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Legal provision on the use of exotic species in forest restoration: eucalyptus leaf decomposition in different Brazilian savannah formations

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Abstract

The Brazilian federal law has established norms for vegetation protection in 2012 for the planting of exotic species for the restoration of altered areas. Given the large number of areas to be recovered in the savannah biome in Brazil (e.g., Cerrado), the use of fast-growing species and high biomass production (e.g., *Eucalyptus* spp.) has been earnestly considered. However, the recommendation of this exotic species must be scientifically supported. This work aimed to evaluate the decomposition process of eucalyptus leaf litter in three different phytophysiognomies in the Cerrado biome (Brazilian Savannah) with three different formation type: Typical Cerrado, Savannah Forest, and Gallery Forest. The leaf decomposition was evaluated by the litter bags that were collected from October 2017 to October 2018. The difference between the initial mass and the masses was evaluated at the different collection periods. After one year, we determined the decomposition rate and the constant *k* using the exponential equation proposed by Olson. The decomposition rate of eucalyptus leaves was high in the three Cerrado formations. The shortest decomposition time was observed in Gallery Forest. The results showed that the main types of Cerrado formation effectively assimilate the organic material to be deposited in the soil. Thus, the study demonstrated the feasibility and legal provision of using exotic species, e.g., eucalyptus in the arduous mission of recovering degraded forest environments.

Keywords: Brazilian Forest Code; Cerrado biome; constant *k*; degraded areas; leaf litter.
Abbreviations: EU: Eucalyptus plantation, GF: Gallery Forest, SF: Savannah Forest, TC: Typical Cerrado.

Introduction

The occupation process of the Brazilian Savannah (known as Cerrado) has resulted in extensive degradation. In 2017, 39% of the Cerrado pasture areas, corresponding to 18.2 million hectares were degraded (Pereira et al., 2018). Between 2008 and 2012, the annual deforestation rates were twice as high as those of the Brazilian Amazon (Lambin et al., 2013). Furthermore, less than half the original area covered by Cerrado ecosystems is currently preserved (Zuin, 2020), compromising its role in the water and carbon cycles (Arantes et al., 2016; Brasil, 2018). The scenario of native vegetation loss is further enhanced by the fire frequency in agricultural areas (Souza et al., 2020).

In addition to the number of altered areas, the chemical properties of Cerrado soils, such as their low natural fertility and high acidity, make restoration initiatives more challenging. The periodic hydric deficit and the weed competition caused by the spread of invasive grasses are also critical factors in restoration processes in savannah environments (Svejcar and Kildisheva, 2017; Sampaio et al., 2019). Other factors include the fragility in monitoring the areas under restoration processes and lack of more assertive public policies (Bustamante et al., 2019). The restoration of degraded environments was duly provided by the Brazilian "New Forest Code", with the enactment of law 12.651 of 2012, which defined as a principle the joint responsibility of the União (Federal Government), States, Distrito Federal (Brazilian Federal District), and Municipalities, in collaboration with civil society to restore native vegetation. Nevertheless, the Cerrado has a deficit of 26% of its total area to be recovered (Vieira et al., 2017). Given the particularities of each region, economic reality, degree of degradation, the viability of species, and silvicultural logistics, no recovery alternative can be disregarded. However, it is preferable that any recommendation has its due scientific backing. It is a consensus that the maintenance of vegetation promotes the cycling of organic matter and nutrients. This process is essential to maintaining fertility in dystrophic soils, as litter decomposition leads to increased organic matter content and mineralization to the release of nutrients for the soil. Thus, the use of exotic species, such as eucalyptus, brings some benefits to forest maintenance. The specie presents a rapid development, providing an accumulation of litter on the ground (Pinto et al., 2016; Barbosa et al., 2017). The use of mixed plantations with native and exotic species, e.g., *Eucalyptus* and *Acacia* spp., increased the labile fractions of carbon and phosphorus (Cabreira et al., 2020) and promotes the fixation of nitrogen in the soil (Santos et al., 2016). Even in monocultures, eucalyptus stand have soil carbon stocks similar to mixed plantations (Balieiro et al., 2020). As the most requested exotic species in Brazil, owing to its fast growth and good adaptability to the Brazilian soil and climate conditions, eucalyptus carried negative stigmas as the commercial plantations are expanding (Balieiro et al., 2020). Nevertheless, the new Forest Code instituted the possibility of plantation of exotic species interspersed with native species in small properties or family rural tenure for the recovery of permanent protection areas (*e.g.*, margins of river courses, mangroves, and hills) and legal reserve areas (biodiversity restricted areas). According to the rules the new plantations to be recomposed by up to a maximum of 50% of the total area that will be restored. However, similar to any new restoration strategy, this approach must consider the type of ecosystem that to be planted and the positive and negative effects prior to large-scale implementation (Brancalion et al., 2020). Hence, any recommendation related to this type of arrangement must pass through scientific trials to prove its effectiveness and determine the ecological particularities. Owing to the rapid growth and high litterfall, eucalyptus stands are major suppliers of organic matter to the soil. Although it is a slowly decomposing material (Valadão et al., 2019) and has high contents of lignin and cellulose (Costa et al., 2005; Lima et al., 2015), the litter layer from such plantations can preserve the seed bank and facilitate the process of forest succession (Miranda et al., 2021). Thus, eucalyptus can be an important ally in tropical forest restoration practices. Furthermore, characteristics such as the production system, landscape structure, soil, and climate must be considered to use this exotic forest specie (Brancalion et al., 2020). In the Cerrado, the distinct edaphic properties of each vegetation types reflect the ability of each ecosystem to assimilate carbon and release nutrients from litter, then what would be the decomposition pattern of eucalyptus leaves in Cerrado vegetation types. This study aimed to evaluate the decomposition of eucalyptus leaf in three different vegetation types of the Cerrado: Typical Cerrado, Savannah Forest, and Gallery Forest.

Results

The eucalyptus leaf decomposition in the different vegetation types was evaluated during a one-year period. It showed significant variations in the different collection intervals. All the vegetation types, exception EU, showed significant biomass loss after 60 days, compared to the beginning of the experiment (Table 2). This decay became constant, i.e., similar to that at the final time point (365 days), at 120 days in SF, TC and GF; at 240 days in the EU (Table 2).

The pattern of leaf biomass decay in the Savanna Forest and Typical Cerrado areas was similar in all the collection periods, until end of the experiment (Table 2). Gallery Forest showed greater loss of leaf biomass in relation to the other areas, at 60, 240, and 365 days, and consequently a lower amount of remaining mass (Table 2), indicating a faster decomposition. After 60 days, the leaf decomposition in the eucalyptus stand was slow compared to the all Cerrado vegetation types. The leaf biomass decomposition curves obtained by exponential regression also showed a higher speed of decomposition in Gallery Forest (Figure 2). Savanna Forest and TC exhibited very similar curves, indicating that the eucalyptus leaves decomposed more slowly in these areas (Figure 2). The decomposition of eucalyptus leaves in Gallery Forest exhibited the highest *k* constant (Table 3). Hence, it was possible to verify, using the half-life ($T^{1/2}$), that in one year, half of the leaf biomass was decomposed (Table 3). Savannah Forest and TC showed higher *k* constant values compared with EU (Table 3).

Discussion

The decomposition of eucalyptus leaves in the Cerrado was similar, and higher than the original of leaf material from the vegetation types in other locations of the same biome. The *k* rates of SF and TC, were higher than the constants obtained for the same formations using native leaves (Sanches et al., 2009; Giacomo et al., 2012; Ribeiro et al., 2018).

The value of the *k* constant in Gallery Forest (0.0019) was higher than that obtained in other studies on the same vegetation type, such as that of Souza et al. (2016) (0.0009), which evaluated the decomposition of leaves from Gallery Forest in Cerrado. This higher rate of leaf biomass loss in GF may be associated with the high moisture of microclimate and the soil, which induces greater microbial activity, and consequently, greater leaf decomposition. Overall, the high content of lignin in eucalyptus leaves leads to low assimilation by soil fauna (Gama-Rodrigues and Barros 2002), since lignin is recalcitrant to decomposition and needs a greater feed specificity of edaphic organisms to lead the organic matter degradation (Hall et al., 2020). Changes in land use, *e.g.*, establishment of forest stands, also result in changes in the composition of edaphic fauna (Rosa et al., 2015). The diversity of substrate composition is reduced to a single type of material, which may cause a biological imbalance (Baretta et al., 2003). However, this assimilation was not compromised in the Cerrado vegetation type, especially those with more closed canopy, such as Savannah Forest and Gallery Forest. The forest formations in the Cerrado are richer and present higher activity of edaphic fauna compared with eucalyptus stand (Mudrek and Massoli Junior, 2014; Nunes et al., 2019). Therefore, the organic residues deposited on the soil via litterfall, even from exotic species in natural savannah environments, can be assimilated by the soil fauna. Leaf decomposition, even under low natural fertility conditions of dystrophic soils, allows fragmentation of organic material from exotic forest species, *e.g.*, eucalyptus. This pattern may be associated with the ability of the soil edaphic fauna to process the coarser material (Briones, 2014; Frouz et al., 2015; Sun et al., 2015). Since it is a homogeneous material, eucalyptus leaf decomposition contrasts with that of litter in the Cerrado vegetation types (Ribeiro et al., 2018).

Therefore, the use of a fast-growing exotic species with an assimilable production of litterfall can be a viable alternative in initiatives of forest restoration, especially under severe alteration conditions. Moreover, as provisioned by law 12.651 of 2012 (BRASIL, 2012), the use of exotic species in areas under recovery, such as areas of permanent preservation (APPs), can be an alternative for rapid soil coverage by plants that exhibit rapid growth and rapid decomposition of organic material, as found in this study. However, the alternation of species composition in APPs by introducing exotic species can lead to changes in the trophic chain, and hence requires further studies on the composition of the edaphic fauna under these conditions.

Table 1. Chemical attributes of soils from different study areas at Fazenda Água Limpa, Distrito Federal.

Layer cm	pH	OM	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	CEC_e	CEC_t	SB	V	m	P-rem
	H2O	dag kg^{-1}	mg dm^{-3}		----------------------- cmol$_c$ dm^{-3} ----------------------							---%---		mg L
		TC												
0-20	4.96	4.94	0.4	29.7	0.08	0.06	0.62	7.38	0.84	7.59	0.22	2.79	74.22	10.88
20-40	5.20	3.50	0.23	16.92	0.06	0.04	0.29	5.4	0.43	5.53	0.14	2.54	66.92	9.18
40-60	5.24	2.80	0.13	9.08	0.06	0.02	0.09	4.03	0.19	4.13	0.10	2.34	28.49	7.21
								EU						
0-20	5.13	4.08	0.43	16.92	0.09	0.04	0.29	6.18	0.46	6.36	0.17	2.73	60.83	7.92
20-40	5.25	3.05	0.28	9.08	0.09	0.03	0.02	4.28	0.16	4.42	0.14	3.23	4.17	5.93
40-60	5.23	2.45	0.17	3.50	0.07	0.02	0.00	3.16	0.09	3.25	0.09	2.98	0.00	4.21
								SF						
0-20	4.99	4.79	0.40	32.00	0.10	0.02	0.57	7.50	0.77	7.70	0.20	2.60	74.00	5.40
20-40	5.17	3.33	0.20	3.00	0.13	0.06	0.19	5.00	0.39	5.20	0.20	3.80	48.70	2.80
40-60	5.16	2.53	0.20	0.00	0.11	0.01	0.00	3.80	0.12	3.92	0.12	3.10	0.00	1.40
		GF												
0-20	4.59	8.11	4.80	34.00	0.14	0.06	2.76	13.20	3.05	13.49	0.29	2.10	90.50	3.70
20-40	4.63	9.71	2.40	15.00	0.12	0.03	2.95	16.00	3.14	16.19	0.19	1.20	93.90	5.90
40-60	4.57	6.25	1.60	10.00	0.13	0.03	3.52	15.10	3.71	15.29	0.19	1.20	94.90	5.70

pH = measure of acidity and alkalinity; OM = organic matter; P = available phosphorus; K = available potassium; Ca^{2+} + Mg^{2+} = traceable calcium + exchangeable magnesium; Al^{3+} = exchangeable aluminum; H+Al = potential acidity; CEC_e = effective cation exchange capacity; CEC_t = total cation exchange capacity; SB = sum of bases; V = base saturation; m = aluminum saturation; P-rem = remaining phosphorus.

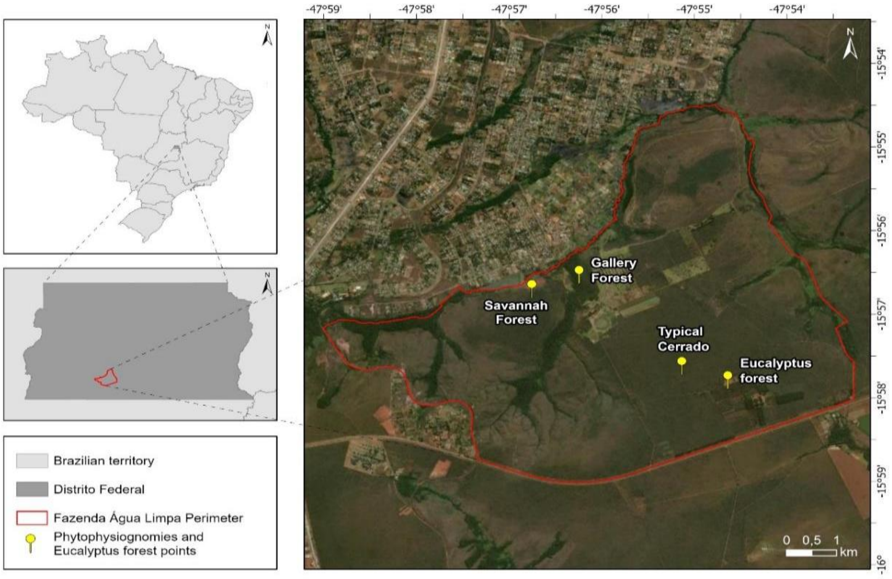

Fig 1. Cerrado biome phytophysiognomies and Eucalyptus forest points, at Fazenda Água Limpa, Distrito Federal.

Table 2. Mean and percentage of remaining eucalyptus leaf biomass at different periods after the beginning of the experiment in the Cerrado phytophysiognomies forms and eucalyptus plantations at Fazenda Água Limpa, Distrito Federal.

Days after start of experiment	SF	TC	GF	EU
0	20aA (100%)	20aA (100%)	20aA (100%)	20aA (100%)
30	17.72abAB (88.60%)	16.63abBC (83.15%)	14.18abC (70.90%)	18.13abA (90.65%)
60	14.51bcB (72.55%)	14.03bcB (70.15%)	10.85bcC (54.25%)	15.36bcA (76.80%)
120	12.75cdB (63.75%)	12.06cdB (60.3%)	10.87bdB (54.35%)	14.42cdA (72.10%)
240	11.33cdB (56.65%)	11.54ceB (57.70%)	8.84cdC (44.20%)	13.01deA (65.05%)
365	10.85deB (54.25%)	10.99deB (54.95%)	8.66cdC (43.30%)	12.11eA (60.55%)

Means followed by the same lower-case letter in the column (comparison between days after the beginning of the experiment) and the same capital letter in the row (comparison between areas) do not differ according to the Kruskal-Wallis test at 5% probability. TC: Typical Cerrado; SF: Savannah Forest; GF: Gallery Forest; EU: eucalyptus plantation.

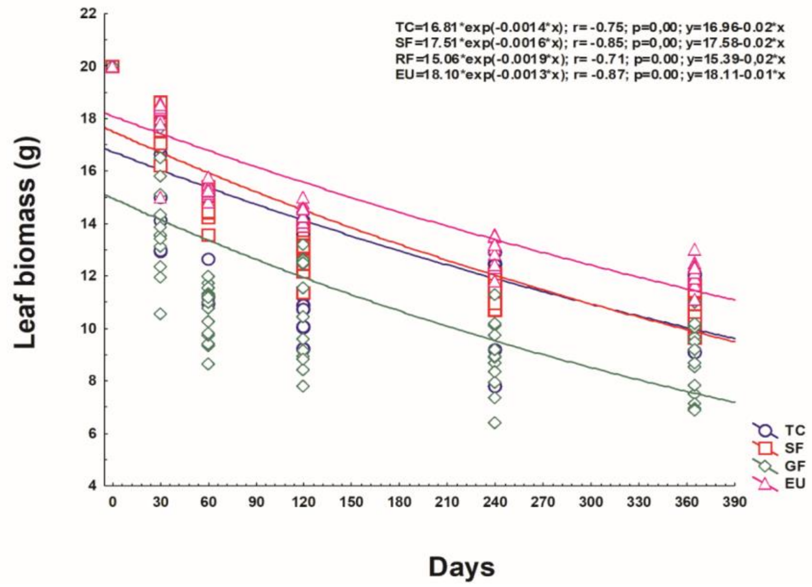

Fig 2. Decomposition curves of eucalyptus leaf biomass (g) at different periods after the beginning of the experiment, in Typical Cerrado (TC), Savannah Forest (SF), Gallery Forest (GF), and eucalyptus forest (EU), at Fazenda Água Limpa, Distrito Federal.

Table 3. Parameters obtained through exponential regression for different phytophysiognomies of the Cerrado biome and eucalyptus forests at Fazenda.

	SF	TC	GF	EU
Equation	$X_t=17.516*e^{-0.0016}$	$X_t=16.815*e^{-0.0014}$	$X_t=15.064*e^{-0.0019}$	$X_t=18.104*e^{-0.0013}$
k	0.0016	0.0014	0.0019	0.0013
$T^{1/2}$ (days)	433	495	365	533

k = decomposition rate after 365 days of field exposure of decomposition bags; $T^{\frac{1}{2}}$ = half-life.

Materials and methods

Conduction of study

The study was conducted in an area of the Cerrado (Savannah) biome, located in the Ecological and Experimental Reserve of the University of Brasília, Fazenda Água Limpa, Distrito Federal - DF, Midwestern region of Brazil (Fig 1). In this locality, the climate is classified as Aw, according to the Köppen classification (Cardoso, 2014), with temperatures ranging from 13 to 26 °C. The average annual rainfall is 1,400 mm, with a pronounced dry season from June to September. The relative humidity between May and September is below 67% and can reach 38% or less in the driest periods, and the average is 56%, according to local meteorological data.

The decomposition of eucalyptus leaves was assessed in three vegetation types of the Cerrado biome according to the classification of Ribeiro and Walter (2008): Typical Cerrado (TC), Savannah Forest (SF), Gallery Forest (GF), and the eucalyptus stand (EU). The freshly fallen leaves were used to assess decomposition rates. The stand was implemented in March 2013, with the planting of the clonal hybrid (GG 100), *Eucalyptus urophylla* x *grandis*, in 3 m x 3 m spacing, with a total area of 23.00 ha. In pre-planting silvicultural practices, soil preparation was performed by subsoiling to a depth of 70 cm and fertilizing with 600 kg ha^{-1} of single superphosphate. The base fertilization was performed with 200 g of NPK 20:05:20 formulation per hole and the fertilizer was applied 15 cm away from the seedling. Complementary fertilization was performed in the following periods: fifteen days, two months, one year, and two years after planting. The soil in TC, SF, and EU is classified as Oxisol (Soil Survey Staff, 2014), with low natural nutrient availability and high aluminum content (EMBRAPA, 2018). Gallery Forest was located on the banks of a perennial stream. The non-floodable soil of GF is classified as Histosol (Soil Survey Staff, 2014), which naturally has high levels of organic matter and high humidity.

Experimental design

Seventy-five litter bags were allocated to each study area to evaluate the rates of leaf decomposition. These bags were fabricated using a 20 cm x 20 cm nylon fabric and had a 2 mm opening to provide the actuation of decomposer organisms. Each litter bag contained 20 g of eucalyptus leaves, which had been oven-dried at 62 °C until they had a constant weight and showed senescence. They were collected from the forest floor, taking into consideration the visual aspect of little or no degradation action.

The litter bags were taken to the field and the collections were performed after 30, 60, 120, 240, and 365 days of exposure, with a total of 15 litter bags in each study area for each period. After collection, the remaining material in each bag was weighed on a 0.01 g precision scale and sorted in the laboratory, where the impurities in the leaves were removed. The remaining leaf material was dried in a forced air circulation oven, heated to 62 °C and weighed.

After the experiment, soil samples were collected for chemical analysis from depths of 0-20, 20-40, and 40-60 cm, using a Dutch auger, with 10 simple soil samples per area forming a composite sample. The soil samples was dried in open air under full shade and the samples were sent for laboratory (Table 1). All the areas studied present low base saturation (V < 50%) and high aluminum saturation (m), and are hence classified as dystrophic soils (Sousa and Lobato, 2004). The four areas exhibit naturally acidic soils, due to the high levels of exchangeable aluminum (Al^{3+}) and potential acidity (H+Al). The soil texture of Typical Cerrado, Eucalyptus stand, and Savannah Forest was considered very clayey, and that of Gallery Forest was clayey.

Statistical analysis

The decomposition was evaluated using the difference between the initial and remaining masses throughout the exposure period, represented by the following equation: remaining mass (%) = (final mass / initial mass) × 100. After one year, it was possible to determine the decomposition *k* constant using the exponential equation proposed by Olson (1963), $X_t = X_0.e^{-kt}$, (X_t = dry weight of the remaining material after t days and X_0 = dry weight of the material at t = 0) and the half-life using the equation, $T^{1/2} = \ln(2) / k$ (k = decomposition constant) (Olson, 1963). The leaf decomposition data were subjected to analysis of variance followed by Tukey's test at 5% significance when the assumptions of homogeneity of variance and normality were met. The non-parametric Kruskal-Wallis test was applied when at least one assumption was not met. The analyses were performed using the Statistica® software.

Conclusions

The results of this study, obtained by monitoring leaf decomposition, support the use of an exotic species in an initiative to recover altered areas of the Cerrado biome. The Brazilian Forest Code enabled the possibility and legally ensures the viability, according to the maximum established percentage, of using eucalyptus as a facilitator species in environments to be recovered. With respect to the percentages provided in the legal provision governing Brazilian forests, when using this species from Oceania, it was found that the main vegetation type of the Brazilian savannah effectively assimilate plant material that will be deposited on the soil. Combining the legal provision with scientific support, this study demonstrated the feasibility of using one more tool in the arduous mission of recomposing ecological functions of altered environments. However, it is necessary to conduct further studies that take into consideration ecological aspects such as the compositions of edaphic fauna and their processes in order to better understand the possible impacts of introducing exotic species into permanent preservation areas.

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Declaration of Competing Interest

The authors report no declarations of interest

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