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BOTANY

Can mulch be effective in controlling exotic grasses and promoting natural regeneration in ecological restoration?

Bruno Santos Francisco[1,*], Felipe Bueno Dutra[1], Emerson Viveiros[2], Lausanne Soraya de Almeida[1], Matheus Fontes Souza[3], Paulo Cesar Souza Filho[4], José Mauro Santana da Silva[1,5] and Fatima Conceição Márquez Piña-Rodrigues[1,5]

[1]Programa de Pós-Graduação em Planejamento e Uso de Recursos Renováveis, Universidade Federal de São Carlos, Rodovia João Leme dos Santos, SP-264, 18052-780, Sorocaba, São Paulo, Brazil. [2]AES Brasil, Bauru, São Paulo, Brazil. [3]Curso de Engenharia Florestal, Universidade Federal de São Carlos, Sorocaba, São Paulo, Brazil. [4]Ceiba Consultoria Ambiental, Bragança Paulista, São Paulo, Brazil. [5]Departamento de Ciências Ambientais, Universidade Federal de São Carlos, Sorocaba, São Paulo, Brazil. *Author for correspondence: brunofrancisco@estudante.ufscar.br

ABSTRACT. Mulching use in agriculture has been known since 1802 as the practice of spreading dry leaves and straw on the soil to prevent erosion and water loss. Our study evaluated the mulch effectiveness in the establishment of regenerating seedlings and its contribution to the control of exotic grasses. The studies were carried out in an ecological restoration area in the municipality of Itapira-SP. The treatment with mulching consisted in chemical desiccation with glyphosate herbicide application, keeping the dry grass on the ground. In the control treatment, after chemical weeding, the grass was removed with manual mowing, exposing the soil. Eight months after implantation, we sampled all regenerating seedlings in 100 plots of 50 x 50 cm in each treatment. We considered as seedlings all individuals of tree species less than 100 cm tall. We calculated richness, abundance, similarity, and the relationship of the frequency of seedlings to the height of the mulch. We sampled eight species with 42 seedlings, with only one not identified. The highest abundance and species richness were found in the treatment with mulch (n = 34 individuals; eight species), the most abundant being *Schinus terebinthifolia* Raddi (14 individuals) followed by *Solanum mauritianum* Scop. (11 individuals), and *Platypodium elegans* Vog. (three individuals). The presence of exotic grasses was lower in the plots of the mulching (13%) compared to the control treatment (67%). The highest frequency of seedlings was obtained with mulch height from 21 to 37 cm. We suggest that adaptive management practices, such as the use of the mulching technique, can be implemented in ecological restoration areas, because they favor the natural regeneration of native seedlings and can contribute to the control of exotic grasses, but the height of the layer must be controlled.

Keywords: active restoration; adaptive management; weed competition; dispersal syndromes; successional class; soil conservation.

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Introduction

The need to restore degraded ecosystems has generated international targets to restore 350 million hectares of native forest by 2030 (Dave et al., 2019), supporting the United Nations - UN resolution that considers the period 2021-2030 the decade of ecosystem restoration (United Nations Organization [UNO], 2019). Ecological restoration is defined as the assisted recovery of an ecosystem that has been degraded or destroyed (Society for Ecological Restoration International [SER], 2004). It is a practice that aims to return to the recovered environment the ecological processes linked to resilience, resistance, and stability (Clewell & Aronson, 2007), which will ensure the continuity of ecological processes.

In Brazil, the goal of restoring 12 million hectares by 2030 was established (Brasil, 2015); however, the areas intended for forest restoration are highly uncharacterized from the point of view of native species composition, represented mostly by degraded pastures (Rodrigues, Brancalion, & Isernnhagen, 2009). Many of these areas to be recovered have coverage of exotic and invasive plants that hinder the establishment of native species, becoming a major cause of failure of ecological restoration (Cornish & Burgin, 2005).

Regardless of the occurrence and interference of exotic plants, measures should be adopted for suppressing the growth and or reducing the number of these plants in the area to be restored until the coexistence with native species (Gazziero, Vargas, & Roman, 2004). The control can be done by applying preventive, biological, cultural, physical, and chemical methods, with the integration between different methods, considered as an effective way to control exotic plants (Silva, Ferreira, Ferreira, & Santos, 2009; Brighenti & Oliveira, 2011).

The physical method uses an agent capable of affecting the survival of the exotic plant community by preventing light radiation from reaching the soil surface (Silva et al., 2009). Mulching acts via shading and soil smothering due to the dead plant biomass from management practices, such as weeding and desiccation by herbicide (Almeida, 1988; Chen et al., 2014; Kader, Senge, Mojid, & Nakamura, 2017). The term mulch is defined as the use of any material, other than the soil itself, that will perform the function of permanent or semi-permanent protective cover over the soil surface (Jordán, Zavala, & Muñoz-Rojas, 2011).

The use of mulching in agriculture according to McCalla and Army (1961) has been known since 1802 as the practice of spreading plant remains such as dry leaves and straw on the soil to prevent erosion and water loss (Jordán et al., 2011), as well as to reduce the weed competition in agriculture with unwanted plants (Chopra & Koul, 2020). Although it is an old practice, it is considered essential for soil conservation (Prosdocimi, Tradolli, & Cerdá, 2016; Kader et al., 2019; Li, Li, & Pan, 2020).

Mulch management is employed in agriculture associated with conservationist practices such as no-till farming (Kader et al., 2017). It aims to inhibit the growth of C4-plants that are highly dependent on light, thus decreasing photosynthetic activity and primary production (Almeida, 1988). Mulching also has an effect on the seeds of some weeds (Mayer & Poljakoff-Mayer, 1989) by decreasing germination rate, loss of vigor, increased seedling mortality, leaf chlorosis, reduced tillering, and root stunting (Sarrantonio & Gallandt, 2003; Gallandt, 2006), as well as potential allelopathic processes from mineralization of plant residue (Theisen, Vidal, & Fleck, 2000).

In addition to weed competition control, mulching has a positive impact on increasing the height of agricultural and forest plants (Chaudhry, Malik, & Sidhu, 2004; Dostálek, Weber, Matula, & Frantík, 2007) and on protecting soil against erosion from post-fire factors in forest areas (Díaz-Raviña et al., 2012). Mulching also improves soil quality (Chen et al., 2014) and promotes seedling establishment in restoration (Benigno, Dixon, & Stevens, 2013; Mollard, Naeth, & Cohen-Fernandez, 2014; Breton, Crosaz, & Rey, 2016). In addition, it reduces the emergence of invasive plants such as *Urochloa decumbens* (Stapf) R.D. Webster (Silva & Vieira, 2017) and contributes to moisture retention and control of temperature fluctuation (Resende et al., 2005) and reduction of soil erosion by rainfall (Montenegro, Abrantes, Lima, Singh, & Santos, 2013; Li et al., 2020).

Despite the already known benefits in agriculture, this practice has been more adopted in the restoration of mining areas (Silva & Corrêa, 2008; Salomão, Júnior Brienza, & Rosa, 2014) or degraded soils (Schirone, Salis, & Vessella, 2011), and in studies on direct seeding (Silva & Vieira, 2017). However, there is still little research focused on the impact of mulching, particularly with regard to active restoration. Given the need to promote conservationist methods to control weed competition and verify its effects on native species, the objective of the study was to analyze the use of mulching and its impact on the community of regenerating plants and its contribution to the control of exotic grasses in an area under ecological restoration.

Material and methods

Study area

The study was conducted in an area of active restoration with three years old after planting native seedlings. The area of approximately 4.3 hectares is located in the municipality of Itapira (Figure 1). Before the ecological restoration it was used for planting sugar cane (*Saccharum officinarum* L.). There is a predominance in the region of Seasonal Semideciduous Forest and Cerrado. According to Koeppen's (1948) classification, the climate is classified as Cfa, with hot and temperate summers and rainfall distributed throughout the year. The average temperature is 21.5°C and the average annual rainfall is 1,448 mm. August is the driest month, with 33 mm. The month with the highest precipitation is January, with an average of 259 mm. The hottest month of the year is February, with an average temperature of 23.9°C. The average temperature in June is 18.0°C, considered the month with the lowest temperature of the year (Climate-Data.org., 2021).

Three years after seedling plantation, the tree community was already installed; however, there was still a large number of exotic grasses in the area. To evaluate the mulching technique, we implemented two trials in this area, one with herbicide-desiccated mulch (MU) and the other, a control with no mulch (CO), i.e., with exposed soil. In the treatment with desiccated mulch (MU), Roundup® herbicide was applied to control exotic grasses at the dosage recommended by the manufacturer. After desiccation of the grasses, manual mowing was not performed, i.e., the desiccated grass continued to be deposited in the area for eight months until data collection. In the control treatment with the soil exposed (CO), we performed a chemical weeding with the application of Roundup® herbicide for the control of exotic grasses, in the manufacturer's dosage. After desiccation of the grasses, they were removed by manual weeding, leaving the soil exposed.

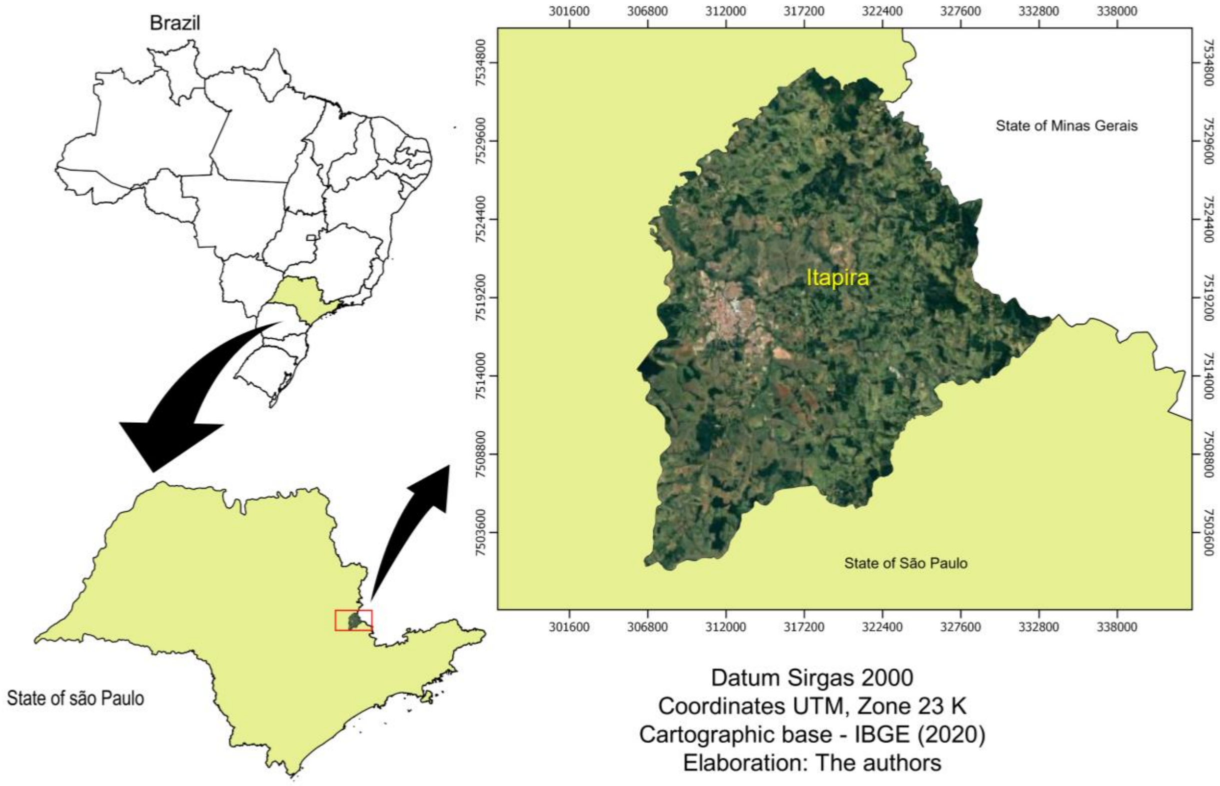

Figure 1. Geographical location of mulch study sites in the municipality of Itapira, state of São Paulo, Brazil.

Sampling

Eight months after the implementation of the two treatments, 200 plots of 50 x 50 cm were randomly distributed throughout the area, 100 plots for each treatment. We sampled all regenerating seedlings of shrubs, trees, and palms under 100 cm tall, as proposed by Felfili, Carvalho and Haidar (2005) for Seasonal Forests. We estimated the percentage of ground cover with exotic grasses in the 50 x 50 cm plots of each treatment.

The height of the mulch was assessed in all 200 plots and seedling species were identified in the field and, when necessary, identified posteriori with the aid of a stereomicroscope and pertinent bibliography. The spelling of the scientific names was verified according to the nomenclatural database VAST - VAScular Tropics (Tropicos.org. Missouri Botanical Garden, 2021), the valid name and synonyms according to The Plant List [TPL] (2013), and author abbreviations according to The International Plant Name Index [IPNI] (2012). Species were included in families according to the system proposed by APG IV (Chase et al., 2016) and the most recent updates of the Angiosperm Phylogeny Website (Stevens, 2001). Species were classified according to their successional group and dispersal syndrome according to the species database for the restoration of São Paulo (Barbosa et al., 2017).

Data analysis

From the data obtained in the field, we calculated richness and abundance parameters according to Moro and Martins (2011). The composition of the natural regeneration was evaluated using presence and absence data with Jaccard's similarity index (Magurran, 1988). To check whether there was a difference in the ground cover with exotic grasses and the number of seedlings between treatments we used the Mann-Whitney test. We calculated from the chi-squared test if there was a higher frequency of seedlings at any mulch height. All analyses were performed in the software R (R Core Team, 2020).

Results

A total of 42 seedlings (8,400 seedlings ha-1) of eight species from seven botanical families were sampled, leaving only a single unidentified individual. The Jaccard index was 0.33, indicating that the similarity between treatments was low. The most abundant species in the treatment with mulch were *Schinus terebinthifolia* Raddi (14 individuals; 33%) followed by *Solanum mauritanum* Scop. (11 individuals; 26.2%) and *Platypodium elegans* (3 ind; 7.1%). The most abundant species in the control treatment with exposed soil (SM) were *P. elegans* and *S. terebinthifolia*, both with three individuals (Table 1). There was a significant difference in abundance between treatments by Mann-Whitney test (p <0.0001) (Figure 2).

Table 1. Floristic list of the species sampled in the regenerating seedling community in the ecological restoration area, in the municipality of Itapira, state of São Paulo. CM = number of seedlings sampled in the treatment with mulch; SM = number of seedlings sampled in the control treatment with exposed soil, Sucessional Class = S. Class, Dispersion Syndrome = D. Synd., ANE = anemochoric, ZOO = zoochoric, and AUT = autochoric. NID = Not identified.

List of regenerating seedling species					
Family	Species	S. Class	D. Synd.	CM	SM
Asteraceae	*Baccharis dracunculifolia* DC.	Pioneer	ANE	2	0
Anacardiaceae	*Schinus terebinthifolia* Raddi	Pioneer	ZOO	14	3
Arecaceae	*Syagrus romanzoffiana* (Cham.) Glassman	Pioneer	ZOO	0	1
Boraginaceae	*Cordia trichotoma* (Vell.) Arráb. ex Steud.	Pioneer	ANE	1	0
Fabaceae	*Mimosa bimucronata* (DC.) Kuntze	Pioneer	AUT	1	0
Fabaceae	*Platypodium elegans* Vogel	Pioneer	ANE	3	3
Myrtaceae	*Eugenia uniflora* L.	Non-Pioneer	ZOO	1	0
NID	NID	NID	NID	1	0
Solanaceae	*Solanum mauritanum* Scop.	Pioneer	ZOO	11	1

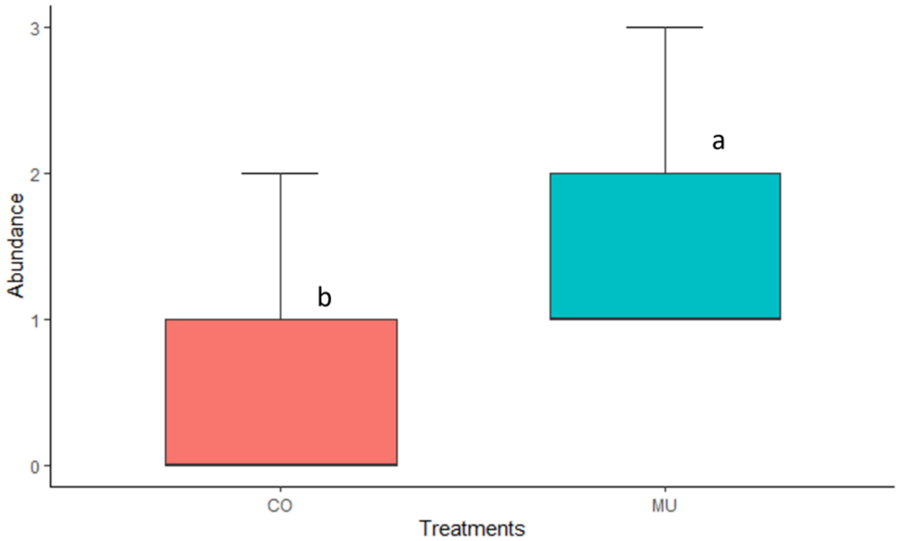

Figure 2. Box-plot of the median and quartiles of the abundance of individuals of the seedling community sampled in the 100 plots of each treatment in the ecological restoration area, in the municipality of Itapira, state of São Paulo. Legend: MU = number of seedlings found in the treatment with mulch, CO = number of seedlings found in the control treatment with exposed soil. Mann-Whitney test (p <0.0001).

According to successional class, 40 seedlings (96% of the individuals) were classified as pioneer, one seedling was classified as non-pioneer, and one seedling was not identified (Table 1). In the treatment with mulch, 32 seedlings (94%) were classified as pioneer, one seedling (3%) was classified as non-pioneer, and one seedling (3%) was not identified. In the exposed soil treatment, we observed only pioneer species (nine individuals).

The most abundant dispersal syndrome was zoochoric with 31 seedlings (73% of the individuals), followed by anemochoric, with nine seedlings (21%), and autochoric with one seedling (2%) and one unidentified individual (2%). In the treatment with mulching (MU), zoochoric (76% of seedlings) and anemochoric (18% of seedlings) dispersions predominated, and one seedling (3%) was not identified (Figure 3). In the control treatment with exposed soil (SM) zoocoria (63% of the seedlings) was also dominant, but less abundant than in the area with mulching, and the same was observed for anemochoric (37% of the seedlings). Among the zoochoric species, ornithocory was dominant with 18 individuals (42.3%) represented by the species *S. terebinthifolia* and *E. uniflora*.

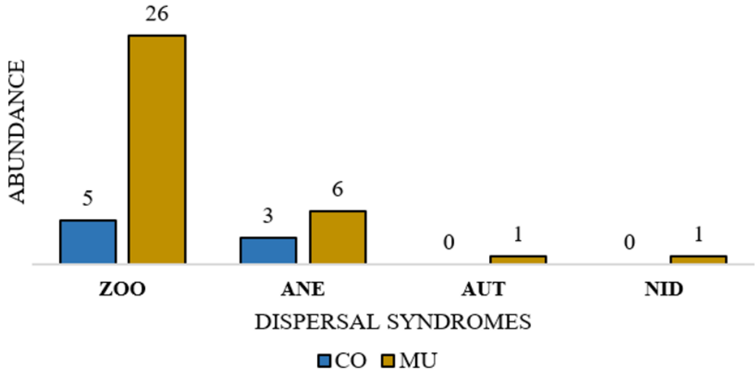

Figure 3. Number of individuals per dispersal syndrome in the seedling community sampled in the ecological restoration area, in the municipality of Itapira, state of São Paulo. Legend: MU= treatment with mulch, CO = treatment with exposed soil. ANE - anemochoric; AUT - autochoric; ZOO - zoochoric; NID - not identified.

We observed the presence of exotic grass cover in 80 plots (40%) and 120 plots (60%) free of exotic grasses. In the treatment with mulch the representative presence of exotic grasses occurred in only 13 plots (13%) and in 87 plots (87%) the presence of exotic grasses was not recorded. In the control treatment with exposed soil, we found 67 plots (67%) with exotic grasses and 33 plots (33%) without exotic grasses (Figure 4). There was a significant difference in the coverage of exotic grasses between treatments by the Mann-Whitney test ($p < 0.0001$) (Figure 5). The chi-square test evidenced the difference between the frequency of seedlings in the different mulching height classes (Figure 4) with a value of $p = 0.009$.

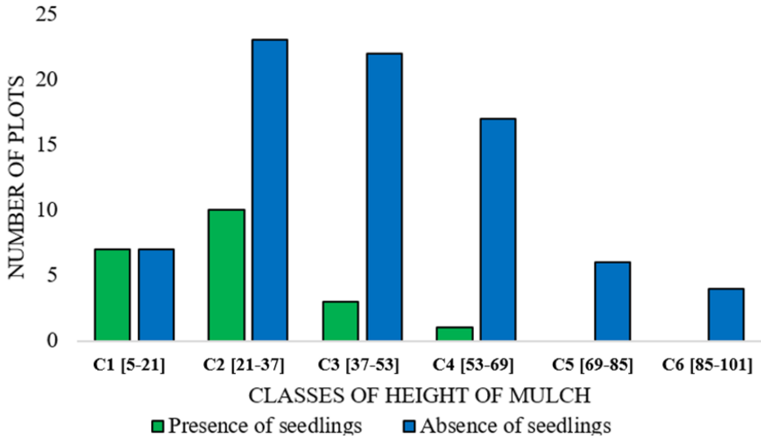

Figure 4. Histogram of the presence and absence of seedlings in different height classes of the mulch in the evaluated plots in the ecological restoration area, in the municipality of Itapira, state of São Paulo. Legend: C1 = class 1, from 5 to 21 cm; C2 = class 2, from 21 to 37 cm; C3 = class, 3 from 37 to 53 cm; C4 = class 4, from 53 to 69 cm; C5 = class 5, from 69 to 85 cm; and C6 = class 6, from 85 to 101 cm.

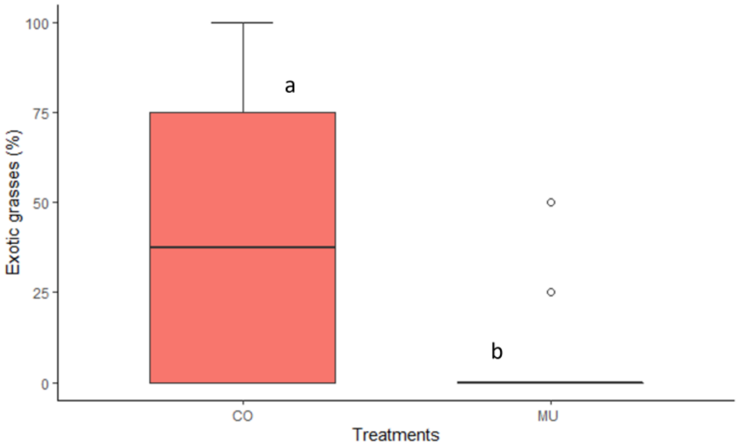

Figure 5. Median graph and quartiles of the coverage of exotic grasses sampled in the plots assessed in the ecological restoration area, in the municipality of Itapira, state of São Paulo. Legend: MU = coverage of exotic grasses in percentage found in the treatment with mulch, CO = coverage of exotic grasses in percentage found in the control treatment with exposed soil. Mann-Whitney test ($p < 0.0001$).

Discussion

In this study, the use of the mulching technique influenced the regeneration of native species, because the treatment with mulching (MU) showed higher abundance (80.9%) and species richness (87.5%) compared to the one with exposed soil. Areas in restoration process with strong presence of exotic grasses present negative impacts on the establishment of herbs, shrubs, and trees (Ferreira, Walter, & Vieira, 2015). Moreover, weed competition can interfere with the composition of naturally regenerating communities (Damasceno et al., 2018), and with the growth and survival of native species seedlings, as observed by Passaretti et al. (2020). We should point out that the greater presence of zoochoric species sampled indicate the possibility of mulch on the ground favoring germination niches for species disseminated by fauna, which was evident with the higher proportion of seedlings with zoochoric dispersal syndromes, mostly ornithochoric. These species tend to have small colored seeds, with more rounded shapes (Gagetti, Piratelli, & Piña-Rodrigues, 2016), which have germination favored by the mulch (Silva & Vieira, 2017). Despite the lower incidence of light on the ground, the desiccated mulch may have provided the maintenance of humidity and ideal temperature for germination of these species, which require temperatures below 30°C (Wielewicki, Leonhardt, Schlindwein, & Medeiros, 2006).

There was low similarity in floristic composition between both treatments, noting the negative effect of the presence of exotic grasses on the composition of the regenerating seedling community. The mulching technique provided higher species richness, a result that was also observed by Doležal et al. (2011), who verified the effect of mulching on the functional diversity of plant species in Prairie regions of Central Europe. Thakur, Singh, Jawandha, and Kaur (2012) observed similar results where mulch was efficient in controlling weeds in an agricultural production area. The use of *U. decumbens* (Stapf) R. D.Webster's own mulch can keep the temperature, as well as the moisture in the soil (Resende et al., 2005; Montenegro et al., 2013) in ideal conditions for native plants caused by increased microbial activity and decomposition rates of organic matter in the system, adding nutrients to the soil (Athy, Keiffer, & Stevens, 2006). The increment of these conditions and resources in the restored area can promote an increase in the survival and establishment of regenerating native plants (Benigno et al., 2013; Mollard et al., 2014; Breton et al., 2016).

We observed that the mulch decreased the emergence of exotic grasses (13%) in relation to the control treatment with exposed soil (67%). There was an 80.6% reduction in the presence of exotic grasses in the treatment with mulch in relation to the control (CO), bringing evidence as to the efficiency of this simple technique for the control of invasive exotic grasses. This is an important fact, because exotic grasses present competitive superiority over native grasses in relation to resource retention (Levine et al., 2003; Tecco, Di, Cabido, & Urcelay, 2010) and in the efficiency of nutrient use even in areas with low availability of these resources (Funk, 2013). Furthermore, grasses of the species *U. decumbens* have allelopathic effects, inhibiting the germination of native species (Barbosa, Pivello, & Meirelles, 2008). The reduction in exotic grasses may have occurred because of the decrease in light entry caused by the mulch barrier, a condition that, for the seeds of exotic grasses, affects their germination rate, vigor loss, and increased seedling mortality, resulting in leaf chlorosis, reduced tillering, and root stunting (Sarrantonio & Gallandt, 2003; Gallandt, 2006.).

Another factor besides the control of weed competition was the height of the mulch on the ground. Our results showed that there is an ideal height of desiccated mulch in the range of 21 to 37 cm, in which we observed a higher frequency of regenerating seedlings. Therefore, it is not enough to propose the practice of mulching with the grass itself after its desiccation; it is also important to control the height of the layer.

The practice of maintaining the mulch to provide nutritional, moisture, and light conditions, and controlling its height should be added to the post-planting management to reduce the risk of invasion of exotic grasses and ensure the development of seedlings arising from natural regeneration (Kader et al., 2019). Our results reinforce the potential of using mulch as a conservationist technique to control exotic grasses that can be complementary to the application of chemical herbicides, provided that the conditions of layer height and initial soil management are maintained.

When compared to other exotic grass control methods, such as herbicide use, manual mowing (Thaxton, Cordell, Cabin, & Sandquist, 2012), and topsoil removal (Buisson et al., 2008), mulching can be considered an adaptive management practice that contributes to reducing inputs and controlling competition while providing crucial conditions for the establishment and survival of naturally regenerating seedlings.

Conclusion

In this study, we verified that the mulching technique with desiccated *U. decumbens* itself favored the natural regeneration of tree species and contributed to the control of exotic grasses. Furthermore, we observed that there is an ideal height of the desiccated mulch and should be between 21 and 37 cm high. We suggest that adaptive management practices such as the mulching technique can be recommended in the preparation stages in ecological restoration areas, as they favored seedling establishment and contributed an 80% rate of exotic grasses control.

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