ISSN 1808-3765

MORPHOLOGICAL ASSESSMENT OF FALL IRRIGATED MAIZE INTERCROPPED WITH TROPICAL FORAGES

FRANCISCO CÉZAR BELCHOR LAGES PEREIRA[1]; LUIZ MALCOLM MANO DE MELLO[2]; CRISTIANO MAGALHÃES PARIZ[3]; VERIDIANA ZOCOLER DE MENDONÇA[4]; ÉLCIO HIROYOSHI YANO[2]; ELKA ELICE VASCO DE MIRANDA[5]; CARLOS ALEXANDRE COSTA CRUSCIOL[6] E JORGE MARTINELLI MARTELLO[7]

[1] Engenheiro Agrônomo. Mestre em Agronomia na Especialidade de Sistemas de Produção. Faculdade de Engenharia (FE/UNESP – Campus de Ilha Solteira). Avenida Brasil 56, Centro, Caixa Postal 31, CEP: 15.385-000, Ilha Solteira, SP - Brasil. E-mail: franciscocezarbl@gmail.com.
[2] Engenheiro Agrônomo. Professor do Departamento de Fitossanidade, Engenharia Rural e Solos. Faculdade de Engenharia (FE/UNESP – Campus de Ilha Solteira). Avenida Brasil 56, Centro, Caixa Postal 31, CEP: 15.385-000, Ilha Solteira, SP - Brasil. E-mail: malcolm@agr.feis.unesp.br; elcio@agr.feis.unesp.br.
[3] Zootecnista. Pós-Doutorando em Zootecnia na Especialidade de Avaliação, Produção e Conservação de Forragens. Departamento de Melhoramento e Nutrição Animal. Faculdade de Medicina Veterinária e Zootecnia (FMVZ/UNESP – Campus de Botucatu). Distrito de Rubião Júnior, s/n, Caixa Postal 560, CEP: 18.618-970, Botucatu, SP - Brasil. E-mail: cmpzoo@gmail.com.
[4] Engenheira Agrônoma. Doutoranda em Agronomia na Especialidade de Energia na Agricultura. Departamento de Horticultura. Faculdade de Ciências Agronômicas (FCA/UNESP – Campus de Botucatu). Rua José Barbosa de Barros, 1.780, CEP: 18.610-307, Botucatu, SP - Brasil. E-mail: veridianazm@yahoo.com.br.
[5] Engenheira Agrônoma. Professora da Universidade Estadual do Mato Grosso do Sul (UEMS) – Campus de Glória de Dourados. Cidade Universitária de Dourados, Caixa Postal 351, Jardim América, CEP: 79.804-970, Dourados, MS - Brasil. E-mail: elkaelice@uems.br.
[6] Engenheiro Agrônomo. Professor do Departamento de Produção e Melhoramento Vegetal. Faculdade de Ciências Agronômicas (FCA/UNESP – Campus de Botucatu). Rua José Barbosa de Barros, 1780, Fazenda Lageado, CEP: 18.610-307, Botucatu, SP - Brasil. E-mail: crusciol@fca.unesp.br.
[7] Engenheiro Agrônomo. Doutorando em Agronomia na Especialidade de Energia na Agricultura. Departamento de Produção e Melhoramento Vegetal. Faculdade de Ciências Agronômicas (FCA/UNESP – Campus de Botucatu). Rua José Barbosa de Barros, 1.780, CEP: 18.610-307, Botucatu, SP - Brasil. E-mail: jorgemartinelli@hotmail.com.

1 ABSTRACT

Fall irrigated maize intercropped with tropical forages can raise the amount of crop residues and relative nitrogen yield and improve land use efficiency without decreasing grain yield. The aim was to evaluate the effect of modalities of fall-irrigated maize (*Zea mays* L.) intercropped with tropical forages on the components of production, grain, straw and relative nitrogen yield, competitive factors in the intercrop and land use efficiency, in no-till (NT) system in the lowland Brazilian Cerrado. A randomized complete block experimental design was used in a 4×3+1 factorial arrangement with one control treatment, constituting 13 treatments, with four replications (n=4). The treatments comprised four tropical forages intercropped with maize: palisade grass (*Urochloa brizantha* cv. Marandu), congo grass (*Urochloa ruziziensis*), and the guinea grass cultivars Tanzânia and Áries (*Panicum maximum* cv. Tanzânia and Áries); three intercropping modalities: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (broadcast) on the same day as maize sowing; and forage sown, mixed with top-dressed fertilizer, at the V4 stage of maize; and one control treatment (maize monoculture). Regardless of the type of tropical forage and intercropping modality, intercropping exhibited minimum competition between crops and did not interfere on the yield components and grain

Recebido em 02/10/2016 e aprovado para publicação em 23/07/2017

DOI: http://dx.doi.org/10.15809/irriga.2017v22n3p512-529

yield of fall-irrigated maize. In addition, it increased the amount of straw, and improved land use efficiency and relative nitrogen yield in comparison to mono-cropped maize. The best options were congo grass sown simultaneously in the maize rows and guinea grass cv. Tanzânia and guinea grass cv. Áries sown broadcast on total area, as they raised the shoot dry matter of maize and forage and land equivalent ratio. Congo grass sown simultaneously in the maize rows also raised the relative nitrogen yield.

Keywords: lowland Brazilian Cerrado, *Panicum*, *Urochloa*, *Zea Mays* L.

PEREIRA, F. C. L. B.; MELLO, L. M. M.; PARIZ, C. M.; MENDONÇA, V. Z.; YANO, E. H.; MIRANDA, E. E. V.; CRUSCIOL, C. A. C.; MARTELLO, J. M.
AVALIAÇÃO MORFOLÓGICA DO CONSÓRCIO DE MILHO OUTONAL IRRIGADO COM FORRAGEIRAS TROPICAIS

2 RESUMO

O consórcio de milho outonal irrigado com forrageiras tropicais, pode elevar a quantidade de palhada e a produtividade relativa de nitrogênio, além de melhorar a eficiência de uso da terra, sem reduzir a produtividade de grãos. Objetivou-se avaliar o efeito de modalidades de implantação do consórcio de milho outonal irrigado com forrageiras tropicais sobre os componentes da produção, a produtividade relativa de nitrogênio, grãos e palhada, os fatores de competição no consórcio e a eficiência de uso da terra, sob sistema plantio direto no Cerrado de baixa altitude. O delineamento experimental foi em blocos casualizados em esquema fatorial (4×3+1) com uma testemunha, constituindo 13 tratamentos com quatro repetições. Os tratamentos foram constituídos por quatro forrageiras: capim-marandu, capim-ruziziensis, capim-tanzânia e capim-áries; e três modalidades de consórcio das forrageiras com o milho: forrageira semeada simultaneamente na linha de semeadura, misturada com o adubo; forrageira semeada simultaneamente a lanço em área total no mesmo dia da semeadura do milho; e forrageira semeada a lanço misturada ao adubo de cobertura no estádio V4 do milho; e uma testemunha constituída pelo cultivo exclusivo do milho. Independente da forrageira e da modalidade de semeadura, o consórcio proporcionou mínima competição entre as culturas e não interfere nos componentes da produção e na produtividade de grãos de milho outonal irrigado, além de elevar a quantidade de palhada, melhorar a eficiência de uso da terra e a produtividade relativa de nitrogênio, em relação ao cultivo exclusivo do milho.

Palavras-chave: Cerrado de baixa altitude, *Panicum*, *Urochloa*, *Zea Mays* L.

3 INTRODUCTION

Currently, the no-till system (NT) is looked upon by many as a way to enable sustainable cropping intensification to meet future agricultural demands (CRUSCIOL et al., 2014). NT also is a viable alternative for sustainability in tropical farming systems, especially for reducing erosion, promoting nutrient cycling, correct use of herbicides, maintenance of straw on the soil surface, crop rotation, water storage, and improvement in soil physical and chemical quality

(BORGHI et al., 2013a). However, most cash crops do not produce enough straw (hereinafter only “straw”) to achieve adequate soil surface (ALLEN et al., 2007).

Associated with the low amount of straw, the climatic characteristics of regions with warm and dry (low and irregular rainfall) winters, such as the low altitude Brazilian Cerrado and African savannas, increase the risks of growing a second crop in the fall (off-season) for grain, silage, or simply straw production (ALLEN et al., 2007). Thus, these areas become unsuitable for crop production for a period of more than seven months (BORGHI et al., 2013a). Furthermore, in these regions straw decomposes rapidly (COSTA et al., 2014; PARIZ et al., 2011a; PARIZ et al., 2016; PARIZ et al., 2017a). Therefore, all these conditions have hampered the sustainability of NT.

In addition to producing large amount of dry matter, which is fundamental for straw production in the NT, perennial tropical forage have high C/N and lignin/N ratios, slowing decomposition and protecting the soil for a long time against erosion and the action of solar radiation (PARIZ et al., 2011a; COSTA et al., 2014; MENDONÇA et al., 2015). Maize also produces large amounts of dry matter and, intercropped with those forages, it is able to increase straw production (CHIODEROLLI et al., 2010, 2012).

However, intercropping grain crops with tropical forages is a technology in a consolidation phase by farmers (CRUSCIOL et al., 2014). Thus, knowledge of forage species and intercropping modalities for different soil management practices and regional environments is extremely important for minimizing water, light, and nutrient competition, as well as to provide suitable conditions for forage development and not compromise grain yield (PARIZ et al., 2011b; PARIZ et al., 2017b). In the intercropping systems it is also important to calculate the relative nitrogen yield, competitive factors between intercropped crops and land use efficiency (BORGHI et al., 2013b; CRUSCIOL et al., 2014; MATEUS et al., 2016; COSTA et al., 2016). These calculations can better assist in understanding the benefits of the intercrop and the competition between crops.

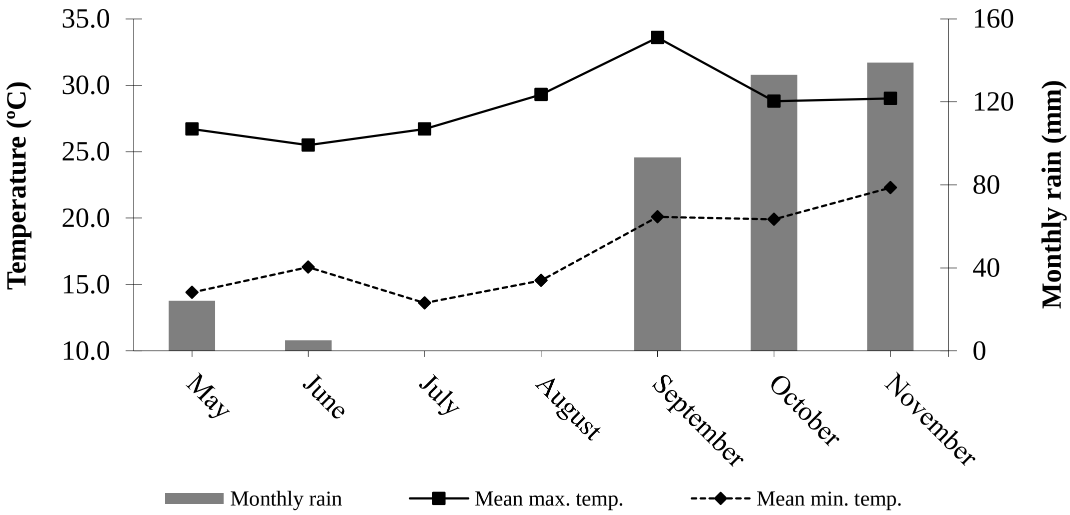
In irrigated areas, for economic reasons farmers do not often plant crops that do not generate direct revenue and are only for straw production (ALFORD; KRALL; MILLER, 2003). In this sense, fall irrigated maize intercropped with tropical forages can benefit the NT, providing satisfactory grain yield when well-managed, as well as increase straw production and nutrient cycling and improve land use efficiency. These features are now essential for optimization and sustainability of agricultural areas in the world (CRUSCIOL et al., 2012, 2014).

In this context, the hypothesis was that the fall irrigated maize intercropped with tropical forages, can raise the amount of crop residues and the relative nitrogen yield and improve land use efficiency, and not decrease the grain yield compared to maize monoculture. Thus, the aim was to evaluate the effect of modalities of fall irrigated maize intercropped with tropical forages on production components, grain, straw and relative nitrogen yield, competitive factors in the intercrop and land use efficiency, in a system under NT in lowland Brazilian Cerrado.

4 MATERIALS AND METHODS

This experiment was conducted in Selvíria, in the state of Mato Grosso do Sul, Brazil (20° 18’ S and 51° 22’ W, 350 m of altitude) in an area under pivot irrigation. According to Köppen climate classification, the climate is Aw, i.e., tropical humid with dry winters and hot and rainy summers. Rainfall and maximum and minimum temperatures were measured during the experiment (Figure 1).

Figure 1. Mean rainfall values (mm), maximum, minimum and mean temperature (°C) from May 2010 to November 2010, Selvíria, Mato Grosso do Sul, Brazil. Source: Laboratory of Hydraulics and Irrigation, São Paulo State University (UNESP), School of Engineering, Ilha Solteira.



The soil was a Typic Haplorthox (SANTOS et al., 2006). The history of the crop sequence in the experimental area was 10 years of NT {rotation of maize for grain and silage, soybean [*Glycine max* (L.) Merr.] for grain, common bean (*Phaseolus vulgaris*) for grain and tropical grasses intercropped with maize for grazing and residues} and the preceding crop was soybean.

The soil chemical and physical attributes in the 0.0-0.2 m soil layer were first analyzed on May 06, 2010 (Table 1), according the methods suggested by Raij et al. (2001) and Embrapa (1997), respectively.

Table 1. Soil attributes at 0-0.20 m layer of the experimental area before initiating the experiment.

Chemical attributes							
pH	SOM**	P (resin)	H+Al	K^+	Ca^{2+}	Mg^{2+}	BS***
$CaCl_2$*	g dm^{-3}	mg dm^{-3}		mmolc dm^{-3}			%
4.9	22.0	25.0	37.0	2.7	15.0	9.0	41.9
Physical attributes							
Granulometry (g kg^{-1})			Bulk Density (Mg m^{-3})	Porosity (m^3 m^{-3})			
Sand	Silt	Clay		Macro	Micro	Total	
220	120	660	1.51	0.074	0.339	0.413	

*0.01 mol L^{-1} $CaCl_2$
**Soil organic matter
***Base saturation

The area was irrigated by sprinklers (pivot) based on optimal irrigation intervals for the crops studied. Available water capacity (AWC) was calculated from the following equation 1:

$$\text{AWC (mm)} = [(\text{FC} - \text{WPP})/100] \times \text{SD} \times \text{ERSD} \quad (1)$$

Where FC is the field capacity (%); WPP is the permanent wilting point (%); SD is soil bulk density; and ERSD is effective root system layer. These data were obtained from a soil-water retention curve. In this equation, the FC was 20.25%, the WPP was 14.58%, the SD was 1.510 Mg m^{-3}, and the ERSD was 0.20 m. Therefore, the AWC of the soil was 17.12 mm.

Water was supplied at an outflow of 3.3 mm h^{-1}. Irrigation was applied each time the maximum crop evapotranspiration (ETm) reached 7.57 mm (i.e., at 44.3% of the AWC). The ETm was estimated from the following equation 2:

$$\text{ETm (mm day}^{-1}) = \text{Kc} \times \text{ETo} \quad (2)$$

Where ETo is the evapotranspiration reference and Kc is the crop coefficient.

The reference evapotranspiration was estimated from the following equation 3:

$$\text{ETo (mm day}^{-1}) = \text{Kp} \times \text{ECA} \quad (3)$$

Where Kp is the Class A pan coefficient and ECA is the Class A pan evaporation (mm day^{-1}).

Water evaporation (mm) was measured daily from the Class A pan. The Kp was calculated as proposed by Doorenbos and Pruitt (1977) and was based on the surrounding area, wind speed, and relative humidity.

A randomized complete block experimental design was used in a 4×3+1 factorial arrangement, with one control treatment and four replications. The treatments consisted of four tropical forages intercropped with maize [*Zea mays* (L.)]: 1) palisade grass {*Urochloa brizantha* cv. Marandu (Hochst. ex A. Rich.) R. D. Webster [syn. *Brachiaria brizantha* cv. Marandu]}, 2) congo grass {*Urochloa ruziziensis* (R. Germ. & C. M. Evrard) Morrone & Zuloaga [syn. *Brachiaria ruziziensis*]}, 3) guinea grass cultivar Tanzânia {*Megathyrsus maximus* cv. Tanzânia (Jacq.) B. K. Simon & S. W. L. Jacobs [syn. *Panicum maximum* cv. Tanzânia]}, and 4) guinea grass cultivar Áries {*Megathyrsus maximus* cv. Áries (Jacq.) [syn. *Panicum maximum* cv. Áries]}; three intercropping modalities: 1) forage sown simultaneously in the maize rows, mixed with fertilizer (Row), 2) forage sown (broadcast) on the same day as maize sowing (Broadcast), and 3) forage sown, mixed with topdressed fertilizer, at the V4 stage of maize (V4); and one control treatment (maize monoculture). Each plot consisted of seven 18-m long rows of maize that were spaced at 0.45 m. The useful area was the three central rows, with 4 m at the end of each plant row and the two outer rows constituting the border area.

On May 10, 2010, weeds were desiccated through glyphosate application (1,920 g acid-equivalent ha^{-1}) using a spray volume of 250 L ha^{-1}. The maize hybrid DKB 390 YG (single hybrid, earlier relative maturity), used for all the treatments, was sown on May 19, 2010 at a depth of 0.03 m by using a no-till drill at a density of 60,000 seeds ha^{-1}. The maize seeds were treated with imidacloprid (2.6 g active ingredient kg^{-1} seed) and thiodicarb (7.9 g active ingredient kg^{-1} seed). For all the treatments, the fertilization in the sowing furrows consisted of 24 kg ha^{-1} N as urea, 84 kg ha^{-1} P_2O_5 as triple superphosphate, and 48 kg ha^{-1} K_2O as potassium chloride (300 kg ha^{-1} N-P-K fertilizer mixture 08-28-16).

Irrespective of the treatment (forage and sowing mode), 510 points ha^{-1} of cultural value

(10 kg ha^{-1} of forage seeds with cultural value of 51%) were used. In the “Row” treatment, forage seeds were mixed with maize fertilizer (MATEUS et al., 2007) and sown simultaneously with the maize at depths of 0.08 and 0.06 m below the soil surface for *Urochloa* and *Panicum*, respectively, in accordance to Crusciol et al. (2012). In the “Broadcast” treatment, the forage seeds were spread on the total area using a Vicon implement (without soil incorporation) and then the maize was sown on the same day. In the “V4” treatment, the forage seeds were mixed with maize topdressed fertilizer and sown at depths of 0.03 m.

As a control, upon sowing intercropped forage species, we also sowed separate forage plots in each replication using the same practices. The separate forage plots were the same size and were used only to calculate the intercropping competition factor and land use efficiency.

Maize seedling emergence occurred at five days after sowing (DAS). The forages emerged at 15, 7 and 7 DAS in the Row, Broadcast, and V4 treatments, respectively. Nitrogen (135 kg ha^{-1} N as urea) and potassium (72 kg ha^{-1} K_2O as potassium chloride) mineral fertilizer were applied in side dressing when the maize plants had four expanded leaves (V4), on June 19, 2010. A fertilizer vehicle for no-tillage side dressing was used, with a chassis frame of 2.30 m, four mismatched double cutting discs (diameter 13” × 15”), and two 220-L recipients. Both fertilization practices (sown and sidedressed) followed the recommendations of Cantarella et al. (1997) for the maize crop.

On June 29, 2010, we applied the herbicide atrazine and 2,4-D dimethylamine (1,000 and 161.2 g acid-equivalent ha^{-1}, respectively) using a spray volume of 200 L ha^{-1} to control the emergence of some annual broadleaf weeds. On July 01, 2010, we applied the insecticides methomyl and triflumuron (172 and 29 g active ingredient ha^{-1}, respectively) to control fall armyworm (*Spodoptera frugiperda*).

On October 24, 2010, the maize grain was harvested from the usable area in each plot using a mechanical harvester. Prior to harvest, the final plant population (PP) and number of ears (NE) per hectare were counted (the number of plants and ears in the two central rows, respectively, excluding 1.0 meter from each end of the row in each plot and extrapolating to plants per hectare). The plant height (PH), stem diameter (SD), and 1000-grain weight (W1000) (130 g kg^{-1} wet basis) were evaluated from 10 plants per plot chosen at random from the usable area. Grain yield (GY) per hectare was also determined (130 g kg^{-1} wet basis), using 13.5 m^2 from the usable area. The crops (maize and forages) were harvested separately from the same usable area, and shoot dry matter was recorded. Shoot dry matter of maize (SDMM) and forage (SDMF First time) together resulted in shoot dry matter at the time of grain harvest (SDMH). On November 12, 2010 (eight days before the sowing soybean in succession), the shoot dry matter of forage was reassessed (SDMF Second time). The sum of SDMF First and Second time resulted in total shoot dry matter of forage (SDMF Total). The sum of SDMM and SDMF Total resulted in total shoot dry matter of maize and forage (SDMMF Total).

The data for all variables were analysed as normal distribution (SHAPIRO and WILK, 1965) and subjected to two-way analysis of variance by the F test using the Sisvar® statistical software package (FERREIRA, 1999). The blocks were considered random effects. The tropical forages and intercropping modalities were considered fixed effects. The mean separations were conducted using the least significant difference test (LSD test), and the data of maize monocropping were compared with the data of intercropping by the orthogonal contrast test. The effects were considered statistically significant at $P \leq 0.05$.

The relative nitrogen yield (RNY) in relation to the RNY of the species in monoculture was calculated as the nitrogen (N) content in the intercrop divided by the N content in the monoculture, based on the time of grain harvest (crop yield multiplied by the %N content of the biomass), following the methods proposed by Lüscher and Aeschlimann (2006). The N concentration in the biomass was determined according to methods proposed by Malavolta, Vitti and Oliveira (1997).

The land equivalent ratio (LER), which was first described by Mead and Willey (1980), was calculated according to the following equation 4:

$$LER = (Y_{1,2} / Y_{1,1}) + (Y_{2,1} / Y_{2,2}) \quad (4)$$

Where Y is the aboveground biomass, and suffixes 1 and 2 denote crop 1 (maize) and crop 2 (forage), respectively.

The relative crowding coefficient (*K*) was calculated according to Agegnehu, Ghizaw and Sinebo (2006) as follows the equation 5:

$$K_1 = (Y_{1,2} \times Z_{2,1}) / [(Y_{1,1} - Y_{1,2}) \times Z_{1,2}] \text{ or } K_2 = (Y_{2,1} \times Z_{1,2}) / [(Y_{2,2} - Y_{2,1}) \times Z_{2,1}] \quad (5)$$

Where Y is the aboveground biomass, and suffixes 1 and 2 denote crop 1 (maize) and crop 2 (forage), respectively. $Z_{1,2}$ is the sown proportion of maize, and $Z_{2,1}$ is the sown proportion of the forage species. We evaluated the plant density of each species on the day of maize harvest by calculating:

The aggressivity (*A*) was calculated according to Agegnehu et al. (2006) as follows the equations 6 and 7:

$$A_{maize} = [Y_{1,2} / (Y_{1,1} \times Y_{1,2})] - [Y_{2,1} / (Y_{2,2} \times Y_{2,1})] \quad (6)$$

$$A_{forage} = [Y_{2,1} / (Y_{2,2} \times Y_{2,1})] - [Y_{1,2} /)Y_{1,1} \times Y_{1,2})] \quad (7)$$

Where Y is the aboveground biomass, and suffixes 1 and 2 denote crop 1 (maize) and crop 2 (forage), respectively. Therefore, $Y_{1,2}$ is the aboveground biomass of maize when grown in mixture with forage, and $Y_{1,1}$ is the yield of maize when grown in monoculture. $Y_{2,1}$ is the above-ground biomass of forage when grown in mixture with maize, and $Y_{2,2}$ is the aboveground biomass of forage when grown in monoculture (BAUMANN; LAMMERT; KROPFF, 2001).

5 RESULTS AND DISCUSSION

Plant population (PP), number of ears (NE) per hectare, plant height (PH), stem diameter (SD), 1000-grain weight (W1000), and grain yield (GY) were not affected by forage intercropping or by intercropping modalities, nor by the interaction of both (Table 2). In the contrast analyses of maize monoculture, there was also no effect on any of these variables. The PP was close to that calculated at sowing time (60,000 plants ha^{-1}), and each plant produced around one ear.

The plant height (PH) is a characteristic inherent to each hybrid, and the values of the present study were similar to those reported by Costa et al. (2012) não está nas referências in similar soil and climatic conditions using the same hybrid (DKB 390 YG) intercropped with palisade grass and congo grass (Table 2). However, in intercropping with tropical forages, the PH may be reduced mainly by the rate of establishment of the forage and increased competition for water, light, and nutrients, as verified by Pariz et al. (2011b). However, the PH values of this study show that such competition was minimal. It is noteworthy that taller plants accumulate more nutrients, translocating them to the ears in the grain-filling period and producing a larger amount of shoot dry matter.

Table 2. Plant population (PP), number of ears (NE) per hectare, plant height (PH), stem diameter (SD), 1000-grain weight (W1000), and grain yield (GY) of maize monoculture or maize intercropped with forages as affected by intercropping modalities and ANOVA significance in factorial arrangement and contrasts tests.

	PP	NE	PH	SD	W1000	GY
	nº ha^{-1}	nº ha^{-1}	m	mm	g	kg ha^{-1}
Forages						
Palisade grass	60,963 a*	58,889 a	2.65 a	24.4 a	341 a	8,416 a
Congo grass	58,938 a	58,889 a	2.59 a	24.6 a	331 a	8,767 a
Guinea grass cv. Tanzânia	58,951 a	60,099 a	2.66 a	24.6 a	331 a	8,673 a
Guinea grass cv. Áries	60,654 a	58,049 a	2.62 a	24.4 a	332 a	7,935 a
2Intercropping modalities						
Row	58,333 a	60,833 a	2.64 a	24.7 a	332 a	8,480 a
Broadcast	60,741 a	59,759 a	2.63 a	24.4 a	331 a	8,031 a
V4	59,630 a	59,351 a	2.65 a	24.8 a	337 a	8,832 a
Maize monoculture	58,333	57,926	2.67	25.0	329	8,107
	ANOVA (F *probability*)					
Factorial						
Forage (F)	0.5354	0.5224	0.3548	0.9145	0.6615	0.4341
Intercropping modality (M)	0.4584	0.5539	0.8412	0.8451	0.7413	0.3384
F × M	0.5124	0.5019	0.6451	0.7154	0.6800	0.4502
Contrasts†						
MMC × MI + PG Row	0.3541	0.2312	0.2845	0.1985	0.3855	0.2614
MMC × MI + PG Broadcast	0.2845	0.3671	0.5841	0.3854	0.3937	0.5309
MMC × MI + PG V4	0.2541	0.1367	0.7412	0.3874	0.6740	0.6734
MMC × MI + CG Row	0.4157	0.2039	0.3485	0.5148	0.5424	0.4046
MMC × MI + CG Broadcast	0.2484	0.8799	0.7514	0.3451	0.5584	0.9273
MMC × MI + CG V4	0.4578	0.7058	0.3545	0.5584	0.3696	0.2217
MMC × MI + GT Row	0.6521	0.1027	0.5148	0.7514	0.7409	0.5386
MMC × MI + GT Broadcast	0.3584	0.2039	0.2254	0.4584	0.7983	0.3866
MMC × MI + GT V4	0.4875	0.4080	0.1785	0.5842	0.8333	0.6096
MMC × MI + GA Row	0.3145	0.8799	0.4125	0.4148	0.7072	0.3160
MMC × MI + GA Broadcast	0.7842	0.8799	0.6485	0.7512	0.9880	0.8106
MMC × MI + GA V4	0.8101	0.9398	0.6582	0.7898	0.3937	0.4650

*Values followed by the same letter in the column are not significantly different at $p \leq 0.05$ according to the LSD test. v

†MMC and MI: maize monoculture and maize intercropped, respectively; PG, CG, GT and GA: palisade grass, congo grass, guinea grass cv. Tanzânia, and guinea grass cv. Áries, respectively; Row, Broadcast and V4: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (Broadcast on total area) on the same day as maize sowing; and forage sown mixed with topdressed fertilizer in the V4 stage of maize, respectively.

The SD of about 25 mm, an appropriate value for the maize crop, was also close to that reported by Costa et al. (2012) não está nas referências (Table 2). Considering the PP obtained, which was recommended for the hybrid used, the lower SD also reflects the competition in maize plants intercropped with forages, as verified by Pariz et al. (2011b). Thicker stem plants have increased nutrient transport ability and were less susceptible to lodging as the effect of wind, rains, and machinery and implement traffic (topdressing, pesticide application, and grain harvest).

The lack of reduction of W1000 and GY also corroborate that competition, especially for water and nutrients, being minimal in intercropping with forage (Table 2). According to Borghi et al. (2012), competition between two species in intercropping may lead to smaller ears and lighter grains in maize plants. The W1000 is important because it is directly related to maize yield potential.

The GY and shoot dry matter of maize (SDMM) in the fall season above 8,000 and 10,000 kg ha^{-1}, respectively, show that cultivation of this crop is possible in a center pivot irrigated area in the soil and climatic conditions of the off-season in low altitude Brazilian Cerrado (Table 2). These yields were even higher than those recorded by Costa et al. (2012) não está nas referências for two summer crops by evaluating doses of up to 200 kg ha^{-1} N in topdressing, and Chioderolli et al. (2010, 2012) for two previous fall crops, all under the same soil and climatic conditions and using the same hybrid intercropped with tropical forages.

The use of maize hybrids with early and very early cycles is the best option in intercropping with tropical forages (CRUSCIOL et al., 2013). In this study, the maize hybrid DKB 390 YG (single hybrid, early maturity) was used to minimize competition between maize and forages. Maize hybrids with early and very early cycles have a high rate of dry matter accumulation in the early stages of development due to their high capacity for interception of photosynthetically active radiation (AMARAL FILHO et al., 2005). This feature reduces intraspecific competition, which favors the development of the grain crop intercropped with forages (SAWYER et al., 2010).

In the first evaluation (time of maize grain harvest), shoot dry matter of forage (SDMF) was not affected by the treatments (Table 3). Shoot dry matter of maize and forage at the time of grain harvest (SDMH) was also the same for all treatments. In the second evaluation (at desiccation), the SDMF was influenced by the interaction between forages and intercropping modalities. SDMF Total and SDMMF Total were also influenced by this interaction. The higher SDMF in the second evaluation, and SDMF Total of guinea grass cv. Tanzânia intercropped in the “Broadcast” treatment was probably due to the better emergence of this grass compared to other intercropping modalities. Guinea grass cv. Tanzânia also had a higher yield potential compared to the other forages evaluated, mainly from early spring (Figure 1 and Table 4) (PARIZ et al., 2011c). The higher SDMF Total of guinea grass cv. Tanzânia intercropped in the “Broadcast” treatment also resulted in a higher SDMMF Total.

The lower SDMF in the second evaluation and SDMF Total of palisade grass when intercropped at the V4 stage of maize without seed incorporation in the soil (Table 4) occur due to lower development time and a lower plant population (Table 5), then demanding more time for tiller formation after maize grain harvest. This also resulted in lower SDMMF Total compared to forage intercropped simultaneously in the maize rows, while guinea grass cv. Áries also provided lower SDMMF Total when intercropped at the V4 stage of maize, however, when compared to intercropping in the "Broadcast" treatment.

Table 3. Shoot dry matter of maize (SDMM), of forage (SDMF), sum of both in the grain harvest moment (SDMH) and total (SDMMF Total) in sole crop or intercropped as affected by intercropping modalities and ANOVA significance in factorial scheme and contrasts.

	SDMM	SDMF$^{\alpha}$ First time	SDMF$^{\alpha}$ Second time	SDMF$^{\alpha}$ Total	SDMH$^{£}$	SDMMF Total$^{¥}$
	kg ha^{-1} of dry matter					
Forages						
Palisadegrass	10,174 a*	2,333 a	3,417	5,750	12,507 a	15,924
Congograss	10,870 a	1,925 a	3,933	5,858	12,795 a	16,728
Guineagrass cv. Tanzânia	12,028 a	2,575 a	3,700	6,275	14,603 a	18,303
Guineagrass cv. Áries	11,554 a	2,208 a	3,400	5,608	13,762 a	17,162
Intercropping modalities						
Row	11,268 a	2,575 a	3,750	6,325	13,843 a	17,593
Broadcast	11,754 a	2,163 a	4,338	6,500	13,916 a	18,254
V4	10,447 a	2,044 a	2,750	4,794	12,491 a	15,241
Maize sole crop	11,393	-	-	-	11,393	11,393
	ANOVA (F *probability*)					
Factorial						
Forage (F)	0.1234	0.1659	0.6064	0.6167	0.0823	0.1362
Intercropping modality (M)	0.1756	0.0930	0.0012	0.0010	0.1172	0.0036
F × M	0.1143	0.2467	0.0482	0.0433	0.1007	0.0415
Contrasts†						
MMC × MI + PG Row	0.7040	-	-	-	0.2665	0.0011§
MMC × MI + PG Broadcast	0.4754	-	-	-	0.4200	0.0133
MMC × MI + PG V4	0.1129	-	-	-	0.7213	0.0483
MMC × MI + CG Row	0.4696	-	-	-	0.0200‡	<0.0001
MMC × MI + CG Broadcast	0.2086	-	-	-	0.9500	0.0095
MMC × MI + CG V4	0.5384	-	-	-	0.6000	0.0297
MMC × MI + GT Row	0.6075	-	-	-	0.1552	0.0017

MMC × MI + GT Broadcast	0.1228	-	-	-	0.0010[‡]	<0.0001
MMC × MI + GT V4	0.9288	-	-	-	0.1145	0.0141
MMC × MI + GA Row	0.8404	-	-	-	0.1198	0.0019
MMC × MI + GA Broadcast	0.2271	-	-	-	0.0123[‡]	<0.0001
MMC × MI + GA V4	0.5097	-	-	-	0.6048	0.0229

[*]Values followed by the same letter in the column are not significantly different at $p \leq 0.05$ according to the LSD test.
[†]MMC and MI: maize monoculture and maize intercropped, respectively; PG, CG, GT and GA: palisade grass, congo grass, guinea grass cv. Tanzânia, and guinea grass cv. Áries, respectively; Row, Broadcast and V4: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (Broadcast on total area) on the same day as maize sowing; and forage sown mixed with topdressed fertilizer in the V4 stage of maize, respectively.
[α]SDMF First time, Second time, and Total = Shoot dry matter of forage at the time of grain harvest, at the time of desiccation, and the sum of the First and Second time, respectively.
[£]SDMH = Shoot dry matter of maize + Shoot dry matter of forage, First time.
[¥]SDMMF Total = Shoot dry matter of maize + Total shoot dry matter of forage.
[‡]Values of SDMH: MI + CG Row; MI + GT Broadcast, and MI + GA Broadcast = 14,923, 16,571, and 15,216 kg ha^{-1}, respectively.
[§]Values of SDMMF Total of the intercrops are presented in Table 4.

In contrast analyses, intercropping with palisade grass planted simultaneously in the maize rows, as well as guinea grass cv. Tanzânia and guinea grass cv. Áries intercropped in the “Broadcast” treatment, raised SDMH (Table 3). All treatments provided higher SDMMF Total compared to the 11,393 kg ha^{-1} of dry matter produced by the maize monoculture. In dry and warm winter conditions, such as those found in the low altitude Brazilian Cerrado, an annual amount of over 12,000 kg ha^{-1} of dry matter becomes necessary due to the rapid decomposition of straw deposited on the soil surface (CHIODEROLLI et al., 2010 2012; PARIZ et al., 2011a). This amount is only possible in production systems that include the use of tropical grasses or cover crops that are intercropped or in rotation with the cash crop, as in the present study, in which the amount of straw from maize and tropical forage exceeded 15,000 kg ha^{-1} of dry matter.

Table 4. Deployment of significant interactions of shoot dry matter of forage (SDMF Second time and SDMF Total) and total shoot dry matter of maize and forage (SDMMF Total) as affected by intercropping modalities.

	Intercropping modalities†		
	Row	Broadcast	V4
	SDMF Second time (kg ha^{-1} of dry matter)		
Forages			
Palisade grass	4,250 aA*	3,150 bA	2,850 aA
Congo grass	4,150 aAB	4,650 abA	3,000 aB
Guinea grass cv. Tanzânia	3,550 aAB	5,600 aA	1,950 aB
Guinea grass cv. Áries	3,050 aA	3,950 bA	3,200 aA
	SDMF Total (kg ha^{-1} of dry matter)		
Forages			
Palisade grass	6,400 aA	5,300 bA	5,550 aA
Congo grass	6,700 aA	6,275 bAB	4,600 aB
Guinea grass cv. Tanzânia	6,350 aB	8,300 aA	4,175 aC
Guinea grass cv. Áries	5,850 aA	6,125 bA	4,850 aA
	SDMMF Total (kg ha^{-1} of dry matter)		
Forages			
Palisade grass	17,280 aA	15,726 bA	14,765 aA
Congo grass	19,073 aA	15,952 bAB	15,160 aB
Guinea grass cv. Tanzânia	17,049 aB	22,171 aA	15,689 aB
Guinea grass cv. Áries	16,971 aAB	19,166 abA	15,350 aB

*Values followed by a different lowercase letter in the column and different uppercase letter in the line are significantly different at $p \leq 0.05$ according to the LSD test.

†Row, Broadcast, and V4: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (Broadcast on total area) on the same day as maize sowing; and forage sown mixed with topdressed fertilizer in the V4 stage of maize, respectively.

Table 5. Aboveground biomass, plant density, nitrogen content, and relative nitrogen yield (RNY) of maize (M) and forage (F) in monoculture or intercropped as affected by intercropping modalities, measured on the day of maize harvest.

Forages and intercrop and monoculture modalities[†]	Aboveground biomass			Plant density		Nitrogen content			RNY
	M	F	Total	M	F	M	F	Total	Total
	g m^{-2} of dry matter			plants m^{-2}		g m^{-2}			
Intercrops									
MI + PG Row	1,088	215	1,303	6.0	5.8	25.9	3.8	29.7	150
MI + PG Broadcast	1,043	215	1,258	6.1	6.4	20.9	4.5	25.4	129
MI + PG V4	921	270	1,191	6.0	5.5	23.9	6.3	30.2	159
MI + CG Row	1,237	255	1,492	5.9	5.5	25.0	5.0	30.1	160
MI + CG Broadcast	968	163	1,130	6.0	6.1	22.4	3.5	26.0	134
MI + CG V4	1,056	160	1,216	5.9	5.3	26.2	4.0	30.1	150
MI + GT Row	1,070	280	1,350	5.9	4.3	24.4	4.9	29.3	139
MI + GT Broadcast	1,387	270	1,657	6.0	4.9	25.1	5.4	30.6	146
MI + GT V4	1,151	223	1,374	5.9	4.1	24.1	4.8	28.9	139
MI + GA Row	1,112	280	1,392	6.0	4.5	19.9	5.0	24.8	126
MI + GA Broadcast	1,304	218	1,522	6.1	5.0	22.0	4.2	26.2	137
MI + GA V4	1,050	165	1,215	6.1	4.2	24.8	3.6	28.3	144
Monoculture									
MMC	1,139	-	1,139	5.8	-	22.7	-	22.7	-
PG Row	-	925	925	-	5.4	-	10.6	10.6	-
PG Broadcast	-	968	968	-	6.0	-	12.2	12.2	-
PG V4	-	729	729	-	5.2	-	11.7	11.7	-
CG Row	-	791	791	-	5.3	-	10.0	10.0	-
CG Broadcast	-	780	780	-	5.9	-	10.1	10.1	-
CG V4	-	608	608	-	5.1	-	11.4	11.4	-
GT Row	-	1,372	1,372	-	3.8	-	15.5	15.5	-
GT Broadcast	-	1,269	1,269	-	4.4	-	15.2	15.2	-
GT V4	-	957	957	-	4.0	-	14.5	14.5	-
GA Row	-	1,092	1,092	-	4.4	-	12.9	12.9	-
GA Broadcast	-	914	914	-	4.8	-	10.7	10.7	-
GA V4	-	660	660	-	4.1	-	10.4	10.4	-

[†]MMC and MI: maize monoculture and maize intercropped, respectively; PG, CG, GT and GA: palisade grass, congo grass, guinea grass cv. Tanzânia, and guinea grass cv. Áries, respectively; Row, Broadcast, and V4: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (Broadcast on total area) on the same day as maize sowing; and forage sown mixed with topdressed fertilizer in the V4 stage of maize, respectively.

All intercrops provided total relative nitrogen yield (RNY) above 100%, and some intercrops provided 150% RNY, indicating higher efficiency in nitrogen content (Table 5). The LER characterises the performance of an intercrop by providing the relative land area under monoculture that is required to produce the yields achieved by intercropping (BAUMANN; LAMMERT; KROPFF, 2001). In all intercrops, the LER was greater than 1, and in some intercrops, this ratio was greater than 1.4 (Table 6). Thus, in these intercrops 40% more area would be required to produce the same amount of aboveground biomass. Therefore, a value of LER greater than 1 could be advantageous due to of nutrient cycling, particularly for poor soils such as those found in the African Savannas or Brazilian Cerrado.

It can be inferred that maize intercropped with tropical forages offers advantages, such as better ground cover throughout the year, straw production for NT, and improved land use (Tables 3, 4, 5, and 6), without reducing grain yield (Table 2). These characteristics are extremely important for agriculture in tropical regions of the world where the most soils are acidic and have low fertility and low cation exchange capacity. The sustainability of these soils depends on the soil organic matter (SOM) content, and through these intercropping systems, we could provide a constant input of SOM to the soil.

Table 6. Land equivalent ratio (LER), relative crowding coefficient (*K*), and aggressivity (*A*) of intercropped maize (M) and forage (F) as affected by intercropping modalities.

Forages and intercropping modalities†	LER			*K*		*A*	
	M	F	Total	M	F	M	F
MI + PG Row	0.95	0.23	1.19	20.50	0.31	-0.0002039	0.0002039
MI + PG Broadcast	0.92	0.22	1.14	11.31	0.27	-0.0001559	0.0001559
MI + PG V4	0.81	0.37	1.18	3.88	0.64	-0.0004940	0.0004940
MI + CG Row	1.09	0.32	1.41	-11.77	0.51	-0.0003873	0.0003873
MI + CG Broadcast	0.85	0.21	1.06	5.73	0.26	-0.0004043	0.0004043
MI + CG V4	0.93	0.26	1.19	11.39	0.40	-0.0007670	0.0007670
MI + GT Row	0.94	0.20	1.14	11.23	0.35	0.0001489	-0.0001489
MI + GT Broadcast	1.22	0.21	1.43	-4.57	0.33	0.0000897	-0.0000897
MI + GT V4	1.01	0.23	1.24	-66.21	0.44	-0.0001675	0.0001675
MI + GA Row	0.98	0.26	1.23	30.69	0.46	-0.0000380	0.0000380
MI + GA Broadcast	1.14	0.24	1.38	-6.49	0.38	-0.0002170	0.0002170
MI + GA V4	0.92	0.25	1.17	8.10	0.48	-0.0006374	0.0006374

†MI: maize intercropped; PG, CG, GT and GA: palisade grass, congo grass, guinea grass cv. Tanzânia, and guinea grass cv. Áries, respectively; Row, Broadcast and V4: forage sown simultaneously in the maize rows, mixed with fertilizer; forage sown (Broadcast on total area) on the same day as maize sowing; and forage sown mixed with topdressed fertilizer in the V4 stage of maize, respectively.

In most intercrops, the relative crowding coefficient (*K*) of both crops exhibited weak interspecific competition (Table 6), but maize was stronger than forages because the maize value (+*K*) was higher than the forage values (+*K*) (ZAROCHENTSEVA, 2012). In these intercrops, the forage values were extremely low and, in general, the maize value was greater than 10. In other intercrops, the forages exhibited weak interspecific competition, but the maize was stronger in interspecific interactions because the maize value was negative (-*K*) and the forage values were positive (+*K*) (ZAROCHENTSEVA, 2012). In these intercrops, the forage values were also extremely low and, in general, the maize value was close to zero, except in intercropping with guinea grass cv. Tanzânia sown mixed with topdressed fertilizer in the V4 stage of maize, in which the *K* value of maize was -66.21, showing higher weak interspecific competition. According to Crusciol et al. (2012, 2013), reducing the period of coexistence favors the development of both crops (cash crop and tropical forage) due to reducing intraspecific competition.

Aggressivity (*A*) is used to determine the competitive relationship between two crops when mixed (TAKIM, 2012). The intercropping values for maize were always negative, whereas the values for forages were always positive, indicating that these forages were the dominant species (Table 6). However, the values were extremely low, indicating that this dominance was minimal and did not affect maize development.

6 CONCLUSIONS

The best intercropping options were congo grass sown simultaneously in the maize rows and guinea grass cv. Tanzânia and guinea grass cv. Áries sown broadcast on total area because raised the shoot dry matter of maize and forage and land equivalent ratio. Congo grass sown simultaneously in the maize rows also raised the relative nitrogen yield.

7 REFERENCES

AGEGNEHU, G.; GHIZAW, A.; SINEBO, W. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. **European Journal of Agronomy**, Montpellier, v. 25, p. 202-207, 2006.

ALFORD, C. M.; KRALL, J. M.; MILLER, S. D. Intercropping irrigated corn with annual legumes for fall forage in the high plain. **Agronomy Journal**, Madison, v. 95, p. 520-525, 2003.

ALLEN, V. G.; BAKER, M. T.; SEGARRA, E.; BROWN, C. P. Integrated irrigated crop-livestock systems in dry climates. **Agronomy Journal**, Madison, v. 99, p. 346-360, 2007.

AMARAL FILHO, J. P. R.; FORNASIERI FILHO, D.; FARINELLI, R.; BARBOSA, J. C. Espaçamento, densidade populacional e adubação nitrogenada na cultura do milho. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 29, p. 467-473, 2005.

BAUMANN, D. T.; LAMMERT, B.; KROPFF, M. J. Competition and crop performance in a leek-celery intercropping system. **Crop Science**, Madison, v. 41, p. 764-774, 2001.

BORGHI, E.; CRUSCIOL, C. A. C.; NASCENTE, A. S.; MATEUS, G. P.; MARTINS, P. O.; COSTA, C. Effects of row spacing and intercrop on maize grain yield and forage production of palisade grass. **Crop and Pasture Science**, Clayton South, v. 63, p. 1106-1113, 2012.

BORGHI, E.; CRUSCIOL, C. A. C.; MATEUS, G. P.; NASCENTE, A. S.; MARTINS, P. O. Intercropping time of corn and palisadegrass or guineagrass affecting grain yield and forage production. **Crop Science**, Madison, v. 53, p. 629-636, 2013a.

BORGHI, E.; CRUSCIOL, C. A. C.; NASCENTE, A. S.; SOUZA, V. V.; MARTINS, P. O.; MATEUS, G. P.; COSTA, C. Sorghum grain yield, forage biomass production and revenue as affected by intercropping time. **European Journal of Agronomy**, Montpellier, v. 51, p. 130-139, 2013b.

CANTARELLA, H.; RAIJ. B.; CAMARGO, C. E. O. Cereais. **Boletim Técnico 100: Recomendação de Adubação e Calagem para o Estado de São Paulo**, Campinas, p.43-71, 1997.

CHIODEROLLI, C. A.; MELLO, L. M. M.; GRIGOLI, P. J.; SILVA, J. O. R.; CESARIN, A. L. Consorciação de braquiárias com milho outonal em plantio direto sob pivô central. **Engenharia Agrícola**, Jaboticabal, v. 30, p. 1101-1109, 2010.

CHIODEROLLI, C. A.; MELLO, L. M. M.; HOLANDA, H. V.; FURLANI, C. E. A.; GRIGOLI, P. J.; SILVA, J. O. R.; CESARIN, A. L. Consórcio de *Urochloa* com milho em sistema plantio direto. **Ciência Rural**, Santa Maria, v. 42, p. 1804-1810, 2012.

COSTA, N. R.; ANDREOTTI, M.; GAMEIRO, R.A.; PARIZ, C.M.; BUZETTI, S.; LOPES, K. S. M. Adubação nitrogenada no consórcio de milho com duas espécies de braquiária em sistema plantio direto. **Pesquisa Agropecuária Brasileira**, Brasília, v. 47, p. 1038-1047, 2012.

COSTA, N. R.; ANDREOTTI, M.; BUZETTI, S.; LOPES, K. S. M.; SANTOS, F. G.; PARIZ, C. M. Acúmulo de macronutrientes e decomposição da palhada de braquiárias em razão da adubação nitrogenada durante e após o consórcio com a cultura do milho. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 38, p. 1223-1233, 2014.

COSTA, N. R.; ANDREOTTI, M.; CRUSCIOL, C. A. C.; PARIZ, C. M.; LOPES, K. S. M.; YOKOBATAKE, K. L. A.; FERREIRA, J. P.; LIMA, C. G. R.; SOUZA, D. M. Effect of intercropped tropical perennial grasses on the production of sorghum-based silage. **Agronomy Journal**, Madison, v. 108, p. 2379-2390, 2016.

CRUSCIOL, C. A. C.; MATEUS, G. P.; NASCENTE, A. S.; MARTINS, P. O.; BORGHI, E.; PARIZ, C. M. An innovative crop-forage intercrop system: early cycle soybean cultivars and palisadegrass. **Agronomy Journal**, Madison, v. 104, p. 1085-1095, 2012.

CRUSCIOL, C. A. C.; NASCENTE, A. S.; MATEUS, G. P.; BORGHI, E.; LELES, E. P.; SANTOS, N. C. B. Effect of intercropping on yields of corn with different relative maturities and palisadegrass. **Agronomy Journal**, Madison, v. 105, p. 599-606, 2013.

CRUSCIOL, C. A. C.; NASCENTE, A. S.; MATEUS, G. P.; PARIZ, C. M.; MARTINS, P. O.; BORGHI, E. Intercropping soybean and palisade grass for enhanced land use efficiency and revenue in a no till system. **European Journal of Agronomy**, Montpellier, v. 58, p. 53-62, 2014.

DOORENBOS, J.; PRUITT, W. O. **Guidelines for predicting crop water requirements**. Rome: FAO, 1977. (FAO Irrigation and Drainage Paper, 24).

EMBRAPA. Centro Nacional de Pesquisa do Solo. **Manual de métodos de análise do solo**. 2. ed. Rio de Janeiro: Embrapa, 1997.

FERREIRA, D. F. **SISVAR**: Sistema de análise de variância. Lavras: UFLA/DEX, 1999.

LÜSCHER, A.; AESCHLIMANN, U. Effects of elevated [CO_2] and N fertilization on interspecific interactions in temperate grassland model ecosystems. In: NÖSBERGER, J.; LONG, S. P.; NORBY, R. J.; STITT, M.; HENDREY, G. R.; BLUM, H. (Ed.). **Managed ecosystems and CO_2 case studies, processes and perspectives**. Berlin: Springer, 2006. p. 337-350.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. **Avaliação do estado nutricional das plantas: princípios e aplicações**. 2. ed. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1997. 319 p.

MATEUS, G. P.; BORGHI, E.; MARQUES, R. R.; BÔAS, R. L. V.; CRUSCIOL, C. A. C. Fontes e períodos de contato de fertilizantes e germinação de sementes de *Brachiaria brizantha*. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, p. 177-183, 2007.

MATEUS, G. P.; CRUSCIOL, C. A. C.; PARIZ, C. M.; COSTA, C.; MARTELLO, J. M.; FRANZLUEBBERS, A. J.; CASTILHOS, A. M. Sidedress nitrogen application rates to sorghum intercropped with tropical perennial grasses. **Agronomy Journal**, Madison, v. 108, p. 433-447, 2016.

MEAD, R.; WILLEY, R. W. The concept of 'Land Equivalent Ratio' and advantages in yields from intercropping. **Experimental Agriculture**, New York, v. 16, p. 217-228, 1980.

MENDONÇA, V. Z.; MELLO, L. M. M.; ANDREOTTI, M.; PARIZ, C. M.; YANO, E. H.; PEREIRA, F. C. B. L. Liberação de nutrientes da palhada de forrageiras consorciadas com milho em sucessão com soja. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 39, p. 183-193, 2015.

PARIZ, C. M.; ANDREOTTI, M.; BUZETTI, S.; BERGAMASCHINE, A. F.; ULIAN, N. A.; FURLAN, L. C.; MEIRELLES, P. R. L.; CAVASANO, F. A. Straw decomposition of nitrogen-fertilized grasses after intercropping with corn crop in irrigated integrated crop-livestock system. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 35, p. 2029-2037, 2011a.

PARIZ, C. M.; ANDREOTTI, M.; AZENHA, M. V.; BERGAMASCHINE, A. F.; MELLO, L. M. M.; 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, p. 875-882, 2011b.

PARIZ, C. M.; ANDREOTTI, M.; BERGAMASCHINE, A. F.; BUZETTI, S.; COSTA, N. R.; CAVALLINI, M. C.; ULIAN, N. A.; LUIGGI, F. G. Yield, chemical composition and chlorophyll relative content of Tanzania and Mombaça grasses irrigated and fertilized with nitrogen after corn intercropping. **Revista Brasileira de Zootecnia**, Viçosa, v. 40, p. 728-738, 2011c.

PARIZ, C. M.; COSTA, C.; CRUSCIOL, C. A. C.; MEIRELLES, P. R. L.; CASTILHOS, A. M.; ANDREOTTI, M.; COSTA, N. R.; MARTELLO, J. M.; SOUZA, D. M.; SARTO, J. R. W.; FRANZLUEBBERS, A. J. Production and soil responses to intercropping of forage grasses with corn and soybean silage. **Agronomy Journal**, Madison, v. 108, p. 2541-2553, 2016.

PARIZ, C. M.; COSTA, C.; CRUSCIOL, C. A. C.; MEIRELLES, P. R. L.; CASTILHOS, A. M.; ANDREOTTI, M.; COSTA, N. R.; MARTELLO, J. M.; SOUZA, D. M.; PROTES, V. M.; LONGHINI, V. Z.; FRANZLUEBBERS, A. J. Production, nutrient cycling and soil compaction to grazing of grass companion cropping with corn and soybean. **Nutrient Cycling in Agroecosystems**, Dordrecht, v. 108, p. 35-54, 2017a.

PARIZ, C. M.; COSTA, C.; CRUSCIOL, C. A. C.; MEIRELLES, P. R. L.; CASTILHOS, A. M.; ANDREOTTI, M.; COSTA, N. R.; MARTELLO, J. M. Silage production of corn intercropped with tropical forages in an integrated crop-livestock system with lambs. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 52, p. 54-62, 2017b.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C.; OLIVEIRA, V. A.; OLIVEIRA, J. B.; COELHO, M. R.; LUMBRERAS, J. F.; CUNHA, T. J. F. (Ed.). **Sistema brasileiro de classificação de solos**. 2. ed. Rio de Janeiro: Embrapa Solos, 2006. 306 p.

SAWYER, J. E.; PEDERSEN, P.; BARKER, D. W.; DIAZ, D. A. R; ALBRECHT, L. Intercropping corn and kura clover: response to nitrogen fertilization. **Agronomy Journal**, Madison, v. 102, p. 568-574, 2010.

SHAPIRO, S. S.; WILK, M. B. An analysis of variance test for normality (complete samples). **Biometrika**, Oxford, v. 52, p. 591-611, 1965.

TAKIM, F. O. Advantages of maize-cowpea intercropping over sole cropping through competition indices. **Journal of Agriculture and Biodiversity Research**, New Delhi, v. 1, p. 53-59, 2012.

RAIJ, B.; ANDRADE, J. C.; CANTARELLA, H.; QUAGGIO, J. A. **Análise química para avaliação da fertilidade de solos tropicais**. Campinas: Instituto Agronômico, 2001. 284 p.

ZAROCHENTSEVA, O. **Adaptation of methodology calculation relative crowding coefficient for evaluation competition of tree species in polyculture**. Ukraine: Yuriy Fedkovich Chernivtsi National University; 2012.