DOI: 10.5433/1679-0359.2019v40n3p1185

Agronomic and productive characteristics of maize and Paiaguas palisadegrass in integrated production systems

Características agronômicas e produtivas do milho e capim-paiaguás em sistemas integrados de produção

Analu Guarnieri[1]; Kátia Aparecida de Pinho Costa[2*]; Eduardo da Costa Severiano[2]; Alessandro Guerra da Silva[3]; Suelen Soares Oliveira[4]; Charles Barbosa Santos[1]

Abstract

Currently, mixed systems for growing annual crops with forage plants of the *Brachiaria* genus represent an excellent alternative for the cultivation of maize by using the area for agricultural and livestock farming, which provides higher income to the grower and sustainability to the agricultural systems of the Cerrado. However, little is known about the best means for sowing such intercropped plants. Thus, the objective of this study was to evaluate the agronomic characteristics of maize (*Zea mays*) as well as the productive and nutritional characteristics of Paiaguas palisadegrass (*Brachiaria brizantha* cv. BRS Paiaguas) as the second crop in integrated production systems. The experimental design used randomized blocks with four replications. The treatments consisted of the following forage systems: monocropped of maize, monocropped of Paiaguas palisadegrass, maize intercropped with Paiaguas palisadegrass in rows, maize intercropped with Paiaguas palisadegrass between rows, and maize with oversown Paiaguas palisadegrass. The results showed that intercropping of maize with Paiaguas palisadegrass does not interfere with the agronomic characteristics or grain yield of maize, regardless of the system that was adopted. Regarding the production of forage, low production of dry matter was found for Paiaguas palisadegrass oversown in maize, though the nutritional value was better. Intercropping maze and Paiaguas palisadegrass is relevant to integrated production systems, as it allows for of a third harvest in the same crop year, which maintains sustainability especially because a smaller arable area is used compared to conventional systems.

Key words: *Brachiaria brizantha*. Sustainability. *Zea mays.*

Resumo

Atualmente, os sistemas mistos com exploração de culturas anuais com forrageiras do gênero *Brachiaria*, representam excelente alternativa para a cultura do milho pela utilização da área para exploração agrícola e pecuária, proporcionando assim maior renda ao produtor e sustentabilidade aos sistemas agrícolas do cerrado. No entanto, pouco se conhece sobre a melhor forma de semeadura das culturas em consórcio. Assim, desenvolveu esse estudo com objetivo de avaliar as características agronômicas do milho (Zea mays), bem como as características produtivas e nutricionais do capim-paiaguás (*Brachiaria brizantha*

[1] Drs. em Ciências Agrárias, Instituto Federal Goiano, Campus Rio Verde, IF Goiano, Rio Verde, GO, Brasil. E-mail: analuguarnieri@gmail.com; charles.bscarvalho@hotmail.com

[2] Profs., Programa de Pós-Graduação em Ciências Agrárias/Agronomia, IF Goiano, Campus Rio Verde, Rio Verde, GO, Brasil. Bolsistas de Produtividade em Pesquisa do CNPq. E-mail: katia.costa@ifgoiano.edu.br; eduardo.severiano@ifgoiano.edu.br

[3] Prof., Programa de Pós-graduação em Produção Vegetal, Universidade de Rio Verde, UniRV, Rio Verde, GO, Brasil. E-mail: silvaag@yahoo.com.br

[4] M.e em Zootecnia, IF Goiano, Campus Rio Verde, Rio Verde, GO, Brasil. E-mail: suelen.rv.zootecnia@hotmail.com

[*] Author for correspondence

Received: Feb. 19, 2018 - Approved: Feb. 13, 2019

cv. BRS Paiaguás) em sistemas integrados de produção, na safrinha. O delineamento experimental utilizado foi o de blocos casualizados, com quatro repetições. Os tratamentos consistiram dos sistemas forrageiros: milho em monocultivo; capim-paiaguás em monocultivo; milho consorciado com capim-paiaguás na linha; milho consorciado com capim-paiaguás na entrelinha e milho com capim-paiaguás na sobressemeadura. O cultivo consorciado do milho com o capim-paiaguás não interferiu nas características agronômicas, bem como a produtividade de grãos do milho, independentemente do método de semeadura. Quando sobressemeado, o capim-paiaguás apresentou baixa produção de forragem, no entanto, com melhor qualidade. O consórcio do milho com o capim-paiaguás é relevante para os sistemas integrados de produção, pois permite uma terceira colheita no mesmo ano agrícola, mantendo a sustentabilidade, principalmente por utilizar menor área agricultável em relação aos sistemas convencionais.
Palavras-chave: *Brachiaria brizantha.* Sustentabilidade. *Zea mays.*

Introduction

Maize has great economic and social importance within agricultural production systems and is one of the main crops in the agro-industrial complex and agricultural cultivation (BRAMBILLA et al., 2009). In some systems, maize production is divided into two periods: the first period is considered to be the harvest or summer crop, whereas the second period is the second crop, occurring after harvest of another crop such as soybean. Despite a recent reduction in the area cultivated during the first harvest, production has been compensated for by increased yield and area for the late-season crop (GALVÃO et al., 2015).

Monoculture and inadequate soil management in agriculture (e.g., excessive use of the harrow) have caused a reduction in carbon stocks, leading to degradation of soil and natural resources and declines in crop productivity. Thus, one of the best options for enhancing the productivity of grain and livestock, as well as the recovery of degraded pastures, is the adoption of intercropping, especially in the Cerrado region in central Brazil (VILELA et al., 2012).

Currently, intercropping systems for agriculture and livestock, involving annual crops and forage plants of the genus *Brachiaria*, stand out as tools for intensifying the development of areas intended for farming in Brazil (SEIDEL et al., 2014). Furthermore, due to the high efficiency of storing carbon in the soil (sequestration of atmospheric carbon) via the root system of plants, intercropping as a type of soil management mitigates the greenhouse effect and preserves the environment in a sustainable manner (CARVALHO et al., 2010). Indeed, intercropping enables the recovery of degraded pasture, increases the amount of biomass to soil coverage for the establishment of no-tillage systems, enables increased yields of the subsequent crop (CHIODEROLI et al., 2010) and might not interfere with the yield of the intercropped annual crop (RIBEIRO et al., 2015; COSTA et al., 2016). Additionally, intercropping of off-season maize and forage plants allows for diversification of the crop without altering the cultivation of soybeans in summer (ALVARENGA et al., 2006).

Brachiaria brizantha cv. BRS Paiaguás (Paiaguas palisadegrass) was recently released in an effort to obtain high yields, especially during periods of low rainfall. This cultivar is adapted to average soil fertility and exhibits high yield, vigor, and seed production (VALLE et al., 2013). These features render it an excellent option for the production of quality forage by the second crop and for the formation of biomass under no tillage in integrated farming-livestock systems, a promising cultivation technique for correct management of maize to avoid competition with *Brachiaria* plants (CECCON et al., 2014; SANTOS et al., 2016; COSTA et al., 2016).

However, little is known regarding the intercropping of Paiaguas palisadegrass with maize under second-crop conditions. Therefore, identification of the best system for planting these crops simultaneously will allow for the development of grain and forage production in the second crop. Thus, the objective of this study was to evaluate the agronomic characteristics of maize (*Zea mays*) as well as the productive and nutritional characteristics of Paiaguas palisadegrass (*Brachiaria brizantha* cv. BRS Paiaguas) as the second crop in integrated production systems.

Materials and Methods

The experiment was conducted in the field (17°48' S; 50°55' W; and 748 m elevation) in the municipality of Rio Verde, Goiás, Brazil, in the 2015 offseason. The soil is dystroferric Red Latosol (EMBRAPA, 2013).

Before planting, soil samples were collected from the 0-20-cm layer to assess the physical and chemical characteristics of the experimental area. The following values were obtained: 580, 140 and 280 g kg^{-1} of clay, silt and sand, respectively; $CaCl_2$ pH 4.93; Ca 2.59, Mg 1.10, Al 0.10, Al+H 5.9, K 0.20 (units $cmol_c$ dm^{-3}); cation exchange capacity (CEC) 9.74 $cmol_c$ dm^{-3}; P (mehlich) 1.65, Cu 3.05, Zn 4.30, and Fe 32.5 (units mg dm^{-3}); organic matter (OM) 25.6 g dm^{-3}.

Prior to the experiment, glyphosate (1260 g ae ha^{-1}) was applied at a spray volume of 100 L ha^{-1} to control weed desiccation. One week before implementation of the experiment, disking was performed followed by the use of a leveling harrow.

The experimental design used randomized blocks with four replications. The treatments consisted of the following forage systems: monocropped of maize, monocropped of Paiaguas palisadegrass, maize intercropped with Paiaguas palisadegrass in rows, maize intercropped with Paiaguas palisadegrass between rows, and maize with oversown of Paiaguas palisadegrass. The maize hybrid AS 1581 (simple hybrid, semi-early, with medium-hard orange-colored grains) and *Brachiaria brizantha* cv. BRS Paiaguas were used.

Sowing was carried out on February 11, 2015, with 240 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of FTE BR 12 depending on the soil analysis and maize requirements. Monocropped and intercropped maize was sown at a depth of 3 cm. Paiaguas palisadegrass was sown in rows at a depth of 6 cm. When intercropped, palisadegrass was sown at a distance of 0.25 m from the maize rows; for the oversown condition, palisadegrass was sown in the inter-row (0.25 m distance) at 10 days after maize sowing.

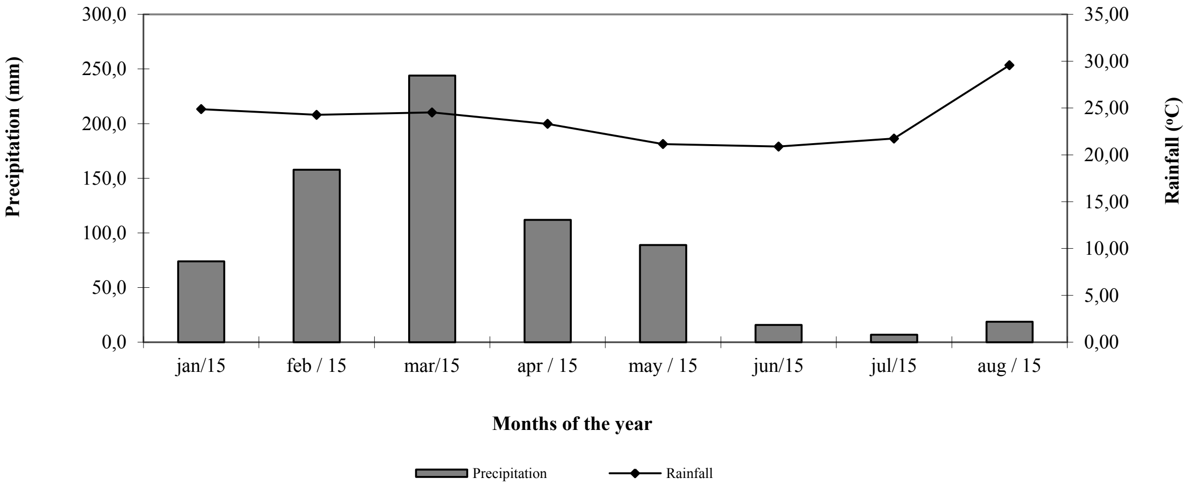
The monocropped and row-intercropped plots were composed of eight rows, 4 m in length, with a spacing of 0.50 m. For intercropping between rows, 15 rows were used, with eight rows of maize and seven rows of Paiaguas palisadegrass, for a total of 16 m². The furrows for sowing of maize and Paiaguas palisadegrass were manually dug with the use of hoes.

Two weeks after seedling emergence, thinning was carried out, aiming to establish population 60,000 plants ha^{-1}. When the maize plants were at the stage of three and six fully developed leaves, cover fertilizations were carried out by applying 150 and 75 kg ha^{-1} of N and K_2O using urea and potassium chloride, respectively.

Hand weeding was performed weekly up to 50 days after emergence to avoid competition between the species (maize and *Brachiaria*). For the control of *Spodoptera frugiperda*, clorantraniliprole applications were performed (0.125 L ha^{-1}) at 40 and 50 days after sowing (DAS). For disease control, picoxystrobin + cyproconazole applications were performed (0.3 L ha^{-1}) at 37 and 44 DAS. Both applications were carried out manually by spraying.

Daily rainfall and mean monthly temperature data were monitored during the experiment (Figure 1).

Figure 1. Rainfall and mean temperature recorded from January 2014 to August de 2015, in Rio Verde-Goias.



For intercropping and monocropped maize, 10 plants in the useful area of the plots were evaluated for the following: plant height (at 30, 60 and 90 DAS based on height of plants to the first leaf node until the end of the last fully developed leaf for the first evaluation and until the end of the tassel for the other evaluation periods), stem diameter at the base (obtained using a caliper, by measuring the base of the stem between the first two internodes), leaf number (all leaves), plant population (the number of plants at harvest), number of grains per ear (spike grains), ear index (ratio between the number of ears per area and to that of the stand), ear length (length between two plants ears), ear weight with the husk and dehusked (average weight of two cobs with and without straw, respectively), thousand-grain weight (with moisture correction to 13%) and grain yield (weight with 13% moisture correction with grains).

After the maize harvest, the Paiaguas palisadegrass plant height was assessed (cm) using a graduated measuring tape; the number of tillers per linear meter were counted, and the dry matter yield was measured until the onset of the rainy season (September). The forage was evaluated over successive cuts (0.20 m from the ground), based on samples of 1 m^2 randomly collected from each plot.

The first cut occurred at the time of the maize harvest on 06/19/15, and the second cut was conducted 63 days after the first cut, on 08/21/15, due to the slow development of the forage grass under low rainfall, i.e., the dry season. After assessment of both cuts, a standard cut of all plants in the experimental area was carried out, at the same height as that used for the evaluated plants, and the resulting residue was removed from the area. Subsequently, the Paiaguas palisadegrass was left to rest for regrowth, allowing it desiccate to form biomass for soybean planting during the next crop season.

The collected material was packed in plastic bags and weighed for determining total dry matter production. The material was then transported to the laboratory where a representative (500 g) sample was collected from each plot and dried in a forced-air oven at 55ºC. Subsequently, the samples were ground in a Wiley mill using a 1-mm diameter sieve and stored in plastic containers for further analysis.

Bromatological analyses were performed to determine the dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) using the methods reported by Silva and Queiroz (2002). In vitro dry matter digestibility

(IVDMD) was assessed using the method described by Tilley and Terry (1963) and was adapted to the artificial rumen developed by ANKON® using the "Daisy incubator" device from Ankom Technology (*in vitro true digestibility*, IVTD).

Data were subjected to analysis of variance, and means were compared using Tukey's test, with a significance level of 5%. For forage evaluation (where two cuttings were implemented), analyses were performed via the split-plot model in accordance with the adaptation of the Gauss-Markov linear model using SISVAR 4.6 software (FERREIRA, 2011).

Results and Discussion

Cultivation of maize

Plant height was influenced by the forage system ($p<0.05$). At 30 and 60 DAS, the presence of the forage plants in the row where maize was sown showed reduced growth in comparison with that occurring under the other methods (Table 1). However, this was not maintained at 90 DAS, a time when the method of forage plant sowing did not affect the development of maize. This reduction in the growth of the maize plants in the initial developmental phase was most likely due to interspecific competition for water, light, and nutrients.

Table 1. Plant height, stem diameter and number of leaves of monocropped maize and intercropped with Paiaguas palisadegrass under different forage systems at 30, 60 and 90 DAS.

Forage systems	**30 DAS**	**60 DAS**	**90 DAS**
		Plant height (m)	
Monocropped maize	0.27 a	1.67 a	1.85 a
Row maize x Paiaguas palisadegrass	0.23 b	1.41 b	1.89 a
Between rows maize x Paiaguas palisadegrass	0.27 a	1.69 a	1.87 a
Oversown maize x Paiaguas palisadegrass	0.27 a	1.63 a	1.90 a
CV (%)	3.48	4.46	4.06
		Stem diameter (mm)	
Monocropped maize	18.74 a	25.19 a	30.75 a
Row maize x Paiaguas palisadegrass	15.01 b	22.01 b	26.50 b
Between rows maize x Paiaguas palisadegrass	19.62 a	24.54 b	30.00 a
Oversown maize x Paiaguas palisadegrass	18.65 a	24.89 a	29.50 a
CV (%)	6.57	4.46	5.03
		Number of leaves	
Monocropped maize	2.75 a	4.70 a	4.75 a
Row maize x Paiaguas palisadegrass	2.50 b	3.95 b	4.25 b
Between rows maize x Paiaguas palisadegrass	2.75 a	4.65 a	4.70 a
Oversown maize x Paiaguas palisadegrass	2.6 a	4.55 a	4.60 a
CV (%)	9.05	5.93	11.71

Averages followed by different letters in the differ among themselves according to the Tukey's test at 5% probability.

Furthermore, competition between the species in the initial phase can be justified by the greater development of the root system in Paiaguas palisadegrass, which showed high accumulation of nutrients, thereby increasing competition for nutrients (especially phosphorus) with intercropped crops (BIANCO et al., 2005). Thus, a greater number of *Brachiaria* plants close to the maize plants corresponds to lower availability of phosphorus for the latter (SILVA et al., 2015), which explains the reduced maize development observed in this study.

Regarding the stalk diameter of the maize plants, sowing of Paiaguas palisadegrass in the same cultivation row caused greater competition, which resulted in a lower stem diameter at 30, 60, and 90 DAS (Table 1). In contrast, no significant difference was found for the other forage methods (p>0.05). This finding illustrates the greater degree of competition between Paiaguas palisadegrass and maize when using this sowing method, with is a greater need for water and nutrients when palisadegrass was sown in the same row as maize. It is worth noting that post-emergence herbicide was not used to suppress the growth of the forage plants.

The effects of competition in intercropping maize with *Brachiaria ruzizienis* have also been reported by Brambilla et al. (2009). In this case, a greater reduction in stalk diameter was observed when sowing was performed in the same row, thus reducing yield. This may be due to the stalk diameter being highly related to grain formation, as stored photoassimilates are relocated during grain filling.

The number of maize leaves revealed a reduction in leaf formation at 30, 60, and 90 DAS when Paiaguas palisadegrass was intercropped in the same row as maize (Table 1). This finding may be a result of intraspecific competition between the species due to the faster germination of Paiaguas palisadegrass in relation to other species of *Brachiaria* (COSTA et al., 2016; SANTOS et al., 2016). Although Paiaguas palisadegrass was sown at a greater depth (6 cm) than was maize, competition for water, light, nutrients, and physical space among the species occurred during the maize growth stage. As two species are grasses, they have the same C4 photosynthetic metabolism and efficiently exploit available light and possess highly efficient root systems for exploiting water and nutrients in soil (TAIZ; ZAIGER, 2010).

However, compared to growing maize alone, there was no significant effect when maize was intercropped with Paiaguas palisadegrass between rows and oversown (p>0.05) for the number of leaves (Table 1). These results demonstrate that either approach did not significantly impair the development of the annual crop.

With regard to plant population characteristics, there was no significant effect (p>0.05) of forage system on the number of grains per ear, ear index, length of maize ears, or husked and dehusked weights (Table 2). These results prove that maize intercropped with Paiaguas palisadegrass can be considered an excellent alternative for use in integrated crop-livestock systems as the second crop because it does not alter the yield characteristics of the maize crop.

Various studies evaluating the intercropping of maize with species of *Brachiaria* have found that intercropping does not influence plant population characteristics (BRAMBILLA et al., 2009; SEIDEL et al., 2014), number of grains per ear (GARCIA et al., 2013), length of ears (FREITAS et al., 2005), or weight of dehusked ears (MAIA et al., 2015). Nonetheless, Pariz et al. (2011) found an influence of forage system on the number of grains per ear due to competition between maize and *Brachiaria brizantha* cv. Marandu, *Brachiaria decumbens*, *Brachiaria ruziziensis*, and *Brachiaria* hybrid cv. Mulato II.

Table 2. Plant population, number of grains per ear, and ear index, length and weight of the husked and unhusked ears of monocropped maize and intercropped with Paiaguas palisadegrass under different forage systems.

Forage systems	Plant population (pls ha^{-1})	Number of grains per ear	Ear index
Monocropped maize	58.750 a	597.42 a	1.75 a
Row maize x Paiaguas palisadegrass	56.250 a	584.79 a	1.40 a
Between rows maize x Paiaguas palisadegrass	60.000 a	604.60 a	1.75 a
Oversown maize x Paiaguas palisadegrass	57.500 a	591.42 a	1.50 a
CV (%)	5.55	5.13	35.14
Forage systems	**Length ears (cm)**	**Weight of ears husked (g)**	**Weight of ears unhusked (g)**
Monocropped maize	19.00 a	319.00 a	269.52 a
Row maize x Paiaguas palisadegrass	19.25 a	281.00 a	250.11 a
Between rows maize x Paiaguas palisadegrass	19.00 a	298.75 a	252.78 a
Oversown maize x Paiaguas palisadegrass	19.00 a	283.75 a	251.74 a
CV (%)	3.74	6.15	8.91

Averages followed by equal letters do not differ among themselves according to the Tukey's test at 5% probability.

The thousand-grain weight and maize grain yield were similar ($p>0.05$) in the different forage systems (Table 3), further demonstrating the feasibility of intercropping methods in which Paiaguas palisadegrass does not hinder the development of maize with respect to the final grain yield.

Table 3. Thousand grain weight and grain yield of monocropped maize and intercropped with Paiaguas palisadegrass under different forage systems.

Forage systems	Thousand grain weight (g)	Grain yield (kg ha^{-1})
Monocropped maize	341 a	11.138 a
Row maize x Paiaguas palisadegrass	305 a	10.143 a
Between rows maize x Paiaguas palisadegrass	326 a	10.658 a
Oversown maize x Paiaguas palisadegrass	329 a	9.565 a
CV (%)	5.05	12.36

Averages followed by equal letters do not differ among themselves according to the Tukey's test at 5% probability.

The behavior of the thousand-grain weight and grain yield is correlated with the plant population, number of grains per ear, ear index, and length of maize ears because these characteristics are influenced by environmental conditions and genotype (DEMETRIO et al., 2008; FREITAS et al., 2013; SEIDEL et al., 2014).

This absence of an effect of the intercropping system on the maize grain yield was similar to the results of studies by Borghi and Cruciol (2007) and Denardin et al. (2008) for maize grown in the summer season and Seidel et al. (2014) for off-season cultivation, regarding intercropping of maize with *Brachiaria brizantha* cv. MG-4.

Alvarenga et al. (2006), when intercropped with *Brachiaria*, maize generally showed an average reduction of 5% in grain yield. In off-season maize, the reduction in productivity is related to competition between the species used and is particularly related to the utilization of light and nutrients (BRAMBILLA et al., 2009) as well as maize and *Brachiaria* populations (CECCON et al., 2014).

The results of this study showed that none of the maize intercropped in any of the forage systems was influenced by the presence of Paiaguas palisadegrass, thus demonstrating that the latter can be recommended as a forage plant in integrated crop-livestock systems for the production of grain by the second crop.

Currently, monocropped of annual crops is not justifiable because there is increasing global concern about the environment, the survival of the planet, and sustainable food production. However, intercropped systems using forage plants can address these concerns, thus promoting sustainability (COSTA et al., 2016; SANTOS et al., 2016).

Cultivation of Brachiaria

The forage system influenced ($p<0.05$) the height of the Paiaguas palisadegrass plants at both cuttings (Table 4). Paiaguas palisadegrass in the oversown system displayed a shorter stature, which affected the development of the forage plants and resulted in increased competition between the plants because the forage plants had been established 10 days after sowing of maize. In addition, there was greater interspecific competition between the plants as well as maize shading during the initial Paiaguas palisadegrass developmental stage.

Table 4. Plant height, number of tillers, leaf blade/stem ratio and dry matter yield of monocropped Paiaguas palisadegrass and intercropped under different forage systems.

Forage systems	**First cut**	**Second cut**
	Plant height (m)	
Monocropped Paiaguas palisadegrass	1.27 Aa	0.80 Ab
Row maize x Paiaguas palisadegrass	1.07 Aa	0.48 Bb
Between rows maize x Paiaguas palisadegrass	0.97 Ba	0.51 Bb
Oversown maize x Paiaguas palisadegrass	0.65 Ca	0.42 Bb
CV (%)	17.05	
	Number of tillers (m)	
Monocropped Paiaguas palisadegrass	332.25 Aa	319.25 Aa
Row maize x Paiaguas palisadegrass	204.75 Ba	206.75 Ba
Between rows maize x Paiaguas palisadegrass	217.75 Ba	221.00 Ba
Oversown maize x Paiaguas palisadegrass	130.50 Cb	188.50 Ba
CV (%)	14.94	
	Leaf blade/stem ratio	
Monocropped Paiaguas palisadegrass	1.55 Ba	1.73 Aa
Row maize x Paiaguas palisadegrass	1.61 Ba	1.85 Aa
Between rows maize x Paiaguas palisadegrass	1.65 Ba	1.64 Aa
Oversown maize x Paiaguas palisadegrass	1.98 Aa	1.74 Aa
CV (%)	23.61	

continue

continuation

	Dry matter yield (kg ha^{-1})	
Monocropped Paiaguas palisadegrass	6.094 Aa	3.394 Ab
Row maize x Paiaguas palisadegrass	5.035 Ba	2.285 Bb
Between rows maize x Paiaguas palisadegrass	5.881 ABa	2.808 ABb
Oversown maize x Paiaguas palisadegrass	2.915 Ca	1.584 Cb
CV (%)	13.24	

Averages followed by different letters within a column (establishment systems) and row (cut) differ according to Tukey's test at 5% probability.

A similar behavior was observed by Seidel et al. (2014), who found a 62.22 and 54.61% reduction in plant height in the rows and between rows, respectively, when the sowing of *B. brizantha* cv. MG4 occurred 25 days after maize had been sown.

At the second cutting, after maize harvesting, the average plant height for the intercropped systems were similar, differing only from that of Paiaguas palisadegrass monocropped (Table 4). Although the oversown method affected plant height at the first cutting, Paiaguas palisadegrass showed good development after maize harvest at the second cutting. The upright growth of both forage plants contributed to the intercropped cultivation and was advantageous for the production of forage in the second crop.

When comparing the cuttings, greater plant heights were observed at the first cutting for all methods due to the increased distribution of rainfall in the growth phase of Paiaguas palisadegrass (Figure 1). At the second cutting, which occurred after the maize harvest, the levels of low rainfall adversely affected growth, the foliar development of the forage and plant height.

When evaluating pearl millet intercropped with Paiaguas palisadegrass in rows, between rows, and oversown, Costa et al. (2016) found that the former did not hinder the development of the latter in rows and between rows, as there was no competition for resources. Similar results for Paiaguas palisadegrass were found in the present study.

Overall, the number of Paiaguas palisadegrass tillers was influenced ($p<0.05$) by the forage system at both cuttings (Table 4). For the first cutting, the oversown system had the greatest effect on this variable. The delay of ten days after sowing, which was associated with the occurrence of shading during the initial development phase of the forage plant, hindered the development of new lateral buds, which are responsible for the formation of new tillers (SOARES et al., 2009). The highest values were obtained in Paiaguas palisadegrass monocropped, corroborating the findings of Costa et al. (2016) and Santos et al. (2016) regarding the intercropping of sunflower and millet, respectively, with Paiaguas palisadegrass via an oversown method.

However, for the second cutting, the results were similar among the systems, further demonstrating the advantage of intercropping, in which good forage development occurs after harvesting the annual crop, even in periods of low rainfall (Figure 1).

The highest leaf blade/stem ratio for the first cutting was obtained in the Paiaguas palisadegrass oversown system, thus differentiating this method ($p<0.05$) from the other systems (Table 4). This result was due to the lower development of the forage in this system, which caused reduced lengthening of the stalk and thus a higher leaf blade/stem ratio. However, for the second cutting, the ratio was similar among the forage systems. It is worth noting that at the second cutting, maize was no longer present in the system; thus, there was more uniform growth of the forage, even during periods when rainfall had not yet stabilized (July and August).

The leaf blade/stem ratio obtained in this study was greater than that reported by Leonel et al. (2009), who obtained a ratio of 1.0 for maize intercropped with Paiaguas palisadegrass. This difference is due to the morphology of Paiaguas palisadegrass, which has a higher proportion of leaf blades (COSTA et al., 2016).

The forage system influenced ($p<0.05$) the production of dry matter of Paiaguas palisadegrass (Table 4) at both cuttings. The methods of monocropped and intercropping between rows of maize produced high yields, demonstrating that such sowing methods do not adversely affect the development of the forage plant.

However, when Paiaguas palisadegrass was oversown with maize, production was inferior to that of the other systems at both cuttings. This can be attributed to the shorter development period because the forage plant was sown ten days after maize, causing greater shading by the latter. Maize grows quickly, and under intercropping conditions, it influences the growth behavior through an etiolating effect on the forage plant, consequently affecting the production of dry matter (GARCIA et al., 2013). The negative effect of oversowing on the production of dry matter of MG-4 palisadegrass was reported by Seidel et al. (2014), with a reduction of 82 and 63% when the forage plant was sown in rows and between rows, respectively, at 25 days after maize was sown.

The average production of dry matter of Paiaguas palisadegrass from the first and second cuttings was 4090 and 2510 kg ha^{-1}, respectively. These results were similar to those of Pariz et al. (2010), who obtained values of 4128 and 4168 kg ha^{-1} for *B. brizantha* cv. Marandu and *B. ruziziensis* intercropped with maize in rows and by broadcast seeding, respectively.

When comparing cuttings, a lower dry matter yield was obtained for the second cutting due to the slower regrowth under low rainfall and also to the decrease in temperature, factors that are important for the development and productivity of forage plants (COSTA et al., 2016). However, despite the influence of climatic factors on the forage yield, Paiaguas palisadegrass exhibited good regrowth ability, showing that this forage plant can be used as a feed supply in the second crop, after harvest of the annual crop, to minimize the seasonality of forage production.

The highest crude protein (CP) content was obtained in the system with oversown Paiaguas palisadegrass, and the result was significantly different from that of the other forage systems ($p<0.05$) (Table 5). This was due to the lower development of the stalk caused by increased competition in this seeding system. Consequently, there was a greater concentration of leaves. It is worth noting that the values obtained for all of the forage systems were greater than 8.3%, which is beneficial with respect to nutritional requirements. Rumen cellulolytic bacteria show improved development at a CP content equal to or greater than 7.0% (VAN SOEST, 1994).

In this study, the levels of CP for the first and second cuttings were similar to those found by Maia et al. (2014), who reported average CP levels of 9.0 to 13.4% for the months of September and October, respectively, when evaluating the bromatological composition of *Brachiaria* forage in the second crop after maize harvest in an integrated crop-livestock system.

When comparing cuttings (Table 5), lower CP levels were obtained in the first cutting for all forage systems. This may be because the first cutting was at the end of the maize cycle at 120 days and because in this period, the Paiaguas palisadegrass had already passed to the maturation stage, reducing the CP level. For the second cutting, *Brachiaria* was cut during the growth cycle at 61 days.

Regarding NDF levels, no significant effect was observed among the forage systems and between the cuttings ($p>0.05$); the results were similar (Table 5). For the first and second cuttings, the average NDF levels were 67.98 and 72.03%, respectively, similar to those reported by Costa et al. (2016) when evaluating the bromatological composition of Paiaguas palisadegrass intercropped with millet, with (for the first seeding period) an average NDF of 68.41% for intercropping in rows, between rows, and oversown and 74.12% for Paiaguas palisadegrass monocropped.

Table 5. Contents of CP, NDF, ADF and IVDMD of monocropped Paiaguas palisadegrass and intercropped under different forage systems.

Forage systems	First cut	Second cut
	CP (g kg^{-1})	
Monocropped Paiaguas palisadegrass	91.5 Bb	113.8 Aa
Row maize x Paiaguas palisadegrass	87.0 Bb	112.5 Aa
Between rows maize x Paiaguas palisadegrass	83.8 Bb	108.4 Aa
Oversown maize x Paiaguas palisadegrass	108.9 Aa	113.0 Aa
CV (%)	9.26	
	NDF (g kg^{-1})	
Monocropped Paiaguas palisadegrass	720.2 Aa	688.0 Ab
Row maize x Paiaguas palisadegrass	726.9 Aa	682.8 Ab
Between rows maize x Paiaguas palisadegrass	722.1 Aa	679.2 Ab
Oversown maize x Paiaguas palisadegrass	712.0 Aa	669.3 Ab
CV (%)	3.93	
	ADF (g kg^{-1})	
Monocropped Paiaguas palisadegrass	440.3 Aa	388.9 Ab
Row maize x Paiaguas palisadegrass	443.0 Aa	370.9 Ab
Between rows maize x Paiaguas palisadegrass	431.1 Aa	376.0 Ab
Oversown maize x Paiaguas palisadegrass	385.2 Ba	378.6 Aa
CV (%)	4.87	
	IVDMD (g kg^{-1})	
Monocropped Paiaguas palisadegrass	527.8 Ab	584.0 Aa
Row maize x Paiaguas palisadegrass	524.2 Ab	605.4 Aa
Between rows maize x Paiaguas palisadegrass	529.4 Ab	607.3 Aa
Oversown maize x Paiaguas palisadegrass	530.7 Ab	602.4 Aa
CV (%)	3.25	

Averages followed by different letters within a column (forage systems) and row (cut) differ according to Tukey's test at 5% probability.
CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; IVDMD: in vitro dry matter digestibility.

The higher NDF levels obtained at the first cutting (Table 5) were associated with the increased heights of the plants at this cutting due to the greater lengthening of the stalk (Table 4), which increases the abundance of supporting tissues in the plant (VAN SOEST, 1994).

As shown in Table 8, a lower ADF was obtained at the first cutting for the oversown Paiaguas palisadegrass system, which differed ($p<0.05$) from that of the other forage systems. This difference was due to the larger leaf blade/stem ratio and higher CP content, which resulted in a lower abundance of fibers.

Regarding the cuttings, lower levels of NDF and ADF were obtained at the second cutting (Table 5) because cutting was performed during the shortest cycle. Moreover, after the maize harvest, new tillers began to emerge, thus providing more digestible forage. These features demonstrate that maize intercropped with Paiaguas palisadegrass should be considered an alternative for use in integrated agriculture-livestock systems as the second crop, when the production and quality of forage is low.

The ADF averages found in this study were similar to those observed by Santos et al. (2016), who reported average levels of 45.29 and 37.8% for first and second cuttings, respectively, when evaluating Paiaguas palisadegrass intercropped with sunflowers in rows, between rows, and oversown.

Lastly, IVDMD was not influenced by the forage system ($p>0.05$) at either cutting, and the results were similar. However, when comparing cuttings, the highest values were obtained at the second cutting due to the lower number of components with a fibrous fraction and the higher CP content.

Conclusion

Intercropping of maize with Paiaguas palisadegrass does not interfere with the agronomic characteristics or grain yield of maize, regardless of the system adopted.

Regarding forage production, Paiaguas palisadegrass oversown in maize results in a low production of dry matter, though the nutritional value is better.

Intercropping maze and Paiaguas palisadegrass is relevant for integrated production systems, as it allows the occurrence of a third harvest in the same crop year, which maintains sustainability especially because it utilizes a smaller arable area compared to conventional systems.

Acknowledgments

We thank the Federal Institute of Goiás for supporting this study.

References

ALVARENGA, R. C.; CRUZ, J. C.; NOVOTNY, E. H. *Sistema de produção*. 2. ed. Sete Lagoas: Embrapa, 2006. Disponível em: http://www.cnpms.embrapa.br/publicações/milho/index.htm>. Acesso em: 12 set. 2017.

BIANCO, S.; TONHAO, M. A. R.; PITELLI, R. A. Crescimento e nutrição mineral de capim-braquiária. *Planta Daninha*, Viçosa, MG, v. 23, n. 3, p. 423-428, 2005.

BORGHI, E.; CRUCIOL, C. A. C. Produtividade de milho, espaçamento e modalidade de consorciação com *Brachiaria brizantha* em sistema plantio direto. *Pesquisa Agropecuária Brasileira*, Brasília, v. 42, n. 2, p. 163-171, 2007.

BRAMBILLA, J. A.; LANGE, A.; BUCHELT, A. C.; MASSAROTO, J. A. Produtividade de milho safrinha no sistema de integração lavoura-pecuária, na região de Sorriso, Mato Grosso. *Revista Brasileira de Milho e Sorgo*, Sete Lagoas, v. 8, n. 3, p. 263-274, 2009. DOI: 10.18512/1980-6477/rbms.v8n03p%25p

CARVALHO, J. L. N.; AVANZI, J. C.; SILVA, M. L. N.; MELLO, C. R.; CERRI, C. E. P. Potencial de sequestro de carbono em diferentes biomas do Brasil. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 34, n. 2, p. 277-289, 2010.

CECCON, G.; SILVA, J. F.; NETO NETO, A. L.; MAKINO, P. A.; SANTOS, A. dos. Produtividade de milho safrinha em espaçamento reduzido com populações de milho e de *Brachiaria ruziziensis*. *Revista Brasileira de Milho e Sorgo*, Sete Lagoas, v. 13, n. 13, p. 326-335, 2014. DOI: 10.18512/1980-6477/rbms.v13n3p326-335

CHIODEROLI, C. A.; MELO, L. M. M. de; GRIGOLLI, P. J.; SILVA, J. O. da R.; CESARIN, A. L. Consorciação de braquiárias com milho outonal em plantio direto sob pivô central. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 30, n. 6, p. 1101-1109, 2010. DOI: 10.1590/S0100-69162010000600011

COSTA, R. R. G. F.; COSTA, K. A. P.; SANTOS, C. B.; SEVERIANO, C. E.; EPIFANIO, P. S.; SILVA, J. T. da; TEIXEIRA, D. A. A.; SILVA, V. R. da. Production and nutritional characteristics of pearl millet and *Paiaguas palisadegrass* under different forage systems and sowing periods in the offseason. *African Journal of Agricultural Research*, Ebène, v. 11, n. 19, p. 1712-1723, 2016. DOI: 10.5897/AJAR2016.10902

DEMETRIO, C. S.; FORNASIERI FILHO, D.; CAZETTA, J. O.; CAZETTA, D. A. Desempenho de híbridos de milho submetidos a diferentes espaçamentos e densidades populacionais. *Pesquisa Agropecuária Brasileira*, Brasília, v. 43, n. 12, p. 1691-1697, 2008.

DENARDIN, J. E.; KOCHHANN, R. A.; SANTI, A.; FAGANELLO, A.; SATTLER, A. *Efeito da consorciação milho-braquiária (Brachiaria brizantha) na mitigação da compactação do solo.* Passo Fundo: EMBRAPA Trigo, 2008. 13 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. EMBRAPA Solos. Centro Nacional de Pesquisa de Solos. Sistema Brasileiro de Classificação de Solos. 3. ed. Rio de Janeiro: EMBRAPA CNPS, 2013. 353 p.

FERREIRA, D. F. *Sisvar*: a computer statistical analysis system. *Ciência e Agrotecnologia*, Lavras, v. 35, n. 6, p. 1039-1042, 2011. DOI: 10.1590/S1413-70542011000600001

FREITAS, F. C. L.; FERREIRA, L. R.; FERREIRA, F. A.; SANTOS, M. V.; AGNES, E. L.; CARDOSO, A. A.; JAKELAITIS, A. Formação de pastagem via consórcio de *Brachiaria brizantha* com o milho para silagem no sistema de plantio direto. *Planta Daninha*, Viçosa, MG, v. 23, n. 1, p. 49-58, 2005.

FREITAS, R. J.; NASCENTE, A. S.; SANTOS, F. L. S. População de plantas de milho consorciado com *Brachiaria ruziziensis*. *Pesquisa Agropecuária Tropical*, Goiânia, v. 43, n. 1, p. 79-87, 2013.

GALVÃO, J. C. C.; MIRANDA, G. V.; TROGELLO, E.; FRITSCHE-NETO, R. Sete décadas de evolução do sistema produtivo da cultura do milho. *Ceres*, Viçosa, MG, v. 61, n. 7, p. 819-828, 2015. DOI: 10.1590/0034-737X201461000007

GARCIA, C. M. P.; ANDREOTTI, M.; TEIXEIRA FILHO, M. C. M.; BUZETTI, S.; CELESTRINO, T. S.; LOPES, K. S. M. Desempenho agronômico da cultura do milho e espécies forrageiras em sistema de Integração Lavoura-Pecuária no Cerrado. *Ciência Rural*, Santa Maria, v. 43, n. 4, p. 589-595, 2013. DOI: 10.1590/S0103-84782013000400005

LEONEL, F. P.; PEREIRA, J. C.; COSTA, M. G.; MARCO JÚNIOR, P. de; SILVA, C. J.; LARA, L. A. Consórcio milho-braquiária e milho: comportamento produtivo das culturas e características nutricionais e qualitativas das silagens. *Revista Brasileira de Zootecnia*, Viçosa, MG, v. 38, n. 1, p. 166-176, 2009.

MAIA, G. A.; COSTA, K. A. P.; SEVERIANO, E. C.; EPIFANIO, P. S.; FLÁVIO NETO, J.; RIBEIRO, M. G.; FERNANDES, P. B.; SILVA, J. F. G.; GONÇALVES, W. G. Yield and chemical composition of *Brachiaria* forage grasses in the offseason after corn harvest. *American Journal of Plant Sciences*, Uzbekistan, n. 5, p. 933-941, 2014. DOI: 10.4236/ajps.2014.57106

MAIA, P. B.; REZENDE, I. S.; TSUMURA, F. H. Desempenho de híbridos de milho e da forrageira *Brachiaria brizantha* em cultivo consorciado. *Revista Verde*, Pombal, v. 10, n. 1, p. 81-87, 2015. DOI: /10.18378/rvads.v10i1.2527

PARIZ, C. M.; ANDREOTTI, M.; AZENHA, M. V.; LIMA, R. C. Produtividade de grãos de milho e massa seca de braquiárias em consórcio no sistema de integração lavoura-pecuária. *Ciência Rural*, Santa Maria, v. 41, n. 5, p. 875-882, 2011.

PARIZ, C. M.; FERREIRA, R. L.; SÁ, M. E. de; ANDREOTTI, M.; CHIODEROLI, C. A.; RIBEIRO, A. P. Qualidade fisiológica de sementes de *Brachiaria* e avaliação da produtividade de massa seca, em diferentes sistemas de integração lavoura-pecuária sob irrigação. *Pesquisa Agropecuária Tropical,* Goiânia, v. 40, n. 3, p. 330-340, 2010.

RIBEIRO, M. G.; COSTA, K. A. P.; SILVA, A. G.; SEVERIANO, E. C.; SIMON, G. A.; CRUVINEL, W. S.; SILVA, V. R.; SILVA, J. T. Grain sorghum intercropping with *Brachiaria brizantha* cultivars in two sowing systems as a double crop. *African Journal of Agricultural Research*, Ebène, v. 10, n. 39, p. 3759-3766, 2015. DOI: 10.5897/AJAR2015.9705

SANTOS, C. B.; COSTA, K. A. P.; OLIVEIRA, I. P. de; SEVERIANO, E. C.; COSTA, R. R. G. F.; SILVA, A. G. da; GUARNIERI, A.; SILVA, J. T. da. Production and nutritional characteristics of sunflowers and *Paiaguas palisadegrass* under different forage systems in the off season. *Bioscience Journal*, Uberlândia, v. 32, n. 2, p. 460-470, 2016. DOI: 10.14393/10.14393/BJ-v32n2a2016-29753

SEIDEL, E. P.; GERHARDT, I. F. S.; CASTAGNARA, D. D.; NERES, M. A. Efeito da época e sistema de semeadura da *Brachiaria brizantha* em consórcio com o milho, sobre os componentes de produção e propriedades do solo. *Semina: Ciências Agrárias*, Londrina, v. 35, n. 1, p. 55-66, 2014. DOI: 10.5433/1679-0359.2014v35n1p55

SILVA, D. J.; QUEIROZ, A. C. *Análise de alimentos:* métodos químicos e biológicos. 3. ed. Viçosa, MG: Imprensa Universitária da UFV, 2002. 235 p.

SILVA, D. V.; PEREIRA, G. A. M.; FREITAS, M. A. M.; SILVA, A. A.; SEDIYAMA, T.; SILVA, G. S.; FERREIRA, L. R.; CECON, P. R. Produtividade e teor de nutrientes do milho em consórcio com braquiária. *Ciência Rural*, Santa Maria, v. 45, n. 8, p. 1394-1400, 2015. DOI: 10.1590/0103-8478cr20140760

SOARES, A. B.; SARTOR, L. R.; ADAMI, P. F.; VARELLA, A. C.; FONSECA, L.; MEZZALIRA, J. C. Influência da luminosidade no comportamento de onze espécies forrageiras perenes de verão. *Revista Brasileira de Zootecnia*, Viçosa, MG, v. 38, n. 3, p. 443-451, 2009.

TAIZ, L.; ZEIGER, E. *Plant physiology*. 5th ed. Sunderland: Sinauer Associates, 2010. 700 p.

TILLEY, J. M. A.; TERRY, R. A. A two stage technique for *in vitro* digestion of forages crops. *Journal of the British Grassland Society*, Britannia, v. 18, n. 2, p. 104-111, 1963. DOI: 10.1111/j.1365-2494.1963.tb00335.x

VALLE, C. B.; EUCLIDES, V. P. B.; MONTAGNER, D. B.; VALÉRIO, J. R.; FERNANDES, C. D.; MACEDO, M. C. M; VERZIGNASSI, J. R.; MACHADO, L. A. Z. BRS Paiaguás: a new *Brachiaria* (*Brachiaria*) cultivar for tropical pastures in Brazil. *Tropical Grasslands - Forrajes Tropicales,* Campo Grande, v. 1, n. 1, p. 121-122, 2013.

VAN SOEST, P. J. *Nutritional ecology of the ruminant.* 2. ed. Ithaca: Cornell University Press, 1994. 476 p.

VILELA, L.; MARTHA JUNIOR, G. B.; MACEDO, M. C. M.; MARCHÃO, R. L.; GUIMARÃES JÚNIOR, R.; PULROLNIK, K.; MACIEL, G. A. Sistemas de integração lavoura-pecuária na região do Cerrado. *Pesquisa Agropecuária Brasileira*, Brasília, v. 46, n. 10, p. 1127-1138. 2012.