Experimental field measurements of soil erosion on newly planted slopes of an excavated sand pit

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Abstract

The main objective of this field investigation was to study the influence of different plant species and the use of geotextiles on soil erosion reduction in sand mining pit recoveries. A field experiment with 24 plots was installed in a freshly excavated pit, arranged in 3 blocks with 8 treatment combinations. Four different types of plantings ('type of vegetation') and two types of soil covering ('bare or with geotextile' - jute) were used. The plant species selected for the experiment were the legume *Arachis repens*, a mix of four locally occurring species (including two grasses) and the grass *Chrysopogon zizanioides*, all introduced as plantlets. Additionally, as a control, a group of plots was left initially bare. The experiment was monitored for 07 months (Nov/20 to Jun/21) with the following measurements or observations taken in each plot: (a) the mass of eroded soil, (b) the collected runoff water volume, (c) plant survival over time. *Arachis repens* showed the best control of soil erosion and the highest survival rate, followed by a mix of local plants. The plants only had effect on soil erosion when 'vegetation cover' was higher than 25%; below this, all treatments showed the same erosion behavior, including the control plots with no initial plants. Somehow surprisingly, use of geotextile did not reduce soil erosion.

Keywords: erosion; vegetation; sand slopes; geotextile.

1. Introduction

The use of vegetation to recover degraded areas by sand extraction activity is a common practice in order to control erosion of artificial mining slopes. It also improves the visual impacts and gives support for the return of wildlife to the site. The effectiveness of vegetation in controlling erosive processes at the soil surface is primarily a result of the roots influence, which assists in the stability of the superficial soil, due to mechanical and hydrological aspects (Styczen & Morgan, 1995; Coppin & Richards, 1990; Greenway, 1987; Vannoppen *et al*, 2017; de Baets *et al*., 2007). In addition, the aboveground components of the vegetation absorb part of the energy from raindrops, water flow and wind (Morgan, 2009) which reduces the soil erodibility. Hence, the effects of vegetation on the control of erosive processes depend on the morphology of individual plants (canopy, stem, root and cover) and on vegetational architecture (structure, density and uniformity of the vegetation cover) (Morgan & Rickson, 1995).

The absence of quantitative information about the contribution of different plant species to control erosion in sand mining sites is a limiting factor, especially in countries like Brazil, where ecological restoration and recovery of degraded areas still need qualification (Overbeck *et al*., 2013; Guerra *et al*., 2020; Michel & Overbeck, 2024 In practice, this can lead to the use of species that may be not the most efficient or appropriate for the sites. And another factor that influences the species choice, is their availability on the market. This is still very limited in the Brazilian market, especially considering native species (Overbeck *et al*., 2013; Rolim *et al*. 2022). The species mostly used in sand mining sites recovery in Southern Brazil are *Melinis minutiflora, Avena strigosa, Lolium multiflorum, Chrysopogon zizanioides, Penissetum americanum,* and *Paspalum notatum* var. *pensacola*. Except for the last, these species are exotic to Brazil.

The use of vegetation combined

with application of geotextiles for the recovery of degraded areas is a common practice. Geotextiles are materials formed by continuous filaments or cut fibers, monofilaments, laminations or yarns, woven or non-woven, many of them with randomly distributed threads in order to build a high-strength blanket (Silva, 2014). This technique has been widely used in engineering and has shown positive results for the development of vegetation cover, due to maintenance of soil moisture (Lekha, 2004; Kertész *et al*., 2011; Vishnudas, 2006), and for soil erosion control (Rickson, 1995; Prambauer *et al*., 2019; Bhattacharyya *et al*., 2011). Its effects are related to the geotextile-induced roughness, water holding capacity, the weight of the geotextile when wet, ability to pond flow, and increased flow depth (Rickson, 2006). However, geotextiles have not been applied much in the recovery of mining sites in Brazil (Bretas, 2019, Paulino & Discacciati, 2014, Botelho & Melo, 2019).

The objective of this study was to investigate the effect of different types of vegetation cover on soil erosion control using (a) 3 different types of vegetation cover, including exotic and native species commonly used or adapted to sand soil and a mix of species found on site, and (b) the use (or not) of geotextile (jute) covering the soil. Experimental plots were established in a sand pit and measurements of eroded soil mass and the collected volume of runoff water were made over a period of 07 months. Additionally, vegetation development was monitored during the period.

2. Materials and methods

2.1 Experimental site

The experiment was conducted on a sand extraction pit site located near the RS 040 highway at Águas Claras, Viamão, Rio Grande do Sul, Brazil. It is located in the eastern region of the state of Rio Grande do Sul approximately 47 kilometers from the city of Porto Alegre. The region has a subtropical climate with medium monthly precipitation between 83 and 136 millimeters (Weather spark, 2020). The region includes fossil dune ridges that delimit an ancient stationary beach line formed predominantly by aeolian deposition (Vilwock, 1972). The deposited soil is classified as medium-grained poorly graded non-plastic sand (fines content close to 10-12%). It is also characterized as acidic soil (average pH of 4.9) and classified as low fertility soil from an agronomic perspective (Stein, 2021).

2.2 Experiment planning and installation

Some data of the species chosen for the experiment are shown in Table 1 and includes (a) species that are commonly used in the region but whose effect on erosion control has not yet been quantified and (b) a mix of species that occur at the experimental site, i.e., that should be adapted to the soil and climatic conditions of the research site.

Table 1 - Species used and their characteristics.

Species	Family	Plant type	Growth Type	Native/ Exotic	Seedling Origin
Chrysopogon zizanioides (L.) Roberty	*Poaceae*	Grass	Caespitose	Exotic	Commercial nursery
Arachis repens Handro	*Fabaceae*	Non-grass forb	Rhizomatous	Native	Commercial nursery
Paspalum nicorae Parodi	*Poaceae*	Grass	Rhizomatous and stoloniferous	Native	Study area
Vernonanthura nudiflora (Less) H.Rob	*Asteraceae*	Sub-Shrub	Xylopode	Native	Study area
Glandularia peruviana (L.) Small	*Verbenaceae*	Non-grass forb	Stoloniferous	Native	Study area
Digitaria eriantha ssp. pentzii.	*Poaceae*	Grass	Rhizomatous and stoloniferous	Exotic	Study area

A commercial jute was chosen as the geotextile soil cover, since it is a material easily accessible in the local market at low cost when compared to other geotextiles, and it is biodegradable. In addition, jute is a material that has a good potential for further investigation and remains poorly studied around the world (Ghosh *et al*, 2014; Prambauer *et al*., 2019). The experiment design consisted of randomized blocks, repeated 3 (three) times, with two investigated (or controlled) factors, 'vegetation' and 'geotextile'. The controllable factor (a) 'vegetation' had 4 levels (a1 – *Chrysopogon zizanioides*; a2 – *Arachis repens*; a3 – a mixture of plants presents in the study area; see Table 1; a4 – control, with no vegetation); and factor (b) 'geotextile' had only 2 levels, jute application or bare soil, leading to 8 treatment combinations with a total of 24 experimental plots (Figure 1).

To set up the experiment, a fresh cut was made in the natural terrain composed by two slopes of 1m height and 30° inclination each, separated by a berm 0.5m wide (Figure 1). The experimental plots were installed in the upper slope with an area of 2m² each. Initially, on the designed plots, the jute was installed in contact with the soil and then 28 seedlings of the chosen varieties were planted in each planned experimental plot (with exception of the bare soil control plots). For the plots with the mix of local plants, the number of individuals used was proportional to the species occurrence around the research site: 10 individuals of *Paspalum nicorae*, 4 of *Vernonanthura nudiflora*, 4 of *Glandularia peruviana* and 10 of *Digitaria eriantha* ssp. pentzii. The plant sizes were also standardized within each species and the distance between seedlings was fixed at 30 cm. After the planting, the structures for sediment collection were installed, including gutters, pipes and 65-liter buckets with filters installed at the entrance of each bucket (made of non-woven geosynthetics). Two manual rain gauges were installed adjacent to the experiment in order to monitor the daily rainfall during the experiment period.



Figure 1 – General view of the experimental setup on January 10, 2021.

The experiment was monitored continuously for 07 months, from Nov/20 to Jun/21. During this period, the measurements of different aspects were carried out at interval as described: (a) the rain measurements were made after the occurrence of any rainfall, (b) the collection of eroded soil was made whenever the retention of a significant weight of sediment by the filter was visually identified, and (c) the accumulated volume of water in the buckets was measured when the filters were replaced. During the first 03 months of the installation, due to high temperatures and low air humidity (summer months), all the seedlings were watered regularly to increase their chance of survival, with care not to cause soil erosion.

The accumulated precipitation was analyzed according to the sediment collection period. The runoff started to be monitored from the installation of the experiment, however, the influence of rainfall on soil erosion was considered after December 5th, so that the soil disturbed by the planting would not influence the results of the experiment, so it was decided to wait for the incidence of some rain events.

In the months of February and June, the survival rate of each planted species was determined, as well as the percentage of vegetation cover of each plot estimated using a Londo scale, as described in Andrade *et al.* (2019).

A variance analysis (ANOVA) was used to analyze the data obtained regarding erosion, runoff from the experiment, and the vegetation cover and survival of the planted individuals. Linear and non-linear models were applied to compare the vegetation cover rate with erosion and runoff.

3. Results

3.1 Precipitation

As indicated in Figure 2, during the first four months of the experiment, only sparse rainfall of low to medium intensity occurred (below or close to the average precipitation measurements, i.e., 83mm). The only rainfall that behaved differently from the others occurred on January 25th, with 35 mm of precipitation in a period of less than 20 (twenty) minutes (manual measurement). After April, as winter approached, the rainfall characteristics changed in relation to the previous months, with precipitation for longer periods, reaching occurrences greater than 24 hours (higher than the maximum precipitation averages, i.e., 136mm).

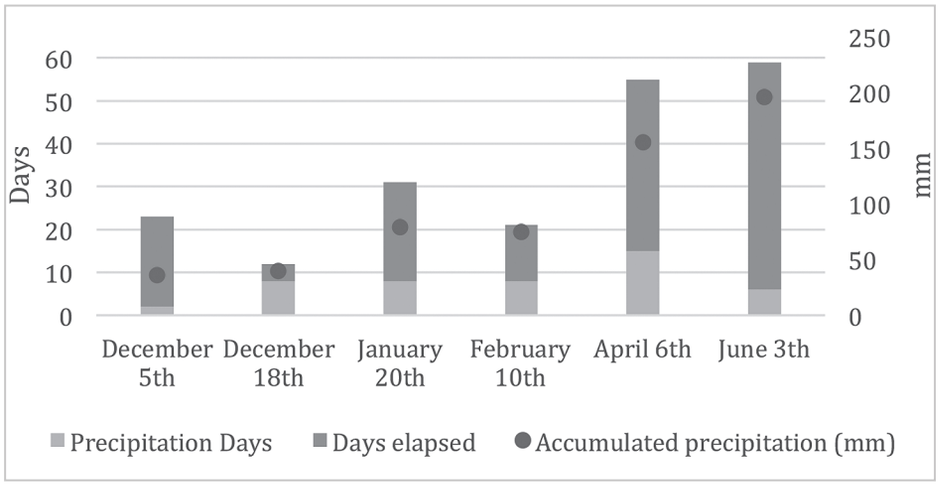


Figure 2 - Accumulated precipitation and number of days with presentation, between the measurement dates, on the sediment collection periods, with monitoring starting from the installation of the experiment.

3.2 Surface runoff

During the experiment, 05 (five) eroded soil mass and water volume (surface runoff) measurements were performed. Some collections from experimental plots had to be discarded, due to specific problems in the plot, such as surface runoff originating beyond the limits of the plots, obstructions of the gutter and pipe by excessive accumulated sediment, and interference from leaf-cutting ants.

For the data analysis, the time elapsed was not taken into account as a third control factor as the frequency, intensity and rainfall duration time between the sampling periods were variable. And, when any of the treatments had field related problems, as reported above, and/or was defined as outlier, the vegetation factor level was disregarded in the analyses, such as *Chrysopogon* on February 10, April 6, and June 3 (Table 2).

Table 2 - Average eroded soil mass (g) per treatment per sampling period. Given are mean values of the three replicates of each treatment combination

Sampling date	Jute				Bare			
	Chrysopogon	*Arachis*	Control	Mix	*Chrysopogon*	*Arachis*	Control	Mix
Dec. 18	47.00	40.50	32.00	38.33	26.00	34.67	28.33	29.33
Jan. 20	55.33	51.00	49.00	47.00	60.33	59.50	43.50	66.00
Feb. 10	1652.00	1326.00	2215.00	1791.33	-	313.50	2604.00	658.50
Apr. 6	-	194.67	183.00	61.33	126.50	51.50	-	51.50
Jun. 3	731.00	501.00	621.00	795.00	-	554.67	716.50	1283.67

Statistical analysis showed that the geotextile factor had a significant difference (Dist f < 5%) in the sampling dates of December 18 and February 10: in those plots in which jute was used, eroded soil mass increased from 40% to 45% when compared to the erosion in bare soil plots.

Regarding the influence of the vegetation factor on soil erosion control, the results showed significant differences (Dist f < 5%) on February 10 and April 6. On February 10, the vegetational types that performed better in terms of erosion control (lower sediment mass) were *Arachis repens* (819.6g) and the local plant mix (1224.7g), while the control plots without vegetation had 2348.7g. In the April 06 sampling, the plant mix worked best at controlling erosion (340 g), followed by *Arachis repens* (904g).

As for the volume of surface runoff water, there was an initial sampling, before performing the sampling of eroded sediments, given that the structure to collect the runoff was installed in the same period of the experiment, except for the filters, which occurred only on December 5 (Table 3). As for the date of January 20, the data generated cannot be analyzed, since the evaporation rate (variable not measured), was higher than the runoff volume in the period, so negative data were generated.

Table 3 - Average volume (liters - l) due to surface runoff for the treatments in the different sampling periods. Given are mean values of the three replicates of each treatment combination.

Sampling date	Jute				Bare			
	Chrysopogon	*Arachis*	Control	Mix	*Chrysopogon*	*Arachis*	Control	Mix
Dec. 05	4.17	4.67	3.33	4.67	2.83	3.17	3.67	3.67
Dec. 18	1.35	1.85	0.70	0.70	0.17	0.90	0.53	0.00
Feb. 10	12.77	11.47	10.80	13.30	-	5.33	9.60	5.35
Apr. 6	-	10.27	11.00	12.83	15.00	8.33	-	13.25
Jun. 3	17.00	10.90	11.73	13.67	16.00	8.83	18.90	14.10

From the runoff statistical analysis, the geotextile (jute) factor showed a significant difference (Dist f < 5%) regarding the accumulated volume on December 5, December 18 and February 10, with the geotextile plots causing a runoff higher than the average of the plots without jute, showing an increase between 50% and 300%.

As for the vegetation factor in surface runoff, only in the sampling performed on December 18 showed a significant difference, with the *Arachis repens* level, with 1.4l, distinguished (Dist f < 5%) from the mix, with 0.3l, and from the control (no vegetation), with 0.6l.

3.3 Plant species survival

The greatest loss of individuals plants occurred between date of planting (November 2020) and February (date of the first survey). Between the first and second survey, there were few additional losses. It is important to note that in several plots of the native plant mix, no individuals of *Glandularia peruviana* and *Vernonanthura nudiflora* survived.

Statistical analysis of the data demonstrated that at the end of the experiment (survey in June) the different species planted showed significantly different survival rates (Dist f < 0.05). The species with the highest survival rate was *Arachis repens*, with 92%, followed by the species *Paspalum nicorae* and *Digitaria eriantha* (60% and 57% respectively), and by the species *Chrysopogon zizanioides*, *Glandularia peruviana* and *Vernonanthura nudiflora* (15%, 21%

and 8% respectively), without significant differences among them. The use of geotextile had no influence on the survival rate of the planted individuals.

3.4 Influence of vegetation cover on erosion processes

The results related to the influence of the vegetation cover on the erosive processes were analyzed by separating the plots with the application of jute from the plots without its application, since this factor (jute) presented a significant difference in several periods in terms of erosion and runoff volume. Besides this, the results obtained in the two periods were not presented in a single graph, since the rainfall events of each period were distinct, in such a way that the rate of erosion and runoff of the periods present distinct magnitudes and behaviors.

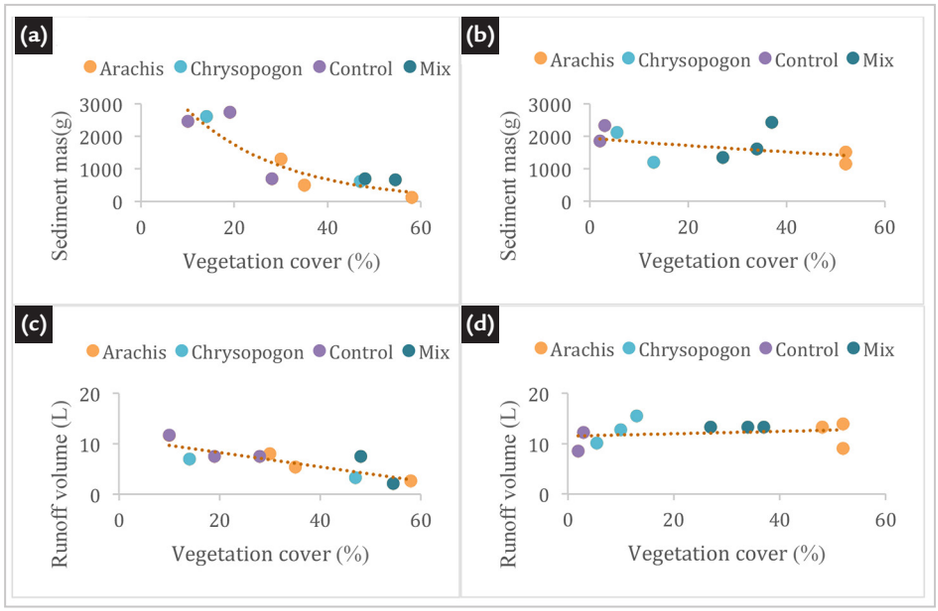


Figure 3 - Comparative plots of eroded sediment mass as a function of vegetation covering measured in February, (a) plots without jute - r of the data -0.878 and r^2 of the exponential equation 0.785, and (b) plots with jute - r of the data 0.420. Comparative plots between runoff volume as a function of vegetation cover measured in February, (c) plots without jute, where the r of the data was 0.900 and the r^2 of the linear equation, 0.810; and (d) plots with jute, where r of the data was 0.202.

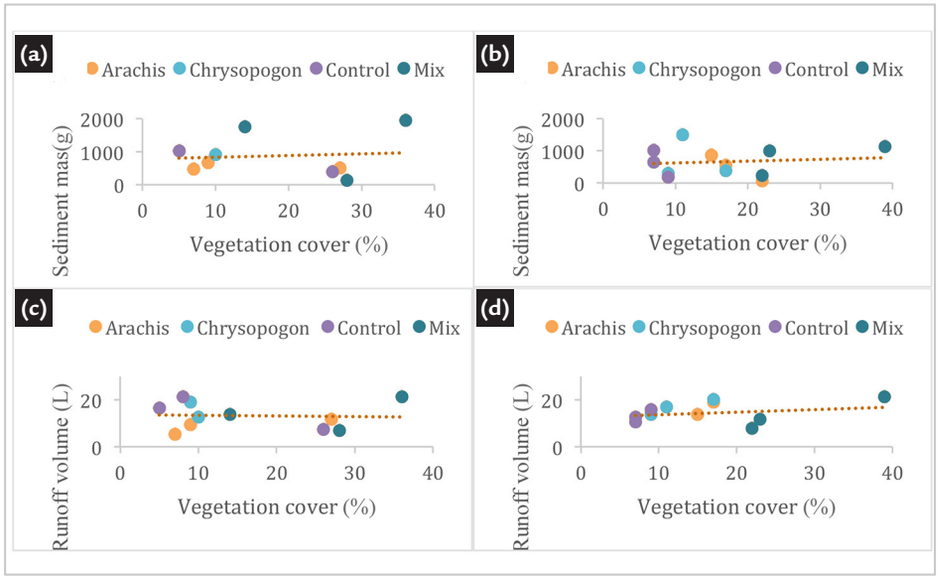


Figure 4 - Comparative plots of eroded sediment mass as a function of vegetation covering measured in June, (a) plots without jute, the r of the data was 0.009; and (b) plots with jute, the r of the data was 0.115. Comparative plots between runoff volume as a function of vegetation cover for measured in June (d) plot of the comparative analysis, in June, between runoff volume as a function of vegetation cover for the plots without jute, the r of the data was -0.052. (e) plot of the comparative analysis, in June, between runoff volume as a function of vegetation cover for the plots with jute, the r of the data was 0.225.

Through the graphs (b) and (d) of Figure 3 and Figure 4 it can be observed that the presence of jute has no relationship between vegetation cover and the eroded soil mass or between vegetation cover and the runoff volume exits. On the other hand, in plots where the plants were planted directly on the soil, in February, a linear re-

duction of the eroded mass with the increase of vegetation covers could be found (Figure 3 - a). Also, a linear relationship was identified between the increase in the vegetational cover and the reduction in surface runoff in February (Figure 3 - c). However, these correlations identified in February were not observed in June.

4. Discussion

4.1 Erosion and surface runoff

In two periods of sampling, jute led to an increase of the soil mass eroded, and for the other periods, it did not have any effect in the erosion control when compared to the plots without jute.

Our results thus contrast with the general indication of a positive effect of geotextile in controlling soil erosion. Mitchell *et al.* (2003) and Datta (2007) had confirmed the efficiency of jute in controlling erosion on sandy slopes with inclinations of up to 15°. However, the variation in slope gradient is a decisive factor in the efficiency of the geotextile in reducing the eroded mass. The steeper the slope, the greater the rate of erosion (Chen *et al*., 2011; Álvarez-Mozos *et al*., 2014). Another factor to be observed is the type of material used as geotextile, since different materials may present significant differences in soil erosion control (Fontes, 2016; Nsiah & Scaaaf, 2019). Jute, as used here, in general has shown less satisfactory results when compared to other materials, such as coconut fiber and synthetic geotextile (Chen *et al*., 2011; Álvarez-Mozos *et al*., 2014).

Regarding the vegetation used, the effectiveness of *Arachis repens* in controlling sediment loss from February to April, in relation to the mix plants, is probably due to the loss of leaves of this species in this period and consequent reduction in vegetation cover.

It is worth noting that *Arachis repens* is characterized by the loss of leaves with the arrival of winter, so that the reduction in coverage is not associated with a reduction in its development.

As for the surface runoff, in three samplings, the accumulated volume in the collectors was higher in the plots with jute than in those with bare soil. This occurred because part of the rainfall that fell on the jute did not infiltrate but ran off in the material surface, as also observed by Rickson, (2006) and Álvarez-Mozos *et al.* (2014). On the other hand, the surface runoff may be reduced, depending on the type of material used as geotextile or the slope gradient (Fontes, 2016). However, not all periods showed significant difference when compared to the plots without jute, which may indicate that the intensity of the rainfall will have a great influence on the surface runoff, which corroborates with the results obtained by Kalibová *et al.* (2017), who found that jute is not able to respond immediately to strong rains of high intensity, which generates an increase in surface runoff when compared to other geotextiles.

4.2 Plant species survival

As for the survival rate, the species that had the best results were *Arachis repens, Paspalum nicorae* and *Digitaria eriantha*. The result obtained regarding the survival rate of *Arachis repens* was similar to the research developed by Pereira (2006), who observed that the survival rate of legumes planted in a sand mining area in the region of Seropédica (RJ-BR) was higher than 90%, as well as higher than other non-legume species tested.

It was interesting to note that *Chrysopogon zizanioides* had a low survival rate: less than 20%. This contrasts to findings by Pereira (2006), among others, who indicate that this species can adapt to any type of soil, as well as be planted in all periods of the year. The reason for the low survival in our case may either be the quality of the plant material, or the specific experimental site conditions. More research on the species should be conducted in this study region.

4.3 Influence of vegetation cover on erosion processes

As for the relationship between vegetation cover and soil erosion rate and runoff for the jute plots, the result showed no relationship between the parameters analyzed. This stems from the fact that the vegetation has developed partially above the jute and partially under the jute, so that some of the influence of erosion and runoff is controlled by the vegetation, and some by the jute.

For the bare plots, the relationship between vegetation cover and the soil erosion rate and between the vegetational cover and runoff was found to be quite strong for the February measurement. The greater the soil cover by vegetation, the more water is infiltrated, as well as retained on the leaves, and the greater the roughness of the soil, so that the volume of runoff and eroded soil mass is inversely proportional to the vegetational cover (Zuazo & Pleguezuelo,2009; Morgan, 2008).

For the June data, it was not possible to verify a relationship between the vegetational cover and the soil erosion rate or the superficial runoff for the plots without jute. This fact can be justified considering that the cover rate in the second sample presented a significant reduction, with values lower than 25%, due to the approach of winter. During this period, the erosion rate and the superficial runoff are influenced in a more accentuated way by other factors, such as the effect of the roots on the shear strength of the soil, as well as the intensity of rainfall and soil roughness.

5. Conclusion

Among the species selected for the experiment, *Arachis repens* performed best in terms of erosion control and runoff reduction and had the best survival rate.

The mix of species present in the study site also had a considerable contribution in erosion control, and this effect is mainly due to the grasses *Paspalum nicorae* and *Digitaria eriantha* ssp. pentzii, which presented around 70% survival rate, while the other two species had a high mortality rate. In contrast to *Arachis repens*, the local species mix showed less vegetation cover reduction with the decrease in temperatures in the autumn, indicating the importance of considering more than one species for the

recovery of degraded areas in subtropical regions. Digitaria eriantha ssp. pentzii, while showing good performance, is not native to the studied region and has been suggested to be invasive (Cezimbra *et al*., 2021); its use should thus be evaluated with caution. Further studies with native species should be conducted in orer to identify species with potential use, and studying the best ways to use them (type of planting, propagation, etc.).

As for *Chrysopogon zizanioides*, our research is not conclusive, because it cannot be ruled out that the low survival rate of the planted individuals was a result of the non-adaptation of this species to the sandy soils of the region or to the poor quality of the seedlings. Also, the time of planting (summer) may have influenced negatively. In this study, the plots with this species behaved similarly to the control plots without any plantings.

The results showed that vegetation cover greater than 25% significantly influences erosion control and runoff reduction: the greater the vegetation cover, the lower the rate of sediment carry-over and surface rainwater flow. For slopes with less than 25% vegetational cover, erosion and runoff are controlled by other factors, such as the presence of roots in the soil, rain intensity and slope roughness. Further studies should be carried out to better understand these factors.

Literature, in general, indicates the use of geotextile as a technique to help control soil erosion, as well as for better development of vegetation. However, in this experiment, which was conducted on sandy soils slopes with 30° inclination, the use of this material did not show satisfactory results. The presence of jute showed negative or no effects in the control of soil erosion: in some sampling periods, the plots that contained the jute produced twice as much sediment as the plots without jute.

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Conflict of interests

The authors declare that there is no conflict of interest.

Data availability

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