e-ISSN 1983-4063 - *www.agro.ufg.br/pat* - Pesq. Agropec. Trop., Goiânia, v. 50, e59809, 2020

Research Article

Soil water dynamics and yield in maize and *Brachiaria ruziziensis* intercropping[1]

Gabriela Sabrine França Silva[2], Aderson Soares de Andrade Júnior[3],
Milton José Cardoso[3], Raimundo Bezerra de Araújo Neto[3]

ABSTRACT

In intercropping systems, a high plant density can delay the biomass accumulation and affect the water availability to plants. This study aimed to evaluate the soil water dynamics and the crop yield performance in maize and *Brachiaria ruziziensis* intercropping under different sowing densities of the forage grass. The experiment was conducted in a randomized block design, with treatments associated to the sowing densities (2 kg ha^{-1}, 4 kg ha^{-1}, 6 kg ha^{-1} and 8 kg ha^{-1}) and the single cropping for both species as controls. The maize plants were evaluated for grain yield and *B. ruziziensis* for number of plants per hectare and shoot fresh and dry matter. The intercropping performance was evaluated using the land-use efficiency index. The soil water dynamics was monitored in two soil depths (0-0.3 m and 0.3-0.6 m) by using the time domain reflectometry method. The evaluation of soil water storage was carried out from plots with four of the crop systems (single maize or *B. ruziziensis*, and intercropping with the extreme sowing densities), at four different times. The increase in the sowing density of *B. ruziziensis* decreased the grain yield of the intercropped maize by 30.8 %. The intercropping system using 2 kg ha^{-1} of the grass seeds resulted in the best land-use efficiency (23 %). In addition, the intercropping treatments promoted a higher extraction of water from the soil, mainly at the maize growth stages with higher hydric demand (e.g., flowering and grain filling). These systems stimulate the extraction of water from deeper soil layers, when compared to maize in single cropping.

KEYWORDS: *Urochloa ruziziensis*, crop-livestock integration, sowing density.

RESUMO

Dinâmica da água no solo e produtividade em consórcio de milho e *Brachiaria ruziziensis*

Em cultivos consorciados, uma alta densidade de plantas pode retardar o acúmulo de biomassa e afetar a disponibilidade hídrica às plantas. Objetivou-se avaliar a dinâmica da água no solo e o desempenho produtivo no consórcio de milho e *Brachiaria ruziziensis* sob diferentes densidades de semeadura desta forrageira. O experimento foi conduzido em blocos casualizados, com tratamentos associados às densidades de semeadura (2 kg ha^{-1}, 4 kg ha^{-1}, 6 kg ha^{-1} e 8 kg ha^{-1}) e ambas as espécies em monocultivo como testemunhas. No milho, avaliou-se a produtividade de grãos e, na braquiária, o número de plantas por hectare e as massas verde e seca da parte aérea. O desempenho do consórcio foi avaliado pelo índice de uso eficiente da terra. A dinâmica da água no solo foi monitorada em duas profundidades (0-0,3 m e 0,3-0,6 m), pela técnica de reflectometria no domínio do tempo. A avaliação do armazenamento de água no solo foi realizada a partir de parcelas com quatro dos sistemas de cultivo (milho ou braquiária em monocultivo, e consórcios com as densidades de semeadura extremas), em quatro períodos. O aumento na densidade de semeadura de *B. ruziziensis* diminuiu a produtividade dos grãos do milho consorciado em 30,8 %. O consórcio usando 2 kg ha^{-1} de sementes da forrageira proporcionou melhor eficiência no uso da terra (23 %). Ademais, os tratamentos com consórcio promoveram maior extração de água do solo, especialmente nas fases de maior exigência hídrica do milho (e.g., florescimento e enchimento de grãos). Estes sistemas simulam a extração de água em maiores profundidades, quando comparados ao milho em cultivo solteiro.

PALAVRAS-CHAVE: *Urochloa ruziziensis*, integração lavoura-pecuária, densidade de semeadura.

INTRODUCTION

Agriculture is responsible for the transformation of environments in the Brazilian Savanna biome due to the use of conventional agricultural systems, which cause physical, chemical and biological degradation of large areas (Kluthcouski & Stone 2003, Maitelli & Oliveira 2011). Contrastingly, the adoption of intercropping systems using grain and forage species has increased, since their adequate

1. Received: Aug. 02, 2019. Accepted: Dec. 10, 2019. Published: May 04, 2020. DOI: 10.1590/1983-40632020v5059809.
2. Universidade Federal do Piauí, Campus do Socopo, Teresina, PI, Brasil.
Email/ORCID: gabriela-sabrine@hotmail.com/0000-0002-0348-5416.
3. Empresa Brasileira de Pesquisa Agropecuária (Embrapa Meio Norte), Teresina, PI, Brasil.
Email/ORCID: aderson.andrade@embrapa.br/0000-0002-0619-1851, milton.cardoso@embrapa.br/0000-0003-2144-0104, raimundo.bezerra@embrapa.br/0000-0003-0037-7126.

use avoids decreases in grain yield. This denotes the importance of information on competition of the species used in these systems for light, nutrients and, as in the case of the present study, water.

The initial competitiveness between intercropped plant species can be reduced by the adoption of cultural practices such as changes in the sowing density to delay the biomass accumulation by forage species and improve the water availability to plants, because the crop growth is directly related to stomatal opening and dry matter production (Borém et al. 2015).

Climate variations, mainly those related to rainfall, determine the production of grass and grain crops. Thus, evaluations and monitoring of soil moisture are needed to quantify variations in water contents, as well as to determine the optimal water interval and understand its relations with the capacity of available water in the soil, to plan strategies for intercropping and irrigation managements (Machado et al. 2015, Anjos et al. 2017, Srivastava et al. 2018).

Few studies have evaluated the soil water dynamics after the adoption of integrated production systems involving annual crops and forage species, in the mid-north region of Brazil. Some studies conducted in the Brazilian Savanna biome in the southwestern Piauí state used the water requirement satisfaction index to subsidize the zoning of climate risks (Andrade Júnior et al. 2017) and determine the Kc (Silva 2011) for maize and *Brachiaria ruziziensis* (syn. *Urochloa ruziziensis*) intercropping.

This study aimed to evaluate the soil water dynamics, as a function of some maize and *B. ruziziensis* (ruzi grass) intercropping systems, and their production performance and land-use efficiency, under different sowing densities of this forage grass.

MATERIAL AND METHODS

The experiment was conducted at the Barbosa Farm, in Brejo, Maranhão state, Brazil (03º42'44"S, 42º55'44"W and 55 m of altitude), from February to July 2018. The climate of the region is Aw, tropical hot and humid, according to the Köppen classification, and presents a mean annual temperature over 27 ºC, mean annual rainfall depth of 1,835 mm, annual relative air humidity of 73-79 %, a wet season from January to June and a dry season from July to December. The climatological variables were recorded by an automated agrometeorological station installed next to the experimental area. The rainfall depth during the experiment totaled 1,242 mm.

The soil in the area is classified as a Typic Hapludult (Argissolo Amarelo distrófico) of sandy loam texture, with presence of a cohesive horizon (Resende et al. 2014). Its chemical, physical and hydraulic characteristics are presented in Tables 1 and 2.

The experiment was carried out in a randomized complete block design, with four replications. The treatments were four ruzi grass sowing densities (2 kg ha^{-1}, 4 kg ha^{-1}, 6 kg ha^{-1} and 8 kg ha^{-1}) in the intercropping system, and the single croppings for maize and forage grass as controls. The plot area was 10.0 m × 6.5 m, with thirteen maize rows spaced 0.5 m apart. An early-cycle maize single cross of high yield potential and responsive to crop managements (30 F 53VYHR - DuPont® Brasil) was grown. Before the sowing, its seeds were treated with fungicides (60 g of carboxin and 60 g of thiram per 100 kg of seeds).

The maize seeds were sowed using a no-till fertilizer seeder, for a stand of 60,000 plants ha^{-1}, both for the single cropping and intercropping systems. Seeds of the forage species *B. ruziziensis* were sowed simultaneously, using selected seeds that presented purity of 30 %, considering the densities of each treatment. The sowing density in the ruzi grass single cropping was 3 kg ha^{-1}.

The seeds were broadcasted manually in each treatment. Weeds were controlled at 36 days after

Table 1. Chemical characteristics[1] of soil from the experimental area.

Soil layer	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^+ + Al^{3+}$	CEC	OM
		mg dm^{-3}	cmol$_c$ dm^{-3}							dag kg^{-1}
0.0-0.1 m	5.60	14.32	0.06	0	1.72	0.54	0.21	6.72	9.05	1,583.74
0.1-0.3 m	5.25	5.59	0.08	0	1.17	0.40	0.51	8.91	10.56	1,546.45
0.3-0.6 m	5.14	3.66	0.03	0	0.88	0.35	0.59	8.86	10.12	1,379.01

[1] pH (H_2O); CEC: cation exchange capacity; OM: organic matter.

Table 2. Physical and hydraulic characteristics[1] of soil from the experimental area.

Soil layer	SD	FC	PWP	Sand	Clay	Silt	Texture
	g cm^{-3}	% in vol.		g kg^{-1}			
0.0-0.1 m	1.517	0.28	0.07	777	148	73	sandy loam
0.1-0.3 m	1.661	0.18	0.07	734	170	94	sandy loam
0.3-0.6 m	1.594	0.19	0.11	674	233	92	sandy-clay loam

[1] SD: soil density; FC: field capacity; PWP: permanent wilting point.

sowing, with the herbicides atrazine (3 L ha^{-1}) and nicosulfuron (0.25 L ha^{-1}) (25 % of the recommended rate). Soil fertilization was done according to the results of the soil chemical analysis and maize crop requirements, based on Sousa & Lobato (2004).

The soil water dynamics was evaluated through an automate device (TDR-100, Campbell Science®) composed of 0.3-m long probes, multiplexers and a datalogger, and programed to execute and store readings every 30 min. The TDR probes were installed in the center of each plot, at the 0.0-0.30 m and 0.30-0.60 m soil layers. The surface probe was installed by fixing it directly in the soil at approximately 0.2 m from the central row of plants in the plot. The installation of the probe in the deeper soil layer evaluated (0.3-0.6 m) required digging the soil to a depth of 0.3 m for its fixation. Both probes were fixed at approximately 0.1 m from each other, to avoid effects of possible variations in soil structure on the soil water dynamics analysis.

The soil moisture was monitored on a daily scale (mean of 48 records per day). The soil water dynamics was monitored from March 9 to July 19, 2018.

The daily soil water storage was calculated by multiplying the daily water volume content (cm^3 of water per cm^3 of soil) by the thickness of the evaluated soil layer (300 mm). The soil moisture was monitored in four developmental stages of the crops: maize at the vegetative stage and *B. ruziziensis* at the emergence (32-50 days after the maize sowing - DAS); maize at flowering and *B. ruziziensis* at the establishment stage (51-84 DAS); maize at the physiological maturation to harvest and *B. ruziziensis* at the vegetative stage (85-127 DAS); harvested maize and *B. ruziziensis* at full growth (128-169 DAS).

The soil water storage at the 0.0-0.3 m and 0.3-0.6 m soil layers was evaluated throughout the period that the soil moisture was monitored with TDR probes, in the evaluated crop systems, considering the degree-day accumulation for both crops (Vila Nova et al. 1972).

The maize was harvested at 134 DAS, and its grain yield was evaluated considering the central 6 m^2 of each plot. Then, the first evaluation of production performance for the forage *B. ruziziensis* was done, considering the plant density calculated by using two replications of a simple counting of plants at the central 0.5 m^2 of each plot, and the fresh and dry weights of shoot plants were determined using four replications of the central 0.5 m^2 of each plot. The forage plants used for evaluations were cut at a height of 0.05 m from the ground, always in different places; however, within the evaluation area of each plot. The forage samples were placed in paper bags and evaluated for fresh weight. A subsample of approximately 0.4 kg was taken for evaluation of dry weight (Embrapa 2005). The second evaluation for fresh and dry weight of *B. ruziziensis* was done at 168 DAS.

The estimated participation of each crop in the intercropping yield was calculated by the land-use efficiency index (Willey 1979), which was applied to each evaluated sowing density.

The soil water storage was evaluated at two soil layers (0.0-0.3 m and 0.3-0.6 m) for the two single croppings and the highest and lowest *B. ruziziensis* sowing densities (2 kg ha^{-1} and 8 kg ha^{-1}, respectively), in order to assess the effects of these sowing densities on the soil water extraction and soil moisture at different depths.

The yield performance data of the crop species were subjected to analysis of variance and, when the treatment means were significantly different by the F-test at 5 % of significance, regression analyses were used to estimate the crop responses to the grass sowing densities. The regression equation with the highest coefficient of determination was adopted. The analyses were carried out using the ExpDes 3.5.1 package of the R software (Ferreira et al. 2013).

RESULTS AND DISCUSSION

Significant differences ($p < 0.05$) in maize grain yield were found for the evaluated *Brachiaria ruziziensis* sowing densities. The data fitted to a decreasing linear regression model (Figure 1). The maize grain yield decreased 226 kg ha^{-1} as the kg ha^{-1} of *B. ruziziensis* seeds was increased, reaching 3.6 Mg ha^{-1} at the density of 8 kg ha^{-1} of *B. ruziziensis* seeds.

The maize grain yield, when grown single in the first crop season of 2017/2018, was 3.5 Mg ha^{-1} in the Maranhão state and 2.5 Mg ha^{-1} in the Chapadinha microregion (IBGE 2018). The mean found for grain yield in the single maize crop system evaluated in the present study was 5.4 Mg ha^{-1}. Thus, the results were adequate to the local conditions and probably improved due to the adoption of technologies that promote higher yields in the region.

The maize grain yield in the intercropping system decreased as the sowing density of *B. ruziziensis* was increased. According to Brambilla et al. (2009), without the forage species, maize plants have better light, water and nutrient availabilities. The increase in the sowing density of *B. ruziziensis* decreased the ear development and grain production of maize plants because of the intensification of the competition between these plant species.

The number of *B. ruziziensis* plants increased in 5.1×10^3 plants ha^{-1} as the kg ha^{-1} of seeds of this forage was increased, reaching 73.7×10^3 plants ha^{-1} when using the sowing density of 8 kg ha^{-1} (Figure 1). According to Kluthcouski & Aidar (2003), the establishment of *B. ruziziensis* plants intercropped with maize can be satisfactorily obtained when using the forage species at sowing densities of 4-6 plants m^{-2} (40,000-60,000 plants ha^{-1}), in general, with no maize grain yield losses. Similar results were found in the present study, with a number of plants between 4.5 plants m^{-2} and 7.3 plants m^{-2} (40,000-73,000 plants ha^{-1}).

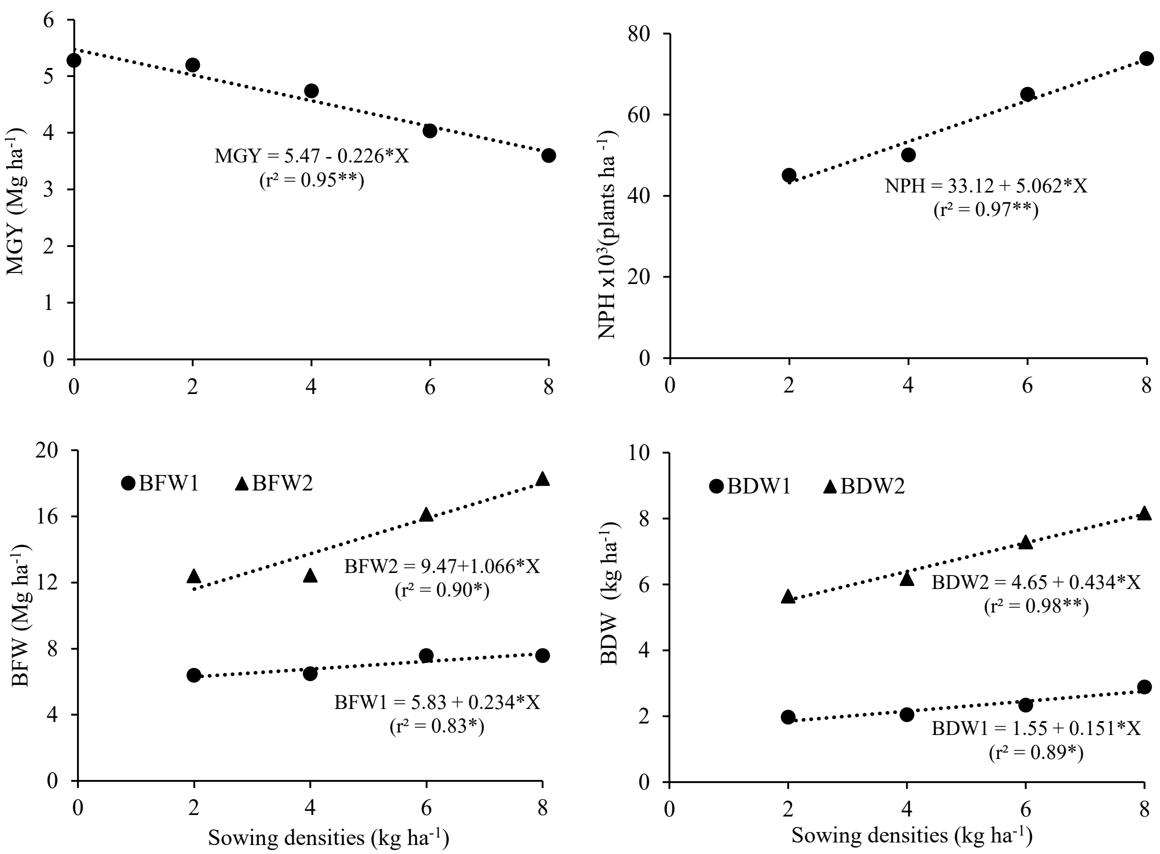

Figure 1. Response of grain yield for maize (MGY) and number of plants per hectare (NPH), shoot fresh (BFW) and dry (BDW) weight for *Brachiaria ruziziensis*, as a function of sowing densities (X) of this forage grass intercropped with maize. The numbers 1 and 2 after BFW and BDW indicate successive evaluations performed at 134 and 168 days after the maize emergence.** and *: significant values at 1 % or 5 % of probability, respectively, by the t-Student test.

Ceccon et al. (2014) found that the increase in the population of *B. ruziziensis* reduced the prolificacy, crop growth and grain filling rates. This reduces the maize mass and grain yield, which may be influenced by the adopted seeding density, as observed in this study.

The first evaluation of fresh weight for *B. ruziziensis* showed an increase of 234 kg ha^{-1} as the kg ha^{-1} of *B. ruziziensis* seeds was increased, reaching 7.6 Mg ha^{-1} when using the sowing density of 8 kg ha^{-1}. The second evaluation showed an increase of 1,066 kg ha^{-1} as the kg ha^{-1} of *B. ruziziensis* seeds was increased, reaching 18.3 Mg ha^{-1} when using *B. ruziziensis* seeds at a sowing density of 8 kg ha^{-1} (Figure 1).

The dry weight of *B. ruziziensis* in the first evaluation had an increase of 151 kg ha^{-1} as the kg ha^{-1} of *B. ruziziensis* seeds was increased, reaching 2.9 Mg ha^{-1} when using the forage seeds at a sowing density of 8 kg ha^{-1} (Figure 1). In the second evaluation, there was an increase of 434 kg ha^{-1} per increased kg ha^{-1} of *B. ruziziensis* seeds because of an increase in the number of plants, reaching 8.2 Mg ha^{-1} when using 8 kg ha^{-1} of *B. ruziziensis* seeds. Considering that producers intend to grow plants for feeding animals in periods between crop seasons, this is an advantageous result for using this intercropping system in the region, because *B. ruziziensis* plants that have a high dry matter production represent more feed for animals.

Batista et al. (2012) evaluated an intercropping of winter maize and forage species in the São Paulo state, Brazil, and found a dry matter accumulation for *B. ruziziensis* of 2.35 Mg ha^{-1} when adopting a sowing density of 9 kg ha^{-1}. The difference for dry biomass production of *B. ruziziensis* found in studies may be explained by the local climatic conditions. The east Maranhão microregion has favorable climatic conditions for the development of forage species, presenting a high mean temperature and solar radiation (Lara 2007).

The land-use efficiency found for the *B. ruziziensis* sowing densities of 2 kg ha^{-1}, 4 kg ha^{-1}, 6 kg ha^{-1} and 8 kg ha^{-1} were 1.23, 1.16, 1.08 and 1.03, respectively (Table 3). The intercropping yield per area was 23 %, 16 %, 8 % and 3 % higher, when compared to the monocultures. Therefore, the increase in the sowing density decreases the land-use efficiency for maize and *B. ruziziensis* intercropping.

Andrade Júnior et al. (2017) evaluated the water requirement satisfaction index of maize and *B. ruziziensis* grown in single cropping and intercropping systems under different soil water availabilities and found a 43 % higher efficiency in the intercropping system, when compared to the single cropping, using water at 100 % of the ETo (reference evapotranspiration), as also found in the present study. The efficiency decreased 4 % when using 80 % of the ETo, denoting that the water availability directly affects the efficiency of the maize and *B. ruziziensis* intercropping.

This difference affects the land-use efficiency in intercropping systems. Therefore, under the conditions of the east Maranhão microregion, the use of *B. ruziziensis* seeds at a sowing density of up to 2 kg ha^{-1} for intercropping with maize may result in low decreases for maize grain yield and a good production of fresh and dry matter, contributing to the forage production for the following crop season. The increase in light interception due to an increased leaf area affects the net photosynthesis, resulting in a higher carbon fixation and biomass production (Pimentel 1998).

Water availability is important for a high productive performance, and the used crop systems affected the soil water storage (Figure 2A). The water content at the 0.0-0.3 m soil layer in all evaluated cropping systems was, on average, 56 mm, except for the single cropping of *B. ruziziensis*, which presented a higher mean (62 mm) because of its slower shoot development and the herbicide application (nicosulfuron). The soil water storage

Table 3. Land-use efficiency of maize and *Brachiaria ruziziensis* grown single or intercropped under different sowing densities of ruzi grass[1].

Crops	Intercropping yield (Mg ha^{-1})				Single yield (Mg ha^{-1})
	2.0	4.0	6.0	8.0	
Maize (grain)	5.197	4.740	4.029	3.594	5.276
B. ruzizensis (dry matter)	5.652	6.180	7.291	8.178	22.824
Land-use efficiency	1.232	1.169	1.083	1.039	-

in all cropping systems showed higher decreases in days subsequent to dry periods, when maize plants presented a degree-day accumulation of 594 to 648 (37 to 45 DAS) and this soil water content was below the critical storage, characterizing a water deficit in the maize vegetative period.

According to Abraham et al. (2014), shading can benefit the growth of forage species under low water availability conditions by decreasing the evapotranspiration and increasing the soil moisture. The maize and *B. ruziziensis* intercropping with the highest ruzi grass sowing density resulted in a lower soil water storage because of its higher water extraction by the two crops, mainly maize (Figure 2).

The rainfall depth in the second monitoring period (Period 2; Figure 2A) was 81 mm, which

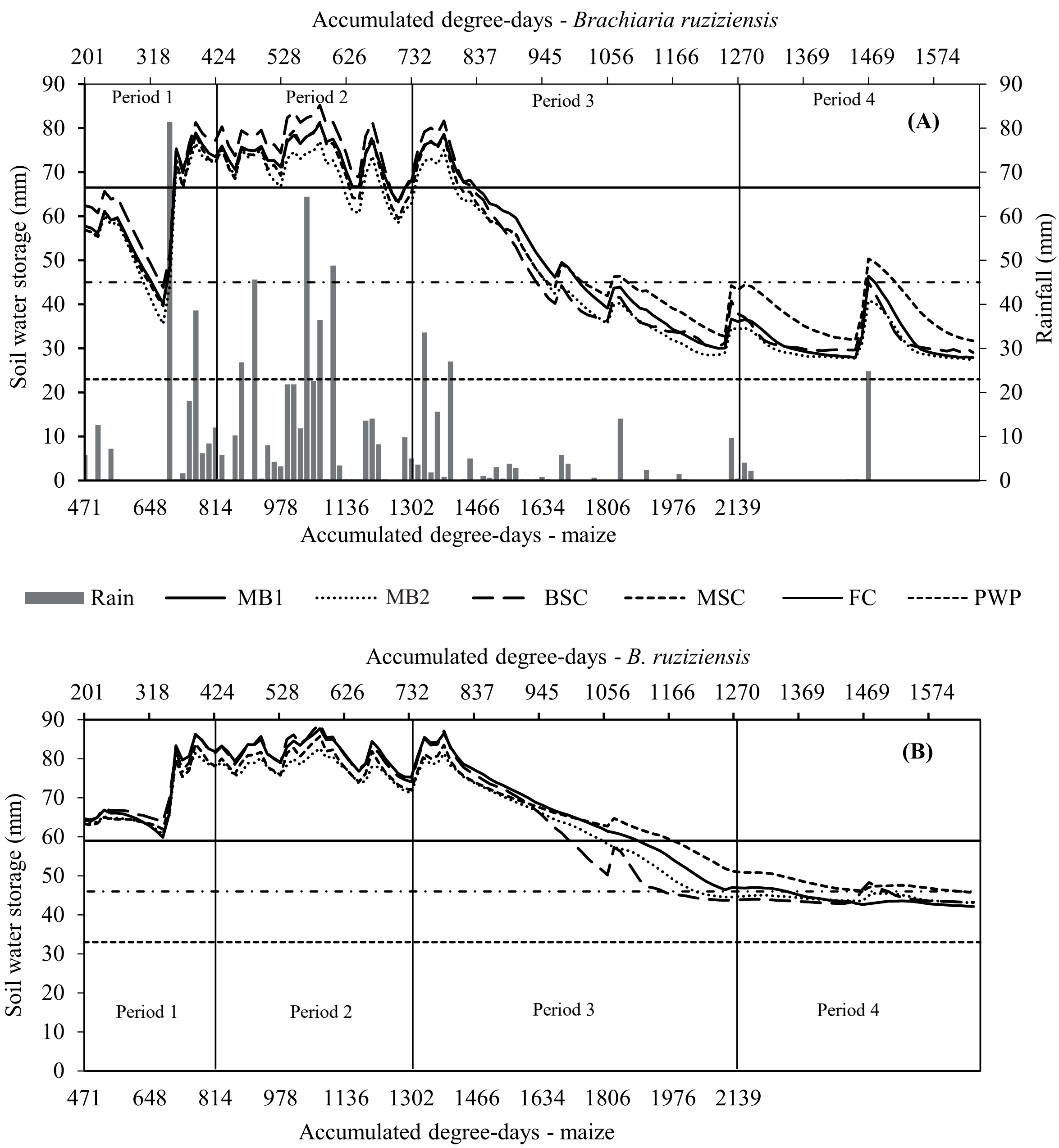

Figure 2. Soil water storage, as a function of degree-day accumulation of each crop evaluated in the intercropping systems, in soil depth layers of 0.0-0.3 m (A) and 0.3-0.6 m (B). Rain: rainfall; MB1 and MB2: intercropping of maize and *Brachiaria ruziziensis* at sowing densities of 2 kg ha^{-1} and 8 kg ha^{-1}, respectively; BSC: *B. ruziziensis* in single cropping; MSC: maize in single cropping; FC: field capacity; PWP: permanent wilting point; CS: critical storage.

increased the soil moisture to the field capacity, extending up to degree-day accumulations of 1,421 and 800 for maize and *B. ruziziensis*, respectively. In this period, the soil water storage was above the critical storage, what is important for the maize flowering and grain filling stages when the water demand is higher, especially when intercropped with ruzi grass. Moreover, the *B. ruziziensis* in single cropping maintained a higher soil moisture (78 mm) due to its slower growth. However, the maize in single cropping presented a soil moisture (73 mm) similar to those observed in the intercropping with the grass sowing densities of 2 kg ha^{-1} (74 mm) or 8 kg ha^{-1} (72 mm).

In this period, maize plants were at the flowering stage, which is a critical period that defines the grain yield (Sans et al. 2001), because of physiological processes connected to zygote formation and grain filling, high transpiration due to a large leaf area, and high energy charge from solar radiation (Bergamaschi et al. 2006).

During the maize physiological maturation stage (Period 3; Figure 2), the rainfall depths decreased. In this period, the soil water storage in the maize single cropping (56 mm) was higher than those in the other cropping systems up to the end of the monitoring. This decrease in soil water extraction was mainly due to a decrease in evapotranspiration of maize plants at the end of the cycle (Allen et al. 2005, Lyra et al. 2010). In this period, maize plants were at the physiological maturation, when all grains of an ear reach their maximum dry weight or maximum dry matter accumulation (Ritchie et al. 1997). This stage is characterized by intensification of leaf senescence, causing a higher decrease of leaf area, which results in lower shading and best conditions for the development of intercropped *B. ruziziensis* plants, as also reported by Sereia et al. (2012).

In the last monitoring period (Period 4; Figure 2), after the maize harvest, the 0.0-0.3 m soil layer presented a higher water extraction in the *B. ruziziensis* single cropping. The intercropping systems presented a soil water storage similar to that of the *B. ruziziensis* single cropping (31 mm), with means of 32 mm and 29 mm for the sowing densities of 2 kg ha^{-1} and 8 kg ha^{-1}, respectively. The water consumption in the intercropping systems with these different sowing densities was similar to that of the *B. ruziziensis* single cropping under water deficit conditions (Figure 2A). Thus, despite the fact that the roots of the forage species reached a depth of 95 cm, the evaluation at the 0.3-0.6 m soil layer satisfactorily represents the intercropping conditions, according to some studies that used the soil water balance method for *B. decumbens* (Silva et al. 2014, Machado et al. 2015) and *B. brizantha* (Gondim et al. 2015) crops.

The soil water storage at the 0.3-0.6 m soil layer (Figure 2B) varied less due to a lower root effective volume in this layer (Silva et al. 2014) and a lower water percolation from the 0.0-0.3 m layer. The soil water storage was above the critical storage up to the maize harvest. After the decrease of rainfall events, the soil under *B. ruziziensis* single cropping dried faster, followed by those under intercropping at sowing densities of 8 kg ha^{-1} and 2 kg ha^{-1}, and maize in single cropping.

The soil water storage at the 0.3-0.6 m soil layer at the end of the cycle tended to be equal in all the evaluated cropping systems because of the decrease in the rainfall events and increase of water extraction from the surface layer. This period showed a water deficit when the soil water storage was below the critical storage.

The two intercropping systems showed a lower soil water storage at the 0.3-0.6 m soil layer. This may be attributed to the competition pressure in previous stages of maize plants, which probably resulted in a higher root development of the forage species to deeper layers, in order to search for water and nutrients. Thus, they explored a higher soil volume than the maize roots. Some studies have also shown that increases in plant density and water availability stimulate the root development of forage species because of the competition for water and nutrients (Cunha et al. 2007, Silva et al. 2000).

CONCLUSIONS

1. The increase in the sowing density of *Brachiaria ruziziensis* intercropped with maize decreases the maize grain yield (30.8 %) and increases the plant density and fresh and dry matter of the forage species (30.9 %);
2. The maize and *B. ruziziensis* intercropping system results in a better land-use efficiency (23 %) when using seeds of the forage species at a sowing density of 2 kg ha^{-1};
3. The intercropping of maize and *B. ruziziensis* promotes a higher soil water extraction, mainly at the 0.0-0.3 m soil layer and when the maize

growth stage demands higher water contents (e.g., flowering and grain filling). However, this system stimulates the extraction of water from deeper soil layers, when compared to maize in single cropping.

REFERENCES

ABRAHAM, E. M.; KYRIAZOPOULOS, A. P.; PARISSI, Z. M.; KOSTOPOULOU, P.; KARATASSIOU, M.; ANJALANIDOU, K.; KATSOUTA, C. Growth, dry matter production, phenotypic plasticity, and nutritive value of three natural populations of *Dactylis glomerata* L. under various shading treatments. *Agroforestry Systems*, v. 88, n. 2, p. 287-299, 2014.

ALLEN, R. G.; PEREIRA, L. S.; SMITH, M.; RAES, D.; WRIGHT, J. L. FAO-56 dual crop coefficient procedure for predicting evaporation from soil and application extensions. *Journal of Irrigation and Drainage Engineering*, v. 131, n. 1, p. 2-13, 2005.

ANDRADE JÚNIOR, A. S. de; SILVA, J. L. da; FERREIRA, J. O. P.; IRENE FILHO, J. Índice de satisfação da necessidade de água do consórcio milho-braquiária. *Agrometeoros*, v. 25, n. 1, p. 199-208, 2017.

ANJOS, J. C. R. dos; ANDRADE JÚNIOR, A. S. de; BASTOS, E. A.; NOLETO, D. H.; MELO, F. B.; BRITO, R. R. de. Armazenamento de água em Plintossolo Argilúvico cultivado com cana-de-açúcar sob níveis de palhada. *Pesquisa Agropecuária Brasileira*, v. 52, n. 6, p. 462-471, 2017.

BATISTA, K.; DUARTE, A. P.; CECCON, G.; MARIA, I. C. de; CANTARELLA, H. Acúmulo de matéria seca e de nutrientes em forrageiras consorciadas com milho safrinha em função da adubação nitrogenada. *Pesquisa Agropecuária Brasileira*, v. 46, n. 10, p. 1154-1160, 2012.

BERGAMASCHI, H.; DALMAGO, G. A.; COMIRAN, F.; BERGONCI, J. I.; MÜLLER, A. G.; FRANÇA, S.; SANTOS, A. O.; RADIN, B.; BIANCHI, C. A. M.; PEREIRA, P. G. Water deficit and yield in maize crops. *Pesquisa Agropecuária Brasileira*, v. 41, n. 2, p. 243-249, 2006.

BORÉM, A.; GALVÃO, J. C. C.; PIMENTEL, M. A. *Milho*: do plantio à colheita. Viçosa: Ed. UFV, 2015.

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*, v. 8, n. 3, p. 263-274, 2009.

CECCON, G.; SILVA, J. F. da; LUIZ NETO NETO, A.; MAKINO, P. A.; SANTOS, A. D. R. I. A. N. O. dos. Produtividade de milho safrinha em espaçamento reduzido com populações de milho e de brachiaria. *Revista Brasileira de Milho e Sorgo*, v. 13, n. 3, p. 326-335, 2014.

CUNHA, F. F.; SOARES, A. A.; SEDIYAMA, G. C.; MANTOVANI, E. C.; PEREIRA, O. G.; ABREU, F. D. S.; SOUZA, D. O. Avaliação do sistema radicular do capim Tanzânia submetido a diferentes níveis de irrigação e turnos de rega. *Engenharia Agrícola*, v. 15, n. 3, p. 200-211, 2007.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (Embrapa). *Manual de laboratórios*: solo, água, nutrição, animal e alimentos. São Carlos: Embrapa Pecuária Sudeste, 2005.

FERREIRA, E. B.; CAVALCANTI, P. P.; NOGUEIRA, D. A. *ExpDes*: experimental designs package. R package version 1.1.2. Lavras: Ed. UFLa, 2013.

GONDIM, P. S. de S.; GONDIM, P. S. D. S.; LIMA, J. R. D. S.; ANTONINO, A. C.; HAMMECKER, C.; SILVA, R. A. da; GOMES, C. A. Environmental control on water vapour and energy exchanges over grasslands in semiarid region of Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 19, n. 1, p. 3-8, 2015.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). *Produção agrícola municipal*. Brejo: IBGE, 2018.

KLUTHCOUSKI, J.; AIDAR, H. Uso da integração lavoura-pecuária na recuperação de pastagens degradadas. *In*: KLUTHCOUSKI, J.; STONE, L. F.; AIDAR, H. (ed.). *Integração lavoura-pecuária*. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2003. p. 185-223.

KLUTHCOUSKI, J.; STONE, L. F. Manejo sustentável dos solos dos Cerrados. *In*: KLUTHCOUSKI, J.; STONE, L. F.; AIDAR, H. (ed.). *Integração lavoura-pecuária*. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2003. p. 59-104.

LARA, M. A. S. *Respostas morfofisiológicas de cinco cultivares de Brachiaria spp.* às *variações estacionais da temperatura do ar e do fotoperíodo*. 2007. Dissertação (Mestrado em Ciência Animal e Pastagens) - Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba, 2007.

LYRA, G. B.; SOUZA, J. L. D.; TEODORO, I.; LYRA, G. B.; ARAÚJO JÚNIOR, R. F. Conteúdo de água no solo em cultivo de milho sem e com cobertura morta na entrelinha na região de Arapiraca - AL. *Irriga*, v. 15, n. 2, p. 173-183, 2010.

MACHADO, C. B.; LIMA, J. R. S.; ANTONINO, A. C. D.; ALVES, E. M.; SOUZA, E. S. de; RIBEIRO, A. A.; FIRMINO, F. H. T. Fluxos de água no consórcio milhopastagem na microbacia hidrográfica do Rio Mundaú, Pernambuco. *Revista Brasileira de Recursos Hídricos*, v. 20, n. 3, p. 731-740, 2015.

MAITELLI, G. T.; OLIVEIRA, H. H. C. de. Desmatamentos e variações climáticas na região norte de Mato Grosso: os exemplos dos municípios de Vera e Sinop. *In*: MARANDOLA JÚNIOR, E.; D'ANTONA, A. de O.; OJIMA, R. (org.). *População, ambiente e desenvolvimento*: mudanças climáticas e urbanização no Centro-Oeste. Campinas: Nepo/Unicamp, 2011. p. 151-167.

PIMENTEL, C. *Metabolismo de carbono na agricultura tropical*. Seropédica: Edur, 1998.

RESENDE, J. M. D. A.; MARQUES JÚNIOR, J.; MARTINS FILHO, M. V.; DANTAS, J. S.; SIQUEIRA, D. S.; TEIXEIRA, D. D. B. Spatial variability of the properties of cohesive soils from eastern Maranhão, Brazil. *Revista Brasileira de Ciência do Solo*, v. 38, n. 4, p. 1077-1090, 2014.

RITCHIE, S. W.; HANWAY, J. J.; THOMPSON, H. E.; BENSON, G. O. *How a corn plant develops*. Ames: Iowa State University of Science and Technology, 1997.

SANS, L. M. A.; ASSAD, E. D.; GUIMARÃES, D. P.; AVELLAR, G. Zoneamento de riscos climáticos para a cultura do milho na região Centro-Oeste do Brasil e para o estado de Minas Gerais. *Revista Brasileira de Agrometeorologia*, v. 9, n. 3, p. 527-539, 2001.

SEREIA, R. C.; LEITE, L. F.; ALVES, V. B.; CECCON, G. Crescimento *de Brachiaria* spp. e milho safrinha em cultivo consorciado. *Revista Agrarian*, v. 5, n. 18, p. 349-355, 2012.

SILVA, J. L. da. *Coeficientes de cultura do milho e Brachiaria ruziziensis em cultivo solteiro e consorciado*. 2011. Dissertação (Mestrado em Solos e Nutrição de Plantas) - Universidade Federal do Piauí, Teresina, 2011.

SILVA, R. A. B. da; SOUSA LIMA, J. R. de; ANTONINO, A. C. D.; GONDIM, P. S. de S.; SOUZA, E. S. de; BARROS JÚNIOR, G. Balanço hídrico em Neossolo Regolítico cultivado com braquiária (*Brachiaria decumbens* Stapf). *Revista Brasileira de Ciência do Solo*, v. 38, n. 1, p. 147-157, 2014.

SILVA, W. da; SILVA, A. D.; SEDIYAMA, T.; FREITAS, R. D. Absorção de nutrientes por mudas de duas espécies de eucalipto em resposta a diferentes teores de água no solo e competição com plantas de *Brachiaria brizantha*. *Ciência e Agrotecnologia*, v. 24, n. 1, p. 147-159, 2000.

SOUSA, D. M. G. de; LOBATO, E. *Cerrado*: correção do solo e adubação. Planaltina, DF: Embrapa Cerrados, 2004.

SRIVASTAVA, R. K.; PANDA, R. K.; CHAKRABORTY, A.; HALDER, D. Comparison of actual evapotranspiration of irrigated maize in a sub-humid region using four different canopy resistance based approaches. *Agricultural Water Management*, v. 202, n. 1, p. 156-165, 2018.

VILA NOVA, N. A.; PEDRO JUNIOR, M. J.; PEREIRA, A. R.; OMETTO, J. C. Estimativa de graus-dia acumulados acima de qualquer temperatura-base, em função das temperaturas máximas e mínimas. *Caderno de Ciência da Terra*, n. 30, p. 1-7, 1972.

WILLEY, R. W. Intercropping: its importance and research needs: part 1. Competition and yield advantages. *Field Crop Abstracts*, v. 32, n. 1, p. 1-10, 1979.