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SOIL LOSSES IN AGRICULTURAL AREA OF THE SEMI-ARID

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abstract

Soil losses caused by erosion are a worldwide problem that brings significant environmental and economic impacts and reduces arable land. Soil conservation practices are efficient alternatives to reduce erosion and maintain crop productivity. The objective was to compare soil losses by water erosion in different agricultural managements in a rural community in the semi-arid region of Ceará. The design used was completely randomized with a factorial scheme (Treatment x period), consisting of four treatments: CNCP - Graviola planting in contour lines associated with stone strings; MACV - Graviola planting downhill, keeping the ground cover; CN - Graviola planting in a contour curve and MASV - Graviola planting downhill, without ground cover, with the period represented by the dates of collection of variables. The height and diameter of soursop trees were analyzed; soil moisture; precipitation and slope. The CNCP conservation management provided the lowest soil losses, while the MASV the highest losses, suggesting that the implementation of conservation practices in semi-arid agriculture reduces soil losses from water erosion and contributes to the sustainability of agricultural production in areas rural areas in the semi-arid region of Ceará.

Keywords: Water Erosion, Runoff, Soil Degradation, Soil Conservation Practices.

Resumo / Resumen

PERDAS DE SOLO EM ÁREA AGRÍCOLA DO SEMI-ÁRIDO

Perdas de solos causadas pela erosão, são um problema mundial que traz impactos ambientais e econômicos significativos e reduz as terras agricultáveis. Práticas conservacionistas dos solos, são alternativas eficientes para reduzir a erosão e manter a produtividade das culturas. Objetivou-se comparar as perdas de solos por erosão hídrica em diferentes manejos agrícolas em uma comunidade rural do semiárido cearense. O delineamento usado foi inteiramente casualizado com esquema fatorial (Tratamento x período), sendo composto por quatro tratamentos: CNCP - Plantio da graviola em Curvas de Nível associadas a cordões de pedra; MACV - Plantio da graviola morro abaixo, mantendo-se a cobertura do solo; CN - Plantio da graviola em curva de Nível e MASV - Plantio da graviola morro abaixo, ausente de cobertura do solo, com o período representado pelas datas de coletas das variáveis. Foram analisados a altura e diâmetro das gravioleiras; a umidade do solo; precipitação e declividade. O manejo conservacionista CNCP foi o que proporcionou menores perdas de solos, enquanto o MASV as maiores perdas, sugerindo que a implementação de práticas conservacionistas na agricultura do semiárido, reduz as perdas de solos por erosão hídrica e contribui para a sustentabilidade da produção agrícola em áreas rurais do semiárido cearense.

Palavras-chave: Erosão Hídrica, Runoff, Degradação Do Solo, Práticas Conservacionistas Do Solo.

PÉRDIDAS DE SUELO EN ÁREA AGRÍCOLA DEL SEMIÁRIDO

Las pérdidas de suelo causadas por la erosión son un problema mundial que trae consigo importantes impactos ambientales y económicos y reduce la superficie cultivable. Las prácticas de conservación de suelos son alternativas eficientes para reducir la erosión y mantener la productividad de los cultivos. El objetivo fue comparar las pérdidas de suelo por erosión hídrica en diferentes manejos agrícolas en una comunidad rural de la región semiárida de Ceará. El diseño utilizado fue completamente al azar con esquema factorial (Tratamiento x período), compuesto por cuatro tratamientos: CNCP - Siembra de Graviola en curvas de nivel asociada a hilos de piedra; MACV - Siembra de Graviola cuesta abajo, manteniendo la cobertura del suelo; CN - Siembra de Graviola en curva de nivel y MASV - Siembra de Graviola cuesta abajo, sin cobertura del suelo, con el período representado por las fechas de recolección de variables. Se analizó la altura y diámetro de árboles de guanábana; la humedad del suelo; precipitación y pendiente. La gestión de conservación del CNCP fue la que proporcionó las menores pérdidas de suelo, mientras que el MASV las mayores pérdidas, lo que sugiere que la implementación de prácticas de conservación en la agricultura semiárida reduce las pérdidas de suelo por erosión hídrica y contribuye a la sostenibilidad de la producción agrícola en zonas rurales. zonas de la región semiárida de Ceará.

Palabras-clave: Erosión hídrica, Escorrentía, Degradación del Suelo, Prácticas de Conservación del Suelo.

INTRODUCTION

Erosion is a cause of significant soil losses and the most worrisome and vast among the categories of anthropogenic soil degradation, mainly because natural rates of soil renewal are often lower than recorded loss rates (RABELO; ARAÚJO, 2019; HUDSON, 1995).

According to data from the Food and Agriculture Organization (FAO) by the United Nations (UN) (2015), about 25 to 40 billion megagrams of soil are lost annually in the world. Recent scientific findings indicate the high vulnerability of many areas to erosion and the possibility that climate change will increase soil loss rates if conservation strategies or adequate land use plans are not applied (RAJ; KUMAR; SOORYAMOL, 2022).

Minimizing impacts related to erosive processes requires understanding such a phenomenon and the factors that potentiate the process. According to Carvalho et al. (2002), water erosion is composed of three ongoing dependent stages: the disintegration of soil particles with the impact of precipitation drops, the transport of particles with surface runoff, and the deposition of eroded material in lower areas.

In this aspect, intrinsic soil and climate-related factors, such as soil class, relief, amount, intensity, and seasonality of precipitation, as well as land use and occupation, can intensify soil losses by erosion (SILVA et al., 2021; FERREIRA et al., 2020; LIMA et al., 2020; COSTA; FALCÃO SOBRINHO, 2019; ALMEIDA et al., 2016; ALBUQUERQUE et al., 2002; CARVALHO et al. 2002).

Examples of negative impacts on the soil are compaction, reduced infiltration, nutrient loss, increased fertilizer costs, and reduced crop productivity, reflecting significant economic loss (WANG et al., 2021; SCHNEIDER; GIASSON; KLAMT, 2007).

Furthermore, the soil losses happen especially where family farmers live because they still use unsustainable conventional soil management techniques, such as planting downhill, fire, and monocultures, which, as a rule, were inherited from their ancestors and are performed continuously over the years (NASCIMENTO NETO; FALCÃO SOBRINHO; COSTA, 2018; FERREIRA et al., 2020).

The abovementioned soil conservation practices – as alternatives to improper management techniques – have proved themselves efficient by reducing the erosion of agricultural soils (LIMA et al., 2020; ALMEIDA et al., 2016; ALBUQUERQUE et al., 2002). However, despite the various findings on the viability of conservationist management, studies that estimate soil losses by water erosion in semi-arid areas are still incipient. It is more often when comparing conservationist and conventional management techniques, which hinders planning for the dissemination of the best tactics for soil management among rural producers in these regions.

Thus, this manuscript has compared soil losses by water erosion in various agricultural management, including the conservationist one, in a community of rural family farmers in the semi-arid region of Ceará.

DESCRIPTION OF THE STUDY AREA

The study area is the community site of São Domingos, a community of family farmers and small animal breeders in the municipality of Sobral, Ceará State, with the geographic coordinates 330273.00 m East and 9580202.00 m South (Figure 1).

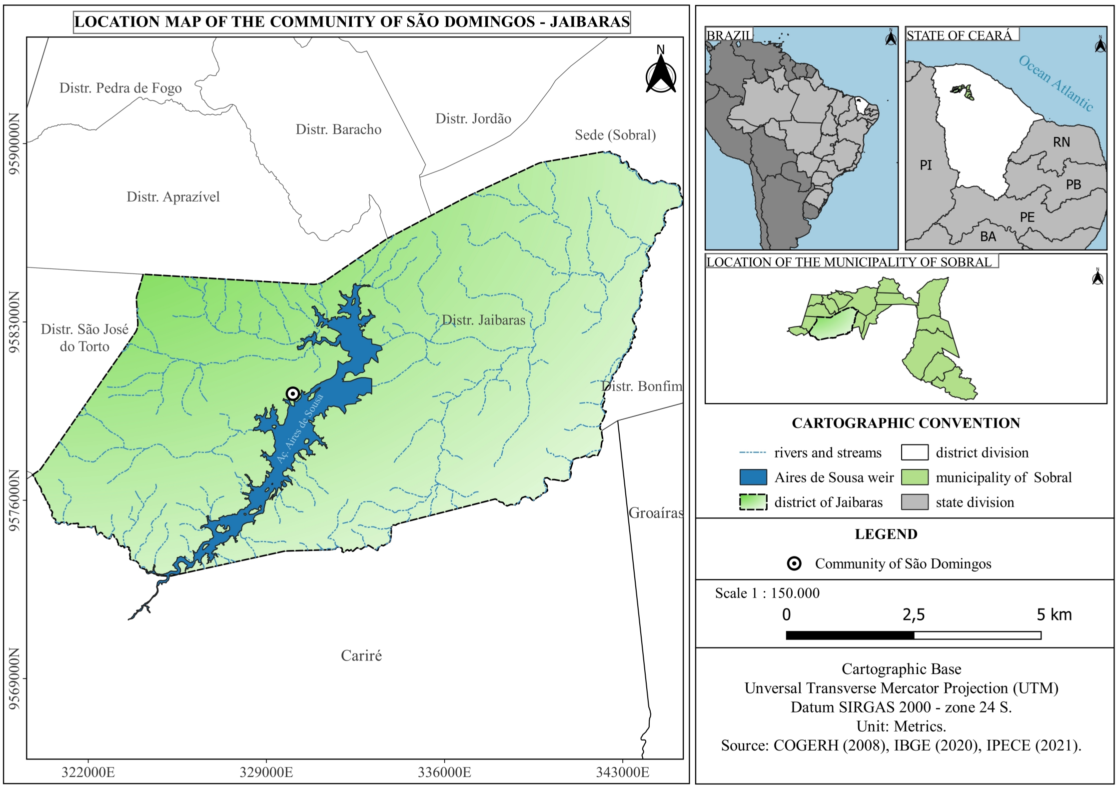

Figure 1 – Location Map of the experimental area. Source: figure elaboration by the author.

The community lies on the banks of the Aires de Souza Dam, which dams the Jaibaras River (Drainage Basin) in central northern Ceará, more precisely in the landscape physiognomy called hinterland surface (FALCÃO SOBRINHO, 2020).

The local terrain altitude ranges between 40 and 350 meters with Precambrian igneous-metamorphic stones (BRANDÃO; FREITAS, 2014). The local lithology contains rocks of the Jaibaras Groups with the Pacujá Formation, standing out siltstone-argillite interspersed sandstones and occurring Litholic Neosol (GOMES; CARVALHO; FALCÃO SOBRINHO, 2021).

The local temperature, whose climate is the hot semi-arid tropical, ranges from 26°C to 28°C with the rainy season from January to May (Instituto de Pesquisa e Estratégia Econômica do Ceará (Institute for Research and Economic Strategy of Ceará, IPECE), 2012). The precipitation data for a seventeen-year historical series, according to the Fundação Cearense de Meteorologia e Recursos Hídricos (Meteorology and Water Resources Foundation of Ceará, FUNCEME), in Jaibaras – about four kilometers from the study area – are in Figure 1. The average annual precipitation is 642.1 mm, with a maximum in the period corresponding to 1,325.70 mm and a minimum of 325.30 mm.

The outstanding local vegetation is the Caatinga, physiognomically classified as Open Shrub Caatinga and Deciduous Thorny Forest (IPECE, 2012), which presents semi-deciduous trees and an annual-growth herbaceous extract.

The opening of three trenches was essential for the local soil classification. The evaluation of the profiles enabled the soil classification in its first categorical level as Litholic Neosol (Empresa Brasileira de Pesquisa Agropecuária, (Brazilian Agricultural Research Corporation, EMBRAPA), 2018). Average data from fertility analyses, obtained from composite samples collected from the A horizon of the areas corresponding to each treatment, were: pH (water) = 6.3; 12.085 mg kg^{-1} of P; 15.53 g kg^{-1} of M. O.; 10.85 cmolc kg^{-1} of CTC; 77.9% of V; and 4.43; 3.38; 0.300 and 0.489 cmolc kg^{-1} of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}, respectively, and loamy textural class.

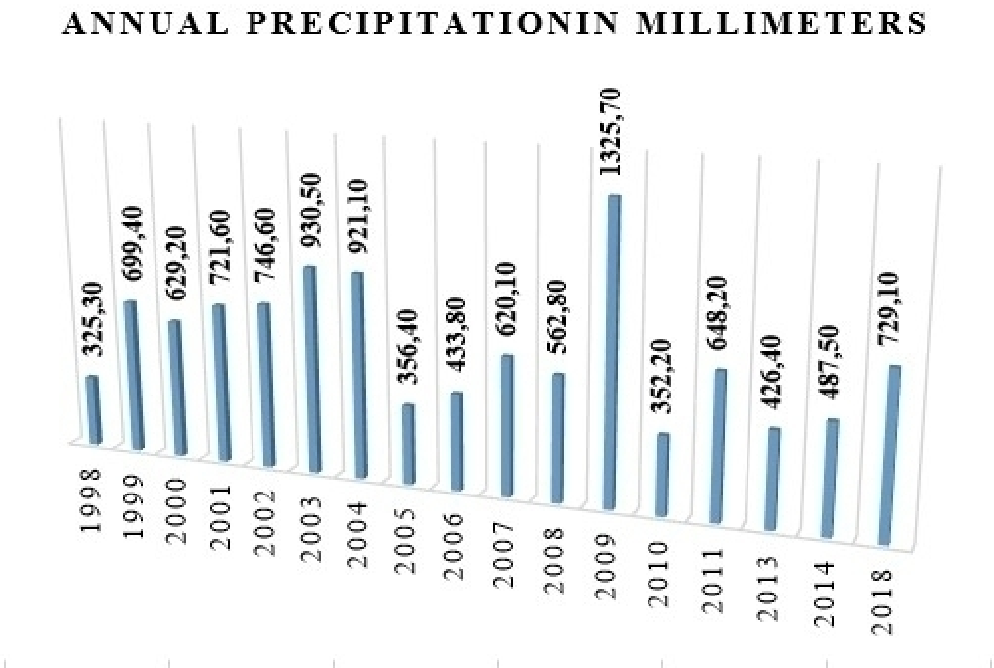

Table 1 – Historical series of precipitation in Jaibaras, Sobral/CE. Source: FUNCEME data (2022). Figure elaboration by the author.

DESIGN, TREATMENTS, AND ASSEMBLY

The experimental design was entirely randomized in a 4 x n factorial scheme (treatment x period), being the treatments formed by four different soil managements: LCRC – soursop (Annona muricata) plantation in Level Curves associated with Rock Cordons; DSC – soursop plantation in a conventional way (Downhill), however, keeping the spontaneous Soil Cover; LC – soursop plantation in Level Curves; and DSV – soursop plantation Downhill without Soil cover. The period representation was according to the dates of data collection, which varied depending on the parameter evaluated.

The layout of each treatment consisted of four rows of soursop plants with a spacing of 7 x 7 m, totaling 20, and the six central ones were useful, in which the evaluations took place.

The actions for the implementation of the experimental area were initiated in the second semester of 2018 and consisted of the stages of cleaning (vegetation weeding); demarcation of the contour lines; opening of the pits; foundation fertilization; planting of the soursop seedlings, irrigation; implementation of the erosion plots and cultural treatments.

Mason level, tape measure, pickets, and nylon line served the contour line demarcation. Besides, a hoe and pickaxe were essential to manually open the (40 x 40 x 40 cm) planting pits.

The soursop sowing in September 2018 included foundation fertilization composed of tanned bovine manure and dolomitic limestone. Cultural treatments consisted of cleaning the base of the plant (crowning), total weeding in the DSV treatment, regular irrigation on plants in all treatments, organic cover fertilization with goat manure, and annual pruning of soursop plants.

VARIABLES

The biometric evaluations, which started two months after sowing, determined the size of the six central plants of each treatment. Regarding height, a tape measure recorded the interval between the base and the apex. Concerning diameter, a digital pachymeter measured the bottom. The evaluations used to occur once a month, five in total.

The gravimetric soil moisture evaluation also happened during the 2018-2019 rainy season. It was a collection of soil located 20 cm from the stem and 0-5 cm deep from the six central plants of each treatment. The collected samples went immediately to sealed metal cans containing lids. After identification, they went to the laboratory for weighing and drying in an oven with forced air circulation. Data from the hair of the can – the weight with the wet and dry soil – assisted the determination of gravimetric moisture, as described by Teixeira et al. (2017).

It is worth pointing out that due to the high mortality of plants in the DSC treatment, it did not get into the statistical analyses of the biometric and soil moisture variables.

Each treatment contained an erosion plot installed in the direction of the slope, a total of four, with approximately 20m² made of zinc and masonry plates and measuring 10m in length, 2m in width, and 0.3 m in height. The installation of the zinc plates at a depth of 0.15m prevented erosion from the external sector and the entry of runoff and soil from adjacent areas. Thus, the surface runoff generated in the plots ran to the masonry trough (COSTA & FALCÃO SOBRINHO, 2019).

The collection system connected to each plot consisted of a 50 mm PVC pipe and three drums with lids with capacities of 20L, 25L, and 50L, respectively. The first and second drums had a system of 12 outlets, with the twelfth part of the runoff generated in the first and second drums and channeled to the next drum. In this case, the second and third buckets were, respectively, similar to the system used by Araújo, 2017.

The performance of thirty-three samplings of precipitation events with erosive processes in each of the treatments happened in 2019, 2020, and 2021. The surface runoff, collected during a 24-hour interval in each bucket of the collection system, underwent laboratory examination, serving as samples. Then, the entire collection system was emptied and cleaned to await the next erosive event.

In the laboratory, each dried sample underwent weighing of eroded silt in g L^{-1}. In determining the soil loss from each plot, there was a multiplication of the amount of sediment in the samples by the number of liters of surface runoff collected in each erosion plot during the corresponding erosion event. The surface runoff and soil loss values per hectare resulted from the extrapolation from each plot area.

A manual rain gauge installed in the experimental area determined the rainfall that occurred in each collection event in the erosion plots, reading it at regular intervals of 24 hours.

The slope measurements used a mason's level, two stakes, and a tape measure, where the difference in level between the first and last row of plants in each treatment was measured and the value divided by the distance between the two points (slope length).

STATISTICAL ANALYSIS

Data on height, diameter, and gravimetric soil moisture underwent the Shapiro-Wilk normality test and variance analysis by the F test. For accurate information, the considered probability in the Tukey test was 5% in the R-project 4.0.2 (R CORE TEAM, 2021).

The data on precipitation, runoff, and soil loss underwent Spearman's correlation matrix, principal component analysis (PCA), and cluster analysis through the SPSS v.16. The sample adequacy analysis happened through the Kaiser-Meyer-Olkin (KMO) test for uniformity and Bartlett's test for sphericity.

RESULT AND DISCUSSION

Data on the analysis of variance of the biometric parameters and soil moisture are in Table 2. There were no effects of interaction between treatments and collection dates. However, there was a significant effect of treatments and collections alone for plant height. There was also an isolated effect on the collection dates for the diameter and handling of the gravimetric soil moisture (Table 2).

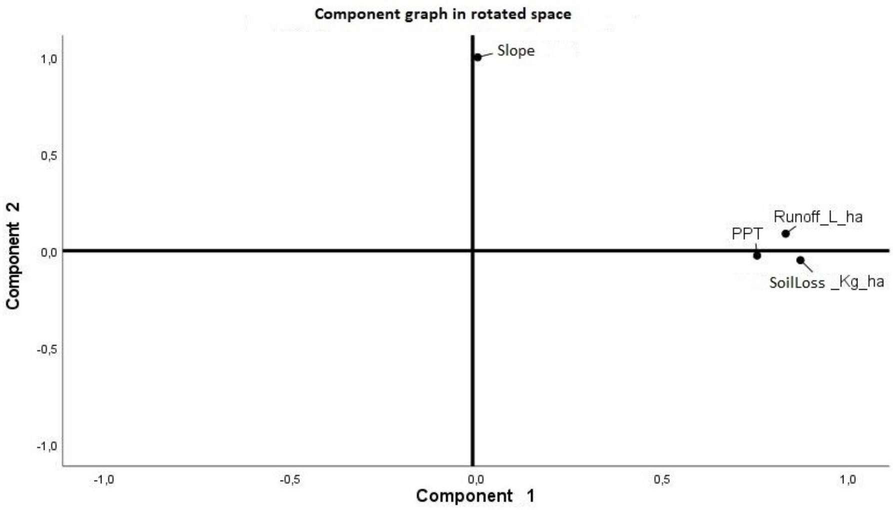

Table 2 – Summary of Analysis of Variance (ANOVA) for the plant height, stem diameter, and gravimetric soil moisture.

** and *Significant correlation is 0.01 and 0.05, respectively, while ns is non-significant.

The highest plants averaged 62.0 cm and were in the planting in level curves associated with rock cordons – LCRC, while the smallest ones were downhill without soil cover – DSV, whose average height was about 29.52% lower (Figure 2A). In the evaluations from March 2019, the plants had an average of 81.2 cm, significantly higher than the heights recorded in other evaluations (Figure 2B).

The average diameter of soursop trees reached 10.95 mm (Figure 2C), and similarly, the height was significantly higher in the March 2019 evaluations, with a value of 16.76 mm (Figure 2D).

The highest height and diameter values in the March 2019 evaluation are consistent with the plant development, indicating that, in this period, the soursop trees had already established themselves in the soil and increased the vegetative growth rate.

There was no significant difference in the gravimetric soil moisture over the years, being 0.15 kg kg^{-1} as the average value (Figure 2E). Concerning the treatments, the humidity was 0.1911 kg kg^{-1} in the DSV, 0.1413 in the LCRC, and 0.1223 kg-1 in the LC.

This finding does not show up frequently in experiments comparing plantings in the LCRC and downhill treatments. For instance, Santos et al. (2009) found in an experiment with simulated rainfall that in LCRC systems, soil moisture was considerably higher than in downhill cultivation because of the lower speed and superior permanence of surface runoff in the planting.

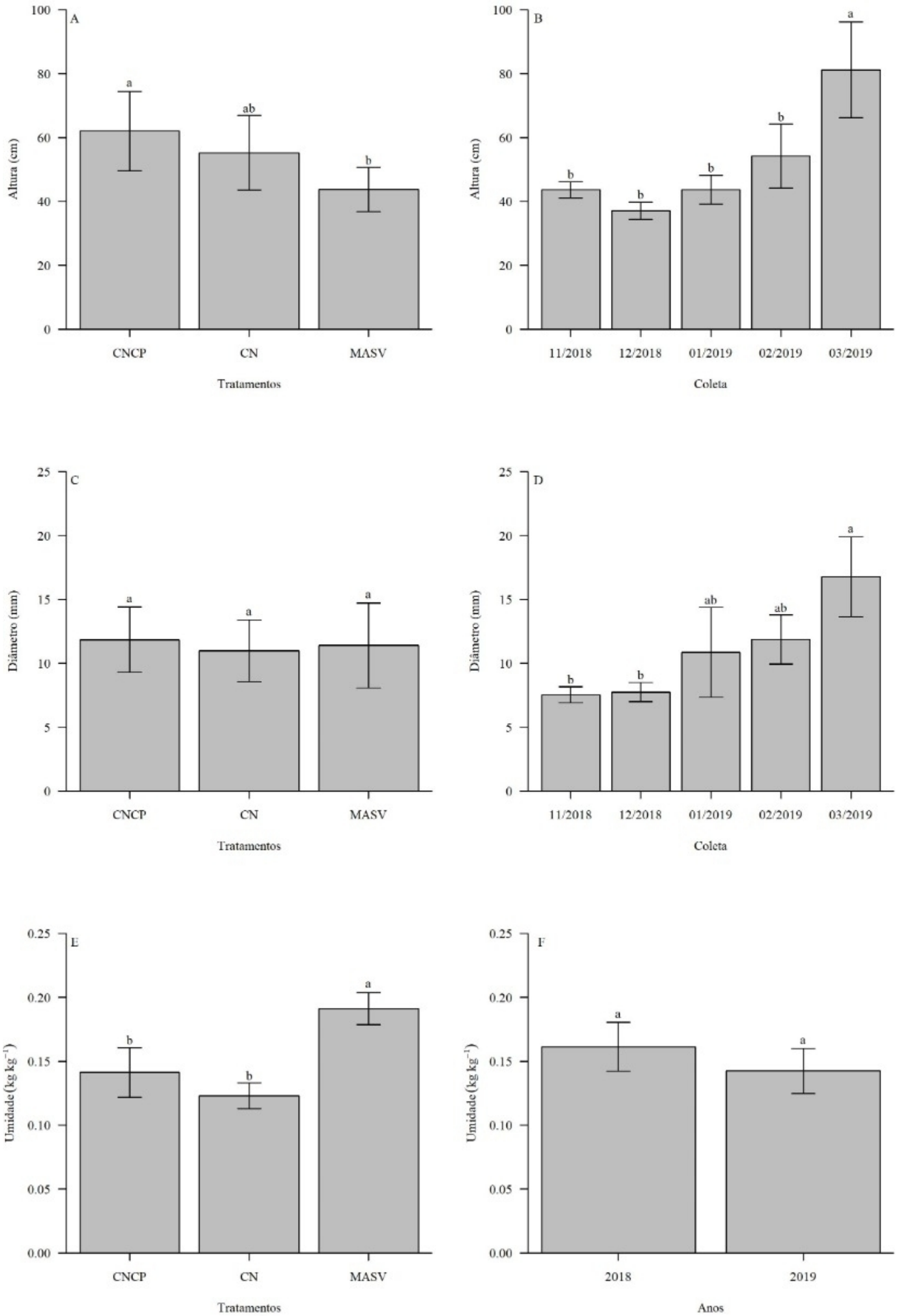

Figura 2 – Height x treatment (A), height x collection date (B), diameter x treatment (C), diameter x collection date (D) of soursop plants, and moisture x treatment (E) and moisture x collection date (F) of soil in the treatments LCRC – level curves associated with rock cordons; DSV – downhill without soil cover; LC – in level curves.

However, the surface runoff in the DSV treatment was higher than in the LCRC and LC, as detailed below. Such a fact may have contributed to the higher humidity, justifying the results observed.

It is also worth noting that the plants in this study were regularly irrigated, including periods of drought during the winter. Thus, the differences in humidity between the treatments, even if significant, may not have caused adverse effects on the hydric status of the plants under conservationist management, thus not interfering with the best plant growth of these treatments.

Spearman's correlation matrix (Table 3) showed that the precipitation, runoff, and soil loss were strongly correlated with each other but did not effectively correlate with the slope.

	PPT	Runoff	Soil Losses	Slope
PPT	1			
Runoff	0.411**	1		
Soil Losses	0.495**	0.623**	1	
Slope	0.000	0.055	-0.0.29	1

Table 3 – Spearman correlation matrix for the variables precipitation (PPT), runoff, soil loss, and slope.

** Pearson correlation significant at the 0.01 level (2 ends).

The Principal Components Analysis (PCA) allowed the identification of two components with an eigenvalue greater than 1.0, which explains 75.8% of the evaluated data (Chart 3). Component 1 (eigenvalue of 50.62%) showed strong association between precipitation (PPT) (0.755), runoff (0.834), and soil loss (0.871). In component 2 (eigenvalue of 25.12%), the association was high but independent of the slope, with a value equal to 0.998.

Factors	Height	Diameter	Moisture
Collection date	10.1862**	5.1979**	2.5089 ns
Treatment	4.8487*	0.1008 ns	11.7031***
Interaction: collection*treatment	0.3839 ns	0.4167 ns	0.2196 ns

Figure 3 – Principal Component Analysis (PCA) for the variables precipitation (PPT), runoff, soil losses, and slope concerning soil management: LCRC – level curves associated with rock cordons; DSV – downhill without soil cover; LC – level curves and DSC – downhill keeping soil cover. KMO test: 0.659 and Bartlett's test: 103.776.

The cluster dendrogram, based on the Euclidean distance as a dissimilarity measure (Figure 4), resulted in two groups in the evaluations performed among the soil management treatments. The first group – the similar LC and DSC treatments – is dissimilar to the second one – LCRC and DSV, which present common characteristics.

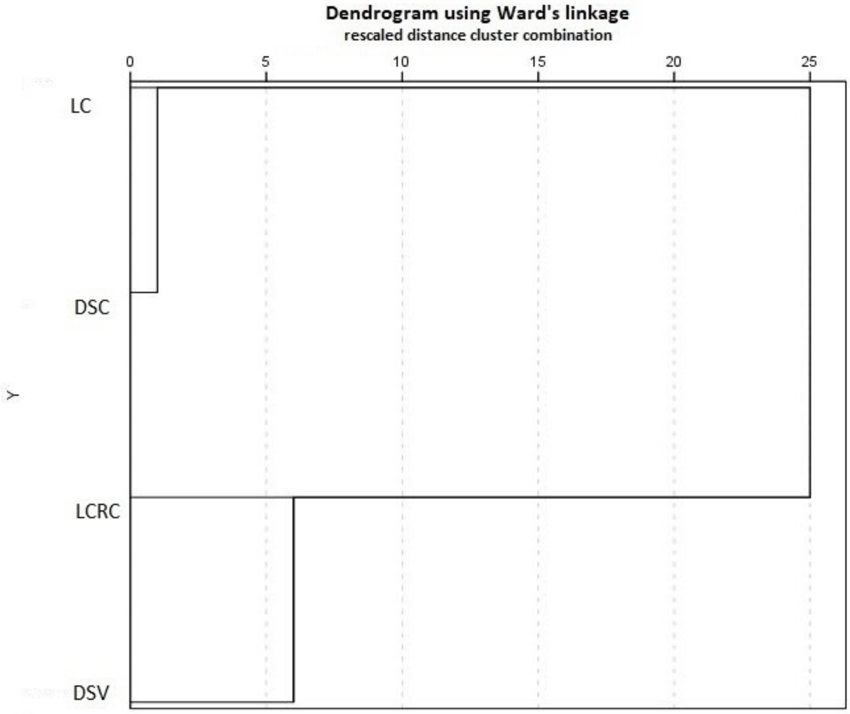

Figure 4 – Cluster dendrogram for soil management: LCRC – level curves associated with rock cordons; DSV – downhill without soil cover; LC – level curves and DSC – downhill keeping soil cover.

The strong relationship between PPT, runoff, and soil loss – evidenced in the principal component analysis (Figure 4) – is consistent with studies such as those of Costa and Falcão Sobrinho (2019) and Carvalho et al. (2002), which show a positive relationship between precipitation, runoff, and soil loss, corroborating the data found in this study.

Descriptive Statistics	Treatment	Precipitation (mm)	Surface Runoff (L ha-1)	Soil Losses (Kg ha-1)
Average	LCRC	20.59	24,735.13	2,600.44
	DSC	20.59	26,030.82	6,247.88
	LC	20.59	19,590.44	2,993.04
	DSV	20.59	19,790.87	3,853.31
Maximum	LCRC	67.00	79,887.22	30,580.51
	DSC	67.00	185,339.44	84,723.78
	LC	67.00	133,928.57	94,081.82
	DSV	67.00	86,134.45	41,721.03
Minimum	LCRC	6.00	2,349.62	1.34
	DSC	6.00	2,123.70	7.51
	LC	6.00	558.04	0.54
	DSV	6.00	3,151.26	5.11

Table 4 – Average, maximum, and minimum values of precipitation (mm), runoff (L ha–1), and soil loss (Kg ha-1) in the treatments LCRC – level curves associated with rock cordons; DSV – downhill without soil cover; LC – level curves and DSC – downhill keeping soil cover.

The grouping of the treatments LC and DSC / LCRC and DSV evidenced in the cluster dendrogram can be better visualized from the analysis of the descriptive statistics data presented in

Table 4. The LC and DSC treatments had very close average runoff and soil loss – 19,690.65 L ha-1 and 3,923.18 Kg ha^{-1}, respectively.

In the LCRC and DSV treatments, the runoff value was high – around 5,692.33 L ha^{-1} – possibly because of the sharp slope, corresponding to 9.0%. On the other hand, the soil losses were distinct. It explains, at least in part, the isolated declivity effect presented in the principal components analysis. The DSV had a slope of 7.0%, while in the LC and DSC, the slopes were 7.0 and 4.0%, respectively.

The DSV treatment, in general, had the highest soil loss (6.25 Mg ha^{-1}) and surface runoff (26.03 m3 ha^{-1}) values in each precipitation event (20.6 mm). The lowest soil losses (2.6 Mg ha^{-1}) took place in the LCRC in each event of 20.6 mm of rainfall, although, in this treatment, the average runoff is higher than in the LC and DSC, possibly because of the sharp slope.

Lima et al. (2020) also found in the studies with conservation practices in a Regolith Neosol that the treatment with exposed soil presented the highest values of runoff and soil loss.

Regarding the low LCRC soil loss, even with the higher runoff values, it possibly results from the rock cordons effect in filtering the runoff. Thus, it shows up as a barrier to sediments that end up accumulating in the spaces.

Concerning DSC, the runoff and soil loss values closer to the ones in the conservationist management may result from the effect of the naturally growing spontaneous vegetation. It has the potential to provide a decrease in surface runoff since it slows the runoff flow by surface roughness, reducing the transport capacity (COSTA; FALCÃO SOBRINHO, 2019; SANTOS et al., 2009).

In the studies of Lima et al. (2020), the authors verified, in events with high precipitation (81.2 and 71.0 mm), the non-occurrence of surface runoff in the conservation treatments that used mulch. On the other hand, average runoff and soil losses reached 7.55 mm and 0.015 kg m^{-2}, respectively, in the treatment with exposed soil, corroborating the trends observed in the study.

The estimated soil loss values found are high, especially when considering the occurrence of several rainfall events equal to or greater than the value of the average rainfall entered throughout the annual rainy season. It is worth pointing out that soil loss values can be very variable, even in the same area, since various factors interfere with the intensity of the stages that make up erosion.

Costa and Falcão Sobrinho (2019), when evaluating soil loss in micro-watersheds of the Acaraú Valley, found variable annual soil losses of more than 50% during the monitoring of a Luvisol for two consecutive years. In the same study, values up to 45.17 Mg ha^{-1} per year were found for annual rainfall of 709.4 mm, while losses were reduced by 51.04% in the previous year, even with only 36.4% less precipitation. In the same study, annual soil losses were even higher when the soil monitored was an Acrisol, which naturally presents greater susceptibility to erosion.

Ebabu et al. (2022), when analyzing 255 articles on the variation of two of the factors of the soil loss equation that suffer influence from human activities and climatic variables, found significant variations in the factors as a function of climate zones, land use types or land cover type, and management practices. They also highlighted that reduced cultivation and use of terraces contribute significantly to the reduction of soil loss.

The findings in the abovementioned studies suggest that factors such as precipitation intensity, erodibility, slope length, slope direction, and the slope itself have significant effects on soil loss and runoff generation, and these effects depend on the interaction among these factors.

Having the rainfall intensity as a reference, Lima et al. (2020) registered the non-generation of runoff for some events above 30 mm, relating it to the low average intenseness.

Andrade (2017) highlighted cases of the total absence of runoff or the occurrence of runoff of less than 7 mm in micro-watersheds in the northeastern semi-arid region during periods of prolonged drought. He stated that, in such cases, there may be a reduction in the soil loss values, which is why it is essential to perform monitoring of soil loss in semi-arid areas.

CONCLUSION

Data obtained in this research lead to conclude that conservationist practices – level curves associated with rock cordons, in level curves alone and keeping the soil cover with soil cover, and even when planting downhill – has the potential to reduce soil loss by water erosion if compared to traditional cultivation in semi-arid areas with average slopes between 4% and 9%, principally on naturally erodible soils such as Litholic Neosol.

It raises the importance of the development of effective interventions for the dissemination of conservationist and more sustainable agricultural practices among farmers in the semi-arid region to favor the reduction of soil degradation and increase planting productivity. Besides, the research shows the best development of plants under conservationist management.

The conception of the actions mentioned above is essential for the maintenance of agricultural production, which is fundamental for society as a reliable source of food for human existence, a source of employment and income, and to promote the coexistence of these traditional populations with the semi-arid region.

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