Production efficiency and agronomic attributes of corn in an integrated crop-livestock-forestry system

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Abstract – The objective of this work was to evaluate the agronomic attributes and production efficiency of corn silage and grains in an integrated crop-livestock-forestry (ICLF) system, with intercropping of eucalyptus, corn, and *Urochloa* cultivars during three crop years. The experimental design was completely randomized, in 2x5x3 split-split plots with four replicates. The plots consisted of corn cropped between eucalyptus rows (ICLF) and in full sun; the subplots, of the forage grasses *U. brizantha* 'Marandu', *U. brizantha* 'Xaraés', *U. brizantha* 'Piatã', *U. ruziziensis*, and *U. decumbens* 'Basilisk'; and the split-split plots, of the 2011/2012, 2012/2013, and 2013/2014 crop years. There was no effect of eucalyptus on the silage and grain yields of corn when intercropped with forages in 2011/2012. The production efficiency of silage and grains decreased by 25 and 48%, respectively, in 2012/2013 (12-month-old eucalyptus). There was also a 56% reduction in grain yield in 2013/2014 (24-month-old eucalyptus), compared with full sun. In the year the ICLF system is established, the production efficiency of corn silage and grains is not affected by eucalyptus, but decreases with the development of the trees in the subsequent crop years.

Index terms: *Urochloa*, agrosilvipasture system, eucalyptus, intercrop.

Eficiência produtiva e atributos agronômicos de milho em sistema integração lavoura-pecuária-floresta

Resumo – O objetivo deste trabalho foi avaliar os atributos agronômicos e a eficiência produtiva de forragem e grãos de milho em um sistema de integração lavoura-pecuária-floresta (ILPF), com consorciação de eucalipto, milho e cultivares de *Urochloa*, durante três safras. O delineamento experimental utilizado foi o inteiramente casualizado, em parcelas 2x5x3 sub-subdivididas, com quatro repetições. As parcelas consistiram de cultivo de milho entre renques de eucalipto (ILPF) e a pleno sol; as subparcelas, das forrageiras *U. brizantha* 'Marandu', *U. brizantha* 'Xaraés', *U. brizantha* 'Piatã', *U. ruziziensis* e *U. decumbens* 'Basilisk'; e as sub-subparcelas, das safras 2011/2012, 2012/2013 e 2013/2014. Não houve efeito do eucalipto nas produtividades de forragem e grãos de milho consorciado com as forrageiras em 2011/2012. A eficiência produtiva de forragem e grãos teve redução de 25 e 48%, respectivamente, em 2012/2013 (eucalipto com 12 meses). Também houve redução de 56% na produtividade de grãos em 2013/2014 (eucalipto com 24 meses), em relação ao cultivo a pleno sol. No ano de implantação do sistema ILPF, a eficiência produtiva de forragem e grãos de milho não é afetada pelo eucalipto, mas é reduzida com o desenvolvimento das árvores nas safras subsequentes.

Termos para indexação: *Urochloa*, sistema agrossilvipastoril, eucalipto, consórcio.

Introduction

The integrated crop-livestock-forestry (ICLF) system has been introduced in several regions of Brazil, as it allows the continuity of food production by intensifying land use, in order to reduce costs and increase income, and also aggregates sustainability to agricultural enterprises. This system relates the optimization of biological interactions to the synergistic effects between trees and agricultural crops and/or animal husbandry, and provides greater production by area in intercrop, rotation, or succession (Balbino et al., 2011; Vilela et al., 2011; Calil et al., 2016).

The good performance of the ICLF system is due to a number of factors, such as the inclusion of species that are more tolerant to shading, the spatial distribution

of the species in the area, and management practices that lead to more efficient yield. The introduction of trees in integrated systems increases the potential for carbon capture, which contributes to greater nutrient availability for intercropping, with effects on yield and soil conservation, compared with monocultures (Cordeiro et al., 2015). However, for this to occur, it is imperative that the trees do not compete excessively with the agricultural crop (Alvarenga et al., 2010).

Compared with other crops, corn (*Zea mays* L.) cultivation for silage or grains is well adapted when integrated with pasture, due to the greater size of the corn plants, which allows them to compete with forage and to be harvested, at ear insertion height, without interference from forage plants (Alvarenga et al., 2010). However, corn may present poor performance in areas shaded by tree canopies in the ICLF system (Mendes et al., 2013).

Forage plant growth, agronomic characteristics, and corn yields in integrated systems are affected by the level of solar radiation that reaches the sub-forest, which is associated with the spatial arrangement and the development of the tree component at the time the cropping system is established (Macedo et al., 2006; Paciullo et al., 2011).

Knowledge about the production efficiency of the annual crop component during the growth of the tree component in ICLF systems is fundamental for technicians and producers to determine the duration of the forest phase of these systems.

The objective of this work was to evaluate the agronomic attributes and production efficiency of corn silage and grains in an ICLF system, with intercropping of eucalyptus, corn, and *Urochloa* cultivars during three crop years.

Materials and Methods

The experiment was conducted in the experimental area of Embrapa Milho e Sorgo in Sete Lagoas, in the state of Minas Gerais, Brazil (19°29'11"S, 44°10'77"W, at an altitude of 708 m). The climate of the region is of the Aw type, according to Köppen's classification, with dry season from May to October and wet season from November to April.

The soil is classified as a Latossolo Vermelho distrófico típico, i.e., an Acrustox, with clayey texture, according to the Brazilian Soil Classification System

(Santos et al., 2013), with smooth undulating relief, under cerrado vegetation. The soil of the experimental area presented 111 g kg^{-1} sand, 84 g kg^{-1} silt, and 805 g kg^{-1} clay, and the following chemical attributes in the 0–20-cm layer: pH (H$_2$O) 5.5, 6.94 cmol^{-1} cm^{-3} H+Al, 18.1 mg^{-1} dm^{-3} P Mehlich 1, 3.42 dag^{-1} kg organic matter, 0.39 cmol^{-1} dm^{-3} Al, 3.16 cmol^{-1} dm^{-3} Ca, 0.35 cmol^{-1} dm^{-3} Mg, 68 mg^{-1} dm^{-3} K, sum of bases of 3.68 cmol^{-1} dm^{-3}, cation exchange capacity of 10.62, base saturation of 35%, and aluminum saturation of 9.57%. In September 2011, 2 Mg ha^{-1} dolomitic limestone were applied in the experimental area. Data on rainfall and maximum and minimum temperatures during the experimental period are shown in Figure 1.

In October 24, 2011, the GG100 cultivar of eucalyptus (*Eucalyptus urophylla* S.T.Blake) was planted in six pastures with a length of 100 m and size of 15x2 m, totaling 333.3 trees per hectare. Clonal seedlings were sown in the furrow and fertilized with 200 kg ha^{-1} single superphosphate, plus 120 g N-P$_2$O$_5$-K$_2$O (06-30-06) per plant, with 0.5% B and 1.5% Zn, half applied on each side of the hole, at a distance of 15 to 20 cm from the seedling. Cover fertilization was performed under crown projection with 120 g N-P$_2$O$_5$-K$_2$O (20-00-20) per plant one week after planting and with 200 g per plant in November 2012. Then, in February 2013, 15 g boric acid were applied per plant under the crown projection of each tree. In September 2013, the trees were stripped to 1/3 of their height. In November 2011, 2012, and 2013, the eucalyptus stands presented mean heights of 0.5, 4.8, and 10.3 m, respectively.

A no-tillage seeder-fertilizer was used to sow AG 8088VT PRO corn seeds simultaneously with 4 kg ha^{-1} viable pure seeds of forage grass in the same planting line, both between the eucalyptus stands and in the area with full sun. For this, three rows were spaced 0.70 m apart, keeping a distance of 1 m between the first line of corn and forage and the eucalyptus tree stand (tree component), up to a final stand of 68,000 plants per hectare. The area planted with corn intercropped with forage and eucalyptus was of 0.867 ha.

The corn seeds were treated with 135 g ha^{-1} imidacloprid + 186 g ha^{-1} thiodicarb. Fertilization at the time of sowing consisted of 400 kg ha^{-1} N-P$_2$O$_5$-K$_2$O (08-28-16), and, when corn reached the V6–V7 phenological stage, the cover crop was fertilized with 250 kg ha^{-1} urea (Souza & Lobato, 2004). The seeds of the grasses were treated with 5 g ha^{-1} fipronil.

The control of invasive plants was carried out between 15 and 21 days after sowing with the application of 1.5 kg ha^{-1} atrazine and 10 g ha^{-1} nicossulfurom to slow down the development of the forage.

The experimental design was completely randomized, in 2x5x3 split-split plots, with four replicates. The treatments consisted of the hierarchical factors: corn in two cropping systems (plot), i.e., between eucalyptus stands (ICLF) and in full sun intercropped with the forage grasses *U. brizantha*

'Marandu', *U. brizantha* 'Xaraés', *U. brizantha* 'Piatã', *U. ruziziensis*, and *U. decumbens* 'Basilisk' in the planting line (subplot); and three crop years (split-split plots), in this case, the 2011/2012, 2012/2013, and 2013/2014 harvests, after the establishment of eucalyptus trees.

Samplings were performed annually when corn reached the point for silage harvest and the grains around 15% moisture. The useful experimental plot in the ICLF system consisted of 2.0x4.9-m (9.8 m^2) areas, perpendicular to the stands, in which 2 linear meters
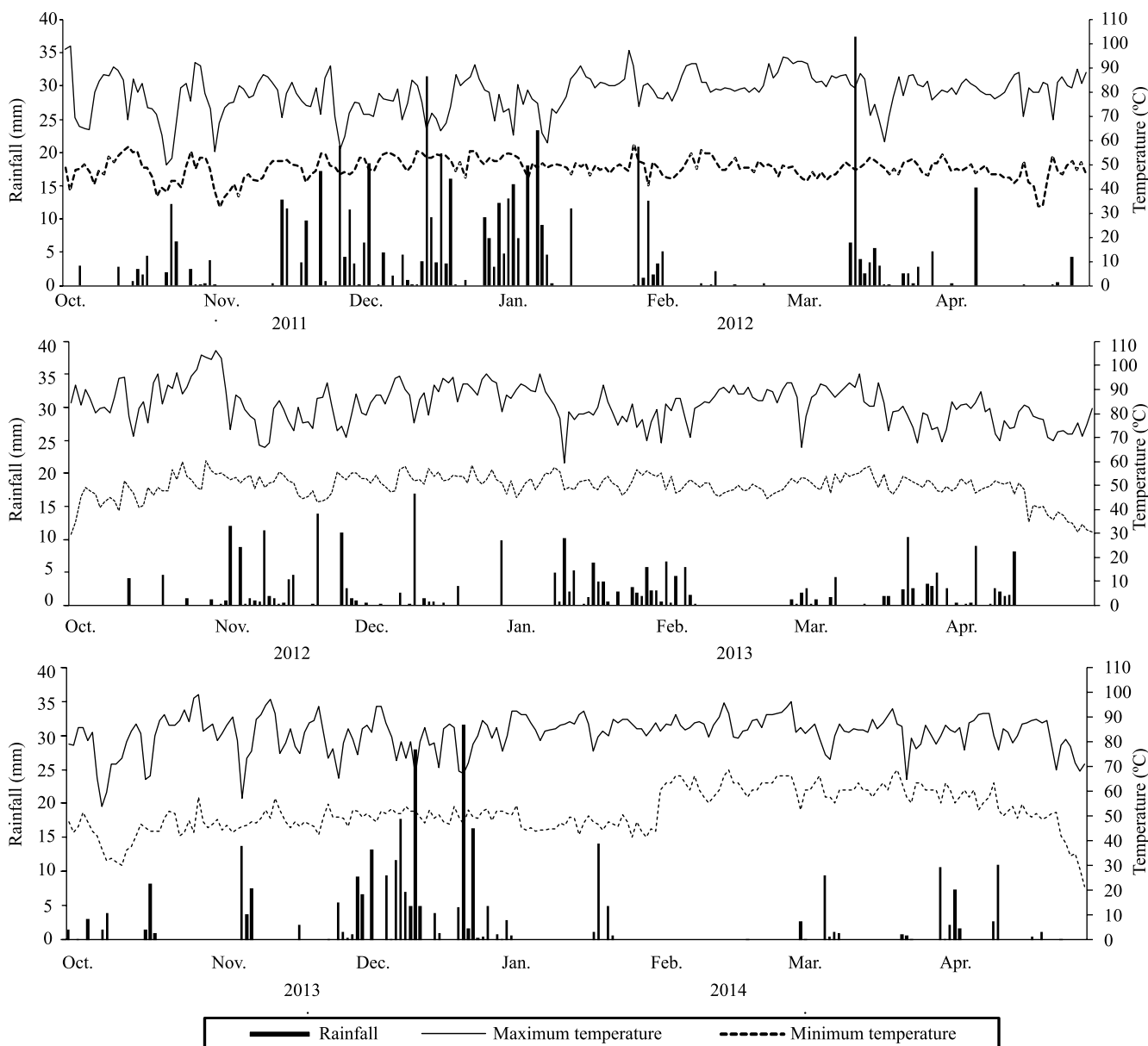

Figure 1. Mean monthly values of maximum and minimum temperatures and accumulation of rainfall during the experimental period in 2011, 2012, and 2013 (INMET, 2016).

were evaluated in the first, third, fifth, and seventh corn rows. In the full sun system, the corn intercrop was evaluated in a useful area of 1.4 m² (2 m length x 0.7 m width), in the direction of the corn planting line.

In order to evaluate corn silage and forage yields at the ensilage point, the plants in the plots were cut at a height of 20 cm, and corn and forage biomass yields were weighed separately. Flag leaf (FLH) and ear insertion (EIH) heights were measured in two plants per 2-m line. Samples of corn silage and grass forage were dried at 65ºC in greenhouses with forced-air ventilation for 72 hours to determine dry matter contents and estimate corn silage (CSY) and forage (FY) yields at ensilage time. Total corn silage and forage yield (TSFY) was estimated at ensilage time by adding the corn and forage yields of each plot.

At grain harvest, new plots were defined, where the number of plants and ears was counted, the ear index was obtained, and ears were manually harvested to obtain grain yield. After mechanical threshing, the 1,000-grain weight (TGW) was determined, as well as moisture content corrected to 13% humidity, in order to calculate the yield and mean weight of grains per ear (MWE), obtained by the relationship between grain weight and the number of ears per plot. With these results, the production efficiency of corn silage (PECS), total corn silage and forage yield (PETSF), and grain yield (PEGY) was calculated. These variables were determined by dividing the estimated silage + forage and grain yields of each treatment in the ICLF system by the average yield of the respective treatment in full sun for each crop year, and the values were converted into percentages.

The data were subjected to the Lilliefors' and Cochran's tests to check normal probability distribution and homoscedasticity, respectively. The analysis of variance was performed, and the means were compared by Tukey's test, at 5 and 1% probability.

Results and Discussion

The effect of the interaction cropping system x forage x crop year was significant for the structural components FLH and EIH (Table 1). The size of the corn plant and EIH are characteristics associated with genotype, which may also be affected by unfavorable climatic conditions during the plant cycle. It was observed that, in the ICLF system, FLH and EIH were negatively affected by tree growth in 2012/2013 and 2013/2014, compared with 2011/2012 (Table 2). The reduction in plant size was significant for corn intercropped with the *U. brizantha* 'Piatã', *U. ruziziensis*, and *U. decumbens* 'Basilisk' forages.

There was a reduction in plant size in the ICLF system compared with full sun in 2012/2013 and 2013/2014, with a mean reduction of 20 and 47 cm in FLH, respectively. This was probably due to the increase in the shading level caused by tree growth. Significant differences were observed for FLH in 2012/2013 in the intercrop with the 'Xaraés' and 'Piatã' forages, and in 2013/2014 in the intercrop with *U. ruziziensis* and *U. decumbens* 'Basilisk' (Table 2).

Table 1. Mean squares, significance of sources of variation, and their interactions for the evaluated parameters[1].

Sources of variation	Mean squares										
	PH	EH	GY	MWE	TGW	EI	PEGY	CSY	TSFY	PECS	PETSF
CS	1.41**	0.53**	1.34x10⁸**	26,251.30**	21,241.88**	80.88ns	23,710.24**	471,760,595.29**	473,342,612.74**	18,116.77**	17,757.51**
Error (a)	4.42	2.42	1278991.	156.11	85.46	21.83	273.21	7770421.74	9191751.70	265.33	285.70
CF	8.29**	3.63**	827879.2*	207.97**	232.40**	37.14ns	73.76ns	16101093.46**	14227394.36**	10.99ns	15.22ns
CS x CF	4.09ns	1.22ns	425370.9ns	19.94ns	398.91*	44.78ns	73.76ns	90780.27ns	78663.58ns	10.99ns	15.22ns
Error (b)	1.82	1.01	243640.5	45.07	142.8783	20.19	54.82	14063281.14	16016395.34	524.42	548.80
Crop year	1.18**	7.70**	1.04x10⁸**	24,232.88**	189,477.1**	20.65**	7,143.41**	171,305,945.26**	233,595,880.21**	5,700.89**	6544.59**
CS x crop year	0.61**	0.16**	3.32x10⁷**	6,702.17**	3,880.98**	23.81ns	7,143.41**	138,031,101.99**	162,949,928.48**	5,700.89**	6544.59**
CF x crop year	7.40**	4.27**	1,805,697.0**	275.22**	712.28**	34.87ns	30.05ns	2392210.74ns	3,541,953.39**	41.09ns	44.64ns
CS x CF x Crop year	7.93**	4.08**	105,602.9ns	55.81ns	181.04ns	36.72ns	30.05ns	1861762.02ns	1,960,859.42ns	41.09ns	44.64ns
Error (c)	1.37	97.92	399,047.5	54.65	105.79	28.84	85.51	15,578,328.26	15,334,993.18	538.42	521.06
CV (%)	5.48	8.34	9.73	7.93	3.87	5.41	10.75	8.69	7.71	8.96	7.80

[1]CS, cropping systems; CF, forage cultivars; PH, corn plant height (m); EH, corn ear height (m); GY, grain yield corrected to 13% moisture (kg⁻¹ ha); MWE, mean weight of ears (g); TGW, 1,000-grain weight (g); EI, corn ear index; PEGY, production efficiency of corn grain yield (%); CSY, corn silage yield (kg ha⁻¹); TSFY, total silage and forage yield (kg ha⁻¹); PECS, production efficiency of corn silage (%); and PETSF, production efficiency of total silage and forage yield (%). * and **Significant at 5 and 1% probability, respectively. nsNonsignificant by the F-test.

In the intercrop with the forage grasses in full sun, in 2011/2012 and 2012/2013, there were no differences regarding FLH (Table 2). Ramella et al. (2013) also did not find any effect on the development and yield of corn when intercropped with *U. brizantha*.

In the full sun system, EIH did not differ between crop years, except when corn was intercropped with the Piatã cultivar, which stood out in 2013/2014 (Table 2). In the ICLF, the intercrop with *U. ruziziensis* and *U. decumbens* presented similar EIH, whereas the others did not differ between crop years. As observed for FLH, tree growth over the crop years also affected EIH, which showed mean reductions of 13 and 26 cm in 2012/2013 and 2013/2014, respectively.

Silva et al. (2016) evaluated the development of 'BRS 1055' corn in an ICLF system, intercropped with *U. ruziziensis* between eucalyptus stands; in the Santa Fé system, also intercropped with *U. ruziziensis*; and in monocrop. The authors found that the structural components EIH and FLH did not differ according to the systems used.

The effect of the interaction year x cropping system was significant for CSY, TSFY, GY, TGW, and MWE (Table 1). In the ICLF system, reductions in yields (MWE and TSFY) were observed over the years (Table 3), possibly because of the increased competition of the tree component due to its growth and interception of light (shoot) and water and nutrients (roots). In this type of system, the forest component may affect the agricultural and livestock components because of the competition for light, water, and nutrients (Mosquera-Losada et al., 2010). When comparing CSY and TSFY in the ICLF and full sun systems in the 2011/2012 crop year, the average

Table 2. Corn (*Zea mays*) plant (PH) and ear insertion (EIH) heights in the integrated crop-livestock-forestry (ICLF) and full sun (FS) systems, intercropped with the forages *Urochloa brizantha* 'Marandú', 'Xaraés', 'Piatã'; *U. ruziziensis*; and *U. decumbens* in three crop years[1].

System	Year	Intercrop with different forage species				
		Marandú	Xaraés	Piatã	Ruziziensis	Decumbens
		Plant height (m)				
ICLF	2011/2012	2.26aA	2.25aA	2.44aA	2.37aA	2.39aA
	2012/2013	1.84aA	1.90aA	1.91bA	1.87bA	1.93bA
	2013/2014	1.88aA	1.91aA	1.90bA	1.82bA	1.74bA
Full sun system	2011/2012	2.26aA	2.34abA	2.22abA	2.39aA	2.37aA
	2012/2013	2.09aA	2.03bA*	2.05bA*	2.15aA	2.16aA
	2013/2014	1.89aB	2.59aA*	2.57aA*	2.19aAB*	2.35aAB*
		Ear insertion height (m)				
ICLF	2011/2012	1.08aA	1.12aA	1.27aA	1.23aA	1.24aA
	2012/2013	1.17aA	1.18aA	1.16aA	1.12abA	1.19abA
	2013/2014	1.04aA	1.11aA	1.03aA	0.94bA	0.93bA
Full sun system	2011/2012	1.20aA	1.26aA	1.10bA	1.17aA	1.21aA
	2012/2013	1.27aA	1.23aA	1.28abA	1.32aA	1.37aA
	2013/2014	1.02aB	1.50aA*	1.41aA*	1.21aAB*	1.21aAB*

[1]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Tukey's test, at 5% probability. *Significant between systems by Tukey's test, at 5% probability.

Table 3. Corn (*Zea mays*) grain yield (GY), 1,000-grain weight (TGW), mean weight of ears (MWE), silage yield (CSY), and total silage and forage yield (TSFY) in the integrated crop-livestock-forestry (ICLF) and full sun (FS) systems in 2011/2012, 2012/2013, and 2013/2014 crop years[1].

System	Grain yield (kg ha^{-1})			TGW (g)			MWE (g)			CSY (kg ha^{-1})			TSFY (kg ha^{-1})		
	2011/ 2012	2012/ 2013	2013/ 2014	2011/ 2012	2012/ 2013	2013/ 2014	2011/ 2012	2012/ 2013	2013/ 2014	2011/ 2012	2012/ 2013	2013/ 2014	2011/ 2012	2012/ 2013	2013/ 2014
ICLF	6,297aB	7,024bA	2,978bC	327.2aA	255.8bB	173.4bC	88.7bB	102.7bA	43.9bC	15,413.2aA	12,969.4bA	8,034.2bB	16,536.7aA	13,167.1bA	8,117.6bB
FS	6,529aB	9,262aA	6,851aB	331.0aA	293.8aB	211.4aC	90.6aC	136.2aA	97.2aB	15,436.8aA	17,439.8aA	15,436.7aA	16,272.1aA	17,581.9aA	15,685.6aA

[1]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Tukey's test, at 5% probability.

silage yields were similar, decreasing in the following crops. It should be noted that, in the studied systems, CSY corresponded to 94.0, 98.8, and 98.6% of TSFY for 2011/2012, 2012/2013, and 2013/2014, respectively, which is an indicative of a low contribution regardless of the system. Gontijo Neto et al. (2014) assessed corn silage and grain yields between lines of 22-month-old eucalyptus and found that the silage yield of corn intercropped with brachiaria decreased around 35% in comparison with that of the area cultivated without the forest component. The authors also observed that, in the following years, corn yield was even more compromised, with a reduction of 48% in silage yield and of up to 63% in grain yield, which can be explained by the greater competition between eucalyptus trees and the crop between stands as the trees grew over the years. Bertomeu (2012) reported a reduction of 19–66% in shoot biomass and corn GY in an ICLF system composed of cloned eucalyptus hybrids, compared with corn in monoculture, which was also attributed to increased competition for light, water, and nutrients.

Regarding GY, there were no significant differences in this component or in TGW and MWE since eucalyptus was established in 2011/2012, which indicates that the trees did not compete with corn and forages (Table 3). When competition occurs between species, plants undergo morphological changes that directly affect the uptake of radiation and accumulation of photoassimilates, with consequences for corn grain yield (Mendes et al., 2013).

In the following crops (2012/2013 and 2013/2014), there was a significant reduction in GY in the ICLF system compared with full sun, with the highest decreases observed in 2013/2014, which is indicative that the competitive pressure exerted by the tree component on corn and forage crops increases with tree growth (Table 3).

The results of the first harvest (2011/2012) were similar to those verified by Porfírio-da-Silva et al. (2015), who did not find a shading effect on corn yield in the ICLF, in the region of Campos Gerais, in the state of Paraná, Brazil. The authors obtained a mean GY of 4.25 Mg ha⁻¹ in the monocrop and of 4.55 in the ICLF system with eucalyptus with 4.8 m in height and spaced at 14x3 m.

No significant effect was observed for the interaction cropping system x intercropped forage cultivars for the variables GY, CSY, and TSFY; however, there was an effect of the interaction crop year x forage on GY and TSFY (Table 1). These results show that the evaluated forage grasses intercropped with corn did not affect CSY and TSFY in the different cropping systems in the first three years of establishment (Table 4). In relation to GY, corn intercropped with 'Marandú' grass stood out in 2011/2012; however, in 2012/2013, together with the Xaraés cultivar, the GY values were the lowest and there was no significant difference between the different forage cultivars in 2013/2014. Tsumanuma et al. (2012) also found that corn crop yield was not affected by *U. brizantha* and that the production of this grass species is very similar to that of *U. decumbens* when intercropped with corn.

Table 4. Corn (*Zea mays*) grain yield (GY), total silage and forage yield (TSFY), 1,000-grain weight (TGW), and mean weight of ears (MWE) when intercropped with the forages *Urochloa brizantha* 'Marandú', 'Xaraés', and 'Piatã'; *U. ruziziensis*; and *U. decumbens* in three crop years[1].

Forage specie	Crop years		
	2011/2012	2012/2013	2013/2014
	Grain yield (kg ha⁻¹)		
Marandú	7,295aA	7,541bA	5,293aB
Xaraés	6,314bB	7,895bA	5,032aC
Piatã	6,230bB	8,722 aA	4,933aC
Ruziziensis	6,032bB	8,034abA	4,646aC
Decumbens	6,192bB	8,523aA	4,669aC
	TSFY (kg ha⁻¹)		
Marandú	15,420.94aA	15,838.74aA	12,205.01aA
Xaraés	17,202.47aA	15,805.28aA	13,029.09aA
Piatã	16,978.31aA	16,360.37aA	12,442.68aA
Ruziziensis	16,794.95aA	14,148.13aAB	10,650.02aB
Decumbens	15,632.85aA	14,720.02aA	10,678.04aA
	TGW (g)		
Marandú	340.82abA	263.91bB	199.41aC
Xaraés	338.08abA	270.78abB	192.96aC
Piatã	324.01bA	281.56aB	190.90aC
Ruziziensis	330.60bcA	277.97aB	189.81aC
Decumbens	311.87cA	279.69aB	188.85aC
	MWE (g)		
Marandú	102.10aB	112.25bA	76.06aC
Xaraés	91.32bA	119.76abB	71.48aC
Piatã	88.15bA	124.76aB	70.69aC
Ruziziensis	83.43bA	118.38abB	66.73aC
Decumbens	83.34bA	121.69abB	67.65aC

[1]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Tukey's test, at 5% probability.

This result contrasts with those of Chioderoli et al. (2010), who reported that autumn corn intercropped with *U. ruziziensis* had higher GY values, differing from *U. brizantha*.

The reductions in GY observed between the ICLF and full sun systems probably resulted from decreases in TGW and MWE, which did not differ between systems in the 2011/2012 crop year. These same parameters showed reductions of approximately 13 and 24.6% and of 18 and 54%, respectively, in 2012/2013 and 2013/2014.

Regarding the corn ear index, there was a year effect (Table 1), with 1.02 ear per plant in 2011/2012 and 0.99 and 0.97 ear per plant in 2012/2013 and 2013/2014, respectively, probably due to increased shading by trees (Paciullo et al., 2011). Considering that the useful area of the ICLF system sown with corn was 0.867 ha, the yields obtained in 1 ha were 5,459, 6,097, and 2,582 kg ha^{-1} grains and 14,337, 11,416, and 7,038 kg ha^{-1} silage in the 2011/2012, 2012/2013, and 2013/2014 crop years, respectively.

It should be pointed out that the silage + forage and grain yields (GY, CSY, and TSFY) in the full sun system were significantly higher in 2011/2012, probably due to the better climatic conditions, i.e., rainfall distribution, during the corn growing cycle (Table 3). When evaluating the production efficiencies of silage + forage (PECS and PETSF) and grain (PEGY) yields in the ICLF system, there was a significant interaction between cropping systems and year (Table 1). In the year the tree component was established (2011/2012), PEGY, PECS, and PETSF showed similar behavior in the first cycle in both cropping systems (Table 5). However, when

compared with the full sun system, ICLF showed a decrease of around 25% in the production efficiency of silage + forage and grain yield in 2012/2013, and of 48% in silage yield and 56% in grain yield in 2013/2014. These reductions in production efficiencies are explained by the interspecific competition for resources, since there is a decrease in the radiation that affects the sub-forest as trees grow (Ding & Su, 2010; Mosquera-Losada et al., 2010; Bertomeu, 2012; Gontijo Neto et al., 2014).

For silage and grain yield efficiencies, there were no significant effects of forage species used in the intercrop or of their interactions with cropping system and year (Table 5). This is indicative that there was no difference between the forage species evaluated for intercropping with corn and eucalyptus in the first three years of the experiment.

Conclusions

1. The agronomic attributes, yield, and production efficiency of corn (*Zea mays*) are not affected by eucalyptus stands in the year of the integrated crop-livestock-forestry (ICLF) system is established.

2. The growth of trees in the harvests following the establishment of the ICLF system increases losses in the production efficiency of corn grains and silage.

3. The cultivars of *Urochloa* sp. evaluated in the intercrop do not affect the production efficiency of corn grains and silage.

Acknowledgments

Table 5. Production efficiency of corn (*Zea mays*) grain yield (PEGY), silage (PECSY), and total silage and forage yield (PETSFY) in the integrated crop-livestock-forestry (ICLF) and full sun (FS) systems in three crop years[1].

Variable	System	Production efficiency (%)		
		2011/2012	2012/2013	2013/2014
PEGY	ICLF	99.85aA	75.86bB	43.39bC
	FS	100.0aA	100.0aA	100.0aA
PECSY	ICLF	99.82aA	74.36bB	52.10bC
	FS	100.0aA	100.0aA	100.0aA
PETSFY	ICLF	101.64aA	74.86bB	51.77bC
	FS	100.0aA	100.0aA	100.0aA

[1]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Tukey test, at 5% probability.

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