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REGULAR ARTICLE

Evaluating the suitability of Brazilian native species for riverbank stabilization and protection.

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Abstract

In Brazil, soil and water bioengineering techniques have mainly been used for hydraulic stabilization, water course management and to re-establish the vegetation in fluvial environments. In these techniques plants are considered as an important structural component and their use requires adequate selection. The present study aimed to evaluate the root system and shoot development traits of the *Allamanda cathartica* L., *Ludwigia elegans* (Camb.) H. Hara and *Sesbania virgata* (Cav.) Pers species. The experiment was conducted in a greenhouse at the Laboratory of Soil Bioengineering at the Federal University of Santa Maria. The following variables were evaluated after 120 days: the survival rate, average height, average root collar diameter, average number and sum of shoot length per plant, average number of primary roots and the sum of primary root length, length of the largest root and root dry mass per plant. The percentage of fine roots and coarse roots and distribution of root dry mass percentage in soil depth were also evaluated. The results confirm the suitability of the *L. elegans*, *S. virgata* and *A. cathartica* species for riverbank stabilization and protection in soil and water bioengineering works.

Keywords

Soil and water bioengineering; Vegetation; Live cuttings; Plant traits; Root system.

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Introduction

Soil and water bioengineering (SWBE) is a nature-based solution and its techniques are well established as an engineering discipline and are applied all over the world for protecting and stabilizing river banks, surface erosion, shallow landslides and stabilizing gullies (Preti et al., 2022; Rauch et al., 2022). These techniques are a way to restore riparian zones and most of their associated ecological services: biodiversity, ecological connectivity, carbon storage, pollutant capture, and bank stabilization (Rauch et al., 2022).

SWBE techniques use plants as living building materials and are based on knowledge of their mechanical and biological traits (Rey et al., 2019). The plant species selected must have a compatible set of biotechnical characteristics considered suitable for use in SWBE, which is a fundamental requirement for the success of these interventions (Ghestem et al., 2014; Stokes et al., 2009). The plants should be native pioneer species, capable of growing quickly and developing a dense root system and good soil cover and regenerating after disturbances (Kettenhuber, Oliveira, et al., 2023; Mira et al., 2021) In addition, the species selection should consider reproductive, ecological and phytosociological criteria of the species and local edaphoclimatic conditions (Durlo & Sutili, 2014; Sutili et al., 2018).

The selected plants for SWBE techniques must be easily propagated and able to produce many seeds or vegetative materials (Mira et al., 2021). Vegetative propagation by cuttings is the preferred reproduction form in SWBE works, as it enables obtaining plant material (live cuttings) from mother plants near the intervention site which are more adapted to the local edaphoclimatic conditions to produce a large quantity of seedlings in a shorter period and with reduced costs (Kettenhuber, Oliveira, et al., 2023; Mira et al., 2022). Furthermore, the use of live cuttings additionally contributes to immediate soil stabilization (G. Menegazi & Palmeri, 2013).

In addition to the ability to propagate vegetatively, other plant characteristics are desirable for SWBE, such as fast and dense shoot and root development and stem flexibility (Sutili et al., 2018). The plant rooting pattern may play an important role in assessing the engineering functions of plants and the maximum effective depth of the plants' rooting can reinforce or anchor the soil (Sousa et al., 2020).

In Brazil, SWBE techniques have mainly been used for hydraulic stabilization, water course management and to re-establish the vegetation in fluvial environments (Kettenhuber, Sousa, et al., 2023). However, knowledge of Brazilian native species' performance above and below ground still is incipient. The aim of this study was to evaluate the cutting

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survival, growth and root system structure of the *Allamanda cathartica* L., *Ludwigia elegans* (Camb.) H. Hara and *Sesbania virgata* (Cav.) Pers. species to provide basic information for the selection and the appropriate use of these species in soil bioengineering works for riverbank stabilization and protection. All these are pioneer shrub species which naturally inhabit riparian zones and have wide geographic distribution throughout the Brazilian Atlantic Forest Biome (Kettenhuber et al., 2019).

Materials and methods

The vegetal material for producing the cuttings was collected in early spring from mother plants located in the municipality of Santa Maria in the state of Rio Grande do Sul, Brazil. Mother plants that appeared to have good phytosanitary conditions, ages and similar morphological characteristics were selected. Branches were preferably collected from the last vegetative cycle, packed into plastic bags and then transported to the Soil Bioengineering Laboratory of the Federal University of Santa Maria (29°43’ S and 53°43’ W).

The cuttings were made from the central part of the branch, without leaves, using a straight cut, with a length of 40 cm, keeping at least two buds in each cutting. The cuttings were planted in the proportion 2/3 buried in 60-liter pots filled with a mixture of medium sand and commercial substrate based on *Sphagnum* peat and expanded vermiculite, in the proportion 2:1. The experiment was conducted in an automated greenhouse at a relative humidity of 70%, with temperatures between 20°C and 30°C and using drip irrigation of 60 mL, three times a day.

The following variables were evaluated after 120 days: the survival rate, average height, average cutting diameter, average number, sum of shoot length and shoot diameter sum per plant, average number of primary roots and sum of primary root length, length of the largest root and root dry mass per plant. It was also possible to calculate the number of roots per meter of buried cutting based on the values of the average number of primary roots to better compare with studies that used different cuttings sizes. The distribution of root dry mass percentage in soil depth and the proportion of fine (< 2 mm) and coarse roots (> 2 mm) per length were also evaluated.

The experimental design was completely randomized with 5 repetitions for each species, totaling 20 cuttings. One-way analysis of variance (ANOVA) was used to detect differences in the measured traits among the studied species. In cases when significant differences were detected ($p < 0.05$), a post-hoc analysis was performed using Tukey’s test. The “ExpDes.pt” package (Ferreira et al., 2014) available in the R Software program was used for the analysis (R Core Team, 2024).

Results and discussion

The plants began to successfully sprout a few weeks after plantation. The highest survival and rooting values were observed for *L. elegans* (100%), while *S. virgata* and *A. cathartica* had a survival rate of 80% (Table 1). These results indicate that all species present good rates of cutting survival. According to Cornelini & Ferrari (2008), plants should present survival rates ≥ 70% in order to be used as cuttings in SWBE interventions.

The species presented satisfactory shoot development. *L. elegans* presented higher shoot production, with an average of 4 shoots per cutting, but did not differ statistically from *A. cathartica* with 3.5. *S. virgata*, despite having the lowest number of shoots (2), was the species that grew the most in height (237 cm), differing significantly from *A. cathartica* (138 cm). Shoot production was like that observed by (Sutili et al., 2018), when studying the live cuttings development of the *Phyllanthus sellowianus*, *Gymnanthes schottiana*, *Salix humboldtiana* and *Salix* x *rubens* species during the same period (spring), which presented 2, 3 and 4 shoots per cutting, respectively.

As for shoot length, *L. elegans* recorded the highest sum of shoot length (543.8 cm) and the highest sum of shoot diameter (36.34 mm) but did not differ statistically from the other species. For the species *A. cathartica* and *S. virgata*, similar values of 392.0 and 393.5 cm were observed for shoot length and 28.92 and 27.01 cm for the sum of shoot diameter.

Table 1. Results of the shoot and root system variables.

Parameter	*A. cathartica*	*L. elegans*	*S. virgata*
Survival rate (%)	80	100	80
Average height (cm)	138b	220a	237a
Average cutting diameter (mm)	15.63b	24.6a	16.4b
Average number of shoots	3.5a	4a	2b
Shoot length sum (cm)	392.0^{ns}	543.8	393.5
Shoot diameter sum (mm)	28.92^{ns}	36.34	27.01
Average number of primary roots	40^{ns}	50.5	45
Primary root length sum (cm)	110.8b	201.8a	158.4ab
Root dry mass (g)	52.7b	62.76b	116.95a
Length of the largest root (cm)	58.0	80	100
Number of primary roots/mr of buried cuttings	100	126.2	112.5

Values are the mean ± standard error. Lowercase letters represent statistical difference between species evaluated by Tukey’s test ($p < 0.05$).

The analysis of the aboveground traits, considering the number, length, and diameter of the shoots, allows to conclude that the species that developed the largest shoot volume in the present study was *L. elegans*, followed by *A. cathartica* and *S. virgata*. The use of species that produce higher shoot volume is indicated for SWBE projects. This characteristic is especially important for controlling surface erosion and soil protection (Coppin & Richards, 2007).

Furthermore, Sousa et al. (2020) and Sutili et al., (2012),recommend that the selected species for riverbank stabilization works should present flexible stems, branched and dense shoots, uniform coverage and be perennial. These traits protect the soil against water flow, aid in the interception, evapotranspiration and infiltration of precipitation, increase surface roughness, assist soil retention and reduce sediment transport. *A. cathartica* and *L. elegans* present a perennial and branched shoot, but moderately flexible and not very resistant stems, as opposed to *S. virgata* which presents a slightly branched and sparse foliage with flexible and resistant stems.

In order to ensure the soil cover, it is recommended the planting of these species in high density (Kettenhuber, 2017).

The root development from the cuttings showed that the three tested species developed numerous roots during the evaluation period (Table 1). There was no significant difference between the species for the number of primary roots. *L. elegans* and *S. virgata* presented a number of primary roots of 50.5 and 45, respectively. A smaller number of primary roots (40) were observed for *A. cathartica*. *S. virgata* was distinguished from the other species by presenting larger root system development, reaching 100 cm in length and higher biomass production below the soil due to the large number of secondary roots. *L. elegans* showed the highest values for the sum of the length of the primary root with 201.8 cm, differing significantly from *A. cathartica* with 110.8 cm.

An analysis of distribution of root dry mass percentage in soil depth of the evaluated species showed that 57.8% of the roots of *L. elegans* were concentrated until 30 cm of soil depth, and the largest roots were about 80 cm, while *S. virgata* the largest roots of about 100 cm and 66.7% of the total roots for this specie were concentrated at this depth. In *A. cathartica* the largest roots were about 58 cm and 80.8% of the total roots were concentrated until at this depth (Figure 1).

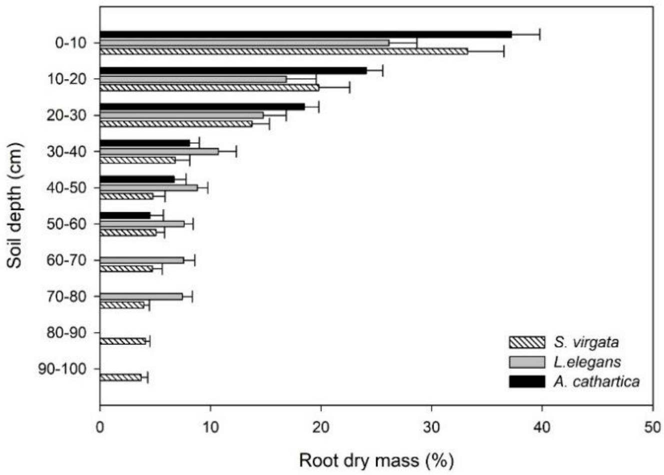

Figure 1. Distribution of root dry mass (%) in soil depth.

The proportion of fine and coarse roots per length show that the species had similar behaviour with values higher than 80% of fine roots, and with *S. virgata* presenting the highest percentage with 90.4% of fine roots (Figure 2).

By analyzing the number of primary roots per meter of buried cuttings, *L. elegans* presented 126.2 roots/m, *S. virgata* had 112.5 roots/m and *A. cathartica* had 100 roots/m. Similar results were observed by Sutili et al. (2018) for *Phyllanthus sellowianus* with 130 roots/m and *Salix X rubens* with 144 roots/m in the spring/summer period, and *Salix humboldtiana* with 74 roots/m and *Gymnanthes schottiana* with 51 roots/m in the autumn/winter 150 days after planting. The biotechnical potential of these species has already been proven and their use is consolidated in SWBE projects (Durlo & Sutili, 2014; Maxwald et al., 2020).

The results about the distribution of root dry mass percentage are relevant for using these species in interventions that aim to control surface erosion and soil stabilization, since fine roots that concentrate in the first layers of soil help in structuring and reducing soil loss, and longer roots act as rods helping to structure the soil layers by anchoring, arching and shoring the soil (Sousa et al., 2020).

The analysis of the root system traits allows concluding that *S. virgata*, *L. elegans* and *A. cathartica* can produce good to excellent initial development of the root traits and have a dense and lateral root system with higher number of fine roots distributed in the soil layers. Dense root systems with a greater number of fine roots help to mechanically structure the superficial layers of soil, as well as to provide mechanical forces. In the case of river slopes, dense root systems are very important because they function as a blanket or mat that structures and confines the soil and protects it by absorbing the hydraulic forces of the water flow (Coppin & Richards, 2007).

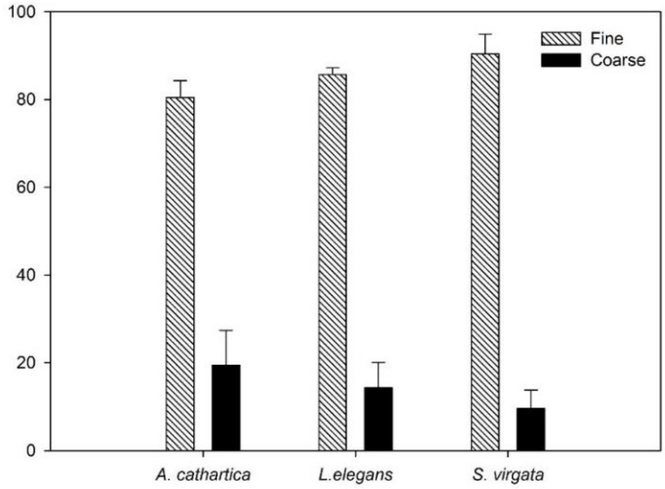

Figure 2. Proportion of fine (< 2 mm) and coarse roots (> 2 mm) per length of the studied species.

Conclusions

The species evaluated in this study proved to have good potential for use in soil and water bioengineering works for riverbank stabilization, water course management and to re-establish the vegetation in fluvial environments.

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