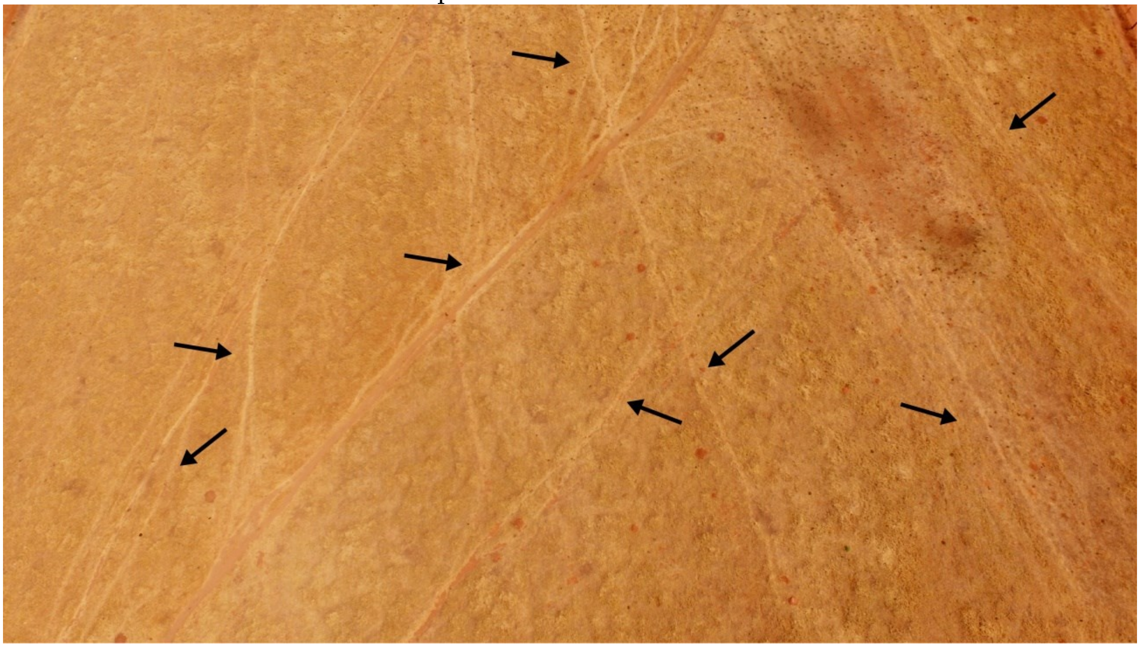
Figure 7 – Bovine hoof prints; pressure promoted by the trampling of a horse, the animal used in the herding of cattle, leading to surface soil compaction and disaggregation of the upper material in the form of clods.



Source: The authors (2019).

When moving, the animals tend to seek the most accessible routes. The constant transit over the same points of the land over time leads to preferential routes (Figure 8), known as trails, which are deprived of vegetation and are more compacted compared with adjacent areas (MARCHÃO et al., 2009), being widely found in the area of studies (Figure 8).

Figure 8 - Spatialization of the network of cattle trails under extensive management in a Brachiaria pasture environment.



Source: The authors (2019).

Experiments

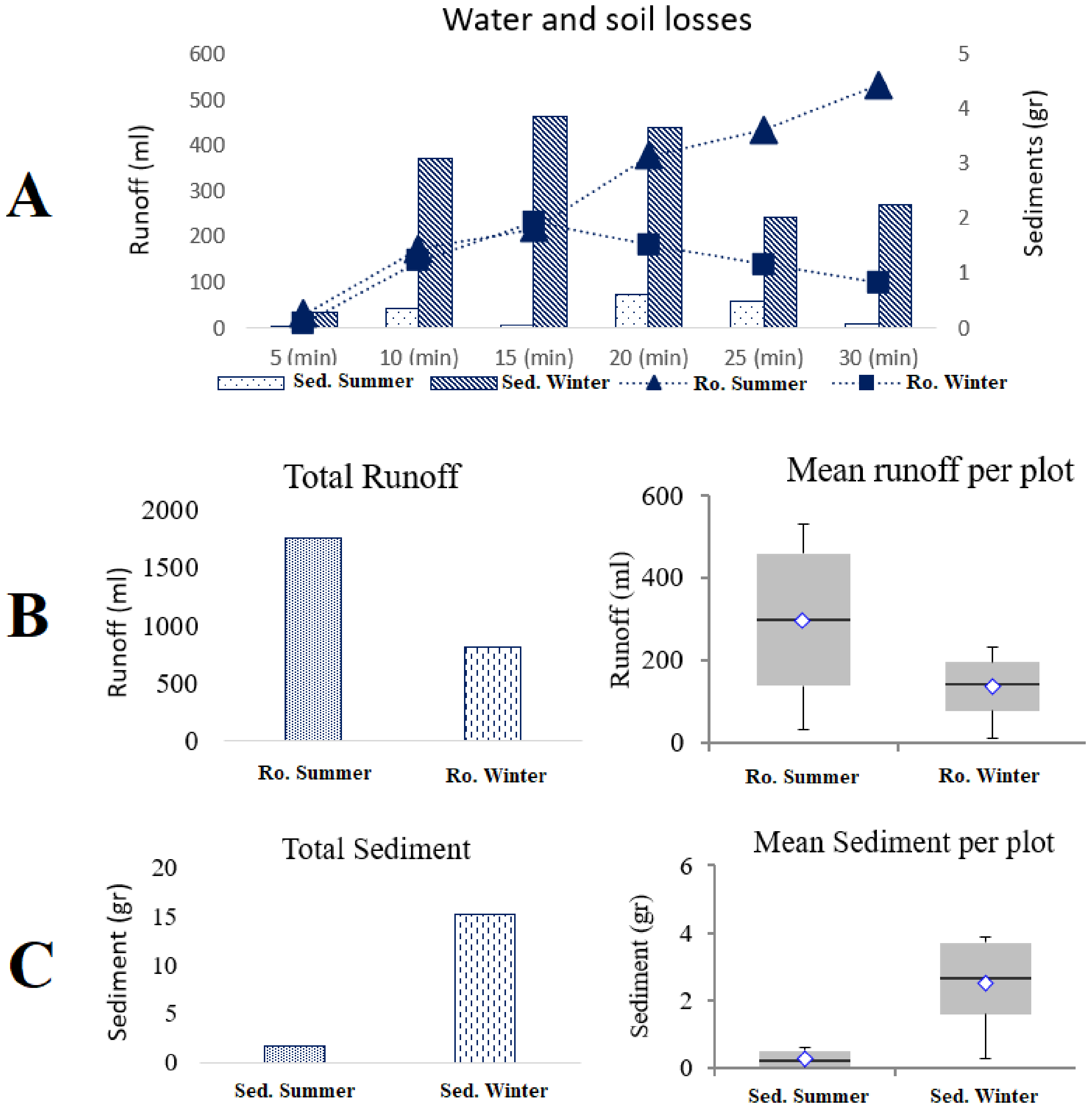
After beginning the experiments, surface runoff started at 3m23s for the summer period and 4m01s in the winter, with initial abstraction 19% higher for the second phase, being 3.6 and 4.3 liters, respectively. The production of surface flows was similar in the two seasons up to halfway through the tests, showing a correlation of r=0,98, whereby, from halfway, the surface flow in the winter started on a decreasing curve until the end of the tests (Figure 9A), leading to a low correlation of water losses between summer and winter (r=0,28).

The discontinuity of the increase in surface flow in the winter may be related to the gradual removal of particles on the surface, which may have been obstructing the soil pores. Upon being removed from the system by the drag from the flow, the surface orifices were unblocked enabling the vertical movement of water in the soil, gradually reducing surface runoff, and increasing infiltration. With this, the summer period presented a volume of superficially drained water 216% greater than the winter period.

The difference in retained water between the seasons is due to the greater rainfall absorption capacity of the soil and vegetation in the winter period. The low moisture conditions arising from a prolonged period without rainfall culminated in drier soils, which presented a higher quantity of empty spaces between the pores, guaranteeing water retention environments. Furthermore, the plants in this period also had a higher volume of dry structures, which also absorb greater volumes of water when compared to structures in full vegetative vigor, as seen in summer.

Sediment production showed a direct correlation with increased surface flow only during the winter (r= 0.95), it not being significant in the summer (r =0.35). The low correlation between the two phases (r=0.37) reflects the more accentuated production of sediments in the winter, which, even with less surface flow, showed values 932% higher than in the summer (Figure 9C).

Figure 9 – Erosion and water loss. Soil and water losses during the period of experiments (A); Water losses (B); Sediment losses (C).



Source: The authors (2019).

The greater sediment production in the winter is intimately connected to rainfall distribution in the region, given that the lower volumes in this period (PETRUCCI, 2018) lead to reduced soil moisture, increasing the quantity of disaggregated material on the surface, creating the possibility of the surface flow easily carrying away the loose particles.

Seasonal variations were observed that directly affected the quality of the pastures generating structural morphological changes in the plants according to water availability. These variations were associated with the vegetative habits of the plants and, consequently, the forms of association with rainfall.

Despite covering almost all the soil in the two test periods, soil protection occurs differently depending on the quality of the cover material, whereby drier material has less capacity to conduct flows in its internal structures, given that the structures are twisted and/or closed, as in the case of the leaves, offering less contact area with the precipitation.

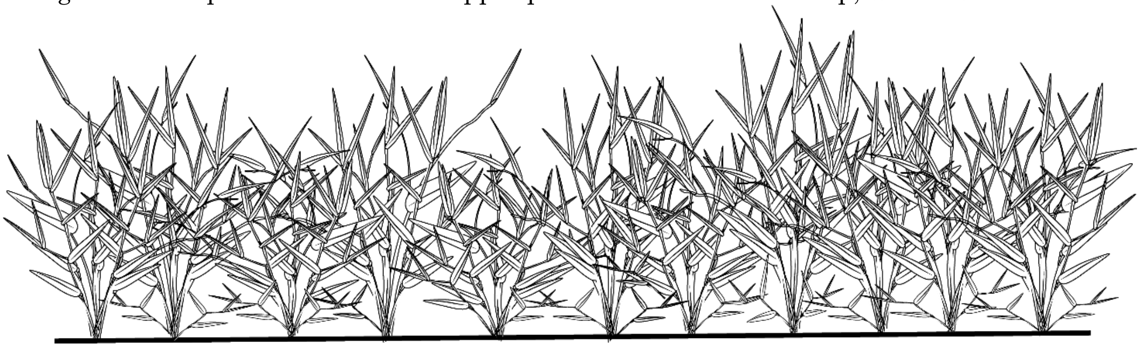
It was also observed that some dry structures of the plants, after being moistened by precipitation, bent over and/or joined to each other, reducing the contact surface and thus the protection of the soil. This allowed, at certain times, the direct passage of raindrops to the soil, resulting in its disaggregation and consequently generating greater losses of sediment (Figure 9).

However, it was noted that for the two test phases there was significant water retention in the system, being 94.5% for the summer (30.4 liters) and 97.4% for the winter (31.3 liters) (Figure 10B). Sediment losses were reduced from those found under cropping, being 16.3 kg/ha in summer and 151.9 kg/ha in winter.

Plant morphology and growth habits also corroborate for the low formation of surface flows, producing good soil coverage. After the establishment of the pasture, the emergence and chaotic growth of the tillers (Figure 10), leads to the structuring of a dense vegetative layer in various strata, contributing to kinetic energy dissipation of raindrops through direct contact with the vegetative structures of the plants.

The growth of the plants as they developed structurally along vertical and horizontal profiles, produced compositions of arrangements in the plants themselves as well as overlapping structures with the surrounding plants, creating more effective protection of the soil (Figure 10).

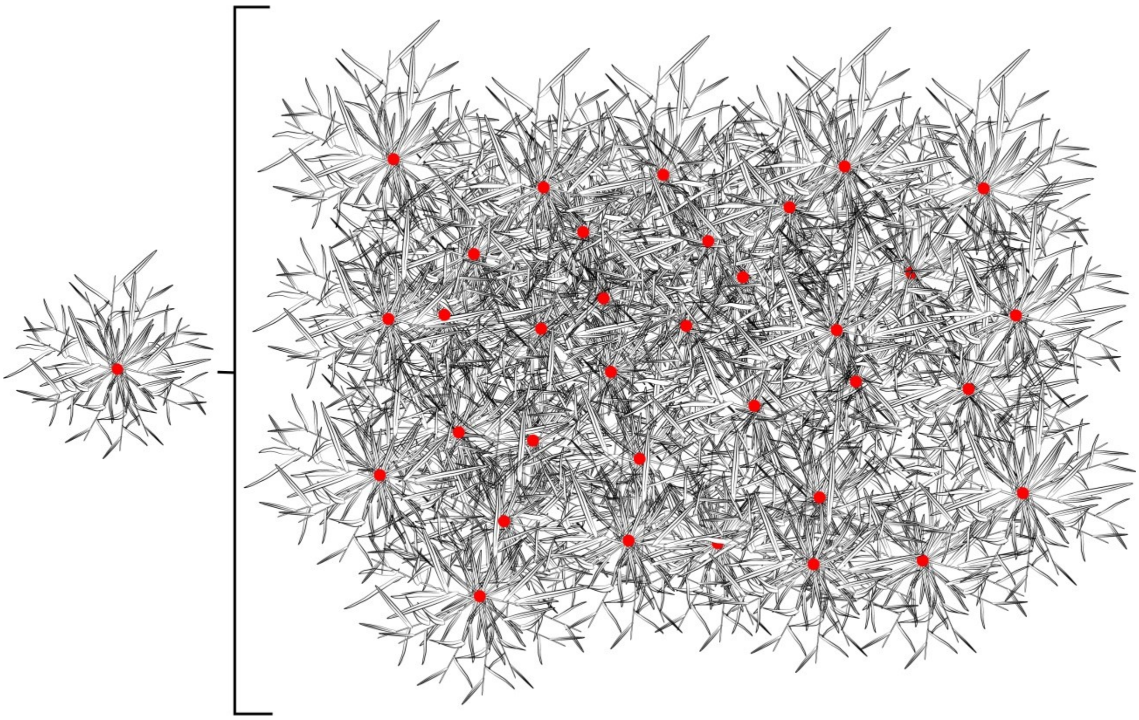
Figure 10 - Representation of the upper part of a Brachiaria clump, with several tillers.



Source: The authors (2022).

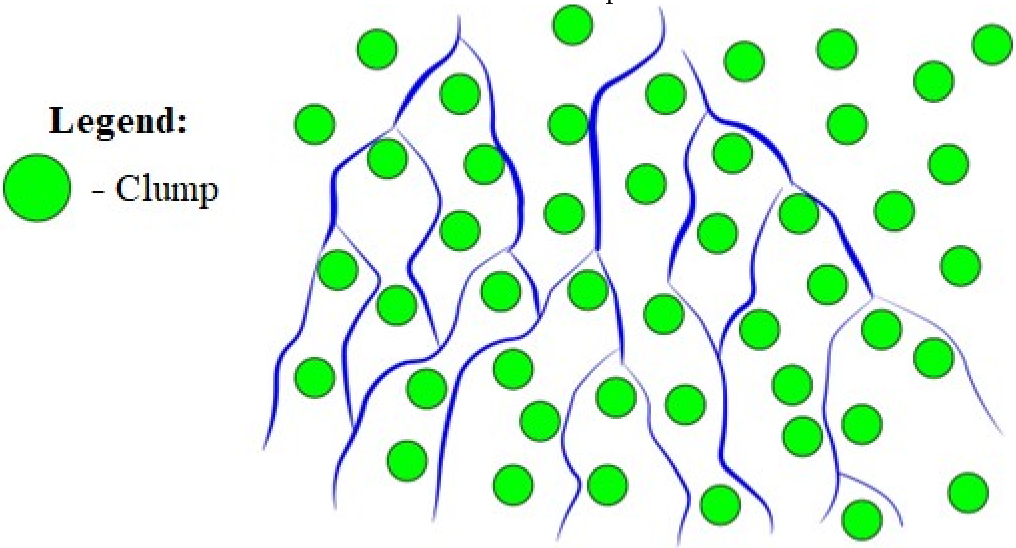
In addition, growth in clumps contributed to the diffusion of water flow over the surface. The random establishment of clumps generated natural barriers reducing surface flow (Figure 11). The clumps acted to diffuse and absorb the kinetic energy of the water movement, helping to lower erosive power and contribute to increased infiltration (Figure 12).

Figure 11 – Aerial view of a hypothetical Brachiaria pasture with the optimal establishment. Random spatialization of the clumps on the surface.



Source: The authors (2019).

Figure 12 - Aerial view of the location of Brachiaria clumps in the pasture environment. Disordered spatialization of the clumps contributed to the decentralization of the surface flows, segmenting it into various parts.



Source: The authors (2019).

FINAL CONSIDERATIONS

Through this study, it is concluded that pastures have a series of conditioning factors that vary in time and space, their quality being a product of management measures, age, climate, soil, and intensity of use. These factors influence characteristics of density, biomass, and coverage, which, in turn, directly reflect on soil protection.

The variation of the seasons of the year expressed in the Cerrado environment directly affected the input of water into the system, producing a seasonal landscape alteration that shows distinct behavior before the action of the rainfall. The rainfall variation between summer and winter led to structural changes in the pastures' plants, limiting physiological processes and altering the growth rate and habits of the plants.

There was no great variation in soil coverage between the two test phases; however, it was noted that the quality of the coverage was inferior during the winter period, whereby the plants had a greater volume of dry structures, with closed and twisted leaves, exposing less contact surface for raindrops.

The surface runoff water volumes in the two seasons are distinct, be it in behavior or volume. A linear increase in the volumes was found for the production curves until the end of the tests for the summer period, and a linear decrease from halfway through the test was found for the winter.

Sediment production also demonstrated variation between seasons, with greater quantities being collected in the winter. This may be because, in this period, in addition to presenting a greater amount of unconsolidated material on the surface, plants demonstrated lower vegetative vigor and had been more foraged. This made the subsequent period of rainfall a more favorable phase for the creation of liabilities related to soil erosion.

This study verified that brachiaria plants have structures and growth habits that help protect the soil and consequently retain water in the system. The dense propagation between the plants leads to an overlap of vegetative structures between the individuals, interweaving branches and covering the soil.

The experiments conducted demonstrated that well-managed pastures assist in increasing the structural quality of the vegetation, which contributes to better soil protection, becoming an act of mutual benefits, offering greater volumes of food to the animals, and guaranteeing greater longevity of the resources.

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AUTHORS' CONTRIBUTION

Jefferson Gomes Confessor conceived the study, carried out experiments, collected, analyzed the data and wrote the text. Lara Luíza Silva analyzed the data and wrote the text. Paula Meirilane Soares de Araújo analyzed the data and wrote the text.