

## Articles

# Efficiency of cover crops, mechanical and chemical control in the management of *Urochloa brizantha* in an agroforestry system

Eficiência de plantas de cobertura, controle mecânico e químico no manejo de *Urochloa brizantha* em sistema agroflorestal

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## ABSTRACT

The study evaluated different methods for controlling *Urochloa brizantha* in an agroforestry system in Rio Claro (RJ), aiming to mitigate its dominance and reduce cultural management costs. Strategies included cultural control using green manure species (in monoculture or mixed sowing), mechanical mowing, and chemical herbicide application. The experiment followed a randomized block design with eight treatments and four replicates. Aboveground biomass of *U. brizantha* and cover crops was measured at 60, 120, and 200 days after sowing, along with operational costs and effects on spontaneous regeneration. Results showed that jack bean (*Canavalia ensiformis*) and pigeon pea (*Cajanus cajan*) were the most effective cover crops in suppressing *U. brizantha*, with performance similar to that of the legume mixture, but at lower costs. Chemical control was the most effective and least expensive method, although it did not provide the ecological benefits associated with cover crops. Cover species temporarily favored the establishment of herbaceous native species, but their short life cycle limited long-term effectiveness. It is concluded that using leguminous cover crops is a viable alternative to chemical control, particularly when considering ecological and sustainability aspects in agroforestry systems.

**Keywords:** Weed control; Cover crops; Agroforestry systems; *Urochloa brizantha*; Management cost

## RESUMO

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O estudo avaliou diferentes métodos de controle de *Urochloa brizantha* em um sistema agroflorestal em Rio Claro (RJ), com o objetivo de mitigar sua dominância e reduzir os custos com manejo cultural. As estratégias incluíram o controle cultural por meio do uso de espécies de adubação verde (em monocultivo ou em semeadura consorciada), o manejo mecânico por roçada e a aplicação de herbicidas. O experimento foi conduzido em delineamento em blocos ao acaso, com oito tratamentos e quatro repetições. A biomassa aérea de *U. brizantha* e das plantas de cobertura foi mensurada aos 60, 120 e 200 dias após a semeadura, juntamente com os custos operacionais e os efeitos sobre a regeneração natural espontânea. Os resultados demonstraram que o feijão-de-porco (*Canavalia ensiformis*) e o guandu-anão (*Cajanus cajan*) foram as plantas de cobertura mais eficazes na supressão de *U. brizantha*, com desempenho semelhante ao da mistura de leguminosas, porém com custos inferiores. O controle químico mostrou-se o método mais eficaz e de menor custo, embora não tenha proporcionado os benefícios ecológicos associados ao uso de plantas de cobertura. As espécies utilizadas como cobertura favoreceram temporariamente o estabelecimento de espécies herbáceas nativas, mas seu ciclo de vida curto limitou a eficácia a longo prazo. Conclui-se que o uso de leguminosas como plantas de cobertura constitui uma alternativa viável ao controle químico, especialmente quando se consideram os aspectos ecológicos e de sustentabilidade nos sistemas agroflorestais.

**Palavras-chave:** Controle de plantas daninhas; Plantas de cobertura; Sistemas agroflorestais; *Urochloa brizantha*; Custo de manejo

## 1 INTRODUCTION

The southern region of Rio de Janeiro State has undergone extensive environmental degradation over the centuries as a result of successive economic cycles based on exploitative land-use practices. The expansion of coffee cultivation in the nineteenth century, followed by extensive cattle ranching, contributed substantially to the deforestation of the Atlantic Forest and soil impoverishment (Teixeira, 2009). Today, this legacy of environmental degradation is compounded by low agricultural productivity and the prevalence of degraded pastures (Marafon, 2011).

The municipality of Rio Claro exemplifies this historical trajectory. As its soils became depleted, cattle ranching replaced coffee cultivation, further intensifying soil degradation and adversely affecting water resources. This situation contrasts with the region's strategic importance to the water supply of Rio de Janeiro State, as the Pirai River, a tributary of the Guandu system, accounts for approximately 15% of the water supplied to the state capital (Paiva; Coelho, 2015).

In this context, agroforestry systems (AFSs) offer a sustainable alternative for reconciling agricultural production with environmental restoration. Integrating tree and crop species in intercropping arrangements promotes soil conservation, enhances biodiversity, and supports nutrient cycling and is widely recommended as part of large-scale ecological restoration strategies (Rodrigues; Brancalion; Isernhagen, 2009; Maia et al., 2006). However, the establishment and management of AFSs face major challenges, including heavy infestations of invasive grasses. Palisade grass (*Urochloa brizantha* (A.Rich.) R.D.Webster) is particularly problematic because of its strong competitive ability and high regenerative capacity, which hinder the establishment of cultivated species and the natural regeneration process (Santos et al., 2020).

Against this background, an agroforestry system intercropping African mahogany (*Khaya grandifoliola* C.DC.) and Tahiti lime (*Citrus × latifolia* (Yu.Tanaka) Yu.Tanaka) was established in 2018 at Fazenda Três Quedas, in Rio Claro, Rio de Janeiro State, and served as the study site.

Although considerable progress has been made in weed management in agricultural systems, information on the comparative effectiveness of different strategies for controlling *U. brizantha* in established agroforestry systems remains limited, particularly regarding approaches encompassing chemical control, mechanical control, and the use of cover crops. Assessing these strategies is important because it enables the identification of management alternatives capable of reducing interference by this invasive grass while accounting for both control effectiveness and cover crop performance.

Accordingly, this study aimed to evaluate the effectiveness of management strategies, including cover crops, mechanical control, and chemical control, in suppressing *U. brizantha* within an agroforestry system.

## 2 MATERIALS AND METHODS

### 2.1 Experimental area

The experiment was conducted within an agroforestry system (AFS) located in the Rio das Pedras watershed, in the district of Lídice, municipality of Rio Claro, in the Middle Paraíba do Sul region of Rio de Janeiro State, Brazil. The watershed lies within the Serra do Mar mountain range, covers an area of 1,500 ha, and has the Piraí River as its main watercourse.

The experimental area covers 1.02 ha and is located on a floodplain along the Parado River. The floodplain is subject to fluctuations in water-table depth and occasional flooding during the rainy season. The predominant soil was classified as a Gleysol. The UTM coordinates are 584,271.00 m E and 7,472,827.00 m S (Zone 23S).

The AFS was established in 2018 by intercropping African mahogany (*Khaya grandifoliola* C.DC.) and Tahiti lime (*Citrus × latifolia* (Yu.Tanaka) Yu.Tanaka) under two planting arrangements that differed in spacing and, consequently, planting density. In the first arrangement, Tahiti lime trees were spaced 4 m apart within rows, and rows of African mahogany and Tahiti lime were alternated at 3-m intervals, resulting in densities of 139 African mahogany trees ha<sup>-1</sup> and 400 Tahiti lime trees ha<sup>-1</sup>. In the second arrangement, African mahogany trees were planted at spacings of 9 m between rows and 6 m within rows, whereas Tahiti lime trees were interplanted within the rows using the same 9 × 6 m spacing, resulting in densities of 185 plants ha<sup>-1</sup> for each species.

*Urochloa brizantha* became established naturally in the experimental area from the soil seed bank and/or vegetative propagules already present at the site; the species was not sown. The evaluated treatments were applied to this naturally occurring, previously established grass infestation under both planting arrangements, and the reported results represent the mean values across the two arrangements.

## 2.2 Experimental design and treatments

The experiment was established in February 2022 using a randomized complete block design with eight treatments and four replicates. Each block measured approximately 50 × 60 m, and the plots were arranged perpendicular to the planting rows.

The following treatments were evaluated:

- T1 – Untreated control (no management);
- T2 – Mechanical control by mechanized mowing and manual ring weeding around the trees;
- T3 – Chemical control with glyphosate application;
- T4 – Cultural control using *Crotalaria breviflora* DC. (shortflower rattlebox);
- T5 – Cultural control using *Cajanus cajan* (L.) Huth (dwarf pigeon pea);
- T6 – Cultural control using *Canavalia ensiformis* (L.) DC. (jack bean);
- T7 – Cultural control using a legume mixture (dwarf pigeon pea, jack bean, and shortflower rattlebox);
- T8 – Cultural control using *Raphanus sativus* L. (forage radish)

In the cover-crop treatments (T4–T8), palisade grass was desiccated before sowing using a glyphosate-based herbicide containing 480 g L<sup>-1</sup> of the isopropylamine salt of N-(phosphonomethyl)glycine, equivalent to approximately 360 g L<sup>-1</sup> of glyphosate acid, applied at a rate of 2.5 L ha<sup>-1</sup>. Furrows spaced 40 cm apart were then opened manually. Sowing was performed manually at the following rates per linear meter: 40 seeds each of shortflower rattlebox and dwarf pigeon pea, 8 jack bean seeds, and 35 forage radish seeds. In the mixture treatment (T7), all three legume species were sown in the same row at the seeding density recommended for each species in the relevant technical literature.

The legume seeds were inoculated with specific rhizobial strains formulated with peat as the carrier, following the recommendations of Embrapa Agrobiologia (Embrapa, 1999).

In the mechanical-control treatment (T2), mowing and manual weeding were carried out at the onset of heading and before seed set. In the chemical-control treatment (T3), glyphosate was applied throughout the treatment area at establishment and selectively reapplied to palisade grass regrowth on two subsequent occasions.

### **2.3 Biomass assessment**

The aboveground dry biomass yields of palisade grass and the cover crops were assessed at 60, 120, and 200 days after sowing (DAS). Sampling was performed using a 1-m<sup>2</sup> quadrat, with three subsamples collected from each plot. Fresh mass was recorded, after which the samples were oven-dried at 65 ± 3 °C for 72 h and reweighed to determine dry mass.

### **2.4 Phytosociological survey**

At 240 DAS, a phytosociological survey of the spontaneously regenerating vegetation was conducted in the experimental plots. The survey involved the field identification and collection of regenerating individuals within the designated sampling areas of each plot. The same sampling area used for biomass assessment was adopted, comprising three 1-m<sup>2</sup> subsamples per plot. Taxa were identified to the family, genus, or species level with the assistance of specialists and botanical literature. The number of individuals per species, species richness, Shannon diversity index (H'), and Pielou evenness index (J') were determined.

### **2.5 Operational cost assessment**

Manual labor and mechanized operations were quantified in person-hours per hectare and machine-hours per hectare, respectively, with the activities classified by phase (establishment and maintenance) and treatment. Labor and input costs were based on prices prevailing in the Rio Claro region during the first half of 2022. Labor cost was set at R\$ 150.00 per 8-h workday, equivalent to R\$ 18.75 per person-

hour, whereas machine time was valued at R\$ 150.00 per machine-hour. Machinery depreciation, fuel consumption, and seed and herbicide prices were also included in the analysis.

## 2.6 Statistical analysis

Aboveground dry biomass data were subjected to analysis of variance (ANOVA), and pairwise mean comparisons were performed using the Tukey-Kramer test at a 5% significance level ( $p \leq 0.05$ ). Residual normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was assessed using Levene's test, both at a 5% significance level ( $p \leq 0.05$ ). Analyses were performed in R version 4.1.3 using the stats package for ANOVA and normality testing, the car package for testing homogeneity of variances, and the emmeans package for pairwise mean comparisons.

## 3 RESULTS AND DISCUSSIONS

### 3.1 Effects of the treatments on palisade grass control and cover-crop biomass production

Palisade grass aboveground dry biomass yield differed significantly among treatments across the assessment dates (Table 1; Figure 1). At 60 days after sowing (DAS), chemical control, the legume mixture, jack bean, and forage radish produced the greatest reductions in palisade grass dry biomass, with suppression levels ranging from 80% to 83% relative to the untreated control. These treatments were significantly more effective than mechanical control, which reduced biomass by only 52% (Table 1).

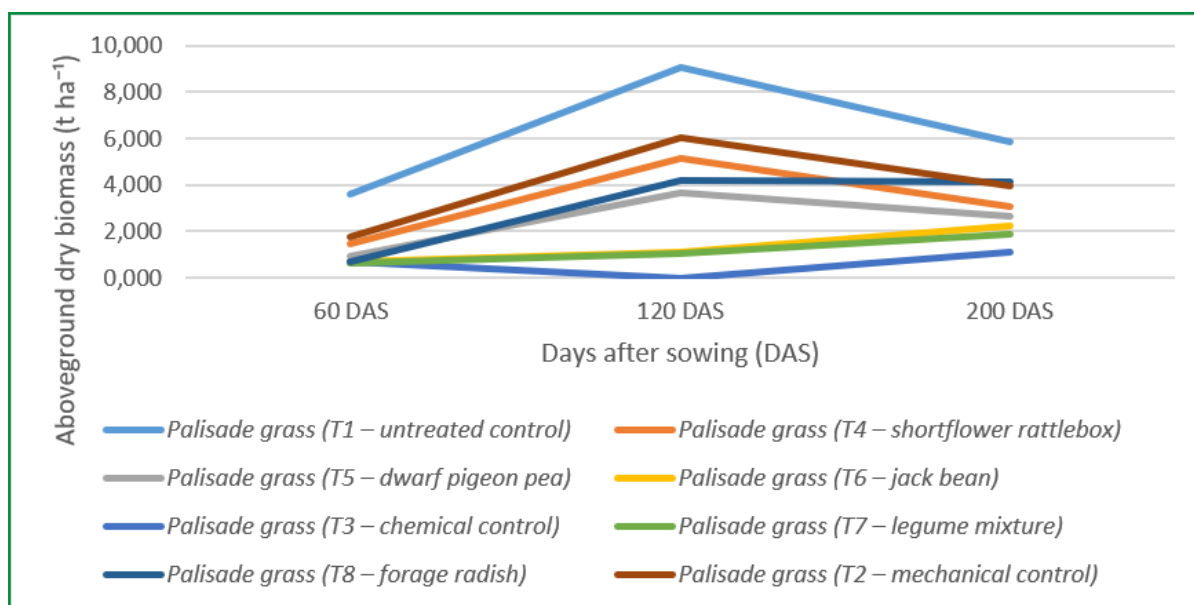
Table 1 – Aboveground dry biomass yield ( $\text{t ha}^{-1}$ ) and relative reduction (RR, %) of palisade grass under different treatments at 60, 120, and 200 days after sowing (DAS)

| Treatment                  | 60 DAS             |      | 120 DAS            |      | 200 DAS            |      |
|----------------------------|--------------------|------|--------------------|------|--------------------|------|
|                            | $\text{t ha}^{-1}$ | % RR | $\text{t ha}^{-1}$ | % RR | $\text{t ha}^{-1}$ | % RR |
| T1 – Untreated control     | 3,61 a             | 0%   | 9,04 a             | 0%   | 5,85 a             | 0%   |
| T2 – Mechanical control    | 1,74 a             | 52%  | 6,06 b             | 33%  | 3,97 ab            | 32%  |
| T3 – Chemical control      | 0,68 b             | 81%  | 0,00 d             | 100% | 1,09 c             | 81%  |
| T4 – Shortflower rattlebox | 1,43 a             | 60%  | 5,15 bc            | 43%  | 3,04 bc            | 48%  |
| T5 – Dwarf pigeon pea      | 0,94 a             | 74%  | 3,64 c             | 60%  | 2,62 bc            | 55%  |
| T6 – Jack bean             | 0,68 b             | 81%  | 1,12 d             | 88%  | 2,22 bc            | 62%  |
| T7 – Legume mixture*       | 0,61 b             | 83%  | 1,05 d             | 88%  | 1,86 bc            | 68%  |
| T8 – Forage radish         | 0,71 b             | 80%  | 4,17 c             | 54%  | 4,16 a             | 29%  |

Source: Authors (2023)

In where: \*Legume mixture comprising shortflower rattlebox, dwarf pigeon pea, and jack bean. Within each column, means followed by the same letter do not differ significantly according to the Tukey-Kramer test ( $p \leq 0.05$ ).

Figure 1 – Aboveground dry biomass yield of palisade grass at 60, 120, and 200 days after sowing (DAS) under the different cover-crop and control treatments



Source: Authors (2023)

At 120 DAS, chemical control achieved a 100% reduction in *Urochloa brizantha* biomass and did not differ significantly from jack bean or the legume mixture, both

of which reduced biomass by 88%. Dwarf pigeon pea produced an intermediate response, suppressing grass biomass by 60%. Forage radish became less effective, reducing grass biomass by only 54%. At 200 DAS, chemical control remained the most effective treatment, with an 81% reduction, and was the only treatment significantly more effective than mechanical control, which produced a 32% reduction ( $p \leq 0.05$ ). The remaining treatments produced reductions ranging from 29% to 68%, indicating declining effectiveness, particularly for the short-cycle legumes, whose senescence allowed renewed palisade grass establishment from the soil seed bank.

When the temporal dynamics of aboveground dry biomass production by the cover crops were examined (Figure 2), jack bean was the best-performing legume, reaching a peak of  $3.4 \text{ t ha}^{-1}$  at 120 DAS when grown as a monoculture. Its dense canopy architecture and broad leaflets reduce light penetration to the soil surface, hindering palisade grass regrowth. These findings corroborate previous studies demonstrating the effectiveness of jack bean in controlling invasive grasses and producing biomass, both as a monoculture and in intercropping systems (Carvalho et al., 2013; Santos et al., 2020).

Dwarf pigeon pea also performed well, reaching a maximum aboveground dry biomass yield of  $3.5 \text{ t ha}^{-1}$  at 120 DAS (Figure 2), corroborating previous findings by Fontanetti et al. (2004) and Fernandes et al. (1999). Like jack bean, this legume contributes to improving soil fertility through biological nitrogen fixation (Lopes, 1998; Fernandes et al., 1999; Teodoro et al., 2011).

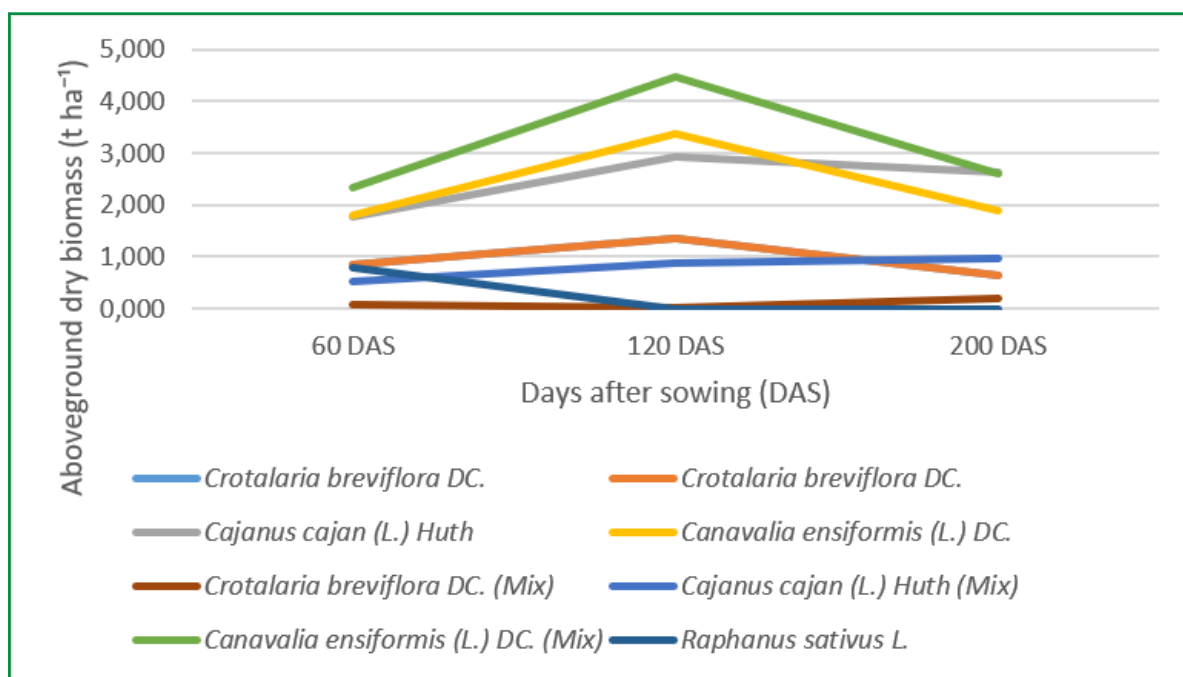
Shortflower rattlebox, in contrast, produced the lowest biomass yield among the legumes, reaching only  $1.4 \text{ t ha}^{-1}$  at 120 DAS (Figure 2). Possible explanations include the slower germination of the seeds used in the experiment and plant-health problems observed under field conditions, which resulted in malformed and curled leaves.

The species included in the legume-mixture treatment exhibited different responses. Jack bean again stood out, producing  $4.5 \text{ t ha}^{-1}$  at 120 DAS and exceeding its performance as a monoculture. Dwarf pigeon pea and shortflower rattlebox, in

contrast, produced significantly less biomass than in their respective monoculture plots, yielding only 1.0 and 0.4 t ha<sup>-1</sup> at 200 DAS, respectively (Figure 2). These findings suggest strong competitive dominance by jack bean within the mixture, resulting in interspecific competition detrimental to the other species.

Forage radish reached its maximum biomass yield at 60 DAS (0.85 t ha<sup>-1</sup>) but was no longer detected in the experimental area at 120 DAS. Early flowering, induced by sowing during the long-day summer period, accelerated its senescence. This species exhibits better agronomic performance when sown in autumn or winter, as described by Theisen (2008).

Figure 2 – Aboveground dry biomass yield of shortflower rattlebox, dwarf pigeon pea, and jack bean grown as monocultures or in the legume mixture, and of forage radish grown as a monoculture, at 60, 120, and 200 DAS



Source: Authors (2023)

Figure 2 also shows a general reduction in cover-crop aboveground dry biomass yield at 200 DAS compared with the peaks recorded at 120 DAS. This trend is consistent with the phenological cycles of the species used, most of which are short-cycle species whose growth and biomass accumulation rates tend to decline after flowering and

senescence. However, this reduction adversely affects palisade grass control because grass regrowth tends to intensify as competition for light and space decreases.

For comparison, Cunha et al. (2012) reported an annual mean palisade grass biomass yield of 14.76 t ha<sup>-1</sup> under different management regimes. This value is substantially higher than that recorded in the untreated control in the present study, illustrating the high competitive potential of the species in the absence of mechanical, chemical, or biological interference.

### 3.2 Effects of the treatments on spontaneous vegetation regeneration

At 240 DAS, the phytosociological survey recorded 14 identified regenerating taxa and one unidentified Lamiaceae taxon, distributed among six families. Asteraceae had the highest richness, with six taxa, followed by Malvaceae with four and Solanaceae with two (Table 2). Fabaceae, Lamiaceae, and Rubiaceae were each represented by one taxon. Although the total number of individuals did not differ significantly among treatments ( $p > 0.05$ ), the Shannon diversity ( $H'$ ) and Pielou evenness ( $J'$ ) indices varied markedly (Table 3).

Chemical control resulted in the highest species richness (9), followed by jack bean (8) and dwarf pigeon pea (6). According to the values reported in Table 3, the highest evenness indices were recorded for the untreated control ( $J' = 0.97$ ), shortflower rattlebox ( $J' = 0.91$ ), and the legume mixture ( $J' = 0.75$ ), indicating a more uniform distribution of individuals among taxa. According to Odum (1988), high evenness values are associated with more balanced systems in which no single species exhibits pronounced dominance.

In the chemical-control treatment, the herbicide was directed exclusively at palisade grass after the initial application. This treatment effectively disrupted grass dominance and allowed the establishment of pioneer herbaceous species that play an important role in ecological succession (Lorenzi, 2008). The cover-crop treatments, although temporarily favoring the emergence of some species, were limited by the

relatively short life cycles of the cover crops. Consequently, palisade grass regained dominance in these treatments after cover-crop senescence.

Table 2 – Spontaneously regenerating taxa recorded under each treatment, by family and taxon

| Treatment                        | Family     | Taxon                                | Density<br>(individuals ha <sup>-1</sup> ) |
|----------------------------------|------------|--------------------------------------|--------------------------------------------|
| T1 –<br>Untreated<br>control     | Asteraceae | <i>Vernonanthura polyanthes</i>      | 91                                         |
|                                  |            | <i>Sida cf. rhombifolia</i>          | 91                                         |
|                                  | Malvaceae  | <i>Sida cordifolia</i>               | 273                                        |
|                                  |            | <i>Triumfetta semitriloba</i>        | 273                                        |
|                                  |            | <i>Urena lobata</i>                  | 909                                        |
|                                  | Solanaceae | <i>Solanum cf. mauritianum</i>       | 182                                        |
| T2 –<br>Mechanical<br>control    | Asteraceae | <i>Ambrosia polystachya</i>          | 273                                        |
|                                  |            | <i>Austroeupatorium inulaefolium</i> | 91                                         |
|                                  | Lamiaceae  | N.I.                                 | 182                                        |
|                                  | Malvaceae  | <i>Triumfetta semitriloba</i>        | 545                                        |
|                                  |            | <i>Urena lobata</i>                  | 545                                        |
|                                  | Solanaceae | <i>Solanum cf. mauritianum</i>       | 182                                        |
| T3 –<br>Chemical<br>control      | Asteraceae | <i>Ambrosia polystachya</i>          | 91                                         |
|                                  |            | <i>Austroeupatorium inulaefolium</i> | 273                                        |
|                                  |            | <i>Baccharis cf. trinervis</i>       | 273                                        |
|                                  |            | <i>Vernonanthura polyanthes</i>      | 455                                        |
|                                  | Fabaceae   | <i>Mimosa invisa</i>                 | 182                                        |
|                                  |            | <i>Sida cf. rhombifolia</i>          | 91                                         |
|                                  | Malvaceae  | <i>Triumfetta semitriloba</i>        | 1182                                       |
|                                  |            | <i>Urena lobat.</i>                  | 364                                        |
|                                  | Solanaceae | <i>Solanum cf. mauritianum</i>       | 182                                        |
| T7 –<br>Legume<br>mixture        | Malvaceae  | <i>Sida cordifolia</i>               | 818                                        |
|                                  |            | <i>Triumfetta semitriloba</i>        | 91                                         |
|                                  |            | <i>Urena lobata</i>                  | 273                                        |
| T4 –<br>Shortflower<br>rattlebox | Asteraceae | <i>Austroeupatorium inulaefolium</i> | 455                                        |
|                                  |            | <i>Chormolaena maximiliani</i>       | 455                                        |
|                                  |            | <i>Vernonanthura polyanthes</i>      | 727                                        |
|                                  | Malvaceae  | <i>Triumfetta semitriloba</i>        | 909                                        |
| T5 – Dwarf<br>pigeon pea         | Asteraceae | <i>Ambrosia polystachya</i>          | 91                                         |
|                                  |            | <i>Chormolaena maximiliani</i>       | 91                                         |
|                                  |            | <i>Vernonanthura polyanthes</i>      | 91                                         |
|                                  | Malvaceae  | <i>Triumfetta semitriloba</i>        | 364                                        |
|                                  |            | <i>Urena lobata</i>                  | 455                                        |
|                                  | Solanaceae | <i>Solanum paniculatum</i>           | 182                                        |

Table 2 – Conclusion

| Treatment             | Family     | Taxon                                | Density<br>(individuals ha <sup>-1</sup> ) |
|-----------------------|------------|--------------------------------------|--------------------------------------------|
| T6 – Jack<br>bean     | Asteraceae | <i>Ambrosia polystachya</i>          | 455                                        |
|                       |            | <i>Austroeupatorium inulaefolium</i> | 273                                        |
|                       |            | <i>Lepidaploa sp</i>                 | 455                                        |
|                       | Malvaceae  | <i>Vernonanthura polyanthes</i>      | 273                                        |
|                       |            | <i>Triumfetta semitriloba</i>        | 364                                        |
|                       |            | <i>Urena lobata</i>                  | 455                                        |
|                       | Rubiaceae  | <i>Borreria verticillata</i>         | 91                                         |
| T8 – Forage<br>radish | Solanaceae | <i>Solanum cf. mauritianum</i>       | 818                                        |
|                       | Asteraceae | <i>Ambrosia polystachya</i>          | 364                                        |
|                       |            | <i>Vernonanthura polyanthes</i>      | 273                                        |
|                       | Malvaceae  | <i>Urena lobata</i>                  | 273                                        |
|                       | Solanaceae | <i>Solanum cf. mauritianum</i>       | 273                                        |

Source: Authors (2023)

In where: U.I. = individual not identified to the species level.

Table 3 – Species richness, Shannon diversity (H'), and Pielou evenness (J') of the regenerating community under the different palisade grass control treatments

| Treatment                         | Species richness | Shannon diversity<br>index (H') | Pielou evenness<br>index (J') |
|-----------------------------------|------------------|---------------------------------|-------------------------------|
| T1 – Untreated control            | 6                | 1,55                            | 0,97                          |
| T2 – Mechanical control           | 6                | 0,78                            | 0,44                          |
| T3 – Chemical control             | 9                | 1,19                            | 0,54                          |
| T7 – Legume mixture               | 3                | 0,83                            | 0,75                          |
| T4 – Shortflower rattlebox sowing | 4                | 1,26                            | 0,91                          |
| T8 – Forage radish sowing         | 4                | 0,57                            | 0,41                          |
| T5 – Dwarf pigeon pea sowing      | 6                | 0,57                            | 0,32                          |
| T6 – Jack bean sowing             | 8                | 1,08                            | 0,52                          |

Source: Authors (2023)

Most of the regenerating taxa observed were herbaceous dicotyledons, suggesting that their seeds were present in the soil seed bank. The reduction in palisade grass dominance under the most effective treatments may have created conditions favorable to germination, including greater light availability and less competition for resources, thereby allowing these pioneer species to become established.

This pattern is consistent with the role of the soil seed bank as an important reservoir of local biodiversity and with its sensitivity to changes in ground-cover conditions. Natural regeneration plays a central role in ecological restoration and can be promoted by reducing competing species and improving local environmental conditions (Souza; Batista, 2004; Garwood, 1989; Martins; Silva, 2006).

Furthermore, the strong competition exerted by palisade grass for light, water, and nutrients is recognized as an inhibiting factor in the emergence and development of native species (Santos et al., 2020), reinforcing the importance of its control in areas intended for ecological restoration.

### 3.3 Comparative analysis of operational costs

Operational costs differed substantially among treatments in terms of both labor and inputs (Tables 4–7). Chemical control with glyphosate had the lowest total cost per hectare (R\$ 1,665.00 ha<sup>-1</sup>) because of its low labor requirement and the relatively low cost of its inputs. The legume-mixture treatment, in contrast, had the highest cost (R\$ 5,460.41 ha<sup>-1</sup>), reflecting the simultaneous use of three species and the additional operations required for sowing (Tables 6 and 7; Figure 3). Similar findings have been reported in economic assessments of AFSs, in which initial establishment and the costs of propagation material and management operations represent a substantial proportion of the investment required to establish the system (Neves et al., 2014).

The legume monocultures had intermediate costs. Jack bean had the highest cost among them (R\$ 3,597.41 ha<sup>-1</sup>), followed by dwarf pigeon pea (R\$ 2,733.41 ha<sup>-1</sup>) and shortflower rattlebox (R\$ 2,220.41 ha<sup>-1</sup>). Because of its lower seeding rate and seed cost, forage radish was the least expensive cover-crop treatment (R\$ 1,583.21 ha<sup>-1</sup>), although it was less effective in controlling palisade grass and persisted for only a short period under field conditions.

Mechanical control, which had traditionally been used in the experimental area, required substantial labor and equipment use, including a brushcutter and hand tools.

Consequently, its total cost was R\$ 2,259.85 ha<sup>-1</sup>, exceeding the costs of some cover-crop treatments (Tables 6 and 7).

Table 4 – Operational requirements and costs of the activities performed under the palisade grass control treatments

| Activity                     | Labor requirement<br>(person-hours ha <sup>-1</sup> ) <sup>1</sup> | Reference value<br>(person-hours ha <sup>-1</sup> ) <sup>2</sup> | Cost (R\$ ha <sup>-1</sup> ) <sup>3</sup> |
|------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------|
| Herbicide application        | 24.00                                                              | 18                                                               | 450.00                                    |
| Furrow preparation           | 28.33                                                              | -                                                                | 531.25                                    |
| Manual sowing of cover crops | 18.89                                                              | -                                                                | 354.16                                    |
| Semi-mechanized mowing       | 13.50                                                              | 20                                                               | 253.13                                    |
| Ring weeding                 | 24.80                                                              | -                                                                | 465.00                                    |

Source: Authors (2023)

In where: <sup>1</sup> Person-hours ha<sup>-1</sup>; <sup>2</sup> Nave et al. (2009); <sup>3</sup> hourly cost reference (Resende; Leles, 2017).

Table 5 – Costs of the inputs used under the palisade grass control treatments

| Input                                     | Quantity<br>(ha <sup>-1</sup> ) | Unit cost<br>(R\$ kg <sup>-1</sup> or R\$ L <sup>-1</sup> ) | Cost<br>(R\$ ha <sup>-1</sup> ) |
|-------------------------------------------|---------------------------------|-------------------------------------------------------------|---------------------------------|
| Herbicide applied over the entire area    | 2.5 L                           | 105.00                                                      | 210.00                          |
| Shortflower rattlebox seeds               | 25 kg                           | 27.00                                                       | 675.00                          |
| Dwarf pigeon pea seeds                    | 40 kg                           | 29.70                                                       | 1,188.00                        |
| Jack bean seeds                           | 120 kg                          | 17.10                                                       | 2,052.00                        |
| Forage radish seeds                       | 3 kg                            | 12.60                                                       | 37.80                           |
| Spot-applied herbicide during maintenance | 0,5 L                           | 105.00                                                      | 52.50                           |
| Gasoline for the brushcutter              | 6.75 L                          | 7.23                                                        | 48.80                           |
| Two-stroke oil for the brushcutter        | 0.13 L                          | 38.00                                                       | 5.13                            |
| Brushcutter depreciation                  | 13.5 h                          | 0.34                                                        | 4.60                            |
| Hand tools                                | 1 unid.                         | 23.27                                                       | 23.27                           |

Source: Authors (2023)

Table 6 – Labor and operational activity costs (R\$ ha<sup>-1</sup>) under the palisade grass control treatments in an agroforestry system in Lídice, Rio Claro, Rio de Janeiro State, Brazil

| Activity                                     | Shortflower<br>rattlebox | Dwarf pigeon<br>pea | Jack bean    | Forage radish | Legume<br>mixture | Chemical<br>control | Mechanical<br>control |
|----------------------------------------------|--------------------------|---------------------|--------------|---------------|-------------------|---------------------|-----------------------|
| Establishment                                | R\$ 1.335,41             | R\$ 1.335,41        | R\$ 1.335,41 | R\$ 1.335,41  | R\$ 1.335,41      | R\$ 450,00          | R\$ 450,00            |
| Herbicide application                        | R\$ 450,00               | R\$ 450,00          | R\$ 450,00   | R\$ 450,00    | R\$ 450,00        | R\$ 450,00          | R\$ 450,00            |
| Furrow preparation                           | R\$ 531,25               | R\$ 531,25          | R\$ 531,25   | R\$ 531,25    | R\$ 531,25        | R\$ 0,00            | R\$ 0,00              |
| Sowing                                       | R\$ 354,16               | R\$ 354,16          | R\$ 354,16   | R\$ 354,16    | R\$ 354,16        | R\$ 0,00            | R\$ 0,00              |
| First maintenance                            | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 450,00          | R\$ 718,13            |
| Mowing                                       | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 0,00            | R\$ 253,13            |
| Ring weeding                                 | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 0,00            | R\$ 465,00            |
| Herbicide application                        | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 450,00          | R\$ 0,00              |
| Second maintenance                           | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 450,00          | R\$ 718,13            |
| Mowing                                       | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 0,00            | R\$ 253,13            |
| Ring weeding                                 | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 0,00            | R\$ 465,00            |
| Herbicide application                        | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00      | R\$ 0,00          | R\$ 450,00          | R\$ 0,00              |
| Total labor and<br>operational activity cost | R\$ 1.335,41             | R\$ 1.335,41        | R\$ 1.335,41 | R\$ 1.335,41  | R\$ 1.335,41      | R\$ 1.350,00        | R\$ 1.886,25          |

Source: Authors (2023)

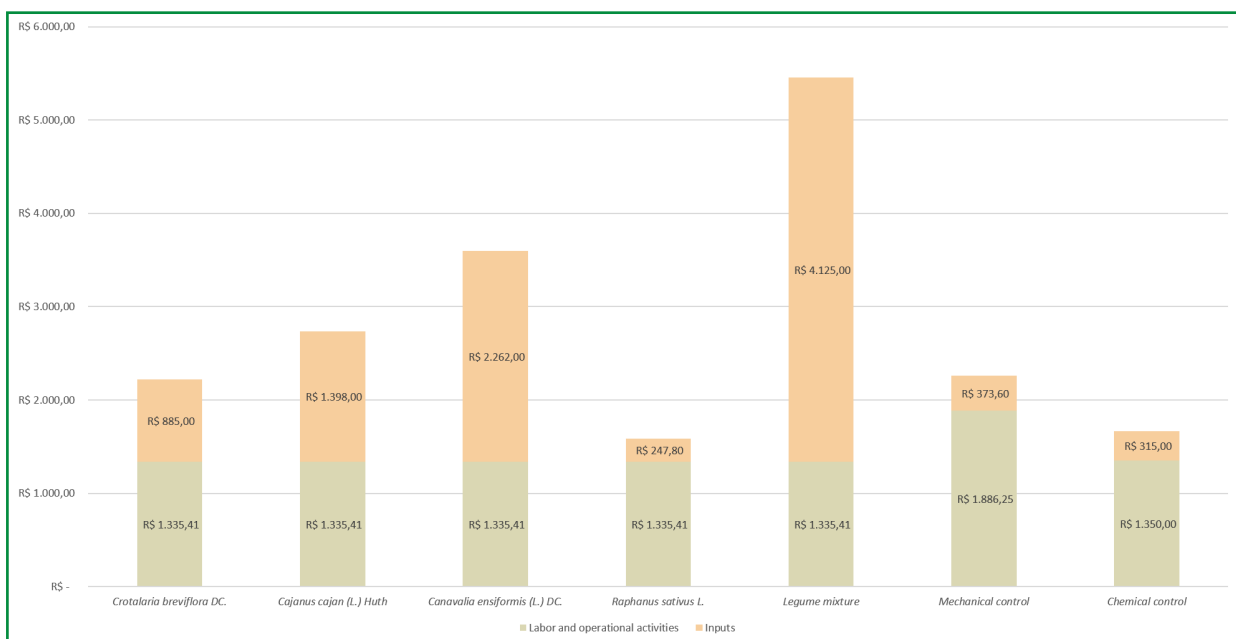
Table 7 – Input costs (R\$ ha<sup>-1</sup>) under the palisade grass control treatments in an agroforestry system in Lídice, Rio Claro, Rio de Janeiro State, Brazil

| Input                                 | Shortflower<br>rattlebox | Dwarf pigeon<br>pea | Jack bean    | Forage<br>radish | Legume<br>mixture | Chemical<br>control | Mechanical<br>control |
|---------------------------------------|--------------------------|---------------------|--------------|------------------|-------------------|---------------------|-----------------------|
| Establishment                         | R\$ 885,00               | R\$ 1.398,00        | R\$ 2.262,00 | R\$ 247,80       | R\$ 4.125,00      | R\$ 210,00          | R\$ 210,00            |
| Herbicide                             | R\$ 210,00               | R\$ 210,00          | R\$ 210,00   | R\$ 210,00       | R\$ 210,00        | R\$ 210,00          | R\$ 210,00            |
| Shortflower rattlebox seeds           | R\$ 675,00               | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 675,00        | R\$ 0,00            | R\$ 0,00              |
| Dwarf pigeon pea seeds                | R\$ 0,00                 | R\$ 1.188,00        | R\$ 0,00     | R\$ 0,00         | R\$ 1.188,00      | R\$ 0,00            | R\$ 0,00              |
| Jack bean seeds                       | R\$ 0,00                 | R\$ 0,00            | R\$ 2.052,00 | R\$ 0,00         | R\$ 2.052,00      | R\$ 0,00            | R\$ 0,00              |
| Forage radish seeds                   | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 37,80        | R\$ 0,00          | R\$ 0,00            | R\$ 0,00              |
| First maintenance                     | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 52,50           | R\$ 81,80             |
| Herbicide                             | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 52,50           | R\$ 0,00              |
| Brushcutter gasoline                  | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 48,80             |
| Two-stroke oil for the<br>brushcutter | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 5,13              |
| Brushcutter depreciation              | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 4,60              |
| Hand tools                            | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 23,27             |
| Second maintenance                    | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 52,50           | R\$ 81,80             |
| Herbicide                             | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 52,50           | R\$ 0,00              |
| Brushcutter gasoline                  | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 48,80             |
| Two-stroke oil for the<br>brushcutter | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 5,13              |
| Brushcutter depreciation              | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 4,60              |
| Hand tools                            | R\$ 0,00                 | R\$ 0,00            | R\$ 0,00     | R\$ 0,00         | R\$ 0,00          | R\$ 0,00            | R\$ 23,27             |
| Total input cost                      | R\$ 885,00               | R\$ 1.398,00        | R\$ 2.262,00 | R\$ 247,80       | R\$ 4.125,00      | R\$ 315,00          | R\$ 373,60            |

Source: Authors (2023)

From the standpoint of operational efficiency, chemical control provided the best direct cost-effectiveness, combining low operational complexity, high effectiveness in suppressing palisade grass, and the lowest total cost (Figure 3). However, this method does not provide the agroecological benefits associated with cover crops, including the addition of plant biomass to the system, improvement of soil quality, nutrient cycling, increases in soil organic matter, suppression of spontaneous vegetation, and the potential biological fixation of nitrogen by legumes (Kocira et al., 2020; Scavo et al., 2022). Therefore, economic comparisons among management strategies should consider not only direct establishment costs but also the ecosystem services associated with conservation-oriented management practices, whose valuation may alter perceptions of treatment feasibility (Pino; Menezes, 2025).

Figure 3 – Total operational cost per hectare (R\$ ha<sup>-1</sup>) of the different palisade grass control treatments



Source: Authors (2023)

Among the legumes, jack bean provided the best balance among cost, effectiveness in controlling palisade grass, and the provision of ecosystem services. It performed similarly to the legume mixture in suppressing the grass but had a lower

cost and resulted in less pronounced dominance by any single regenerating species. Dwarf pigeon pea also performed reasonably well and had a lower cost than jack bean.

Thus, considering the three principal dimensions of the study—effectiveness in controlling palisade grass, promotion of natural regeneration, and operational cost—jack bean and dwarf pigeon pea emerged as the most balanced options for agroforestry systems under similar conditions. These alternatives make it possible to align economic feasibility with the ecological and sustainability objectives required in such systems.

## 4 CONCLUSIONS

The management strategies evaluated differed in their ability to suppress *Urochloa brizantha* within the agroforestry system. Chemical control provided the greatest and most persistent suppression of palisade grass over the evaluation period. By combining high control efficacy with a relatively low operational cost, this treatment offered the best direct cost-effectiveness among the evaluated strategies.

Among the cover crops, jack bean provided the greatest suppression of palisade grass, performing similarly to the legume mixture, whereas dwarf pigeon pea exhibited intermediate performance. Although these treatments were less effective than chemical control, cover crops contributed plant biomass to the system and represent management options that can be integrated into agroforestry systems. Because all cover-crop treatments were preceded by glyphosate desiccation, their results should be interpreted as part of an integrated management strategy rather than as exclusively nonchemical control.

Under the conditions and evaluation period of this study, the selection of a management strategy should consider palisade grass suppression, control persistence, operational costs, and the intended agroecological functions of the production system. Chemical control is the most suitable option when maximum suppression and direct cost-effectiveness are the primary objectives. Jack bean, in turn, provided the best balance between grass suppression, operational feasibility, and integration with the agroforestry system, whereas dwarf pigeon pea represents an intermediate-performing alternative with a lower operational cost than jack bean.

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Datasets related to this article will be available upon request to the corresponding author.

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