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Sustainable Production of Maize with Grass and Pigeon Pea Intercropping

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Abstract: This study aimed to assess the impact of intercropping pigeon pea (*Cajanus cajan* cv. Super N) with maize (*Zea mays* cv. AG 5055) and Paiaguás palisadegrass (*Urochloa brizantha* cv. BRS Paiaguás) on grain yield, silage chemical composition, and post-harvest grazing forage. The experiment was conducted on the School Farm of Instituto Federal Goiano, Campus Iporá. The experiment treatments consisted of three cropping systems: pigeon pea and Paiaguás palisadegrass intercropping (PPPG), maize and Paiaguás palisadegrass intercropping (CPG), and maize, pigeon pea, and Paiaguás palisadegrass intercropping (CPPPG), respectively. It was observed after the fermentation process that the PPPG silage promoted the lowest values of forage mass (FM) and a reduction in the dry matter (DM) concentration. The PPPG silage showed higher values of crude protein (75.28 g kg^{-1} DM), while the CPPPG silage showed proportionately higher values of total digestible nutrients (616.11 g kg^{-1} DM). The intercropping did not affect the corn grain productivity, thus obtaining an average value of 4.78 Mg ha^{-1}. After the silage harvest, during the dry season, a similar forage availability was obtained between the treatments (3.73 Mg ha^{-1}). All three cultivation strategies produced abundant forage for grazing, showing that integrated intercropping systems can mitigate the seasonality in tropical forage production.

Keywords: BRS Paiaguás; Cerrado; forage mass; silage; pasture; tropical forage

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1. Introduction

The Brazilian savannah (Cerrado) has a great potential for food production. However, environmental constraints must be considered, as most of its soil is naturally acidic, with a low nutrient availability and low levels of organic matter [1]. Therefore, the agricultural production in these regions relies heavily on chemical fertilisation [2–6].

Inorganic fertilisers effectively release nutrients for plants, but dependence on them increases economic risks. Specifically, the use of nitrogen sources, such as urea, negatively affects the soil chemical composition because the nitrification process releases ammonia (NH_4^+), which is then oxidised to nitrate (NO_3^-) and releases two hydrogen ions (H^+). These hydrogen ions fill the negative charges in the colloid particles in the soil, leading to soil acidification and requiring frequent liming [7–10]. Therefore, the utilization of legumes as a nitrogen source is a crucial strategy for enhancing the sustainability of food production. By incorporating legumes into the production system, this stimulates the development of rhizobial bacteria, facilitating biological nitrogen fixation [11,12]. This reduces reliance on synthetic nitrogen fertilizers and contributes to soil fertility. This reduces reliance on synthetic nitrogen fertilizers and contributes to soil fertility.

To improve the productive performance of Cerrado soils in Mato Grosso do Sul, Brazil, Guimarães et al. [13] observed that soils cultivated with pigeon pea (*Cajanus cajan*) had a lower resistance to penetration compared to those with maize (*Zea mays*) cultivation. Furthermore, the use of nitrogen-fixing plants (legumes) with forage grasses reduces the need for chemical fertilisers, as observed by Gitti et al. [14] in a study conducted in the same region. These authors found a reduction in production costs of wheat (*Triticum aestivum* L.) when intercropping with pigeon pea and pearl millet (*Pennisetum glaucum*), as this combination added 50 to 75 kg of N ha^{-1} to the soil.

In an integrated crop–livestock system, Pariz et al. [15] showed that the triple intercropping of summer crops (pigeon pea, maize, and *Urochloa brizantha* cv. Marandu) with black oat (*Avena strigosa*) cultivation in the winter increased the silage production and improved the system productivity in both seasons. Additionally, Ligoski et al. [16] found that excellent-quality silage was produced by triple intercropping with pigeon pea, maize, and Xaraés palisadegrass (*Urochloa brizantha* cv. Xaraés) in the Brazilian Cerrado region.

One challenge in tropical regions, such as savannas, is ensuring year-round grazing forage production, which can be hampered by water deficits and temperature reductions [17]. However, integrated crop–livestock systems can minimize the impact of these abiotic events and improve the forage production by combining different types of plants intercropping to maximize the soil use [15]. This approach helps to maintain the soil productivity and improve the quality and quantity of the forage available for animals, thereby enhancing the economic performance of the production system [18,19]. Additionally, to maximize production during the offseason, the inclusion of Paiaguás palisadegrass (*Urochloa brizantha* cv. BRS Paiaguás) may be a promising alternative, as this grass exhibits a phenotypic plasticity for the dry season, ensuring sufficient forage production despite water scarcity [20].

This study aims to assess the potential of intercropping legumes with grasses, based on the following hypotheses: (I) the triple intercropping of pigeon pea, maize, and Paiaguás palisadegrass will result in silage with an improved chemical composition. (II) Intercropping with pigeon pea can enhance maize yield. (III) The residual effects of the intercropping system after the silage harvest will contribute to the favourable agronomic performance of Paiaguás palisadegrass during the dry season. To test these hypotheses, experiments will be conducted to evaluate the parameters of the silage chemical composition, maize yield, and agronomic performance of Paiaguás palisadegrass. The obtained results will provide valuable insights into the feasibility of intercropping legumes with grasses, contributing to the development of sustainable and efficient agricultural practices.

Therefore, we evaluated the chemical composition and silage production, corn yield, and forage production through the three intercropping strategies involving pigeon pea, corn, and Paiaguás palisadegrass.

2. Materials and Methods

2.1. Experimental Field Characterisation

The experiment was conducted on the School Farm of Instituto Federal Goiano, Campus Iporá (16°25′29″ S, 51°09′04″ W). Based on the Köppen–Geiger classification [21], the climate of the region is Aw (tropical with summer rains), with an annual average precipitation of 1785 mm, 87% of which is concentrated between March and October. The region has an annual period of five months with a water deficit [22]. The climatic information during the experiment was obtained in an automatic meteorological station (Code A028) of the Instituto Nacional de Meteorologia (INMET), located in Iporá, Goiás (Figure 1).

2.2. Experimental Design and Treatments

The data collection began on 22 January 2015 and ended on 17 October 2015. The experimental design use was completely randomised, with three repetitions for each treatment. The treatments were composed using three strategies of intercropping cultivation: pigeon pea (*Cajanus cajan* cv. Super N) and Paiaguás palisadegrass (*Urochloa brizantha* cv. BRS Paiaguás) intercropping (PPPG), maize (*Zea mays* cv. AG 5055) and Paiaguás palisadegrass intercropping (CPG), and maize, pigeon pea, and Paiaguás palisadegrass intercropping (CPPPG). The experimental field was 4.5 ha, which was divided into nine paddocks of 0.5 ha each. Each paddock was considered to be one repetition and three paddocks were randomly allocated for each treatment. Since the intention was to produce pasture for the dry season, each experimental unit was separated by only one fence, with a 4 m wide access corridor to carry out animal management during the grazing phase (Figure 2).

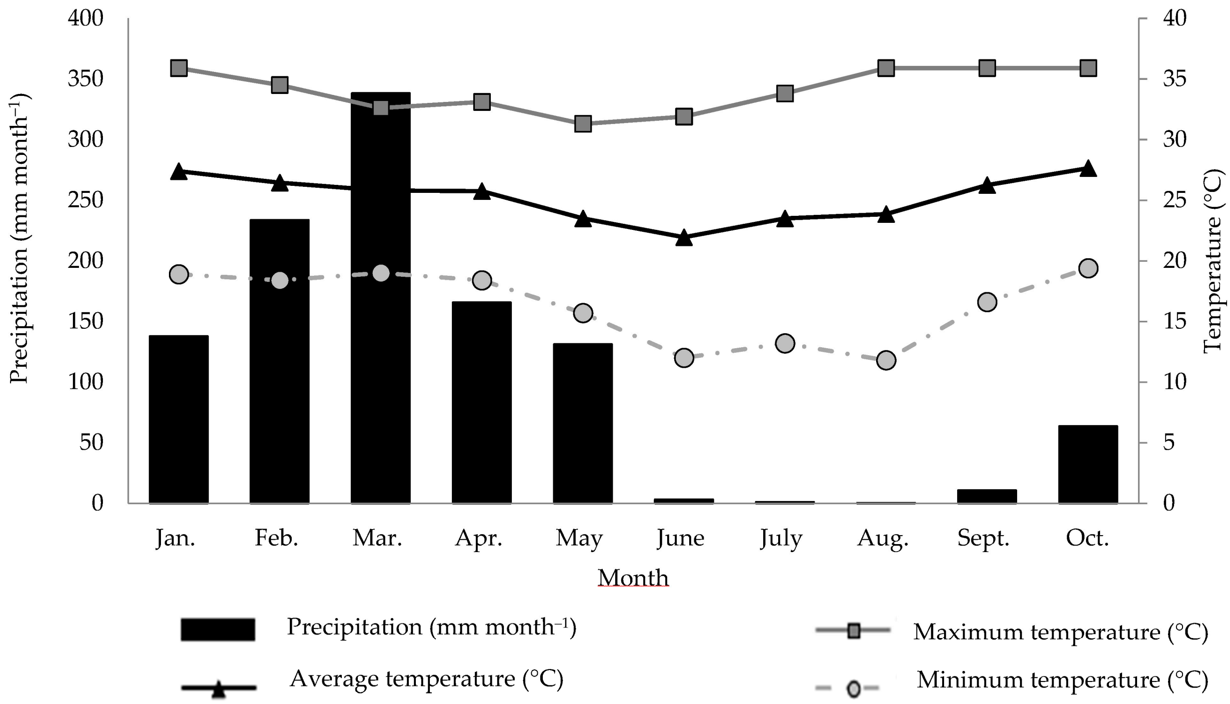

Figure 1. Precipitation and temperature (maximum, minimum and average) from January to October 2015.

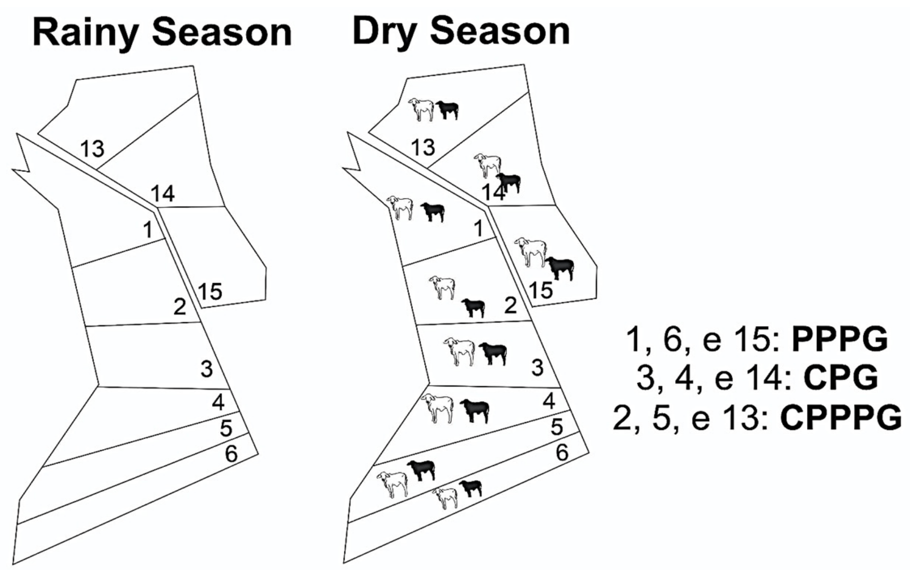

Figure 2. Experimental sketch of intercropping sowing time during the rainy season and grazing management during the dry season. PPPG: pigeon pea and Paiaguás palisadegrass intercropping; CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea, and Paiaguás palisadegrass intercropping. Paddock numbers 1, 6, and 15 were allocated for the PPPG treatment; paddock numbers 3, 4, and 14 were designated for the CPG treatment; and paddock numbers 2, 5, and 13 were dedicated to the CPPPG treatment.

2.3. Soil Fertilisation and Experimental Procedures

The soil sampling (to a depth of 0–20 cm) and analyses were performed before the experiment began. The soil was classified as Cambisol [23] with 560 g of sand, 270 g of clay, and 170g of silt. The analysis of the chemical composition of the sample revealed the following results: 5.2 pH in CaCl2; 2.7 cmolc dm^{-3} of calcium (Ca); 1.5 cmolc dm^{-3} of magnesium (Mg); 2.5 cmolc dm^{-3} of potential acidity (H+Al); 7.1 cmolc dm^{-3} of cation exchange capacity (CEC); 3 mg dm^{-3} of phosphorus (Melich); 0.38 cmolc dm^{-3} of potassium (K); 1 mg dm^{-3} of sodium (Na); 6 mg dm^{-3} of sulphur (S); 0.2 mg dm^{-3} of boron (B); 0.7 mg dm^{-3} of copper (Cu); 39 mg dm^{-3} of iron (Fe); 97 mg dm^{-3} of manganese (Mn); 4.5 mg dm^{-3} of zinc (Zn); 1.6% of organic matter (OM); and 64% of base saturation (V%) [24].

Gypsum (1.0 Mg ha^{-1}) was applied, followed by 32′ disc harrowing and later levelling. The sowing of the three treatments was carried out on 22 January 2015, using a multiple seeder that distributed the maize seeds in rows spaced 0.5m apart (62,000 seeds ha^{-1}). In order to prevent the pigeon pea and Paiaguás palisadegrass from compromising the development of the maize in the intercrops of CPG and CPPPG, broadcasting seeding was performed at rates of 13.3 kg ha^{-1} (pigeon pea) and 9.36 kg ha^{-1} (Paiaguás palisadegrass) of pure and viable seeds. The same sowing criterion was adopted for the intercropping involving only PPPG. No inoculation was performed on the pigeon pea seeds.

The base fertilisation was 197.5 kg ha^{-1}, using 04-30-10 (N-P-K) fertiliser. During the development of the maize plants, two nitrogen fertilisations were performed at 19 and 29 days after sowing, totalling 70.6 kg of N ha^{-1}.

2.4. Chemical Composition of Silage

At 93 days after seeding, (when the maize reached the milk-line maturity stage, it had a dry matter (DM) content ranging from 30% to 35%, as can be observed in Table 1), four samples of 1 m2 were cut from each repetition (paddock), and the maize was cut at a height of 10 cm above the ground, allowing for the determination of the amount of forage mass (FM Mg ha^{-1}) available for ensiling. Two samples were weighed and separated into maize, pigeon pea, and Paiaguás palisadegrass. These were placed in a 65°C oven for 72 hours and then weighed again to obtain the dry matter (DM g kg^{-1}) content. Then, the samples were ground at 1 mm in a Willey mil for bromatological analyses.

Table 1. Chemical compositions of forage sources before ensilage.

	Forage Sources		
Component	**Pigeon Pea**	**Maize**	**Paiaguás Palisadegrass**
PPPG (%, FM)	41.35	-	58.65
CPG (%, FM)	-	83.09	16.91
CPPPG (%, FM)	3.33	89.87	6.80
DM (g kg^{-1})	343.31	337.64	302.18
Ash (g kg^{-1} DM)	47.03	29.91	66.17
CP (g kg^{-1} DM)	151.92	46.80	70.02
NDF (g kg^{-1} DM)	741.85	763.53	737.76
ADF (g kg^{-1} DM)	592.52	358.76	448.67
LIG (g kg^{-1} DM)	218.72	51.98	63.00
TDN (g kg^{-1} DM)	547.54	532.80	550.33

PPPG: pigeon pea and Paiaguás palisadegrass intercropping; CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea and Paiaguás palisadegrass intercropping. DM: dry matter; Ash: ash content; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; LIG: lignin; and TDN: total digestible nutrients.

The chemical compositions comprised measurements of the DM (g kg^{-1}), Ash (ash g kg^{-1} M), crude protein (CP g kg^{-1} DM) according to the AOAC methodologies [25]. Neutral detergent fibre (NDF g kg^{-1} DM), acid detergent fibre (ADF g kg^{-1} DM) were analyzed following the methodology of Mertens [26], while for lignin (LIG g kg^{-1} DM), the methodology of Van Soest et al. [27] was used. The CP was measured via an acid digestion of the sample and a quantification of the nitrogen content, while the ash was measured via a quantification of the mineral residue present after the sample was calcined. The total digestible nutrients (TDN) were estimated using the equation (TDN = 105.2 − 0.68 × (NDF)), proposed by Chandler [28] (Table 1).

Two samples of fresh forage were chopped and stored under anaerobic conditions in PVC tube microsilos (100 mm), which simulated the anaerobic conditions of ensiling. The microsilos were opened 110 days after closure and the forage samples were collected. When the experimental microsilos were opened, the silages from the three treatments proved to have a light colour and an acidic and sweet smell with notes of fermentation, indicating that the fermentation process occurred as desired [29]. Subsequently, the samples were weighed and dried in a 65 °C oven for 72 h to determine the DM content. Then, the material was ground to measure its chemical composition [25–28].

2.5. Maize Grain Yield

To determine the best course of action between harvesting maize for silage or grain production in integrated production systems, the following procedure was executed: prior to the silage harvest, four points per plot were randomly selected to assess the grain productivity megagrams per hectare (Mg ha^{-1}). During the point selection stage, the team avoided the borders. Therefore, the grain production samples were taken from the closest part to the centre of the experimental unit. These specific points were not harvested for the silage and the plants were left in the field for 117 days after sowing to allow for proper grain development. At each point, the grain yield was measured in ten randomly selected plants and the results were adjusted for plant stand. The grain weight was also corrected for moisture content, set to 13%.

2.6. Forage Evaluation during the Dry Season

During May and June 2015, the negative field was used to accumulate the FM. Then, from July to October 2015, each treatment was managed under continuous stocking grazing management with two heifers per paddock (seven months old and 180 kg of live weight), one being Nelore and the other F1 (Nelore × Angus). They represented an initial average stocking rate of 1.9 AU ha^{-1} and a final average stocking rate of 2.2 AU ha^{-1}.

The canopy height (CH, cm) was measured with a centimetre-graduated ruler. The CH of each point corresponded to the average height of the curvature of the upper leaves.

Forage samples were collected every 28 days after the start of the animal grazing. Four points of 0.25 m^2 were sampled per paddock and the cut was made at a height of 10 cm from the ground to avoid soil contamination in the sample. Afterwards, the samples were placed in an oven at 65 °C for 72 hours and weighed again to determine the FM (Mg ha^{-1}). The samples were then ground and subjected to a bromatological analysis, as previously explained [25–28].

2.7. Statistical Analyses

The silage FM, chemical composition, and grain yield data were analysed using two models: Model I: Yij = μ + SCi + εij, where Yij represents the observed values of the silage and grain yield, μ represents the mean, SCi represents the treatment effect on the silage chemical composition (SCi = PPPG, CPG, and CPPPG), and εij represents the experimental error related to Yij. Model II: Yij = μ + GCi + εijk, where Yij these represent the observed values for grain yield, GCi represents the observed effect in the maize grain yield (GGi = CP and CPPPG), and εijk represents the experimental error related to Yij.

The forage data, including the CH, FM, and chemical composition, were analysed using a subdivided plot model: Model III: Yijk = μ + Fi + εij + Dj + FDij + εijk, where Yijk represents the observed values of the forage data, μ represents the mean, Fi represents the observed effect of the treatment (Fi = PPPG, CPG, and CPPPG), Dj represents the effect of the grazing days (Dj = 0, 28, 56, 84, and 112 days), FDij represents the interaction effect of the treatment and grazing days, and εij and εijk represent the experimental errors related to Yijk.

When significant effects were observed, the means were compared using the Scott-Knott test ($p < 0.05$). The ExpDes package [30] was used for Models I and III and the easyanova package [31] was used for Model II. The analyses were performed in software R version 4.2.1 [32].

3. Results

3.1. FM and Chemical Composition of the Silage

The PPPG silage promoted the lowest FM values, and a reduction in the DM concentration was observed after the fermentation process. However, this type of forage resource resulted in high concentrations of ash and CP. On the other hand, PPPG had higher levels of ADF and LIG. The CPPPG silage had a lower NDF concentration and, consequently, higher TDN levels (Table 2).

Table 2. Chemical composition of silage from different intercropping systems of pigeon pea, maize. and Paiaguás palisadegrass.

	Intercropping Treatments				
Component	**PPPG**	**CPG**	**CPPPG**	**MSE**	***p*-Value**
FM (Mg ha^{-1})	2.25 b	9.03 a	7.78 a	0.618	<0.001
DM (g kg^{-1})	276.75 b	352.44 a	322.63 a	10.32	0.008
Ash (g kg^{-1} DM)	59.08 a	32.39 b	34.20 b	3.30	<0.001
CP (g kg^{-1} DM)	75.28 a	57.66 b	52.53 b	3.96	0.036
NDF (g kg^{-1} DM)	767.15 a	741.13 a	641.01 b	22.18	0.038
ADF (g kg^{-1} DM)	535.85 a	340.98 b	359.20 b	22.97	<0.001
LIG (g kg^{-1} DM)	136.71 a	46.08 b	60.83 b	11.81	<0.001
TDN (g kg^{-1} DM)	530.33 b	548.02 b	616.11 a	15.08	0.038

PPPG: pigeon pea and Paiaguás palisadegrass intercropping; CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea and Paiaguás palisadegrass intercropping. DM: dry matter; Ash: ash content; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; LIG: lignin; and TDN: total digestible nutrients. Means followed by a lowercase letter in the same row differ in the Scott-Knott test ($p < 0.05$). MSE: mean standard error.

3.2. Maize Grain Yield

The productivity of the maize did not show any differences among the intercropping systems. Therefore, the mean grain productivity for the intercropping systems with maize was 4.78 Mg ha^{-1} (Table 3).

Table 3. Maize grain yield in different intercropping systems of pigeon pea, maize. and Paiaguás palisadegrass.

Intercropping	Yield (Mg ha^{-1})	MSE	*p*-Value
CPG	5.52 A	0.502	0.148
CPPPG	4.05 A		

CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea and Paiaguás palisadegrass intercropping. Means followed by a different uppercase letter in the same column differ in the Scott-Knott test ($p < 0.05$). MSE: mean standard error.

3.3. Height, FM and Chemical Composition of Forage during the Dry Period

The intercropping and number of days of grazing did not interact for the CH, FM, and CP (Table 4). A higher CH was observed in PPPG. The intercropping systems, with regard to the FM and CP, showed no differences; therefore, mean values of 3.73 Mg ha^{-1} and 41.37 g kg^{-1} were generated for the three strategies (Table 4). During the dry season, the CH was higher at 56 days. Concerning the CP, a lower mean was measured at 112 days of grazing (Table 4).

Table 4. CH, FM and CP concentration during the dry season of three different intercropping systems of pigeon pea, maize. and Paiaguás palisadegrass.

Variable	Intercropping			Number of Days of Grazing (Days)					MSE	*p*-Value		
	PPPG	CPG	CPPPG	0	28	56	84	112		I	D	I × D
CH (cm)	52.83 a	31.24 b	34.12 b	40.94 b	37.82 b	59.56 a	34.30 b	24.36 b	2.70	0.006	<0.001	0.113
FM (Mg ha^{-1})	4.08 a	3.11 a	3.99 a	4.37 b	6.67 a	2.52 c	2.48 c	2.61 c	0.365	0.446	<0.001	0.151
CP (g kg^{-1} DM)	39.10 a	41.57 a	43.43 a	53.39 a	33.20 b	48.80 a	45.41 a	26.03 b	2.24	0.590	<0.001	0.136

PPPG: pigeon pea and Paiaguás palisadegrass intercropping; CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea and Paiaguás palisadegrass intercropping. CH: canopy height; FM: forage mass; and CP: crude protein. Means followed by a lowercase letter in the same row differ in the Scott-Knott test ($p < 0.05$). MSE: mean standard error. I: intercropping treatment effect; and D: number of days of grazing.

The ash, fibrous fractions (NDF and ADF), LIG, and TDN of the palisade grass forage showed an interaction effect between the treatment and the number of grazing days. The number of grazing days did not affect the ash content in the forage. The grass forage of the CPPPG intercropping had a lower ash content at 0 and 112 days of grazing. The pasture cultivated with the pigeon pea intercropping showed lower NDF levels at 0 and 58 days of grazing, while the grass coming from the CPPPG intercropping had higher NDF levels at 112 days of grazing (Table 5).

Table 5. Chemical composition of forage during the dry season from three different intercropping systems of pigeon pea, maize. and Paiaguás palisadegrass.

Number of Grazing Days (Days)	Intercropping			MSE	*p*-Value		
	PPPG	CPG	CPPPG		I	D	I × D
		Ash (g kg^{-1} DM)					
0	50.04 Aa	53.36 Aa	30.42Bb	2.15	0.786	<0.001	0.005
28	52.45 Aa	65.48 Aa	76.24Aa				
56	59.32 Aa	66.24 Aa	59.74Aa				
84	63.32 Aa	53.83 Aa	63.36Aa				
112	57.35 Aa	47.18 Aa	36.87Ba				
		NDF (g kg^{-1} DM)					
0	813.90 Ba	794.81 Ba	799.43 Ba	5.22	0.169	0.003	<0.001
28	858.54 Aa	785.79 Bb	811.61 Bb				
56	792.46 Ba	785.10 Ba	804.56 Ba				
84	828.79 Aa	840.64 Aa	832.50 Ba				
112	845.43 Ab	860.60 Ab	894.78Aa				
		ADF (g kg^{-1} DM)					
0	563.17 Aa	557.35 Aa	554.40 Ba	7.79	0.818	0.227	0.022
28	607.88 Aa	517.26 Ab	536.76 Bb				
56	552.17 Aa	524.79 Aa	551.56 Ba				
84	561.42 Aa	562.77 Aa	550.11 Ba				
112	510.16 Aa	621.71 Aa	643.98 Aa				
		LIG (g kg^{-1} DM)					
0	122.75 Aa	127.64 Aa	153.37 Aa	3.48	0.286	<0.001	0.010
28	132.07 Aa	87.30 Bb	94.14 Bb				
56	110.85 Aa	92.45 Ba	99.10 Ba				
84	104.27 Aa	100.47 Ba	99.41 Ba				
112	114.78 Aa	128.99 Aa	144.11 Aa				
		TDN (g kg^{-1} DM)					
0	498.54 Aa	511.52 Aa	508.38 Aa	3.55	0.169	<0.001	0.003
28	468.19 Bb	517.66 Aa	500.10 Aa				
56	513.12 Aa	518.13 Aa	504.89 Aa				
84	488.41 Ba	480.36 Ba	485.89 Aa				
112	477.10 Ba	466.79 Ba	443.54 Bb				

PPPG: pigeon pea and Paiaguás palisadegrass intercropping; CPG: maize and Paiaguás palisadegrass intercropping; and CPPPG: maize, pigeon pea and Paiaguás palisadegrass intercropping. Ash: ash content; NDF: neutral detergent fibre; ADF: acid detergent fibre; LIG: lignin; and TDN: total digestible nutrients. I: intercropping; and D: number of days of grazing. Means followed by a lowercase letter in the same row and uppercase in the column differ in the Scott-Knott test ($p < 0.05$). MSE: mean standard error.

At 28 days of grazing, the palisade grass of the CPG and CPPPG intercroppings had lower ADF values. For the PPPG intercropping, the ADF fraction did not vary during the grazing period, with a mean value of 558.96 g kg^{-1}. In the palisade grass from the CPPPG intercropping, the ADF levels were reduced at 28, 56, and 84 days of grazing (Table 5).

The number of days did not affect the grazing for the LIG levels of the forage from the PPPG intercropping, with a mean value of 116.9 g kg^{-1}. The other intercroppings showed lower LIG levels at 28, 56, and 84 days of grazing (Table 5). The CPG and CPPPG pastures showed higher TDNs at 28 and 112 days of grazing compared to the PPPG intercropping (Table 5).

4. Discussion

4.1. FM and Chemical Composition of the Silage

The intercroppings of two (CPG) or three species (CPPPG) ensured a high DM production for silage-making (Table 2). These results demonstrate that the formation of a diverse agricultural environment strategically combines species with distinct forage abilities and promotes positive and sustainable increases in forage production. The potential competition for abiotic resources among plants can lead to a better utilization of the available nutrients, resulting in the maximum productivity potential of the intercropped plants [33,34].

To produce maize silage in monoculture and intercropping systems, carrying out ensiling when plants have a DM concentration ranging from 300 g kg^{-1} to 350 g kg^{-1} is recommended [35,36], as can be observed in Table 1. Based on this parameter, ensuring that fermentation processes occur adequately without compromising the quality of the produced forage resource is possible.

The high values of ash content measured in the PPPG silage are consistent with previous observations of legume–grass intercropping silage [37]. Garland et al. [38] demonstrated that pigeon pea intercropping affected the soil's chemical composition by increasing the reserve of organic phosphorus, which had a positive effect on the root development and increased the contact area between the roots and the nutrients in the soil. As a consequence, the plants could uptake more mineral elements from the soil.

In the Brazilian cerrado (the same region as the present study), Rezende et al. [39] observed that Paiaguás palisade grass, when intercropped with pigeon pea (as in the PPPG treatment), exhibited a higher concentration of minerals in its leaves compared to monoculture. Since legumes improve the chemical composition of soil by increasing its organic matter and nitrogen levels, they provide positive agronomic benefits for plants grown in intercropping systems with legumes [12–14]. Therefore, the hypothesis is that an addition of legumes to silage can increase the mineral content in the diet of ruminants, potentially reducing the demand for inorganic supplements. Thus, further investigations are important to understanding which minerals (N, P, K, and S) increase in their concentrations in the silage after intercropping with pigeon pea.

Legumes naturally present a higher CP compared to other forage resources [40,41]. Therefore, their addition to silages can increase their nutritional value [42–44]. Silage from PPPG intercropping can be an important alternative when other protein sources are lacking and/or are too expensive to compose the ruminant diet.

The CP content in the silage from the CPG intercropping was below the recommended levels by Paludo et al. [45] for this specific mixture. In the case of the CPPPG intercropping, the silage did not exhibit higher levels of crude protein due to the lower proportion of pigeon pea contribution (Table 2: two types of grass versus one legume) to the total FM. This was attributed to the triple intercropping system, where the maize had a significant contribution to the total forage mass.

Teixeira et al. [46] argued that forage from intercropping systems has a higher protein and carbohydrate degradability than forage from monocultures. According to these authors, the grasses intercropped showed phenotypic plasticity, that is, the plants changed their growth pattern due to the competition for abiotic resources (e.g., light). Consequently, this caused a reduction in the stem diameter, thus decreasing the allocation of photosynthesis products and energy towards the deposition of structural carbohydrates, such as cellulose and lignin polymers, which could potentially enhance the nutritive value of intercropped grasses [47,48].

The silage from the CPPPG intercropping had lower NDF and higher TDN contents. Therefore, triple intercropping can increase the energy available in the silage, which can increase the animal performance or decrease the use of concentrated energy sources in diets (e.g., maize, wheat, and sorghum). Moreover, lower ADF and LIG (Table 2) can enhance the ruminal degradability and overall digestibility [49,50], leading to a higher efficiency of the feed. Ligoski et al. [16] showed that pigeon pea, maize, and grass intercropping can contribute to lowering enteric methane emissions.

4.2. Maize Yield

The results obtained for the maize grain yield in the two cropping systems (Table 3) followed Batista et al. [51], who observed that intercropping maize with different species of *Urochloa* spp. (ruziziensis grass, decumbens grass, and Marandu palisadegrass) did not affect the maize productivity. Santos et al. [52] also found no influence on the maize grain yield produced by intercropping with *Urochloa ruziziensis* and *Megathyrsus maximus* cv. BRS Zuri (Zuri guinea grass).

However, the use of this intercropping strategy, coupled with a crop rotation system, can benefit the soil and system yield in the long term, due to the intensification of nutrient cycling [14]. Morais et al. [53] observed increases in biomass deposition due to pigeon pea and Paiaguás palisadegrass intercropping, which increased the yield of Vigna unguiculata (yardlong bean) in sandy soils. Muniz et al. [54] showed that tropical grasses (*Urochloa* spp. and *Megathyrsus maximus*) had a higher carbon-to-nitrogen ratio (30:1), slowing down the residue decomposition, which can enhance the organic matter formation.

4.3. Height, FM and Chemical Composition of Forage during the Dry Period

The pasture established by the PPPG intercropping had higher values of CH. However, the dry mass was similar for the three cultivation strategies (Table 4). Thus, the phenotypic plasticity of the Paiaguás palisade grass in these different conditions can be verified; with the pigeon pea competition for light, the pasture had a greater height, with long tillers and more leaves. However, this higher canopy generated a lower number of tillers compared to the pasture with a low height. Therefore, the number of tillers changes the forage density [55–57].

In the dry season, the three strategies promoted a higher forage availability than that which was found in the literature on grass monocultures, for example, Euclides et al. [20] and Fernandes et al. [58] (2.66 Mg ha^{-1} and 2.63 Mg ha^{-1}, respectively). The benefits of an integrated crop–livestock system for pasture establishment have already been observed by Dias et al. [59]. These authors showed that *Urochloa* spp. (Ruziziensis and Xaraés palisadegrass) and *Megathyrsus maximus* (Mombaça guinea grass and BRS Tamani guinea grass) after soybean intercropping had a higher forage production with a better nutritive value, increasing the animal performance during the dry season.

At the end of the grazing period (112 days), due to the successive defoliation and lack of precipitation (Figure 1), the pasture showed a low CH, dry mass, and CP, as expected (Table 4). Notwithstanding this, the remaining biomass was enough to protect and cover the soil, allowing good conditions for the next crop season [60].

In pastures of *Urochloa brizantha*, the normally seen NDF values are between 720 g kg^{-1} and 740 g kg^{-1}, and higher values are found in grasses in the reproductive phase and/or high shoot and dead material participation on sward [61,62]. Well-managed Paiaguás palisadegrass should exhibit values close to 418 g kg^{-1} of ADF [63] and 31.90 g kg^{-1} of LIG [64].

4.4. Considerations about Intercropping Systems

Additionally, intercropping with pigeon pea did not have any negative impact on the grain yield in the short term (during the first year of the system implementation). However, to fully understand the long-term implications of these intercropping strategies, further research should be conducted into their effects on soil microorganisms and the availability of organic nutrients, especially the N and OM deposition in the soil.

Intercropping systems represent an important option for production systems in the Brazilian savannah, as this region has a long period without rain and a strong water deficit, when having a good forage for grazing is challenging [58–66]. Thus, the cultivation of plants with distinct functionalities assures a good production of conserved forage (silage) and a simultaneously good forage for grazing during the drought period. Therefore, more research involving the use of other forage species to verify the potential for silage and pasture production during periods of water scarcity should be conducted.

5. Conclusions

Under the experimental conditions, intercropping between two or more forage resources did not improve the chemical composition of the produced silage, as reported in the literature. This could be related to the low contribution of the pigeon pea to the production of the silage. However, all three cultivation strategies resulted in a high forage mass production for grazing, demonstrating that integrated systems involving intercropping with multiple species are an excellent alternative to reducing the seasonality in forage production during the dry periods in tropical regions.

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