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Article

WEED SEED BANK IN AN AGROFORESTRY SYSTEM WITH EUCALYPTUS IN SUBTROPICAL BRAZIL

Banco de Sementes de Plantas Daninhas em Sistema Agroflorestal com Eucaliptos no Subtrópico Brasileiro

DEISS, L.[1]*
MORAES, A.[1]
PELISSARI, A.[1]
PORFÍRIO-DA-SILVA, V.[2]
SCHUSTER, M.Z.[1]

ABSTRACT - Trees can modify the weed seed bank composition and distribution in the cropped area of an agroforestry system. This study aimed at analyzing the eucalyptus (*Eucalyptus dunnii*) effect on spatial distribution, functional traits abundance and weed seed bank botanic composition in an agroforestry system under no-tillage in Subtropical Brazil. The experiment was conducted in a randomized block design with five replications, and five positions between 4.5-year-old eucalyptus double rows [(4x3) x 20 m] as treatments. Soil sampling was performed at 0-20 cm and the method to quantify and identify seeds was the seedling emergence in trays, inside a greenhouse. Weed phytosociological indices (relative density, frequency and importance), functional traits abundance (life cycle, shade tolerance, reproduction, spread and seed form) and seed densities (m^{-2}) of families and species were evaluated; 17 weed families and 49 species were found. The indices that contributed to the relative importance of families and species differed among the positions between rows. Eucalyptus grown as an intercrop changed the composition and size of the weed seed bank, in a different way for functional traits, families and species depeding on the distance from trees.

Keywords: alley cropping, phytosociology, integrated weed management, integrated crop-livestock systems, functional traits, spatial distribution patterns.

RESUMO - Este estudo teve como objetivo analisar o efeito de eucaliptos (Eucalyptus dunnii) sobre a distribuição espacial, a abundância das características funcionais e a composição botânica do banco de sementes de plantas daninhas em sistema agroflorestal sob plantio direto no subtrópico brasileiro. A amostragem do solo (0-20 cm) foi realizada em cinco posições entre linhas duplas de eucaliptos [(4x3) x20 m] com 4,5 anos. O delineamento experimental foi em blocos casualizados, com cinco repetições e cinco distâncias entre árvores. O método utilizado para quantificação de sementes foi a identificação da emergência de plântulas em casa de vegetação. Foram avaliados os índices fitossociológicos, a abundância das características funcionais e as densidades de sementes (m^{-2}) de monocotiledôneas e dicotiledôneas, das famílias e das espécies de plantas daninhas. Foram encontradas 17 famílias e 49 espécies de plantas daninhas. Os índices que compõem a importância relativa das famílias e espécies foram diferentes nas posições entre as linhas de árvores. Para as características funcionais, o tipo de ciclo de vida diferiu entre as posições. Os renques de eucaliptos alteraram a composição e o tamanho do banco de sementes, de forma diferente para as características funcionais, famílias e espécies, modificando a sua importância e abundância em relação à distância do componente arbóreo.

Palavras-chave: cultivo de aleias, fitossociologia, manejo integrado de plantas daninhas, sistemas integrados de produção agropecuária, características funcionais, padrão de distribuição espacial.

*** Corresponding author:**
<leonardodeiss@gmail.com>

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[1] UFPR, Universidade Federal do Paraná, Curitiba-PR, Brasil; [2] Embrapa Florestas, Colombo, Paraná-PR, Brasil.

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INTRODUCTION

In order to improve an integrated weed management, the weed seed bank must be understood as the main source for future weed infestations; the spatial distribution of seeds in the soil profile and surface area, as well as agronomic and environmental influence on weed dynamics, are important features to be considered. Knowing the seed bank characteristics enables the development of less vulnerable weed control methods, for example, by using hydrothermal models to predict weed emergence flows in response to environmental and agronomic practices (Bullied et al., 2012).

A soil seed bank can be defined as the number of viable seeds that are in the soil profile at a given time. The seed bank composition depends on the balance between seeds input (input, persistence, quiescence, and dormancy) and output (germination, deterioration, predation, and pathogenicity), which imply seasonal variability derived from inputs and outputs variations. Its dynamics is influenced by environmental factors and by the anthropic influence (Gardarin et al., 2012). Seed distribution in the soil profile and area depends on the plant-spread syndrome and on the mother-plant growth, as well as on the intensity of spreading agents, such as wind, water, animals, agricultural implements, and humans.

Some studies related seed bank dynamics to soil tillage (Colbach et al., 2014; Schutte et al., 2014), crop rotation (Cardina et al., 2002), weed management (Legere et al., 2005), soil fertility (Shiratsuchi et al., 2005), integrated crop-livestock systems (Ikeda, 2007), cattle grazing (Haretche and Rodrígues, 2006), and herbicides (Vasileiadis et al., 2007). Among several studies, a few of them have studied the influence of trees on the seed bank composition of cropped areas.

As a response to society claims, agroforestry systems (AFS) arose with the purpose of allying improvements in the agricultural production with environmental quality, promoting, therefore, greater efficiency on input usage and nutrient cycling (Lemaire et al., 2014). Agroforestry systems are complex and involve many temporal and spatial interactions among biotic and abiotic factors, resulting from trees, crops, grazing, and animal interactions (Moraes et al., 2014).

In these systems, the weed seed bank assessment may have to consider agronomic practices applied to each component, and the interaction among those practices. According to Cardina et al. (2002) and Schuster et al. (2016), crop rotation, herbicides, soil management, and grazing intensities are important filters, which determine the composition and the trait abundance of the weed species. Based on this rationale, the influence promoted by trees, animals, and crops should be assessed as weed filters in AFS.

Many studies evaluating seed banks in agroforestry systems were conducted as for vegetation regeneration and conservation purposes (Kozlowski, 2002; Diemont et al., 2006; Loha et al., 2008; Costa and Mitja, 2009; Moreira et al., 2011; Moressi et al., 2014). Moreover, fewer studies gave more emphasis to the productive aspects of agroforestry systems and the potential risks of the negative interference of weeds on crops (Akobundu et al., 1999; Ekeleme et al., 2003; López-Pintor et al., 2003; Ekeleme et al., 2005). Some findings about trees affecting weeds on herbaceous cropped areas were that trees can promote weed species segregation in the seed bank due to biophysical variations within agroforestry systems (López-Pintor et al., 2003). Fallow management can be more effective in weed seed bank management than natural fallow (Akobundu et al., 1999), and Ekeleme et al. (2005, 2013) determined various effects of planted fallows, land-use intensities, and tillage on the weed seed bank for tropical environments. However, the spatial distribution patterns of weed seed banks in agroforestry systems from subtropical regions is still barely known, especially when these systems are under no-tillage management, and herbaceous crops are interacting with perennial species for timber production.

Therefore, trying to fill this knowledge gap, a hypothesis according to which trees can modify the weed seed bank composition and spatial distribution in the cropped area of a young AFS under no-tillage in the Subtropical region of Brazil was tested. This study aimed at analyzing the effect of trees on the weed seed bank spatial distribution, in positions between 4.5-year-old eucalyptus double rows, assessing the seed bank phytosociology, size, composition, and functional trait abundance.

MATERIAL AND METHODS

In order to study the seed bank, soil samples (0-20 cm depth) were collected in Ponta Grossa, Paraná state, Brazil, where there is an AFS located at 25°06’19"S latitude and 50°02’38"W longitude. The region belongs to the Second Plateau of Paraná and the annual rainfall averages are between 1600 and 1800 mm, with 500 to 600 mm occurring during the rainiest period (December, January, and February), and 250 to 350 mm during the driest period (June, July, and August). The average annual temperature ranges between 17 and 18 °C, varying between 23 and 24 °C during the hottest period (December, January, and February) and from 12 to 13 °C during the coldest period (June, July, and August). According to Köppen, the climatic classification is Cbf-type, Humid Meso-thermal Subtropical, found on the highest regions of the Second Plateau of Paraná.

Eucalyptus dunnii Maiden was planted in double hedgerows, with 20 m between hedgerows, 4.0 m between rows and with 3.0 m between trees within the rows (Figure 1). Trees were planted on the slope contour in order to promote water and soil conservation (Porfírio-da-Silva et al., 2009). The slope ranged from 4 to 8%. Herbaceous crop cultivation was carried out on a 18 m width of the total 20 m width between hedgerows, because the implements used for cropping required at least a 1 m distance from trees. Before the agroforestry system was established, the area was previously covered with native grassland composed by a variety of C3 and C4 species. At the time of sampling, trees were 4.5 years old and 9 m tall. Sample collection occurred after the harvest of soybean (*Glycine max* L.), in March 2010, with black oat (*Avena strigosa* Schreb.) as a winter cover crop, and corn as a previous summer crop. Weed control management was performed with herbicides on the herbaceous cropped area (always as required for crops) and mechanically between trees within the rows (more frequently during the first and second years after the establishment of the experiment, and less frequently after that period).

The experiment was carried out in a completely randomized block design, with five replications and five positions between hedgerows as treatments (n=25). Treatments were five equidistant positions between hedgerows, considering only the area under herbaceous crop cultivation (i.e., 18 m). As trees were planted on the slope contour, the determination of the position started at the lowest elevation of the slope between hedgerows. The positions were: A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m. Each position covered 3.6 m, perpendicularly to the hedgerows.

Each experimental unit had samples composed of three subsamples, which were collected from three perpendicular transects in relation to the hedgerows, each spaced 10 m apart. Soil was collected on May, the 1st 2010 using a shovel, at a 0 to 20 cm, depth covering a soil surface area of ~400 cm².

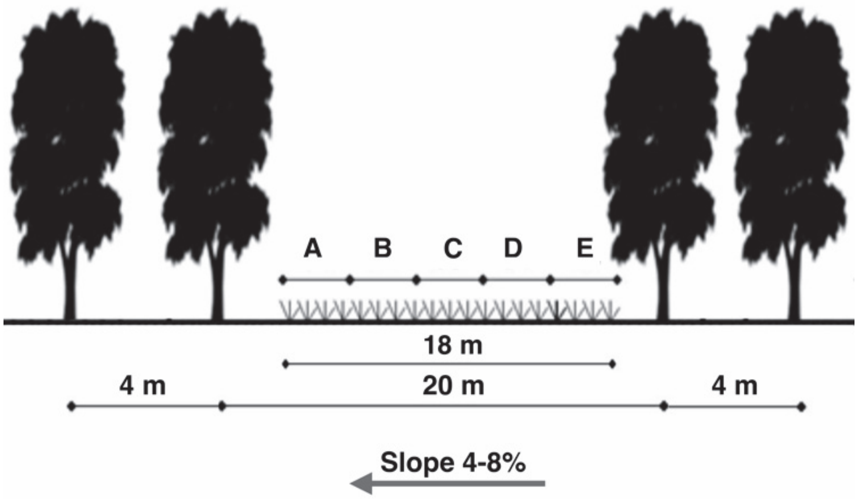


Figure 1 **-** Weed seed bank sampling positions between adjacent 4.5-year-old eucalyptus (*Eucalyptus dunnii* Maiden) double hedgerows [20 m (4 m x 3 m)], at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the hedgerow placed on slope’s lower position in an agroforestry system, Ponta Grossa, Paraná state.

In order to quantify the soil seed bank, soil samples were placed in individual trays inside a greenhouse, and for eight months, emerged seedlings were counted. In the greenhouse, the tree subsamples per experimental unit were combined and homogenized in order to form one composite sample per experimental unit. For each experimental unit, 1.5 kg of soil was placed in individual trays, resulting in a 2.0 cm layer of soil. These trays had a total volume of 4000 mL (34.0 x 23.0 x 7.0 cm). Watering was done regularly throughout the experiment, increasing frequency to almost daily on hotter months, and decreasing frequency to once or twice a week on colder months. At the end of the seventh experimental month, in December 2010, watering was interrupted for 15 days in order to break seed dormancy (Cauwer et al., 2010). After 15 days, watering began once again following the normal schedule.

The number of seeds was determined by the cumulative number of seedlings that emerged in each tray throughout the whole experimental period. Seedling counting was made according to the occurrence of emergence flushes, varying from weeks to a period of one month. Species identification was performed on mature plants, obtained from three or more seedlings transplanted into pots (Ekeleme et al., 2005), and they were identified by the Botanic Museum of Curitiba. To analyze seed density per unit area, the formula proposed by Monquero and Silva (2007) was used, modified to m^2, where the number of non-dormant seeds per m^2 was calculated with a soil density coefficient of 1.22 g cm^{-3} (Silveira Junior et al., 2012).

The phytosociological parameters were relative density and relative frequency, determined according to Mueller-Dombois and Ellenberg (1974) and Pitelli (2000), and the relative importance index of the seed bank was given by the sum of relative density and relative frequency (Ikeda, 2007).

According to literature (Kissmann and Groth, 1997, 1999, 2000; Basel and Berlin, 1980a,b), weeds were classified according to their functional traits: i) plant: botanic division (monocots and dicots), life cycle (annual, biennial – two growth seasons to complete the life cycle, and perennial – development during two or more seasons), and tolerance to shading (tolerant or intolerant, according to the authors); and ii) reproduction and spread: reproduction (exclusive by seeds or not), reproduction of seeds per plant (0-100, 100-1000, 1000-10000, >10000), and main spread manner (anemocoria, zoocoria, hydrocoria, selfcoria) (Table 1).

From the functional trait classification, the relative abundance for each trait was calculated (number of individuals with a given trait divided by the total number of individuals). As for the functional trait analysis, the species *Wahlenbergia linarioides* A. DC., *Lobelia nummularioides* Cham., *Desmanthus tatuhyensis* Hoehne, *Stylosanthes guianensis* (Aubl.) Sw., *Juncus tenuis* Willd. were eliminated because information about these species was not available.

Seed density m^{-2} of total seed bank, monocots and dicots, main families and species, as well as functional trait abundance, were submitted to the Shapiro-Wilk test and analysis of variance. When the position effect was significant, the variables were submitted to simple regression analyses to determine the linear, squared, and cubic curve responses. The mathematical models were selected according to the best adjustment, corroborated by the determination coefficient and regression F test significance.

RESULTS AND DISCUSSION

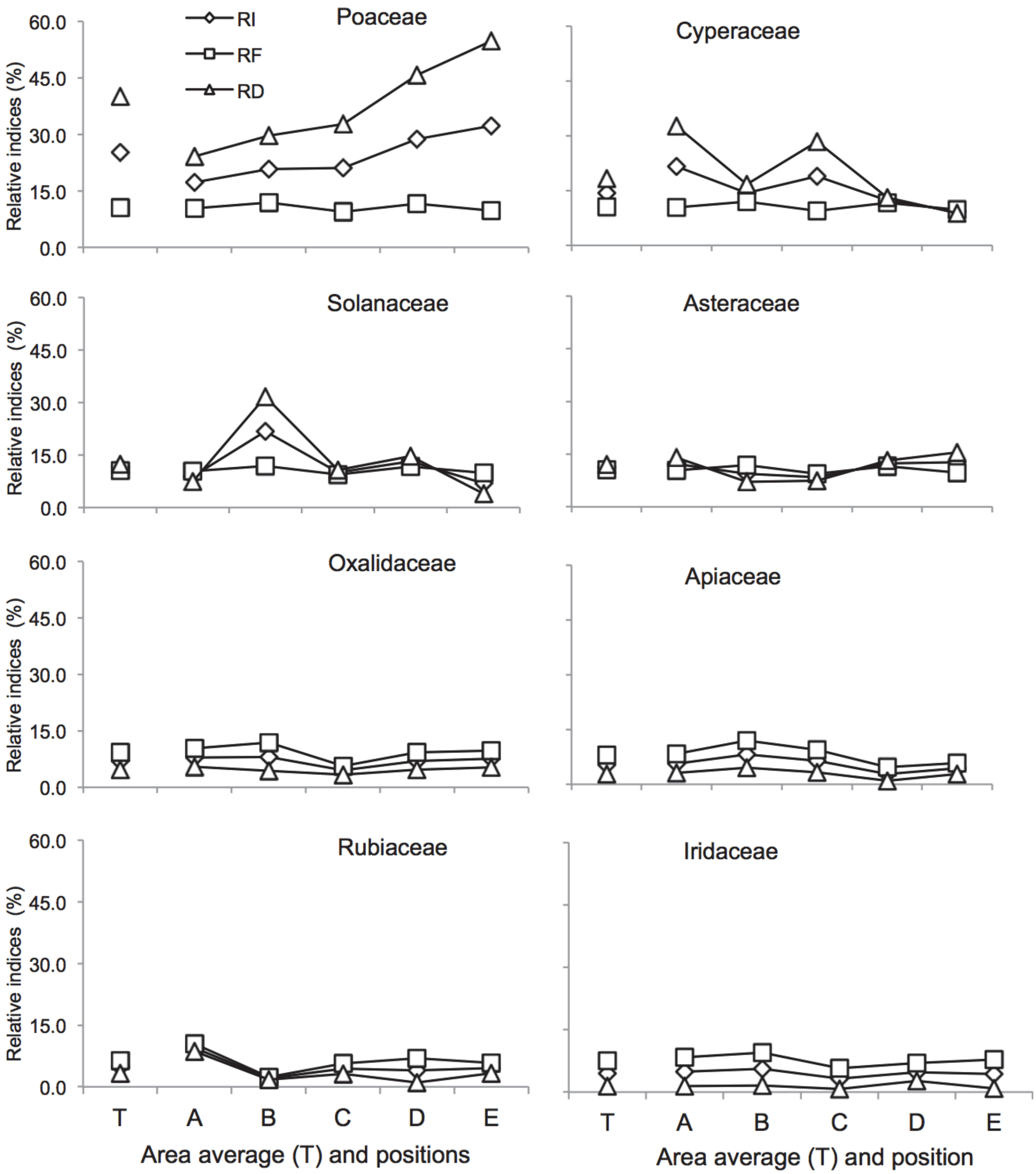
It was possible to find 17 families and 49 species out of a total of 2,585 non-dormant seeds from the seed bank. Nine morphotypes were not identified; being considered here as other seedlings. The total seed density m^{-2}, monocot seed density m^{-2} and dicot seed density m^{-2} did not differ among positions between hedgerows ($p>0.10$). The predominant family was Asteraceae with nine species, followed by the Poaceae family with six species, and the Solanaceae as well as Fabaceae families with three species each (Table 1).

The phytosociological indices (relative density, frequency and importance) distributions in the positions between hedgerows differed for families (Figure 2) and species (Figure 3). The most important eight families and nine species represented 84.3% and 70.5%, respectively, of the seed bank relative importance (Table 1). There was phytosociological segregation in the variation of the indices that composed the relative importance or by the intensity of the same indices

Table 1 **-** Functional traits and phytosociology of the weed seed bank (0-20 cm) in an agroforestry system with 4.5-year-old eucalyptus in Ponta Grossa, Paraná state, Brazil

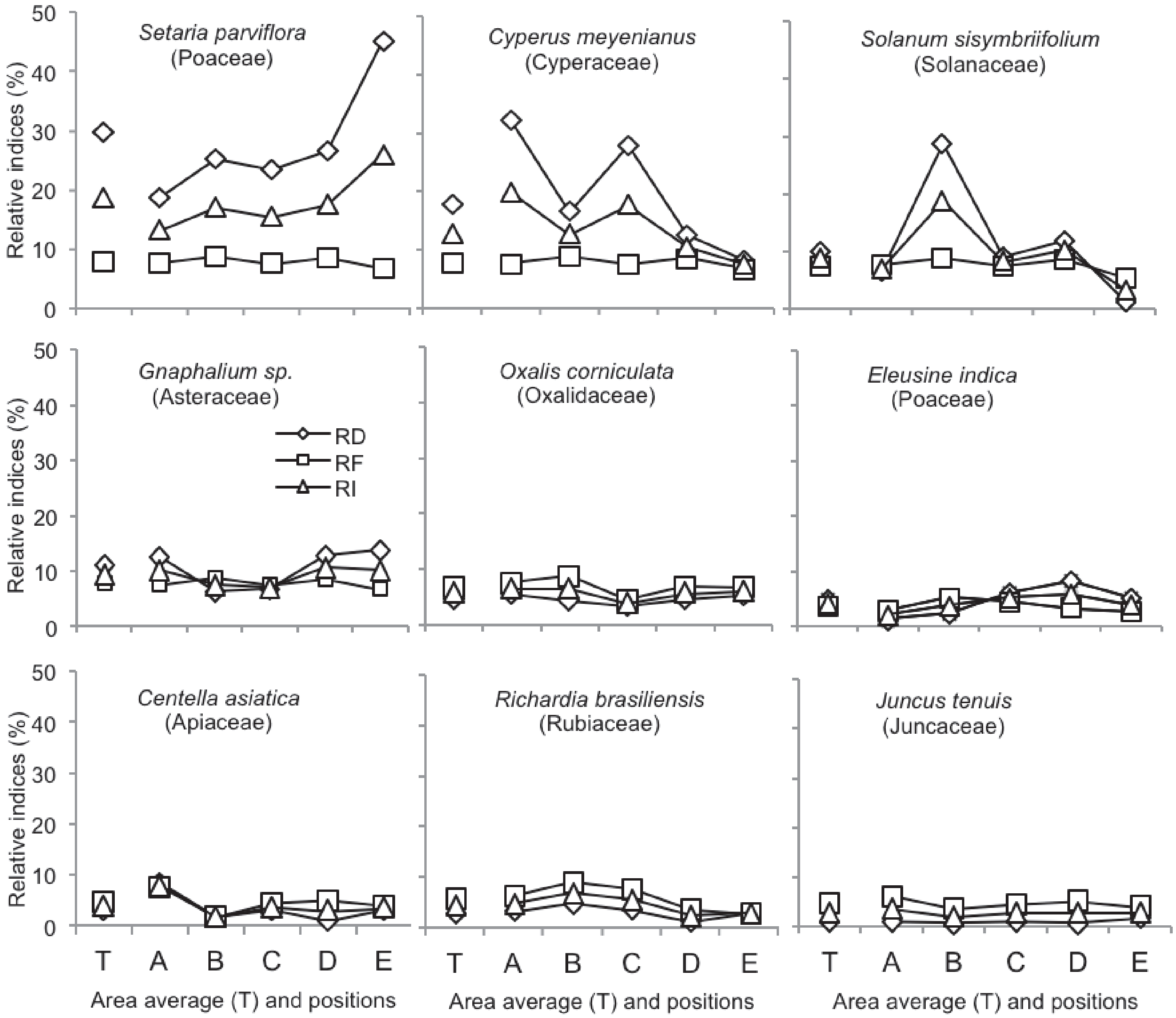
Family	Species	BD(1)	C(2)	S(3)	D(4)	R(5)	Seed Production	RD(6)	RF(6)	RI(6)
Apiaceae	*Apium leptophyllum* (Pers.) F. Muell.	D	A	T	B	S	0-100	0.04	0.31	0.17
Apiaceae	*Centella asiatica* (L.) Urb.	D	P	T	B	SO	0-100	2.75	5.56	4.15
Araliaceae	*Hydrocotyle leucocephala* Cham. & Schltdl.	D	P	I	B	SO	0-100	0.5	2.47	1.49
Asteraceae	*Baccharis caprariifolia* DC.	D	P	I	A	SO	100-1000	0.23	1.23	0.73
Asteraceae	*Bidens pilosa* L.	D	A	I	Z	S	1000-10000	0.19	0.93	0.56
Asteraceae	*Conyza bonariensis* (L.) Cronquist	D	A	I	A	S	>10000	0.04	0.31	0.17
Asteraceae	*Erechtites valerianifolius* (Link ex Spreng.) DC.	D	A	T	A	S	1000-1000	0.15	0.93	0.54
Asteraceae	*Galinsoga parviflora* Cav.	D	A	T	A	S	1000-10000	0.04	0.31	0.17
Asteraceae	*Gnaphalium* sp.	D	B	T	B	S	-	11.03	7.72	9.37
Asteraceae	*Hypochaeris brasiliensis* (Less.) Benth. & Hook.f. ex Griseb.	D	B	T	A	SO	-	0.08	0.62	0.35
Asteraceae	*Senecio langei* Malme	D	P	I	B	S	1000-10000	0.12	0.93	0.52
Asteraceae	*Sonchus oleraceus* L.	D	B	I	A	S	>10000	0.19	1.54	0.87
Campanulaceae	*Lobelia nummularioides* Cham.	D	-	-	-	-	-	0.15	1.23	0.69
Campanulaceae	*Wahlenbergia linarioides* Lam.	D	-	-	-	-	-	0.15	0.93	0.54
Cyperaceae	*Cyperus meyenianus* Kunth	M	P	I	B	SO	>10000	17.76	7.72	12.74
Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl	M	P	I	B	S	>10000	0.5	2.78	1.64
Fabaceae	*Chamaecrista nictitans* Moench	D	P	I	B	S		0.15	0.93	0.54
Fabaceae	*Desmanthus tatuhyensis* Hoehne	D	-	-	-	-	-	0.08	0.31	0.19
Fabaceae	*Stylosanthes guianensis* (Aubl.) Sw.	D	-	-	-	-	-	0.04	0.31	0.17
Hypericaceae	*Hypericum connatum* Lam.	D	P	I	B	S	1000-10000	0.08	0.31	0.19
Hypericaceae	*Hypericum teretiusculum* A.St.-Hil.	D	P	I	B	S	1000-10000	0.15	0.62	0.39
Hypoxidaceae	*Hypoxis decumbens* L.	M	P	T	H	SO		0.04	0.31	0.17
Iridaceae	*Sisyrinchium luzula* Klotzsch ex Klatt	M	P	I	H	SO		0.43	2.47	1.45
Iridaceae	*Sisyrinchium micranthum* Cav.	M	P	T	H	SO		1.01	3.4	2.2
Juncaceae	*Juncustenuis* Willd.	M	-	-	-	-	-	0.97	4.63	2.8
Malvaceae	*Sida rhombifolia* L.	D	P	T	B	S	100-1000	0.74	2.78	1.76
Oxalidaceae	*Oxalis corniculata* L.	D	P	T	B	SO		4.68	6.79	5.74
Plantaginaceae	*Scoparia dulcis* L.	D	A	I	B	S	>10000	0.04	0.31	0.17
Poaceae	*Avena strigosa* Schreb.	M	A	I	B	S	-	0.04	0.31	0.17
Poaceae	*Brachiaria mutica* (Forssk.) Stapf	M	P	T	B	SO	1000-10000	0.04	0.31	0.17
Poaceae	*Brachiaria plantaginea* (Link) Hitchc.	M	A	I	B	S	-	4.02	1.23	2.63
Poaceae	*Digitaria horizontalis* Willd.	M	A	I	B	SO	-	1.43	3.09	2.26
Poaceae	*Eleusine indica* (L.) Gaertn.	M	A	I	B	S	>100000	4.95	3.7	4.33
Poaceae	*Setaria parviflora* (Poir.) Kerguélen	M	A	I	B	S	-	29.59	7.72	18.65
Polygonaceae	*Polygonum aviculare* L.	D	P	I	B	S	-	0.35	0.62	0.48
Rubiaceae	*Richardia brasiliensis* Gomes	D	A	I	B	S	-	3.29	4.63	3.96
Rubiaceae	*Spermacoce latifolia* Aubl.	D	A	T	B	S	1000-10000	0.08	0.62	0.35
Solanaceae	*Solanum aculeatissimum* Jacq.	D	A	I	B	S	100-1000	0.66	1.54	1.1
Solanaceae	*Solanum americanum* Mill.	D	A	I	B	S	100-1000	1.7	3.4	2.55
Solanaceae	*Solanum sisymbriifolium* Lam.	D	A	I	B	S	100-1000	10.06	7.41	8.73

(1) Botanical Division: M – Monocotyledons, and D – Dicotyledons. (2) Cycle: A – Annual, B – Biennial, and P – Perennial. (3) Shading: T – Tolerant, and I – Intolerant. (4) Dispersion: S – Barachorous, A – Anemochorous, H – Hydrochoric, Z – Zoochoric. (5) Reproduction: S – seed, and SO – seed and other. (6) Phytosociological indices: RD – Relative Density, RF – Relative Frequency, and RI – Relative Importance. Non-available data were indicated with "-".



The vertical bars indicate the standard error. Position T represents the average of positions A-E. Panels are ordered according to the Relative Importance (from left to right, up to down).

Figure 2 **-** Weed seed bank (0- 20 cm) distribution of the most important families (RD: Relative Density, RF: Relative Frequency, and RI: Relative Importance) in positions between adjacent 4.5-year-old eucalyptus (*Eucalyptus dunnii* Maiden) double hedgerows [20 m (4 m x 3 m)], at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the hedgerow placed on slope's lower position in an agroforestry system, Ponta Grossa, Paraná state.



The vertical bars indicate standard error. Position T represents the average of positions A-E. Panels are ordered according to the Relative Importance (from left to right, up to down).

Figure 3 **-** Weed seed bank (0-20 cm) distribution of the most important species (RD: Relative Density, RF: Relative Frequency, and RI: Relative Importance) in positions between adjacent 4.5-year-old eucalyptus (*Eucalyptus dunnii* Maiden) double hedgerows [20 m (4 m x 3 m)], at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the hedgerow placed on slope's lower position in an agroforestry system, Ponta Grossa, Paraná state.

among positions between hedgerows. Some families and species had a larger contribution of relative density than relative frequency; meanwhile others had the opposite behavior (Figures 2 and 3).

The relative functional trait abundance is presented in Table 2. In the AFS, monocot abundance (56%) was higher than dicot abundance (43%) and the predominant life cycle was the annual one (52%), followed by the perennial one (35.3%), and biennial one (12.6%). Those species, considered as shade-tolerant in literature, accounted for 24% of the weed community. Reproduction type occurred predominantly as exclusive per seeds (64%), when compared to other reproduction types, and the main seed spread type was the selfcorica (97%). Species with rounded seeds accounted for 41% of the total, followed by the elongated (26%), oblong (18%), and flattened (15%) types. As for functional traits, the different one among positions between hedgerows was the plant life cycle (Table 2). Species with a biennial life cycle had increased abundance near hedgerows (Figure 4A).

Table 2 - Functional traits of the weed seed bank (0-20 cm) in an agroforestry system with 4.5-year-old eucalyptus in Ponta Grossa, Paraná state, Brazil

A) PLANT	p value[(1)]	Relative abundance (%)[(2)]
Botanic division		
Monocot	0.81	56.21
Dicot	0.81	43.78
Life cycle		
Annual	0.12	52.08
Biennial	0.08	12.62
Perennial	0.10	35.29
Tolerant to shading	0.34	23.73
B) REPRODUTION AND SPREAD		
Exclusive per seed	0.20	64.36
Seeds per plant		
0-100	0.55	11.18
100-1000	0.22	36.57
1000-10000	0.13	2.88
>10000	0.20	49.36
Spread form		
Anemochorous	0.98	0.81
Barachorous	0.63	97.42
Hydrochoric	0.65	1.58
Zoochoric	0.30	0.20

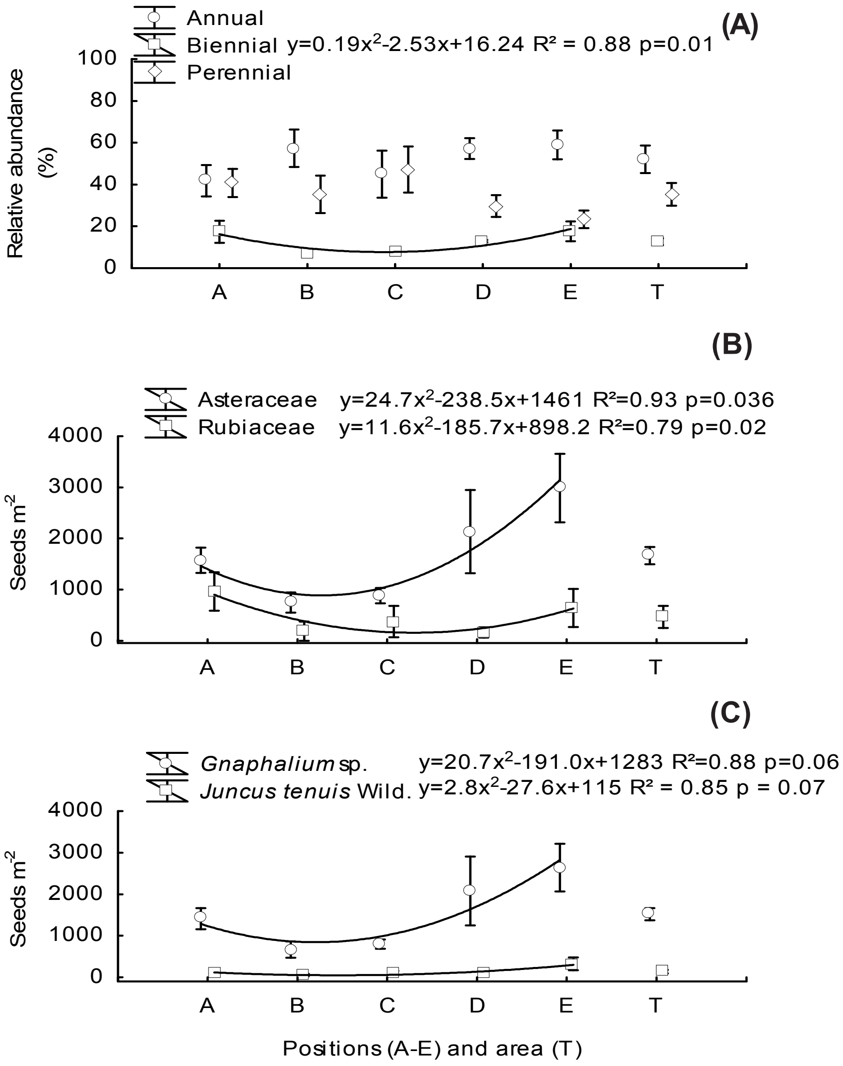
(1) p value from the analysis of variance of positions between adjacent 4.5-year-old eucalyptus (*Eucalyptus dunnii* Maiden) double hedgerows [20 m (4 m x 3 m)], at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the hedgerow placed on the slope's lower position. (2) Average of the positions.

Among the main families and weeds species, differences in seed density^{-2} among positions between hedgerows were observed for the families Asteraceae ($p<0.05$) and Rubiaceae ($p<0.1$) (Figure 4B) and for the species *Gnaphalium* sp. ($p<0.1$) and *J. tenuis* ($p<0.1$) (Figure 4C). Both families and species declined in seed density in positions that were farther from the trees (Figure 4B,C). Many factors could have contributed to weed segregation in positions between hedgerows in the AFS, including the weed morphophysiological tolerance to tree interference (i.e., water, light and nutrients), weed control management, and biophysical alterations promoted by trees acting over the weed spread.

Trees were able to segregate weed species in this AFS, because of the different adaptation degrees of weed species to biophysical variations promoted by the arboreal component. According to López-Pintor et al. (2003), the floristic composition of the seed bank in positions from shrub legumes *Retamas phaerocarpa* (on the center of the shrub, at the sub-wood's surroundings, and outside the treetop), consisted in species with distinct physiological and morphological functional traits that segregated them. In this experiment, segregation in relation to arboreal components was observed for some species, including the relative seed density of *S. sisymbriifolium* (Figure 3) and the seed density of *Gnaphalium* sp. and *J. tenuis* (Figure 4C), and also for the life cycle type functional trait (Figure 4A). Moreover, weed control management could have also influenced weed segregation between hedgerows.

S. *sisymbriifolium* and *Gnaphalium* sp. demonstrated a distinct behavior as for the relative seed density distribution between hedgerows (Figure 3). This can be explained by *Gnaphalium* sp. adaptability to shade (Kissmann and Groth, 1999) and smaller wind intensity that could be acting over its seed spread, since trees reduce air displacement within the AFS (Tsonkova et al., 2012). However, future studies determining the impacts of air displacement reduction on seed dispersal (i.e seed deposition gradient from mother-plants) are required. On the other hand, *S. sisymbriifolium* prefers well-illuminated areas (Kissmann and Groth, 2000) and its spread syndrome is barocoria (selfcoria subgroup); thus, fruits and seeds tend to remain closer to mother-plants.

Agroforestry has a different spectral irradiance, red:far-red ratio, and a photosynthetically active radiation when compared to sole-cropping system (Jose et al., 2004; Quinkenstein et al., 2009; Tsonkova et al., 2012). Many weed species have light quality dependence for germination (Valio, 1972) and the AFS could have promoted different patterns of seedling emergence. Moreover, as a response to shade, some plants increase their leaf chlorophyll content (mainly chlorophyll b), reduce their light compensation point, and increase their photosystem II ratio to I (Valladares and Niinemets, 2008; Gommers et al., 2013). Beyond possible light differences in AFS, trees can also compete for water and nutrients. Thus, non-tolerant species could have reduced their emergence, growth and seed production, which might have contributed to increase the abundance of tolerant species next to the hedgerows. A negative interference promoted by eucalyptus in *S. sisymbriifolium* infestation and dispersion in AFS was verified in other investigation (Deiss et al., 2017a). Deiss et al. (2017b) found that biomass of all weeds, as well as specifically of *Bidens pilosa* and *Sida rhombifolia*, decreased nearest the trees.



The vertical bars indicate standard error. T represents the average of positions A-E.

Figure 4 **-** Life cycle type abundance (A) and seed density of families (B) and species (C) of weeds in the seed bank (0 20 cm), in positions between adjacent 4.5-year-old eucalyptus (*Eucalyptus dunnii* Maiden) double row hedgerows [20 m (4 m x 3 m)], at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the hedgerow placed on slope's inferior position in an agroforestry system, Ponta Grossa, Paraná state.

A management factor that possibly contributed to the weed seed bank increase near the hedgerows was the lower frequency of weed control within hedgerows than the herbaceous cropped area. Therefore, hedgerows could have served as a seed spread source. This agrees with José-María et al. (2011), who verified an increased number of weeds on the cropped area edges, caused by seed deposition from plants located on the borders, where weed control was not performed. This could have contributed to the segregation of the life cycle functional trait. Most biennial plants have their vegetative growth during the first year, producing seeds only in the second year (Ellenberg, 1988). As weed control was not performed with the same frequency, within and outside hedgerows, this could have enabled biennials to finish their cycle, and therefore, to produce seeds. The same could be thought for perennials, but many of them already produce seeds in the first year (Ellenberg, 1988), such as many perennial C4 grasses.

Another factor that could have contributed to weed segregation was that trees were planted on the slope contour, which introduced biophysical alterations related to water, wind, and solar radiation incidence on the relative positions between hedgerows. Hence, by presupposition, treatment E was always in the slope's superior elevation, compared with position A, which is why the former position could have had a larger influence on the water that had been intercepted and redistributed by trees. Treetops intercept and redistribute rainwater (Ghazavi et al., 2008) through drainage from trunk, leaves, and branches (Siles et al., 2010). Therefore, the water dynamics could have altered weed seed distribution, as a function of the land slope and tree position.

The dispersive action of water over seeds possibly increased the weed seed concentration near the hedgerows on position E. The relative density of *S. parviflora* (Figure 3) and the seed density m^{-2} of *Gnaphalium* sp. and *J. tenuis* were greater on the upper position of the slope (Figure 4c). Perhaps this was a result of rainwater effects, affecting the dispersal of the seeds deposited within hedgerows. According to Gonçalves et al. (2008), the presence of *S. parviflora* seeds in the seed bank is more pronounced within *Eucalyptus grandis* sub-woods, compared to their own clearing and according to Kissmann and Groth (1999), *Gnaphalium* sp. has high adaptability to shade.

Moreover, water dynamics could have influenced seed penetration into soil and their horizontal displacement. Benvenuti (2007) verified that the greater the seed mass, the lesser is their penetration into soil due to rainfall, and seeds with spherical, elongated, and discoidal shapes have greater soil penetration compared with semi-spherical, flatten, and pyramidal shaped seeds. Thus, seed penetration facility might have favored the greater relative density and importance of *S. parviflora* seeds near the hedgerows. This species has the fertile anthecium, nude caryopsis or, less frequently, spikelet as its spreading unit (Kissmann and Groth, 1997).

It was possible to conclude that the botanical composition, biennial life cycle abundance, and weed seed bank size were modified in positions between adjacent eucalyptus double hedgerows in subtropical Brazil. Therefore, when planning an integrated weed management as well as future studies about AFS, the spatial distribution of weed seed banks should be considered. Site-specific weed management practices can be implemented based on the weed seed bank spatial distribution; however, weed emergence and growth characteristics may also need to be considered. Since trees are still in an earlier growing stage, similar or stronger effects can be expected for the following years of this AFS.

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