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ORIGINAL ARTICLE

Propagation and establishment of rupestrian grassland grasses for restoration of degraded areas by mining

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Abstract
Investigations on the propagation and establishment of native grasses of rupestrian grassland on degraded substrates are essential to enable their use in the restoration of degraded areas, thus reducing the use of exotic species. This study aimed to evaluate the sexual and asexual propagation, establishment and growth of *Axonopus laxiflorus* (Trin.) Chase and *Sporobolus metallicolus* Longhi-Wagner & Boechat, two native grasses from rupestrian grassland developed on laterite substrate of an area degraded by bauxite mining. In greenhouse experiments, *A. laxiflorus* was propagated by tillers and *S. metallicolus* by seeds and tillers. Both species were also evaluated for germination in a germination chamber on the treatments: control, addition of potassium nitrate and heating at 80 °C for 2 min. In these evaluations, success of *S. metallicolus* germination was between 77 and 90%, without significative difference among treatments, whereas *A. laxiflorus* did not germinate. In the laterite substrate, *S. metallicolous,* propagated by seeds, showed 29% of survival, whereas in the vegetative propagation all plants of the two species survived. Eight months after starting the tiller experiment, *S. metallicolus* and *A. laxiflorus* presented a biomass increase of 239 and 75%, respectively. Although *A. laxiflorus* showed root biomass approximately seven times higher than *S. metallicolus*, the two species presented similar root length, that is, *S. metallicolus* contained more fine roots. The results show that the species can efficiently propagate vegetatively and, in the case of *S. metallicolus,* sexually. The success of the species in a substrate poor in nutrients and rich in Al, Fe and Mn indicates that they can be used in the restoration of areas degraded by bauxite and iron mining, which are important mining activities in Brazil.

Keywords Germination · Poaceae · Revegetation · Rock outcrops · Vegetative propagation

1 Introduction

The Brazilian rupestrian grasslands are among the most diverse phytophysiognomies in the world. Even though they occupy only 0.78% of the Brazilian territory, these environments harbor 14.7% of the known vascular plant species in Brazil (Silveira et al. 2015). Among the great botanical diversity of the rupestrian grassland, grasses stand out for presenting great diversity and abundance in this environment. Indeed, they have been reported, in several surveys, as one of the families with the greatest species richness (Viana and Lombardi 2006; Mourão and Stehmann 2007; Messias et al. 2011; Jacobi and Carmo 2012; Carvalho et al. 2014), as well as high dominance (Messias et al. 2011, 2012; Carvalho et al. 2014; Carmo et al. 2016). These species are adapted to extreme environmental conditions such as shallow and dystrophic soils with low water retention (Benites et al. 2007; Vincent and Meguro 2008; Messias et al. 2013), similar to those found in degraded environments (Bradshaw 1997; Teixeira and Lemos Filho 1998; Wang et al. 2008). This is the reason why many of these species have been indicated for use in

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the restoration of degraded areas (Jacobi et al. 2008; Figueiredo et al. 2012; Lima et al. 2016).

Coincidentally, there is a great demand for these plants for the restoration of degraded areas in the rupestrian grassland (Lima et al. 2016), especially in areas impacted by mining, widely present in these environments (Jacobi et al. 2007; Neves et al. 2016). In the severely impacted areas by mining (Castro et al. 2011), grasses adapted to extreme soil conditions can establish more easily, promoting the coverage of the substrate, reducing the erosion and facilitating the establishment of other species in the area (Lima et al. 2016).

In spite of the great diversity and abundance of grasses in the rupestrian grassland and the demand for native species in the restoration of degraded areas, so far, grasses of this phytophysiognomie are not used for this purpose. The non-use of native grasses in the restoration of degraded areas is mainly due to the lack of knowledge about management practices and the reproductive biology of native species (Fernandes et al. 2016; Nunes et al. 2016). In general, the few studies on the sexual propagation of native grasses of rupestrian grassland show low-germinability success, due as much to the low number of viable seeds and to the presence of some kind of dormancy in the seeds of many species (Figueiredo et al. 2012; Le Stradic et al. 2015).

Despite the guidelines of Brazilian legislation (IBAMA 2011) and the interest of some companies in using native species in the restoration of degraded areas (Griffiith and Toy 2001), the limited knowledge about native species, especially grasses, contributes to the situation that companies to use exotic and invasive species, which can bring even more damages to the rupestrian grassland (Barbosa et al. 2010; Fernandes et al. 2015; Fernandes and Barbosa 2013). Thus, it is necessary to continue investigating the germination and establishment of species not yet studied and to evaluate other propagation forms, such as, for example, vegetative propagation. Vegetative propagation may be an option or complementation to sexual propagation of many grasses of rupestrian grassland that present low percentages of germination (Figueiredo et al. 2012; Le Stradic et al. 2015) and difficulty in seedling establishment in inhospitable environments, commonly found in degraded areas (Le Stradic et al. 2014). Thus, vegetative reproduction can represent a means that allows the use of the diverse flora of grasses of the rupestrian grassland in the degraded areas restoration, as it has been successfully carried out with *Echinolaena inflexa (Poir.) Chase*, a native grass of rupestrian grassland used in the revegetation of gullies (Marques et al. 2014).

Studies on forms of propagation with native grasses are one of the first steps to allow the use of these species in the restoration of degraded areas (Fernandes et al. 2016). In the case of native species with some degree of extinction, threat studies on forms of reproduction can help in the conservation of the species. In addition to the natural benefits of the use of native grasses in the restoration of degraded areas, the management of these species, for example collection and processing of the seeds, can provide source of income for the local populations and, concomitantly, arouse in this population to greater interest in the preservation of rupestrian grassland (Rede de Sementes Xingu 2016).

Axonopus laxiflorus (Trin.) Chase and *Sporobolus metallicolus* Longhi-Wagner & Boechat are native grasses of rupestrian grassland which present potential for application in the restoration of degraded areas due to their morphological characteristics and tolerance to extreme soil conditions. The scarce knowledge about these species is exemplified, in the case of *A. laxiflorus,* in the description of its occurrence and dominance in some areas of the rupestrian grassland (Messias et al. 2011, 2012). With regard to *S. metallicolus*, it is known that the species is vulnerable to the risk of extinction (COPAM 2008) and indicated for use in the restoration of degraded areas (Lima et al. 2016).

Thus, the objective of this study is to evaluate the establishment, sexual and asexual propagation of *S. metallicolus* and *A. laxiflorus*, two native grasses of Minas Gerais rupestrian grassland, in laterite substrate of an area degraded by bauxite mining.

2 Materials and methods

Substrate collection and characterization – The substrate used in this study was collected in a degraded area of an abandoned bauxite mine, located in the Cachoeira das Andorinhas Environmental Protection Area, Ouro Preto, Minas Gerais, Brazil. The mine was closed more than 40 years ago, and it is mostly devoid of vegetation, mainly due to the inhospitable characteristics of the substrate, as the lack of essential nutrients for plant development and the high content of toxic elements to plants (Machado et al. 2013; Figueiredo et al. 2015).

The climate of the region, according to Koppen classification (Alvares et al. 2014), is Cwb, mesothermic moist, with mild and rainy summers and dry winter. A weather station (Watch Dog 200) installed near the collection area in 2012 and measurements taken in 2010 supplied the annual rainfall and average temperature of 1188 mm and 17 °C, respectively. In this period, about 93% of the recorded precipitation occurred from October to April (Valim et al. 2013; Figueiredo et al. 2015).

At the spots of this degraded area where the substrate was non-cohesive, 0.108 m^3 of the first 20 cm of the superficial substrate was collected. After collection, the substrate was homogenized and evenly distributed in nine wooden boxes measuring 50 cm × 50 cm in area and 10 cm in height. Subsequent to the homogenization of the substrate, five samples were taken for physical (grain size) and chemical analyses (total concentration of chemical elements and fertility).

The laterite substrate used in this study showed the predominance of coarser grain-size fractions. The fractions gravel, granule and very coarse sand constituted approximately 60% of the material. On the other hand, less than 5% of the material belonged to fractions with dimensions smaller than 230 µm (silt and clay) (Table 1). The fertility and chemical composition of the substrate presented very low values for macronutrients and parameters important to plant development, such as P, N, Mg, Ca, K, cation exchange capacity (CTC), organic matter content and pH. On the other hand, potentially toxic elements such as Al, Fe, Ti and V were present in very high concentrations (Table 1).

Plant material – The vegetative portions and spikelets of *A. laxiflorus* (voucher-29148) and *S. metallicolus* (voucher-29150) grasses used in this study were collected in natural populations located in an area of ferruginous rupestrian grassland, in the Brígida mountain range (20°21′S, 43°30′W), in Ouro Preto, Minas Gerais, Brazil.

The spikelets were collected manually, totaling at least 50 individuals per species, and when they were in the natural process of dispersal, that is, with mature diaspores. The spikelets of *A. laxiflorus* were collected in February 2014, dried in the shade, stored in paper bags and stored under refrigeration (8 °C) until the start of the germination experiments, as suggested by Salomão and Silva (2003). The spikelets of *S. metallicolus* were collected in July 2015, dried in the shade and immediately sent to the germination experiments.

Prior to the germination experiments, the diaspores of both species were submitted to a selection process, to remove impurities (wraps that covered the caryopses, empty spikelets and other materials). Initially, the shells covering the caryopses were detached by the slight friction of a portion of spikelets between the palm of the one hand and the thumb of the other hand. Afterward, the spikelets and full caryopses were separated from the other impurities by density (Figueiredo et al. 2012). Due to the difficulty in removing the wrapping adhered to the *A. laxiflorus*

Table 1 Fertility, total concentration of chemical elements and percentage of grain-size fractions in the laterite substrate

Fertility

pH	OM	N	P-rem	P	K	Ca^{2+}	Mg^{2+}	H+Al	SB	CTCef	CTCpH7	V	m
	dag kg^{-1}		mg l^{-1}	mg dm^{-3}		cmolc dm^{-3}						%	
5.12	1.44	0.22	12.9	0.63	4.2	0.27	0.03	4.14	0.31	0.37	4.45	7.04	24.2

Total Concentration

	Macronutrients mg kg^{-1}							Micronutrients mg kg^{-1}				
	Ca	Mg	K	P	S			Cu	Fe	Mn	Mo	Zn
	285	287	364	679	381			48	182539	340	4,4	44
Non-essential Elements mg kg^{-1}												
Al	Ba	As	Co	Cr	Ni	Sc	Sr	Th	Ti	V	Y	Zr
157217	26	68	24	366	28	12	64	40	15201	367	24	345

Grain Size %

CGR	GR	VCS	CS	MS	FS	VFS	S/A
31.2	14.4	12.9	12.8	8.8	9.2	5.8	4.9

OM organic matter, *P-rem* remnant phosphorus *SB* sum of bases, *CTCef* effective cation exchange capacity, *CTCpH7* cation exchange capacity in pH 7.0, *V* base saturation, *m* aluminium saturation. *CGR* coarse gravel (> 4 mm); *GR* gravel (> 2 mm); *VCS* very coarse sand (> 1 mm); *CS* coarse sand (> 0.5 mm), *MS* medium sand (> 0.25 mm), *FS* fine sand (> 0.125 mm); *VFS* very fine sand (> 0.063 mm); *S/A* silt and clay (< 0.063 mm). Fraction classification based on Wentworth (2011) caryopses, only the outermost wrapping was removed. In *S. metallicolus*, all the wrappings were removed leaving only caryopses. During the selection process, the percentage of full spikelets of *A. laxiflorus* was determined as suggested by Brasil (2009). To facilitate the description, the *A. laxiflorus* spikelets and the *S. metallicolus* caryopses used in the experiments will be referred to as seeds.

After the selection, samples of the seeds were used to determine the mass of one thousand seeds, according to the methodology proposed by Brasil (2009). Another portion of the seeds was used for the germination tests in the laboratory, in order to evaluate their germinability (percentage of germination) (Ranal and de Santana 2006). These tests were performed on petri dishes lined with two sheets of filter paper and sealed with adhesive tape that prevent loss of water by evaporations and avoid necessity of water addition during the experiment. For each treatment, four plates were used, in which 25 seeds were placed. The numbers of seeds and replicates used were defined based on the quantity of available seeds for all experiments. The plates were kept in a germinating chamber (B.O.D.) under photoperiod and at controlled temperature. The position of the plates in the chamber was altered daily, as well as the occurrence of germination was measured by the observation of the radicle emergence to the naked eye (when it reached about 2 mm in length). The germination experiments were considered finished 7 days after the last germination.

We applied three treatments: control, nitrate treatment and heat treatment. In the control treatment, the seeds were placed to germinate in photoperiod with 12 h of light, constant temperature of 25 °C and moistened with 4 ml of Nystatin solution (1000 IU/L), in order to moisten the seeds and reduce the fungi development. The germinability was also assessed with the addition of 0.2% of potassium nitrate to the Nystatin solution. Some grasses from savanna environments are stimulated to germinate in the presence of nitrate ions (Carmona et al. 1997, Figueiredo et al. 2012). Under field conditions, the presence of nitrate ions indicates the decomposition of the organic matter and, consequently, a more fertile environment to establishment of seedlings. (Carmona et al. 1997). In addition to these treatments, germinability was evaluated in the heat treatment, where the seeds were submitted to a temperature of 80 °C for 2 min, before being placed in the germination chamber under conditions similar to those of the control treatment. The heating of seeds for 2 min simulates the passage of fire which stimulates the germination of some grasses (Figueiredo et al. 2012; Le Stradic et al. 2015).

To verify the existence of significant differences between the percentages of germination in the different treatments, analyses of variance (ANOVA) were performed, preceded by tests of normality and homogeneity of variances. Since ANOVA showed no significant differences between the treatments, no post hoc test was used. Statistical tests were performed at 5% significance using the software MINITAB 16.0®.

Germination, establishment and growth of *S. metallicolus* on laterite substrate from the area degraded by bauxite mining were also evaluated. This evaluation was not performed with the *A. laxiflorus*, since the seeds of this species did not present germination in any of the treatments tested. The 3850 seeds of *S. metallicolus*, available for this test, were uniformly sown in three germination boxes containing the laterite substrate. These boxes were kept in a greenhouse at constant temperature of 25 °C, natural light, humidity of 60% and irrigation of 3.6 mm, distributed four times a day. The irrigation volume used in the experiment is equivalent to the rainfall average in the region where the seeds were collected.

Seven months after planting the seeds, the number of plants in each germination box was counted. Subsequently, six sample units of 6.28 cm^2 each were randomly demarked in each germination box. The plants in these sample units (total of plants in the samples units in each plot 24, 28 and 47) were collected and used to determine the dry biomass, length of the roots and percentage of roots with diameter less than 0.5 mm. The values obtained were used to calculate these parameters per square meter. Dry biomass was determined after washing and drying the plants at 100 °C up to constant weight. To determine the root length and diameter, the roots were scanned still fresh using an Epson 11000 scanner. The images were analyzed using the Winrhizo arabidopsis ® software.

Vegetative propagation – In July 2015, clumps of *A. laxiflorus* and *S. metallicolus* were collected in the area of natural occurrence and divided into tillers. The aerial portion and the roots of *A. laxiflorus* tillers were cut with approximately 8 and 2 cm, respectively (mean dry biomass 3.56 g), while tillers of *S. metallicolus* were trimmed with about 2 and 1 cm of shoot and roots, respectively (mean dry biomass 0.18 g). At the time of collection, 30 tillers of each species were randomly separated for the determination of the mean dry biomass of the collected tillers. These tillers were washed, dried in an oven at 100 °C until constant mass and weighed with a precision balance.

Forty eight *A. laxiflorus* tillers were equally distributed and planted in three wooden boxes previously filled with laterite substrate. For *S. metallicolus*, which had a smaller size, 75 tillers were also divided equally into three boxes. These boxes were kept in a greenhouse under the same conditions as the boxes of the *S. metallicolus* germination and establishment tests, in laterite substrate, as previously described.

Eight months after planting the tillers, all plants were collected and the survival rate, dry biomass of the roots and aerial part of all plants were determined. In order to determine the length and diameter of the roots, three individuals of *S. metallicolus* per box were randomly separated. Five samples of *A. laxiflorus* roots were randomly selected per box, due to the impossibility of individualizing the roots of each individual. Root samples of *A. laxiflorus* and root of selected individuals of *S. metallicolus* were digitized for the determination of the root length and diameter. After the digitization, these plants were washed and dried at 100 °C until constant weight and the dry biomass was determined. The values of the dry biomass obtained in each box and the values of dry biomass and roots length per sample were used to calculate the values of these parameters for each species per square meter.

3 Results

The seeds of both species presented small dimensions, with a thousand full seeds (seeds with caryopses) mass of *A. laxiflorus* and *S. metallicolus*, respectively, 0.124 and 0.010 g. The full seeds of *A. laxiflorus* represent only 0.75% of seeds collected. Although in absolute values *S. metallicolus* presented a slightly higher germinability under the heat treatment of the seeds (90%), this value was not significantly different from the other treatments that presented a mean germinability of 79% (± 2%). The germination of the *S. metallicolus* seeds occurred during 66 days, and 60% of the seeds germinated during the first 14 days of the experiment. Seeds of *A. laxiflorus* did not germinate with the treatments used.

Eight months after planting *S. metallicolus* seeds on the laterite substrate, an average of 369 (± 58) plants was recorded in each germination box. However, it was observed that some individuals died during the experiment, possibly due to competition caused by the high density of plants. Due to the small size and the large number of seedlings, neither the number of dead seedlings nor the time of death was quantified. It is important to note also that 8 months after planting, about one percent of the *S. metallicolus* plants started the seed production.

Regarding vegetative propagation, both species showed 100% chance of survival and good growth in the laterite substrate. *Axonopus laxiflorus* and *S. metallicolus* presented a biomass increase of, respectively, 75 and 239%. By the end of the experiment, 75% of *S. metallicolus* individuals had already begun seed production. The values of the parameters related to the biomass and morphology of the both species evaluated in vegetative and seed propagation are summarized in Table 2.

4 Discussion

Laboratory germination – *Sporobolus metallicolus* presented high germinability under controlled conditions, demonstrating that the species presents a high percentage of viable seeds and does not have any type of dormancy that could be a hindrance to sexual propagation when synchronized germination is desired for the restoration of a degraded area, for example. Considering the diversity of reports in the literature describing the difficulty of propagating native grasses of savannas (Carmona et al. 1998, 1999; Figueiredo et al. 2012; Kolb et al. 2013), grasses such as *S. metallicolus*, which present germinability around 90%, should be considered as promising for use in the restoration of degraded areas.

The high viable seed production observed in *S. metallicolus*, together with the absence of dormancy, facilitates the management of the species for the restoration of degraded areas or for the conservation of the species. In addition, rapid and synchronous germination provides rapid coverage of the area to be occupied (Aires et al. 2013) and reduces the chances of damaging the seeds, such as those caused by pathogens and predators or their transport to other places by ants (Beckman and Muller-Landau 2011; Leite et al. 2013).

Contrary to *S. metallicolus*, the full seeds of *A. laxiflorus* did not germinate under the conditions evaluated. Probably, such failure was due to the presence of some kind of dormancy in the seeds, possibly allied to the low number of viable seeds. Studies with other species of the genus *Axonopus* native of Cerrado revealed that most of them present very low-germinability or viable seeds (Carmona et al. 1998, 1999; Aires et al. 2013; Kolb et al. 2016). Previous research showed that seeds of *Axonopus pressus* did not germinate (Kolb et al. 2016), whereas two other studies presented germinability for *Axonopus brasiliensis* of less than 4% (Kolb et al. 2016; Aires et al. 2013).

In the present study, in addition to the absence the germination of full seeds of *A. laxiflorus,* this species showed very low percentage of this kind of seeds (0.75%). In spite of the negative results for sexual propagation, *A. laxiflorus* seems to have an efficient vegetative propagation strategy, because in some areas of the rupestrian grassland this species presents significant coverage index (Messias et al. 2011, 2012). The failure to germinate abundant and dominant native grasses of rupestrian grassland has been reported for other species (Figueiredo et al. 2012), evidencing the need to deepen the studies on seed viability, dormancy, strategies to prevent dormancy and forms of storage (Carmona et al. 1998; Kolb et al. 2016). Another hypothesis to be considered is that sexual reproduction is not the main form of propagation of some grasses in savannas, as speculated by some authors (Aires et al. 2013; Le Stradic et al. 2015).

Propagation by seeds in laterite substrate – The laterite substrate used in this study is characterized by the lack of

Table 2 Plant parameters measured in the *S. metallicolus* vegetative and sexual propagation and *A. laxiflorus* vegetative propagation (mean ± SD)

	S. metallicolus seed	*S. metallicolus*	*A. laxiflorus*
Root/shoot biomass	0.41 ± 0.02	0.51 ± 0.04	0.54 ± 0.13
Root dry biomass (g m^{-2})	4.42 ± 1.05	20.7 ± 4.91	139.5 ± 31.5
Shoot dry biomass (g m^{-2})	10.8 ± 2.56	40.6 ± 6.97	260 ± 6.5
Root length (km m^{-2})	0.66 ± 0.11	3.12 ± 0.81	3.31 ± 0.62
$D < 0.5$ (%)	100 ± 0	100 ± 0	81 ± 2.63
$0.5 < D < 1$ (%)	0 ± 0	0 ± 0	19 ± 2.6

$D < 0.5$—root length percentage with diameter less than 0.5 mm; $0.5 > D > 1$—root length percentage with diameter between 0.5 and 1 mm

macro- and micronutrients essential for plant development (Table 1). However, it is common in substrates from areas degraded by iron and bauxite mining (Teixeira and Lemos Filho 1998; Machado et al. 2013; Figueiredo et al. 2015). In addition, the substrate is acid, which enhances the toxicity of elements like Al, Fe and Mn (Haridasan 2008). Together with Cr and V, the concentrations of these elements were above the values considered as reference for soils (Shanker et al. 2005; Kabata-Pendias 2011).

Despite the dystrophic substrate used, *S. metallicolus* showed high efficiency in sexual propagation. Seven months after sowing, the wooden boxes had a mean density of 1475 (± 234) individuals per square meter, representing about 29% (± 5%) of the number of seeds used in planting. The results obtained with *S. metallicolus* are even more promising when compared with the results presented by other Cerrado grasses established in soil. Lima et al. (2014) obtained a maximum of 18% of germination when evaluating the establishment of native Cerrado grasses in a mixture of manure and organic soil under irrigation and different levels of exposure to the sun. Kolb et al. (2016), when evaluating the establishment of 13 species of native grasses of Cerrado in soil, obtained germination percentages lower than 16% for nine species. When evaluating the establishment of 14 native grasses of the Cerrado under field conditions, in the rainy season and in Cerrado soil, Aires et al. (2013) obtained, after six months of planting, a density of 672 individuals per square meter, being sown 4.5 g of seeds per square meter.

Vegetative propagation – The vegetative reproduction was very efficient for the two species studied, proving to be a good alternative for *A. laxiflorus* propagation, which presented limitations on seed propagation. Even for species in which sexual propagation is efficient, vegetative propagation may be interesting when there is limited seed availability, when seedling establishment is hampered by inhospitable environmental conditions (Coelho et al. 2008), or when a fast revegetation is required (Perez 2008). In the case of *S. metallicolus*, for example, the use of 100 tillers per square meter increased four times both dry biomass and root length at the end of the experiment, when compared to the plots revegetated with seeds (Table 2).

Although vegetative propagation appears to be an alternative for grass reproduction, the use of this technique should be accompanied by care to reduce the loss of genetic diversity, which usually occurs in vegetatively propagated populations. (Williams and Davis 1996). The genetic diversity of the plants used in the restoration of degraded areas can interfere in the establishment success, potential to adapt to new environmental conditions, and in the relations with other species of the local. (McKay et al. 2005, Hugles et al. 2008, Willians 2001, Bucharova et al. 2017). The adoption of procedures, such as collecting tillers in large areas and in different populations, planting tiller of different populations in close proximity to facilitate sexual reproduction, when possible, guide tiller collection based on studies on the genetic structure of donor populations and associating vegetative propagation with sexual reproduction can significantly reduce the loss of genetic diversity in populations propagated predominantly by vegetative means. (Vellend 2006, Sommerville et al. 2013; Rogers and Mcguire 2015).

Sporobolus metallicolus presented an increase in biomass about three times greater than *A. laxiflorus*. In addition, most of the individuals of the first species were already producing seeds 7 months after planting. This indicates that *S. metallicolus* is more suitable for use in revegetation of substrates such as the one evaluated in the present study. Although *A. laxiflorus* has about seven times the root biomass of *S. metallicolus*, the two species presented approximately the same root length, that is, *S. metallicolus* contained more fine roots (Table 2). Studies have shown that root system with higher proportion of fine is more efficient to contain erosion (Burylo et al. 2012), which is a common problem in degraded areas (Craw et al. 2007).

Both species present higher investment in the biomass of the aerial portion, however, with values lower than those observed in exotic grasses (Silva and Haridasan 2007; Fontaneli et al. 2009), commonly used in revegetation of degraded areas. Low aerial biomass may limit the propagation and volume of fire (Rossi et al. 2014), common in savannas (Veldman et al. 2015). One of the problems of using exotic grasses with fast growing rate in the revegetation of degraded areas is that these species facilitate the propagation and intensity of fires, increasing the risk to other plant species, especially to tree species (Silvério et al. 2013; Fernandes et al. 2014; Rossi et al. 2014). Another advantage of short grasses in the restoration of degraded areas is to allow and even facilitate the germination and establishment of other species in such localities, thus increasing the diversity in the area and contributing to the efficiency of the succession process at the site (Yang et al. 2013). The large biomass of exotic grasses, such as those of the genus *Urochloa* sp. and *Melinis minutiflora* P. Beauv. (Silva and Haridasan 2007; Fontaneli et al. 2009), causes a rapid and intense shade at the site, making the germination and establishment of other species difficult (César et al. 2014). In addition, invasive grasses can compete for water and nutrients in the soil, making it even more difficult to establish other species in the field (Levine et al. 2003).

The fact that the studied species showed good growth in a nutrient-poor substrate rich in Al, Fe and Mn indicates that they can be used successfully in the restoration of areas degraded by bauxite and iron mining. In addition, there are indications that *S. metallicolus* may accumulate large concentrations of potentially toxic elements, when compared to other plant species. High concentrations of Al (5400 mg kg^{-1}), Fe (5100 mg kg^{-1}) and Ti (63 mg kg^{-1}) were found in the root tissues of this species in an exploratory evaluation (author information, unpublished data). In the same way, medium concentrations of Al (341 mg kg^{-1}), Fe (697 mg kg^{-1}) and Mn (332 mg kg^{-1}) were measured in the shoot tissues (Schettini et al. 2017). The values of Al, Fe e Ti found in the *S. metallicolus* roots are higher than the maximum limits of these elements concentration in plants (Kabata-Pendias 2011).

The use of the studied species in the restoration of degraded areas could be carried out initially by the sustainable collection of seeds and vegetative portions of these species in natural populations. However, the commercial production of seeds and vegetative propagules in order to implement projects to the restoration of degraded areas is a possible and desirable activity. Further studies should be carried out to evaluate the germination of *A. laxiflorus* under other conditions, the effects of storage on the viability of *S. metallicolus* seeds and the vegetative establishment and by seeds of both species under field conditions. Additionally, further species should be studied for their use in restoration of degraded areas.

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