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Productivity and nutrient export in a maize and forage grasses intercropping under semiarid conditions

Produtividade e exportação de nutrientes em um consórcio de milho e gramíneas forrageiras nas condições do semiárido

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ABSTRACT

The aim was to evaluate the productive performance and nutrient export of maize intercropped with drought-tolerant forage grasses. The experimental design was a randomized blocks in a 2x2x2+1 factorial scheme (two forage grasses species – Massai and Buffel; two forage sowing methods - in the furrow and broadcast; and two forage sowing times - anticipated and simultaneous; and monoculture maize as an additional control), with three replicates. The maize+forage intercropping promoted greater competition for resources, especially water, limiting N uptake, chlorophyll synthesis, and biomass production by maize under semiarid conditions. Early sowing gave forage plants a competitive advantage, favoring forage establishment before or immediately after the sowing of maize. Thus, the simultaneous sowing of forage grasses in a semiarid environment is a more appropriate option considering the importance of high levels of chlorophyll to ensure high photosynthetic activity in maize plants and greater capacity of biomass synthesis. Massai intercropped with maize exhibits a

greaterpotential for biomass production than Buffel under semiarid conditions. Maize+Buffel result in highest macronutrient export by maize, while maize+Massai result in highest macronutrient exports by total forage biomass under a semiarid environment. The choice of the forage species and its sowing time in relation to maize are the main determinants of successful intercropping systems under semiarid conditions.
Keywords: C*enchrus ciliaris*, forage accumulation, integrated crop-livestock system, *Megathyrsus maximus*, *Zea mays*

RESUMO

O objetivo foi avaliar o desempenho produtivo e a exportação de nutrientes do consórcio de milho com gramíneas forrageiras tolerantes ao estresse hídrico. O experimento foi delineado em blocos casualizados em esquema fatorial 2x2x2+1 (duas espécies de gramíneas forrageiras – Massai e Buffel; dois métodos de semeadura – no sulco e a lanço; e duas épocas de semeadura – antecipada e simultânea; e monocultivo de milho como um controle adicional), com três repetições. O consórcio milho+forragem promoveu maior competição por recursos, principalmente água, limitando a absorção de N, síntese de clorofila e produção de biomassa pelo milho para condições semiáridas. A semeadura precoce deu vantagem competitiva às plantas forrageiras, favorecendo seu estabelecimento antes ou imediatamente após a semeadura do milho. Assim, a semeadura simultânea de gramíneas forrageiras em ambiente semiárido é uma opção mais adequada, considerando a importância de garantir altos teores de clorofila e, consequentemente, alta atividade fotossintética nas plantas de milho para garantir a capacidade de síntese de biomassa.Massai consorciado com milho apresenta maior potencial para produção de biomassa do que Buffel em condições semiáridas.Milho+Buffel resulta em maior exportação de macronutrientes pelo milho, enquanto milho+Massai resulta em maior exportação de macronutrientes pela biomassa forrageira total em ambiente semiárido.A escolha da espécie forrageira e sua época de semeadura em relação ao milho são os principais determinantes do sucesso do consórcio no semiárido.
Palavras-chave: acúmulo de forragem, C*enchrusciliaris*, *Megathyrsusmaximus*, sistema de integração lavoura-pecuária,*Zea mays*

INTRODUCTION

Inadequate cultural practices such as monocrops have caused loss of productivity, soil degradation, and a decrease in natural resources (Oliveira et al., 2020). The success of agricultural activities requires the adoption of more sustainable systems, which enable the reversal of soil degradation and increased productivity (Masvaya et al., 2017). Integrated production systems are an alternative to recover soil quality since they allow synergistic effects on the environment (Araújo et al., 2020). In these systems, the cultivation of annual species with forage grasses can provide greater productivity and land use, in addition to greater production of biomass available to growers in periods of food shortage (Baldé et al., 2011).

Intercropping of annual crops with forage grasses is a practice developed and successfully adapted to the conditions of the Central-South Region of Brazil (Crusciol et al., 2015; Canisares et al., 2021). Likewise, intercropping of annual crops with

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forage species can provide promising results in regions with high temperatures and little rainfall (Masvaya et al., 2017). In semiarid regions, intercropping can increase productivity per unit area, increasing the chances of crop success, especially due to the more effective complimentary use of available resources (Li et al., 2014).

There are several forage species adapted to the formation of pastures. Among them, Buffel grass (*Cenchrus ciliaris*) stands out for being a grass of remarkable adaptation to conditions of low water availability, due to its drought tolerance (Al-dakheel& Hussain, 2016). Another potential species is the Massai grass (*Megathyrsus maximus*), which is a promising alternative to the conditions of the Brazilian semiarid, especially due to its high production of dry biomass, determined by the high accumulation rates of foliage (Luna et al., 2014).

However, despite the recognized potential of some forage species for cultivation in regions with low water availability, practically no research has evaluated forage crops intercropped with annual crops, such as maize. Therefore, this study aimed to evaluate the development of forage grasses, with recognized tolerance to drought, intercropped with maize under two sowing methods (in the furrow and broadcast) and two sowing times (simultaneous and early).

MATERIAL AND METHODS

The study was conducted from February to June 2017 at the facilities of Embrapa Goats and Sheep, in Sobral, Ceará, Brazil (3º45'14' S; 40º21'13' W; 80 m of altitude). The soil is a Haplic Luvisol (*Luvissolo Háplico*). Data of soil particle-size and chemical attributes (Teixeira et al., 2017) from the experimental area are: pH (H_2O) = 5.8; OM (organic matter) = 1.4 %; P = 8.6 mg dm-³; K^+ = 0.93 $cmol_c$ dm^{-3}; Na^+ = 0.0 $cmol_c$ dm^{-3}; Ca^{2+} = 6.7 $cmol_c$ dm-3; Mg^{2+} = 3.6 $cmol_c$ dm^{-3}; H+Al (potential soil acidity) = 3.1 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; CEC (cation exchange capacity) = 13.7 $cmol_c$ dm^{-3}; BS (base saturation) = 77.0%; clay = 25 %; silt = 12 %; sand = 63 %. According to the Köppen-Geiger classification the climate is BSh (hot semiarid), with an average annual temperature of 27.4 ºC and average annual rainfall of 750 mm. The rainfall data from February to June 2017 is presented in Figure 1.

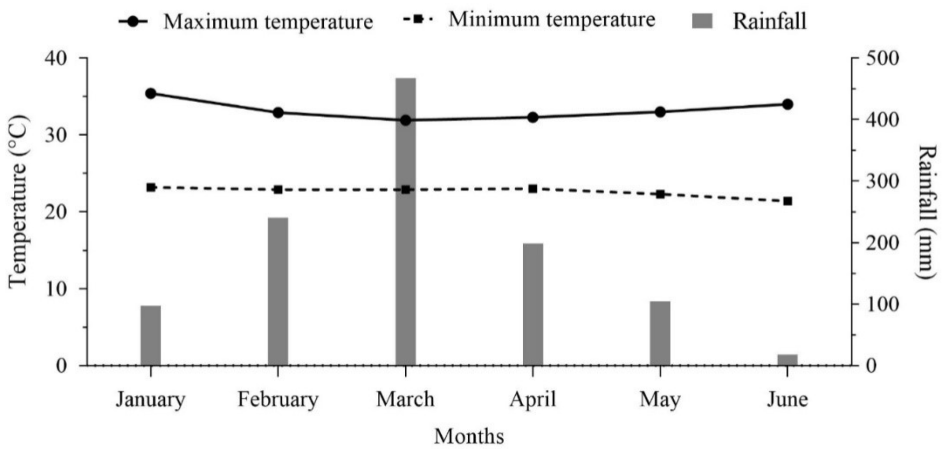

Figure 1. Rainfall, maximum and minimum temperatures from January to June 2017. Sobral, Ceará, Brazil

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The experiment was established with maize sown after plowing the soil at a depth of 0.2 m, followed by light harrowing. The double hybrid maize BRS 2020 (short cycle and small plants) was sown at 0.75 m spacing between rows and 0.20 m spacing between plants within the row, with a population of 66,667 plants ha^{-1} (Pereira-Filho, 2015). Maize was fertilized at phenological stage V4 (four fully expanded leaves) using 100 kg ha^{-1} of urea (45 kg ha^{-1} of N) and 60 kg ha^{-1} of KCl (36 kg ha^{-1} of K_2O) (Fernandes, 1993). Seeds of the forage species *Megathyrsus maximus* cv. Massai (40% crop value) and *Cenchrus ciliaris* cv. Buffel Aridus (35% crop value) were either broadcast or sown in furrows. The amount of Massai seeds used in the intercropping was 10 kg ha^{-1} and 6.25 kg ha^{-1} for broadcast sowing and sown in furrows, respectively. For Buffel, 11.4 kg ha^{-1} and 7.14 kg ha^{-1} of seeds were used for broadcast sowing and sown in furrows, respectively (Gontijo-Neto, 2006).

The experiment was designed in randomized blocks in a 2x2x2+1 factorial scheme. The treatments consisted of two species of forage grasses intercropped with maize (Massai and Buffel); two methods of sowing (broadcast and sown in the furrow between maize rows); and two times of sowing (anticipated fifteen days before maize sowing, and simultaneous to maize sowing), in addition to a control treatment with monoculture maize, with three replicates. The experiment had nine treatments distributed in 27 plots. Each experimental plot consisted of four maize rows and three forage rows 4.0 m long cultivated between central maize rows.

In the VT maize development stage (tasseling), diagnostic leaves were sampled for macronutrients contents determination (Miyazawa et al., 2009). SPAD (Soil Plant Analysis Development) Index was determined using a chlorophyll meter (Minolta SPAD 502®) (Argenta et al., 2004) to estimate the relative chlorophyll index (RCI) in the same diagnostic leaves. Maize plant height was recorded by measuring the distance from the plant's collar to the end of the flag leaf. Cob insertion height was recorded by measuring the distance from the plant collar to the base of the cob. Plants in the phenological stage between milk and farinaceous grain (R2 – R4) were cut to estimate the total production of maize biomass forage. Cobs were harvested in the physiological maturity phase of the grains (~120 days after planting). The number of cobs were determined, and the cobs were weighed without the straw and threshed. Grain yield was estimated by correcting the grain moisture to 13%.

For the forages, the number of tillers on an area of 0.25 m^2 was recorded to estimate the final plant population and total biomass production. Plants were cut 2 cm above the soil surface, on the central row of each plot. The plant material was weighed to estimate dry biomass production. The canopy's height was measured and the number of expanded living leaves of five plants from each plot was determined after the emission and expansion of the panicles. All the material harvested from the maize central rows and from the forage central row was removed from the plots to simulate the export of plant biomass for silage production. From the maize and forage dry mass samples, the contents of N, P, K, Ca, Mg, and S were determined (Miyazawa et al., 2009). Total nutrients accumulation was calculated based on plant dry mass productivity and nutrient content estimates.

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Once the basic assumptions were met, the data were submitted to the analysis of variance. F test was used to discriminate the levels of the treatments within each factor when the differences were significant. Treatments related to nutrient export by intercropped forages were compared using the Scott Knott clustering test (5%). Finally, the Dunnett test was used to compare the treatment data of the intercropping systems with the control. All analyses were performed using the R software (R Core Team, 2017).

RESULTS

Nutrient contents in maize leaf showed no significant interaction between intercropping, sowing methods, or forage sowing times. However, of the sowing methods, sowing in the furrow resulted in higher sulfur content compared to broadcast (Table 1).

Table 1. Mean values, F test and coefficient of variation of leaf nutrient contents and relative chlorophyll index (RCI) in the maize diagnostic leaf, as a function of intercropping, sowing method and forage sowing times

Treatments	N	P	K	Ca	Mg	S	RCI
	g kg^{-1}						
Intercropping							
Maize+Buffel	20.3	2.2	17.1	2.9	1.2	1.0	43.5
Maize+Massai	19.7	2.1	16.7	2.9	1.1	1.1	41.1
F test	0.63^{ns}	0.53^{ns}	0.32^{ns}	0.16^{ns}	0.52^{ns}	0.52^{ns}	1.55^{ns}
Sowingmethods							
Broadcast	19.7	2.1	16.4	2.8	1.1	1.0b	41.9
Furrow	20.3	2.2	17.4	3.0	1.2	1.2a	42.6
F test	0.42^{ns}	0.43^{ns}	1.51^{ns}	1.04^{ns}	0.12^{ns}	8.33*	0.15^{ns}
Sowing times							
Simultaneous	20.0	2.1	16.2	2.9	1.1	1.0b	44.3a
Anticipated	20.0	2.2	17.6	2.9	1.2	1.2a	40.2b
F test	<0.01^{ns}	0.36^{ns}	3.14^{ns}	<0.01^{ns}	1.01^{ns}	5.00*	5.01*
CV (%)	9.8	17.9	11.9	13.6	16.0	15.3	11.1

N: nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur; RCI: relative chlorophyll index. Means followed by different letters in the columns differ from each other by the F test ($p<0.05$). ns and *: not significant and significant at 5% probability, respectively.

Apart from maize+Massai with anticipated sowing in the furrow, the other intercropping treatments had lower foliar N concentrations than the control (monoculture maize). Likewise, RCI values for the control were significantly higher than those observed in maize+Buffel with anticipated sowing, regardless of the sowing method, and in maize+Massai with anticipated broadcast sowing and with simultaneous sowing in the furrow (Table 2).

Table 2. Mean values of leaf nutrient contents and relative chlorophyll index (RCI) as a function of intercropping systems, sowing methods and forage sowing times compared to monoculture maize

Intercropping	Methods	Times	N	P	K	Ca	Mg	S	RCI
			------------------------ g kg^{-1}					--------------------	
Maize+Buffel	Broadcast sown	Anticipated	20.06$^{***(-)}$	2.19	18.20	2.83	1.27	0.96	36.9$^{*(-)}$
Maize+Buffel	Broadcast sown	Simultaneous	21.23$^{*(-)}$	2.25	15.03	2.93	1.21	1.00	47.4
Maize+Buffel	Furrow	Anticipated	19.36$^{**(-)}$	2.33	18.40	2.90	1.09	1.30	41.3$^{*(-)}$
Maize+Buffel	Furrow	Simultaneous	20.76$^{*(-)}$	2.22	17.03	3.20	1.16	1.06	45.7
Maize+Massai	Broadcast sown	Anticipated	17.96$^{***(-)}$	2.20	16.80	2.90	1.12	1.10	39.4$^{**(-)}$
Maize+Massai	Broadcast sown	Simultaneous	19.83$^{**(-)}$	1.90	15.66	2.73	0.97	0.96	43.8
Maize+Massai	Furrow	Anticipated	22.86	2.23	17.26	3.10	1.29	1,36	43.2
Maize+Massai	Furrow	Simultaneous	18.20$^{***(-)}$	2.19	17.06	2.86	1.13	1,10	40.4$^{*(-)}$
Maize			25.9	2,69	18.66	2.96	1.22	1.10	52.1

N: nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur; RCI: relative chlorophyll index. *, ** and ***: significant at 5, 1 and 0.01 % for the Dunnett test, respectively, when comparing the averages with monoculture maize. (+) and (-): Average differs from monoculture maize with higher or lower values, respectively.

Maize+Buffel resulted in more maize biomass, greater canopy height, and higher number of leaves per forage tiller. Maize+Massai resulted in higher maize grain yield than maize+Buffel and a higher number of tillers and the total amount of forage biomass produced. Anticipated planting resulted in highest number of tillers and forage biomass production. In turn, simultaneous sowing of forage and maize resulted in higher grain yield, maize biomass, and total maize biomass+forage yield (Table 3).

Table 3. Mean values, F test and coefficient of variation of biometric and biomass attributes, depending on the intercropping, sowing methods and forage sowing times

Treatments	HP	HIC	GRAINS	MB	HC	NT	NLT	FB	TB
	--------------- Maize			---------------	--------------- Forage			---------------	Maize+Forage
	------ m ------		------ t ha^{-1} ------		-------------- m		-------------	---------- t ha^{-1}	---------
Intercropping									
Maize+Buffel	1.7	0.8	3.5b	6.2a	0.6a	316.0b	8.9a	2.0b	8.1b
Maize+Massai	1.6	0.8	4.6a	3.9b	0.5b	1103.0a	3.1b	7.5a	11.4a
F test	0.18^{ns}	<0.01^{ns}	2.4*	11.2*	30.5**	389.7**	585.7**	53.2**	7.9*
Sowingmethods									
Broadcast	1.7	0.9	3.5	4.7	0.52	736.6	5.8	4.5	9.3
Furrow	1.6	0.8	4.6	5.3	0.55	682.3	6.1	4.9	10.2
F test	0.5^{ns}	0.3^{ns}	0.2^{ns}	0.7^{ns}	2.0^{ns}	1.9^{ns}	1.8^{ns}	0.2^{ns}	0.7^{ns}
Sowing times									
Simultaneous	1.7	0.9	3.5a	7.7a	0.52	614.3b	6.0	3.4b	11.2a
Anticipated	1.6	0.8	1.7b	2.3b	0.56	804.6a	6.0	6.0a	8.4b

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F test	3.7^{ns}	0.16^{ns}	54.2^{**}	62.7^{**}	2.6^{ns}	22.8^{**}	$<0.01^{ns}$	12.2^{*}	6.1^{*}
CV (%)	8.9	15.2	0.11	0.04	9.8	13.7	9.9	0.04	0.03

HP: height of maize plants, HIC: height of insertion of maize cobs, GRAINS: maize grain yield, MB: maize biomass, HC: height canopy, NT: number of tillers, NLT: number of leaves per tiller; FB: forage biomass; TB: total biomass. ns, * and **: not significant, significant at 5 and 1 % probability, respectively. Means followed by the different letters in the column differ from each other by the F test (p<0.05).

Maize grain yield was lower in maize+Buffel and in maize+Massai both with anticipated broadcast sowing and simultaneous sowing in the furrow, compared to monoculture maize. Likewise, the production of total maize biomass was significantly lower in maize+Buffel with anticipated sowing, either broadcast sown or sown in the furrow, compared to the control. Forage biomass production could not be compared with the control. However, the Scott-Knott test revealed that maize+Massai with anticipated sowing, both broadcast and sown in the furrow, had highest forage biomass yields, followed by maize+Massai with simultaneous sowing (irrespective of sowing method). Forage biomass productivity was lower in maize+Buffel (Table 4).

Table 4. Average values of variation of biometric and biomass attributes, as a function of intercropping, sowing methods and forage sowing timescomparedto monoculture maize

Intercropping	Sowingmethods	Times	HP	HC	GRAINS	MB	FB£	TB
			------------------ Maize			-----------	Forage	Maize+Forage
			-------- m -------		------------------ t ha^{-1}			----------------------
Maize+Buffel	Broadcast	Anticipated	1.64	0.86	$1.5^{*(-)}$	$3.0^{*(-)}$	3.0 c	6.0
Maize+Buffel	Broadcast	Simultaneous	1.84	0.89	4.9	8.8	0.9 c	9.8
Maize+Buffel	Furrow	Anticipated	1.60	0.82	3.9	$2.9^{*(-)}$	2.9 c	5.8
Maize+Buffel	Furrow	Simultaneous	1.76	0.90	$1.6^{*(-)}$	10.0	1.0 c	11.0
Maize+Massai	Broadcast	Anticipated	1.67	0.91	$0.5^{*(-)}$	$1.2^{*(-)}$	8.5 a	9.7
Maize+Massai	Broadcast	Simultaneous	1.73	0.87	4.3	$5.8^{*(-)}$	5.8 b	11.6
Maize+Massai	Furrow	Anticipated	1.64	0.84	$1.7^{*(-)}$	$1.9^{*(-)}$	9.9 a	11.8
Maize+Massai	Furrow	Simultaneous	1.69	0.84	3.2	$6.5^{*(-)}$	5.9 b	12.4
Monoculturemaize			1.90	0.90	5.6	11.1	-	11.1

HP: height of maize plants, HIC: height of insertion of maize cobs, GRAINS: maize grain yield, MB: maize biomass; FB: forage biomass; TB: total biomass. *: significant at 5% by Dunnett's test, comparing the averages with single maize. £Means followed by the same letters in the column referring to FB, belong to the same group, according to the Scott-Knott test (p<0.05). (+) and (-): Average differs from monoculture maize with higher or lower values, respectively.

Intercropping with forage plants influenced nutrient export by removing the total maize biomass from the area. Maize+Buffel exhibited a greater export of N, P, K, Ca, and Mg compared to maize+Massai. Likewise, the sowing time governed the amount of macronutrients exported by the total maize biomass, with highest values in simultaneous sowing. Maize+Massai exported significantly more nutrients from the forage (N, P, K, Ca, Mg, and S) than maize+Buffel. However, unlike the total maize biomass, nutrient export by forages was highest with anticipated

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sowing. Forage sowing method did not influence the amount of nutrients exported (Table 5).

Table 5. Mean values, F test and coefficient of variation of maize and forage nutrient export, as a function of intercropping, sowing method and forage sowing time

Treatments	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
	Maize						Forage					
Intercropping												
Maize+Buffel	58.5a	10.4a	75.6a	12.9a	10.2a	4.6	22.6b	3.1b	44.8b	5.2b	3.8b	1.7b
Maize+Massai	36.2b	6.6b	43.0b	6.6b	5.7b	3.3	93.9a	10.8a	126.2a	25.5a	15.3a	7.2a
F test	13.3^{*}	8.6^{*}	10.9^{ns}	16.2^{*}	11.6^{*}	2.8^{ns}	33.2*	32.6^{**}	28.4^{**}	55.3^{**}	50.9^{**}	38.1^{**}
Sowingmethods												
Broadcast	44.7	7.6	53.6	9.2	7.3	3.9	52.2	6.8	82.9	15.8	9.3	4.2
Furrow	50.1	9.4	65.0	10.4	8.5	4.1	64.3	7.1	88.1	14.9	9.8	4.7
F test	0.8^{ns}	1.9^{ns}	1.4^{ns}	0.7^{ns}	0.9^{ns}	0.1^{ns}	0.9^{ns}	0.04^{ns}	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.4^{ns}
Sowing times												
Simultaneous	72.4a	13.1a	87.7a	14.7a	12.0a	6.1a	41.9b	5.2b	59.6b	11.5b	6.9b	3.3b
Anticipated	22.4b	4.0b	30.9b	4.9b	3.8b	1.9b	74.5a	8.7a	111a	19.2a	12.2a	5.6a
F test	66.7^{**}	50.6^{**}	33.2^{**}	38.9^{**}	39.6^{**}	30.4^{**}	6.9^{*}	7.1^{*}	11.5^{*}	8.1^{*}	10.7^{*}	7.1^{*}
CV (%)	5.2	36.9	4.4	24.9	25.2	74.6	5.4	32.0	1.6	18.3	23.2	66.9

N: nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur. ^{ns}, * and **: not significant, significant at 5 and 1 % probability, respectively. Means followed by the different letters in the column differ from each other by the F test (p<0.05).

There was highest export of all nutrients but P in maize+Massai by the total biomass of maize and forage. Simultaneous sowing of maize and forage resulted in greater export of N and P compared to anticipated sowing. The sowing method did not influence the amounts of nutrients exported. The decreasing order of macronutrients exports by maize biomass was K > N > P > Ca > Mg > S; for forage biomass the decreasing order of macronutrient export was K > N > Ca > Mg > P > S (Table 6).

Table 6. Mean values, F test and coefficient of variation of maize+forage nutrient export, as a function of intercropping, sowing method and forage sowing time

Treatments	N	P	K	Ca	Mg	S
	Maize+Forage					
Intercropping						
Maize+Buffel	81.2b	13.5	120.5b	18.2b	14.0b	6.4b
Maize+Massai	130.2a	16.5	169.2a	32.2a	21.0a	10.6a
F test	9.4^{*}	2.9^{ns}	7.2^{*}	16.9^{**}	9.7^{*}	9.1^{*}
Sowingmethods						
Broadcast	96.9	14.5	136.5	25.0	16.6	8.1
Furrow	114.4	16.5	153.2	25.4	18.3	8.8

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F test	1.2^{ns}	0.8^{ns}	0.8^{ns}	0.01^{ns}	0.6^{ns}	0.3^{ns}
Sowing times						
Simultaneous	114.4a	18.2a	147.3	26.2	19.0	9.4
Anticipated	97.0b	12.7b	142.4	24.2	16.0	7.5
F test	1.2*	5.9*	0.07^{ns}	0.4^{ns}	1.8^{ns}	1.8^{ns}
CV (%)	1.8	18.2	1.8	12.5	11.4	26.3

N: nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur. ^{ns}, * and **: not significant, significant at 5 and 1 % probability, respectively. Means followed by different letters in the column differ from each other by the F test (p<0.05).

Maize+Buffel with simultaneous sowing (broadcast or sown in the furrow) did not influence the amount of nutrients exported by the maize biomass, compared to the control. Additionally, maize+Massai with simultaneous broadcast sowing did not affect the amount of N exported; maize+Massai with simultaneous sowing in the furrow did not affect the amounts of P and K exported. All other treatments reduced nutrient exports by maize biomass compared to monoculture maize. The treatments only influenced Ca concerning the total production of maize biomass+forage. In general, maize+Massai exported highest amounts of Ca by the biomass removed from the area than the monoculture maize, regardless of the time or method of sowing (Table 7).

Table 7. Comparison of nutrient export mean from maize and maize+forages, as a function of the control treatment (monoculture maize)

Intercropping	Sowingmethods	Times	N	P	K	Ca	Mg	S
			Maize					
			kg ha^{-1}					
Maize+Buffel	Broadcast	Anticipated	29.30$^{*(-)}$	5.33$^{*(-)}$	34.33$^{*(-)}$	6.00$^{*(-)}$	5.20$^{*(-)}$	2.33$^{*(-)}$
Maize+Buffel	Broadcast	Simultaneous	82.13	14.03	102.96	18.90	14.03	7.26
Maize+Buffel	Furrow	Anticipated	34.70$^{*(-)}$	5.23$^{*(-)}$	52.13$^{*(-)}$	7.56$^{*(-)}$	5.20$^{*(-)}$	2.43$^{*(-)}$
Maize+Buffel	Furrow	Simultaneous	88.00	17.16	113.23	19.46	16.23	6.60
Maize+Massai	Broadcast	Anticipated	9.40$^{*(-)}$	1.83$^{*(-)}$	15.03$^{*(-)}$	2.13$^{*(-)}$	1.76$^{*(-)}$	1.03$^{*(-)}$
Maize+Massai	Broadcast	Simultaneous	58.03	9.56$^{*(-)}$	62.13$^{*(-)}$	9.60$^{*(-)}$	8.20$^{*(-)}$	5.00
Maize+Massai	Furrow	Anticipated	16.30$^{*(-)}$	3.70$^{*(-)}$	22.33$^{*(-)}$	3.90$^{*(-)}$	3.03$^{*(-)}$	1.83$^{*(-)}$
Maize+Massai	Furrow	Simultaneous	61.40$^{*(-)}$	11.66	72.56	10.96$^{*(-)}$	9.76$^{*(-)}$	5,63
Maize			111.53	20.13	112.80	19.73	18.06	7.80

Intercropping	Sowingmethods	Times	Maize+Forage					
			kg ha^{-1}					
Maize+Buffel	Broadcast sown	Anticipated	59.43	10.20	106.30	14.70	11.43	4.93
Maize+Buffel	Broadcast	Simultaneous	94.06	15.46	125.86	21.63	15.93	8.13
Maize+Buffel	Broadcast	Anticipated	72.30	9.73	111.83	14.53	10.53	4.90
Maize+Buffel	Furrow	Simultaneous	99.10	18.93	138.03	22.10	18.10	7.63
Maize+Massai	Furrow	Anticipated	104.53	13.60	159.73	32.73$^{*(+)}$	18.00	8.90
Maize+Massai	Broadcast	Simultaneous	129.86	18.83	154.33	31.10$^{*(+)}$	21.33	10.43

Maize+Massai	Broadcast	Anticipated	151.80	17.60	191.93	34.80*(+)	24.13	11.53
Maize+Massai	Furrow	Simultaneous	134.70	19.86	170.96	30.23*(+)	20.73	11.46
Maize			111.53	20.13	112.80	19.73	18.06	7.80

N: nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur. *: significant at 5% by Dunnett's test, comparing the averages with single maize. (+) and (-): Average differs from monoculture maize with higher or lower values, respectively.

DISCUSSION

The present study showed that intercropping maize withthe forage grasses Massai and Buffel significantly reduced foliar N and chlorophyll content in maize grown in semiarid conditions. These results suggest that intercropping systems under these conditions limit the availability of N and chlorophyll synthesis in plants and may lead to lower plant efficiency in biomass synthesis and, therefore, in forage productivity.

However, the available data on the behavior of foliar nutrient content in maize intercropped with forage crops are generally the result of studies conducted predominantly in the Central-South region of Brazil (Crusciol et al. 2015; Oliveira et al., 2020), where the prevailing climatic conditions are entirely distinct from the semiarid region. In the study conducted by Oliveira et al. (2020), the positive effects of intercropping on foliar N content of maize were only evident when cultivated in the main crop period, when the climatic conditions were more favorable to plant development compared to the cultivation in the second crop (off-season crop). Thus, maize and forage grasses intercropping evaluated in the present study may have led to greater competition for water (Li et al., 2014), with the consequent reduction in soil water availability, limiting N uptake by maize plants, thereby resulting in lower foliar contents of this nutrient.

Around 50% of all foliar N content is somehow involved with photosynthetic processes, either as a component of enzymes or, mainly, in the constitution of chlorophyll (Bänziger et al., 2020). Therefore, the reduction in foliar N content possibly caused by water deficit also resulted in decreased relative chlorophyll indices in the present study, especially in treatments with early sowing of Buffel and Massai grass. Early sowing gave forage plants a competitive advantage, favoring their establishment before or immediately after the sowing of maize. Competition between species in intercropping systems can be minimized by adjusting the planting dates (Masvaya et al., 2020). Thus, the simultaneous sowing of forage grasses in a semiarid environment is a more appropriate option considering the importance of ensuring high levels of chlorophyll and, consequently, high photosynthetic activity in maize plants to ensure the capacity of biomass synthesis.

The higher biomass productivity of Massai grass compared to that of Buffel grass was decisive for the higher total forage production in the maize + forage intercropping, accounting for 65% of the total biomass produced. In turn, the share of Buffel grass in the composition of the total forage biomass produced in intercropping was only 25%. The Massai grass has been reported as a forage species with greater capacity for establishment and development in semiarid conditions (Luna et al., 2014) and showing good tolerance to water deficits (Oliveira et al., 2022) than the

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Buffel grass. The total biomass production of Massai in this study was slightly lower than that obtained by Edvan et al. (2011) in semiarid conditions. However, unlike in the present study, the forage was sown as monocrop, and the productivity was determined after successive harvests.

Early sowing of forage in the intercropping limited the development of maize, resulting in lower grain productivity, maize biomass, and total biomass. Contrary to the results of this study, several studies have shown that intercropping with forage grasses does not interfere with the development and productivity of maize (Baldé et al., 2011; Canisares et al., 2021; Oliveira et al., 2020). However, these studies were normally conducted in intercropping systems with simultaneous sowing of maize and forage species and, above all, under climatic conditions distinct from those prevailing in the semiarid region. It is possible that the early sowing of forage has led to a lower capacity of maize plants to intercept photosynthetically active radiation, even more considering the initial stage of the crop, critical for the accumulation of biomass (Borghi et al., 2013). It is also possible that the early sowing of forage plants resulted in greater competition for water when the maize crop was at the beginning of its establishment, resulting in conditions that prevented maize development in the intercropping system (Jakelaitis et al., 2004).

In several regions in the world where maize is cultivated, the highest grain yields were obtained when water availability varies from 500 to 800 mm throughout its biological cycle (Pereira-Filho et al., 2015). Although this rangeis close tothe limit observed in this study (823 mm), the available water had to meet the demand of maize and the forage species. Silva et al. (2020) showed that the maize-forage grasses intercropping promotes greater water extraction from the soil, especially in the phases of higher water demand of maize, restricting its productivity under high forage densities.

Thus, the hypothesis of water limitation in the present study is supported by the fact that, although the simultaneous sowing of forage did not reduce grain productivity in relation to maize monocrop, it reduced the production of total maize biomass in the intercropping with Massai (Lin et al., 2020) due to the rapid establishment and development of this forage species. This was confirmed by the high number of tillers produced and greater biomass production, consequently, resulting in higher competitiveness and demand for water. Fontinele et al. (2022) state that the number of tillers is an interesting response to guarantee the perenniality of the forage in the following production cycles. Besides, these data indicate that the main factors to be considered under semiarid conditions are the choice of intercropping species and the definition of the sowing season in relation to maize throughout its biological cycle.

Intercropping systems were preponderant factors to determine the intensity of macronutrient export. The greater vegetative development of maize in the intercropping with Buffel grass resulted in the largest nutrient exports by the grain crop, while the high production of Massai grass was decisive for the largest nutrient export by the total biomass of forage produced. Similar to that observed in the present study, Mendonça et al. (2015) and Pereira et al. (2016) also observed higher K uptake, followed by N, with similar amounts of P and Ca and, finally, of Mg by forages intercropped with maize.

In addition to intercropping systems, the present study's data showed that the early sowing of forage substantially reduced the amount of nutrients exported by maize but did not influence nutrient export by the total forage biomass (maize+forage), except for Ca, which was exported in larger quantities to the total forage biomass in Massai grass. Unlike nutrients such as P and K, whoseabsorption is drastically limited under water deficit conditions, Ca uptake is affected in smaller proportions under these conditions (Hu &Schmidhalter, 2005), even in limiting water conditions. These results indicate that, although the maize+forage intercropping results in numerous benefits for soil fertility (Baldé et al., 2011; Crusciol et al., 2015; Mendonça et al., 2015), there is a need to ensure the replenishment of nutrients under semiarid conditions when the biomass production resulting from the intercropping is destined for animal feed, especially with its removal from the area by haymaking or silage processes.

The average export of macronutrients per ton of dry mass of maize harvested was 10.0, 1.8; 10.2; 1.8; 1.6, and 0.7 kg t^{-1} of dry mass for silage, 11.6, 1.6, 23.0, 2.7, 1.9, and 0.9 kg t^{-1} of dry mass for Buffel, and 12.5, 1.4, 16.8, 3.4, 2.0, and 1.0 kg t^{-1} of dry mass for Massai for N, P, K, Ca, Mg, and S, respectively.

CONCLUSION

The maize+forage intercropping promotes greater competition for resources, especially water, limiting N uptake, chlorophyll synthesis, and biomass production by maize in a semiarid environment. Anticipated sowing gives forage grasses a greater competitive advantage, to the detriment of maize. Massai intercropped with maize has a greater potential for biomass production than Buffel under semiarid conditions. Maize+Buffel intercropping results in highest macronutrient export by maize, while maize+Massai intercropping results in highest macronutrient exports by the total forage biomass under a semiarid environment.

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