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Scientific Note

Evaluation of the biotechnical characteristics of vetiver and paspalum grasses for use in soil reinforcement techniques under erosion threat[1]

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ABSTRACT

Soil erosion on slopes demands the use of techniques that promote soil cohesion, increasing its shear strength, while contributing to the floristic-landscape recovery. This study aimed to analyze the morphological characteristics of vetiver and paspalum grasses, in order to understand their contribution to soil stabilization, under greenhouse conditions. The following parameters were evaluated: plant height; number of tillers per plant; root length, diameter, volume and dry matter. Both species showed similar values for root length and diameter, while the number of tillers per plant was higher for the paspalum grass. Concerning the plant height, no statistical differences were identified, showing that both can promote a good soil cover. The paspalum grass presented a similar performance in several morphometric characteristics, when compared to the vetiver grass, showing a strong potential to be adopted as part of the techniques on the recovery of degraded areas related to soil stabilization.

KEYWORDS: *Chrysopogon zizanioides* (L.) Roberty, *Paspalum millegrana* Schrad, soil bioengineering, soil stabilization.

RESUMO

Avaliação das características biotécnicas dos capins vetiver e paspalum para uso em técnicas de reforço do solo sob ameaça de erosão

A erosão em encostas ou taludes demanda o uso de técnicas que promovam a coesão do solo, aumentando sua resistência ao cisalhamento, ao mesmo tempo que contribuam para a recuperação florístico-paisagística. Objetivou-se analisar as características morfológicas dos capins vetiver e paspalum, a fim de compreender sua contribuição para a estabilização do solo, em casa-de-vegetação. Os seguintes parâmetros foram avaliados: altura da planta; número de perfilhos por planta; comprimento, diâmetro, volume e matéria seca da raiz. Ambas as espécies mostraram valores semelhantes para comprimento e diâmetro da raiz, embora o número de perfilhos por planta tenha sido maior para o capim paspalum. Em relação à altura da planta, não foram identificadas diferenças estatísticas, mostrando que ambas podem promover boa cobertura do solo. O capim paspalum apresentou desempenho semelhante em várias características morfométricas, quando comparado ao capim vetiver, demonstrando forte potencial para ser adotado como parte das técnicas de recuperação de áreas degradadas relacionadas à estabilização do solo.

PALAVRAS-CHAVE: *Chrysopogon zizanioides* (L.) Roberty, *Paspalum millegrana* Schrad, Poaceae, bioengenharia de solos, estabilização de solos.

As an environment for the development of plant species or enabling ecosystem services (Poesen 2018), soil is a finite resource, generally under a degradation threat represented by erosion. The mitigation of soil degradation processes demands techniques that bring quick and efficient benefits, and with less environmental and landscape impact. Therefore, soil bioengineering techniques have proved to be an important alternative (Bischetti et al. 2021).

Of multidisciplinary nature, soil bioengineering uses living natural materials such as plants - or wood logs - in order to stabilize watercourse banks and natural or built slopes, using biologically active tools (Holanda et al. 2010, Solera et al. 2014, Janssen et al. 2019) to solve soil displacement problems such as erosion, shear and slope instability present in occupied urban areas (Holanda et al. 2008, Giupponi et al. 2019). Soil bioengineering techniques are also responsible for ecological restoration strategies in permanent preservation areas previously occupied by agriculture, or rebuilding those environments modified by floods (Zhanga et al. 2019, Lopes et al. 2020, Ngilangil & Quinquito 2020).

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To achieve a maximum efficiency in the implementation of biotechnologies, it is necessary to select plant species that present suitable morphological characteristics (Machado et al. 2015) on the soil reinforcement. Plants with high root density work as strong tools to increase soil cohesion and prevent possible mass movements, because the shear stress is reduced when the soil moves along the sliding plane (Capilleri et al. 2019). The roots also induce the formation of soil macropores, formed as a result of their senescence and decomposition, which allow a better water movement in the soil profile (Ogilvie et al. 2021).

Although the vetiver and paspalum grasses present different leaf architectures, both species have biotechnical properties of great importance within the context of soil stabilization and mitigation of erosive processes (Holanda et al. 2017), such as fasciculated roots with the ability to reach great depths and expressive root volume (Machado et al. 2018, Carvalho et al. 2020). It is also important to highlight that the grass root fibers increase the soil resistance mainly considering its vulnerability to shear, once they elongate, hindering possible mass movements (Zhu & Zhang 2016).

This study aimed to analyze the morphological characteristics of vetiver and paspalum grasses, in order to understand their contribution to soil stabilization. The experiment was carried out in a greenhouse at the Universidade Federal de Sergipe, in São Cristovão, Sergipe State, Brazil (11º01'53"S; 37º12'23"W), Brazil.

Chrysopogon zizanioides, in a previous research (Machado et al. 2018), showed a more linear growth during the period of 5 months after sprouting, showing that this period might be ideal to identify the best morphophysiological expression. This was the reason for establishing the evaluation period from February to June 2019, in the present study.

Six PVC tubes were used, each measuring 2 m in height, 30 cm in diameter and with capacity for 141 kg of soil. Vetiver grass [*Chrysopogon zizanioides* (L.) Roberty] tillers extracted from the same mother plant were planted in three PVC tubes, under greenhouse conditions. In the remaining tubes, paspalum grass (*Paspalum millegrana* Schrad) seeds were planted, collected from clumps grown in an experimental area near the greenhouse.

Initially, three tillers of vetiver grass were planted, once it does not propagate by seeds, and paspalum grass seeds were sown. After one month of planting, a selection was carried out among the vetiver grass tillers, leaving only the ones that presented the best vegetative development in the tubes (Figure 1). For the paspalum grass, over one month, the seedlings were thinned, with three of the most vigorous ones remaining, and later only the one with the best vegetative development. All tillers and seedlings discarded from both species and tubes were incorporated into the soil.

The soil is classified as Neossolo (Embrapa 2018) or Entisol (USDA 2014) and was collected at the Universidade Federal de Sergipe, in the same area where the vetiver grass tillers and the paspalum grass seeds were collected. The soil used in the PVC pipes was uniformly fertilized considering the values of 4,105 g of $(NH_4)_2SO_4$, 90.46 g of KCl and 225.6 g of simple superphosphate for each kilogram of soil (Santos et al. 2010).

Photos: Francisco Sandro Rodrigues Holanda

Figure 1. Plants of vetiver (A) and paspalum (B) grasses grown in PVC tubes.

The plants were daily irrigated, thus maintaining a humidity equivalent to the field capacity. Soil samples from each treatment were collected for analysis on their chemical properties after the plants were collected and showed CEC values of 2.93 cmol dm^{-3}, pH (H_2O) of 5.4 and V of 61.29 %. Table 1 presents the soil analysis results for each replicate.

After 4 months of planting, the plants were collected (shoot and root matter) from the tubes. To collect the root system without damaging the roots, the tubes were tilted and shaken to cause the soil collapse, in order to reduce the cohesion force between soil and roots, thus facilitating the latter removal. After collecting the plants, a 1-mm mesh sieve was used to collect the finer roots.

All the collected material was taken to the laboratory, to carry out measurements of plant height and root length, using a tape measure, as well as the manual count of the number of tillers of each plant. It was necessary to undo the entanglement of the roots at the bottom of the PVC tubes to identify the length of those that exceeded 2 m in height, as well as washing them to remove the soil. The root upper (neck), medium (branching zone) and lower (cap) diameters were evaluated with the aid of a caliper, and these values were collected in the longest roots of each plant, in a total of 18 roots for the two species, and dried at 60 ºC, for 72 hours. After drying, the shoot and root matter were weighed.

The root volume was calculated by the equation: $V = [(\pi/4) \times d^2] \times C$, where *d* is the average root diameter and *C* the root length.

To analyze and compare the morphometric characteristics of the studied species, the following parameters were evaluated: plant height; number of tillers per plant; shoot dry matter; root length, diameter, volume and dry matter. All the collected data were processed using the IBM SPSS software and the Kruskal-Wallis test, at 5 % of probability, to identify possible statistical differences in the values of the selected parameters. The performance for root length was similar for both species, with no statistical differences (Figure 2). Considering the so-called importance of the vetiver grass as part of the soil bioengineering techniques, due to its high root growth (Singh et al. 2019) and strength, the absence of statistical difference between the species shows that the paspalum grass also has a high potential to be used in soil bioengineering works. Chen et al. (2015), working with species of the Poaceae family, demonstrated that greater root lengths and densities result in a greater initial resistance to soil erosion, allowing a greater structuring, due to the increased carbon contribution and greater concentration of fulvic and humic acids in soils cultivated with grasses.

The fact that the experiment was conducted in an Entisol, characterized by the absence of structure (single grains), became a very favorable environment for the full development of the root system, allowing a more reliable evaluation. Carvalho et al. (2020), studying the root system of paspalum grass cultivated in the same type of soil and using the trench method, showed long roots to the deepest layers of the soil profile (greater than 1.70 m). Holanda et al. (2017), studying the development of the root system of paspalum grass in pots (more confined environment)

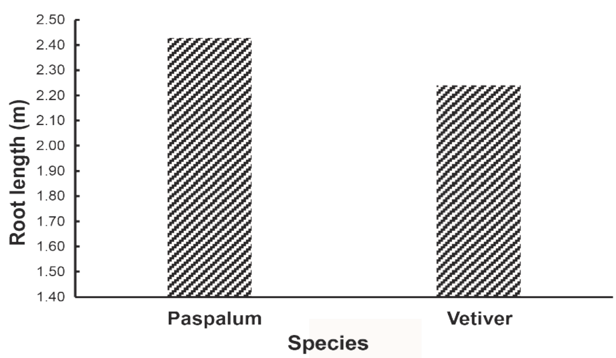

Figure 2. Root length of the paspalum and vetiver grasses.

Table 1. Average data for the soil chemical parameters.

pH (H_2O)	OM (g kg^{-1})	Ca	Mg	K	Na	P	CEC	SB	Al	V (%)
		cmol dm^{-3}								
Paspalum grass										
5.4	0.94	1.16	0.22	0.06	0.24	41.87	2.93	1.70	0.00	57.94
Vetiver grass										
5.4	0.91	1.32	0.07	0.04	0.22	156.40	2.80	1.69	0.00	59.80

and different doses of phosphorus, identified root lengths reaching up to 1.50 m.

The studied species has fasciculated roots, with a large volume of very fine roots occupying a large part of the tube area. According to Ola et al. (2015), fine roots may lead to a remarkable increase in the soil shear strength, hence contributing to anchoring the effect performed by species of the Poaceae family. The stabilizing effect of vegetation from the mechanical interactions between soil and plant roots on slopes (Maffra et al. 2017) and the way the roots are distributed play an important role on the efficiency of biotechnologies. Then, the architectural characteristics of the roots play a very important role in the mechanical soil properties (Ghestem et al. 2014).

In the evaluation of plant height, although the vetiver grass had a higher average data, when compared to the paspalum grass, both species did not show significant differences for the p-value at 0.5 % (Figure 3). Those species have similar potentialities, reaching a maximum height close to 1.65 m, not differing from the findings by Lal et al. (2018), who claim that the vetiver grass can reach up to 2 m in height. It is important to note that despite the weak statistical differences among values for the treatments, numerically, the vetiver grass showed higher plant height values than the paspalum grass, even though it presents a better performance related to root length in the comparison of the two species.

In the development of biotechniques to minimize the effects of accelerating erosion processes, in addition to understanding the root characteristics, it is necessary to pay close attention to the soil cover promoted by the shoot matter. Thus, it is essential to consider the architecture of the plant represented by the arrangement of the shoot or its growth habit.

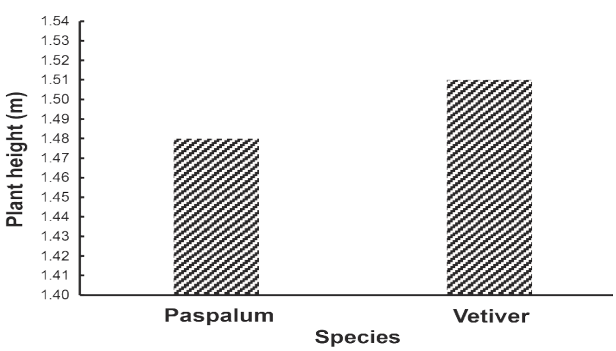

Figure 3. Plant height of the paspalum and vetiver grasses.

Both the paspalum and vetiver grasses have a cespitose growth habit, which refers to the way that some plants grow by releasing tillers, forming a clump. However, the paspalum grass has a more open clump architecture, unlike the vetiver grass, which forms a more upright, more compact clump architecture (Figure 4). This difference in the paspalum grass architecture contributes to a greater soil cover and, consequently, a greater contribution of the shoot matter to erosion control.

Figure 5 shows the total length of the paspalum and vetiver grasses in each of the replications. In a quick view, it is possible to note a more compact and higher plant for the vetiver grass, even though a bigger difference between the two species is not so apparent.

By evaluating the number of tillers per plant, it is shown that the paspalum grass presented values ranging from 22 to 32 tillers per plant, being different in comparison to the vetiver grass, which presented more homogeneous values. Despite this, the values showed no statistical difference between the species (Figure 6).

Tillering in cespitose growth habit is a result from developing axillary buds, which, when located at the stem base, are called basilar buds. The good tillering of both species, in addition to promoting a good soil cover, reinforces the soil cohesion. Machado et al. (2018) reported that the presence of species such as the vetiver grass contributes to the reduction of resistance to soil penetration, due to the greater soil aggregation promoted by its roots, as well as the shoot matter (tillers) promoting a higher rate of recovery of soil aggregation, especially in degraded

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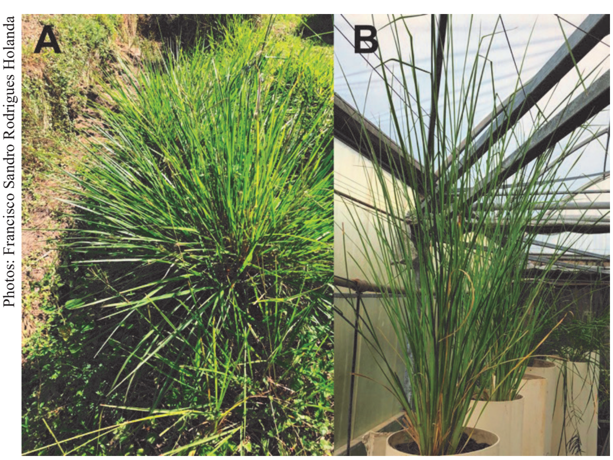

Figure 4. Clumps of the paspalum (A) and vetiver (B) grasses.

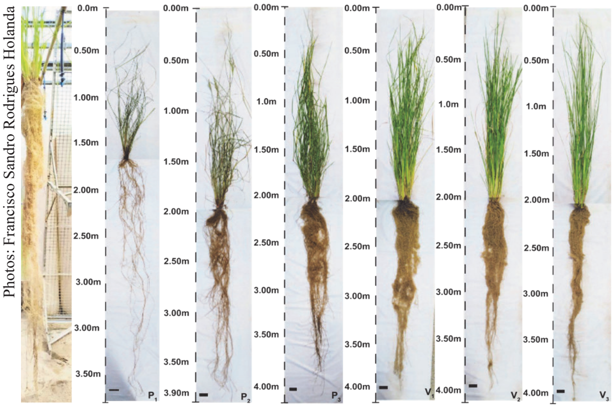

Figure 5. Total length (shoot + root) of the paspalum (P1: paspalum sample 1; P2: paspalum sample 2; P3: paspalum sample 3) and vetiver (V1: vetiver sample 1; V2: vetiver sample 2; V3: vetiver sample 3) grasses.

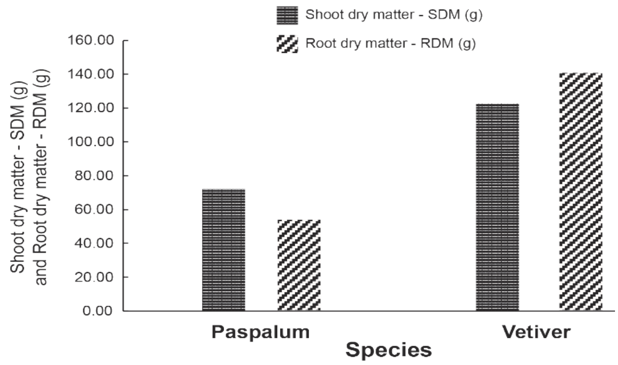

Figure 7. Shoot and root dry matter of the paspalum and vetiver grasses.

soils. It is also important to highlight that a good soil cover directly influences the reduction of *splash*, which promotes the rupture of soil aggregation, sequenced by the sealing of its pores, consequently affecting the water infiltration into the soil.

In the root dry matter analyses, a higher numerical difference was observed for the vetiver grass, when compared to the paspalum grass (Figure 7), possibly due to the exceeding presence of thicker roots. The paspalum grass propagation was through the planting of seeds, and then it likely most showed a great genetic variability, which resulted in performance variation among the data. The vetiver grass presented more homogeneous plants, justified by the planting of tillers from a single mother plant. It was then noticed that, although the paspalum grass presented a greater root length, it also presented a lower root dry matter.

A deeper understanding of root biomass is necessary to assess the importance of its density, since a high root density influences the soil structure (Veylon et al. 2015). This effect is noticed mainly in the shallower layers, where the soil is more vulnerable to erosive processes. It is possible to observe that the density of the root system decreases as depth increases, what may be explained by the characteristics related to the root architectural development in the depth, as well as by the availability of nutrients in the deeper soil layers (Machado et al. 2015).

Regarding the shoot dry matter, no statistical differences could be identified between the studied species. Such finding leads to believe that both species have a similar development potential when dealing with shoot biomass, even though the shoot architecture is more open for the paspalum and more compact for the vetiver grass.

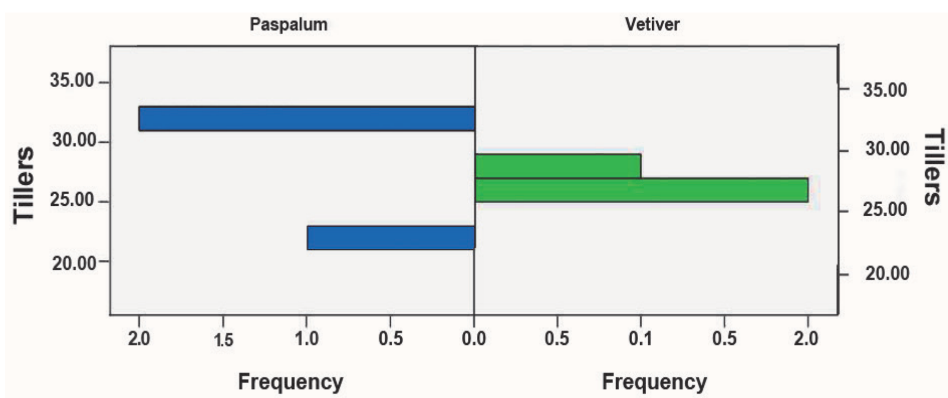

Figure 6. Frequency of tillers of the paspalum and vetiver grasses.

Considering that the vetiver grass is a worldwide studied species (Chong & Chu 2007, Jotisankasa et al. 2014, Santos et al. 2018, Ngilangil & Quinquito 2020), regarding its morphological characteristics with a focus on its use in soil bioengineering techniques for soil stabilization, this similarity in shoot and root dry matter also places the paspalum grass as a species with strong potential for adoption as part of these biotechniques.

It was also measured the upper (neck), medium (branching zone) and lower (cap) diameters of the three largest roots in each PVC tube. In the upper diameter, both species presented statistically equal values, where the paspalum grass varied between 0.38 and 0.92 mm and the vetiver grass between 0.35 and 1.47 mm, showing the largest upper diameter (Figure 8). In the medium plant diameter, both species also presented statistically equal values, with the paspalum grass ranging between 0.34 and 0.78 mm and the vetiver grass between 0.4 and 0.54 mm, also presenting one of the replications that reached 1.69 mm. For the lower diameter, the species showed statistically equal values, with the paspalum grass presenting values between 0.38 and 0.66 mm, differently from the vetiver grass, which varied between 0.35 and 0.51 mm.

The role of superficial roots, especially those with larger diameters, is very important for the plant nutrition balance (Kaushal et al. 2020), due to the direct contact promoted with ions and the kinetics of uptake by root interception. This path of ion uptake is very important for nutrients such as phosphorus, an element of great importance in plant rooting. It is also known that the roots of paspalum and vetiver grasses are fasciculated, presenting several derivations (thin roots) originating from the main axis, roots with smaller diameters, stronger and essential to increase the shear strength (Machado et al. 2015). Liu et al. (2016), studying the vetiver grass, reported that the smaller root diameter present in *Hippophae rhamnoides* is more effective in reducing soil loss in ravines. In this way, thinner roots make possible to increase the density of the root system, forming a dense mesh that boosts the soil resistance (Hao et al. 2020).

Concerning the root volume, statistically significant differences were observed for the p-value at 0.5 % in the paspalum grass (M = 0.437; p-value = 0.543), showing greater values in comparison to the vetiver grass (M = 0.389; p-value = 0.543). While the values for the paspalum grass varied between 0.439 and 0.510 cm^3, the vetiver grass presented values between 0.379 and 0.428 cm^3. The greater root volume of the paspalum grass (Figure 9) may be explained by the contact surface of its roots, which tends to be bigger due to higher values of root length.

In order to understand the contribution of the root volume related to its biotechnical properties, it is important to mention that a greater root volume in the superficial layers can improve the physical conditioning of the soil, such as soil density, porosity and soil organic matter (Zhang et al. 2020). Root systems with a higher surface area to volume ratios generally have a higher nutrient uptake efficiency and gas diffusion rates under normal conditions without water extraction (Guo et al. 2016).

The selection of species to compose the biotechniques is the first step, mostly related to the need of the species that respond positively to increase the root density (Carvalho et al. 2020). The paspalum grass presented values of root length and volume higher than for the vetiver grass, very important morphological characteristics for the best soil anchorage. Although the paspalum grass had

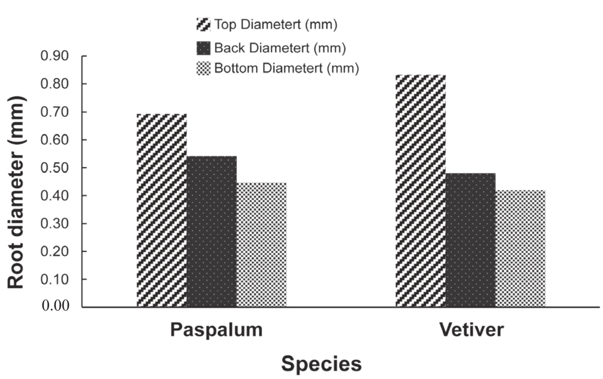

Figure 8. Root diameter of the paspalum and vetiver grasses.

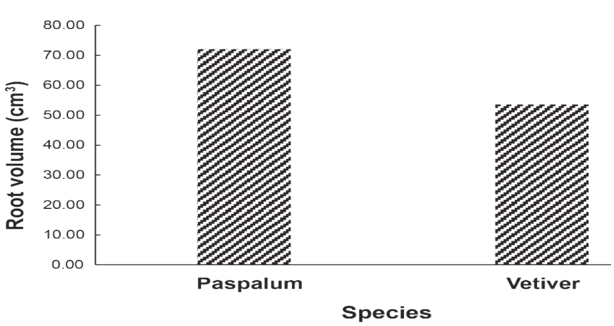

Figure 9. Total root volume of the paspalum and vetiver grasses.

a higher root volume, the vetiver grass showed a greater branching along the main axis of the roots (Figure 5). The vetiver grass has a greater amount of fine roots, a very important characteristic, as stated by Zhu et al. (2016) when reporting that the stress generated during traction will be distributed among the thinner roots, avoiding rupture and preserving the main root. According to Hundek et al. (2017), the finer roots also provide greater amounts of carbon to the organic content, contributing to chemical and physical characteristics such as soil fertility and a greater stability of soil aggregates.

Even though *Paspalum millegrana* is a species that still needs to be studied, and consequently adopted as part of soil bioengineering researches, there is a strong potential to be used in the recovery of degraded areas on soil stabilization, bearing similitudes to *Chrysopogon zizanioides* in many biotechnical characteristics.

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