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Selectivity of herbicides for pigeon pea grown in intercropping with maize

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Abstract

No common herbicides are advised for corn and pigeon pea, complicating the intercropping process. Thus, the objective of this work was to evaluate the selectivity of some herbicides for pigeon pea grown in intercropping with maize and the effects of intercropping on the development and yield of intercropped crops, as well as on the nutritional quality of the produced silages. The experimental design was randomized blocks with four replications, and the treatments were arranged in split-plots. The monoculture of corn and the intercropping of corn with pigeon pea variety IAC Fava Larga, as well as corn with pigeon pea variety Bonamigo 2 Super N, were allocated in the plots. The subplots were comprised of, the control, weeding, and the mixtures of the herbicides S-metolachlor+flumioxazin, S-metolachlor+saflufenacil, and S-metolachlor+mesotrione. The combination of S-metolachlor and mesotrione resulted in the least weed density and dry mass production. The herbicide that most injured pigeon pea was the mixture of S-metolachlor+mesotrione. There was no effect of herbicides on plant height, final plant population, and fresh and dry biomass productivity of pigeon pea. The intercropping of corn with pigeon pea did not influence corn yield but increased the crude protein, mineral matter, ether extract, and decreased dry matter, total digestible nutrients and in vitro dry matter digestibility contents of the produced silage. All of the herbicides showed potential use for the pigeon pea cultivars studied here.

Key words: Grass, legume, *Cajanus cajan*, *Zea mays*, feed analysis.
Abbreviations: ADF_acid detergent fiber; CO2_carbon dioxide; CP_crude protein; CS_cropping systems; CS:WC_interaction between treatments; CV_coefficient of variation; DAA_days after application; DM_dry matter; EE_ether extract; Flu_Flumixazin; IVDMD_in vitro dry matter digestibility; LIG_lignin; Meso_Mesotrione; MM_mineral matter; NDF_neutral detergent fiber; RI_relative importance; Saflu_Saflufenacil; SE_means standard error; SM_S-metolachlor; TDN_total digestible nutrients; VEP_visual evaluation of phytotoxicity; WC_weed control; WW_witness – weeded.

Introduction

Intercropping between crops provides economic and environmental improvements, contributing to production efficiency increase (BESSA et al., 2018). The use of leguminous forage in this system promotes the maintenance or enhancement of productivity. Pigeon pea (*Cajanus cajan*), for instance, has the potential to enhance soil nitrogen levels by temporarily immobilizing it through biological fixation. This, in turn, can decrease the dependence on nitrogen fertilizers in subsequent crops, as highlighted by Gomes et al. (2021). Additionally, the authors note that legumes can serve as silage in ruminant feeding, augmenting crude protein content and diminishing the reliance on protein sources that contribute to higher diet expenses.
The intercropping of maize and pigeon pea considers that the grass, when ensiled, must be harvested between 90-120 days of the cycle, when the grain will be in the hard floury stage. Pigeon pea, in turn, can produce 10-30 tons of green mass during the period, depending on factors such as the association with symbiotic bacteria for high productivity (Costa et al., 2017).
However, in intercropping productive systems, possible competition between the species that will be used can occur, in addition to natural weed competition. This makes the correct planning of herbicide use around fundamental importance. The goal is to control the weeds and only partially suppress the intercropped crop, aiming to avoid productivity losses in the intercropping systems which occurs due to competition with weeds and the potential competition between the intercropped cultures (Macedo, 2009).
There are no common recommended herbicides for both corn and pigeon pea, making it necessary to find herbicides that are recommended for corn and other legumes such as soybeans or common beans. Therefore, this work was carried out with the objective of evaluating the selectivity of herbicides for pigeon pea intercropped with corn and the effects of the intercropping on the development and yield of the intercropped crops, as well as on the nutritional quality of the produced silage.

Results

Presence of weeds under application of selective herbicides

The occurrence of thirteen weed species distributed across ten botanical families was observed at 40 DAA of the herbici-

Table 1. Relative importance (RI) of weed species found in maize alone and intercropped with pigeon pea evaluated at 40 DAA.

Species	Weed Control			
	Witness - weeded	SM+Flu	SM+Saflu	SM+Meso
ACAHI	11.83	60.50	39.90	31.14
ALTTE	67.02	13.67	39.05	57.10
BIDPI	0.00	2.10	0.52	0.00
CENEC	1.54	0.00	0.00	0.00
COMBE	6.10	8.33	0.86	0.00
DESTO	0.00	0.47	3.13	0.40
EUPIR	0.53	0.00	0.00	0.00
IPOMO	2.11	8.93	4.95	0.00
NICPH	4.11	0.00	0.48	0.00
POROL	1.97	0.52	1.41	0.00
RICCO	4.78	4.65	9.71	10.46
SENMA	0.00	0.00	0.00	0.91
SIDRH	0.00	0.83	0.00	0.00

Values in %. *Acanthospermum hispidum* (ACAHI), *Alternanthera tenella* (ALTTE), *Bidens pilosa* (BIDPI), *Cenchrus echinatus* (CENEC), *Commelina benghalensis* (COMBE), *Desmodium tortuosum* (DESTO), *Euphorbia irta L.* (EUPIR), *Ipomoea sp.* (IPOMO), *Nicandra physaloides* (NICPH), *Portulaca oleracea* (POROL), *Ricinus communis* (RICCO), *Senna macranthera* (SENMA), *Sida rhombifolia* (SIDRH). SM = S- metolachlor; Flu = Flumixazin; Saflu = Saflufenacil; Meso = Mesotrione.

des application (Table 1). The present species were: *Acanthospermum hispidum* (ACAHI), *Bidens pilosa* (BIDPI) belonging to the Asteraceae family, *Alternanthera tenella* (ALTTE) (Amaranthaceae), *Cenchrus echinatus* (CENEC) (Poaceae), *Commelina benghalensis* (COMBE) (Commelinaceae), *Desmodium tortuosum* (DESTO) and Senna *macranthera* (SENMA) (Fabaceae), Euphorbia hirta L. (EUPHI) and *Ricinus communis* (RICCO) (Euphorbiaceae), *Ipomoea sp*. (IPOMO) (Convolvulaceae), *Nicandra physaloides* (NICPH), (Solanaceae), *Portulaca oleracea* (POROL) (Portulacaceae), and *Sida rhombifolia* (SIDRH), belonging to the Malvaceae family.

The highest RI values were observed for *Alternanthera tenella* and *Acanthospermum hispidum* (Table 1), demonstrating that herbicide tank mixtures and manual weeding did not efficiently control these weeds, allowing reinfestation of the area. For *Commelina benghalensis* and *Ipomoea sp*., intermediate RI values were observed in the treatment where S-metolachlor + flumioxazin was applied (Table 1), showing lower efficacy of this treatment in relation to the other species. Considering the RI values for *Ricinus communis*, the herbicide mixtures S-metolachlor + saflufenacil and S-metolachlor + mesotrione showed a lower percentage of control of this species compared to the other treatments (Table 1). Martins et al. (2018) consider RI values below 8% as low. Therefore, the other species in the different treatments showed low RI values (Table 1).

There was a significant effect of the weed control on the density and dry mass productivity of the aerial part of weeds ($p < 0.05$). The mixture of S-metolachlor + saflufenacil showed the highest weed density and also one of the highest values of dry mass accumulation (Table 2). The S-metolachor + flumioxazin mixture showed the lowest weed density, but it was the treatment that obtained the highest dry mass productivity of the aerial part of these plants (Table 2). The mixture of S-metolachlor + mesotrione showed low values of density and dry mass accumulation (Table 2).

Effect of selective herbicides on corn

For the variables of plant height and insertion of the first ear of corn, there was no significant effect of the weed control, cropping systems, or the interaction between them ($p > 0.05$). There was a significant effect of cropping systems for stem diameter, as well as for the interaction between cropping systems and weed control ($p < 0.05$), but there was no significant effect of weed control ($p > 0.05$). Interaction data are shown in Table 3. There was no significant effect of cropping systems, weed control, or the interaction between them for yield estimates as well as for the plant population of corn ($p > 0.05$).

Effect of selective herbicides on pigeon pea

The effects of cultivar and the interaction between weed control and cultivar types for the visual evaluation of phytotoxicity were not significant ($p > 0.05$), but the isolated effect of weed control for this same variable was significant ($p < 0.05$). The treatment that caused the most injuries to pigeon pea in the evaluations with 7 and 14 DAA was the one that contained the mixture of S-metolachlor + mesotrione (Table 4). The injuries caused by the treatments containing S-metolachlor + flumioxazin and S-metolachlor + saflufenacil were statistically equal to the 7 DAA, but significant when compared to the control - weeded (Table 4). At 14 DAA, it was observed that the phytotoxic effects caused by these treatments reduced, being considered statistically equal to the control, in which the plants were practically completely recovered from the phytotoxic effects caused by these treatments (Table 4).

At 28 DAA, there was no more phytotoxic effect, where the plants were fully recovered for all treatments containing herbicide application. Despite the phytotoxicity caused by the herbicides, it was not significantly reflected in the yield of fresh and dry biomass, plant height, or the final plant population of pigeon pea. Thus, there was no significant effect of weed control on these measures ($p > 0.05$). Similarly, for these same variables, there was no effect of cultivar or interaction between cultivar and weed control ($p > 0.05$).

Nutritional quality of the produced silage

In Table 5, the means comparison regarding the nutritional quality of the produced silages are presented. Only for NDF, there was no significant effect ($p > 0.05$) from at least one of the factors. For the others, there was a significant effect ($p < 0.05$) from at least one factor, and this factor was the cropping system. It can be noted that the contents of mineral matter, ether extract, crude protein, acid detergent fiber, and lignin increased with the presence of pigeon pea in the silage, thus showing the same behaviour. The opposite was occurred with the variables of dry matter

Table 2. Means comparison considering the effects of weed control for density (plants m^{-2}) and aerial part dry mass productivity (g m^{-2}) of weeds found in maize alone and intercropped with pigeon pea.

Weeds	Weed Control				SE
	WW	SM+Flu	SM+Saflu	SM+Meso	
Density	24.00 a	14.00 b	27.00 a	21.00 ab	3.450
Dry mass	7.83 ab	14.48 a	15.57 a	5.34 b	3.510

WW – witness - weeded; **SM** – S- metolachlor; **Flu** – Flumioxazin; **Saflu** – Saflufenacil; **Meso** – Mesotrione; **SE** – standard error. Means with different letters on the same line were considered different by Tukey's test.

Table 3. Means comparison of stem diameter (mm) of maize considering the interaction between cropping system and weed control.

Weed Control	Cropping System	
	Intercropped	Single
Witness - weeded	24.1 Aa	23.7 Ab
SM+Flumioxazin	24.3 Ba	27.3 Aa
SM+Saflufenacil	23.9 Ba	25.9 Aab
SM+Mesotrione	24.3 Aa	24.4 Ab

Line comparison, with capital letters, referring to the unfolding of cropping systems within each level of weed control. Column comparison, with lowercase letters, referring to the unfolding of weed control within each level of cropping systems. Means with different capital letters on the same line were considered different by Tukey's test. Means with different lowercase letters in the same column were considered different by Tukey's test. **SM** = S-metolachlor.

IVDMD, and TDN, which had their values reduced by the presence of pigeon pea in the silage.

Discussion

As seen before, the most important weed species were *Alternanthera tenella* and *Acanthospermum hispidum*. The reinfestation of *Alternanthera tenella* may have happened due the fact that this weed is one of the main dominant species in the vegetation of the Brazilian interior, where it is particularly difficult to control (Timossi et al., 2006; Martins et al., 2018). Moreover, it naturally has high RI values in Brazilian agriculture due to its dissemination and higher infestation density (Canossa et al., 2008; Martins et al., 2018). In relation to *Acanthospermum hispidum*, this species has relatively large seeds; thus, having a greater energy reserve and uneven germination flow, allowing it to germinate when conditions are more favourable for the development of this weed. Another factor that may have contributed to reinfestation is the presence of a high seed bank in the soil of the area for the *Alternanthera tenella* and *Acanthospermum hispidum* species.

Regarding the variables of density and dry mass productivity of the aerial part of weeds, it was observed that the weed control that provided the highest values for these variables was the mixture of S-metolachlor + saflufenacil. However, in these treatments, 78% and 76% of the total variables were represented by *Alternanthera tenella* and *Acanthospermum hispidum*, respectively. These species are considered more important relative to others, thereby reducing the effectiveness of all treatments in controlling them. The same was observed for the mixture S-metolachor + flumioxazin, which showed one of the highest accumulations of dry mass of weeds, but *Acanthospermum hispidum* was responsible for 86% of the total accumulation. This species presented the highest RI values along with *Alternanthera tenella*.

It was observed that none of the factors were significant for the variables analyzed in corn. What draws attention is the lack of significance of the effects of the cropping system. According to Macedo (2009), there may be a possible competition between intercropped species. This result indicates that there was no competition between maize and pigeon pea, which can be explained by the fact that the initial growth of pigeon pea is slow (Reddy et al., 2016), thus allowing maize to establish itself as the main crop.

Bessa et al. (2018) and Gomes et al. (2021) reported similar results, where the authors did not report a significant effect of intercropping maize with pigeon pea on the variables of plant height and insertion of the maize first ear, as well as on the yield estimates and final population of maize plants. Bessa et al. (2018) also attributed these results to the slow initial growth of pigeon pea. Guimarães et al. (2017) worked with corn intercropped with a pigeon pea population of 200.000 plants ha^{-1}, and also did not detect a significant difference in corn dry mass productivity.

There was a significant effect of weed control on the visual evaluation of phytotoxicity, and the treatment that most injured the pigeon pea at 7 and 14 DAA was the mixture of S-metolachlor + mesotrione. Verzignassi et al. (2010) consider 40% of phytotoxicity as the maximum value for the plant not to have compromised development and yield. In the evaluation of 7 DAA, the phytotoxic effects caused by the treatment containing S-metolachlor + mesotrione were found, being on average, within this limit. At 14 DAA, there was a reduction in the phytotoxic effects caused by this treatment, but they were still significant when compared to the control - weeded, being on average, slightly below the maximum acceptable limit for selectivity. Injuries caused by treatments containing S-metolachlor + flumioxazin and S-metolachlor + saflufenacil, despite being significant when compared to the control (weeded), were on average, considerably below 40%.

Despite the phytotoxic effects caused by herbicides, there was no significant effect of weed control on the variables analyzed in pigeon pea. Singh and Virk (2018), working with the effect of integrated weed management on the growth of these plants and the productivity of pigeon pea, observed that the plant height of pigeon pea varied from 157.4 to 204.5 cm in the different treatments. Singh et al. (2016), working on the integration of pre- and post-emergence herbicides for weed management in pigeon pea, reported pigeon pea plant heights of 147.7 to 191.9 cm for the different treatments. The plant height values found here were, on average (159 cm), lower than the values reported by the authors above. This is due to the different stages of development, in which the plants were at different times. In the present work, the pigeon pea plants were still in the

Table 4. Means comparison considering the effects of weed control for the visual evaluation of phytotoxicity in pigeon pea at 7 and 14 DAA.

VEP	Weed Control				SE
	WW	SM+Flu	SM+Saflu	SM+Meso	
7	0 c	10 b	10 b	41 a	2.6
14	0 b	5 b	6 b	29 a	2.9

VEP - visual evaluation of phytotoxicity**; WW –** witness – weeded; **SM** – S-metolachlor; **Flu** – Flumioxazin; **Saflu** – Saflufenacil; **Meso** – Mesotrione; **SE** – standard error. Means with different letters on the same line were considered different by Tukey's test.

Table 5. Means comparison considering the effects of cropping system for the nutritional quality of corn silages obtained from the cropping systems of single corn and corn intercropped with pigeon pea.

Variables	Means comparison		SE	CV	
	Cropping Systems				
	Single	Intercropped		CS	WC
DM	35.32 a	32.81 b	0.270	2.7	2.4
MM	3.43 b	4.55 a	0.130	10.5	8.8
EE	2.68 b	3.27 a	0.090	10.2	12.4
CP	7.56 b	9.34 a	0.130	4.9	3.7
NDF	60.51	60.39	0.290	1.6	6.5
ADF	23.04 b	32.27 a	0.480	5.4	11.4
LIG	1.24 b	3.68 a	0.120	14.2	24.3
IVDMD	62.87 a	54.85 b	0.280	1.6	5.8
TDN	62.81 a	54.60 b	0.280	1.6	5.9

DM = dry matter; **MM** = mineral matter (%DM); **EE** = ether extract (%DM); **CP =** crude protein (%DM); **NDF** = neutral detergent fiber (%DM); **ADF** = acid detergent fiber (%DM**)**; **LIG =** lignin (%DM)**; IVDMD =** in vitro dry matter digestibility (%DM); **TDN =** total digestible nutrients (%DM); * = significant at 5%; **CS** = cropping systems; **WC** = weed control; **SE** = standard error; **CV** = coefficient of variation (%). Means with different letters on the same line were considered different by Tukey's test at 5% significance.

vegetative stage, while in the works of the authors mentioned above, the plants had already reached maturity.

Regarding the dry mass yield of pigeon pea, Singh and Virk (2018) reported productivity of up to 8418 kg ha^{-1}, and Singh et al. (2016) reported values ranging from 5650 to 8260 kg ha^{-1}. The values found here for this variable were, on average (9091 kg ha^{-1}), higher than those reported by the authors. Suman et al. (2017), who worked with weed management strategies in pigeon pea in alfisol and vertisol, reported dry mass yields of 9247 and 9942 kg ha^{-1} for pigeon pea, similar to the results obtained here.

According to Costa et al. (2017), when intercropped with corn or sorghum for silage production, pigeon pea can produce around 10000 to 30000 kg ha^{-1} of fresh matter. In the current study, pigeon pea produced 26622 kg ha^{-1} of fresh matter, thus falling within the range reported by the authors. Therefore, the results obtained here with pigeon pea show that the yield of pigeon pea was not compromised, despite the phytotoxicity caused by the mixture of herbicides, especially the mixture of S-metolachlor + mesotrione. This demonstrates the potential use of the herbicide mixtures tested here for the pigeon pea cultivars IAC Fava Larga and Bonamigo Super N.

The DM content was reduced by the presence of pigeon pea in the silage. The reduction in the DM content caused by the presence of pigeon pea in the silage could be due to the earlier stage of development exhibited by the pigeon pea plants at the time of harvest, as they were wetter than the corn plants, which were drier (Kerguelén et al., 2019). Pinedo et al. (2012) and Kerguelén et al. (2019) reported similar results. The authors worked with the inclusion of pigeon pea in sorghum and corn silages and found that the DM levels reduced with the addition of this legume to the silages. Despite the differences between treatments, both silages had DM levels within the range described by Nussio et al. (2001), who consider DM values between 30% and 35% as ideal for corn silages.

The EE and MM contents were higher in the corn silage with pigeon pea. Gomes et al. (2021) and Serbester et al. (2015) also reported higher EE levels in corn silages that included pigeon pea and soybean. Marques et al. (2021) observed greater EE and MM contents with the inclusion of soybean in the corn silage.

As mentioned earlier, the presence of pigeon pea in the silage increased the CP values. According to Ligoski et al. (2020), this increase is provided by the high protein content of pigeon pea, as this legume can reach values of up to 27% CP. Ligoski et al. (2020) and Gomes et al. (2021) reported similar results. The authors observed that the CP content was higher in the silage with the inclusion of pigeon pea compared to exclusive corn silage. Pereira et al. (2019), working with the addition of pigeon pea in sugarcane silage, also noted that CP levels increased with the presence of this legume in the silage. Therefore, intercropping with legumes could allow for a change in the concentrate-to-roughage ratio in diets, reducing the cost of feeding due to the lower addition of protein supplements (Ribeiro et al., 2017; Ligoski et al., 2020).

The ADF content was increased by the presence of pigeon pea in the silage. This increase can be explained by the fact that the pigeon pea stem is very fibrous (Pires et al., 2006; Pereira et al., 2019). Similar results for ADF levels were reported by Kerguelén et al. (2019), Ligoski et al. (2020), and Pereira et al. (2019). These authors, working with the inclusion of pigeon pea in corn and sugarcane silages, found an increase in ADF levels with the presence of the legume in the silages.

The lignin values were also greater in the corn silage with pigeon pea. This increase may be due to the fact that pigeon pea naturally has a high lignin content (Pereira et al., 2019). Stella et al. (2016), Pereira et al. (2019), and Ligoski et al. (2020) observed the same behaviour in relation to lignin contents. These authors noted that lignin levels are increased when pigeon pea is included in corn and sugarcane silages.

The IVDMD and TDN values were reduced by the presence of pigeon pea in the silage. This may be due to the higher ADF content found in this silage, as there is a negative correlation between these variables and the ADF content. Foods with high ADF contents generally have low energy and digestibility contents (Van Soest, 1994).

Materials and methods

Study area

The experiment was carried out in Rio Verde, Goiás, at coordinates 17º48'67'' S and 50º54'18'' W, with an elevation of 754 m. The soil in the area, classified as Dystrophic Red Latosol, has the following characteristic physical-chemical properties at a depth of 0-20 cm: pH (CaCl2) 5.2; 11 mg dm-3 of P; 246 mg dm-3 of K; 5.77 cmolc dm-3 of Ca; 1.63 cmolc dm-3 of Mg; 0.03 cmolc dm-3 Al; V% of 64.6; and granulometry of 46, 10, and 44 dag kg-1 of clay, silt, and sand, respectively. The climatic data of temperature, relative humidity, and precipitation referring to the experimental period are shown in Figure 1.

Before planting, the area was chemically desiccated with herbicide to eliminate weeds. The herbicide used was glyphosate at a dose of 1.92 kg i.a. ha-1. Twenty days after desiccation, planting was done. The planting of the consortium was simultaneous, done in a single operation between corn and pigeon pea. The spacing between the maize rows was 90 cm, and between the pigeon pea rows was also 90 cm. The spacing between the maize rows and the pigeon pea rows was 45 cm. The planting fertilization was 400 kg ha^{-1} of the formulated (N-P-K) 4-14-8. The coverage, in the corn V4 phase, was 110 kg ha^{-1} of N applied in the form of urea.

Maize and pigeon pea cultivars

The corn (*Zea mays*) hybrid used was the FEROZ VIP 3 with 6 seeds per linear meter. The pigeon pea (*Cajanus cajan*) varieties were Bonamigo 2 Super N (16 seeds per meter), with a semi-perennial cycle, and IAC Fava Larga (20 seeds per meter), with a long cycle.

Experimental design

The design used was a randomized block with four replications. Treatments were arranged in a split-plot scheme (3x4), with three cropping systems (CS) and four types of weed control (WC). The cropping systems (CS) were allocated in the plots: maize monoculture, maize intercropped with pigeon pea variety IAC Fava Larga, and maize intercropped with pigeon pea variety Bonamigo 2 Super N. The weed controls (WC) were allocated in the subplots: a witness, weeded plot; and tank mixes of S-metolachlor + flumioxazin; S-metolachlor + saflufenacil; and S-metolachlor + mesotrione.

Herbicides application

The herbicides were applied in pre-emergence, carried out 1 day after planting the consortium, using a backpack sprayer model TT11002® pressurized with CO_2, equipped with a 2 m aluminum bar and four spray nozzles. It was sprayed at a constant pressure of 2.2 bar and syrup volume of 250 L ha^{-1}. At the time of application, the relative humidity was 49.6%, wind speed was 6.6 km/h, and the temperature was 31.5°C.

The doses of the herbicides applied in the tank mix were: 1680 g i.a. ha-1 of S-Metolachlor (Dual Gold®, 960 g L-1 of metolachlor), 25 g i.a. ha-1 of flumioxazin (Sumyzin 500 SC®, 500 g L-1 of flumioxazin), 35 g i.a. ha-1 of saflufenacil (Heat®, 700 g kg-1 of saflufenacil), and 240 g i.a. ha-1 of mesotrione (Callisto®, 480 g L-1 of mesotrione). As for the weeded plots, two weedings were carried out, at 15 and 30 days after the application of the herbicides, with intervals of 15 days between them, until 40 days after the application.

Weed evaluation

The evaluation of the weed infesting community was carried out 40 days after the application (DAA) of the herbicides. Four samples were taken per plot, with a random placement of a square measuring 0.25 m2 (0.5x0.5 m). The plants inside the square were identified, separated by species and quantified. The plants were then cut close to the ground, and the aerial parts were placed in paper bags and dried in a forced ventilation oven at 65°C until a constant weight was reached. They were later weighed. The description of the weed community was carried out using the phytosociological variable relative importance (RI) of the species. This variable characterizes a weighted percentage measure of the frequency, density, and dry mass accumulation of the weed species (Concenço et al., 2013).

Data collection

The evaluation of phyto-intoxication in pigeon pea caused by herbicides was carried out at 7, 14, and 28 DAA through visual evaluation and attribution of scores ranging from 0 to 100%, where 0 represents no injury and 100% represents the death of the plants. This assessment was done according to the EWRC scale, modified by Frans (1972). The corn plant height and corn ear insertion were determined through biometric measurements of heights, using the soil surface as a reference and measuring the insertion of the flag leaf (plant height) at 5 random points in each plot, as well as measuring the insertion of the first ear of corn. The corn stem diameter was measured using a caliper at a point 5 cm above the ground, at 5 random points in each plot. Plant height, ear insertion, and stem diameter evaluations were performed at the flowering stage of the main crop, corn. The heights of pigeon pea plants were measured with the soil surface and the apical meristem of the plants as references. This measurement was also taken at the flowering stage of the main crop, in 5 random points in each plot.

Ensilage

At the time of ensiling, the plants were harvested using a backpack mower when the corn grain had reached 1/3 of the grain in the milk line, corresponding to the hard-farinaceous grain stage. During this process, the plant population count for maize and pigeon pea in the useful area of each plot was evaluated. After harvesting, the material was chopped into particles of approximately 10 mm using a stationary chopper. The fresh mass and dry mass of maize and pigeon pea plant parts were determined. Aliquots of the material were then collected for ensiling in PVC tubes. The PVC tubes had dimensions of 10 cm in diameter and 50 cm in length. To collect the effluent produced during ensilage, 500 g of fine dry sand was added to the bottom of each silo, separated from the plant mass by a white TNT fabric. Using a wooden socket, the plant mass was compacted until reaching a density of 600 kg m^{-3}. The silos were sealed with a lid and adhesive tape and stored in a covered area at room temperature for 56 days, after which they were opened. A portion of the fermented material,

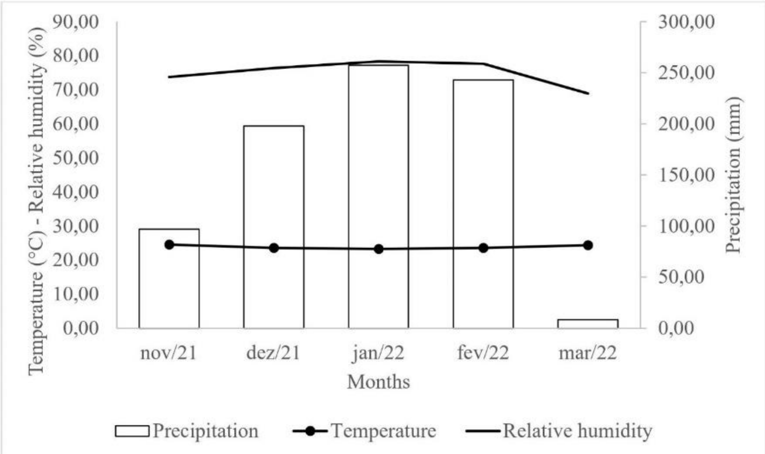

Fig 1. Precipitation, temperature and relative humidity during the experimental period.

weighing 0.5 kg, was placed in a forced ventilation oven at 55°C for 72 hours. After the oven drying period, the material was ground using a "Wiley" type mill with a 1 mm sieve. Subsequently, the ground material was stored in plastic containers for the subsequent determination of bromatological variables.

Chemical-bromatological analyses of the silage, including dry matter (DM), crude protein (CP), ether extract (EE), and mineral matter (MM), were performed according to the methodologies proposed by AOAC (1990). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) analyses were conducted following the methods outlined by Van Soest et al. (1991). Lignin content in 13.51 M sulfuric acid was determined as per Van Soest and Robertson (1985). The total digestible nutrient (TDN) content was calculated using the equation proposed by Weiss (1999):

$$\mathrm{TDN} = \mathrm{CPd} + \mathrm{NFCd} + \mathrm{NDFcpd} + (\mathrm{EEd} \times 2.25),$$

Where; CPd, NFCd, NDFcpd, and EEd represent digestible crude protein, digestible non-fibrous carbohydrates, digestible ash-protein corrected neutral detergent fiber, and digestible ether extract, respectively.

IVDMD (in vitro dry matter digestibility) was determined using the methodology proposed by Tilley and Terry (1963), adapted to the artificial rumen, created by ANKON®, using the tool “Daisy incubator” by Ankon Technology (in vitro true digestibility – IVTD).

Statistical data analysis

The results were submitted to statistical analysis using the R program version R-3.1.1 (R Core Team, 2021). The variables were initially subjected to exploratory, residual, and variance homogeneity analyses, with data considered as outliers and influential points being removed. Outliers were identified using the outlierTest function of the car package (Fox and Weisberg, 2019). The normality of the residuals was evaluated using the Shapiro-Wilk test through the Shapiro.test function. Variance homogeneity was assessed using the Levene's test via the leveneTest function, also from the car package (Fox and Weisberg, 2019).

The analysis of variance was performed using the *aov* function, considering cropping systems (CS), weed control (WC), the interaction between them, and the block as fixed effects for all data analyzed, except for pigeon pea. Since the pigeon pea cropping systems were differentiated by cultivars, the type of cultivar, weed control (WC), the interaction between them, and the block were considered as fixed effects for pigeon pea. The *p*-values were determined using the *Anova* function of the *car* package. Means were estimated using the *emmeans* function of the *emmeans* package (Lenth et al., 2020), with Tukey's test used for comparing means.

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Conclusion

All the herbicide mixtures applied caused injuries to pigeon pea. However, they did not significantly affect the yield and development of the plant. They still showed good weed control, except for the species *Acanthospermum hispidum* and *Alternanthera tenella*. Thus, in the edaphoclimatic conditions and soil type of the area where the experiment was conducted, all herbicide mixtures applied with S-Metolachlor tested here showed potential for use with the two pigeon pea cultivars studied. The intercropping of corn with pigeon pea, despite not influencing the productivity and development of corn, caused changes in the nutritional quality of the produced silage.

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