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WEED COMPETITION WITH SOYBEAN IN NO-TILLAGE AGROFORESTRY AND SOLE-CROP SYSTEMS IN SUBTROPICAL BRAZIL

Competição entre Plantas Daninhas e Soja em Sistema Integrado de Produção Agropecuária com Árvores e Cultivo Solteiro em Semeadura Direta no Subtrópico Brasileiro

ABSTRACT - Weed competition on soybean (*Glycine max*) growth and yield was expected to be different when managed in an agroforestry system as compared with sole-cropping without trees. Therefore agronomic practices to control weeds might need to be modified in agroforestry systems. We analyzed weed competition effects on soybean growth, grain yield, and yield components at different distances from 4-year-old eucalyptus (*Eucalyptus benthamii*) in an alley cropping system, as well as in a sole-crop system in southern Brazil. Above-ground soybean biomass was collected throughout the growing season and a logistic function was used to model crop growth. Weed above-ground biomass sampled during the soybean cycle, and grain yield and yield components at the end of the growing season were evaluated using regression analysis across positions between tree lines, and results compared to those without influence of trees. Soybean yield components were mostly reduced between tree lines compared with sole-cropping without trees. Soybean growth and yield within the eucalyptus agroforestry system was not affected by weed competition. However, weeds reduced soybean growth and yield in sole-cropping without trees. Reduction in soybean yield in the agroforestry system was rather caused by competition from trees. Therefore, tree interference may limit both weed and soybean growth potential.

Keywords: *Eucalyptus benthamii*, fire, *Glycine max*, growth analysis, interference, integrated crop-livestock system.

*RESUMO - O efeito da competição das plantas daninhas sobre o crescimento e produtividade da soja (**Glycine max**) pode acontecer de maneira diferente quando manejado em sistema integrado de produção agropecuária (SIPA) com árvores, em comparação ao cultivo solteiro de lavouras (sem árvores). Portanto, as práticas agronômicas para controlar as plantas daninhas podem necessitar de adaptação nos SIPA$_s$ arborizados. Foi analisado o efeito da competição de plantas daninhas no crescimento da parte aérea, na produtividade de nos grãos e componentes de produtividade da soja, em diferentes posições entre renques de eucaliptos (**Eucalyptus benthamii**) com quatro anos de idade, em sistema de aleias, bem como em sistema de cultivo solteiro, no sul do Brasil. A biomassa da parte aérea da soja foi coletada durante o ciclo de crescimento da cultura, e uma função logística foi usada para modelar o seu crescimento. A biomassa da parte aérea de plantas daninhas, durante o ciclo da soja, e a produtividade da soja e seus componentes, no final do ciclo da cultura, foram avaliadas com análise de regressão, nas posições entre os renques de árvores (SIPA), sendo os resultados comparados com aqueles*

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sem a influência das árvores. Os componentes de produtividade da soja foram afetados entre os renques de árvores (SIPA), em relação ao cultivo solteiro sem árvores. O crescimento e a produtividade da soja no SIPA com eucaliptos não foram afetados pela competição com as plantas daninhas, porém estas plantas os reduziram no cultivo solteiro sem árvores. A redução na produtividade da soja nos SIPA$_s$ foi, por sua vez, causada pela competição com as árvores. Esses resultados sugerem que as árvores interferem negativamente tanto no potencial de crescimento da soja quanto no das plantas daninhas.

INTRODUCTION

Agriculture today faces many challenges. Rather than a goal of high yielding crops only, additional emphasis is being placed on system performance for the environment, as well as achieving social equality and broader economic outcomes. A focus on better utilization of land and natural resources promotes long-term balanced development based on diversification of the production system (Lemaire et al., 2014; Lipper et al., 2014; Mbow et al., 2014).

Integrating trees into agricultural land may enhance sustainable land use management (Tsonkova et al., 2012). The combination of components in space and time determine the structure of these systems. Integration could be of trees, crops, and/or pasture with or without animals. Such integrated systems could provide an array of benefits for animals and cultivated plants (Quinkenstein et al., 2009; Anghinoni et al., 2013), as well as maximizing the provision of ecosystem goods and services (Tsonkova et al., 2012; Mbow et al., 2014).

Tree lines in agroforestry systems could enhance or reduce annual crop growth and yield by altering the microclimate or interspecific competition for water, nutrients, and light (Tsonkova et al., 2012), as well as allelochemical interference. Investigation of the interactive relationships between species needs to consider all biotic and abiotic elements that can influence their coexistence. Plant response to the interaction of detrimental and beneficial factors can be different than the response promoted by individual factors. For example, shade could improve performance of shade tolerant species under the negative influence of drought, while shade intolerant species may perform better in drought at intermediate light intensity (Holmgren et al., 2012).

Various factors affecting crop-weed competition have been investigated. For example, the impact of light quality on soybean growth and yield (Green-Tracewicz et al., 2011) or on the critical period for weed control in soybean (Green-Tracewicz et al., 2012) or maize (Page et al., 2009) have been studied. In an agroforestry system all factors regarding light, water, nutrients, temperature, wind and allelochemicals will simultaneously interact to some degree, depending on weed-crop dynamics. The effect of weeds on soybean production within an agroforestry system is currently poorly understood.

As in the transition from a conventional-tillage system to a no-tillage system, agronomic practices in agroforestry systems need to be fully evaluated and possibly modified for relevance and effectiveness. To take a step to fill this gap, we addressed issues related to soybean production, one of the main crops used in traditional no-tillage agriculture around the world.

Our hypothesis was that tree lines in an agroforestry system can alter weed competition in a soybean crop, such that agronomic practices in an agroforesty system may need to be modified compared with a sole-cropping system. Our objective was to analyze the degree of weed competition on soybean growth, as well as on yield and its components within a no-tillage agroforestry system. We evaluated different positions within the cropped alley between 4-year-old eucalyptus tree lines and compared responses within this agroforestry system with more conventional no-tillage agriculture without trees.

MATERIALS AND METHODS

This study was conducted in Ponta Grossa, Paraná, Brazil (25º06'19" S 50º02'38" W, 1020 m above mean sea level). The region belongs to the Second Plateau of Paraná. Mean annual

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precipitation is 1,600 to 1,800 mm with 500 to 600 mm in the rainiest quarter (December, January, and February) and 250 to 350 mm in the driest quarter (June, July, and August). Mean annual temperature is 17 to 18 °C, varying from 23 to 24 °C in the hottest quarter (December, January, and February) and from 12 to 13 °C in the coldest quarter (June, July, and August). According to Soil Survey Staff (2010), the soil is classified as a Haploperox. Prior to the experiment, soil was sampled at 0-0.2 m depth and chemical results are presented in Table 1.

Table 1 - Soil fertility in a no-tillage agroforestry system in subtropical Brazil at distances of 2.8 m (A), 6.4 m (B), 10.0 m (C), 13.6 m (D), and 17.2 m (E) from the tree line at the lowest elevation of the slope

Position	pH		Al^{+3}	$H^+ + Al^{+3}$	K+	P	C	V	Ca/Mg
	$CaCl_2$	SMP[1]		(cmol$_c$ dm^{-3})		(mg dm^{-3})	(g dm^{-3})	(%)	
A	5.7	6.6	ND[2]	3.2	0.12	14.9	10.5	61	1.67
B	5.8	6.8	ND	2.7	0.15	12.4	12.4	65	1.53
C	5.8	6.8	ND	2.7	0.14	09.6	12.4	68	1.67
D	5.7	6.9	ND	2.5	0.14	11.0	13.3	64	1.75
E	5.7	6.9	ND	2.5	0.11	10.8	14.3	64	1.69
F	5.6	6.7	ND	3.0	0.14	08.8	10.5	62	1.67

[1] pH SMP: SMP buffer solution (Shoemaker et al., 1961). [2] ND: non-detected.

Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line). No tillage agriculture without trees was characterized in Position F.

The agroforestry tree was *Eucalyptus benthamii*, which was planted in December 2008 in single line tracks. No-tillage agriculture without trees was used as a control and this system was located ~200 m from the agroforestry system. Tree lines were planted on the contour with guideline level. The tree line located in the middle of the hillslope was leveled and adjacent lines were placed in parallel up and down the slope. This is a practice currently used in hilly sites in Brazil to reduce runoff and promote soil and water conservation compared to strict east-west orientation of trees (Porfirio-da-Silva et al., 2009). Spacing between two adjacent tree lines was 20 m and spacing between trees in a line was 2 m.

In January 2012, average tree height and distance from ground of lowest limbs was 12.9 ± 0.007 m (mean ± standard error) and 9.33 ± 0.006 m, respectively, as measured with a clinometer (Haglöf EC II Electronic Clinometers) (n = 327). On the same date, average stem diameter at 1.3 m height was 49.6 ± 0.04 cm. Rate of tree mortality and trees with ≤2 m height was 16.4% (from an original total of 391 trees). Annual crops were planted 1 m from the tree stems due to physical limitation of agricultural implements, making cropped alleys 18 m wide.

Both areas (i.e. with and without trees) were previously covered with native grassland and had the same crop sequence since the beginning of the experiment in 2008. The previous summer crop was corn.

In the winter before soybean was seeded, the area was hit by a fire, which started at *Vila Velha* State Park (located a few km from the experiment). This fire burned almost all of the previous corn straw, and damaged oat cover crop seedlings. The area was affected homogeneously. After the fire, oat was re-seeded as a cover crop prior to soybean. In the agroforestry system, trees did not incur significant damage, since the fire was quick and shallow and because trees had been recently pruned.

Two weeks prior to sowing soybean (*Glycine max* cv. 'BRS 284'), glyphosate (0.9 kg a.e. ha^{-1}) was applied to eliminate weeds and desiccate oat. Soybean was sown with a no-tillage system and fertilized with 400 kg ha^{-1} of 0-20-20 (N-P$_2$O$_5$-K$_2$O).

The experiment was carried out as a split-plot within six main treatment combinations. Main treatments were replicated four times. Main plots were six positions (five positions between two eucalyptus tree lines and one position in the sole-cropping system without influence of trees). Weed management [with weed control (- weeds) and without weed control (+ weeds)] was

the split-plot in each main plot. For growth analysis, samples were collected in four blocks, except at the last date when only three blocks were harvested.

The five positions between the eucalyptus tree lines were denoted as A, B, C, D, and E and the one position outside the agroforestry system was denoted as F. Position A represented the lowest elevation of the slope and Position E was the highest elevation of the slope between two tree lines. This denotation was possible because trees were planted on the contour with guideline level. Positions A, B, C, D, and E were 2.8, 6.4, 10.0, 13.6, and 17.2 m from the tree line at the lowest elevation, respectively.

Each experimental unit had seven crop rows that were 4 m long with 0.4 m between rows (11.2 m^2). The central three rows and 1 m long were the primary sampling areas (1.2 m^2) for crop yield measurements. Weeds were carefully removed manually by hand and hoe within the entire experimental unit area with care to minimally disturb soil.

Soybean plant samples were collected from weed-free and unweeded plots by harvesting 1 m row lengths at 10, 25, 40, 55, 70 and 130 days after emergence (DAE) of the soybean growing season. Two samples per experimental unit (two 0.5 m row length) were always collected from the second outside rows (Rows 2 and 6) for growth analysis. Plants were dried at 65 ^{o}C and weighed after reaching a constant weight.

Weeds were sampled in a 0.5 x 0.4 m frame at two points of each experimental unit at the same place that soybean was collected for growth analysis at 70 DAE. Aboveground parts of weeds were collected and separated into species in the laboratory. After that, plants were dried and weighed as for soybean plants.

At soybean maturity, population of soybean plants was counted in 5 rows of 1 m each. In each experimental unit, 20 plants were harvested to count number of pods and determine weight of 400 grains. Components were dried at 65 ^{o}C and weighed after reaching a constant weight. Pod number per plant, grain number per pod, 400 grain weight, grain yield, and harvest index were calculated.

Statistical analyses were performed using contrasts with SAS software, testing (i) systems (agroforestry versus sole-cropping), (ii) weeds (- and + weeds), and (iii) system x weed interaction. Additionally in the agroforestry system we tested the position effect (both linear and quadratic responses) and position x weed interaction.

Soybean plant growth curves were analyzed only at three positions between eucalyptus tree lines and at one position of the sole-cropping system. Positions closest to tree lines (A and E) were averaged, positions intermediate from tree lines and the center of the alley (B and D) were averaged, while positions C and F were unique.

Plant growth (biomass accumulation in kg ha^{-1}) was fit to a sigmoidal logistic function (Seber and Wild, 1989), described as:
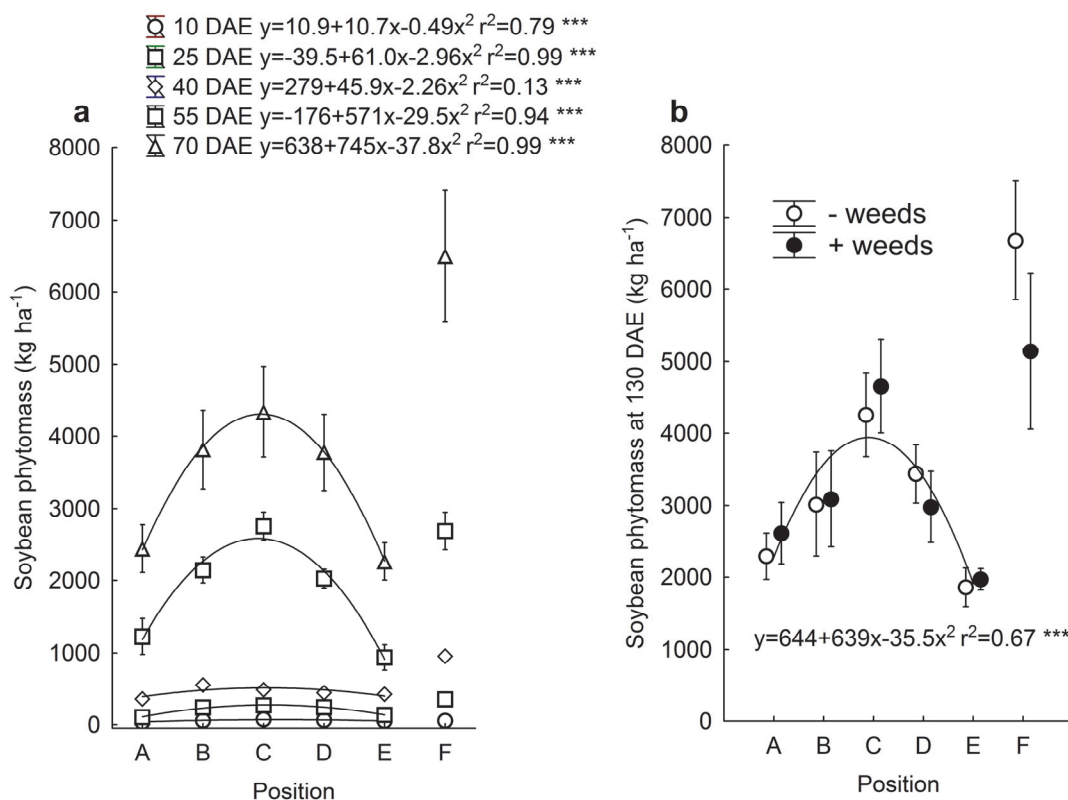
$$y = \frac{a}{1 + e^{-k(x-x_c)}} \tag{eq. 1}$$

where y = dry matter (kg ha^{-1}), a is the amplitude, x_c is the point of inflection (DAE), and k is a constant.

The sigmoidal logistic equations were fitted using the OriginPro 8 SRO software (Origin ®, Northampton, MA, USA).

RESULTS AND DISCUSSION

Soybean biomass accumulation was not different between the agroforestry system and sole-cropping up until 10 DAE (p>0.05). At all later measurement times (25 to 130 DAE), soybean accumulated greater biomass in sole-cropping than in the agroforestry system (p≤0.001). Interaction between weed management and agricultural system was detected at 130 DAE (p≤0.01) (Figure 1). The presence of weeds (+ weeds) reduced soybean biomass accumulation, but only in sole-cropping. There was no difference in soybean biomass accumulation due to presence of

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$\bar{Q}$ 10 DAE y=10.9+10.7x-0.49x^2 r^2=0.79 ***
$\boxdot$ 25 DAE y=-39.5+61.0x-2.96x^2 r^2=0.99 ***
$\bar{\boxtimes}$ 40 DAE y=279+45.9x-2.26x^2 r^2=0.13 ***
$\boxdot$ 55 DAE y=-176+571x-29.5x^2 r^2=0.94 ***
$\bar{\triangle}$ 70 DAE y=638+745x-37.8x^2 r^2=0.99 ***

y=644+639x-35.5x^2 r^2=0.67 ***

- No-tillage agriculture without trees was characterized in Position F. Vertical bars denote standard error. *** indicates significance at P≤0.001.

- Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line).

Figure 1 - Soybean growth in a no-tillage agroforestry system in subtropical Brazil at distances of 2.8 m (A), 6.4 m (B), 10.0 m (C), 13.6 m (D), and 17. 2 m (E) from the tree line at the lowest elevation of the slope. Panel (a) is growth from 10 to 70 days after emergence (DAE) and panel (b) is at 130 DAE, with weed control (- weeds) and without weed control (+ weeds).

weeds in any of the positions between trees (p>0.05). Soybean biomass was greatest at the mid-point between trees when compared to the other positions within the agroforestry system (i.e. quadratic response to alley position) at all times during development.

Soybean biomass accumulation during the growing season fit very well to the logistic model (r^2 ≥ 0.93 and p ≤ 0.001) (Table 2). In sole-cropping, weeds had a greater negative impact on soybean growth (Figure 2). This can be visualized by comparing Position F with and without weeds. The amplitude coefficient (*a*) of Position F without weeds was 33% greater than with weeds (Table 2). At positions within the agroforestry system, differences between weeded and unweeded plots regarding the amplitude coefficients were lower and reached a maximum difference of 11% at Position B-D. Among positions in the agroforestry system and in sole-cropping, the inflection point (x_c) varied from 50.5 ± 1.3 to 56.4 ± 1.7 DAE (mean ± standard deviation) and the growth rate constant (*k*) varied from 0.12 ± 0.02 to 0.22 ± 0.18 (Table 2).

The amplitude coefficient (*a*) also illustrated effects of proximity to trees in affecting soybean biomass accumulation (Table 2). In sole-cropping (Position F), soybean biomass accumulation was greater than in all positions in the agroforestry system. In the agroforestry system, biomass accumulation at Position C (mid-way point between tree lines) was greater than at Positions B-D and A-E (closest to tree lines) (Table 2). Therefore, strong negative effects on soybean growth, including all positions between tree lines, was observed due to the presence of 4-year-old eucalyptus. Since trees are still in an earlier growing phase, the same or stronger effects can be expected for the following years of this agroforestry system.

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Table 2 - Logistic curve coefficients of soybean growth analysis (complement to Figure 2) with weed control (- weeds) and without weed control (+ weeds) in a no-tillage agroforestry system in subtropical Brazil at distances of 2.8 m (Positions A and E), 6.4 m (Positions B and D), and 10.0 m (Position C) from the tree line at the lowest elevation of the slope

Position	a		x_c		k		Adjusted r^2
	Value	± se [1]	Value	± se	Value	± se	
A-E - weeds	2282.5	234.5	56.2	2.6	0.22	0.18	0.93
A-E + weeds	2290.8	40.5	55.1	0.6	0.12	0.01	0.99
B-D - weeds	3534.3	262.8	53.7	2.2	0.17	0.07	0.96
B-D + weeds	3181.8	124.2	50.5	1.3	0.18	0.03	0.99
C - weeds	4273.2	87.6	51.3	0.7	0.16	0.01	0.99
C + weeds	4514.3	136.6	52.0	0.9	0.19	0.03	0.99
F - weeds	6964.0	413.2	56.4	1.7	0.17	0.05	0.98
F + weeds	5307.2	222.5	53.8	1.5	0.12	0.02	0.99

[1] se represents standard error of the mean. Sigmoidal logistic function (Seber and Wild, 1989): $y = \frac{a}{1+e^{-k(x-x_c)}}$, where y = dry matter (kg ha^{-1}), a is the amplitude, x_c is the point of inflection (days after emergence), and k is a constant.
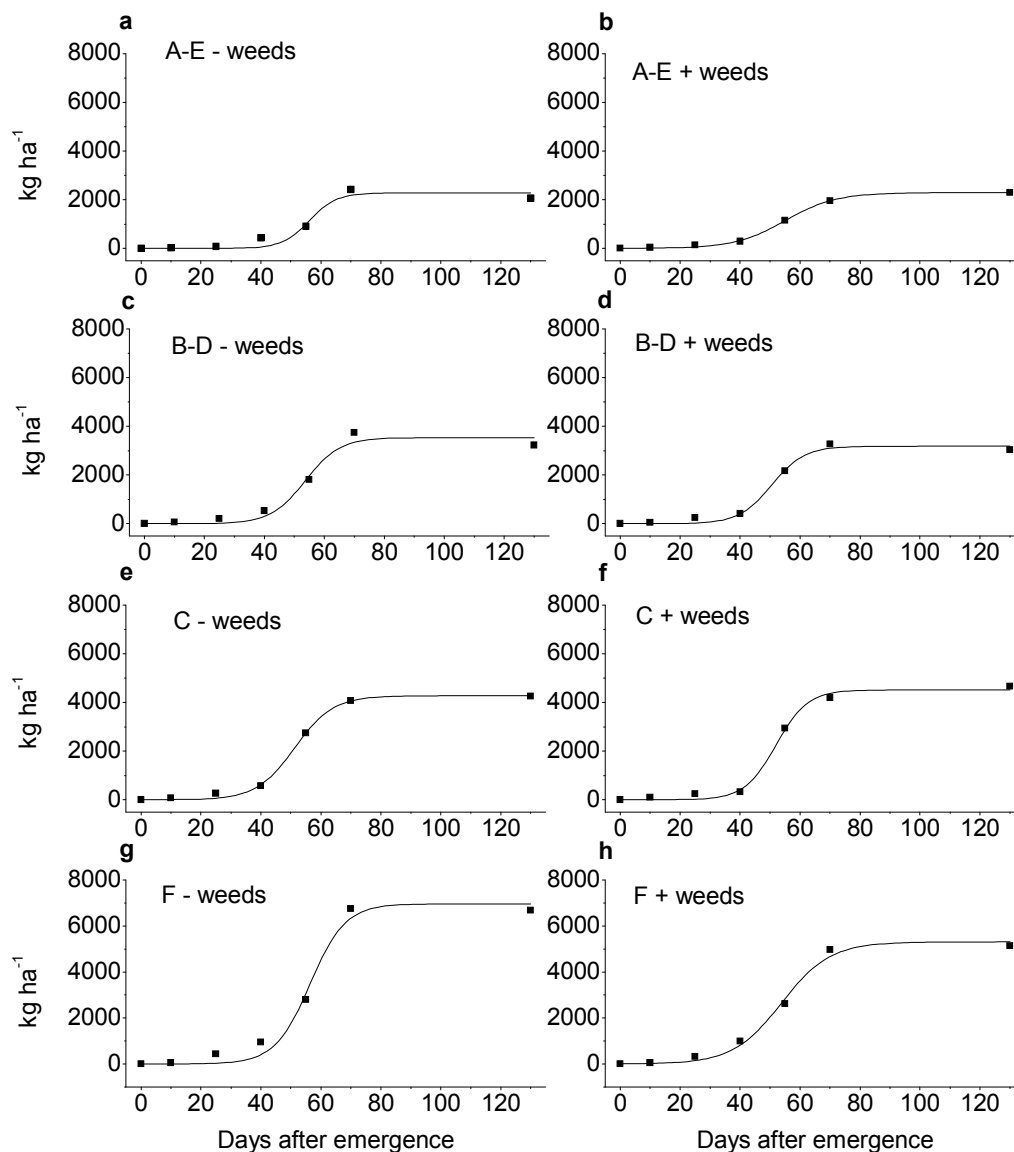
Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line). No tillage agriculture without trees was characterized in Position F.

Weed biomass was evaluated at 70 DAE when it was expected that the botanical composition could be defined and canopy closure was occurring to hinder new weed emergence and growth. Biomass of all weeds and of *Bidens pilosa* was greater in sole-cropping than in the agroforestry system (Figure 3). Total weed biomass and individual main weed species biomass, *Bidens pilosa* and *Sida rhombifolia*, had a quadratic response to distance from trees within the agroforestry system. Eucalyptus also promoted a negative interference in *Solanum sisymbriifolium* Lam. infestation and dispersion, to a greater extent closer to the tree component (Deiss et al., 2017a). *Bidens pilosa* abundance was also lower at both positions next to eucalyptus, as demonstrated by the poorly significant quadratic response (BIPIL=0.67+0.07*POSITION^2-0.005, r^2=0.07, p>0.05). *Bidens pilosa* abundance was dominant in the sole-cropping system (>99%).

Soybean yield components differed in how they responded to tree presence, distance from trees, and weed management. Interaction between agricultural system and weed management occurred for number of grains per pod (p≤0.05), in which presence of weeds reduced the number of grains per pod, but only in sole-cropping (3. grains per pod without weeds and 2.1 grains per pod with weeds). Number of pods per plant (p≤0.001) was lower in the agroforestry system than in the sole-cropping system (Figure 4). Within the agroforestry system, number of grains per pod was the same (2.4 grains per pod), irrespective of weed management and position between tree lines (p>0.05). Position within the agroforestry system affected number of pods per plant and 1,000 grain weight, both of which had lower values near trees than farther away (Figure 4).

Soybean grain yield response behaved similarly to agricultural system, position within the agroforestry system, and weed management as that described for soybean biomass. Soybean grain yield was greater in the sole-cropping system than in the agroforestry system (p≤0.01), and weeds reduced soybean grain yield only in sole-cropping (p≤0.001). Within the agroforestry system, soybean grain yield was lower near trees than farther away (Figure 4). Harvest index was affected by position between tree lines (p>0.05), being greater nearer trees than farther away within the agroforestry system.

Although our results are only one year of response, the high soybean yield with weed control outside the agroforestry system (4,766 ± 676 kg ha^{-1}, mean ± standard error) enabled us to explore a year with few climate restrictions on yield, and therefore, to fully explore ecological changes associated with presence of trees and lack of weed control. It is recognized that soybean growth and yield response in an agroforestry system may be year dependent due to the age and size of trees, as well in this case of the fire that hit the area to create a unique condition. We also need to be cautious in interpreting the results, since the soybean cultivar (BRS 284) has not gone through a breeding program to determine suitability in an agroforestry system. However, we do

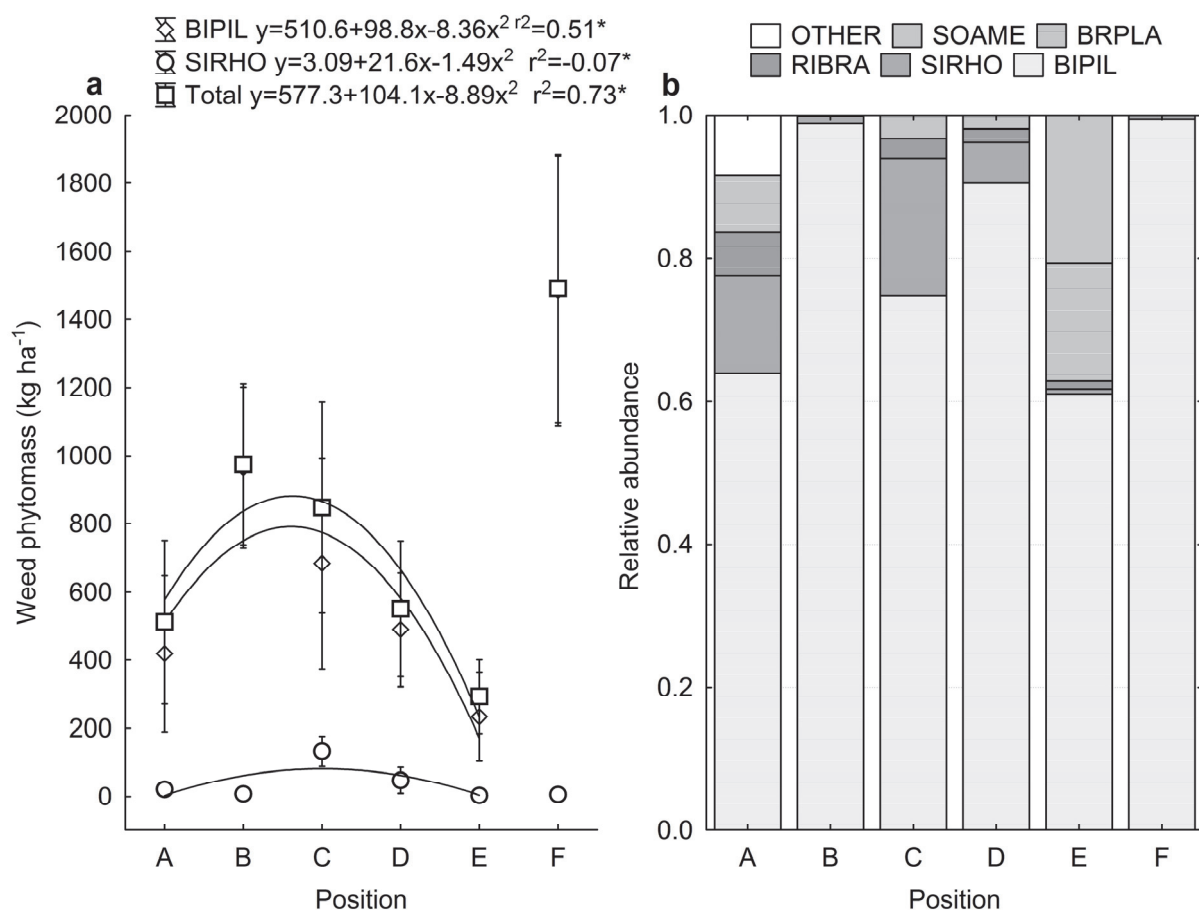- No-tillage agriculture without trees was characterized in Position F (panels g and h).

- Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line).

Figure 2 - Soybean growth (kg biomass ha^{-1}) with weed control (- weeds) and without weed control (+ weeds) in a no-tillage agroforestry system in subtropical Brazil at distances of 2.8 m (Positions A and E, panels a and b), 6.4 m (Positions B and D, panels c and d), and 10.0 m (Position C, panels e and f) from the tree line at the lowest elevation of the slope.

not know of any soybean cultivar available in the Brazilian market that has undergone genetic breeding focusing on suitability for crop-tree interaction.

Soybean growth and yield did not differ due to weed pressure in the agroforestry system. However, strong negative effects on soybean growth and yield were observed due to the presence of trees. This result appears to be a consequence of the strongly reduced capacity of this soybean genotype, as well as the weeds, to develop under eucalyptus competition. The diversified weed community with differing degrees of adaptation to different environments was not enough to counteract the strong influence of trees in the agroforestry system.

The weed community could have been progressively modified in this agroforestry system since establishment of trees. We found that in both the agroforestry and sole-cropping systems the dominant weed was *Bidens pilosa*. Biomass of all weeds, as well as specifically of *Bidens pilosa*
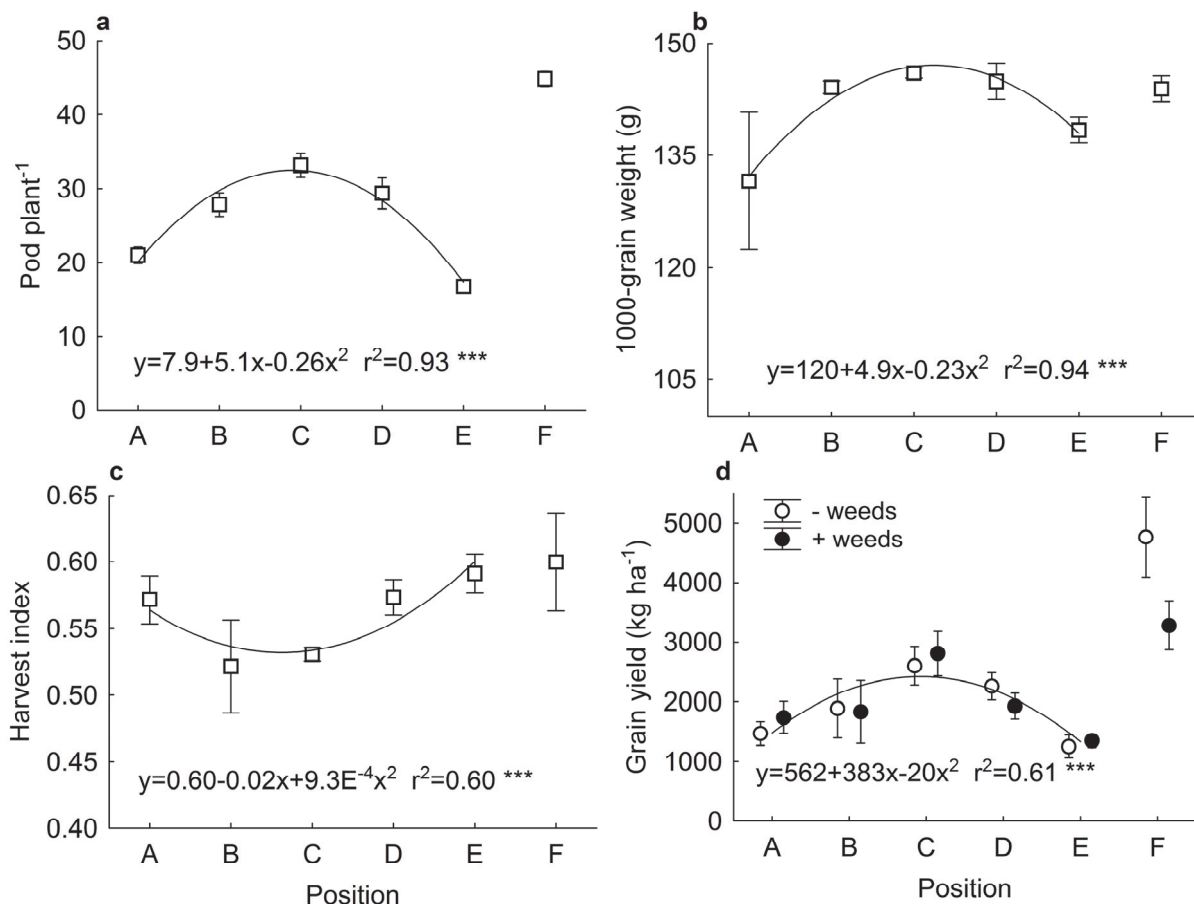
BIPIL $y=510.6+98.8x-8.36x^2$ $r^2=0.51*$
SIRHO $y=3.09+21.6x-1.49x^2$ $r^2=-0.07*$
Total $y=577.3+104.1x-8.89x^2$ $r^2=0.73*$

- No-tillage agriculture without trees was characterized in Position F. Vertical bars denote standard error. * indicates significance at p≤0.05
  BIPIL: *Bidens pilosa*, SIRHO: *Sida rhombifolia,* RIBRA: *Richardia brasiliensis,* BRPLA: *Brachiaria plantaginea,* SOAME: *Solanum americanum.*

- Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line).

Figure 3 - Weed biomass (panel a) and botanical composition (i.e. proportional abundance) (panel b) 70 days after soybean emergence in a no-tillage agroforestry system at distances of 2.8 m (A), 6.4 m (B), 10.0 m (C), 13.6 m (D), and 17.2 m (E) from the tree line at the lowest elevation of the slope.

and *Sida rhombifolia,* decreased nearest the trees. López-Pintor et al. (2003) found that the weed seed bank composition was altered as a function of distance from the shrub legume, *Retamas phaerocarpa,* in a manner based on physiological and morphological functional traits. According to them, trees in an agroforestry system could increase weed species concentration in certain locations due to adaptation to biophysical variations within the system. Adding to that, eucalyptus grown as an intercrop changed the composition and size of the weed seed bank, in a manner that was different for functional traits, families and species (Deiss et al., 2017b). Moreover, trees can create different ecological niches in an agricultural landscape (Tsonkova et al., 2012). Greater weed diversity was found in our agroforestry system compared to sole-cropping. The domininat weed, *Bidens pilosa,* was in lower abundance nearest trees, and therefore, may become suppressed with time. Moreover, *Bidens pilosa* has light quality dependence for germination (Valio, 1972) and agroforestry could have promoted late emergence conditions, possibly after the critical period of interference, and, or, reduced density of emerged seedlings for this specie. Agroforestry has different spectral irradiance, red:far-red ratio, and photosynthetically active radiation when compared to sole-cropping system (Jose et al., 2004; Quinkenstein et al., 2009; Tsonkova et al., 2012). However, with our results, we could not confirm if these effects occurred, therefore we suggest future experiments to investigate plant density, emergence characteristics, and the critical period of interference on agroforestry systems.

Panel a: $y = 7.9 + 5.1x - 0.26x^2$ $r^2 = 0.93$ ***

Panel b: $y = 120 + 4.9x - 0.23x^2$ $r^2 = 0.94$ ***

Panel c: $y = 0.60 - 0.02x + 9.3E^{-4}x^2$ $r^2 = 0.60$ ***

Panel d: $y = 562 + 383x - 20x^2$ $r^2 = 0.61$ ***

- No-tillage agriculture without trees was characterized in Position F. Vertical bars denote standard error. *** indicates significance at p≤0.001.

- Eucalyptus (*Eucalyptus benthamii*) trees were arranged in single lines (20 m between lines and 2 m between trees within a line).

Figure 4 - Soybean yield components (panels a-c) and yield (panel d) in a no-tillage agroforestry system in subtropical Brazil at distances of 2.8 m (A), 6.4 m (B), 10.0 m (C), 13.6 m (D), and 17.2 m (E) from the tree line at the lowest elevation of the slope.

Trees negatively interfered with soybean growth and yield components more than weeds did. Yang et al. (2014) showed that quality and quantity of radiance (spectral irradiance, red:far-red ratio, and photosynthetically active radiation) in the soybean canopy decreased when intercropped with corn. This change in light characteristics altered morphological responses and consequently reduced soybean aboveground biomass. Green-Tracewicz et al. (2011) found that low red:far-red ratio on soybean seedlings reduced pod number per plant, seed number per plant, and yield per plant, but did not alter seed number per pod, 1000 seed weight, and harvest index. When competition occurs between species of similar size, the response is mainly from plasticity of shade avoidance (Gommers et al., 2013). Our results were that weeds within the agroforestry system did not reduce soybean yield components and grain yield. The larger effects were due to trees on pods per plant and 1,000 grain weight, and consequently on soybean grain yield. Further experiments should be conducted to evaluate if this non-weed effect occurs with other kinds of weed communities and with different soybean varieties under eucalyptus-based agroforestry systems.

The pod per plant reduction, mainly caused by tree competition in our experiment, could be intrinsically linked to a shade influence on soybean branching. Green-Tracewicz et al. (2011) attributed a reduction in branching on poor light quality. However, we believe that light was not the only factor that may have limited crop growth and weeds under this agroforestry system. According to Peng et al. (2009), 4-year-old walnut (*Juglans regia*) and plum (*Prunus salicina*)

reduced soil moisture, which was strongly correlated with soybean net assimilation, growth, and yield. Additionally, soybean intercropped with apple (*Malus pumila*) affected soil moisture, which was the primary factor affecting crop yield, followed by light (Gao et al., 2013).

A fire hit the area where the experiment was conducted and this could have changed weed dynamics and composition. Fire can lead to weed encroachment (Hatcher and Melander, 2003). In a review, D' Antonio (2000) verified that in the majority of cases (~80%) fire resulted in the increase of invasive species. In a no-tillage area, this effect can be even greater, because fire removes the straw, a protective layer of the soil that protects seed exposure to light and changes soil moisture and temperature, all important agents on controlling weed emergence. However, in contrast, fire could have acted as a weed-controlling factor. Bebawi and Campbell (2002) verified that fire reduced germination and viability of *Jatropha gossypiifolia* seeds, with a negative correlation between seed germination and fire peak temperature. Also they observed decreasing fire temperature as soil depth increased. Bebawi and Campbell (2000) verified similar fire effects on *Cryptostegia grandiflora* seeds. Therefore, fire could have reduced viability of *Bidens pilosa* and other fragile seeds deposited on the soil surface. "It is possible that seed characteristics such as hard-seededness and seed size may affect germination behaviour of seeds" to tolerate fires (Bebawi and Campbell, 2000). In accordance with Mbalo and Witkowski (1997), smaller seed size and softer seed coats can have lower tolerance to high temperatures of fire. However, even though fire could have impacted the surface weed seed bank, we observed that *Bidens pilosa* was the most abundant species at 70 DAE and the residual seed bank was enough to reduce soybean growth and yield in the sole-cropping system, something that did not occur in the agroforestry system. Therefore, we believe that seeds that were present in a deeper seed bank were responsible to the emerged plants, and, or the fire was not strong enough to destroy *Bidens pilosa* seeds in the surface soil.

We conclude that weed competition did not reduce soybean (cultivar BRS 284) growth and yield in a no-tillage agroforestry system with 4-year-old eucalyptus. A reduction in soybean yield was rather caused by competition with trees. In the no-tillage sole-cropping system, weed competition was mainly from *Bidens pilosa*, which reduced soybean growth and yield. These results suggest that the presence of trees may limit both weed and soybean growth potential.

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