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Articles

Potentiality of *Bambusa*, *Phyllostachys* and *Urochloa* species to vegetate degraded areas

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Abstract - Bamboos and forage grasses (Poaceae) can be used as recovery plants in degraded tropical areas, because of their fast plant growth and dense root systems. This study evaluated the survival, growth and dry matter production of four bamboo species (*Bambusa gracilis*, *Bambusa vulgaris*, *Phyllostachys aurea* and *Phyllostachys* sp.) and one forage grass (*Urochloa decumbens*) in two substrates. The experiment was established in a completely randomized design: 5 × 2 factorial scheme, with five recovery plants and two substrates (chemical or organic), with five replicates. Seedlings survival and several root growth parameters were evaluated at 60, 120 and 180 days after planting. Organic substrate increased the survival of the recovery plants compared to the chemical one. *Phyllostachys aurea* produced the highest root dry matter, surface area and volume of roots and *U. decumbens* also showed the highest length and the same root growth parameters. The maximum length of thin roots was observed in *Phyllostachys* sp. and in *B. vulgaris*. The studied species are recommended as recovering plants in degraded areas, due to their high incidence of thin roots in larger proportions than thick roots.

Potencialidade de espécies de *Bambusa*, *Phyllostachys* e *Urochloa* para vegetar áreas degradadas

Resumo - Bambus e capins (Poaceae) podem ser usados como plantas de cobertura para solos degradados, devido ao seu rápido crescimento e ao seu denso sistema radicular. Este trabalho avaliou a sobrevivência, o crescimento e a produção de matéria seca de quatro espécies de bambu (*Bambusa gracilis*, *Bambusa vulgaris*, *Phyllostachys aurea* e *Phyllostachys* sp.) e de uma gramínea forrageira (*Urochloa decumbens*) como plantas de cobertura, em dois substratos. O experimento foi um fatorial 5 × 2, em delineamento inteiramente casualizado, com cinco espécies de plantas de cobertura e dois tipos de substratos (mineral ou orgânico), com cinco repetições. Foi avaliada a sobrevivência das mudas e parâmetros de crescimento das raízes aos 60, 120 e 180 dias após plantio. O substrato orgânico aumentou a sobrevivência das plantas de cobertura. *Phyllostachys aurea* produziu a maior quantidade de matéria seca, área superficial e volume de raízes, assim como *U. decumbens,* que apresentou o maior comprimento de raízes e as maiores taxas de crescimento de raízes. O maior comprimento máximo de raiz ocorreu em *Phyllostachys* sp. e em *B. vulgaris*. A maior incidência de raízes finas em relação às raízes grossas afeta a sua fixação no solo, recomendando-se as espécies estudadas para cobertura em áreas degradadas.

Part of Master work of Cibele Dutra de França, University of Brasilia, 2011.

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Introduction

The rapid establishment of forest vegetation reduces erosive processes in tropical degraded areas, providing the soil surface with intense root growth and plant coverage. The frequent rain flood events in tropical areas contribute to erosive processes, intensifying the movement of the soil particles (Basilio et al., 2019; Nascimento et al., 2019).

Some plant species with rapid establishment and growth have been used as recovery in degraded areas, such as *Urochloa decumbens* (Stapf) R. D. Webster (Nery et al., 2017; Oliveira et al., 2020) and bamboo species, specially to control slope erosion (Shinohara et al., 2019; Silva et al., 2020). These plants have fast growth and high biomass production (Darabant et al., 2014), which can reduce soil erosion and improve the physical characteristics of the soil. *Urochloa decumbens* is largely used as a forage grass in Central Brazil, presenting good management practices during its growth and development to avoid becoming a problem to other cultivated plants (Sodré Filho et al., 2020). *Bambusa vulgaris* Schrad. ex J. C. Wendl., *Bambusa gracilis* hort. ex Rivière & C. Rivière and *Phyllostachys* Siebold & Zucc. are well adapted to tropical soils (Rusch et al., 2019; Qiu-Fang et al., 2020) and have potential to be used to recover degraded areas (Gallien et al., 2012), and even *Phyllostachys aurea* Carrière ex A. & C. Rivière – all of them exotic species in Brazil. However, there is a lack of studies involving the efficacy of bamboo to prevent erosive processes in slopes of tropical soils (Sandhu et al., 2018; Moura, 2019), even as the interaction between exotic bamboo species with Brazilian flora (Farias & Rios, 2021), considering that the majority of them present high ability to scatter (Guilherme et al., 2017; Hall et al., 2020). So, it is important that the Poaceae species in the present study must not be cultivated nearby natural forests or vulnerable vegetation areas.

One of the main parameters used to evaluate the performance of different species in degraded slope recovery projects is the growth analysis of plants, such as their leaf area and seedlings survival. The dry matter of the roots and their consequently strengthening of the soil are closely related parameters (García-Ramírez et al., 2015). Other desirable characteristics of coverage plants include (Mudoi et al., 2013; Hall et al., 2020): deep and vigorous root growth, seedlings and seeds availability in the local market and the efficiency to recover the soil. Bamboo species have some of these characteristics, including a variety of propagation methods (Anand et al., 2013; Guilherme et al., 2017). Moreover, the majority of clumpy plants – mainly *Bambusa* spp. – are characterized by short and thick rhizomes with lateral buds, which develop new rhizomes that can emit stalks. Bamboos are generally propagated with segments of stalks containing gems (Beraldo & Azzini, 2004). In addition, clumpy plants subjected to different management systems can enhance physical soil conditions, due to their positive effects on soil aggregation (Qiu-Fang et al., 2020).

The objective of this study was to evaluate the survival, growth and biomass production of four exotic bamboo species and a forage grass, also exotic, cultivated in two substrates, as recovery plants for degraded areas.

Material and methods

The experiment was carried out at Fazenda Água Limpa, University of Brasilia, Brasilia, Federal District, Brazil (15º56'S, 47º55'W, altitude of 1,100 m). The climate is Aw (Köppen), with rainy summer and dry winter seasons (Alvares et al., 2013). The experimental design was a factorial with five plant species and two substrates in five replications. The recovery plants comprised four species of bamboo (*Bambusa gracilis*, *Bambusa vulgaris*, *Phyllostachys aurea* and *Phyllostachys* sp.) and one grass (*Urochloa decumbens*). The substrates tested were: chemical (a 2:1 mix of soil + sand) with 180 g of NPK 4-14-8; and organic (an 1:1:1 mix of soil + cattle manure + sand). The soil was a Latossolo Vermelho, according to the Brazilian Soil Classification (Santos et al., 2013), a Typical Acrustox (Soil Survey Staff, 2014). The size of the experimental area was 217.8 m^2 containing 180 flexible polyethylene pots of 0.5 m of diameter × 0.5 m of height, arranged in the field with a 0.6 m distance between each one. All pots also received 100 g of dolomitic limestone. A supplementary irrigation was provided by a conventional sprinkler system (an average of 11 mm of water day^{-1}) in the experiment, because of the low rainfall precipitation during the rainy season. Chemical and physical analyses of the substrates were carried out prior to the installation of the experiment and after 180 days after planting (DAP), as presented in Table 1.

The experiment was conducted from January 2010 to July 2010. In the first month, bamboo species were propagated using standardized rooted cuttings of

Table 1. Chemical and physical analysis of the substrates at 0 and 180 days after planting (DAP).

Substrates	pH	P	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	CEC	BS	OM	clay	sand	silt
	(H_2O)	(ppm)	------------------($cmol_c\ dm^{-3}$)------------------					(%)	----------------($g\ kg^{-1}$)----------------			
0 DAP												
Chemical	5.5 bB	15.2 aA	0.1 aA	0.8 bB	0.4 bB	0.34 aA	5.99 bA	1.69 bB	13.2 bA	250 aB	670 aA	250 aA
Organic	7.0 aB	19.8 aA	0.0 aA	3.0 aA	1.9 aA	0.33 aA	7.22 aA	5.32 aA	45.8 aA	300 aA	620 aB	260 aA
180 DAP												
Chemical	8.0 aA	6.0 bB	0.0 aA	2.8 aA	1.1 aA	0.18 aB	5.72 aA	4.22 aA	18.2 bB	320 aA	600 aB	270 aA
Organic	8.1 aA	7.5 aB	0.0 aA	2.1 aB	1.2 aA	0.17 aB	5.03 aB	3.53 bB	40.0 aB	250 bB	700 aA	250 aA

Al^{3+}, Ca^{2+} and Mg^{2+} extracted by KCl mol L^{-1}; P and K extracted by Mehlich; CEC = cation exchange capacity; BS = base saturation; OM = organic matter. Different small letters represent differences between substrates in the same sampling date, and capital letters represent differences between sampling dates by the F-test ($p \leq 0.05$).

Phyllostachys sp., *P. aurea* and *B. gracilis*, while *B. vulgaris* was propagated by one-year-old culms with one internode. An amount of 2.25 g of high purity seeds of *U. decumbens* (90% of germination) were sown in each pot, and 40 days after the emergence, only one plant was left per pot. Then, all pots were placed in the field.

Analyses and measurements

In March 2010, the plants of bamboo species were weighed and pruned to standardize the length of the root system. At 40 DAP, the survival rate of the plants was estimated, which was defined by the relation between the number of live plants with active root growth and the total number of plants. Then, at 60, 120 and 180 DAP, one plant of each pot was collected (totaling five samples of each plot) and removed from the pots using water jets in order to separate aerial structures (culm, stems and leaves) from subterranean structures (rhizome and roots). Roots were separated from soil with a 0.42 mm mesh sieve.

Culms, stems, leaves, roots and rhizomes were put separately in a 210 × 279 × 10 mm glass and scanned to calculate the surface area, length and volume, using the Safira software (Jorge & Silva, 2010). Roots were separated in two diameter groups: thin roots (≤ 1.61 mm) and thick roots (> 1.61 mm). The samples were oven-dried at 65 °C for 72 h in order to estimate the dry matter.

Statistical analysis

All data were submitted to a non-parametric analysis. Previously to the analysis, the survival rate was transformed using the Formula 1.

The analysis of variance (ANOVA) was performed using the Sisvar software version 5.6 (Ferreira, 2011) and the F-test ($p \leq 0.05$) was applied to check for null treatment effects. Whenever significant effects were observed, the averages were compared by the Tukey test ($p \leq 0.05$).

$$y = arc\ sine\sqrt{\chi\ /100} \qquad (1)$$

Where: y = the response variable used for statistical analysis; x = the original survival rate.

Regression modeling was carried out to the dependent variables: thin roots length, thick roots length, thin roots volume, thick roots volume, thin roots surface area and thick roots surface area for each species to the sampling dates – 60, 120 and 180 DAP –, using the models (linear or polynomial regression) with the highest coefficients of determination and significant by the F-test ($p \leq 0.05$).

Results

There was an interaction ($p \leq 0.05$) between the growth parameters of the recovery plants and the substrates, except for root length at 180 days after planting (DAP) and for volume of leaves and stems at 60, 120 and at 180 DAP for the organic treatment, whose average contents did not differ according to the substrate.

Chemical and physical analysis of the substrates presented increased values in the organic matter and base saturation contents, before and after the use of the recovery plants. Ca was one of the chemical elements that presented increased values in the mineral treatment, from 0.8 $cmol_c\ dm^{-3}$ to 2.8 $cmol_c\ dm^{-3}$ (Table 1).

Table 2. Effect of chemical and organic substrates on survival rate (40 days after planting), total dry matter of leaves, stems and culms and dry matter of roots and rhizomes (180 days after planting) of recovery plants.

Recovery plants	Survival (%)		Dry matter (g)					
			Leaves, stems and culms		Roots		Rhizomes	
	Chemical substrate	Organic substrate	Chemical substrate	Organic substrate	Chemical substrate	Organic substrate	Chemical substrate	Organic substrate
Bambusa gracilis	66.7 bcA	66.7 cA	5.98 cB	6.59 bA	13.46 cB	15.03 cA	6.32 cB	6.71 cA
Bambusa vulgaris	72.2 bB	83.3 bA	14.17 aA	14.37 aA	18.62 bA	18.28 cA	0.00 dA	0.00 dA
Phyllostachys aurea	61.1 bcA	65.0 cA	7.44 bA	7.45 bA	35.14 aB	37.21 aA	8.41 bA	8.49 bA
Phyllostachys sp.	55.6 cB	65.0 cA	6.97 bcB	9.68 abA	28.57 abB	29.97 bA	14.65 aB	15.44 aA
Urochloa decumbens	100 aA	100 aA	3.06 dA	3.44 cA	25.10 bB	27.55 bA	-	-
CV (%)	7.36	6.45	5.91	4.12	4.48	2.76	9.50	3.25

CV = coefficient of variation. Means followed by the same letter, lowercase in the columns and capital letters in the lines, do not differ by the Tukey test ($p \leq 0.05$).

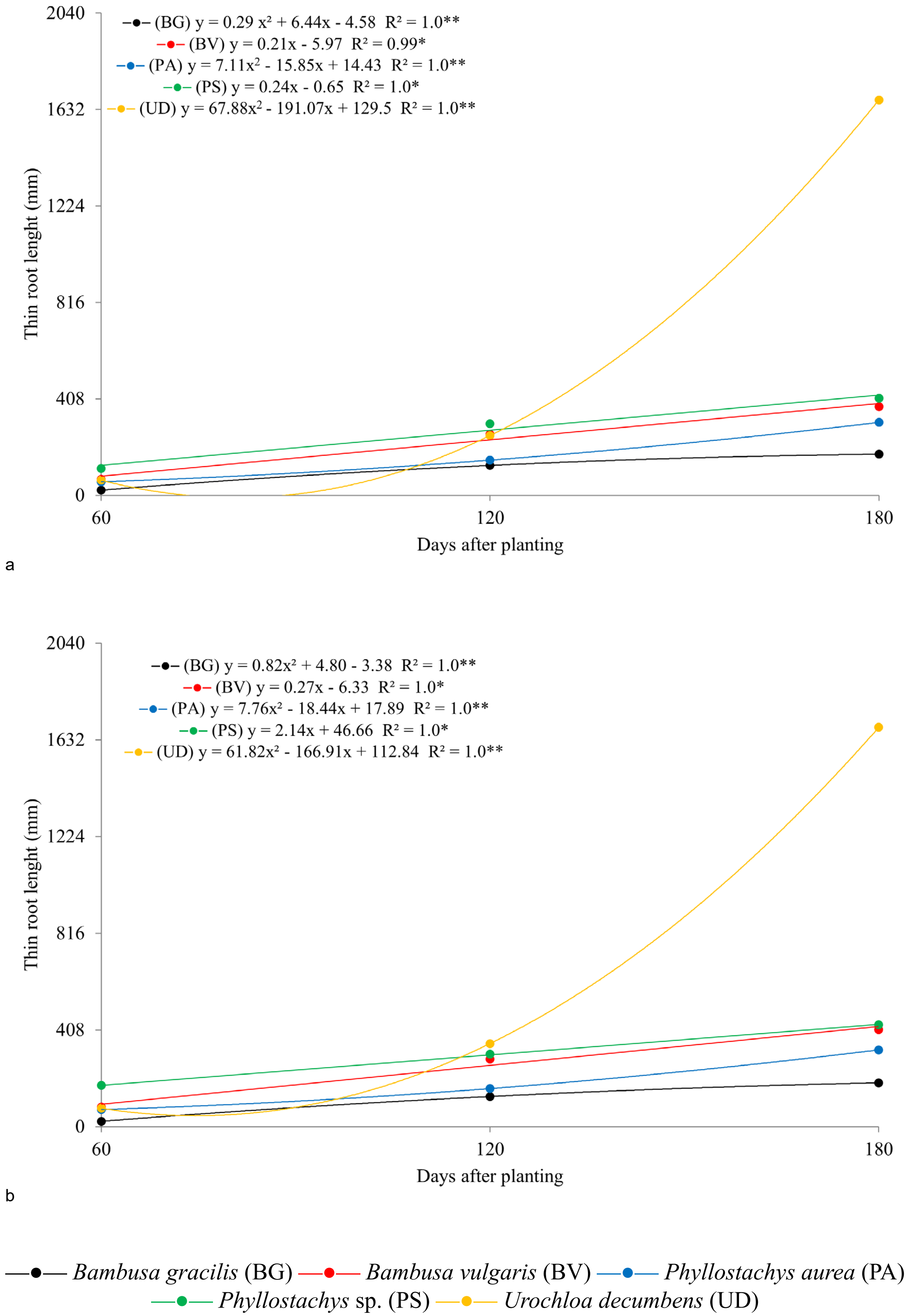
No difference was observed comparing organic or chemical fertilization for plants survival, except for *Bambusa vulgaris* and *Phyllostachys* sp. (Table 2). The plant survival rate of *Urochloa decumbens* was 100%, while in the bamboo species it varied from 55.6% to 83.3%. The lowest survival rate occurred in *Phyllostachys* sp., with chemical fertilizer (55.6%) and organic fertilizer (65.0%), while in *Bambusa gracilis* the survival rate was 66.7% on both substrates.

Thin root length of the bamboos species reached average values of 0.40 m. Thin roots make up to 17% to 43% of the dry matter of the roots, although the amount varied according to the evaluation period. *U. decumbens* showed the maximum length of thin roots of 1.5 m, which corresponded to 47% of the total root dry matter.

Thin roots of all recovery plants reached higher maximum length than thick roots, according to a polynomial ascending pattern (Figures 1a to 1d), but in *B. vulgaris* and *Phyllostachys* sp. it increased according to a linear pattern. The linear growth pattern of thick root length of *B. vulgaris* showed that its development continued beyond the analyzed period (Figures 1c and 1d). Other bamboo species showed polynomial ascending patterns, while *Phyllostachys* sp. and *U. decumbens* showed linear growth patterns.

Thin and thick root volumes showed a linear growth pattern over time for most of the recovery plants (Figures 2a to 2d), except for *B. gracilis* and *U. decumbens*, that showed a polynomial pattern for thick root volume (Figures 2c and 2d). *U. decumbens* showed higher thin root volume, followed by *Phyllostachys aurea* and *Phyllostachys* sp.

The bamboo species tested produced the highest root dry matter and proportion of thin roots. The rhizomes dry matter of the bamboos varied from 6.32 g $plant^{-1}$ to 15.44 g $plant^{-1}$ and these species also showed the highest growth rate of leaves, culms and steams (Table 2). *U. decumbens*, *P. aurea* and *Phyllostachys* sp. presented the highest root surface area (Figures 3a and 3b).


(BG) y = 0.29 x² + 6.44x - 4.58 R² = 1.0**
(BV) y = 0.21x - 5.97 R² = 0.99*
(PA) y = 7.11x² - 15.85x + 14.43 R² = 1.0**
(PS) y = 0.24x - 0.65 R² = 1.0*
(UD) y = 67.88x² - 191.07x + 129.5 R² = 1.0**
Thin root lenght (mm)
2040
1632
1224
816
408
0
60
120
180
Days after planting
a
(BG) y = 0.82x² + 4.80 - 3.38 R² = 1.0**
(BV) y = 0.27x - 6.33 R² = 1.0*
(PA) y = 7.76x² - 18.44x + 17.89 R² = 1.0**
(PS) y = 2.14x + 46.66 R² = 1.0*
(UD) y = 61.82x² - 166.91x + 112.84 R² = 1.0**
Thin root lenght (mm)
2040
1632
1224
816
408
0
60
120
180
Days after planting
b
Bambusa gracilis (BG)
Bambusa vulgaris (BV)
Phyllostachys aurea (PA)
Phyllostachys sp. (PS)
Urochloa decumbens (UD)

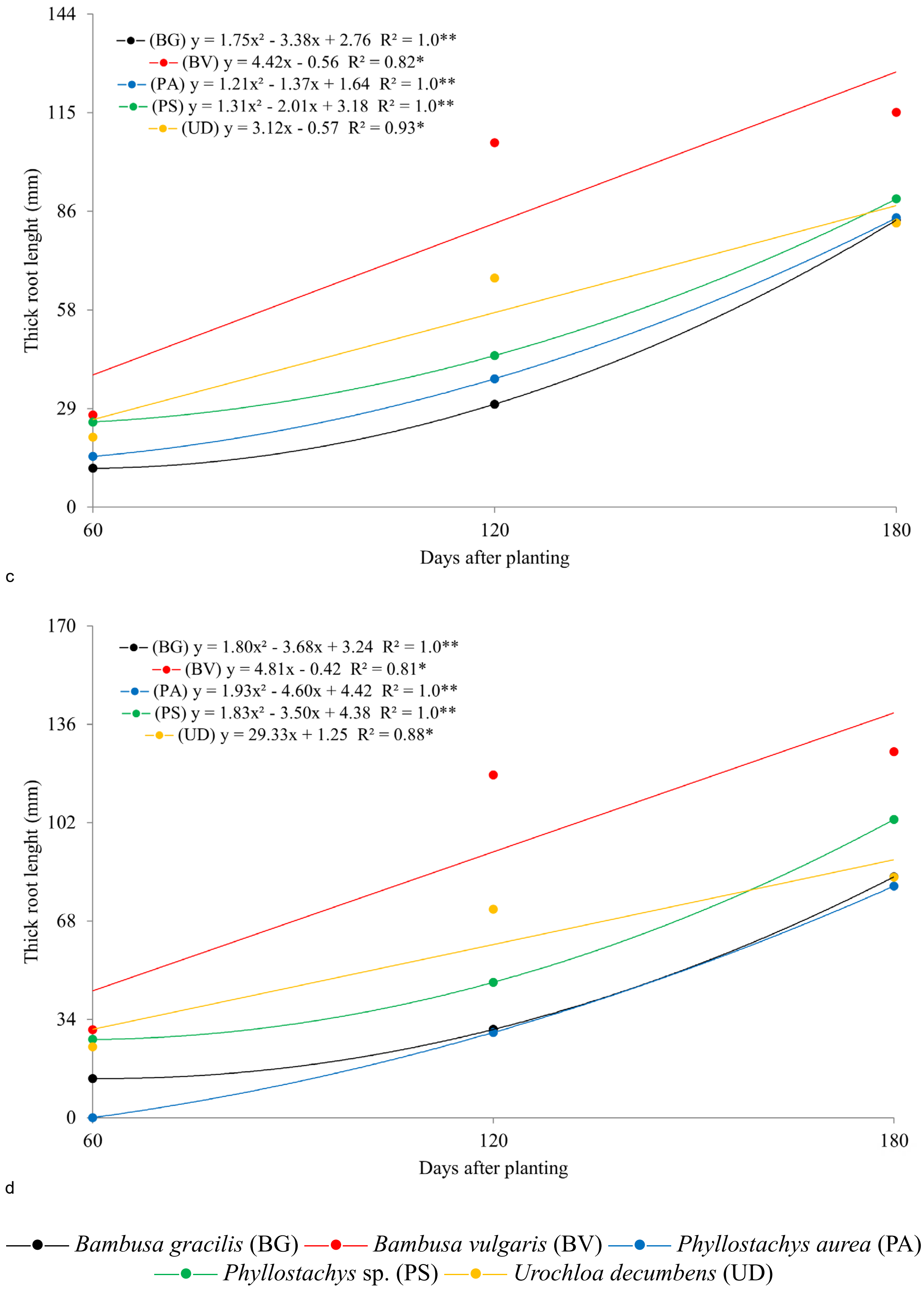
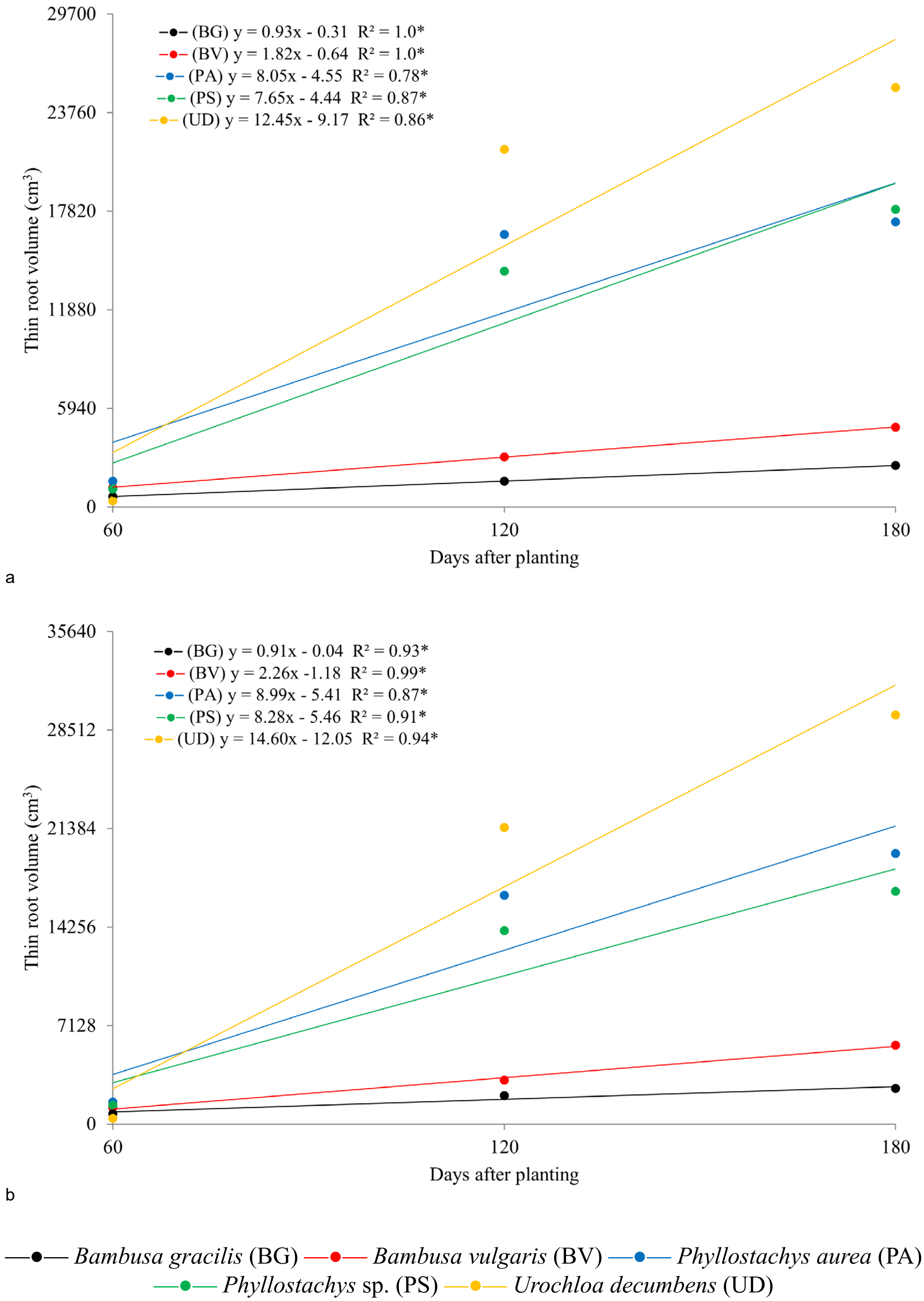


Figure 1. Thin root length in chemical (a) and organic substrates (b), and thick root length in chemical (c) and organic substrates (d) of recovery plants, from 60 to 180 days after planting. *, ** = significant coefficients of linear and polynomial regression, respectively ($p \leq 0.05$).


(BG) y = 0.93x - 0.31 R² = 1.0*
(BV) y = 1.82x - 0.64 R² = 1.0*
(PA) y = 8.05x - 4.55 R² = 0.78*
(PS) y = 7.65x - 4.44 R² = 0.87*
(UD) y = 12.45x - 9.17 R² = 0.86*
Thin root volume (cm³)
29700
23760
17820
11880
5940
0
60
120
180
Days after planting
a
(BG) y = 0.91x - 0.04 R² = 0.93*
(BV) y = 2.26x -1.18 R² = 0.99*
(PA) y = 8.99x - 5.41 R² = 0.87*
(PS) y = 8.28x - 5.46 R² = 0.91*
(UD) y = 14.60x - 12.05 R² = 0.94*
Thin root volume (cm³)
35640
28512
21384
14256
7128
0
60
120
180
Days after planting
b
Bambusa gracilis (BG)
Bambusa vulgaris (BV)
Phyllostachys aurea (PA)
Phyllostachys sp. (PS)
Urochloa decumbens (UD)

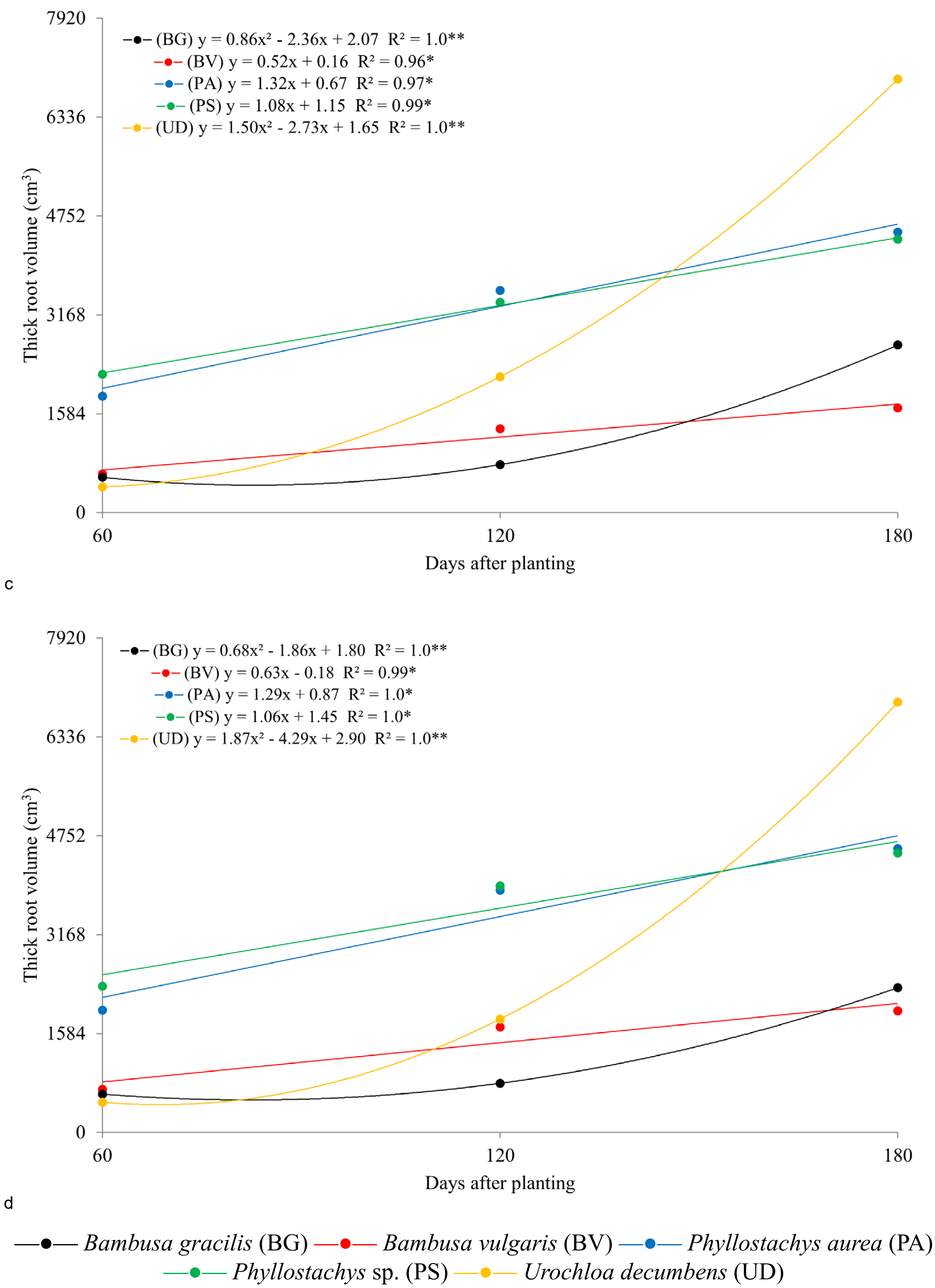


Figure 2. Thin root volume in chemical (a) and organic substrates (b), and thick root volume in chemical (c) and organic substrates (d) of recovery plants, from 60 to 180 days after planting. *, ** = significant coefficients of linear and polynomial regression, respectively ($p \leq 0.05$).

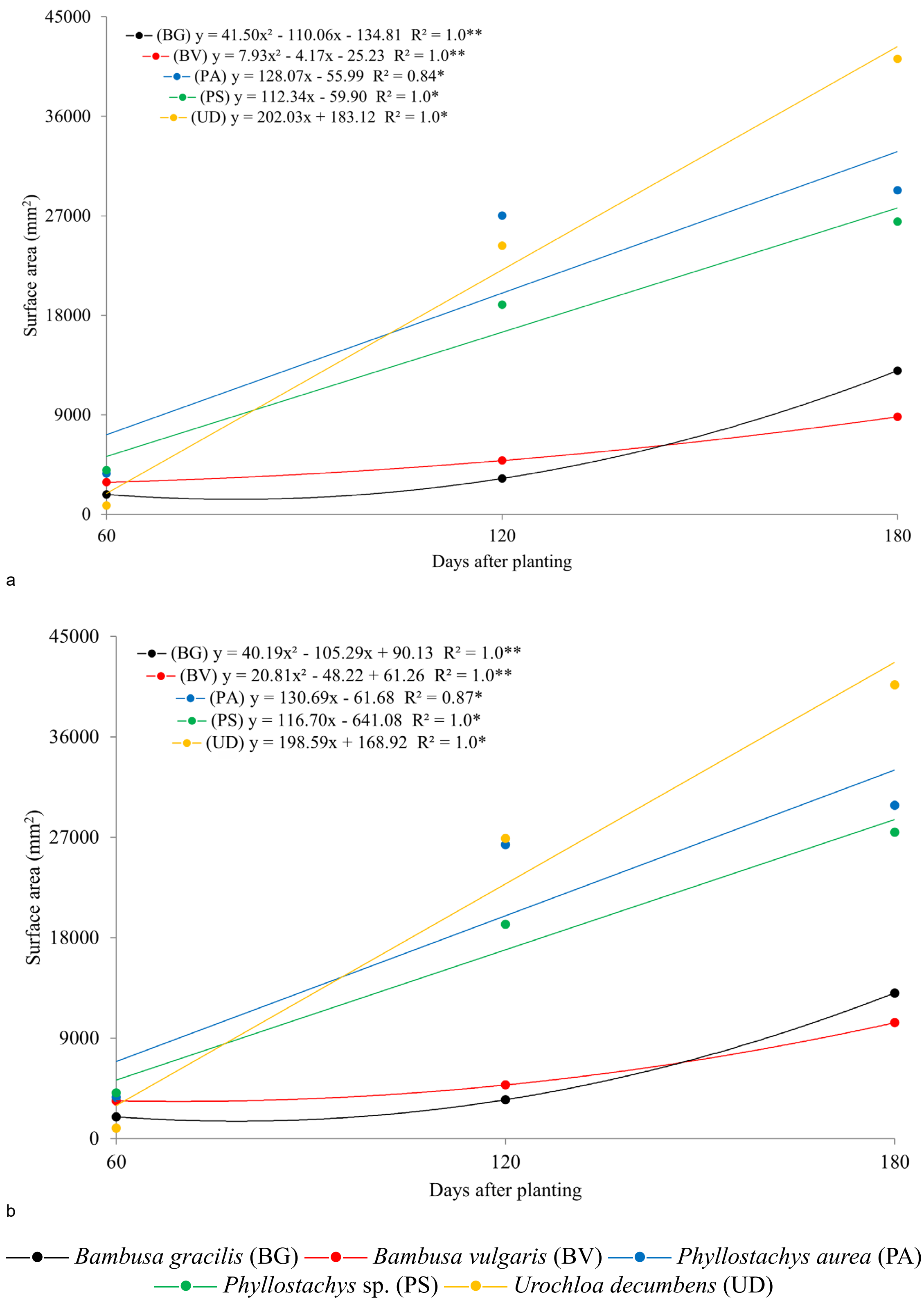


Figure 3. Average root surface in chemical (a) and organic substrates (b) of recovery plants, from 60 to 180 days after planting. *, ** = significant coefficients of linear and polynomial regression, respectively ($p \leq 0.05$).

Discussion

In the organic substrate the nutrients are released slowly to the soil solution compared to the mineral substrate (Nascimento et al., 2019). This is due the slow decomposition rate of organic matter by microorganisms and temperature (Eberhardt et al., 2021). Nevertheless, there is no consensus about the right form of application of lime to promote bamboo growth and development (Wang et al., 2019).

The organic substrate was classified as eutrophic due to the values of base saturation in its chemical analysis (Table 1). The increase in Ca contents in the chemical substrate can be promoted from the interaction between root surface in this substrate (Figure 3b), although the organic substrate showed positive effects on plant growth of the bamboo species (Table 2). Once the dry matter production of *Urochloa decumbens* also increases with organic fertilization (Pereira et al., 2019; Oliveira et al., 2020), it was expected differences between both substrates tested for this grass.

The lowest plant survival rates observed in *Phyllostachys* sp. can be explained by the fact that it is adapted to cold regions. The survival rates were low when the plants were exposed to high tropical temperatures during the field experiment period, resulting in a decrease in the growing rate and emission of new roots (Wang et al., 2019). On the other hand, high temperatures stimulate the development of *Bambusa vulgaris* – a typical tropical plant (García-Ramírez et al., 2015; Guilherme et al., 2017).

Organic compounds used as manure can contribute to stimulate plant development by increasing water penetration and retention in the soil and by increasing cation exchange capacity and pH (Beraldo & Azzini, 2004; Eberhadt et al., 2021). This tendency was observed in the chemical contents of the organic substrate, which provided higher survival rates for the bamboos, except for *Bambusa gracilis* (Table 2). The shallow bamboo root system is more sensitive to soil-water conditions than the deeper roots of other species, which can affect bamboo plant survival (Darabant et al., 2014; Vale et al., 2019).

The high incidence of thin roots positively affects soil fixation in degraded areas, due to the increase in strength and surface area, while the root diameter decreases (Bordron et al., 2019). Most of the bamboo roots were classified as thin and accounted from 17% to 43% of the total root dry matter. The highest proportion of thin roots and root surface area was observed in *U. decumbens*, *Phyllostachys aurea* and *Phyllostachys* sp. High incidence of thin roots affects soil fixation in slope areas, once the higher the proportion of thin roots, the greater the root surface area and, consequently, the greater is the landslide soil stability. The concentration of roots in soil upper layers is normally associated with nutritional and aeration functions (Nery et al., 2017).

There are advantages for the development of the roots in the superficial layer to control erosive processes and in vegetative recovery of degraded areas. In this context, the density of roots near the soil surface and the plants above the soil can be considered more important than the depth of roots or their physical strength. Superficial erosion is restricted to the first soil layer, but the accumulation of roots in only one layer can disaggregate the soil particles and difficult water infiltration, increasing erosive processes (Nascimento et al., 2019; Silva et al., 2020).

The concentration of thin roots in the first 0.4 m soil layer plays an important role in bamboos' biomass production in areas of difficult vegetative establishment (Darabant et al., 2014; Valle et al., 2018), although the effectiveness of the depth and density of bamboo root system in controlling erosive processes are not confirmed. The development of thin roots in the upper layers of the soil is generally associated with higher efficiency of plant nutritional functions (Wang et al., 2019). In these layers, airflow is greater, and available nutrients ions are more effectively and immediately absorbed by the root system, resulting in a faster response to fertilization than in deeper layers of the soil (Eberhardt et al., 2021).

In order to minimize the disadvantages related to the natural tendency of the bamboos to produce roots near the soil surface, the strategy of combination of plants with complementary characteristics compared to the bamboo root system, like growing further into soil depth, may be successful. The success in establishing vegetation to cover degraded areas increases when bamboo is associated with species with deep root systems and short cycle, such as *U. decumbens*. This grass completes the growth cycle from 90 to 120 days after planting (Pereira, 2006; Pereira et al., 2019). Moreover, it can be easily desiccated with herbicides for the introduction of other species (Sodré Filho et al., 2020).

Other desirable characteristic of pioneer plants to vegetate degraded areas refers to the development of rhizome structures, which guarantees reproduction, especially when substrate carry-over occurs (Sandhu et al., 2018; Hall et al., 2020). In this aspect, *Phyllostachys* sp. and *P. aurea* produced 15.44 g and 6.71 g of dry mass rhizomes, respectively, at 180 DAP in organic substrate, what can be considered a satisfactory production of this plant structure (Table 2). The rhizome plays an important role for plant growth in degraded slopes, because it can guarantee the development under sliding conditions (Stokes et al., 2007; Valle et al., 2018). Therefore, these bamboos can be useful for the recovery of degraded slopes, once soil conservation practices are developed for their cultivation in Brazilian conditions (Gallien et al., 2012), which can be an alternative to prevent landslides. Furthermore, attention must be taken to avoid the aggressive scattering of *P. aurea* (Wang et al., 2019; Qiu-Fang et al., 2020), which can alter the community of plants in forested areas (Farias & Rios, 2021). In addition, *Urochloa decumbens* can also become a problem in cultivated fields (Oliveira et al., 2020) or to vulnerable vegetation.

Bamboos do not produce a good proportion of aerial biomass/roots ratio (Truong et al. 2008; Mudoi et al., 2013) although it cannot diminish their capacity to aggregate soil in sloping places (Shinohara et al., 2019). In the present study, the imbalance of leaves/roots ratio over 180 DAP was observed. During this period, dry matter values of roots and rhizomes were higher than those of the aerial structures, like stems, culms and leaves (Table 2). However, in declivities above 30%, it is recommended to avoid plants with higher phytomass, such as *B. vulgaris*, because although it shows longer root length, its aerial biomass contributes to its vulnerability to strong winds (Pereira, 2006). So, in order to provide fast and effective soil covering in degraded areas, the use of recovery plants with low biomass and with fast growth such as the recovery plants presented in this study, is recommended.

Conclusions

The survival rate and the incidence of thin roots of *Bambusa vulgaris*, *Phyllostachys* spp. and *Urochloa decumbens* showed potential to recover degraded areas, especially when using organic substrates. The high survival rate of the tested species was due to the higher contents of organic matter and carbon in the organic substrate. Attention must be taken when cultivating *Phyllostachys aurea* and *U. decumbens* near natural Brazilian vegetation, because of their fast and invasive growth.

The present study shows the potential of bamboo species in recovering degraded areas, but further studies are necessary about plant growth and development of *Phyllostachys* spp. in sloping areas.

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To Prof. Carlos Alberto da Silva Oliveira, in his memory.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

CRediT authorship contribution statement

Cibele Dutra de França: conceptualization, formal analysis, investigation, methodology, supervision, writing – original draft, writing – review & editing. **Joilson Sodré Filho**: formal analysis, writing – review & editing.

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