

# Yield of soybean, pasture and wood in integrated crop-livestock-forest system in Northwestern Paraná state, Brazil<sup>1</sup>

## Rendimento de soja, forragem e madeira em sistema integração lavoura-pecuária-floresta no Noroeste do Paraná

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**ABSTRACT** - The integrated crop- livestock-forest system can enhance the production of soybeans, meat and wood in regions characterized by sandy soils and warm climate. The aim of this study was to evaluate the yield of soybean, *Urochloa ruziziensis* grass and eucalyptus in an integrated system during the first four years after the establishment of eucalyptus in the northwestern region of Paraná state, Brazil. The experiment was established in October 2009, using soybean (summer) -*U. ruziziensis* (autumn/winter) succession between single rows of *Corymbia maculata* (eucalyptus species). The spacing between tree rows and eucalyptus plants in the row were 14 and 4.2 m, respectively. Adjacent plots had the same soybean-*U. ruziziensis* succession, but without eucalyptus. The spatial variability of soybean grain yields and grass shoot dry matter production was evaluated with and without trees, and the data was analyzed using geostatistics, with the results expressed as spatial variability maps. The tree component did not significantly affect soybean yield in the first two growing seasons. In the 3rd and 4th growing season (2011/12 and 2012/13), the interference of eucalyptus reduced the soybean grain yield by 2.9 and 27.0%, respectively, and the effect was stronger close to the tree rows. In July 2012, the tree component reduced the shoot dry matter productivity of *U. ruziziensis* by 29.2%. At 19 and 35 months after eucalyptus planting, the cumulative wood volume production was 0.73 and 5.17 m<sup>3</sup> ha<sup>-1</sup>, respectively.

**Key words:** Eucalyptus. *Glycine max* L.. *Urochloa ruziziensis*. Sandy soil. Spatial and temporal variability.

**RESUMO** - O sistema integração lavoura-pecuária-floresta pode viabilizar a produção de soja, carne e madeira em regiões que apresentam solos arenosos e clima quente. O objetivo desse trabalho foi avaliar a produtividade de soja, *Urochloa ruziziensis* e eucalipto em sistema integrado, durante os quatro primeiros anos de implantação, na região Noroeste do Paraná. O experimento foi implantado em outubro de 2009, usando a sucessão soja-*U. ruziziensis* nos entre renques simples de *Corymbia maculata* (espécie de eucalipto utilizada). Os espaçamentos entre renques e plantas foram de 14 e 4,2 m, respectivamente. Em área contígua, foi usada a mesma sucessão de culturas, mas sem o eucalipto. Os rendimentos de soja e de capim foram avaliados na ausência e presença de árvores, de forma espacializada, sendo os dados analisados por geoestatística e os resultados expressos por mapas de variabilidade espacial. O componente arbóreo não afetou a produtividade de soja nas duas primeiras safras. Na terceira e quarta safras, 2011/12 e 2012/13, a redução de produtividade ocasionada pela interferência do eucalipto foi de 2,9 e 27,0%, sendo mais intensa nas proximidades das árvores. Em julho de 2012, constatou-se que o componente arbóreo reduziu em 29,2% a produtividade de massa seca do capim. Aos 19 e 35 meses após a implantação, a produção acumulada de madeira foi de 0,73 e 5,17 m<sup>3</sup> ha<sup>-1</sup>.

**Palavras-chave:** Eucalipto. *Glycine max* L.. *Urochloa ruziziensis*. Solo arenoso. Variabilidade espacial e temporal.

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## INTRODUCTION

Agriculture has faced great challenges such as the production of food in high quality and quantity, energy, fiber, wood and other products with a minimum negative impact on the environment, as well as the mitigation of gases causing the greenhouse effect (FOLEY *et al.*, 2005; NAIR *et al.*, 2010). In this context, the most appropriate alternative is the use of production systems that efficiently utilize the resources available in the agro-system, with a view to improve the quality of soil, water and air, reduce the consumption of inputs and the generate higher income per area (BALBINOT JR *et al.*, 2011; CARVALHO *et al.*, 2010). A production system that can be used to achieve this goal is the integrated crop-livestock-forest system (CLFS), especially in environments with limitations for crop and animal production as isolated activities (NAIR, 2011; REGANOLD *et al.*, 2011).

The CLFS can be an important strategy for increasing the sustainability of agriculture in the Northwest of Paraná. This region occupies a total area of 3.2 million hectares, representing approximately 16% of the total area of the state (SÁ; CAVIGLIONE, 1999). Medium and sandy-textured soils originated from Caiuá sandstone, with high susceptibility to erosion and low water storage capacity, are predominant in this region (FIDALSKI *et al.*, 2013). The sand contents reach 850-900 g kg<sup>-1</sup>, and the contents of phosphorus, potassium, calcium, magnesium and organic matter are generally critical for crop growth (COSTA *et al.*, 2012). The climate is humid subtropical (Cfa, according to the Köppen's classification), with high temperatures, especially in the summer. Therefore, considering the soil and climate characteristics, the grain production in this region is highly susceptible to losses resulting from abiotic stresses, especially drought.

The tree component in CLFS can provide environmental and economic benefits, such as soil and water conservation, carbon sequestration, wood production, and improved animal welfare, which can increase milk and beef production. However, it is necessary to evaluate the tree component effects on annual crops and forage species that compose the system, since all the components of the CLFS compete for environmental resources (water, light and nutrients) (ROZADOS-LORENZO *et al.*, 2007). Thus, the study of spatial and temporal variability of grain yields and forage production can be a useful tool to assess the arboreal component effects on these crops (PACIULLO *et al.*, 2011). These effects are likely associated with the proximity to tree rows as well as the age of the trees. In this context, geostatistical analysis has been used to

study the spatial variability of productivity of pastures and grain species (LIMA *et al.*, 2009; MIGUEL *et al.*, 2009; SILVA *et al.*, 2008).

The hypothesis of this research is that the yield of soybean and grass are affected by tree component, and the magnitude of this effect is spatial and time-dependent. Therefore, this study aimed to evaluate the yield of soybean grains, *U. ruziziensis* dry matter, and eucalyptus wood in a CLFS during the first four years after the establishment of eucalyptus, in the northwestern region of Paraná State, Brazil.

## MATERIAL AND METHODS

The experiment was established in October 2009 in an area of 10 ha, located in the municipality of Santo Inacio, northwest region of Paraná State, Brazil (latitude 22°45'56" S, longitude 51°50'30" W and altitude 386 m). The soil was classified as Typic Haplustox according to USDA Soil Classification System. Some soil physical and chemical properties determined before the establishment of the experiment are presented in Table 1. Prior to the establishment of the trees, the area was cultivated with perennial pasture, *Urochloa brizantha* cv. Marandu. The CLFS started with the cultivation of soybean and eucalyptus species *Corymbia maculata* Hill & Johnson (*Eucalyptus maculata* Hook), planted in single rows spaced 14 m, with a spacing of 4.2 m between trees in a row, resulting in a density of 170 trees ha<sup>-1</sup>. The eucalyptus seedlings were obtained from seeds. For the eucalyptus planting, a reference row was marked in level, and then the other rows were placed keeping a uniform distance of 14 m between rows to ensure soil and water conservation and facilitate the mechanized operations. Prior to the eucalyptus planting, a subsoiler was used to prepare the soil only in the planting rows. After the eucalyptus planting, the fertilizer (NPK 08-24-18) was applied at a rate of 0.25 kg per plant, at 10 cm depth and 25 cm alongside the tree. The weed control in the tree rows was carried out manually in the first year, and with application of glyphosate in the 2nd year.

In 2009/10, 2010/11, 2011/12 and 2012/13 growing seasons, the soybean was sown in the experimental area in November using a row spacing of 50 cm, and 250,000 plants ha<sup>-1</sup>. The cultivars used were FTS Campo Mourão RR (2009/10 and 2010/11), and BMX Potência RR (2011/12 and 2012/13). In all growing seasons, the soybean was fertilized with 20 kg ha<sup>-1</sup> of nitrogen, 80 kg ha<sup>-1</sup> of phosphorus, and 80 kg ha<sup>-1</sup> of potassium, applied 0.05 m below and alongside the seeds simultaneously with the sowing. Soybean seeds were inoculated with *Bradyrhizobium elkanii* and *B. japonicum* every growing

**Tabela 1** - Some soil physical and chemical properties of the experimental site, Santo Inácio, PR

Soil layers (cm)	pH <sup>1</sup>	K	Ca	Mg	CTC <sup>2</sup>	V <sup>3</sup>	P <sup>4</sup>	OC <sup>4</sup>	Clay	Silt	Sand
		cmol <sub>c</sub> dm <sup>-3</sup>				%	mg dm <sup>-3</sup>		g kg <sup>-1</sup>		
0-25	4.7	0.07	1.25	0.34	5.43	30.3	10.0	10.6	101	18	881
25-50	4.6	0.05	1.03	0.30	4.72	29.3	1.8	5.3	150	15	835

<sup>1</sup>Soil pH (0.01 mol L<sup>-1</sup> of CaCl<sub>2</sub>). <sup>2</sup>CEC: cation exchange capacity at pH 7.0. <sup>3</sup>V = base saturation. <sup>4</sup>P = phosphorus available by Mehlich-1 solution. <sup>5</sup>C = organic carbon by Walkley-Black method

season. Weed control was achieved using glyphosate at a dosage of 720 g a.e. ha<sup>-1</sup>. Other management practices including crop management, and control of pests and diseases strictly followed the technical recommendations for soybean production in the region. The soybean was harvested in March of each growing season. From March to October 2013, the experimental area was cultivated with *Urochloa ruziziensis*, sown with row spacing of 20 cm and without fertilizer application.

In 2009/10 and 2010/11 growing seasons, soybean yield was assessed in 20 samples of 3 m<sup>2</sup> collected within and outside tree rows. In 2011/12 and 2012/13, from a total of 26 soybean rows cultivated between two eucalyptus rows, samples composed by two soybean rows of 3m long were collected in the rows 2 and 3; 7 and 8; 13 and 14; 19 and 20; 24 and 25. The sampling was repeated 17 times at intervals of 10 meters in each pair of soybean rows, totaling 85 samples along a total distance of 160 m. Additionally, an area measuring 160 m long x 11.25 m wide (26 soybean rows) was delimited outside the eucalyptus rows, and samples composed by two soybean rows were taken in the rows 2 and 3; 7 and 8; 13 and 14; 19 and 20; 24 and 25. Similarly to the procedure adopted in the area between the eucalyptus rows, the sampling was repeated 17 times at intervals of 10 meters in each pair of soybean rows, totaling 85 samples. After sampling, soybean plants were threshed, cleaned and the grains weight. The soybean grain yield was corrected to a moisture content of 130 g kg<sup>-1</sup>. The soybean yields were mapped for each growing season, and comparing the areas located outside with those between the eucalyptus rows, it was possible to infer the spatial and temporal variability in soybean yields resulting from the presence of eucalyptus.

In July 2012, 30 days after the removal of the cattle from de pasture, the shoot dry mass yield of the grass were evaluated. Samples were collected from an area of 0.5 m<sup>2</sup> at seven equidistant positions between two eucalyptus rows (transversally to the direction of the eucalyptus rows) and eight segments, 8 m apart each other in the direction of the tree rows, resulting in a distance of 56 meters and a total of 56 samples. This procedure was repeated in an

adjacent area with similar soil conditions, but without eucalyptus interference. Then, the grass samples were dried in a forced-air oven at 65 °C to constant weight to determine the shoot dry mass yield.

The soybean yields and shoot dry mass yield of the grass were subjected to geostatistical analysis (VIEIRA *et al.*, 2002). In order to determine the spatial dependence of the variables, autocorrelation was obtained by fitting semivariogram functions using Spherical, Gaussian and Exponential models. Kriging was done to interpolate the data, enabling the spatial mapping according to the model that resulted in the best fit as shown in Table 2.

In order to enable comparisons among different growing seasons, the soybean grain yields and the shoot dry mass production of the grass were normalized to the respective maximum value obtained without the presence of eucalyptus, according to the formula:  $Y_N = (Y_p/Y_M) * 100$ , where:  $Y_N$  = normalized soybean yield or normalized shoot dry mass yield of the grass;  $Y_p$  = Soybean or shoot dry mass yield (kg ha<sup>-1</sup>) at a given point between two eucalyptus rows ; and  $Y_M$  = Maximum soybean or shoot dry mass yield without the tree component.

At 19 and 35 months after the eucalyptus planting, the tree density was evaluated and the following variables were measured in 20% of the tress: tree height, using a steel telescopic ruler; the trunk diameter at breast height (DBH), by means of a tape-measure; average volume of wood per tree, estimated by the equation: tree volume (m<sup>3</sup>) = 0.7854 \* DBH<sup>2</sup> \* height \* 0.33; and the wood volume per hectare estimated by multiplying the tree volume by the tree density.

## RESULTS AND DISCUSSION

The soil of the experimental area is characterized by very low clay and high sand contents (Table 2). Due to the low physical protection of organic matter exerted by clays and the warm climate of the region (FRANCHINI *et al.*, 2011), the organic carbon contents are low, especially in the 25-50 cm layer, resulting in low CEC and natural

**Table 2** - Parameters of the semivariogram models fitted to the soybean grain yield and shoot dry mass production of *Urochloa ruziziensis*, within and outside the eucalyptus rows during the 2011/12 and 2012/13 growing seasons, at Santo Inácio, PR

	Model <sup>a</sup>	Parameters <sup>b</sup>			R <sup>2</sup>
		C <sub>0</sub>	C <sub>1</sub>	a	
2011/12 (soybean)					
Within	EXP	6.54	11.92	38.47	0.87
Outside	EXP	5.32	4.58	6.73	0.44
2012/13 (soybean)					
Within	GAU	46.97	15.36	6.57	0.68
Outside	SPH	23.83	16.88	21.84	0.52
2012 (Grass)					
Within	GAU	0.20	0.097	9.24	0.67
Outside	SPH	0.08	0.041	14.77	0.37

<sup>a</sup>EXP (Exponential), GAU (Gaussian), SPH (Spherical); <sup>b</sup>C<sub>0</sub> = nugget effect; C<sub>1</sub> = structural variance; a = range

fertility. As a result of the sandy texture and low organic matter content, which act in the formation of aggregates, the soil structure is poor and consequently, the soil water retention is limited. The low soil water retention associated with high evapotranspiration and temperature, make the environment very fragile in terms of crop yield. Furthermore, the sandy texture and the poor soil structure, associated with the occurrence of long slopes and low soil cover with crop residues, result in high soil susceptibility to erosion.

In 2009/10 and 2010/11 growing seasons, the average soybean yields were 3,120 and 3,300 kg ha<sup>-1</sup>, respectively. There was no difference in the soybean yields grown with and without the tree component. In these growing seasons, the only loss related to soybean was the absence of soybean plants within a strip of 1.5 m wide at each side of the eucalyptus rows. The similar soybean performance with or without the tree component can be attributed to the relatively small size of the eucalyptus plants in the first two years, resulting in low shading and competition for water, light and nutrients.

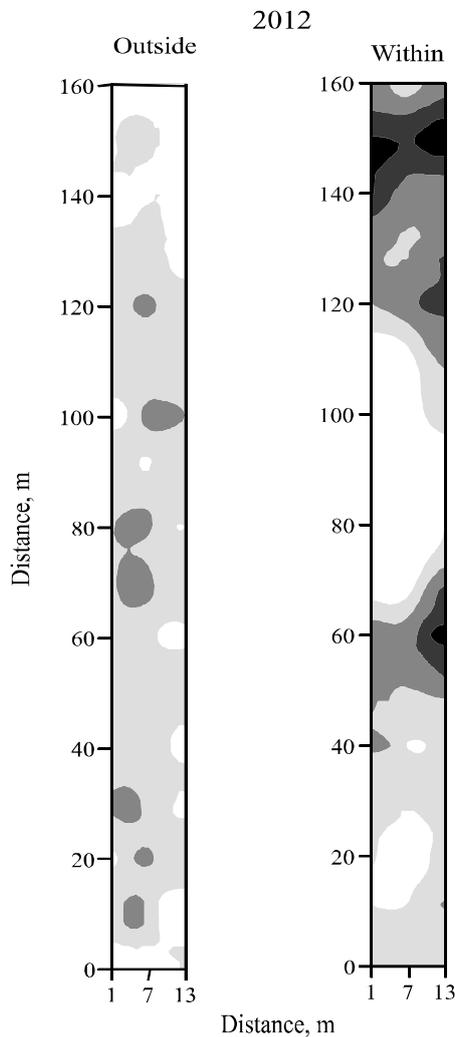
In 2011/12, the maximum soybean yield observed in the area without eucalyptus was 2.790 kg ha<sup>-1</sup>, and this value was used to normalize the soybean yields in this growing season. Therefore, the normalized average soybean yield was 96.2% (ranging from 73.4 to 100.0 %) in the absence and 93.3% (ranging from 55.7 to 106.8%) in the presence of eucalyptus. The average loss in soybean yields caused by eucalyptus was 2.9%. The variability of soybean yields was higher within than outside the eucalyptus rows, 137.7% to 21.9%, respectively. According to Garcez Neto *et al.* (2010), the tree component provides a spatially heterogeneous microclimate, leading to high spatial yield

variability in understory crops. In the 3rd year after the eucalyptus planting, the soybean yields near the tree rows were significantly lower than in the area without the tree component (Figure 1), most likely due to the competition for environmental resources (light, water, and nutrients) imposed by the eucalyptus.

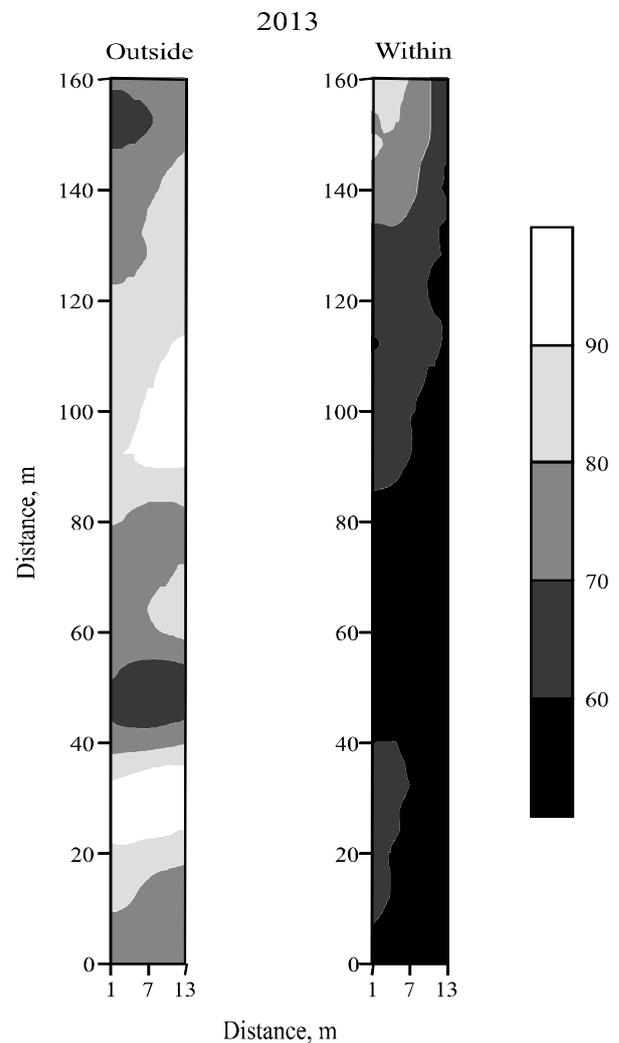
In 2012/13, the normalized average soybean yield in relation to the highest yield value outside the eucalyptus rows (2,964 kg ha<sup>-1</sup>) was 97.6% (ranging from 63.6 to 100.0 %) without trees, and 70.6 % (ranging between 39.5 and 85.1 %) in the presence of trees. The average yield loss caused by the trees in 2012/13 was higher than 2011/12, reaching approximately 27.0% (Table 2, Figure 2). Similarly to 2011/12, the soybean yield variability was higher between the tree rows relative to the area without trees, 100.0% to 60.9%, respectively. Accordingly, in a CLFS with low density of eucalyptus plants, but with narrow row spacing (14 m), the soybean can be grown without significant yield reduction only until the 3rd growing season after the eucalyptus planting.

The tree component led to substantial soybean yield losses in the 4th growing season (2012/13), mainly due to the higher capacity of the eucalyptus to compete for light, water and nutrients. Thus, for the soybean yield determination, the negative effect exerted by the eucalyptus competition for environmental resources overcame possible benefits on the understory microclimate, such as lower maximum temperatures, increased relative humidity and decreased evapotranspiration (BERNARDINO, GARCIA, 2009; SOUZA *et al.*, 2010). One way to reduce the negative effect of eucalyptus on the soybean yield is using a wider tree row spacing (more than 14 m, used in this

**Figure 1** - Maps of the normalized average soybean yield (%) from areas within and outside the tree rows in an integrated crop-livestock-forest farming system, in 2011/12 growing season, at Santo Inácio-PR



**Figure 2** - Maps of the normalized average soybean yield (%) from areas within and outside the tree rows in an integrated crop-livestock-forest farming system, in 2012/13 growing season, at Santo Inácio-PR

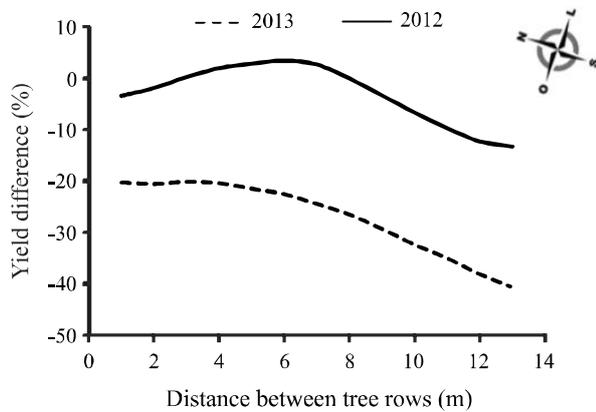


study), leading to lower light interception, water and nutrients use by the trees.

The percent differences between the normalized soybean yields within and outside the eucalyptus rows were highly dependent on the sampling position between the eucalyptus rows, as well as on the growing season (Figure 3). On average, the soybean yield losses were higher in the closer positions to the tree rows in both growing seasons. In 2011/12, the average soybean yields were reduced in 2.5% in the shaded positions during the afternoon (left side of Figure 3). When the soybean plants were exposed to the sun light in the afternoon (right side of Figure 3), the yield losses

were increased to 8.9%. In contrast, soybean yields were 2.9% higher in the intermediate portion (4 to 7 m) of the tree row spacing than in the area without eucalyptus. The results obtained in 2011/12 were partially repeated in 2012/2013, with lower soybean yield losses in shaded (21.2%, left side of Figure 3) than in sun-exposed (33.6%, right side of Figure 3) positions during the afternoon. However, the soybean yield losses caused by the eucalyptus were larger in 2012/13 comparatively 2011/12. Additionally, none of the positions between eucalyptus rows presented higher soybean yield when compared with the non-forested area in 2012/13 (Figure 3).

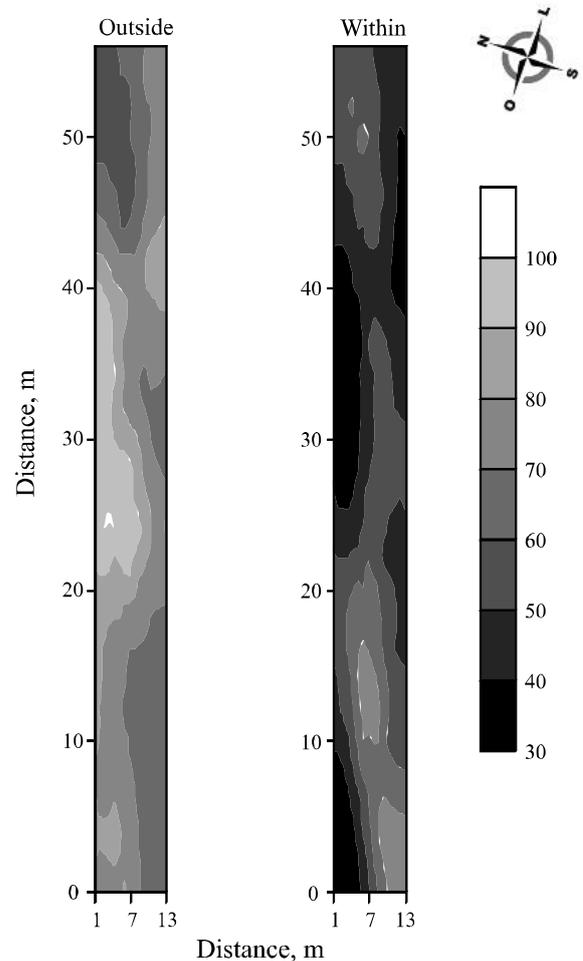
**Figure 3** - Normalized soybean yield difference between areas within and outside tree rows in an integrated crop-livestock-forest farming system, in 2011/12 and 2012/13 growing seasons, at Santo Inácio-PR



The increase in the tree height leads to a larger shaded area between the tree rows, but this effect seems to be less important than competition for water to explain the soybean yield losses caused by the eucalyptus presence in a CLFS. The hypothesis that the competition between trees and annual crops is mostly for water is supported by the higher soybean yield losses in sun-exposed than in shaded positions during the afternoon. Accordingly, plants exposed to the sun during the afternoon probably require more water, which in turn is less available due to the consumption by the trees. Moreover, the low water storage capacity related to the high soil sand content in the experimental area (Table 1) probably increased the effects of the competition for water on soybean yields.

The shoot dry mass production of *U. ruziziensis* at 33 months after the eucalyptus planting was substantially reduced by the tree component (Figure 4). This evaluation was carried out in July 2012, at a period characterized by low water availability. Similarly to the soybean, the greatest reduction in the shoot dry matter production of *U. ruziziensis* was observed near the eucalyptus rows due to increased competition for water, light and nutrients. Paciullo *et al.* (2011) found lower fodder production of *U. decumbens* close to the tree rows compared to the central region between tree rows, which were spaced 30 m apart. The same authors observed increased fodder production and crude protein content in a strip located at 7 to 10 m from the tree rows. Oliveira *et al.* (2007) also found higher *Urochloa brizantha* fodder production in the central region between the eucalyptus rows than near the tree rows. Considering that the response to partial shading is widely variable among grass species (PACIOULLO *et al.*, 2008), it is necessary to evaluate the performance

**Figure 4** - Maps of normalized shoot dry mass production (%) of *Urochloa ruziziensis* from areas within and outside the tree rows in an integrated crop-livestock-forest farming system, at 33 months after the eucalyptus planting (July/2012), at Santo Inácio-PR



of other forage species in silvopastoral systems in the Northwestern Paraná, Brazil.

The eucalyptus density at 19 months after planting was 165 plants ha<sup>-1</sup>, indicating a loss of only 5 plants ha<sup>-1</sup>, which represents approximately 3% of the total plant population at planting (Table 3). The mortality rate at 35 months after planting increased to about 14%, which is higher than the mortality rate of 8% after 7.6 years reported by Matrangolo *et al.* (2010) in a single planting. This high mortality rate may be attributed mainly to the tree breaking caused by the wind action, which has been frequent in conditions of low plant density, commonly observed in CLFS. Furthermore, the growth rate of any forest species is greater in agricultural areas with high soil fertility than in the marginal areas normally used for forestry, and this faster growth can increase the tree susceptibility to the breaking by wind. From 19 to 33

**Table 3** - Eucalyptus growth variables in an integrated crop-livestock-forest farming system, at Santo Inácio, PR

Age (months)	Density (plants ha <sup>-1</sup> )	Plant height (m)	Trunk diameter (m)	Wood volume (m <sup>3</sup> plant <sup>-1</sup> )	Wood volume (m <sup>3</sup> ha <sup>-1</sup> )
19	165	5.6	0.055	0.0044	0.73
35	146	10.1	0.116	0.0350	5.12

months after the eucalyptus planting, the eucalyptus plant height, trunk diameter and wood volume increased from 19 to 33 months after planting, demonstrating the high potential of this species for timber production in Northwestern Paraná.

## CONCLUSIONS

1. The tree component did not affect soybean yield in the first two years, but in the 3rd and 4th growing seasons, the soybean yield losses caused by the eucalyptus were 2.9 and 27.0%, respectively, being more intense near the trees rows;
2. The tree component reduced the shoot dry mass production of *U. ruziziensis* by 29.2% at 33 months after eucalyptus planting;
3. The eucalyptus wood production was 0.73 and 5.17 m<sup>3</sup> ha<sup>-1</sup> at 19 and 35 months after planting, respectively.

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