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Article

High Sunflower Densities as a Weed Control Strategy in an Integrated Crop-Livestock System

Adensamento Populacional da Cultura do Girassol Como Estratégia de Manejo de Plantas Daninhas em Sistema Integrado de Produção Agropecuária

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ABSTRACT - Sunflower is an important crop for Integrated Crop-livestock Systems (ILCS), and one of the main management difficulties identified in this crop is weed control, especially under no-till conditions when chemical weed control is not allowed. Therefore, the aim of this research was to evaluate the effect of greater sunflower population density on weed control, and its impact on sunflower yield, in an ILCS with eucalyptus in an Environmental Protection Area. Two population densities were tested (45 and 90 thousand pl. ha^{-1}) in two crop systems (sunflower monoculture and sunflower-eucalyptus integration). An additional treatment was provided in the sunflower-eucalyptus integration, and 5 positions (2,4; 4,8; 7,2; 9,6; and 12 m) between the tree rows were evaluated. In a randomized block design, with eight repetitions, weed density and weed dry matter were determined at 40, 70 and 100 days after crop emergence. Also, phytosociological indices were calculated. The following yield components were evaluated: head diameter, number of achenes per head, and 1000-achene weight. There was lower weed infestation on the high density treatment in both systems. There was no difference of weed occurrence in the 5 positions between the tree rows. Sunflower yield was higher in the greatest population density in both systems. Increasing population density in sunflower crop is a practicable management to control weeds and to gain higher yield under free-herbicide conditions.

Keywords: cultural weed management, Environmental Protection Area, herbicide-free no-till system.

RESUMO - O girassol é uma cultura importante para os sistemas integrados de produção agropecuária (SIPA), e uma das principais dificuldades de manejo nessa cultura consiste no controle de plantas daninhas, especialmente em condições em que o controle químico não é permitido. Portanto, o objetivo desta pesquisa foi verificar o efeito do adensamento populacional do girassol no controle de plantas daninhas e seu impacto na produtividade da cultura, em SIPA integrado com eucalipto de um ano, em uma Área de Proteção Ambiental. Foram testadas duas populações (45 e 90 mil pl. ha^{-1}) em dois sistemas de produção (monocultivo de girassol e integração girassol-eucalipto). Ainda, nas áreas de integração girassol-eucalipto, as avaliações ocorreram em cinco posições (2,4; 4,8; 7,2; 9,6; e 12 m) entre os renques de árvores. Em um delineamento em blocos ao acaso, com oito repetições, determinou-se a densidade e a matéria seca de plantas daninhas por espécie, aos 40, 70 e 100 dias após a emergência da cultura. Também foram calculados índices fitossociológicos. Os componentes de rendimento do girassol analisados foram: diâmetro do capítulo, número de aquênios por capítulo e peso de mil aquênios. Nas áreas com população adensada houve menor infestação de plantas daninhas, em ambos os sistemas. Não houve diferença na ocorrência de plantas daninhas nas posições entre os renques de árvores. A produtividade de

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girassol foi superior na população mais adensada em ambos os sistemas. O adensamento populacional na cultura do girassol mostrou-se uma prática de manejo viável, tanto do ponto de vista de controle de plantas daninhas como de produtividade de aquênios em condições de livre convivência com plantas daninhas.

Palavras-chave: manejo cultural de plantas daninhas, Área de Proteção Ambiental, plantio direto sem uso de herbicidas.

INTRODUCTION

Integrated Crop-Livestock Systems (ICLS) are considered as an alternative to sustainable intensification of crop production (Carvalho et al., 2014). As these systems are inherently diverse and complex (Anghinoni et al., 2013) from an agricultural point of view, one of their premises is crop rotation.

Sunflower is an important crop for rotations in ICLS (Brighenti and Castro, 2013) because it is highly adaptable and versatile (Amabile et al., 2003; Silva et al., 2012). In addition, sunflower plants have desirable features, e.g., increased drought tolerance and good capacity of using waste from previously fertilized crops, thereby increasing the ability to use the soil, machinery and factors of production (Brighenti and Castro, 2013).

The importance of ICLS and rustic crops (such as sunflower) is greater in areas where use of inputs, especially pesticides, is restricted. One example is crop farming in Environmental Protection Areas (APAs), which poses two major challenges: implementation of no-till farming and weed control.

Especially in sunflower crops, weed management is difficult to implement even under traditional farming conditions based on chemical control. The reason lies in the fact that only two herbicides are registered for sunflower crops in Brazil: alachlor and trifluralin (Brazil, 2016). As a consequence, weed management activities are considerably limited, because the action of such products is restricted to the main class of weeds that infest sunflower crops: dicotyledons (Castro et al., 1997; Brighenti et al., 2003, 2004; Adegas et al., 2010; Silva et al., 2012). In addition to this limitation on the use of herbicides on sunflower crops, these pesticides must be used very carefully in integrated crop-livestock-tree systems, especially in the early years, so as not to reach the leaves and branches of trees.

For the above-mentioned reasons, weed management strategies based on cultural weed control are highly desirable. According to Constantin (2011), the most important component of weed management programs is the crop itself. One way to use a crop for weed suppression purposes is to increase planting density. High density allows a crop population, through shading resulting from greater canopy closure, to suppress weeds, thus increasing the effect of their initial size advantage over the first weed emergence (Weiner et al., 2010; Marín and Weiner, 2014).

High density of sunflower crops is expected to be used as a weed management strategy in integrated crop-livestock-tree systems, when chemical control cannot be used. The use of this practice has been reported for other crops, e.g., corn (Marín and Weiner, 2014) and wheat (Olsen et al., 2012). However, validation of this strategy in sunflower crops requires an assessment of the impact of high crop density on yield of sunflower under coexistence with weeds.

Thus, the aim of this study was to evaluate the effect of seeding density on occurrence and composition of a weed community in two sunflower production systems: sunflower monoculture and sunflower integrated with one-year-old eucalyptus plants (ICLS), in an Environmental Protection Area (EPA). Another objective of this research was to evaluate the impact of plant population density on sunflower crop yield under non-limiting edaphoclimatic conditions and under coexistence with weeds, in the two systems mentioned above.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station of Canguiri, in the city of Pinhais - PR (25°23’30" S and 49°07’30"), with average altitude of 920 m. According to the Köppen classification, the climate is Cfb, i.e., humid temperate climate with mild summers, characterized by average annual rainfall of 1,400 mm, maximum average temperature of 22.5 °C and minimum average temperature of 12.5 °C. There is no definite dry season, and frosts may occur.

The experimental area contains the following classes of soils: Latosols, Cambisols and associations of both types. There are also small portions of Gleysols. Soil analysis showed that there were no restrictions on plant development. In the experimental area, there was no toxic aluminum (Al^{+3}), and the base saturation (V%) values ranged between 61 and 77, in July 2014.

The experiment used a randomized block design with eight repetitions. In the experiment, two sunflower populations were tested: 45 thousand and 90 thousand plants per hectare (pl. ha^{-1}) (P45 and P90, respectively), in two production systems, sunflower monoculture and sunflower-eucalyptus integration (ICLS). The ICLS arrangement consists of the integration between sunflower and *Eucalyptus benthamii* Maiden et Cambage. Moreover, within the sunflower-eucalyptus integration treatment, five positions were evaluated in terms of distance from tree rows (usable area of 12 m), namely, 2.4; 4.8; 7.2; 9.6; and 12 meters.

The experiment was set up in the agricultural year 2014/2015, which corresponded to the second summer season of ICLS, when the eucalyptus plants were one year old, with height and average diameter of 3.05 m and 3.03 cm, respectively. The eucalyptus seedlings were planted in October 2013, in a single row with inter-row spacing of 14 m and within-row spacing of 2 m, in a total area of 357 trees ha^{-1}, approximately. The planting hole was fertilized with 200 g NPK 8:20:20 per seedling. The eucalyptus rows were allocated at right angles to the direction of the predominant slope of the terrain, following a master line in a level curve.

Corn was the summer crop that preceded the sunflower crop, and the winter cover crop consisted mostly of oats. Sunflower (hybrid Aguará 6) was established in a no-tillage system. On September 22, 2014, sunflower seeds were sown over the winter cover crop, with 0.45 spacing between rows. At that point, the oats crop was at the beginning of maturation. Thus, the mechanical effect of the seed drill, per se, established the straw, which had a volume 9 t ha^{-1} on average. Germination was performed at 10 days after sowing (DAS) because of low temperatures, whose mean value was 14.3 °C for that period.

The crop was fertilized with 200 kg of P_2O_5 (natural phosphate) in order to prevent nutrient competition from limiting the development of sunflower populations, while 200 kg of N and 100 kg K_2O was used for topdressing fertilization at 20 DAS. Thinning was performed between stages V4 and V6 for establishment of populations. Because the experiment was established in an Environmental Protection Area (EPA) by the basis of the Iraí river, no pesticide was used.

The weeds were assessed at three times: at 40, 70 and 100 DAE. The samplings were carried out by randomly throwing an iron quadrat with internal area of 0.25 m^2. Three repetitions were used per experimental unit. After being cut close to the ground, the samples were taken to the laboratory for identification of weed species and counts of the number of individuals per species. In the case of species of the family Poaceae, the number of tillers was counted; in the species *Alternanthera philoxeroides* and *Rumex obtusifolius*, counts were made of the number of stalks in the sampled quadrat. Finally, dry matter (DM) was determined for each weed species. The samples were dried in a forced air oven at 65 °C to constant weight. Based on these evaluations, density and dry matter of weeds were estimated per square meter for each treatment.

In order to study the composition of the weed community in different treatments, the following phytosociological parameters (proposed by Mueller-Dombois & Ellenberg in 1974) were calculated: absolute frequency (Fr) = no. of quadrats where the species was found/total no. of quadrats; Relative Frequency (RFr) = frequency of species x 100/total frequency of species; absolute density (De) = total no. of individuals of the species/sampled area; relative density (RDe) = density of species x 100/total density of species; absolute abundance = total no. of individuals of the species/total no. of quadrats where the species was found; absolute dominance (Do) = weed dry matter of species/sampled area; relative dominance (RDo) = dominance of species x 100/total dominance of species; Relative Importance Index (RII) = RFr + RDe + RDo, of the same species. To compare the systems, the similarity coefficient was also calculated, according to the formula proposed by Sorensen (1972): 2 x no. of species commonly found in the two production systems/number of species in the monoculture + number of species in the sunflower-eucalyptus integration.

The harvest occurred in the last week of February. The heads were collected manually, with the aid of pruning shears. Two 5 m rows were sampled in each experimental unit.

In the laboratory, the heads were dried in a forced air oven at 40 °C to remove excess moisture. After that, flower remnants were removed, and the diameter of all sampled heads was determined with a tape measure by measuring two perpendicular positions among themselves in order to determine the mean value. Hand threshing was performed. After that, the achenes were removed from each head. First, they were passed through a 2 mm sieve to remove fine residues, then straw and empty seeds were cleaned off by a seed blower (General model). The samples were weighed on a precision balance with 0.01 g readability. The moisture content of the achenes was determined by the indirect method, with a G600 grain moisture meter, from a sample composed of 150 g of all heads from the same experimental unit. To estimate 1000 achene weight, 400 achenes were counted in each treatment. The estimate of number of achenes per head was extrapolated from the weight, since the achenes of each head were threshed, cleaned and weighed separately. The data on yield and 1000 achene weight were corrected to 11% moisture content.

The variables were analyzed within the sunflower-eucalyptus integration treatment, with the positions as subplots, to check the effect of distances from the tree rows. For comparison of the systems, the mean value of positions was taken into account in the sunflower-eucalyptus integration. Especially in the analysis of productivity, the yield of the sunflower-eucalyptus integration treatment was compared to that of the monoculture in two ways: a comparative analysis was performed while considering the area occupied by the tree rows (in the ICLS, 85.7% of the area was available for sunflower cultivation); and another analysis was made of the yield of the usable area between the tree rows, extrapolated to hectares. Pearson correlation analysis was performed between productivity and yield components.

The variables were analyzed in the software R, version 3.1.1. The assumptions of homogeneity of variance and normality of residuals were checked, and then followed by analysis of variance (ANOVA) and the test of means, when there was a significant difference ($p<0.05$). Polynomial regressions were analyzed in the software R, and graphs were designed in the software MS Excel® 2013.

RESULTS AND DISCUSSION

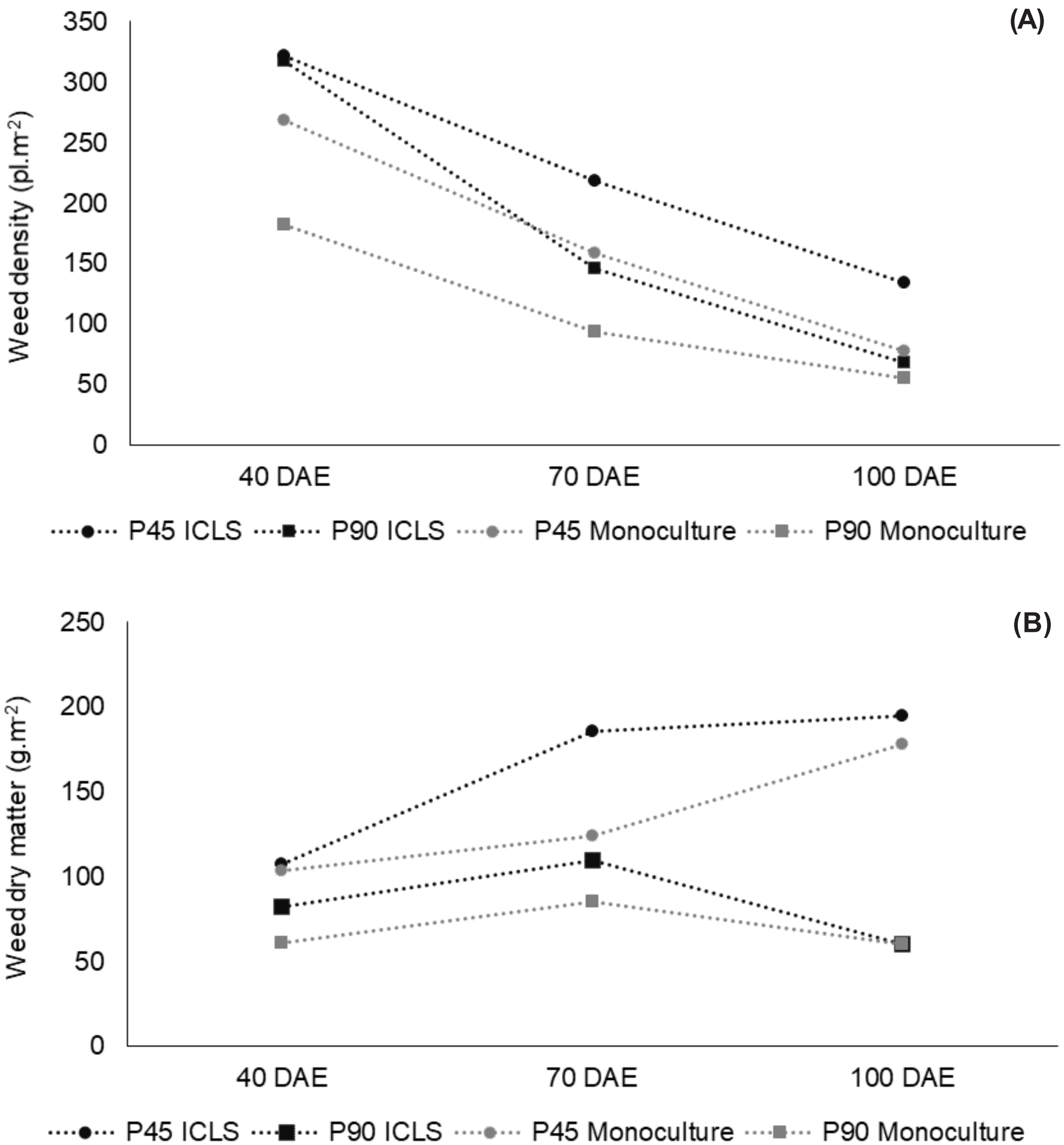
In sunflower-eucalyptus integration, there was no effect of distance from the tree rows on density and dry matter of weeds, at the times of assessment, in the two sunflower populations. Thus, the discussion of the present study was focused on the effect of the sunflower populations and the two systems on the incidence and dynamics of the weed community.

The denser population of sunflowers (90 thousand pl. ha^{-1}) showed lower means for both density ($p<0.01$) and dry matter ($p<0.01$) of weeds per m^2. Only at 40 DAE there was no difference in weed density among populations (P45 and P90) in the sunflower-eucalyptus integration (Population-System-Time interaction, $p = 0.095$) (Figure 1A). However, density behavior at 40 DAE did not affect dry matter of weeds, which was 23% lower in P90 than in P45, in this period.

By contrast, at the last third of the growth cycle of sunflowers, mean weed density in the monoculture was 78.0 pl. m^{-2} in P45 and 55.3 pl. m^{-2} in P90, which represents a 29.06% reduction of weeds. In the sunflower-eucalyptus integration, the reduction in weed density was almost 50%, with means of 134.0 and 68.6 pl. m^{-2} for P45 and P90, respectively. The effect of density is evident in the data on weed dry matter (Figure 1B), because there was a 66.2% reduction in the monoculture and a 69.2% reduction in the sunflower-eucalyptus integration, at 100 DAE.

Generally, seeding density promotes weed suppression, as previously reported for winter cereals (Olsen et al., 2005; Weiner et al., 2010; Olsen et al., 2012) and in corn crops (Mohammadi et al., 2012; Marín and Weiner, 2014).

In terms of mean values of weed dry matter, both Brighenti et al. (2004) and Silva et al. (2012), in their studies on sunflower crops, also found means higher than 100 g m^{-2} in crops with populations of 42.8 thousand pl. ha^{-1}, under coexistence with weeds. This finding shows that the



P45 and P90 are abbreviations for the populations of 45 thousand pl. ha^{-1} and 90 thousand pl. ha^{-1}, respectively. ICLFS and monoculture refer to the sunflower-eucalyptus integration system and the sunflower monoculture, respectively.

Figure 1 - Density (A) and (B) dry matter of weeds, according to the production system, at different evaluation times.

study area falls into the weed infestation patterns reported in previous experiments with sunflower crops.

When the systems were compared, higher means were found for weed density (pl. m^{-2}) ($p<0.01$) in the sunflower-eucalyptus integration, in the two sunflower populations. As regards dry matter accumulated by weeds, in P45, the shaded system also showed higher means ($p<0.01$), with overall mean between assessment times of 162.55 g m^{-2} compared to 135.18 g m^{-2} in the monoculture. However, there was no difference between the systems in P90, i.e., at the last evaluation time, the same mean weed dry matter accumulation (60 g m^{-2}) was found in the two systems.

It is believed that the higher incidence of weeds in the sunflower-eucalyptus integration, especially in P45, may be due to the area occupied by the tree rows. In that particular strip, which accounts for 14.3% of the area of the field, there is no weed control. Thus, the vegetation found in the area occupied by the tree rows could be a source of spread of potential weeds for the crops of the interrow (Mézière et al., 2016). However, high crop density could avoid this problem in the area with the tree rows, because weed dry matter (g m^{-2}) did not differ between the systems, at the three evaluation times, in this treatment (P90).

As far as assessment times are concerned, weed density decreased over time, not only in the two populations but also in the two systems (Figure 1A). It is noteworthy that in the sunflower-eucalyptus integration, in the population of 90 thousand pl. ha^{-1}, there was greater reduction in density between 40 and 70 DAE (Population-System-Time interaction, $p = 0.095$). This behavior of weed density reduction over time was also reported by Brighenti et al. (2004) and Silva et al. (2012) in sunflower crops, because the first germination is always greater, providing higher densities in the initial development of the crop.

With respect to dry matter accumulation by weeds, there was a significant interaction between weed population and time of assessment ($p<0.01$). At P45, weed dry matter accumulation increased over time. This is expected, since there is usually maximum weed infestation at the end of the crop cycle (Adegas et al., 2010). This is the reason why some researchers, such as Brighenti et al. (2003), chose the end of the cycle of sunflower to make their phytosociological analyses.

For P90, despite the tendency of greater accumulation at 70 DAE (Figure 1B), there was no difference between assessment times. A similar behavior was found by Spadotto et al. (1994) in weeds infesting soybean crops and by Brighenti et al. (2004) in sunflower, and it was attributed to the death of plants and, especially, the higher rate of senescence of leaves and branches.

In all evaluations made in the experiment, 27 species were identified and grouped into 16 families (Table 1). The main families were Asteraceae and Poaceae, with seven and six species, respectively. The other families were represented by one species only. Asteraceae and Poaceae are two of the main families of weeds that exist in Brazil. They are commonly found in traditional agricultural production areas, such as those with sunflower crops (Brighenti et al., 2003; Adegas et al., 2010).

Most of the species were identified at all sampling times (Table 1). Twenty-five species were identified in the sunflower-eucalyptus integration while 20 were identified in the monoculture. Between systems, similarity index was 0.8. It was considered to be high, as the two systems had 18 species in common.

Considering the entire experiment, the main species identified was *Bidens pilosa* (hairy beggarticks). This species was well distributed in all treatments over time, with frequencies ranging from 0.83 to 0.98. Only in the evaluation at 40 DAE, hairy beggarticks (*B. pilosa*) was the second most important species in the weed community (Figure 2A, B), in which *Lolium multiflorum* was the main species.

In the study conducted by Brighenti et al. (2004), in Londrina, hairy beggarticks was also the main weed species affecting the sunflower crop. Other studies on weeds in sunflower crops (Brighenti et al., 2003; Adegas et al., 2010; Silva et al., 2012) identified other species with higher RII, as they were developed in the Cerrado region.

At 40 DAE, in addition to *B. pilosa*, the main species that composed the weed community were *L. multiflorum* (Italian ryegrass), *Avena strigosa* (black oats), *Raphanus raphanistrum* (wild radish) and *Panicum maximum* (buffalo grass), in both systems (Figure 2A, B). These species, identified as the major species in this experiment at 40 DAE, were the same found by Adegas et al. (2010) in a phytosociological study at the initial stages of growth of a sunflower crop, in Rio Grande do Sul. Oats, Italian ryegrass and wild radish are species typically found in the autumn/winter in the South Region of Brazil (Lorenzi, 2000). Therefore, their importance decreased in a subsequent evaluation, and they were no longer found at 100 DAE.

Conversely, buffalo grass was well distributed in both systems at 40 DAE (RFr between 0.75 and 0.50). However, the absolute dominance values of buffalo grass were not higher than 6 g m^{-2}, because there were new tillers at that time of sampling. The importance of the species increased over time in both systems, as a result of an increase in frequency and relative dominance (Figure 2A, B). Buffalo grass was the second most important species according to the phytosociological analysis made at 70 and 100 DAE. Another important species in both systems at 70 and 100 DAE was *Urochloa plantaginea* (Alexander grass). It was found to be very frequent,

Table 1 - List of weeds identified throughout the experiment, distributed by family and species, with time of identification

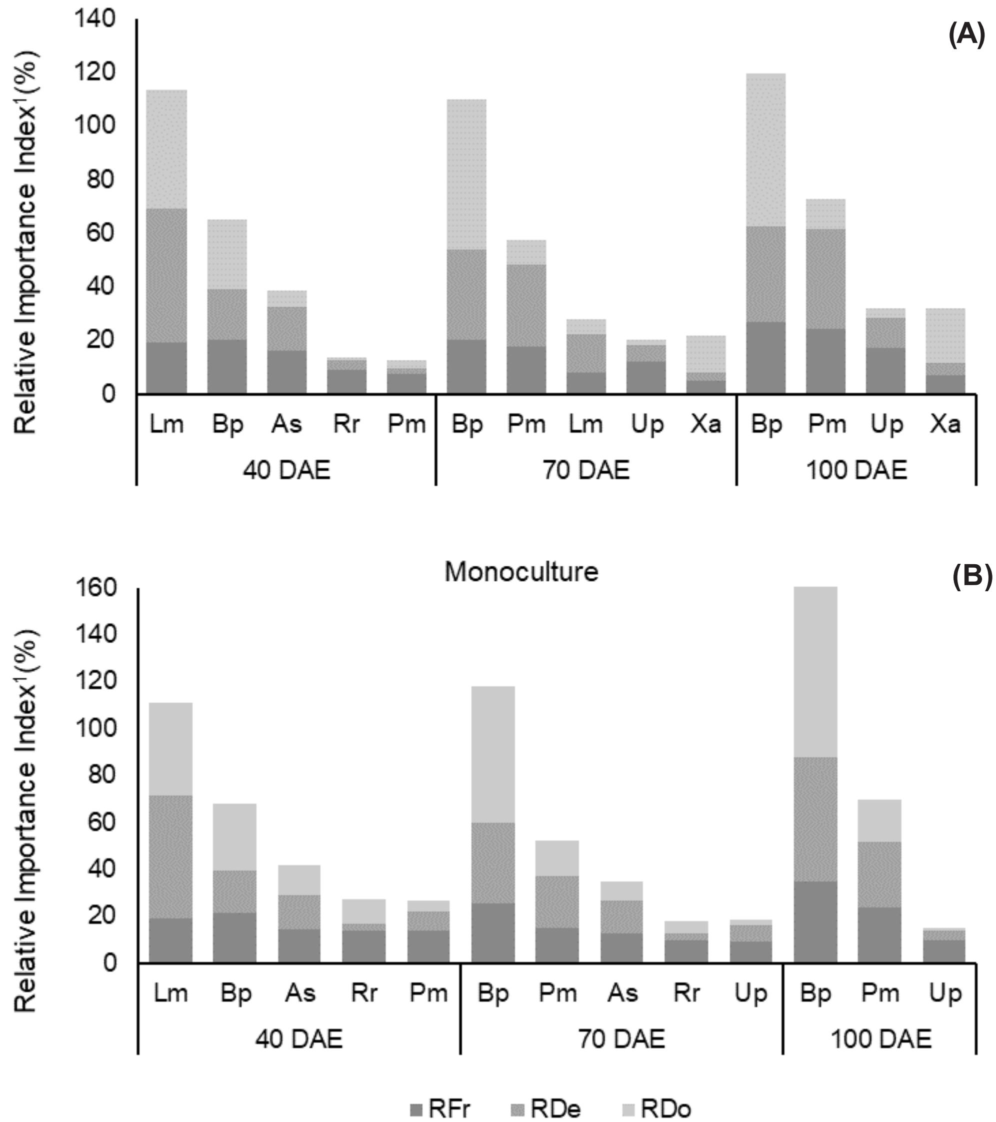
Family	Species	Time of identification (DAE)		
		40	70	100
Alliaceae	*Nothoscordum gracile* (Aiton) Stearn		x	x
Apiaceae	*Daucus pusillus* Michx.		x	
Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.	x	x	x
Asteraceae	*Ageratum conysoides* L.		x	
Asteraceae	*Artemisia verlotorum* Lamotte	x	x	x
Asteraceae	*Bidens pilosa* L.	x	x	x
Asteraceae	*Coniza bonariensis* (L.) Cronquist	x	x	x
Asteraceae	*Galinsoga parviflora* Cav.	x	x	x
Asteraceae	*Sonchus oleraceus* L.		x	
Asteraceae	*Xanthium strumarium* L.	x	x	x
Convolvulaceae	*Ipomea purpurea* (L.) Roth	x	x	x
Brassicaceae	*Raphanus raphanistrum* L.	x	x	x
Cyperaceae	*Cyperus esculentus* L.	x	x	x
Euphorbiaceae	*Euphorbia heterophylla* L.	x	x	x
Fabaceae	*Vicia sativa* L.	x		
Poaceae	*Avena strigosa* Schreb.	x	x	
Poaceae	*Cynodon* sp.	x	x	x
Poaceae	*Lolium multiflorum* Lam.	x	x	
Poaceae	*Panicum maximum* Jacq.	x	x	x
Poaceae	*Pennisetum clandestinum* Hochst. ex Chiov.	x	x	x
Poaceae	*Urochloa plantaginea* (Link) R. D. Webster	x	x	x
Labiatae	*Stachys arvensis* L.	x	x	x
Malvaceae	*Sida rhombifolia* L.	x	x	x
Oxalidaceae	*Oxalis corniculata* L.	x	x	x
Polygonaceae	*Rumex obtusifolius* L.	x	x	x
Rubiaceae	*Richardia brasiliensis* Gomes		x	
Solanaceae	*Solanum americanum* Mill.		x	

but it presented low absolute dominance rates, which resulted in low relative dominance rates (between 1.2% and 3.5%, when the two systems were analyzed at 70 and 100 DAE).

The populations had an effect on density and absolute dominance of the main species found in the two systems. However, there was no difference in density and relative dominance (%) of the main species found in the two populations. In other words, in terms of importance, the community of weeds had the same main species in both populations, as well as in the two systems (Figure 2A, B).

High crop density resulted in higher achene yield ($p<0.01$) in both systems. There was an interaction between system and population ($p<0.01$) because of the difference in the magnitude of response. The reason is that, in the monoculture, the mean increase of productivity as a function of density was 22.8%, while in sunflower-eucalyptus integration, it was 39.3% (productivity of the shaded system considering the yield of usable area between the tree rows, extrapolated to hectares) (Table 2).

The yield of the sunflower-eucalyptus integration was higher ($p<0.01$) in the two populations, in a comparison in which the yield of the usable area between the tree rows was extrapolated to hectares (Table 2). In the estimate of productivity of the same treatment, which considers the area occupied by the tree rows, productivity in P45 did not differ from that of the monoculture: 769 and 792 kg ha^{-1}, respectively (System-Population interaction, $p<0.01$). For P90, the yield of the sunflower-eucalyptus integration was higher (1,267 kg ha^{-1} as compared to 1,026 kg ha^{-1} of the monoculture), even when a 14.3% loss of the area was taken into account.



These species represent 80% of total RII (300%); Species: *Lolium multiflorum* (Lm); *Bidens Pilosa* (Bp); *Avena strigosa* (As); *Raphanus raphanistrum* (Rr); *Panicum maximum* (Pm); *Urochloa plantaginea* (Up); *Xanthium strumarium* (Xa). (1) Relative Importance index (RII) = Relative frequency (RFr) + Relative density (RDe) + Relative dominance (RDo).

Figure 2 **-** Relative importance index of the main species found in sunflower plants in the sunflower-eucalyptus integration system (ICLS) (A) and in the sunflower monoculture (B), at the three evaluation times.

Table 2 **-** Yield and yield components of sunflower, head diameter (cm), number of achenes per head and 1000-achene weight (g), in populations and production systems

System	Yield (kg ha^{-1})		Head diameter (cm)		No. of achenes per head		1000-achene weight (g)	
	P45(1)	P90	P45	P90	P45	P90	P45	P90
Monoculture	792.2 bB(2)	1026.4 aB	13.23 aA	11.09 bA	598.58 aA	485.49 bB	32.83 aA	28.33 bB
ICLS	897.6 bA	1478.2 aA	12.52 aA	11.75 aA	584.50 aA	508.16 bA	34.14 aA	32.28 bA

(1) P45 and P90 are abbreviations for the populations of 45 thousand pl. ha^{-1} and 90 thousand pl. ha^{-1}, respectively. (2) Values in the same row followed by identical lowercase letters did not differ at 5% by Tukey's test, while values in the same column followed by identical uppercase letters do not differ at the level of 5 % by Tukey's test. (3) Comparison which considers the yield of the usable area with tree rows in sunflower-eucalyptus integration (ICLS), extrapolated to hectares.

The data on yield components of sunflower offer further insights into these results (Table 2). One of the components that most affect yield is head diameter, as it influences both achene size and number of achenes per head (Rasool et al., 2015). This characteristic was crucial for the occurrence of higher yields in the denser population. It was strongly correlated with yield (r = 0.74) and affected the number of achenes per head, a characteristic directly related to the yields found in the two populations (r = 0.95).

In the monoculture, head diameter in P45 was higher than in P90 ($p<0.01$): means of 13.23 and 11.09 cm, respectively. This difference in size was small, whereas in other studies involving populations of sunflowers, there were reductions between 4 and 14 cm in head diameter when the population was as twice as dense (Sedghi et al., 2008; Rasool et al., 2015).

The small difference in head size in the monoculture and the lack of such difference in the sunflower-eucalyptus integration (System-Population interaction, $p<0.01$) are due to higher incidence of weeds in the population of 45 thousand pl. ha^{-1}. Weed competition negatively influences head size (Silva et al., 2012). Thus, as a result of interspecific competition, head size in P45 was similar to that of P90, in which there is also intraspecific competition. Therefore, in the monoculture, there was a smaller difference in yield between the populations, because the heads were a little bigger in P45. In the sunflower-eucalyptus integration, because there was no difference in head size, productivity was almost 40% higher where there were more plants per area.

Number of achenes per head and 1000 achene weight were higher in the population of P45 ($p<0.01$ for both characteristics). This inverse relationship between these characteristics and the increase in plant population are due to increased competition between plants (Castro et al., 2011; Rasool et al., 2015).

For the same characteristics, the systems differed only in P90 (significant interaction, $p<0.05$), in which the sunflower-eucalyptus integration showed higher means: 508.2 achenes per head and 32.3 g of 1000 achene weight, compared to 485.5 achenes per head and 28.3 g of 1000 achene weight in the monocrop.

As far as the systems are concerned, the lowest yield found in the monocrop, particularly in the population of 90 thousand pl. ha^{-1}, is believed to be due to the visual observation of greater severity of Alternaria leaf blight (*Alternaria helianthi*) in sunflower plants in the monoculture. For the same reason, weight and number of achenes per head were lower in the monoculture in P90. In general, Alternaria leaf blight is more severe in denser populations of sunflower crops (Bauer et al., 2013).

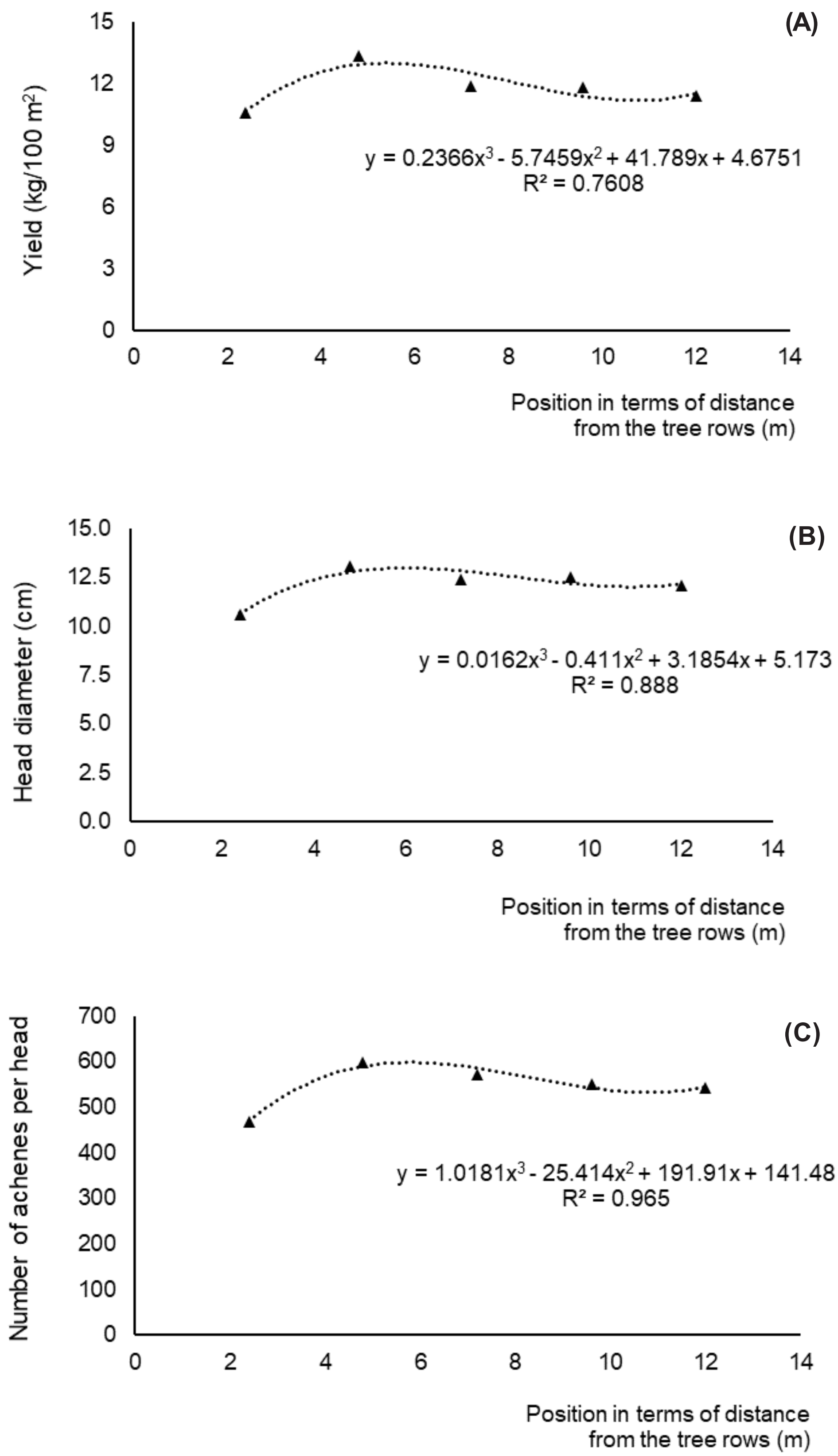
In the sunflower-eucalyptus integration, the presence of tree rows may have offered windbreak protection, thus negatively influencing the dispersion of the disease between the rows. This effect of windbreak shelter on incidence and severity of diseases in shaded areas was discussed by Sudmeyer and Speijers (2007), in tropical conditions.

Within a shaded system, assessments of the different positions in terms of distance from tree rows highlight the same behavior of the two populations of sunflowers in all the study parameters. Both populations had the same responses in different positions.

The plants evaluated in the 2.4 m position were less productive, with shorter head diameter and, consequently, a smaller number of achenes per head ($p<0.01$) (Figure 3A, B and C). The value for 1000 achene weight was greater at 2.4 m in comparison to 7.2 and 9.6 m, but it did not differ between 4.8 and 12 m.

The lower results achieved by the plants in the 2.4 m position for productivity and main yield components (head diameter and number of achenes per head) show that this position had a limiting effect. This limitation may have been due to longer shading of the area, because this position is further southwest of the tree rows.

The 4.8 m position was remarkably the most productive, with a tendency to greater head diameter and a higher number of achenes per head (Figure 3). It can be hypothesized that moderate shading can be beneficial to sunflower yield, since it is a C3 plant, which shows photorespiratory losses and considerable evapotranspiration (Taiz and Zeiger, 2013).



As there was no interaction between population and position, regressions were presented with the mean values of the two populations in five positions for each variable.

Figure 3 - Regressions of sunflower yield (A), head diameter (B) and number of achenes per head (c) in the sunflower-eucalyptus integration (SIPA).

However, sunflower yield in a shaded area (ICLS) was not limited by shading on the second crop, because productivity of the 2.4 m position was offset by that of the 4.8 m position and the yields from the sunflower-eucalyptus integration were higher than those of the monoculture.

The results confirm that weed control by means of higher sunflower crop density was technically feasible for reduction of weeds and increased sunflower crop yield.

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