Quantification of water, soil and nutrient losses in the Farinha river basin, Carolina - MA, in the Cerrado biome

Quantificação das perdas de água, solo e nutrientes na bacia hidrográfica do rio Farinha, Carolina - MA, no bioma Cerrado

Cuantificación de las pérdidas de água, suelo y nutrientes en la cuenca del río Farinha, Carolina - MA, en el bioma Cerrado

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Cristiane Matos da Silva
Master in Dam Engineering and Environmental Management
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brazil
E-mail: cristiane.silva@uemasul.edu.br

Luciana Gomes de Brito
Graduate in Agronomic Engineering
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brasil
E-mail: lucianabrito.20200002951@uemasul.edu.br

Matheus Matos Araújo da Silva
Graduating in Agronomic Engineering
Instituição: Universidade Federal Rural do Rio de Janeiro
Address: Seropédica, Rio de Janeiro, Brazil
E-mail: matossilva39@gmail.com

Antonio Expedito Ferreira Barroso de Carvalho
Master in Forest Sciences
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brazil
E-mail: expebarroso@uemasul.edu.br

Joaquim Paulo de Almeida Júnior
Master of Science in Education
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brazil
E-mail: joaquimjunior@uemasul.edu.br

Marcelo Francisco da Silva
Doctor in Biology of Infectious and Parasitary Agents
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brazil
E-mail: silvamf@uemasul.edu.br

Wilson Araújo da Silva
Doctor in Agronomy - Soil Science
Institution: Universidade Estadual da Região Tocantina do Maranhão
Address: Imperatriz, Maranhão, Brazil
E-mail: wilson@uemasul.edu.br

Jurandir Pereira Filho
Doctor in Ecology and Natural Resources
Institution: Universidade do Vale do Itajaí
Address: Itajaí, Santa Catarina, Brazil
E-mail: jurandir@univali.br

ABSTRACT

Natural resources, such as soil and water, play a crucial role in sustaining life on Earth. When used appropriately, these resources can mitigate environmental impacts. However, inadequate soil management practices can result in negative effects, such as the intensification of erosion processes and significant losses of soil, water and nutrients essential for plant growth. Thus, considering that the Farinha River basin - MA is located in the Cerrado biome and has a large part of its area occupied by highly erodible soils, the aim was to quantify water, soil and nutrient losses using a rainfall simulator. The experimental design adopted was entirely randomised (DIC), in a bifactorial scheme with 5 replications. Factor 1 considered two types of soil management systems (Anthropised Area and Non-Anthropised Area), while factor 2 involved three simulated rainfall intensities ($80mm.h^{-1}$, $110mm.h^{-1}$ and $130mm.h^{-1}$). The response variables assessed were losses of water, soil and nutrients and organic matter.The averages were subjected to analysis of variance and, if significant, the Tukey test was applied at 5% probability using Past 4.03 software. The results indicated significant losses of soil, water and nutrients associated with both the soil management system and the rainfall intensities, as well as making it possible to quantify the nutrients lost in runoff water on site. The conclusion is that the combination of inadequate soil management practices and intense rainfall can exacerbate erosion processes and the leaching of macro and micronutrients, resulting in an increasing need to incorporate fertilisers and correctives into agroforestry activities. Furthermore, it is important to emphasise that water erosion also contributes to an increase in soil and nutrient loss, which can lead to adverse environmental impacts, such as contamination of water resources and degradation of soil quality.

Keywords: Soil Management. Watershed. Erosion. Rainfall Simulator.

RESUMO
Os recursos naturais, tais como solo e água, desempenham um papel crucial na sustentabilidade da vida na Terra. Quando utilizados de maneira apropriada, esses recursos podem mitigar os impactos ambientais. Contudo, práticas inadequadas de manejo do solo podem resultar em efeitos negativos, como a intensificação dos processos erosivos e perdas significativas de solo, água e nutrientes essenciais ao crescimento das plantas. Desse modo, considerando que a bacia hidrográfica do rio Farinha - MA localiza-se no bioma Cerrado e, apresenta grande parte de sua área ocupada por solos de alta erodibilidade, objetiva-se quantificar as perdas de água, solo e nutrientes, utilizando um simulador de chuva. O delineamento experimental adotado foi inteiramente casualizado (DIC), em um esquema bifatorial com 5 repetições. O fator 1 considerou dois tipos de sistemas de manejo do solo (Área Antropizada e Área Não Antropizada), enquanto o fator 2 envolveu três intensidades de chuvas simuladas (80mm.h-¹, 110mm.h-¹ e 130mm.h-¹). As variáveis respostas avaliadas foram as perdas de água, solo e nutrientes e matéria orgânica. As médias foram submetidas à análise de variância e, em caso de significância, foi aplicado o teste de Tukey a 5% de probabilidade utilizando o software Past 4.03. Os resultados indicaram perdas significativas de solo, água e nutrientes associadas tanto ao sistema de manejo do solo, quanto às intensidades de precipitação, além de possibilitar a quantificação in loco dos nutrientes perdidos na água do escoamento superficial. Conclui-se que a combinação de práticas inadequadas de manejo do solo e chuvas intensas pode exacerbar os processos erosivos e a lixiviação de macro e micronutrientes, resultando na necessidade crescente de incorporação de adubos e corretivos nas atividades agrossilvipastoris. Além disso, é importante ressaltar que a erosão hídrica também contribui para o aumento da perda de solo e nutrientes, podendo acarretar impactos ambientais adversos, como a contaminação dos recursos hídricos e a degradação da qualidade do solo.

Palavras-chave: Manejo do Solo. Bacia Hidrográfica. Erosão. Simulador de Chuva.

RESUMEN
Los recursos naturales, como el suelo y el agua, desempeñan un papel crucial en el mantenimiento de la vida en la Tierra. Cuando se utilizan adecuadamente, estos recursos pueden mitigar los impactos ambientales. Sin embargo, las prácticas inadecuadas de gestión del suelo pueden tener efectos negativos, como la intensificación de los procesos de erosión y pérdidas significativas de suelo, agua y nutrientes esenciales para el crecimiento de las plantas. Así, considerando que la cuenca del río Farinha - MA está situada en el bioma del Cerrado y tiene gran parte de su área ocupada por suelos altamente erosionables, el objetivo fue cuantificar las pérdidas de agua, suelo y nutrientes utilizando un simulador de precipitaciones. El diseño experimental adoptado fue totalmente aleatorizado (DIC), en un esquema bifactorial con 5 repeticiones. El factor 1 consideró dos tipos de sistemas de manejo del suelo (Área Antropizada y Área No Antropizada), mientras que el factor 2 involucró tres intensidades de lluvia simuladas (80mm.h-¹, 110mm.h-¹ y 130mm.h-¹). Las variables de respuesta evaluadas fueron las pérdidas de agua, suelo y nutrientes y materia orgánica. Las medias se sometieron

a análisis de varianza y, en caso de ser significativas, se aplicó el test de Tukey al 5% de probabilidad utilizando el software Past 4.03. Los resultados indicaron pérdidas significativas de suelo, agua y nutrientes asociadas tanto al sistema de gestión del suelo como a las intensidades de precipitación, además de permitir cuantificar los nutrientes perdidos en el agua de escorrentía in situ. La conclusión es que la combinación de prácticas inadecuadas de gestión del suelo y precipitaciones intensas puede exacerbar los procesos erosivos y la lixiviación de macro y micronutrientes, lo que se traduce en una creciente necesidad de incorporar fertilizantes y correctores en las actividades agroforestales. Además, es importante destacar que la erosión hídrica también contribuye a aumentar la pérdida de suelo y nutrientes, lo que puede tener efectos medioambientales adversos, como la contaminación de los recursos hídricos y la degradación de la calidad del suelo.

Palabras clave: Gestión del Suelo. Cuencas Hidrográficas. Erosión. Simulador de Precipitaciones.

1 INTRODUCTION

Natural resources are essential for life on planet Earth (Facco *et al*., 2021). However, poor management of these resources can have a negative impact on the environment (Freitas, Manzatto, Coutinho, 2001; Castro Filho *et al*., 2002; Confessor, 2019). And, one of the most investigated environmental problems is soil erosion, which leads to the loss of soil and nutrients, causing flooding, silting of rivers and water pollution (Panachuki *et al.,* 2006; Wang *et al.,* 2016).

The rate of erosion is related to the physical properties of rainfall, such as intensity, droplet diameter and kinetic energy, and characterising these properties is fundamental for planning conservation agriculture (Santos L. *et al.,* 2018; Machado *et al.,* 2008). Rainfall simulators are used to determine soil erosion. They apply water by sprinkling in a similar way to natural precipitation, allowing data to be collected and soil and water losses to be quantified (Carvalho *et al.,* 2005; Carvalho *et al.,* 2012).

The use of rainfall simulators is advantageous because it makes it possible to determine the time, intensity and repetitions of rainfall, which is impossible under real conditions. In addition, these simulators allow researchers to introduce the desired rainfall pattern, generating data that is closer to reality (Confessor, 2019). One example of a simulator is the portable infiltrometer developed by Alves Sobrinho (1997), which reproduces simulated rainfall with characteristics similar to those of natural rainfall.

Most studies using rainfall simulators are carried out on soils with higher clay contents, such as LATOSSOLOS, ARGISSOLOS and NITOSSOLOS (Oliveira *et al.,* 2015). However, this study focuses on QUARTZARENIC NEOSSOLO soils, which are poorly evolved soils with a sandy texture and low clay concentration (Santos H. *et al.,* 2018). The Farinha river basin in Maranhão is largely occupied by highly erodible soils, which makes this study even more important.

Therefore, the aim of this study is to quantify the loss of water, soil and nutrients in the Farinha River Basin using a rainfall simulator. This research aims to provide information for the development of management and conservation strategies for natural resources in the region, in order to reduce soil erosion and protect watercourses from pollution caused by the loss of soil and nutrients. By understanding these processes, it will be possible to implement appropriate management measures to mitigate the negative impacts of erosion and guarantee the environmental sustainability of the region.

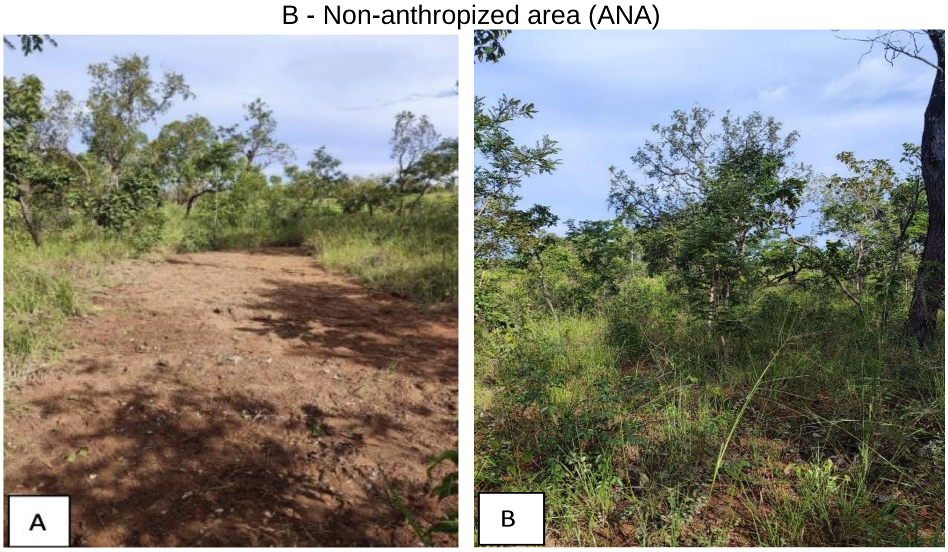
2 MATERIAL AND METHODS

The study was conducted in the Farinha River basin, on a rural property in the municipality of Carolina - MA, between the coordinates 6°53'38.95"S and 47°25'48.07"O. The soil was classified as QUARTZARENIC NEOSSOLO and has an average slope of 4.34% in the experimental area. The climate, according to the Köppen-Geiger climate classification, is characterised as tropical (AW'), with two well-defined seasons: the rainy season, from November to May, and the dry season, from June to October.

Two areas were used to estimate the loss of water, soil, organic matter and nutrients: the Anthropised Area (AA), where the vegetation cover was re-moved, and the Non-Anthropised Area (ANA), where the natural vegetation was preserved (Figure 1). In each area, ten soil samples were collected at a depth of

0 cm to 20 cm and sent for analysis to a certified soil laboratory. Following the experiment, a portable rainfall simulator developed by Alves Sobrinho *et al.* (2008) was used. This consists of a device equipped with Veejet 80-150 sprinkler nozzles, installed at a height of 2.30 metres, duly levelled in relation to the ground with the aid of a bubble level, which generates drops of 2 mm in average diameter, under a pressure of 5 psi, with its sides protected by tarpaulins against the action of the wind. It also uses a 1 hp motor pump that sucks water from a drum with a maximum capacity of 250 litres. The equipment's data collection area consists of a rectangular device made from galvanised steel sheets measuring 0.7 m wide by 1.00 m long (0.70 m²), allowing the volume of water drained in this area to be collected (Figure 2).

Figure 1. Detail of the simulator's data collection areas. A - Anthropized area (AA) and B - Non-anthropized area (ANA)



Source: Prepared by the authors themselves.

Figure 2. Rainfall simulator. (A) Detail of the simulator and the 0.70m² experimental plot and (B) Detail of the simulator prepared for data collection.

Source: Prepared by the authors themselves.

To simulate rainfall in the field, rainfall intensities determined using the heavy rainfall equation (Da Silva & Pereira Filho, 2024) were used, with a duration of 30 min and return times of 5 years, 25 years and 100 years, in order to determine water erosion in the field. To do this, the device was calibrated to apply rainfall intensities of 80 mm.h^{-1}, 110 mm.h^{-1} and 130 mm.h^{-1}. The rainfall application time was defined based on the Erosivity Index (EI30), with the rainfall applied over a maximum time of 30 minutes, considered from the start of surface runoff, where each collection lasted two minutes, with intervals of four minutes between them, totalling 6 samples collected. The runoff samples were collected in the simulator's gutter and the volume was read using a beaker, which was then placed in 1-litre plastic bottles. During use of the equipment, the working pressure was constantly checked (5 psi) and calibrated when necessary. At the end of each repetition, the actual intensity of the rain applied was checked. The kinetic energy of the applied rain was calculated using the EnerChuva computer programme developed by Alves Sobrinho *et al.* (2001).

At the end of the field trials, the collected and duly identified samples were taken to the Irrigation, Hydraulics and Hydrology Laboratory (LIHH) at the Agricultural Sciences Centre (CCA) of the State University of the Tocantins Region of Maranhão (UEMASUL) for measurements of the mass of soil and drained sediment. In the laboratory, the six samples from each repetition were weighed on a precision scale to obtain the mass of water plus sediment, and the values were entered into a spreadsheet for subsequent calculation of water loss ($L.ha^{-1}$) (Equations 1, 2 and 3).

$$PA_p = (M_1 - M_2) - \overline{Pg} \qquad \text{Eq. 01}$$

$$PA_{mean} = \frac{\sum R_n}{6} \qquad \text{Eq. 02}$$

$$PS_{total} = ((PS_{mean} * 10.000) / 0,70) / 1000 \qquad \text{Eq. 03}$$

Where:

PA_P = Water loss in the plot per bottle collected (mL);

M_1= Mass of water + Sediment + bottle (g);

M_2= Sediment + Filter (g);

$\overline{Pg}$ = Average weight of twelve empty bottles (g);

$AP_{average}$ = Average of the water loss values in the plot over an area of 0.70 m^2 (rainfall simulator data collection area) ($mL.m^{-2}$);

$\sum R_n$ = Sum of the water loss values in the plot per bottle collected (g);

PS_{total} = Total water loss ($L.ha^{-1}$).

The samples were then taken to the Ecology and Limnology Laboratory at the Center for Exact, Natural and Technological Sciences (CCENT) of the State University of the Tocantins Region of Maranhão (UEMASUL) to be filtered using a vacuum pump with a 47mm diameter filter and a pore size of 0.45 µm. Initially, these filters were identified and weighed on a precision scale, dried in an oven at a temperature of 60ºC for 3 hours and weighed again on a precision scale. Both values were entered into a spreadsheet so that soil loss ($g.ha^{-1}$) could later be determined (Equations 4,5 and 6).

$$PS_p = M_2 - Tara \qquad \text{Eq. 04}$$

$$PS_{mean} = \frac{\sum R_n}{6} \qquad \text{Eq. 05}$$

$$PS_{total} = (PS_{mean} * 10.000) / 0,70 \qquad \text{Eq. 06}$$

Where:

PS_P = Soil Loss in the plot per bottle collected (g);

M_2= Sediment + Filter (g); Tara = Weight of filter without sediment (g);

PS_{mean} = Average of the soil loss values in the plot over an area of 0.70 m² (rainfall simulator data collection area) ($g.m^{-2}$);

$\sum R_n$ = Sum of the values of soil loss in the plot per bottle collected (g);

PS_{total} = Total soil loss ($g.ha^{-1}$).

Subsequently, the samples were filtered in a vacuum pump with the filters already identified and weighed. After filtering, the filters were placed in petri dishes and taken to an oven at 60°C for 24 hours to quantify the soil losses. After 24 hours, these filters were weighed and their masses duly recorded in a spreadsheet. After weighing, the same filters were placed in a muffle furnace at 550ºC for a period of 4 hours to determine the organic matter (Equations 7, 8, 9, 10 and 11, respectively).

$$PF_{\text{before the muffle}} = (PCS_{\text{with filter}} - PCS_{\text{No filter}}) \qquad \text{Eq. 07}$$

$$PF_{\text{after the muffle}} = (PF_{\text{before the muffle}} - PCS_{\text{No filter}}) \qquad \text{Eq. 08}$$

$$MO = (PF_{\text{before the muffle}} - PF_{\text{after the muffle}}) \qquad \text{Eq. 09}$$

$$PMO_{mean} = \frac{\sum R_n}{6} \qquad \text{Eq. 10}$$

$$PMO_{total} = ((MO_{mean} * 10.000) / 0,70) / 1000 \qquad \text{Eq. 11}$$

Where:

$PF_{\text{before muffle}}$ = Filter weight before going into muffle (g);

$PCS_{\text{with Filter}}$ = Weight of dry crucible with filter (g);

$PCS_{\text{Without filter}}$= Weight of Dry Crucible without filter (g);

MO = Organic Matter on filter (g);

$\sum R_n$ = Sum of the organic matter values in the filter per bottle collected (g);

PMO_{mean} = Average of the Organic Matter loss values in the plot over an area of 0.70 m² (rainfall simulator data collection area) ($g.m^{-2}$);

PMO_{total} = Loss of Total Organic Matter ($g.ha^{-1}$).

A 30 mL aliquot of the water filtered through the vacuum pump was used to determine the nutrients present in the runoff. To this aliquot was added 300 µL of hydrochloric acid (HCl). After preparing the samples, they were read on the Shimadzu ICP-9000 Multipoint Emission Plasma Spectrometer (EPA 6010B) located in the Environmental Chemistry Laboratory at CCENT/UEMASUL, where the nutrient results were recorded on a spreadsheet so that the loss of each nutrient could later be determined in ($g.L^{-1}.ha^{-1}$) (Equations 12, 13 and 14, respectively).

$$PNut. = \frac{PNut\ ICP}{1000} \quad \text{Eq. 12}$$

$$PNut_{mean} = \frac{\sum R_n}{6} \quad \text{Eq. 13}$$

$$PNut_{total} = ((PNut_{mean} * 10.000) / 0{,}70) / 1000 \quad \text{Eq. 14}$$

Where:

$PNut.$ = Nutrient loss ($g.L^{-1}$);
$PNut\ ICP$ = Nutrient loss read by ICP ($mg.L^{-1}$);
$PNut_{mean}$ = Average of the nutrient loss values in the plot over an area of 0.70 m² (rainfall simulator data collection area) ($g.L^{-1}m^{-2}$);
$\sum R_n$ = Sum of nutrient loss values per bottle collected ($g.L^{-1}$);
$PNut_{total}$= Total nutrient loss ($g.L^{-1}.ha^{-1}$).

The experimental design adopted was completely randomized (DIC), in a bifactorial scheme with 5 repetitions. Factor 1 consisted of 2 types of soil management systems (Anthropized Area and Non-Anthropized Area) and factor 2 consisted of 3 types of simulated rainfall intensities ($80mm.h^{-1}$, $110mm.h^{-1}$ and $130mm.h^{-1}$). The response variables evaluated will be losses of water, soil, nutrients and organic matter. The averages obtained were subjected to analysis of variance and, if significant, the Tukey test was applied at 5% probability using the Past 4.03 computer package.

3 RESULTS AND DISCUSSIONS

The soil samples collected in the field were sent to the Soil Analysis Laboratory in Goiânia - GO and the results obtained were compared to the values recommended for interpreting Embrapa's soil fertility analysis (Sobral *et al.*, 2015), as can be seen in Table 1.

Table 1. Comparison of soil analysis values in the anthropized area and the non-anthropized area with the reference values used to interpret soil analysis results.

	Non-anthropised area	Anthropised Area	Embrapa Reference Values (2015)	Classification
Phosphorus (P) (mg.kg-¹)	1.19	1.24	0 - 10	LOW
Clay (g.kg-¹)	30.00	30.00	< 150	ARENOSA
Organic Matter (g.kg-¹)	9.02	6.61	< 15	LOW
pH	4.51	4.67	< 5.0	LOW
Aluminium (Al) (cmolc.kg-¹)	0.36	0.31	< 0.5	LOW
Calcium (Ca) (cmolc.kg-¹)	0.15	0.10	< 1.6	LOW
Magnesium (Mg) (cmolc.kg-¹)	0.13	0.07	< 0.4	LOW
Potassium (K) (cmolc.kg-¹)	0.05	0.04	< 30	LOW
Eff. CEC (cmolc.kg-¹)	0.70	0.56	< 2.0	LOW
CEC (pH 7.0) (cmolc.kg-¹)	2.25	1.96	< 5.0	LOW
Base saturation (V) (%)	15.73	12.68	< 50.0	LOW
Percentage of exchangeable sodium (PST) (%)	1.33	1.54	< 6.0	LOW
Aluminium saturation (m) (%)	49.67	55.67	30 - 50 > 50	MEDIUM HIGH

Source: Prepared by the authors themselves.

Based on this comparison, it was possible to observe that, in the anthropized area and in the non-anthropized area, the soil fertility indices were considered low for organic matter (M.O), phosphorus (P), pH, aluminum (Al), potassium (K), magnesium (Mg), calcium (Ca), effective cation exchange capacity (eff. CEC), cation exchange capacity (CEC) (pH 7.0); in the sum of bases (V) and in the percentage of exchangeable sodium (PST) (PST = (Na^+/potential CEC) *100). Aluminum saturation (m) was the only factor that differed in terms of concentration, being considered medium in the non-anthropized area and high in the anthropized area.

The average value for aluminum saturation (m%) in the unmanaged area can be explained because in this area the values for organic matter (M.O) (9.02 $g.kg^{-1}$), cation exchange capacity (CEC) (pH 7.0) (2.25 $cmolc.kg^{-1}$), effective cation exchange capacity (CEC ef.) (0.70 $cmolc.kg^{-1}$) and phosphorus (P) content (1.19 $mg.kg^{-1}$) were slightly higher than the values found in the anthropized area (M.O = 6.61 $g.kg^{-1}$; CTC (pH 7.0) = 1.96 $cmolc.kg^{-1}$; CTC ef. = 0.56 cmolc.kg-¹; P = 1.24 $mg.kg^{-1}$). And although the pH of the non-anthropized area (4.51) was more acidic than that of the anthropized area (4.67), the values of M.O, P, CTC (pH

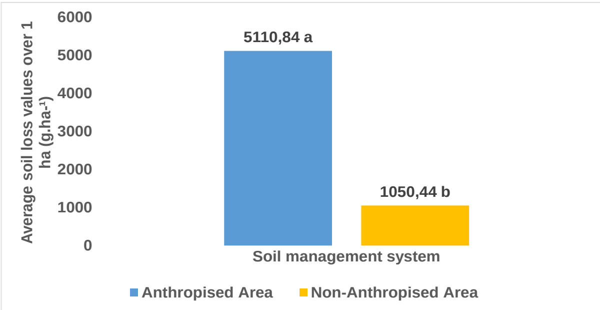
7.0), and CTC eff. contributed to the aluminum saturation in the non-anthropized area (49.67%) being average when compared to the anthropized area (55.67%). Another factor that should be taken into account is that in these areas (anthropized and non-anthropized) there is no history of any type of soil correction with plastering or liming.

Sousa *et al.* (1985) and Conceição, Ruggieri and Silva (2014) report that acidity correction is necessary to obtain better crop productivity and lower fertilizer losses. And that aluminum toxicity and low calcium and magnesium levels are characteristic of most soils under Cerrado vegetation. In addition, the organic matter, phosphorus and micronutrient levels in QUARTZARENIC NEOSSOLS are very low, and nitrate leaching is intense due to their essentially sandy texture, in agreement with Almeida, Zaroni and Santos (2021), corroborating the results found in this study.

Knowing the potential for soil erosion is important for understanding environmental problems, as it allows us to identify the practices that most contribute to soil preservation and/or conservation (Sousa and Paula, 2019). In addition, before surface runoff, some of the fine soil particles can occupy the soil's pore spaces and cause it to become waterproof, reducing its infiltration capacity (Oliveira, 2019). In this sense, when using the EnerChuva programme developed by Alves Sobrinho *et al.* (2001), as a function of rainfall intensity (Ip), to determine the ratio between the kinetic energy of the rainfall produced by the rainfall simulator (EcSimulator) and the kinetic energy of natural rainfall (EcNatural), it was obtained that the ratio between the kinetic energies corresponded to values of 91.69%, 89.30% and 88.10%, respectively for rainfall of 80mm.h^{-1}, 110mm.h^{-1} and 130mmh^{-1}, demonstrating the efficiency of standardising water application in the surface runoff portion of the rainfall simulator. These values for the ratio between EcSimulator and EcNatural are above the minimum value required for the use of rainfall simulators, which is 75 per cent, according to Meyer and McCune (1958). The average data on soil loss (g.ha^{-1}), water loss (L.ha^{-1}) and organic matter loss (g.ha^{-1}) were subjected to statistical analysis for a factorial experiment to see if there was an interaction between the two soil management systems (Anthropized Area and Non-Anthropized Area) and the three rainfall intensities (80 mm.h^{-1}; 110

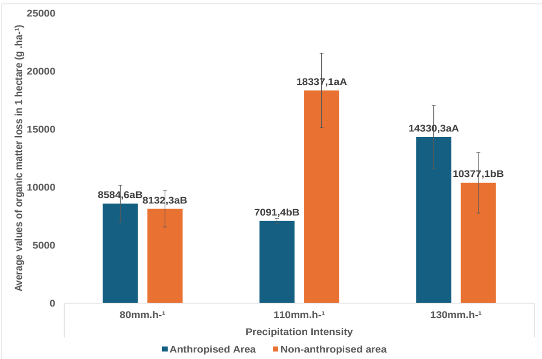
mm.h^{-1} and 130 mm.h^{-1}) simulated. This analysis showed that for soil loss (g.ha^{-1}) only the management system was statistically significant (Figure 5) and for water loss (L.ha^{-1}) (Figure 6) and organic matter loss (g.ha^{-1}) (Figure 7) there was an interaction between the management system and rainfall intensities, making it necessary to carry out the Tukey test at the 5% probability level.

Figure 5. Average values of the treatments (g.ha^{-1}) made with the rainfall simulator for soil loss in a 1 ha area.



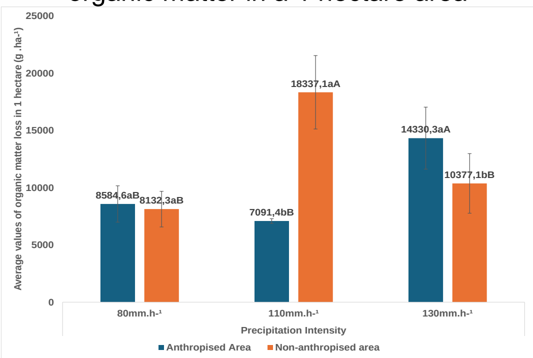
Source: Prepared by the authors themselves.

Figure 6. Average values of the treatments (L.ha^{-1}) made with the rainfall simulator for water loss in a 1ha area.



Source: Prepared by the authors themselves.

Figure 7. Average values of the treatments (g.ha^{-1}) made with the rainfall simulator for loss of organic matter in a 1 hectare area



Source: Prepared by the authors themselves.

The results of this study indicate that soil loss is significantly higher in Quartzene Neosols in the anthropised area than in the non-anthropised area. The presence of soil cover was essential in reducing erosion and sediment production. Previous studies by Santos *et al.* (2000), Silva *et al.* (2005), Santos *et al.* (2009), Carvalho *et al.* (2009) and Santos *et al.* (2012) also confirm this relationship between soil cover and soil and sediment loss.

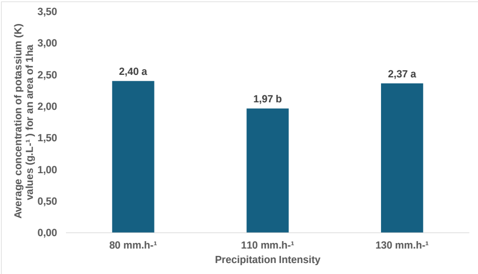
This study also showed that for water loss, the soil management system and rainfall intensities also influence the higher water losses in anthropised areas, indicating that simple manual weeding of the soil can result in significant water losses, which can aggravate erosion processes, nutrient loss and water contamination by pesticide residues. Dechen *et al.* (2015), in an area with LATOSSOLO VERMELHO distroférrico and a high altitude tropical climate (Cwa), obtained results of a reduction in water loss of 51.97% and soil loss of 54.44% in areas with vegetation cover, compared to areas without cover. Silva *et al.* (2023) state that soils covered with maize straw and biomanta reduced water loss by 81.22% and 67.42% respectively, corroborating the results found in this study.

The loss of soil organic matter is also an important factor in erosion and the eutrophication of drainage water (Oades,1984; McGregor *et al.,*1990 and Schaefer *et al.,* 2002). The loss of organic matter occurs at different stages of the erosion process, from the impact of raindrops to the deposition of water with soil residues in lower areas of the land (Schumacher, Hoppe, 1999). In this study, it was observed that the intensity of rainfall is directly related to the loss of organic matter, regardless of the type of soil management.

Macronutrients and micronutrients are essential for the healthy development of plants, and their absence in the soil requires the incorporation of chemical or organic fertilisers. This practice must be carried out in a sustainable manner, with a view to preserving the environment and improving plant quality (Alcântara, 2024). Therefore, with the results of the average values of the macronutrients (Potassium (K), Calcium (Ca), Magnesium (Mg) and Sodium (Na))and the micronutrient (Copper (Cu)) obtained in $g.L^{-1}.ha^{-1}$, in the anthropized area and the non-anthropized area when they were subjected to rainfall intensities of $80mm.h^{-1}$; $110mm.h^{-1}$and $130mm.h^{-1}$for a runoff time of 30 minutes, carried out using the rain simulator and analyzed using the Shimadzu ICP-9000 Multipoint Emission Plasma Spectrometer (ICP-AES) (EPA 6010B), a statistical analysis was carried out for the factorial experiment to check for interaction between the two soil management systems and the three simulated rainfall intensities, considering an area of 1 ha.

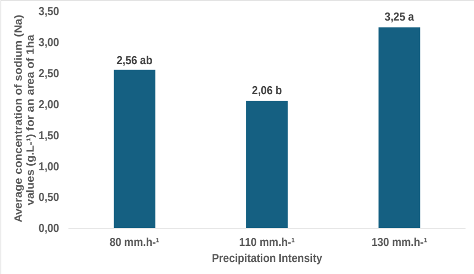
The result of the statistical analysis for Potassium (K) and Sodium (Na) showed that only rainfall intensity was statistically significant, making it necessary to carry out the Tukey test at the 5% probability level (Figure 8 and Figure 9).

Figure 8. Average concentration of potassium (K) values ($g.L^{-1}.ha^{-1}$) to assess the influence of simulated rainfall intensities.



Source: Prepared by the authors themselves

Figure 9. Average concentration of sodium (Na) values ($g.L^{-1}.ha^{-1}$) to evaluate the influence of simulated rainfall intensities.



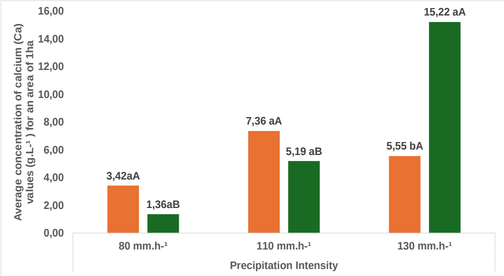
Source: Prepared by the authors themselves

Analysing the runoff water obtained with the rainfall simulator revealed that regardless of rainfall intensity, potassium losses occur in the soil, with the greatest losses of this nutrient being observed at intensities of $80mm.h^{-1}$ and $130mm.h^{-1}$. The solubility of potassium is a determining factor in losses in suspension, which have been shown to be greater than losses in sediment (Oliveira *et al*., 2010). Potassium is an essential macronutrient for plants, helping to conserve water levels and transport nutrients (Sitio Pema, 2020). Therefore, losses due to water erosion result in a large financial loss due to the need to replace it with fertilisers and lime, increasing the cost of crop production (Alfsen *et al*., 1996; Dos Santos *et al*., 2007).

According to Freire *et al.* (2014) and Lins (2020), the presence of sodium salts in the soil can result in structural problems, such as reduced permeability to air and water, negatively affecting crop production and increasing erosion processes. Matos *et al.* (2013) and Andreguetto *et al.* (2014) state that high rainfall intensities result in a higher concentration of sodium ions, due to their weak potential to compete with other cations present in the soil. These studies are in agreement with the results obtained, which show that the highest average sodium concentration occurs at a rainfall intensity of 130 $mm.h^{-1}$, followed by a rainfall intensity of 80 $mm.h^{-1}$, demonstrating similarity to the results obtained in the potassium analysis. This indicates that these rainfall intensities can have a significant impact on the leaching of sodium and potassium from soils.

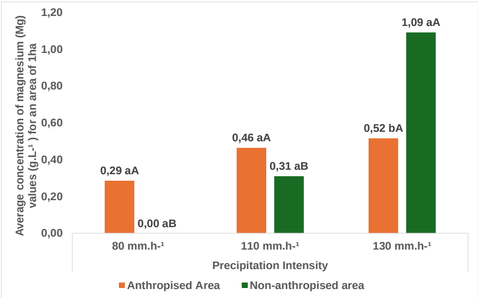
The result of the statistical analysis for Calcium (Ca) and Magnesium (Mg) showed that the interaction between the management systems and the rainfall intensities was statistically significant, making it necessary to carry out the Tukey test at the 5% probability level (Figure 10 and Figure 11).

Figure10. Average concentration of calcium (Ca) values (g.L-¹.ha-¹) to assess the influence of simulated rainfall intensities.



Source: Prepared by the authors themselves

Figure 11. Average concentration of magnesium (Mg) values (g.L-¹.ha-¹) to assess the influence of simulated rainfall intensities.

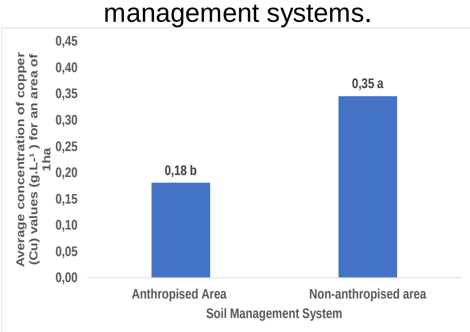


Source: Prepared by the authors themselves

Rainfall intensity and soil management have a significant impact on calcium and magnesium loss. More intense rainfall results in greater calcium loss, with 130mm.h^{-1} being the most pronounced. In addition, anthropised areas, which suffer human interference, show greater calcium losses due to rainwater run-off. This indicates that manual weeding negatively influences calcium loss, requiring the incorporation of this nutrient through liming. Adding calcium to the soil in large quantities during liming and removing it through erosion also accelerates soil re-acidification (Schick *et al*., 2000); Bertol *et al*.,2003; Pinheiro, 2013). As for magnesium loss, the highest average is related to rainfall intensity of 130mm.h^{-1}, and the anthropised area also contributes to intensifying this loss. Corroborating this study, Rios *et al.* (2008) state that acidic soils have low concentrations of calcium and magnesium, even though these elements are abundantly present in different soil materials. Soil management is a determining factor in the transport of ions such as sodium, magnesium and calcium, with more cultivated soils having a higher transport load (Andreguetto *et al.,* 2014).

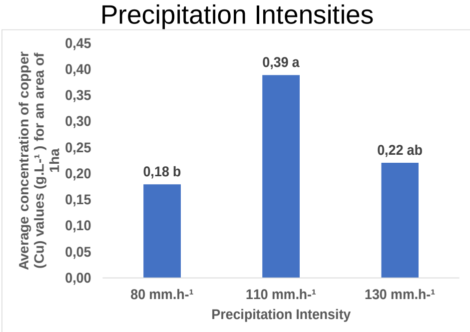
The result of the statistical analysis for copper (Cu) showed that the soil management system (Figure 12) and rainfall intensity (Figure 13) were statistically significant, requiring Tukey's test at the 5% probability level.

Figure 12. Average values of copper (Cu) loss ($g.L^{-1}ha^{-1}$) to evaluate the influence of soil management systems.



Source: Prepared by the authors themselves

Figure 13. Average values of Copper (Cu) loss ($g.L^{-1}ha^{-1}$) to evaluate the influence of Precipitation Intensities



Source: Prepared by the authors themselves

It was observed that the greatest loss occurred in the non-anthropised area, due to the higher organic matter content present in this area. Copper is an element with low availability in cerrado soils and its availability depends on factors such as pH, texture and organic matter content (Sfredo *et al*., 1997; Couto, Klamt, 1999; Lopes, 1999; Hansel; Oliveira, 2016). The ideal pH for copper availability is between 5.0 and 6.5, and organic soils have a greater potential for copper loss, while clay soils retain more of the element (Ferreira, 2003; Dias dos Santos *et al.*, 2021). In relation to rainfall, the highest concentration of copper occurred at an intensity of 110mm.h^{-1}. This can be explained by the fact that this intensity of rainfall was collected during a dry period in the region of the study area, which results in a greater input of nutrients and, consequently, a greater loss of copper (Haag, 1985; Castro, 2023).

4 CONCLUSIONS

It was concluded that the use of the rainfall simulator highlighted the delicate relationship between inadequate soil management practices and intense rainfall, increasing erosion processes and the loss of soil nutrients. This highlights the growing need to apply fertilisers and correctives in agroforestry activities.

As for the soil's natural fertility, both areas showed low levels of several essential nutrients, such as organic matter, phosphorus and pH. There was also greater aluminium saturation in the anthropised area, highlighting the urgent need for soil acidity correction and nutrient supplementation to improve fertility and increase agricultural productivity.

It is also important to emphasise that water erosion contributes to increased soil and nutrient loss and can cause adverse environmental impacts, such as contamination of water resources and degradation of soil quality. This research contributes to the scientific understanding of soil management, fertility and water erosion, and can support future research and advances in agronomy and environmental sciences.

One of the limitations of this study lies in the fact that the rainfall simulation in the catchment was conducted on a single soil type, with fixed rainfall intensities and on only one slope. It is therefore recommended that future studies in this same catchment consider the use of rainfall simulators that allow for variation in rainfall intensity over the duration of the rainfall, as well as repeating the experiment on different soil types and terrain slopes.

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