Floresta Ambient., Rio de Janeiro, 2023; 30(3): e20220088
https://doi.org/10.1590/2179-8087-FLORAM-2022-0088
ISSN 2179-8087 (online)

ORIGINAL ARTICLE – Silviculture

# Selecting Native Species for Soil and Water Bioengineering Techniques: Alternative to Restore Areas in Brumadinho, MG, Brazil

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## Abstract

Soil and water bioengineering (SWBE) is a feasible, economical and ecologically friendly alternative to restore the riparian forest areas affected by the Brumadinho mining tailings dam rupture. We evaluated the vegetative propagation capacity by cuttings and initial development of nine native riparian species of the Paraobepa River for use in SWBE techniques. From the results it is possible to separate the species into two distinct groups, namely those that can resprout and produce roots from their cuttings (group 1: *Acnistus arborescens* (L.) Schltdl., *Croton urucurana* Baill., *Gymnanthes schottiana* Müll.Arg., *Indigofera suffruticosa* Mill. and *Sesbania virgata* (Cav.) Poir.) and are suitable for use as live cuttings in SWBE techniques; and those which were only able to produce shoots (group 2: *Casearia decandra* Jacq., *Chrysophyllum marginatum* (Hook. & Arn.) Radlk., *Inga vera* Willd. and *Schinus terebinthifolia* Raddi) and should only be used in seedling form to increase the diversity of the interventions.

**Keywords:** Nature-based solution, riparian forest, cuttings, resprouting, rooting.

## 1. INTRODUCTION AND OBJECTIVES

After the Brumadinho mining tailings dam ruptured in Brazil (Rotta et al., 2020; Thompson et al., 2020), forest restoration activities are among the priority actions to repair the environmental damage caused, especially in the riparian forest areas of the Feijão stream and the Paraopeba River. These areas provide a wide range of key ecosystem functions and services (García-Martínez et al., 2017), such as stabilizing riverbank soil, controlling erosion and sedimentation, connecting different habitat fragments, and providing important habitats for much wildlife (Moraes et al., 2014; Rieger et al., 2014; Fremier et al., 2015).

Soil and water bioengineering (SWBE) is a nature-based solution that comprises a diverse group of low environmental impact techniques in which plants are used as living building materials alone or in combination with inert materials (Zaimes et al., 2019; Bischetti et al., 2021; Preti et al., 2022). These techniques can be used as an ecological alternative or complementary measures to conventional hydraulic or civil engineering approaches to control shallow landslides and soil erosion (von der Thannen et al., 2021; Rauch et al., 2022). In addition to technical effects, SWBE can increase the site biodiversity by promoting vegetation succession and enhancing the quality and diversity of wildlife habitats (Schmitt et al., 2018; Janssen et al., 2019; Zhang et al. 2020; Tisserant et al. 2020). SWBE is therefore a feasible, economical and ecologically friendly alternative to restore the riparian forest areas affected by the Brumadinho mining tailings dam rupture and to reestablish successional trajectories of the ecosystem.

The plants used in SWBE techniques must be native pioneer species that are easily propagated and able to grow quickly in degraded areas and under adverse conditions, developing a dense root system and providing good ground cover. Furthermore, the selected plants should preferably exhibit high tolerance to flooding and burial, drought resistance and ecological value (Evette et al., 2012; Ghestem et al., 2014; Stokes et al., 2014; Mira et al., 2022).

Vegetative propagation is a low-cost, fast and effective way to obtain plant material for the basic SWBE techniques such as live stakes, live fascines, brush mattresses, brush layers, or even for seedling production (Mira et al., 2021, 2022).

This type of propagation enables using native local or regional species harvested from surrounding areas of the intervention site which are more adapted to the local edaphoclimatic conditions, and the production of a large number of seedlings in a shorter time and with reduced costs (Kettenhuber et al., 2019; Díaz-Páez et al., 2021). The successful establishment of cuttings is species-specific and of genetic predisposition (Bischetti et al., 2021) and can be influenced by many physiological and environmental factors, such as cutting age, size and lignification, collection season, auxins, water availability and temperature (Dias et al., 2012; Owusu et al., 2014; da Silva et al., 2017; Davies et al., 2017; Stuepp et al., 2018).

Considering that SWBE has only been implemented in a broader context in the last decade in Brazil (Durlo and Sutili, 2014; Maxwald et al., 2020), there is still little knowledge about the vegetative propagation capacity by cuttings of native species (Vieira et al., 2013; Stuepp et al., 2018) and their potential for use in SWBE works. In addition, the few existing studies are concentrated in some regions of the country, such as the South (Sutili et al., 2012, 2018; Kettenhuber et al., 2017, 2019; Dewes et al., 2019; Maffra et al., 2021) and Northeast (Holanda et al., 2012, 2021; Santana et al., 2012; Araújo-Filho et al., 2013; Rocha et al., 2021). According to Sutili and Gavassoni (2017), the lack of information about local species is often an obstacle to SWBE application in Brazil, and in many cases leads to the use of exotic species or non-vegetative interventions such as geotextile or even concrete.

In this context, the main objective of this study was to select native riparian small trees and shrubs of the Paraobepa River for use in SWBE techniques to restore the riparian forest areas affected by the rupture of the Brumadinho tailings dam through their vegetative propagation capacity by cuttings and initial development of the above- and belowground traits.

## 2. MATERIALS AND METHODS

### *2.1. Species preselection and material collection*

Expeditions to the riparian forest of the Paraopeba River (20° 9' 44" S and 44° 9' 39" W) in Brumadinho, Brazil, were carried out to identify the most abundant and widely available species in the location. We selected this site because it is close to the areas affected by the tailings of the Córrego do Feijão dam. A literature review of these species was then conducted to investigate the available information on their potential for use in SWBE techniques. Nine species of native trees and shrubs were selected (Table 1) considering the following criteria: i) pioneer and hardiness species; ii) high flooding and burial tolerance; iii) drought resistance and iv) ecological value of the species. The *G. schottiana* species has already been successfully used in SWBE studies in Southern Brazil (Durlo and Sutili, 2014; Kettenhuber et al., 2017; Maxwald et al., 2020), especially for streambank stabilization, due to its functional traits and will therefore be used in this study as a reference species. This species is classified by (Marchiori, 2000) as a hygrophilous species, having flexible branches that are very resistant to breakage (Sutili et al., 2012) and good resistance to uprooting (Dewes et al., 2019), which makes it able to resist the force of water during floods and suitable for protecting and stabilizing streambanks.

**Table 1.** The selected nine plant species of the riparian forest of Paraobepa River according to their Latin name, family, growth form, height, ecological traits and value.

| Specie | Family | Growth form | Height | Ecological traits and value | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 |
| *Acnistus arborescens* (L.) Schltdl.[a] | Solanaceae | shrub | 3 to 8 m | ● | ● | ● | ● | |
| *Casearia decandra* Jacq.[b,c] | Salicaceae | tree | until 18 m | ● | | | ● | |
| *Chrysophyllum marginatum* (Hook. & Arn.) Radlk.[c,d] | Sapotaceae | tree | 5 to 10 m | ● | | | ● | |
| *Croton urucurana* Baill.[c,e] | Euphorbiaceae | tree | until 15 m | ● | ● | ● | | |
| *Gymnanthes schottiana* Müll.Arg.[f,g] | Euphorbiaceae | shrub | 1.5 to 6 m | ● | ● | ● | | |
| *Indigofera suffruticosa* Mill.[h] | Fabaceae | shrub | until 1.5 m | | ● | ● | | ● |
| *Inga vera* Willd.[c,i] | Fabaceae | tree | until 25 m | ● | ● | ● | ● | ● |
| *Schinus terebinthifolia* Raddi[c,j] | Anacardiaceae | tree | 2 to 10 m | ● | | ● | ● | |
| *Sesbania virgata* (Cav.) Poir.[c,h,l] | Fabaceae | shrub | 1.5 to 3 m | ● | ● | ● | | ● |

1 – Tolerance to flooding; 2 - Tolerance to burial; 3 - Drought resistance; 4 – Food for wildlife; 5 - Biological nitrogen fixation
[a](Aximoff et al. 2020); [b](Carvalho 2010); [c](Silva et al. 2012); [d](Lorenzi 1998); [e](Carvalho 2014); [f](Durlo and Sutili 2014); [g](Kettenhuber et al. 2017); [h](Moreira and Bragança 2010); [i](Carvalho 2008); [j](Carvalho 2003); [l](Rocha et al. 2021).

The vegetal material for producing the cuttings was collected during the rainy season (November 2021) from mother plants that appeared to have good phytosanitary conditions, age and similar morphological characteristics. The region's climate is classified as Cwa according to the Köppen classification, defined as humid subtropical zone with dry winter and hot summer (Alvares et al., 2013). Branches were preferably collected from the last vegetative cycle, packed into plastic bags to maintain the humidity and transported to the Forest Restoration Laboratory of the University Federal of Viçosa (20° 46' 27" S and 44° 52' 35" W).

## *2.2. Experimental design and conditions*

The cuttings were made from the central part of the branch without leaves using a bevel cut in the lower part and a straight cut in the higher part, with a length of 20 cm and a diameter ranging from 7 to 13 mm, keeping at least two buds in each cutting. The leaves were removed to reduce dehydration. The cuttings were planted in the proportion 2/3 buried in 3.6-liter pots filled with medium-sifted sand. Sand is a very easy substrate for growing plants and harvesting roots (Freschet et al., 2021a). No additional treatment was applied before planting. The experiment was conducted in an automated greenhouse at a relative humidity of 70%.

The experimental design was completely randomized with 4 repetitions with 4 cuttings (4 stakes/pot) for each species at each period evaluated (45 and 90 days), totaling 32 stakes for each of the nine species evaluated (N= 288 stakes total). The vegetative propagation capacity and the initial development of the above- and belowground traits were estimated through the survival and rooting rate, aboveground traits (aboveground biomass (AGB), total shoot length (LS) (Kettenhuber et al., 2019), leaf surface area (LA) (Schneider et al., 2012) and specific leaf area (SLA) (Bochet and García-Fayos, 2015; Boldrin et al., 2017) and belowground traits (belowground biomass (BGB), roots number (NR), total root length (LR) (Kettenhuber et al., 2019) and specific root length of primary roots (SRL) (Freschet et al., 2021b), which were evaluated at 45 and 90 days after planting. Water pressure was used to wash the roots of soil. Primary roots were considered as those directly attached to the cutting (Kettenhuber et al., 2019). The survival rate was defined as the number of live cuttings with shoots and roots.

## *2.3. Statistical analysis*

First, we logit transformed the variables of cutting resprouting rates at 45 days and the total shoot length, leaf area, above- and belowground biomass at 90 days before analysis because the data violated the normality assumption. One-way analysis of variance (ANOVA) was used to detect differences in the measured variables 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 (RCoreTeam 2022). Lastly, the t-test ($p < 0.05$) was used to detect differences between the periods evaluated for each species.

## 3. RESULTS

The results showed that there was a significant difference between species for all variables analyzed at both 45 and 90 days after planting, except for belowground biomass at 45 days and the specific root length at 45 and 90 days (Figures 1, 2 and 3). The plant cuttings of all tested species were able to resprout and produce leaves in the first 45 days. The species *A. arborecens* (Aa), *I. suffruticosa* (Is) and *S. virgata* (Sv), showed the highest rates of sprouting, however, considering both evaluations, they only differed significantly from *C. decandra* (Cd) and *I. vera* (Iv) (Figure 1a).

The species presented resprouting rates between 100% and 18.75% at 45 days and 100% and 6.25% at 90 days. However, only five species cuttings (Aa, Cu, Gs, Is and Sv) were able to produce roots. Among the species that rooted, rooting was higher in Aa when compared to Cu (at 45 and 90 days), Is (45 days), and Gs (90 days), but did not differ significantly from Sv in both evaluations (Figure 1b).

Although not significantly different from the other rooted species at 45 days, Gs reduced its rooting rate from 75% to 43.75% at 90 days. Conversely, Is and Cu increased their rooting rate from 45 to 90 days, with rates going from 50% and 37.5% to 87.5% and 62.5%, respectively, but there was only a significant difference for Is between the evaluated periods.

The species that presented higher and faster development of the aboveground traits were Gs, Aa and Sv (Figure 2). AGB (at 45 days) and LS (at 45 and 90 days) of the Gs cuttings were significantly greater compared to Cu cuttings (45 days) (Figures 2a and 2b). The Aa cuttings showed higher values of LA (at 45 days) and SLA (45 and 90 days), compared to Cu and Is cuttings (Figures 2c and 2d). However, over time, the Gs and Aa cuttings lost some leaves and sprouts, which was verified in the evaluation at 90 days, with a decrease in the AGB, LS and LA variables (Figures 2a, b, c). On the other hand, Sv, Is and Cu significantly increased their AGB and LA at 90 days. These species also increased their LS, but a significant difference was only detected for Is between the periods evaluated (Figure 2b). Sv showed the highest LA and AGB values at 90 days, differing significantly from all other species tested, as well as Aa for SLA (Figure 2d).

Aa and Sv showed the highest NR and LR at both 45 and 90 days but did not differ from some species with lower root growth, such as Is (Figure 3). The BGB at 90 days and the RN verified for the Sv cuttings was higher than that for Cu and Gs cuttings (at 45 and 90 days, respectively) (Figures 3a and 3b). On the other hand, higher values of RL were recorded for the Aa cuttings when compared to the Gs cuttings (at 45 and 90 days) (Figure 3c). Although all species showed an increase in BGB, NR and LR at 90 days (Figure 3a, b, c), significant differences between the evaluated periods were only detected in the BGB of Aa, Cu and Is, and the root length of Is. No significant differences between both the species or the evaluated periods were detected in the SRL.

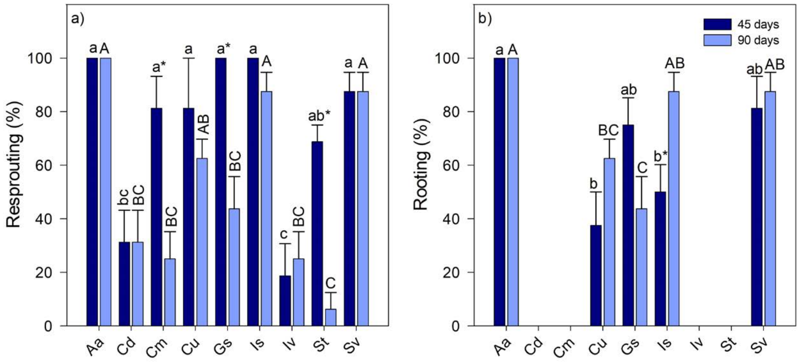

**Figure 1.** Resprouting (%) and rooting (%) of the species in 45 and 90 days after planting. Aa: *Acnistus arborescens*; Cd: *Casearia decandra*; Cm: *Chrysophyllum marginatum*; Cu: *Croton urucurana*; Gs: *Gymnanthes schottiana*; Is: *Indigofera suffruticosa*; Iv: *Inga vera*; St: *Schinus terebinthifolia*; Sv: *Sesbania virgata.* Values are the mean ± standard error. Lowercase letters represent statistical difference between species in the 45 days evaluated. Capital letters represent statistical difference between species in the 90 days evaluated by Tukey's test ($p < 0.05$). *Indicate significant difference between the periods evaluated for each species (t-test $p < 0.05$).

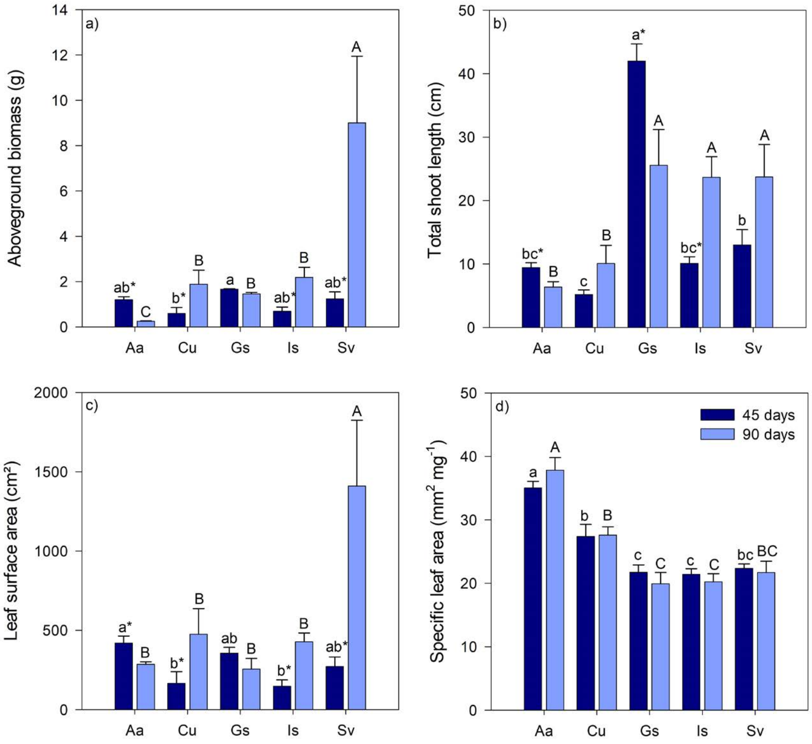

**Figure 2.** Aboveground biomass (AGB, g) (a), total shoot length (LS, cm) (b), leaf surface area (LA, $cm^2$) (c) and specific leaf area (SLA, $mm^2 mg^{-1}$) (d) of the species in 45 and 90 days after planting. Aa: *Acnistus arborescens*; Cu: *Croton urucurana*; Gs: *Gymnanthes schottiana*; Is: *Indigofera suffruticosa*; Sv: *Sesbania virgata.* Values are the mean ± standard error. Lowercase letters represent statistical difference between species in the 45 days evaluated. Capital letters represent statistical difference between species in the 90 days evaluated by Tukey's test ($p < 0.05$). *Indicate significant difference between the periods evaluated for each species (t-test $p < 0.05$).

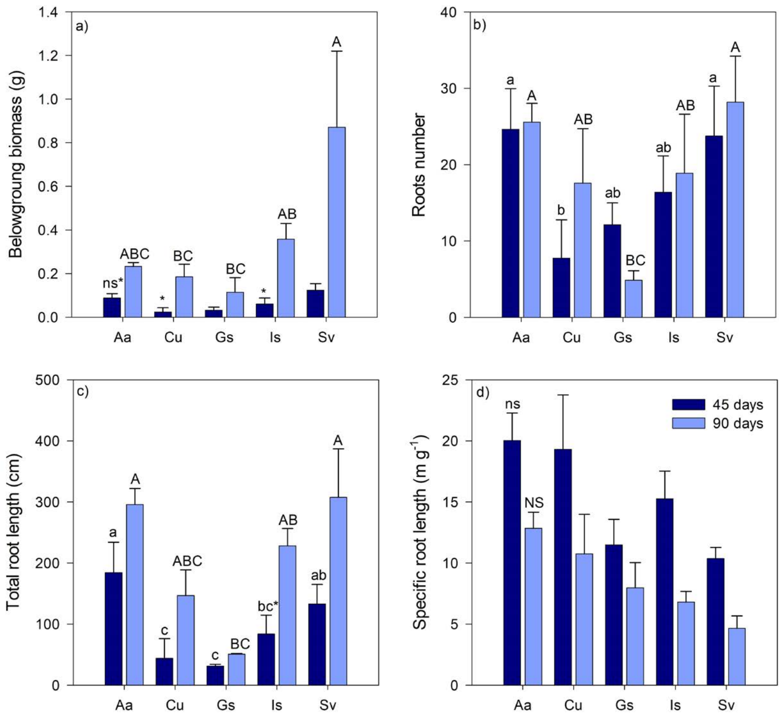

**Figure 3.** Belowground biomass (BGB, g) (a), roots number (RN) (b), root length (RL, cm) (c) and specific root length (SRL, m g$^{-1}$) (d) of the species in 45 and 90 days after planting. Aa: *Acnistus arborescens*; Cu: *Croton urucurana*; Gs: *Gymnanthes schottiana*; Is: *Indigofera suffruticosa*; Sv: *Sesbania virgata.* Values are the mean ± standard error. Lowercase letters represent statistical difference between species in the 45 days evaluated. Capital letters represent statistical difference between species in the 90 days evaluated by Tukey's test ($p < 0.05$). *Indicate significant difference between the periods evaluated for each species (t-test $p < 0.05$).

## 4. DISCUSSION

The use of plants in river engineering projects requires the right choice of species depending on the techniques used and the environmental conditions (Rauch et al. 2022). From the results, it is possible to separate the species into two distinct groups, namely those that can resprout and produce roots from their cuttings (*A. arborecens*, *C. urucurana, G. schottiana*, *I. suffruticosa* and *S. virgata*) that we call group 1, and those that were only able to produce shoots (*C. decandra*, *C. marginatum*, *I. vera* and *S. terebinthifolia*) belonging to group 2. The survival rate is the first indicator of the success of SWBE techniques (Liu et al. 2014). Schiechtl (1973) suggested that only species with survival rates of 70% or higher should be considered for use in bioengineering practice. In contrast, Lammeranner et al. (2005) considered 50% survival rates as sufficient; accordingly, all species belonging to group 1 showed greater survival rates than the suggested satisfactory rate in at least one of the evaluated periods and can therefore be recommended for SWBE construction works.

*G. schottiana,* the reference species, initially produced longer shoots and the second largest leaf area; however, many cuttings of the species lost leaves and shoots between the first and second evaluation. This may have happened due to the inability of these cuttings to root, which decreases from 75% at 45 days to 43.5% at 90 days. In studying the same species in southern Brazil, Sutili et al. (2018) also found variations in the rooting rate of the species, which ranged from 77% to 43% in different experiments, constituting very similar values to those found in this study. Even though its survival rates are not very high, this species has been used successfully in SWBE works as previously mentioned. In comparing the measured traits of this species with the other species belonging to group 1, we can assume that these species are also suitable for use in SWBE practices.

The species of group 1 generally showed good and fast initial development of AGB and BGB, which are considered essential parameters to assess the expected beneficial engineering effects of the selected plant species. According to Weissteiner et al. (2019), the geotechnical protective function against soil erosion of the cuttings depends on their development of the above- and belowground biomass, and therefore the faster the biomass development is, the faster a high erosion protection function will be established (Sousa and Sutili, 2017). These species showed similar both AGB and BGB in the first evaluation at 45 days after planting, while greater differences between the species were detected at 90 days (Figures 2a and 3a). Higher proportions of AGB than BGB biomass were found in both evaluations. According to Carpenter et al. (2008) and Letty et al. (2021), cuttings first use their non-structural carbohydrate reserves to grow new shoots until a sufficient leaf area is re-established and new carbohydrates are obtained by photosynthetic activities, and they can then start the root development only after that. The same behavior was observed by Weissteiner et al. (2019) who evaluated the early growth performance of *Salix purpurea* L. for use in SWBE. For these authors, the protective effects provided by the cuttings in the initial growth phase are due to the AGB, which covers the surface and acts as a protective layer, and a more expressive development of the BGB only occurs after about 4 months.

The *S. virgata* species had the highest AGB, LA, BGB, NR and LR in the last evaluation, followed by *I. suffruticosa* for AGB and BGB. Both species belong to the Fabaceae family, which has many fast-growing pioneer species capable of colonizing degraded areas. These species play a fundamental role in the ecosystem functioning and the recovery of degraded soils due to their ability to fix atmospheric nitrogen through their symbiosis with *Rhizobium* bacteria (Fort et al., 2015). In addition, *S. virgata* is a flood-tolerant species, often inhabiting riverbanks, floodplains, or modified soils (Davanso-Fabro et al., 1998; Moreira and Bragança, 2010). *S. virgata* also has a moderate ability to compete with grasses and stump regrowth after cutting or fire (Araujo et al., 2004) and produces a large quantity of long-term viable seeds (Rocha et al., 2021). The AGB and BGB of cuttings of the species were higher than those found by Kettenhuber et al. (2019) in the autumn/winter period in the southern region of Brazil. These authors reported high mortality of cuttings in the same period evaluated (spring/summer) due to the attack of larvae which feed inside the cuttings.

The SLA and SRL of the five species of group 1 ranged between 19.9 and 37.8 $mm^2\ mg^{-1}$ and 4.65 to 20.03 $m\ g^{-1}$, which was consistent with the range found in species suggested as suitable plants for SWBE in Europe (Erktan et al., 2013; Boldrin et al., 2017). *A. arborecens* showed the highest survival rate regardless of the period evaluated, with all of its cuttings producing shoots and roots. In addition, the species had the highest SLA and SRL and the second highest root length. These are acquisitive trait values which are usually associated with fast initial growth. SLA is positively related to the growth rate due to high light interception, photosynthesis and net carbon gain (Gastauer et al., 2020), and SRL with a fast-growth plant strategy (Hogan et al. 2020). Furthermore, high SRL implies more numerous thinner roots and low SRL means less but thicker roots (Stokes et al., 2009). Plants with high SRL are therefore desirable to reduce soil erosion because fine roots are more efficient in soil fixation and have higher tensile strength values, thereby more effectively contributing to increasing soil shear strength (Reubens et al., 2007; Hudek et al., 2017). Aximoff et al. (2020) indicate the use of the species *A. arborecens* as an attractive plant in the nucleation process during the recovery of disturbed sites in the Atlantic Forest. In addition to its pioneering behavior, the species' large supply of flowers and fruits attracts a wide assemblage of nectarivorous and frugivorous birds, which bring propagules from other forest areas and favor local ecological succession.

*C. urucurana* showed the second highest SLA and SRL values, confirming that the species has rapid growth and the ability to survive disturbances. This species is recommended for restoration of riparian forests, where it tolerates waterlogging and flooding, and can be planted in depletion areas up to 1 m of water column (Carvalho, 2014) and has been successfully used for forest restoration in mined areas (Martins et al., 2021).

Among the species belonging to group 1, the shrub growth form prevailed. These results confirm those found by Mira et al. (2021) in studying the asexual reproductive characteristics of native species for SWBE in the West Indies, where shrubs showed greater ease of rooting from cuttings than trees. According to these authors, the high resprouting ability of smaller plants, such as shrubs, is a strategy to compensate for their frequent vulnerability to disturbance, while trees are less vulnerable to many disturbances due to their more robust size. Furthermore, in many cases, the branches of tree species are more lignified than those of shrubs and may possess anatomical barriers to rooting due to the development of a fiber ring composed of highly lignified sclerenchyma cells. Several authors have also suggested that the rooting capacity of the species depends on the hormonal balance and physiological condition of the donor plant, such as the presence of auxins that stimulate rooting and the content of carbohydrate reserves present in the cuttings (Dias et al., 2012; da Silva et al., 2017; Davies et al., 2017; Stuepp et al., 2018). One of these factors or a combination of them probably explains the lack of rooting of *I. vera, S. terebinthifolia, C. decandra*, and *C. marginatum*.

Santos et al. (2011) did not find rooted cuttings of *I. vera*, even with the application of indol butyric acid (IBA). These authors attributed the absence of rooting to the high sclerification degree of the species cuttings. The absence of rooting for *S. terebinthifolia* cuttings is contrary to the results found by Holanda et al. (2012), who verified 47.1% rooting without the use of IBA and 66.8% with the use of IBA at a concentration of 2500 $mg.L^{-1}$ in the northeast region of Brazil. According to Pilatti (2018), this species presents great phenotypic and genetic variability depending on the region where it occurs, being able to colonize new areas by ecological fitting. This may explain the differences in the rooting rate of cuttings collected in different regions of the country. Even though *I. vera*, *S. terebinthifolia*, *C. decandra*, and *C. marginatum* did not present satisfactory development for their use in the form of cuttings, they have morphological and ecological characteristics (Table 1) which qualify them to be used in SWBE and can be propagated by seeds and used to increase the diversity of species.

In addition to the use of SWBE techniques, the use of vegetative propagation by cuttings is an alternative to produce native seedlings of the species tested for restoration of degraded ecosystems in the Atlantic Forest (de Oliveira and Ribeiro, 2013; Stuepp et al., 2018). Negative aspects of using vegetatively propagated plants can be overcome by using a large number of plant donors to increase genetic variability and by using these plants only for the first restoration steps before using those propagated from seeds (Ramos-Palacios et al., 2012). If applied consistently, vegetative propagation can be an excellent alternative to produce plants for environmental purposes.

## 5. CONCLUSIONS

Overall, the results of this study enable applying SWBE techniques using native species to restore the riparian forest areas affected by the Brumadinho tailings dam collapse and will contribute to increase the number of SWBE interventions in Brazil. The *A. arborecens*, *C. urucurana, G. schottiana*, *I. suffruticosa* and *S. virgata* species were suitable for using their live cuttings in SWBE techniques, unlike the *I. vera*, *S. terebinthifolia*, *C. decandra*, and *C. marginatum* species which should only be used in the form of seedlings to increase the diversity of the interventions. More efforts should be made to know the potential of native species in the form of cuttings to improve SWBE practices in Brazil as a restoration technique, including field studies and longer monitoring periods.

## SUBMISSION STATUS

Received: 30 Nov. 2022
Accepted: 01 Aug. 2023
Associate editor: Marcos Gervásio Pereira

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Paula Letícia Wolff Kettenhuber: Conceptualization (Equal), Data curation (Lead), Formal analysis (Lead), Investigation (Lead), Methodology (Equal), Validation (Equal), Writing – original draft (Lead), Writing – review & editing (Lead).
Diego Aniceto dos Santos Oliveira: Conceptualization (Supporting), Resources (Lead), Writing – review & editing (Equal).
Sebastião Venâncio Martins: Conceptualization (Equal), Data curation (Supporting), Formal analysis (Supporting), Funding acquisition (Lead), Methodology (Equal), Project administration (Lead), Supervision (Lead), Validation (Equal), Writing – original draft (Supporting), Writing – review & editing (Equal).

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