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Effect of eucalyptus proximity and weed presence on soybean grown in a CFI system

Efeito da proximidade ao eucalipto e da presença de plantas daninhas sobre a soja cultivada em sistema ILF

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Abstract

The growing demand for food, bioenergy, and forest products requires solutions that encourage socioeconomic development without compromising the sustainability of natural resources. It is in this scenario that the integration strategy has been pointed as an alternative to reconcile conflicts of interest. This study evaluates possible changes in nodulation, photosynthetic efficiency, and yield of soybean grown in a Crop-Forest Integration system with eucalyptus as a tree component. The experiment was conducted in a randomized complete block design with four replications. Treatments were arranged in a 3x5 factorial scheme, corresponding to three sowing conditions (near eucalyptus stands; 3.0 meters away from the stands, in a clean seedbed; and 3.0 m away from the stands, among the vegetation) and five points of distance between soybean and the stands, represented by planting rows, namely: 1st, 2nd, 3rd, 11th, and 21st row. We evaluated morphophysiological and productive variables of soybean plants. Soybean cultivation near eucalyptus stands does not affect the number and dry matter of soybean nodules, but reduces yield in the first two rows. The presence of weeds in the range between eucalyptus stands and soybean plants impaired the photochemical apparatus and the chlorophyll *α* fluorescence of soybean crop, decreasing the shoot dry matter accumulation, number and dry matter of nodules, and yield of plants present in the first planting rows.

Additional keywords: *Eucalyptus* sp; *Glycine max;* photosynthesis, *Rhizobium*.

Resumo

A demanda crescente por alimentos, bioenergia e produtos florestais requer soluções que permitam incentivar o desenvolvimento socioeconômico sem comprometer a sustentabilidade dos recursos naturais. É nesse cenário que a estratégia de integração tem sido apontada como alternativa para conciliar esses conflitos de interesse. O objetivo deste trabalho foi avaliar possíveis alterações na nodulação, eficiência fotossintética e produtividade de soja cultivada no sistema de integração Lavoura-Floresta tendo o eucalipto como componente arbóreo. O experimento foi conduzido em delineamento experimental de blocos ao acaso, com quatro repetições e os tratamentos dispostos em esquema fatorial 3x5, sendo três condições de semeadura (próximo ao renque, semeada a 3,0 metros de distância do renque no limpo e 3,0 metros de distância do renque no mato) e cinco pontos de distâncias das plantas de soja ao renque, representado por linhas de plantio, a saber: 1ª, 2ª, 3ª, 11ª e 21ª linha. Foram avaliadas as variáveis morfofisiológicas e produtivas das plantas de soja. Constatou-se que o cultivo de soja realizado próximo ao renque de eucalipto não interfere no número e matéria seca de nódulos, mas reduz a produtividade nas duas primeiras linhas de semeadura. A presença de plantas daninhas na faixa localizada entre o renque e a soja ocasionou danos ao aparato fotoquímico e nas características da fluorescência da clorofila *α* da cultura diminuindo o acúmulo de matéria seca da parte aérea, número e a matéria seca dos nódulos e a produtividade das plantas presentes nas primeiras linhas de semeadura.

Palavras-chave adicionais: *Eucalyptus* SP; fotossíntese; *Glycine max; Rhizobium*.

Introduction

Monoculture and inadequate agronomic cultural practices have caused yield losses, increased insect and disease occurrence, and degradation of soil and natural resources. Crop-Livestock-Forest Integration (CLFI) represents a new approach to these systems, aiming to combine sustainable production with preservation of agroecosystems (Macedo, 2009).

The growing demand for food, bioenergy, and forest products, as opposed to the need to reduce deforestation and mitigate greenhouse gas emissions, requires solutions that enable socioeconomic development without compromising the sustainability of natural resources. Intensified land use in agricultural areas and increased efficiency of production systems can help harmonize these interests. In this scenario, the CLFI strategy has been pointed as an alternative to reconcile conflicts of interest (Balbino et al., 2011).

Productive areas using this integrated production technology are currently expanding in the country, with a growth trend in the coming years (Wink et al., 2018). According to current estimates, the area under CLFI systems in Brazil exceeds 11.5 million hectares. Mato Grosso State accounts for 1.5 million hectares, or 13% of the national total. However, the forest component is estimated to be present in only 10% of this area (Tonini et al., 2016).

There are different production systems based on Crop-Livestock-Forest Integration, which are premised on the integrated presence of at least two of the three components, configuring as CLFI modalities the following arrangements: livestock-forest integration (LFI), crop-livestock integration (CLI), and crop-forest integration (CFI) (Soratto et al., 2011).

The genus *Eucalyptus* is one of the most widely used tree components in CLFI areas. Its adoption in this type of cropping system is due to the large number of genotypes/phenotypes available, adaptation to Brazilian climatic conditions, multiplicity of uses in timber and nontimber products, rapid growth, and high yield (Tonini et al., 2016).

The agricultural components generally used are already traditional crops such as corn, sorghum, coffee, millet, beans, soybeans, rice, and sunflower. However, soybean cultivation is still the most recommended in integration areas due to operational ease, low production cost, highly productive and adapted cultivars, and short life cycle (Franchini et al., 2014).

Notwithstanding, research results on the performance of crops under intercropping systems are incipient, especially between forest species and annual grain crops. There are still many doubts about possible depressive effects caused by tree species on crop performance (Almeida et al., 2014). Therefore, further research is needed to help better understand the relationship between trees and the different components of CLFI systems to define a minimum distance between tree rows and the agricultural component that can favor positive interactions (Diel et al., 2014).

Furthermore, there are no studies in the literature that indicate whether the presence of weeds between tree and agricultural components can influence the morphological and productive characteristics of plants. The presence of weeds in areas cultivated with soybeans is known to influence important agronomic characteristics resulting in reduced yield due to interference caused by competition when resources are scarce (Moraes et al., 2009).

Given the above, the present study analyzes how much the eucalyptus (tree component) and the presence of weeds influence photosynthesis, nodulation, and yield characteristics of soybean (crop component) grown in a Crop-Forest Integration (CFI) system.

Materials and methods

The experimental phase of this project was conducted in a CFI (Crop-Forest Integration) Technology Reference Unit (URT) in Barra do Garças city, Mato Grosso State, whose geographical coordinates are 15º00'58.1” S and 52º15'58.5” W. According to the Köppen classification, the climate of the region is Aw, with average temperatures over 27 °C from November to February, and over 18 °C from June to August. Annual rainfall averages are between 1000 mm and 1500 mm, distributed in two well-defined periods: heavy rain season from October to March, and clear dry season from April to September (Marchi et al., 2017).

The experiment was conducted in a randomized complete block design with four replications. Treatments were arranged in a 3x5 factorial scheme, with three sowing conditions as sources of variation (sown 0.45 m away from the row – “near”; sown 3.0 m away from the row with subsequent weed control - “clean”; and sown 3.0 m away from the row without later weed control - “vegetation”) and five points of distance between soybean plants and the stands, represented by planting rows of 10.0 m in length, namely: 1st (0.45 m), 2nd (0.90 m), 3rd (1.35 m), 11th (4.95 m), and 21st row (9.45 m) (Figure 1).

Soil composite samples were collected and sent for laboratory analysis. The chemical and physical characteristics of the soil were: pH ($CaCl_2$) of 4.8; 22.0 g dm^{-3} organic matter; 4.0 mg dm^{-3} P_{resin}; 44.6% V; K, Ca, Mg, and H+Al contents of 3.1, 18.0, 6.0, and 34.0 mmol$_c$ dm^{-3}, respectively; 706 g kg^{-1} sand; 85 g kg^{-1} silt; and 209 g kg^{-1} clay. Based on soil analysis, the fertility and acidity corrections consisted of 255 kg ha^{-1} of the 00-30-10 formulation in the sowing furrow and a cover fertilization of 120 kg ha^{-1} KCl at 30 days after soybean emergence (DAE).

The soybean variety MONSOY 8866 was used at a sowing density of 15 plants m^{-1} and spacing of 0.45 m between rows. Seed inoculation was performed in the sowing furrow by applying Biomax® Premium Liquid Soybean inoculant at 360 mL ha^{-1}. The eucalyptus species used was a 2-year-old *Eucalyptus grandis* x *E. camaldulensis* (*Camaldugrandis*) hybrid, planted in a double row with 22 m spacing between rows, in the east-west direction.

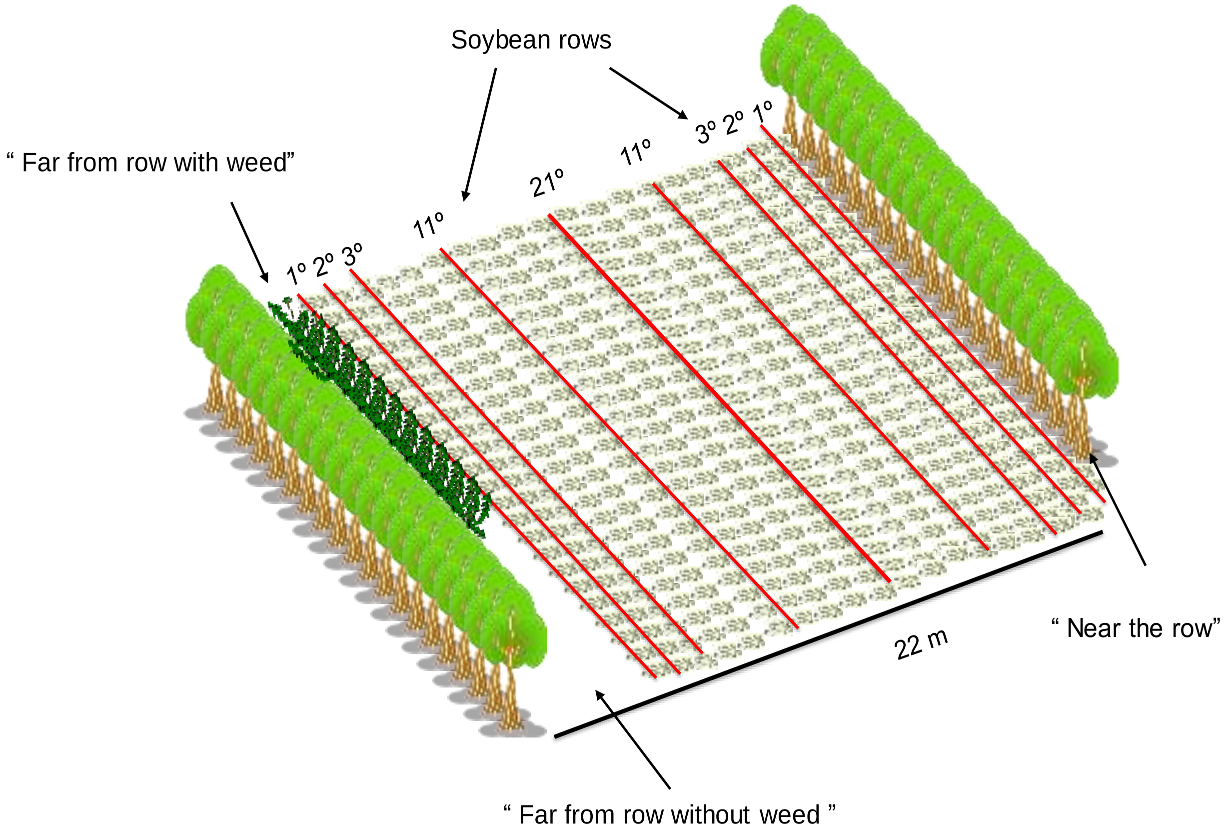

Figure 1 - Detail of treatment distribution in the experimental area.

Weeds were eliminated before sowing by applying the herbicide glyphosate at 740 g ai ha^{-1}, which allowed the soybean crop to be established without weeds. For the soybean crop and for soybean plants sown 3.0 m away from the stands with subsequent weed control ("clean"), weeds were managed by associating the herbicides ethyl chlorimuron at 100 g ai ha^{-1} and lactofen at 120 g ai ha^{-1}, applied at 25 days after emergence of soybean seedlings (DAE), in addition to the herbicide haloxyfop-p-methyl at 36 g ai ha^{-1}, applied at 33 DAE. Spraying was carefully done to prevent the herbicide syrup from reaching the canopy of eucalyptus plants.

Weeds were characterized by individually collecting and identifying all weed species present between the stands and the soybean crop at the end of the experimental period. The specimens were taken to the laboratory and dried in a forced air oven at 65 ºC for three days. After this procedure, the accumulated dry matter of the collected species was determined with the aid of a 0.01 g precision scale.

The kinetics of maximum chlorophyll *α* fluorescence was evaluated with the aid of a handheld chlorophyll fluorometer (model OS-30p) to determine the photochemical efficiency of photosystem II (*Fv/Fm*). Evaluations considered the third trifoliate from the top of the plant, and were carried out in the early hours of the morning to ensure the adaptation of leaves to the dark. Four evaluation points were considered along 10 m of each row, analyzing three plants at each point, totaling 12 plants per row.

To evaluate the nodulation of soybean plants, we followed the methodology proposed by Brandelero et al. (2009) and collected plants along 10 m of each row, within 4 sampling points, each composed of 3 plants. The samples were taken to the laboratory where the number of branches per plant was counted and the shoots and roots separated. Then, we separated and counted the nodules present in the roots of soybean plants. The nodules and all material obtained in the shoots were placed separately in paper bags and kept in a greenhouse with forced air circulation at 65 ºC for 72 hours to determine the dry matter of these plant fractions. All these procedures were performed when at least 50% of the plants reached the phenological stage R5.

At the end of the experimental period, when the crop reached the harvest point (stage R9), soybean plants present in the 10 m section of each row were manually collected within 4 sampling points, being then properly threshed. The obtained grains were weighed in a 0.01 g precision scale and, thus, we obtained the yield in kg ha^{-1} and the 100 grain weight of soybean, both variables corrected to 13% moisture.

The results were analyzed by the F test and the effects of treatments compared by the Scott-Knott test at 5% probability using the AgroEstat statistical program (Barbosa & Maldonado Jr., 2015).

Results and discussion

Evaluations carried out during the experimental period showed the presence of four eudicotyledonous weed species. From the data on dry matter (g m^{-2}) accumulation by weeds, it can be seen that the species present in the area had high dry matter production and could compete with the soybean crop and use common resources such as water, light, and nutrients. Species *Sida santaremnensis* and *Senna obtusifolia* stood out for dry matter accumulation compared to the other species (Table 1).

Table 1 - List of species and dry matter (g m^{-2}) accumulated by weeds during experimental period.

Common name	Species	Dry mass (g m^{-2})
Guanxuma	*Sida santaremnensis* H. Monteiro	1532
Fedegoso	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	728
Mata pasto	*Diodia Teres* Walter	28
Malva relógio	*Sida carpinifolia* (L)	50
Total	-------	2238

In this study, *S. santaremnensis* had the largest relative amount of environmental resources transformed into dry matter throughout the experiment. As a result, it was considered as the weed that most competed with the soybean crop, consequently influencing its productive characters. This finding can be explained since this species is characterized by being a perennial weed with high nutrient absorption capacity when compared to other species (Soares et al., 2015).

Species *S. obtusifolia* also allocated a large amount of dry matter and also established a strong competitive pressure on the soybean crop. It is noteworthy that *S. obtusifolia* is an annual weed that has as its main characteristic a fast initial growth, with strong competition in the early development of annual crops such as soybeans (Marchi et al., 2017). According to Wandscheer et al. (2014), weeds with early emergence, high seedling vigor, dense canopy formation, high height, and long development cycle are considered to be better competitors.

The efficiency of the photosynthetic apparatus of soybean plants (*Fv/Fm*) was little affected by sowing conditions, and significant reductions were observed only when weeds (“vegetation” condition) were present in the first planting row (Table 2).

Table 2 - Effect of condition and planting proximity on the photosystem II quantum efficiency (*Fv/Fm*) of soybean plants.

Line	*Fv/Fm*		
	Near	Far	
		Clean	Vegetation
1	0.632 Aa	0.659 Aa	0.604 Bb
2	0.639 Aa	0.652 Aa	0.632 Aa
3	0.649 Aa	0.643 Aa	0.645 Aa
11	0.631 Aa	0.646 Aa	0.654 Aa
21	0.649 Aa	0.658 Aa	0.640 Aa
Variation sources	F values		
Condition (C)	3.80*		
Line (L)	1.36^{NS}		
C x L	1.85*		
Block	14.13		
C.V. (%)	3.06		

^{NS} – Not significant. * Significant to F test ($p < 0.05$). Means followed by the same uppercase letter in the column and lowercase in the row do not differ by Scott-Knott test ($p > 0.05$).

The competition between weeds and soybean plants for environmental resources was substantially harmful to the photochemical apparatus and chlorophyll *α* fluorescence (*Fv/Fm*) of the soybean crop, since photosynthesis is extremely dependent on environmental factors such as light, temperature, CO_2, water, and mineral nutrient availability (Corrêa & Alves, 2010). Changes in the kinetics of maximum chlorophyll *α* fluorescence of photosynthetic organisms are the result of frequent changes in photosynthetic activity, especially regarding the quantum efficiency of electron transport through photosystem II in leaves, thus evidencing the disturbances caused by the competition imposed by weeds (Yusuf et al., 2010).

The “near” eucalyptus stands condition did not negatively influence the soybean crop variable *Fv/Fm* due to the spatial arrangement of the integration system. The stands were planted in the east-west direction, so there was a higher incidence of light and practically no shading over the crop established between them (Almeida et al., 2014).

The number of branches of soybean plants was significantly affected by the proximity to eucalyptus stands and by the presence of weeds only in the first planting row. Considering only the row factor, no significant effects were observed under any of the imposed conditions. The "vegetation" condition also influenced the shoot dry matter production of soybean plants in the first three planting rows. For soybean sown "near" eucalyptus stands, the first and second rows showed a significant reduction in dry matter production (Table 3).

Table 3 - Effect of condition and planting proximity on the number of branches and shoot dry matter of soybean plants.

Line	Number of branches per plant		
	Near	Far	
		Clean	Vegetation
1	12.0 Ab	15.2 Aa	11.0 Ab
2	12.3 Aa	14.0 Aa	10.7 Aa
3	13.7 Aa	13.0 Aa	10.5 Aa
11	13.5 Aa	12.5 Aa	11.8 Aa
21	13.3 Aa	13.5 Aa	12.0 Aa
Variation sources	F values		
Condition (C)	4.88*		
Line (L)	0.11^{NS}		
C x L	0.60*		
Block	6.09		
C.V. (%)	20.28		
Line	Shoot dry mass (g)		
	Near	Far	
		Clean	Vegetation
1	109.0 Bb	132.0 Aa	96.8 Bb
2	95.8 Bb	129.2 Aa	100.5 Bb
3	127.7 Aa	126.8 Aa	88.5 Bb
11	135.4 Aa	130.8 Aa	119.3 Aa
21	135.2 Aa	138.2 Aa	126.5 Aa
Vatiation sources	F values		
Condition (C)	5.29*		
Line (L)	5.30*		
C x L	1.33*		
Block	1.28		
C.V. (%)	16.25		

^{NS} – Not significant. * Significant to F test ($p < 0.05$). Means followed by the same uppercase letter in the column and lowercase in the row do not differ by Scott-Knott ($p > 0.05$).

The presence of weeds reduces trifoliate formation and dry matter accumulation throughout the soybean cycle, with greater damage as infestation levels increase (Pittelkow et al., 2009). The proximity of the tree component to the first soybean planting rows influenced branch development and shoot dry matter production, supposedly due to competition for space and soil nutrients. When grown close to soybean, eucalyptus plants compete strongly for water and nutrients, depriving soybean plants of these fundamental resources for growth and formation of reproductive structures (Svoma et al., 2016).

The presence of weeds between eucalyptus stands and the soybean crop ("vegetation" condition) also negatively influenced the amount and dry matter production of nodules by soybean plants in the first and second row. Significant effects were observed when the crop was conditioned "near" eucalyptus stands (Table 4).

Damage to the photochemical apparatus and chlorophyll *α* fluorescence of soybean caused by competition with weeds was critical in reducing the number and dry matter of nodules, as disturbances to the photosynthetic apparatus of plants can interfere with the size of roots and nodule production, making nitrogen absorption difficult and directly influencing yield (Gal et al., 2015).

Cultivation in the presence of weeds ("vegetation") also negatively influenced soybean yield in the first three planting rows, with a reduction of approximately 31% compared to the most distant planting rows. Yield in the "clean" planting condition (away from eucalyptus stands and without weeds) was practically uniform, with a significant contrast only in the first planting row, in which it was statistically superior to the other planting rows, which was possibly due to higher branch yield as a function of plant spatial arrangement. In turn, cultivation "near" eucalyptus stands significantly influenced soybean yield in the first two planting rows (Table 5).

Table 4 - Effect of planting condition and proximity on the number and dry matter of nodules obtained at different growing conditions.

Line	Number of nodules per plant		
	Near	Far	
		Clean	Vegetation
1	122.0 Aa	155.8 Aa	76.0 Bb
2	113.5 Aa	145.8 Aa	74.8 Bb
3	141.5 Aa	111.5 Aa	138.3 Aa
11	148.0 Aa	124.0 Aa	134.5 Aa
21	126.5 Aa	127.3 Aa	114.0 Aa
Variation sources	F values		
Condition (C)	2.72^{NS}		
Line (L)	0.74^{NS}		
C x L	1.64*		
Block	1.09		
C.V. (%)	30.70		
Line	Dry mass of nodules (g)		
	Near	Far	
		Clean	Vegetation
1	2.45 Ba	2.85 Aa	1.77 Ab
2	2.27 Ba	2.68 Aa	1.78 Ab
3	3.15 Aa	2.53 Aa	2.60 Aa
11	2.08 Ba	1.80 Ba	1.88 Aa
21	1.80 Ba	1.97 Ba	1.80 Aa
Variation sources	F values		
Condition (C)	3.75*		
Line (L)	5.82*		
C x L	1.42*		
Block	1.99		
C.V. (%)	23.53		

^{NS} – Not significant. * Significant to F test ($p < 0.05$). Means followed by the same uppercase letter in the column and lowercase in the row do not differ by Scott-Knott ($p > 0.05$).

Table 5 - Effect of condition and planting proximity on yield and weight of 100 soybean grains obtained at different growing conditions.

Line	Yield (kg ha^{-1})		
	Near	Far	
		Clean	Vegetation
1	2583.0 Bb	3382.5 Aa	2020.3 Bc
2	2475.3 Bb	2789.7 Ba	2300.0 Bb
3	2973.9 Aa	3013.3 Ba	2526.7 Ab
11	2720.8 Aa	2961.7 Ba	2961.7 Aa
21	3152.6 Aa	2788.9 Ba	2694.8 Aa
Variation sources	F values		
Condition (C)	11.25*		
Line (L)	2.91*		
C x L	4.55*		
Block	3.10		
C.V. (%)	11.05		
Line	Weight of 100 grains (g)		
	Near	Far	
		Clean	Vegetation
1	10.67 Ba	10.56 Ba	10.56 Ba
2	10.62 Ba	10.60 Ba	10.60 Ba
3	11.31 Aa	10.40 Ba	10.40 Ba
11	11.46 Aa	11.64 Aa	11.64 Aa
21	11.62 Aa	11.50 Aa	11.50 Aa
Variation sources	F values		
Condition (C)	1.17^{NS}		
Line (L)	8.98*		
C x L	1.37*		
Block	2.37		
C.V. (%)	4.39		

^{NS} – Not significant. * Significant to F test ($p < 0.05$). Means followed by the same uppercase letter in the column and lowercase in the row do not differ by Scott-Knott ($p > 0.05$).

The 100 grain weight was little influenced by the experimental factors, since no significant contrast related to the sowing condition was observed. Notwithstanding, considering only the “planting row” factor, there was a significant difference in the 100 grain weight of soybean plants for the rows closest to eucalyptus stands, regardless of the imposed condition (Table 5).

In this experiment, the reduction in the number of reproductive branches and in the dry matter of soybean shoots due to the proximity to the tree component resulted in a significant loss of crop yield (approximately 19% loss). Corroborating this result, Werner et al. (2017) comment that in CFI systems, the closer the eucalyptus stands are, the lower the soybean growth and nitrogen accumulation in its dry matter due to competition for environmental resources, causing significant losses in grain yield.

Considering the high competitive pressure of weeds, the "vegetation" condition promoted the most severe effects in this experiment, since the observed reductions in yield, especially in the first row of soybean cultivation, were more significant than those observed in the "near” eucalyptus stands condition. According to Pittelkow et al. (2009), high weed infestations affect the number of pods per plant, grain weight, and grain yield, leading to yield losses.

Conclusions

Soybean cultivation carried out near eucalyptus stands does not interfere with the photochemical apparatus, chlorophyll *α* fluorescence, and the number and dry matter of nodules. Notwithstanding, this condition reduces the number of branches, shoot dry matter, and yield (by up to 19%) in the first two planting rows compared to the most distant rows.

The presence of weeds in the range between stands and planting areas impaired the photochemical apparatus and the chlorophyll *α* fluorescence of soybean, decreasing the shoot dry matter accumulation, number and dry matter of nodules, and yield of the plants present in the first planting rows.

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