Restoration of natural grasslands in the Pampa biome: short-term vegetation responses to selective chemical control of *Eragrostis plana* Nees

Restauração de pastagens naturais no bioma da Pampa: respostas da vegetação a curto prazo ao controle químico seletivo da *Eragrostis plana* Nees

Restauración de praderas naturales en el bioma de la Pampa: respuestas a corto plazo de la vegetación al control químico selectivo de *Eragrostis plana* Nees

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Bruno Bervig Collares
Ph.D. in Agricultural Engineering
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: collaresbb@gmail.com

Fabiane Granzotto
Ph.D. in Forest Engineering
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: fabianegranzotto@yahoo.com.br

Guilherme Diego Fockink
Ph.D. in Forest Engineering
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: guilhermefockink@gmail.com

Pedro Seeger da Silva
Bachelor's Degree in Forestry Engineering
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: pedrosseeger@gmail.com

Jhonitan Matiello
Master's Degree in Agricultural Engineering
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: jhonitan.matiello@yahoo.com.br

Sabrina Nicoletti
Bachelor's Degree in Biology
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: sabrinanicoletti396@gmail.com

Ana Paula Moreira Rovedder
Ph.D. in Soil Science
Institution: Universidade Federal de Santa Maria
Address: Santa Maria, Rio Grande do Sul, Brazil
E-mail: anarovedder@gmail.com

ABSTRACT
The expansion of *Eragrostis plana* (*Eragrostis plana* Nees.) is one of the main threats to the ecological integrity of the native grasslands of the Pampa biome, damaging biodiversity and livestock productivity. This study evaluated the short-term effects of selective chemical control of this invasive species on two family livestock farms in southern Brazil, using the "Campo Limpo" equipment for localized application of glyphosate. Floristic and ground cover surveys were carried out before and after control, with statistical analysis of the data. Selective control significantly reduced the abundance of *Eragrostis plana* and ruderal species, promoting an increase in the dominance of forage grasses, especially the Paspalum genus. Although there was a reduction in total diversity and species richness, there was a qualitative improvement in the plant community, resulting in greater resistance to grazing disturbances and improved forage quality. The variables that demonstrate this increase in quality were the increase in the percentage of native field cover and the replacement of ruderal species with species of high forage value. Selective control proved to be effective, but requires periodic reapplications due to the species' high potential for regrowth and re-establishment from the soil seed bank. The results indicate that selective chemical control is a promising tool for the productive recovery of degraded grasslands, as long as it is integrated with adaptive conservation strategies and the sustainable use of native grasslands.

Keywords: biological invasion, grasslands ecology, Pampa biome, tough lovegrass.

RESUMO
A expansão da *Eragrostis plana* (*Eragrostis plana* Nees.) é uma das principais ameaças à integridade ecológica das pastagens nativas do bioma da Pampa, prejudicando a biodiversidade e a produtividade pecuária. Este estudo avaliou os efeitos de curto prazo do controle químico seletivo dessa espécie invasora em duas fazendas de pecuária familiar no sul do Brasil, utilizando o equipamento "Campo Limpo" para aplicação localizada de glifosato. Foram realizados levantamentos florísticos e de cobertura do solo antes e após o controle, com análise estatística dos dados. O controle seletivo reduziu significativamente a abundância de *Eragrostis plana* e de espécies ruderais, promovendo um aumento na dominância de gramíneas forrageiras, especialmente do gênero Paspalum. Embora tenha havido uma redução na diversidade total e na riqueza de espécies, observou-se uma melhoria qualitativa na comunidade vegetal, resultando em maior resistência aos distúrbios causados pelo pastoreio e melhor qualidade da forragem. As variáveis que demonstram esse aumento na qualidade foram o aumento da porcentagem de cobertura de campo nativa e a substituição de espécies ruderales por espécies de alto valor forrageiro. O controle seletivo mostrou-se eficaz, mas requer reaplicações

periódicas devido ao alto potencial da espécie para rebrote e restabelecimento a partir do banco de sementes do solo. Os resultados indicam que o controle químico seletivo é uma ferramenta promissora para a recuperação produtiva de pastagens degradadas, desde que seja integrado a estratégias de conservação adaptativa e ao uso sustentável das pastagens nativas.

Palavras-chave: invasão biológica, ecologia de pastagens, bioma da Pampa, capim-amor-duro.

RESUMEN
La expansión de *Eragrostis plana* (*Eragrostis plana* Nees.) constituye una de las principales amenazas para la integridad ecológica de los pastizales autóctonos del bioma de la Pampa, ya que perjudica la biodiversidad y la productividad ganadera. Este estudio evaluó los efectos a corto plazo del control químico selectivo de esta especie invasora en dos explotaciones ganaderas familiares del sur de Brasil, utilizando el equipo «Campo Limpo» para la aplicación localizada de glifosato. Se realizaron inventarios florísticos y de cobertura del suelo antes y después del control, con análisis estadístico de los datos. El control selectivo redujo significativamente la abundancia de *Eragrostis plana* y de especies ruderales, lo que favoreció un aumento del dominio de las gramíneas forrajeras, especialmente del género Paspalum. Aunque se observó una reducción de la diversidad total y de la riqueza de especies, se produjo una mejora cualitativa en la comunidad vegetal, lo que se tradujo en una mayor resistencia a las perturbaciones del pastoreo y en una mejor calidad del forraje. Las variables que evidencian este aumento de la calidad fueron el incremento del porcentaje de cobertura del campo por especies autóctonas y la sustitución de especies ruderales por especies de alto valor forrajero. El control selectivo demostró ser eficaz, pero requiere reaplicaciones periódicas debido al elevado potencial de rebrote y restablecimiento de la especie a partir del banco de semillas del suelo. Los resultados indican que el control químico selectivo es una herramienta prometedora para la recuperación productiva de los pastizales degradados, siempre que se integre con estrategias de conservación adaptativas y el uso sostenible de los pastizales autóctonos.

Palabras clave: invasión biológica, ecología de los pastizales, bioma de la Pampa, pasto amoroso resistente.

1 INTRODUCTION

The Brazilian Pampa biome, restricted to the state of Rio Grande do Sul, covers approximately 193,000 km², corresponding to 68% of the state territory and around 2% of the national territory (IBGE, 2019). Its main phytophysiognomies are made up of natural grasslands, which are widely used for livestock farming, a fundamental activity for the local economy and for maintaining these landscapes. However, inadequate management practices, such as overgrazing, have intensified environmental degradation processes, altering soil characteristics and favoring the proliferation of invasive species, such as *Eragrostis plana* (*Eragrostis plana* Nees) (Ajorlo *et al.*, 2011). Even with the

increase in studies focused on this region, there is still a need for studies that promote restorative production systems and combine biodiversity conservation with income generation (Trevisan *et al.*, 2023).

Eragrostis plana stands out as one of the most aggressive and difficult-to-control invasive species in the Pampa biome, with seeds that are highly persistent in the soil and a high percentage of regrowth (Medeiros and Focht, 2007; Medeiros, 2014). Its presence reduces livestock productivity and has negative allelopathic effects on native flora, damaging the conservation of native grasslands. The species is especially common in areas subject to overgrazing, cattle corridors and roadsides (Medeiros *et al.*, 2009).

Eragrostis plana control is hampered by the species' resistance to traditional methods, such as mechanical mowing and the indiscriminate application of herbicides, which can compromise the conservation of native grasslands. In this context, selective chemical control, carried out with the "Campo Limpo" equipment, allows targeted application of the herbicide, minimizing impacts on native species (Perez, 2010). However, the floristic and structural diversity of natural grasslands requires adaptive approaches, taking into account the specificities of each area (Nabinger *et al.*, 2009).

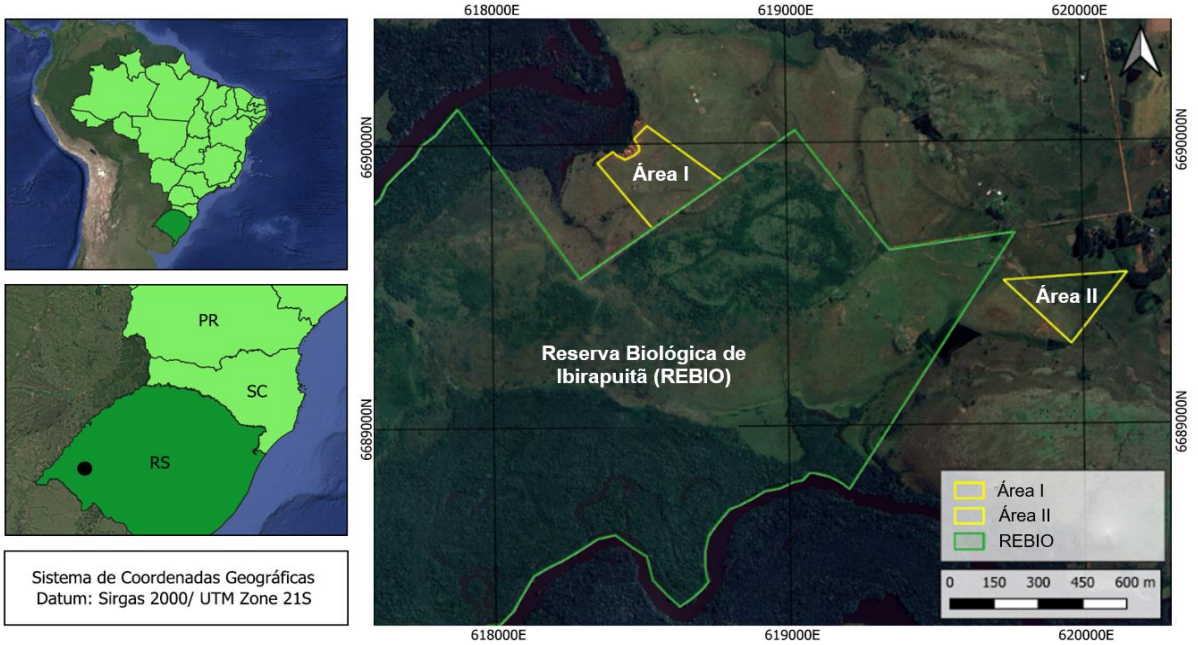
Given this scenario, this study aimed to evaluate the effectiveness of selective chemical control of *Eragrostis plana* on floristic composition and soil cover in areas of native grassland degraded by overgrazing and biological invasion. We sought to answer the following questions: 1) Is selective chemical control using the "Campo Limpo" implement effective in reducing invasion by *Eragrostis plana*? and 2) Is this control strategy effective in recovering native vegetation?

2 METHODS

The study was carried out on two rural properties in the Pampa biome in southern Brazil. The experiment took place between September 2022 and March 2023. The areas studied are located in a transitional region between the phytophysiognomies of Campos dos Areais and Campos de Soos Rasos (Hasenack *et al.*, 2023), with a predominance of species from the Poaceae and Asteraceae families. The climate is Cfa (Peel *et al.*, 2007), with an average annual rainfall of 1,500 mm, of which 874 mm falls between September and March. However, during the period of this study, the water balance was only 328 mm, representing only 37.5% of the historical average, and marking a period of severe drought (INMET, 2023).

The properties were chosen because they are located in an area of importance for the preservation of grassland ecosystems, bordering the Ibirapuitã Biological Reserve, and could serve as a gateway for biological invasion into the reserve (Figure 1). Both properties are characterized by a history of extensive livestock farming in native grasslands. There is a predominance of Red-Yellow Argisols with a sandy texture and gently undulating topography, with the presence of rocky outcrops in higher areas (Rovedder *et al.*, 2025). The region shows varying degrees of degradation caused by overgrazing, with limited or no use of animal load adjustment techniques, causing low animal development and the disappearance of forage species, as well as extensive areas of exposed soil and erosion, conditions conducive to biological invasion (Rovedder and Eltz, 2008).

Figure 1. Delimitation of the study area in two rural properties (Area I and Area II), located around the Ibirapuitã Biological Reserve, in the municipality of Alegrete, Rio Grande do Sul, Brazil.

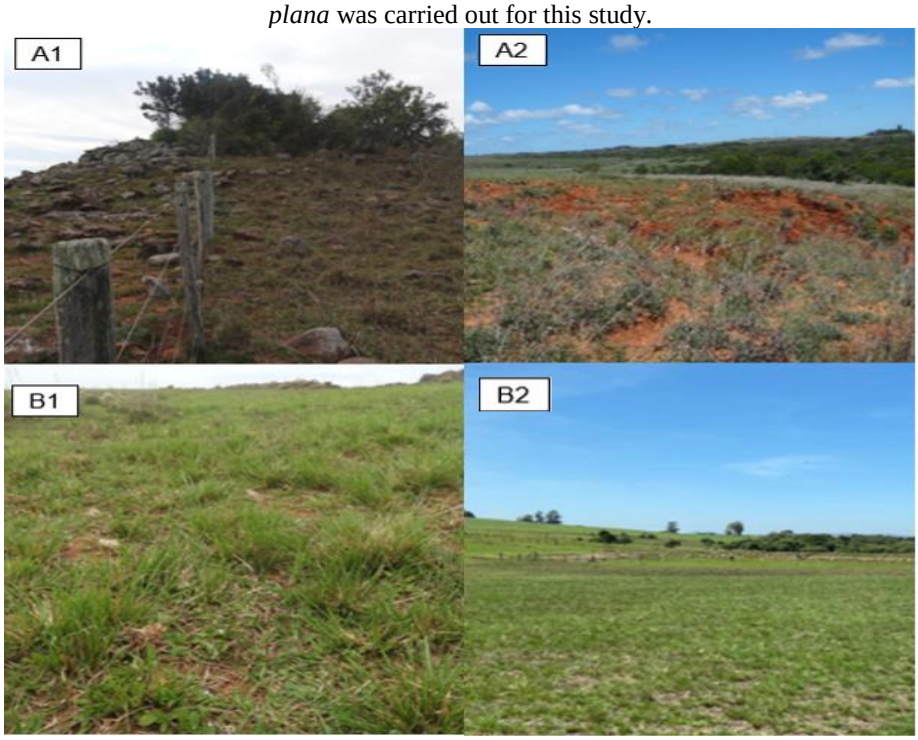


Source: Prepared by the authors (2026).

Together with the owners, an area was established on each property for the selective control of *Eragrostis plana*. In Area I (-29.915705, -55.77147), control took place in a 22 ha area used for cattle farming, with an animal load of 0.95 animal units per hectare (Ua/ha). The history of use is animal production in native grassland, in an extensive system, with continuous grazing and no use of inputs. The animal load was considered high as it showed signs of degradation due to overgrazing, such as low forage supply and outbreaks of sanding. Area II (-29.920687, -55.758757) consisted of 10 ha,

with an animal load of 1.26 Ua/ha, with a mixed herd of cattle and sheep, in an extensive system with continuous grazing. The area has a history of over-seeding with forage species, such as rye-grass (*Lolium multiflorum*). However, the animal load was also considered high, as it showed signs of overgrazing such as low forage supply and soil compaction.

Figure 2. Representative photos of areas I (A) and II (B) where selective chemical control of *Eragrostis plana* was carried out for this study.



Where: Rocky outcrops are present in Area I (A1), fields invaded by E. plana with pockets of sandification and erosion in Area I (A2), fields invaded by E. plana in Area II (B1), fields invaded by E. plana with patches of exposed soil (B2).
Source: Prepared by the authors (2026).

The actions were divided into five stages: 1) initial vegetation survey (T0) carried out at the end of September 2022; 2) grazing exclusion period, during the month of October, in order to differentiate vegetation strata and enable chemical control to reach only the clumps of the target species; 3) selective chemical control of *Eragrostis plana* carried out at the beginning of November 2022 and grazing resumed after one week; 4) grazing exclusion period at 30 days after control (T1), carried out at the beginning of December 2022 and grazing resumed after one week; 5) chemical control at 30 days after control (T1) carried out at the beginning of December 2022 plana was carried out at the beginning of November 2022 and grazing was resumed after a week; 4) vegetation survey

at 30 days after control (T1), carried out at the beginning of December 2022; 5) vegetation survey 120 days after control (T2), carried out at the beginning of March 2023.

For chemical control, glyphosate was applied (Merotto *et al.*, 2022), using the "Campo Limpo" implement (Perez, 2010), which consists of a chemical brush cutter for selective control of unwanted herbaceous plants, acting mainly on the variation in height between the strata of the field (Figure 3A). In areas where the tractor cannot access, such as rocky outcrops, a manual chemical hoe model (Perez, 2008) was used, recommended for controlling unwanted species with contact herbicide (Figure 3B). Control in both methods occurs through direct contact of the implement with the upper portion of the invasive species, preserving the lower stratum of native species. Thus, the herbicide is not sprayed, which reduces drift, minimizing the dangers of inhalation and contamination of soil, water, or non-target species (Perez, 2010). The solution used contained 20% glyphosate and 80% water, the volume recommended by experts, with a total of 4 L/ha of herbicide applied.

Figure 2. Application of selective chemical control of *Eragrostis plana* Nees. using the Campo Limpo implement (A), and a hand-held chemical hoe (B), in Area I, a rural property located around the Ibirapuitã Biological Reserve.



Source: Prepared by the authors (2026).

Vegetation and land cover analysis was carried out on 10 fixed 1 m² plots in each area, with a minimum distance of 50 m between each point (Müller-Dombois and Ellenberg, 1974). Land cover analysis was carried out using the manual land cover classification interface per pixel sampled on a regular grid, using the free SamplePoint® software version 1.60 (Booth *et al.* 2006). The photographs used for the manual classification were taken with a mobile phone digital camera, with a resolution of 12 MP, at a height of approximately 1.50 m from the ground. Analysis of these images in the software made it possible to determine the soil cover during the monitoring period,

assigning a regular grid of pixels categorized as exposed soil (SE), green biomass cover (CBV) and dry biomass cover (CBS).

Floristic data was collected from the same ground cover plots (1 m2). The species recorded were identified to species level based on regional bibliography, consultation of herbaria and specialists, following the APG IV system (The Angiosperm Phylogeny Group, 2016). The richness and number of vegetative units per species were quantified for each plot. In this study, the term vegetative unit is used to represent the count of individuals of each species, or in the case of stoloniferous species, the tiller count (Nabinger and D'allagnol, 2020) of each species. The species identified were divided into three categories considered relevant to the study: Poaceae and Fabaceae (PF), as they are families with great forage potential; invasive exotic species, especially *Eragostis plana* Nees (EPN); and other botanical families (OFB), including native species that have low or no forage potential for use in cattle feed, such as herbaceous species with low forage potential and shrub species. The Shannon (H') and Pielou (J') diversity indices were also determined and then analyzed using Hutcheson's t-test (Hutcheson, 1970), using Past software version 4.13 (Hammer *et al.* 2001).

Statistical analyses were carried out on the land cover data and the number of vegetative units for each species in R Studio (R Development Core Team, 2024). The Shapiro-Wilk and Bartlett tests confirmed the assumptions of normality and homogeneity of variance in the data obtained. The variables that did not meet the assumptions were transformed using logarithmic transformation, and then their differences were determined using the ANOVA test ($p<0.05$). In addition, an NMDS (Non-Metric Multidimensional Scaling) analysis was carried out to verify differences in the floristic composition of the vegetation as a function of the monitoring times (T0, T1 and T2), with the significance of its results verified by permutational analysis of variance (PERMANOVA). To do this, a matrix of abundance of vegetative units per species was used. Dissimilarity was obtained using the Bray-Curtis method. The suitability of the analysis was assessed using the stress value. The vegan package (Oksanen *et al.*, 2019) was used for the analysis.

3 RESULTS

The percentages of cover by green biomass (CBV) and dry biomass (CBS) in area I differed statistically between the surveys, as a result of the selective control of *Eragrostis plana* (Table 1). The proportion of exposed soil (SE) showed no statistical

difference during monitoring. The coefficients of variation for the land cover data indicate that, in Area I, the relative variability was 9.5% for CBV, 10.5% for CBS and 19.6% for SE. In Area II, there was a statistical difference in the percentage of SC at 30 days after selective chemical control (T1). CBV and SE showed no statistical difference in their results. The coefficients of variation were 15.5% for CBV, 13.3% for CBS and 24.7% for SE.

Table 1. Analysis of variance (ANOVA) for soil cover (percentage data), in the categories exposed soil (SE), green biomass cover (CBV) and dry biomass cover (CBS) in experimental areas I and II (Area I and Area II), during the initial survey (T0), 30 days after selective chemical control (T1) and 120 days after selective chemical control (T2).

	Area I			Area II		
Categories	T0	T1	T2	T0	T1	T2
CBV	72,6^{a}	57,8^{b}	85,5^{a}	57,8^{a}	45,3^{a}	64,2^{a}
CBS	19,0^{a}	35,2^{b}	10,5^{a}	25,2^{a}	42,7^{b}	16,6^{a}
SE	8,4^{a}	7,0^{a}	4,0^{a}	17,0^{a}	12,0^{a}	19,2^{a}

*Values preceded by the same letter in the line for each area did not differ by the Tukey test ($p < 0.05$).
Source: Prepared by the authors (2026).

The increase in soil cover by green biomass (CBV) in Area I is directly linked to the increase in the number of individuals of species from the Poaceae family, which represented 40.51% of the plant community at T0 and 65.83% at T2. The main species responsible for this change was Paspalum notatum, which went from 172 vegetative units in T0 to 439 vegetative units recorded in T2. In area II, this pattern was repeated, but to a lesser extent and was not statistically significant.

Table 2 shows the results for the abundance of each category of species identified within the plant community. In area I, only the abundance of *Eragrostis plana* Nees (EPN) and other botanical families (OFB) differed significantly between monitoring times. The abundance of EPN and OFB was lower at T2. In area II, the abundance of EPN was lower at T2 and the abundance of OFB at T1 and T2. The coefficients of variation show that, in Area I, the relative variability was 47.5% for *Eragrostis plana*, 17.2% for Poaceae and Fabaceae (PF), 24.7% for other botanical families. In Area II, the coefficients of variation were 19.0% for EPN, 24.1% for PF and 8.0% for OFB. The list of species identified in both areas can be found in Appendices A (Area I) and B (Area II).

Table 2. Number of vegetative units identified, divided between Poaceae and Fabaceae (PF), *Eragrostis plana* Nees. (EPN) and Other botanical families (OFB), in the experimental areas (Area I and Area II), during the initial survey (T0), 30 days after selective chemical control (T1) and 120 days after selective chemical control (T2).

	Area I			Area II		
Categories	T0	T1	T2	T0	T1	T2
PF	551[a]	654[a]	722[a]	429[a]	513[a]	593[a]
EPN	187[a]	182[a]	60[b]	288[a]	117[ab]	107[b]
OFB	572[a]	411[ab]	252[b]	1748[a]	205[b]	380[b]

* Values followed by the same letter in the row for each area did not differ significantly by the Tukey test ($p < 0.05$).
Source: Prepared by the authors (2026).

With regard to the diversity indices (Table 3), there was no significant difference between the treatments in terms of species diversity (H') using the Hutcheson test. The data showed normality according to the Kruskall-Wallis test for Area I ($p = 0.9863$) and Area II ($p = 0.004767$). A decrease in species diversity was observed, especially between the T1 and T2 evaluations, where a statistical variation in the Shannon index was observed. The values found for Shannon (H') and Pielou (J') are shown in Table 3.

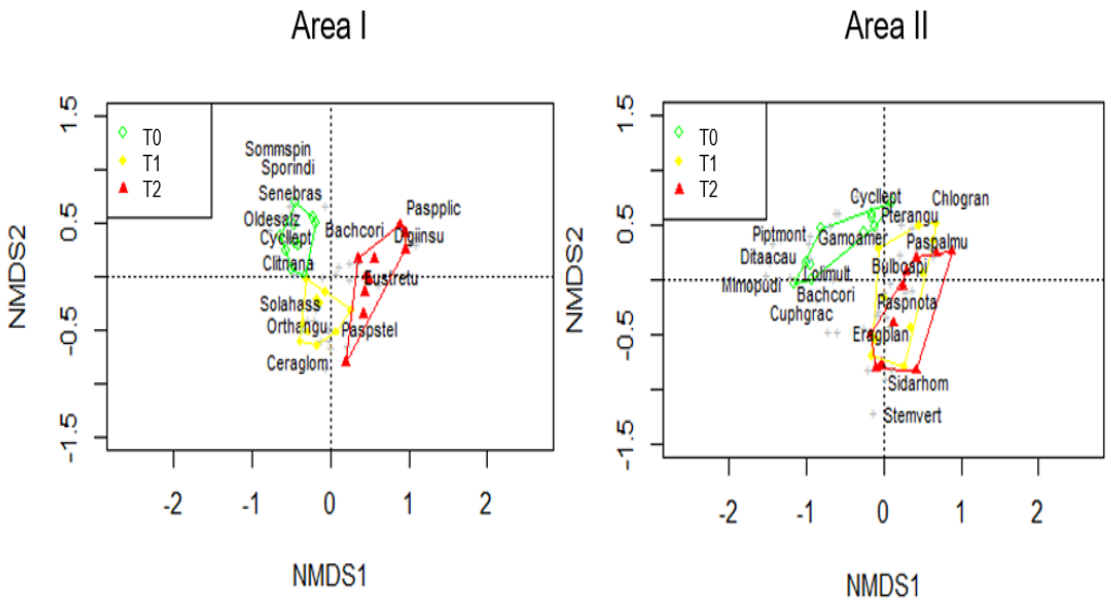
Table 3. Shannon diversity index (H') and Pielou equitability index (J') in experimental areas I and II (Area I and Area II), during the initial survey (T0), 30 days after selective chemical control (T1) and 120 days after selective chemical control (T2).

Index	Area I			Area II		
	T0	T1	T2	T0	T1	T2
Shannon (H')	2,67[a]	2,63[a]	2,53[b]	3,06[a]	2,69[b]	2,45[c]
Pielou (J')	0,73	0,72	0,70	0,78	0,72	0,68

* Values followed by the same letter in the row for each area did not differ significantly by the Hutcheson test ($p < 0.05$).
Source: Prepared by the authors (2026).

The NMDS analysis (Figure 4) showed a statistical difference by permutational analysis of variance (PERMANOVA), with $p = 0.001$. The stress values of the analysis were 9.54% for Area I and 8.62% for Area II, which is adequate for interpretation. The analysis showed a transition in the plant community, with a reduction in species with low forage value and an increase in the participation of grasses adapted to grazing. The results were consistent in the two areas studied.

Figure 4. NMDS (Non-metric Multidimensional Scaling) analysis of the number of vegetative units per species in both areas, during the initial survey (T0), 30 days after selective chemical control (T1) and 120 days after selective chemical control (T2).



Where: Bachcori = *Bacharis cloridifolia*; Bulbocapi = *Bulbostylis capillaris*; Ceraglom = *Cerastium glomeratum*; Chlogran = *Chloris grandifolia*; Clitnana = *Clitoria nana*; Cuphgrac = *Cuphea gracilis*; Cyclleptt = *Cyclospermum leptophyllum*; Digiinsu = *Digitaria insularis*; Ditaacau = *Ditaxis acaulis*; Eragplan = *Eragrostis plana*; Eustretu = *Eustachys retusa*; Gamoamer = *Gamochaeta americana*; Lolimult = *Lolium multiflorum*; Mimopudi = *Mimosa pudica*; Oldesalz = *Oldenlandia salzmannii*; Orthangu = *Orthopappus angustifolius*: Paspalmu = *Paspalum almum*; Paspnota = *Paspalum notatum*; Paspplic = *Paspalum plicatulum*; Paspstel = *Paspalum Stellatum*; Piptmont = *Piptochaetium montevidense*; Pterangu = *Pterocaulon angustifolium*; Senebras = *Senescio brasiliensis*; Sidarhom = *Sida rhombifolia*; Solahass = *Solanum hasslerianum*; Sommspin = *Sommerfeltia spinulosa*; Sporindi = *Sporobulus indicus*; Stemvert = *Stemodia verticillata*
Source: Prepared by the authors (2026).

4 DISCUSSION

In both areas, there was a change in the floristic and structural composition of the vegetation over the course of the study. Initially, under degradation due to overgrazing and the dominance of *Eragrostis plana*, the areas were characterized by species of low forage value, such as *Cyclospermum leptophyllum* (Pers.) Sprague ex Britton & P.Wilson and *Gamochaeta americana* (Mill.) Wedd., species that corroborate the observations of Rovedder *et al.* (2005), who analyzed the floristic composition of fields degraded by the phenomenon of sandification in the southwestern region of Rio Grande do Sul. According to the same authors, the phenomenon of sandification is common in the region, also conditioned by the effects of overgrazing associated with sandy soil conditions. This phenomenon often originates from conventional agricultural crop management and

intensive livestock farming, above the carrying capacity of the field, which causes the formation of furrows and gullies and the removal of vegetation cover, exposing the sandy soil to the action of the winds (Souto, 1984; Ab'saber, 1995).

In fact, in Area I, it was possible to observe the presence of sand pockets. This phenomenon often originates from conventional agricultural practices and intensive livestock farming, above the carrying capacity of the field, which cause the formation of furrows and gullies and the removal of vegetation cover, exposing the sandy soil to the action of the winds (Souto, 1984; Ab'saber, 1995). Therefore, as with the phenomenon of sandification, the marked presence of these ruderal species in the initial surveys can be seen as a consequence of overgrazing by cattle, which hinders the development of soil cover by forage species and opens up space in the plant community for the occurrence of ruderal species, in addition to favoring patches of exposed soil.

In Area I, T1 still reflected a vegetation pattern similar to the initial state (T0). Comparing T0 to T2, ruderal species were gradually replaced by grasses and legumes with high forage potential, which can be considered one of the objectives for the productive restoration of native fields in the Pampa biome (Silva *et al.*, 2022). Grasses were primarily responsible for the increase in native species coverage, with the genus Paspalum standing out. Legumes, although less significant, also showed an increase in population. In particular, the development of new vegetative units of Paspalum notatum was observed during the surveys, a species that can contribute to high forage production (Steiner *et al.*, 2017), an important factor for the conservation of native fields subjected to grazing regimes. In Area II, this transition occurred earlier, with periods T1 and T2 showing similar composition, but distinct from T0. The pattern of replacement of ruderal species by forage species remained similar to Area I. The higher number of Poaceae species is a natural pattern of the Pampa fields, being part of the typical physiognomy of this region (Silva *et al.*, 2022), and may reflect forage quality. On the other hand, a predominance of Asteraceae species or ruderal species is associated with degradation processes, reflecting the impacts of overgrazing due to high stocking rates. This relationship between overgrazing and stocking rates is even more important for a region characterized by sandy soils, as is the case in the areas of this study (Rovedder and Eltz, 2008), demonstrating that their predominance is an indicator of degradation, as these species proliferate in environments disturbed by factors such as overgrazing and cattle trampling (Guimarães *et al.*, 2002).

After control, there was an increase in dry biomass. It is important to note that this variation was initially caused by the accumulation of dead material due to the effect of herbicide on E. plana clumps (Figure 5). This value decreases from T1 to T2 due to the recovery of the native field. The species Paspalum notatum was the most representative in this structural change, registering the highest number of vegetative units in the final evaluations (Appendices A and B). This increase in the number of Paspalum vegetative units is explained by the negative effects of the invasive species on grass development, a phenomenon already observed in other species of this genus, such as P. plicatulum and P. dilatatum, which is also a factor contributing to the greater presence of ruderal species in the initial surveys (Baggio *et al.*, 2018).

Figure 5. Effect of glyphosate applied to *Eragrostis plana* Nees. clumps using a hand-held chemical hoe for selective chemical control of unwanted species.



Source: Prepared by the authors (2026).

The reduction in diversity and species richness observed was mainly due to the decline in ruderal species and the progressive dominance of grasses, which indicates a qualitative improvement in plant composition. Previous studies, such as that by Fedrigo *et al.* (2018), show that under favorable conditions and with proper management, diversity can recover over time, especially after periods of deferred grazing. This pattern suggests that, although species diversity and richness have decreased, the plant community is now composed of species of greater forage interest and adapted to the disturbances caused by herbivory. Therefore, despite a lower diversity of species, due to the current composition of the plant community, the field has an adequate structure to resist the possible impacts of cattle grazing.

It was observed that the grazing deferral period and selective control were positive for the development of cover by native species of greater forage interest in areas previously dominated by ruderal plants, this being a response to the reduction of overgrazing and selective chemical control of *E. plana*, factors that, together with the seasonality of the native field in the cold season, hindered the development of new species in these areas. These factors have already been identified as the main sources of degradation in animal production systems based on native fields in the Pampa biome (Diaz-Perera *et al.*, 2020).

From T0 to T1 there was still an increase in the abundance of some ruderal species, as in the case of *Conyza bonariensis* and *Pterocaulon angustifolium*, which is why these assessments were carried out at the start of the growing season. These species were later replaced by more dominant prostrate and stoloniferous grasses such as *Paspalum notatum*, which made a positive contribution to ground cover (between T1 and T2). Another positive change at T2 was the emergence of native *Eragrostis* species, such as *Eragrostis neesi* and *Eragrostis airoides*, as well as other grass genera such as *Mnesithea selloana*, *Paspalum plicatulum* and *Paspalum stellatum* and an increase in the number of vegetative units of Fabaceae such as *Desmodium incanum* and *Stylosanthes leiocarpa*.

However, the emergence of these species and others that were also recorded at the end of the study may have been driven by the seasonality of the native grassland, as the study extended from the beginning of spring (T0) to the end of summer (T2), and was not an exclusive result of the control of the invasive species, although the effects of this control had a positive influence on the qualitative recovery of the areas. This transition enhances the restoration process by replacing ruderal species, which are generally adapted to disturbed environments, with grasses that are more resistant to trampling, have greater forage potential and are better adapted to livestock management.

These ruderal species that were replaced in the course of the study, as highlighted by Zhang *et al.* (2020), play an important role as temporary stabilizers in degraded areas. They are able to quickly colonize disturbed environments, protecting the soil from erosion and providing organic matter and nutrients essential for the development of other plants. Although their predominance may indicate degradation, these species create favorable conditions for the advancement of ecological succession, facilitating the entry and establishment of more demanding native species as management is adjusted. Therefore, the high initial presence of ruderals, although indicating the level of degradation of the grasslands, should not be seen only as a negative sign, but as part of the natural cycle of

grassland recovery, provided that it is accompanied by management strategies that promote a qualitative recovery of this grassland, stimulating the development of more adapted species of greater interest for livestock management.

Selective chemical control proved effective in reducing *Eragrostis plana* and promoting the recovery of native vegetation in areas of native grassland. In addition, a reduction in the number of vegetative units of Senescio spp. was also observed, a species that shows high toxicity to cattle (Krabbe *et al.*, 2017). The results of the analysis indicated significant differences between the treatments, especially for green and dry biomass, showing the positive impact of the selective application of the herbicide on the invasive plant, without compromising the forage grasses of interest. The use of the "Campo Limpo" equipment allowed the localized application of glyphosate, reaching the clumps of *Eragrostis plana* due to the difference in height in relation to the native pasture, while preserving the other species in the plant community. Positive results were also found by Merotto Jr *et al.* (2022), when assessing the effectiveness of glyphosate in the selective chemical control of *Eragrostis plana*. In this way, selective chemical control stands out as a viable and efficient tool for restoring forage quality, and consequently the productivity of native grasslands in the Pampa biome.

Selective chemical control, on the other hand, requires periodic reapplications and must be integrated with complementary strategies, such as the introduction of native species, in order to achieve longer-lasting results. Single herbicide applications are not enough to completely eliminate *Eragrostis plana*, as the species can survive due to sublethal translocation of the product, which favors regrowth and the persistence of the invader in the area (Caratti *et al.*, 2022). Therefore, the adoption of adaptive and continuous management is fundamental to the success of ecological restoration and the effective containment of invasive species.

Despite the negative influence of the drought on the development of forage species, and the difficulties faced by local producers in adjusting the livestock load, which may have compromised integrated management, the results can be considered highly positive. It is also noteworthy that the chemical control applications were carried out at only one time of year and monitored for a limited period, which restricts understanding of the seasonal and long-term effects on *Eragrostis plana* and the native vegetation. Therefore, future studies should consider different application times and longer monitoring to improve management and ecological restoration strategies.

5 CONCLUSION

Selective chemical control proved effective in reducing the invasion by *Eragrostis plana*, promoting a qualitative improvement in the forage potential of the grassland cover. Although the results indicate that quantitative improvements in floristic richness and diversity can be observed, a longer period of monitoring may be necessary, accompanied by reapplications of selective control and the continuation of conservation practices in livestock management, such as adjusting the animal load and deferring grazing to recover the areas. This continuous approach is fundamental to consolidating ecological restoration combined with animal production, and guaranteeing the sustainability of the natural grasslands of the Pampa biome. The main limitations of this study were the short monitoring period, the occurrence of severe drought, and the fact that the control measures were implemented during only one season of the year. Future studies on this topic should evaluate different application times and frequencies, longer monitoring periods, and different grazing management conditions.

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AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed with contributions of all authors. The first draft of the manuscript was written by Bruno Bervig Collares and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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