Occurrence of weed species due to the implementation of a crop succession system and early fertilization[1]

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ABSTRACT

The combination of management practices affects weed populations and biodiversity. The objective was to evaluate the infesting weed community in the implementation of a corn silage (*Zea mays* L.) /pearl millet (*Pennisetum glaucum* L)/corn silage succession system subjected to early potassium fertilization in the winter crop. The experiment began in October 2019 under fallow area. In the 2019/20 summer season, corn silage was grown in a complete area. In the 2020 fall/winter season, the plots consisted of pearl millet, six doses of potassium fertilization (0, 30, 60, 90, 120 and 150 kg ha^{-1}) and one fallow. In the 2020/21 summer season, the treatments consisted of corn silage and six doses of K_2O, complementing the treatment applied in the previous harvest (120, 90, 60, 30, 0 kg ha^{-1}) and one with recommended fertilization. Phytosociological evaluations of weeds were performed using a 0.25 m^2 square. The density and number of species increased in the first year. Early fertilization at doses of 90, 120 and 150 kg ha^{-1} of K_2O increased the dry weight of weeds before planting and at V_4 stage of the corn silage cultivated in sequence; however, were lower than those for plots fallowed in the winter.

Keywords: phytosociology; corn silage; pearl millet.

INTRODUCTION

Corn (*Zea Mays* L.) is one of the most cultivated cereals in the world, and due to its nutritional characteristics and high biomass production, it is widely used in silage production (Von Pinho *et al.,* 2006). However, in whole-plant silage, is common high extraction of nutrients, mainly K, found mostly in corn biomass (Ambrosini *et al.,* 2022), and consequent poor soils and reduced productivity in subsequent crops. Therefore, the management of potassium fertilization and the adoption of cover crops succession are one of the main tools to ensure high productivity, especially in regions where producers keep the soil bare during the off-season. According to Assis *et al.* (2016), fallow in agricultural systems may not be a good option, as it increases weed infestation and control costs in the area.

Weeds are plants that develop in an undesirable location, are aggressive in their development and have a strong capacity to produce seeds or propagules with high viability and longevity that can germinate in adverse environments and conditions or even remain dormant while awaiting conditions favorable to their growth and development (Vasconcelos *et al.*, 2012). Weeds are one of the main factors limiting the productivity of agricultural systems, either due to competition for water, light and nutrients (Castro *et al.* 2011) or because they are hosts of pests, diseases and

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nematodes (Chipomho *et al.,* 2018). Some species have allelopathic effects, are toxic to animals and humans and are harmful to harvesting commercial crops (Vasconcelos *et al.,* 2012). Therefore, studies allowing an understanding of the behavior of weeds in the use of sustainable agriculture in tropical soils are of substantial relevance considering the losses caused by these species, mainly in crops with a lower competition capacity (Concenço *et al.,* 2013a).

The intrinsic characteristics of each production ecosystem can influence biodiversity and the weed population, promoting or not promoting the development of a given species (Concenço *et al.,*2013b; Ulguim *et al.,* 2018; Travlos *et al.,* 2018). The use of crop succession and/or rotation with the use of cover crops can lead to a reduction in the seed bank and weed diversity (Travlos *et al.,* 2018; Nichols *et al.,* 2020). The straw formed by cover crops forms a barrier with a direct influence on light and temperature, affecting the germination of seeds and other weed propagules (Caratti *et al.,* 2018). However, the higher soil moisture promoted by cover crops residues can increase weed seed germination (Gerhards *&* Schappert, 2019). Some cover crops also have allelopathic potential by suppressing weeds (Jabran *et al.,* 2015). On the other hand, in areas that are kept in fallow in the off-season, high reproduction of these plants is evident, resulting in an increase in the seed bank in the soil and thus contributing to greater infestations in crops in sequence, increasing costs and hindering control (Lima *et al.,* 2014).

Another factor influencing weed populations is the difference in the concentration and availability of nutrients in the soil (Cheimona *et al.,* 2016; Travlos *et al.,* 2018). Management practices such as the application of different fertilizers such as N and P can cause changes in the density and composition of weed species (Than *et al.,* 2017). According to Jiang *et al.* (2018), N affects the density of different weeds, P affects the species that are already present, and K has an unknown effect, but the authors report that the composition of the weed community is related to the joint action of several environmental factors. For Chipomho *et al.* (2018), the weed biomass is influenced by the combination of organic compounds and mineral fertilizers (NPK).

Phytosociological surveys of weeds represent an evaluation method that aims to provide information on the composition and distribution of weed species in a plant community (Concenço *et al.,* 2013b). The use of phytosociological surveys is of considerable importance in cultivation areas because through these surveys, the species that stand out in relation to frequency, density and abundance can be identified through indices (Teixeira Júnior *et al.,* 2020). In addition, treatments or areas can be compared according to the plant species found (Concenço *et al.,* 2013a), allowing the use of viable control strategies within each system (Teixeira Júnior *et al.,* 2020). Thus, knowledge of the diversity of species to understand the dynamics of weeds in relation to cultivated plants is also relevant in different growing periods (Castro *et al.,* 2021), especially in Brazil, where the use of rotation and succession of crops is common.

The objective of this study was to evaluate the infesting weed community during the implementation of a succession system of corn silage (*Zea mays* L.)/pearl millet (*Pennisetum glaucum* L.)/corn silage subjected to different doses of potassium fertilization applied in advance in the winter crop.

MATERIALS AND METHODS

The experiment was conducted during the 2019/2020 summer season, in the 2020 fall/winter season and in the 2020/2021 summer season at the Center for Technology Development and Transfer (Centro de Desenvolvimento e Transferência de Tecnologia – CDTT), which belongs to the Federal University of Lavras (Universidade Federal de Lavras - UFLA), in Ijaci (21°10’S and 44°55’W), MG, Brazil. The climate of the region is characterized as humid temperate (Cwa), with hot and humid summers and dry and cold winters, with an average annual temperature of 19.4 °C and an average annual rainfall of 1,530 mm. The soil of the region is classified as dystrophic Red-Yellow Latosol (dRYL) (Santos *et al.,* 2018). A soil analysis performed in October 2019 for the 0-20 cm layer before the soil tillage showed the following characteristics shown in the Table 1.

Before the establishment of the experiment until October 2019, the area used was two years under fallow and was previously used in summer crops for the conventional cultivation of corn silage (Cs). To facilitate sampling, the plots were delimited; however, treatments were not applied. The experimental design was a randomized block with four replications.

In December 2019, the soil was prepared with two harrows. Before the last harrowing, liming was performed using 1.61 t ha^{-1} limestone ($CaCO_3$) according to the soil analysis. For the 2019/2020 summer season, the experimental plots were composed of four of five-meter-long corn silage rows spaced 0.50 meters apart, totaling 12.5 m^2.

Table 1: Soil analysis results performed in October 2019 (Oct 2019) and March 2020 (Mar 2020) for the 0-20 cm layer

Soil analysis time	pH H_2O	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	CEC	P (Rem)	K^+	Base saturation	clay	silt	sand
	cmolc dm^{-3}						mg dm^{-3}		%	g kg^{-1}		
Oct 2019	5.3	2.5	0.4	0	3.3	6.7	17.9	180.2	51	640	51	309
Mar 2020	6.9	3.2	0.6	0	1.8	6.0	17.5	142.2	70	640	51	309

Corn silage (P3646 YHR hybrid) was sown, with a stand of 4.5 seeds/m. Plant fertilization was performed as recommended to the crop for all treatments, with 400 kg ha^{-1} of fertilizer 08 28 16, and for topdressing fertilization, 200 kg ha^{-1} of urea (46% N) was used. Weed control occurred in vegetative stage V_4 of Cs using the herbicides glyphosate (720 g ai ha^{-1}) and atrazine (1.25 kg ai ha^{-1}). The harvest of Cs for ensiling took place in March 2020 and the second soil sampling was performed.

For the 2020 fall/winter season, the soil was again prepared with two harrows and the furrows were opened with the aid of a furrower. The experimental plot consisted of ten rows by five meters long spaced 0.25 meters apart, totaling 12.5 m^2. Millet (*Pennisetum glaucum* L.) (BRS 1501cultivar) was sown at 15 kg ha^{-1} of seeds. Sowing was performed manually in April 2020. At seeding 150 kg ha^{-1} of monoammonium phosphate (10% N, 50% P_2O_5) was applied. Forty-seven days after sowing, K fertilizer was broadcast applied as muriate of potash (KCl, 57% K_2O) at 0, 30, 60, 90, 120 and 150 kg K_2O ha^{-1} (Table 2), also, 130 kg N ha^{-1} as urea (46% N) were broadcast applied. One plot per replication was left fallow.

In July 2020 (100 days after sowing), the millet was cut close to the ground with a backpack brush-cutter and then the residues were distributed within each plot. Due to lack of rainfall in the region which makes a third crop season impossible, the area remained in fallow until the 2020/2021 summer season and millet biomass remained in the soil as cover until November 2020. In November 2020, to eliminate existing weed and possible re-sprouting, all plots were desiccated using the herbicide Glyphosate (2.00 kg ai ha^{-1}).

For the 2020/2021 summer season, the experimental plot consisted of five-meter-long Cs rows spaced 0.50 meter apart, totaling of 12.5 m^2. The experimental design was a completely randomized block with four replications and the treatments was established under the treatments of the previous crop season (2020 fall/winter season). In December 2020, Cs (R9080 PRO2 hybrid) was sown. At seeding 350 kg ha^{-1} of monoammonium phosphate (11% N, 52% P_2O_5) was applied. After sowing, 30 kg K_2O ha^{-1} as KCl was manually broadcast on the soil surface for all but two treatments – the treatment that had previously received 150 kg K_2O ha^{-1} applied to the Millet and the fallow treatment (without millet biomass) (Table 2). The fallow treatment received the standard recommendation for Cs – 60 and 90 kg K_2O ha^{-1} applied at planting and the V_4 stage, respectively (Souza & Lobatto, 2004). The remaining treatments received the K_2O doses complementary the previous doses applied to the millet (30, 60, 90, 120 kg K_2O ha^{-1}) (Table 2). Also, at V_4, 180 kg N ha^{-1} were broadcast by urea (46% N). Glyphosate (2.00 kg ai ha^{-1}) and atrazine (1.25 kg ai ha^{-1}) were broadcast applied at V_4 Cs stage to all plots. Cs harvest took place in April 2021 (112 days after sowing).

The infesting weed community was evaluated at six different periods during the experiment, always before the weed control: October 2019 (before soil preparation to the 2019/2020 harvest), November 2019 (corn silage at V_4 stage, 2019/20 summer season, before the chemical control of weeds), March 2020 (millet management, at 120 days before the desiccation of the area), November 2020 (corn silage at V_4 stage, 2020/21 summer season, before the chemical control of weeds) and April 2021 (before harvesting corn silage, 2020/21 summer season as shown in Table 3. The weed control was performed to ensure the good corn development and productivity as recommended to the crop.

For the survey of weed species, a metallic frame (0.5 m x 0.5 m) was randomly released once within the useful area of each plot. In each frame sampled, the weeds were identified, and the amount of each species was determined. The values obtained were used to calculate the total plant density m^{-2} and number of species m^{-2}. To obtain the dry weight (DW), the collected material was dried in an oven with forced circulation at 65 °C and then weighed, and the values were expressed in g m^{-2}. Subsequently, the species were grouped and classified according to family, period of evaluation and treatment.

To calculate the importance value index (IVI), which indicates which species are most important within the study area, the following phytosociological parameters were previously calculated: the frequency, which allowed

Table 2: Composition of the treatments and rates of K applied to millet and corn silage

Identification	2019	2019/20	2020	2020/21
FCMC120	Fallow	Corn silage	Millet + 0 kg ha^{-1} of K_2O in advance	Corn silage + broadcast with 120 kg ha^{-1} of K_2O
FCMC90	Fallow	Corn silage	Millet + 30 kg ha^{-1} of K_2O in advance	Corn silage + broadcast with 90 kg ha^{-1} of K_2O
FCMC60	Fallow	Corn silage	Millet + 60 kg ha of K_2O in advance	Corn silage + broadcast with 60 kg ha^{-1} of K_2O.
FCMC30	Fallow	Corn silage	Millet + 90 kg ha^{-1} of K_2O in advance	Corn silage + broadcast with 30 kg ha^{-1} of K_2O
FCMC0	Fallow	Corn silage	Millet + 120 kg ha^{-1} of K_2O in advance	Corn silage without broadcast K_2O
FCMC	Fallow	Corn silage	Millet + 150 kg ha^{-1} of K_2O in advance.	Corn silage without K_2O as starter and broadcast
FCFCRec	Fallow	Corn silage	Fallow land without cover crops and without early fertilization	Corn silage + standard fertilization

evaluation of the distribution of plant species in each plot, density, which is the number of plants of each species per unit area, and abundance, which provides information on the concentration of species in the area. The relative frequency (RF), relative density (RD) and relative abundance (RA) were calculated from the results, which allowed us to obtain information on the relationship of each species with the other species found in the area (Tuffi Santos *et al.,* 2004). To calculate the indices described, the formulas shown in Table 4 were used according to Mueller-Dombois & Ellenberg (1974).

For statistical analysis purposes, the data referring to the total plant density m^{-2}, number of species m^{-2} and DW m^{-2} were transformed using the $\log_e(x)$ formula to meet the statistical assumptions for the analysis of variance. Then, the transformed data were subjected to analysis (F test), which allowed evaluation of the effects of the treatments (plots) and of the evaluation periods (subplots) as well as the interaction between these factors. When significant, the means were subjected to the Tukey test using the statistical program R Studio (R Core Team, 2021) and the package ExpDes.pt version 1.2.1. (Ferreira *et al.,* 2021). For graphing, the data were transformed again.

RESULTS

Nineteen species of plants distributed in nine distinct families were identified. The families with the highest number of individuals were Asteraceae, with ten species identified, followed by the Poaceae family, with two species. For the families Amaranthaceae, Commeliaceae, Euphorbiaceae, Cyperaceae, Covolvulaceae and Portulaceae, only one species was identified per family. Some small plants that could not be identified were named “others”. Among the species, *Commelina benghalensis* L. was found in all evaluation periods, followed by *Bidens pilosa* L., *Richardia brasiliensis* Gomes and *Tridax procumbens* L., which were found in five of the six evaluation periods (Table 5).

The plant species present in each treatment and the IVI found in each evaluation period are shown in Table 6. For

Table 3: Periods of evaluations of infesting weed communities

Identification	Periods	Occasion
2019 (Fallow)	October 2019	Before soil preparation, 2019/20 summer season
2019/20 (CsV_4)	November 2019	Corn silage at V_4 stage, 2019/20 summer season, before chemical control of weeds.
2019/20 (Cs harvest)	March 2020	Before harvesting corn silage, 2019/20 summer season.
2020 (M+K_2O)	November 2020	Millet management, at 120 days before desiccation of the area.
2020/21 (CsV_4)	January 2021	Corn silage at V_4 stage, 2020/21 summer season, before chemical control of weeds.
2020/21 (Cs harvest)	April 2021	Before harvesting corn silage, 2020/2021 summer season.

Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; M+K_2O = millet at different doses of K_2O.

the evaluations performed in 2019 (Fallow), the species with the highest IVI were *C. benghalensis* in the FCMC30 treatment (300%) and *R. brasiliensis* in the FCMC0 (300%) and FCMC90 treatments (231.9%), followed by *T. procumbens* in the FCFCRec (170%), FCMC (152.9%) and FCMC120 treatments (150%) and *R. brasiliensis*, which also presented an IVI of 150% for the FCMC120 treatment.

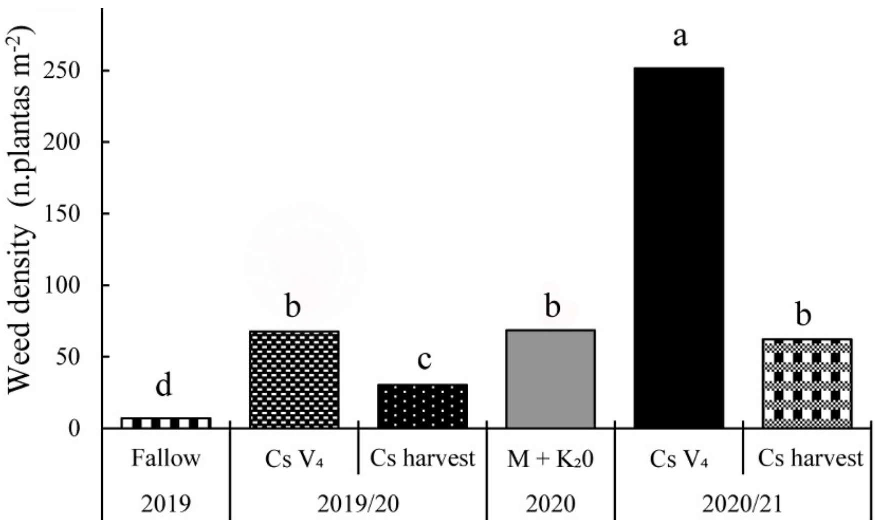
In the evaluations of 2019/20 (CsV_4), the species *Portulaca oleracea* L. and *T. procumbens* were found in all treatments and were among those with the highest IVI (Table 6). In the 2019/20 period (Cs harvest), the species *C. benghalensis* and *Melampodium perfoliatum* (Cav.) Kunth were found in all treatments; however, the highest IVI was observed for the species *M. perfoliatum* (Cav.) Kunth.

In 2020 ($M+K_2O$), three species were identified in common among the treatments: *Acanthospermum hispidum* DC, *C. benghalensis and R. brasiliensis. A. hispidum* DC was among the species with the highest IVI in all treatments (Table 6). In 2020/21 (CsV_4), *A. hispidum* DC and *R. brasiliensis* remained in all treatments; however, the highest IVI was observed for *P. oleracea*, which was also present in all treatments. In the evaluations performed in 2020/21 (CsV_4), lower IVI values were also observed, except for the species *P. oleracea,* when compared with the species already present in previous evaluations. In the last evaluation period (2020/21 (Cs harvest)), the species *R. brasiliensis* remained present in all treatments, together with *Gamochaeta coarctata* (Willd.) Kerguélen, which stood out as the species with the highest IVI (Table 6).

The individual results for weed density m^{-2} and the number of species m^{-2} are shown in Figures 1 and 2. No significant interactions were observed between treatments x evaluation period for weed density ($p > 0.05$) and weed species ($p > 0.05$). However, a significant difference was found for the evaluation periods and were thus analyzed in isolation (Figures 1 and 2).

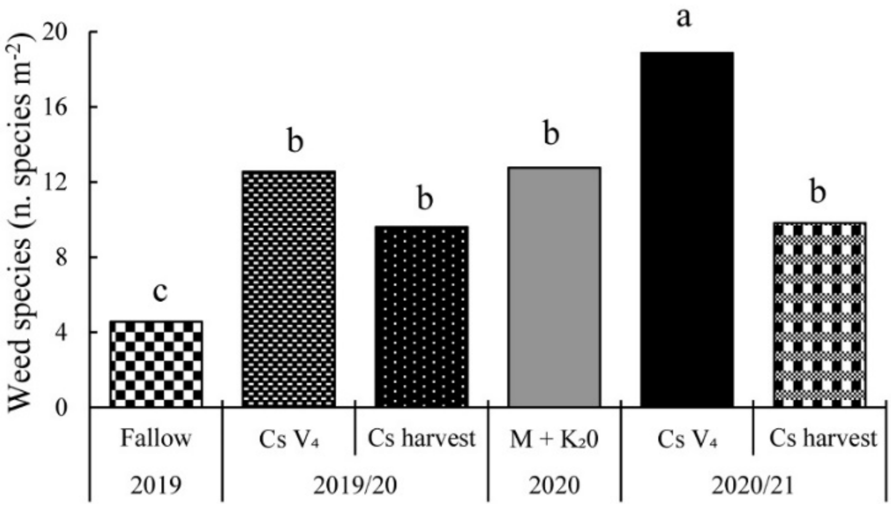
Table 4: Formulas used to determine phytosociological parameters according to Mueller-Dombois & Ellenberg (1974)

Index	Formula
Frequency (F)	No. of plots containing the species/no. of plots used
Density (D)	total number of individuals per species/total area sampled
Abundance (A)	total number of individuals per species/total number of plots containing the species
Relative frequency (RF)	Frequency of species *100/total frequency of all species
Relative density (RD)	Density of species *100/total density of species
Relative abundance (RA)	Abundance of species *100/total abundance of all species
Importance value index (IVI)	RF+RD+RA



Means followed by the same letter do not differ by Tukey's test at 5% (Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; $M+K_2O$ = millet at different doses of K_2O).

Figure 1: The total weed density (number of plants m-2) in each evaluation period.



Means followed by the same letter do not differ by Tukey's test at 5% (Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; $M+K_2O$ = millet at different doses of K_2O).

Figure 2: Weed species (number of species m^{-2}) in each evaluation period.

Table 5: Distribution of weed species by species, family and evaluation period collected in the experimental area

Scientific name	Family	2019 Fallow	2019/20 Cs V_4	2019/20 Cs harvest	2020 $M+K_2O$/ Fallow	2020/21 Cs V_4	2020/21 Cs harvest
Acanthospermum hispidium DC	Asteraceae				x	x	x
Ageratum conyzoides L.	Asteraceae					x	x
Bidens pilosa L.	Asteraceae	x	x	x	x	x	
Commelina benghalensis L.	Commelinaceae	x	x	x	x	x	x
Cenchrus echinatus L.	Poaceae		x		x	x	
Chamaesyce hirta (L.) Millsp.	Euphorbiaceae					x	
Cyperus rotundus L.	Cyperaceae		x		x		
Eleusine indica (L.) Gaertn	Poaceae				x		
Emilia fosbergii NICOLSON	Asteraceae			x	x	x	
Galinsoga parviflora Cav.	Asteraceae			x		x	x
Galinsoga quadriradiata Ruiz & Pav.	Asteraceae		x	x			
Gamochaeta coarctata (Willd.) Kerguélen	Asteraceae						x
Ipomoea acuminata (Vahl) Roem. & Schult.	Convolvulaceae		x				
Jaegeria hirta (lag.)Less	Asteraceae		x				
Melampodium perfoliatum (Cav.) Kunth	Asteraceae			x		x	x
Outros	*					x	x
Portulaca oleraceae L.	Portulaceae		x		x	x	
Richardia brasiliensis Gomes	Rubiaceae	x		x	x	x	x
Tridax procumbens L.	Asteraceae	x	x	x	x	x	

Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; $M+K_2O$ = millet at different doses of K_2O.

Table 6: Weed species in each treatment and the importance value index (IVI) in the different evaluation periods. (IVI = importance value index; Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; $M+K_2O$ = millet at different doses of K_2O)

Tret.[1]	Species	IVI (%)					
		2019	2019/20	2019/20	2020	2020/21	2020/21
		Fallow	Cs V_4	Cs harvest	$M+K_2O$/ Fallow	Cs V_4	Cs harvest
FCMC120	*Acanthospermum hispidium* DC	-	-	-	131.1	35.2	38.0
	Ageratum conyzoides L.	-	-	-	-	21.9	-
	Bidens pilosa L.	-	-	50.0	19,9	-	-
	Commelina benghalensis L.	-	24.0	50.0	80.6	-	16.8
	Cenchrus echinatus L.	-	24.0	-	-	7.8	-
	Galinsoga parviflora Cav.	-	-	-	-	33.3	16.8
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	198.0
	Melampodium perfoliatum (Cav.) Kunth	-	-	150.0	-	-	-
	Outros	-	-	-	-	63.6	-
	Portulaca oleraceae L.	-	90.6	-	-	104.6	-
	Richardia brasiliensis Gomes	150.0	-	-	48.6	34.3	30.5
	Tridax procumbes L.	150.0	161.5	50.0	19.9	-	-
FCMC90	*Acanthospermum hispidium* DC.	-	-	-	65.9	36.4	-
	Ageratum conyzoides L.	-	-	-	-	6.8	39.7
	Amaranthus deflexus L.	-	-	-	-	6.8	-
	Bidens pilosa L.	-	101.4	-	13.9	-	-
	Commelina benghalensis L.	68.1	-	56.9	46.8	6.8	29.9
	Cenchrus echinatus L.	-	-	-	-	9.3	-
	Emilia fosbergii NICOLSON	-	-	-	28.2	-	-
	Galinsoga parviflora Cav.	-	-	36.0	-	6.8	-
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	99.3
	Melampodium perfoliatum (Cav.) Kunth	-	-	171.2	-	-	32.4
	Outros	-	-	-	-	60.6	-
	Portulaca oleraceae L.	-	64.4	-	75.5	109.7	-
	Richardia brasiliensis Gomes	232.0	-	-	69.7	44.2	98.8
	Tridax procumbes L.	-	134.4	36.0	-	12.7	-
FCMC60	*Acanthospermum hispidium* DC.	-	-	-	89.3	61.1	27.1
	Ageratum conyzoides L.	-	-	-	-	-	34.3
	Bidens pilosa L.	-	52.7	-	-	-	-
	Commelina benghalensis L.	-	14.0	90.8	95.4	9.5	-
	Cyperus rotundus L.	-	23.8	-	-	-	-
	Emilia fosbergii NICOLSON	-	-	-	-	16.5	-
	Galinsoga parviflora Cav.	-	-	-	-	-	41.4
	Galinsoga quadriradiata Ruiz & Pav.	-	77.8	-	-	-	-
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	134.3
	Melampodium perfoliatum (Cav.) Kunth	-	-	116.2	-	18.9	-
	Outros	-	-	-	-	58.3	-
	Portulaca oleraceae L.	-	86.7	-	33.5	97.0	-
	Richardia brasiliensis Gomes	150.0	-	-	59.5	38.8	62.9
	Tridax procumbes L.	150.0	45.0	93.0	22.3	-	-

Continue

Continuation

Tret.[1]	Species	IVI (%)					
		2019	2019/20	2019/20	2020	2020/21	2020/21
		Fallow	Cs V_4	Cs harvest	M+K_2O/Fallow	Cs V_4	Cs harvest
FCMC30	*Acanthospermum hispidium* DC.	-	-	-	57.7	28.2	51.8
	Ageratum conyzoides L.	-	-	-	-	14.0	-
	Bidens pilosa L.	-	95.4	-	-	-	-
	Commelina benghalensis L.	300.0	17.2	58.4	68.1	-	-
	Cenchrus echinatus L.	-	25.4	-	-	11.4	-
	Cyperus rotundus L.	-	12.8	-	-	-	-
	Eleusine indica (L.) Gaerth	-	-	-	13.0	-	-
	Galinsoga parviflora Cav.	-	-	-	-	40.3	-
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	158.9
	Ipomoea acuminata (Vahl) Roem. & Schult.	-	12.8	-	-	-	-
	Melampodium perfoliatum (Cav.) Kunth	-	-	171.2	-	-	-
	Portulaca oleraceae L.	-	48.7	-	105.6	126.3	-
	Richardia brasiliensis Gomes	-	-	-	55.0	30.9	89.3
	Tridax procumbes L.	-	87.8	67.5	-	49.0	-
FCMC0	*Acanthospermum hispidium* DC.	-	-	-	115.7	37.5	21.2
	Ageratum conyzoides L.	-	-	-	-	27.5	36.8
	Bidens pilosa L.	-	-	-	-	7.4	-
	Commelina benghalensis L.	-	45.2	49.3	63.0	7.4	21.3
	Cenchrus echinatus L.	-	-	-	22.6	16.2	-
	Cyperus rotundus L.	-	45.9	-	-	-	-
	Emilia fosbergii NICOLSON	-	22.7	-	-	-	-
	Galinsoga parviflora Cav.	-	-	-	-	19.2	-
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	136.9
	Melampodium perfoliatum (Cav.) Kunth	-	-	179.0	-	-	-
	Outros	-	-	-	-	42.4	-
	Portulaca oleraceae L.	-	45.2	-	59.9	111.2	-
	Richardia brasiliensis Gomes	300.0	-	-	38.9	31.2	83.9
	Tridax procumbes L.	-	141.0	74.7	-	-	-
FCMC	*Acanthospermum hispidium* DC.	-	-	-	59.5	26.3	-
	Ageratum conyzoides L.	-	-	-	-	19.3	22.8
	Bidens pilosa L.	73.6	84.2	-	-	-	-
	Commelina benghalensis L.	-	16.2	63.1	95.2	9.3	-
	Cenchrus echinatus L.	-	88.1	-	-	17.6	-
	Emilia fosbergii NICOLSON	-	-	19.0	31.0	-	-
	Galinsoga parviflora Cav.	-	-	-	-	20.9	29.0
	Gamochaeta coarctata (Willd.) Kerguélen	-	-	-	-	-	170.5
	Melampodium perfoliatum (Cav.) Kunth	-	-	148.3	-	-	-
	Outros	-	-	-	-	52.4	-
	Portulaca oleraceae L.	-	61.0	-	73.8	119.3	-
	Richardia brasiliensis Gomes	73.6	-	26.9	40.6	35.0	77.7
	Tridax procumbes L.	152.9	84.2	42.7	-	-	-

Continuation

Tret.[1]	Species	IVI (%)					
		2019	2019/20	2019/20	2020	2020/21	2020/21
		Fallow	Cs V_4	Cs harvest	M+K_2O/Fallow	Cs V_4	Cs harvest
FCFCRec	*Acanthospermum hispidium* DC.	-	-	-	86.7	3.3	24.8
	Ageratum conyzoides L.	-	-	-	-	-	-
	Bidens pilosa L.	-	122.2	59.3	64.2	13.0	-
	Commelina benghalensis L.	-	18.1	75.3	36.2	7.3	-
	Cenchrus echinatus L.	-	-	-	-	31.6	-
	*Chamaesyce hirta (*L.) Millsp.	-	-	-	-	7.3	-
	Galinsoga parviflora Cav.	-	-	-	-	25.8	-
	Gamochaeta coarctata (Willd.)Kerguélen	-	-	-	-	-	134.9
	Melampodium perfoliatum (Cav.) Kunth	-	-	165.5	-	-	-
	Outros	-	-	-	-	51.0	77.3
	Portulaca oleraceae L.	-	81.7	-	13.4	82.4	-
	Richardia brasiliensis Gomes	130.0	-	-	81.1	49.3	63.0
	Tridax procumbes L.	170.0	78.0	-	18.5	-	-

[1] FCMC120 = Fallow + corn silage + 0 kg K_20 ha $^{-1}$ at millet + 120 kg K_2O ha^{-1} broadcast at corn silage; FCMC90 = Fallow + corn silage + 30 kg K_20 ha $^{-1}$ at millet + 90 kg K_2O ha^{-1} broadcast at corn silage; FCMC60 = Fallow + corn silage + 60 kg K_20 ha $^{-1}$ at millet + 60 kg K_2O ha^{-1} broadcast at corn silage; FCMC30 = Fallow + corn silage + 90 kg K_20 ha $^{-1}$ at millet + 30 kg K_2O ha^{-1} broadcast at corn silage; FCMC0 = Fallow + corn silage + 120 kg K_20 ha $^{-1}$ at millet + 0 kg K_2O ha^{-1} broadcast at corn silage; FCMC = Fallow + corn silage + 150 kg K_20 ha $^{-1}$ at millet + 0 kg K_2O ha^{-1} broadcast at corn silage; FCFCRec = Fallow + corn silage + Fallow and 0 kg K_2O ha^{-1} + standard fertilization at corn silage.

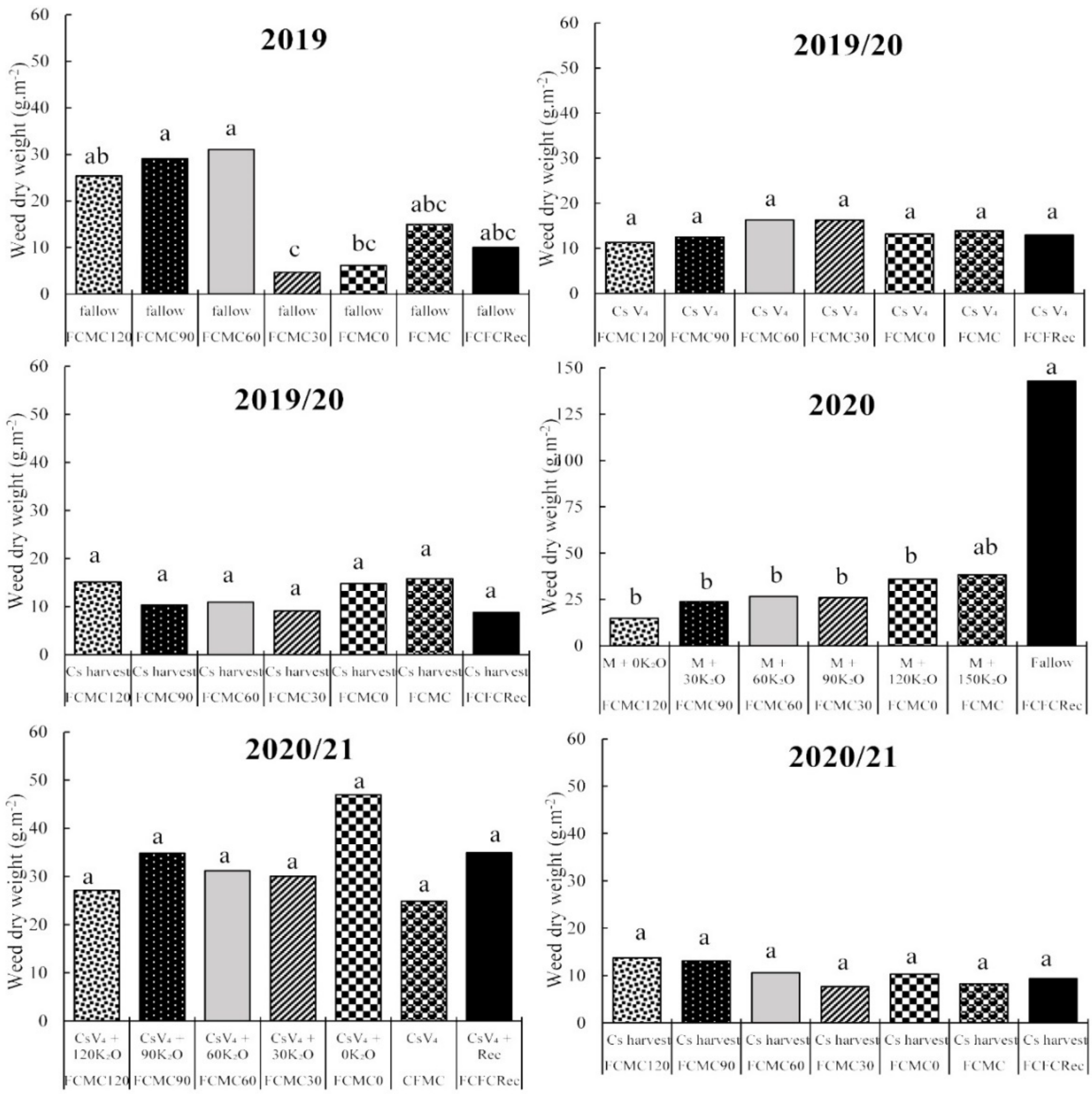
The weed density was higher for the 2020/21 evaluation period (CsV_4) (251.4 plants m^{-2}), while the lowest density was observed in the 2019 evaluation period (Fallow) (7.1 plants m^{-2}) followed by the 2019/20 evaluation period (Cs harvest) (30.2 plants m^{-2}). The highest number of weed species was also observed for the 2020/21 evaluation period (CsV_4) (18.86 species m^{-2}), and the lowest number was observed for the 2019 evaluation period (Fallow) (4.6 species m^{-2}). Conversely, the other periods (2019/20 (CsV_4); 2019/20 (Cs harvest); 2020 (Fallow) and 2020/21 (Cs harvest) showed no significant difference between them, with an average of 11.2 species of plants m^{-2}.

For the DW variable, a significant interaction was observed between treatments and evaluation period ($p < 0.05$) (Figures 3 and 4). Between the evaluation periods (Figure 3), the treatments differed only in the 2019 (Fallow) and 2020 (M+K_2O) periods. For 2019 (Fallow), the highest DW means were found for treatments FCMC60 (31.0 gm^{-2}) and FCMC90 (29.9 gm^{-2}), followed by FCMC120 (25.4 gm^{-2}), and the lowest mean was found in the FCMC30 treatment (4.7 gm^{-2}). In the 2020 period (M+K_2O), the highest mean DW was found for the FCFCRec treatment (143.0 gm^{-2}).

Comparing the effects of each treatment between the evaluation periods (Figure 4), the highest DW means were observed in the FCMC30 (30.1 and 26.02 gm^{-2}), FCMC0 (36.0 and 47.0 gm^{-2}) and FCMC (38.3 and 24.9 gm^{-2}) treatments in the 2020 (Fallow) and 2020/2021 (CsV_4) harvests, respectively. The lowest DW means were observed in the FCMC30 treatments (4.7 gm^{-2} and 7.7 gm^{-2}) for the 2019 (Fallow) and 2020/21 (Cs harvest) harvests, the FCMC0 treatment (6.1 gm^{-2}) for the 2019 harvest (Fallow) and the FCMC treatment (8.3 gm^{-2}) for the 2020/21 harvest (Cs harvest). For the FCFCRec treatment, the highest DW value was observed in the 2020 harvest (Fallow) (143.0 gm^{-2}), and the lowest values were observed in the 2019/20 (Cs harvest) (8.8 gm^{-2}) and 2020/21 (Cs harvest) harvests (9.4 gm^{-2}). For the other treatments, FCMC120, FCMC90 and FCMC60, no differences were observed.

DISCUSSION

The Asteraceae and Poaceae families contributed the largest number of species in agricultural areas under dystrophic Red Latosol in southwest Goiás in a soybean production system in succession with corn, sorghum, millet and fallow (Santos *et al.,* 2016) and in a corn crop with different doses of nitrogen in a dystrophic red–yellow Latosol in Minas Gerais (Ferreira *et al.,* 2019). The Asteraceae family is one of the largest families and can be found worldwide, being present in different crops in Brazil (Tavares *et al.,* 2013; Hani *et al.,* 2017). According to Lorenzi

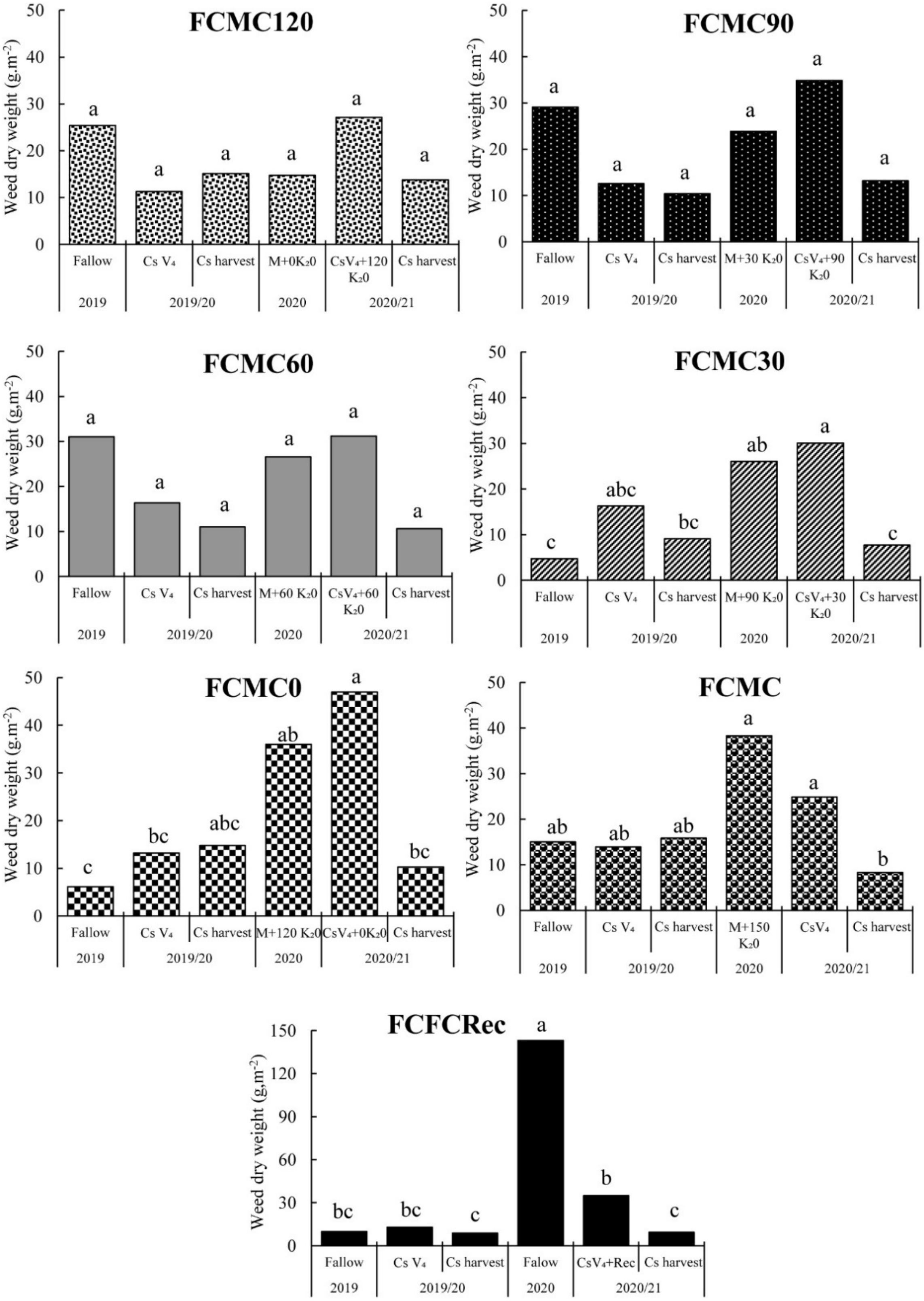


Means followed by the same letter in the same evaluation period do not differ by Tukey's test at 5%. (Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; M+K_2O = millet at different doses of K_2O; Rec = standard fertilization). The first line in the legend of the x-axis indicates the treatments present in the evaluation period, and the second line indicates the identification of the complete treatment [(1)] in the plots. [(1)] FCMC120 = Fallow + corn silage + 0 kg K_20 ha $^{-1}$ at millet + 120 kg K_2O ha^{-1} broadcast at corn silage; FCMC90 = Fallow + corn silage + 30 kg K_20 ha $^{-1}$ at millet + 90 kg K_2O ha^{-1} broadcast at corn silage; FCMC60 = Fallow + corn silage + 60 kg K_20 ha $^{-1}$ at millet + 60 kg K_2O ha^{-1} broadcast at corn silage; FCMC30 = Fallow + corn silage + 90 kg K_20 ha $^{-1}$ at millet + 30 kg K_2O ha^{-1} broadcast at corn silage; FCMC0 = Fallow + corn silage + 120 kg K_20 ha $^{-1}$ at millet + 0 kg K_2O ha^{-1} broadcast at corn silage; FCMC = Fallow + corn silage + 150 kg K_20 ha $^{-1}$ at millet + 0 kg K_2O ha^{-1} broadcast at corn silage; FCFCRec = Fallow + corn silage + Fallow and 0 kg K_2O ha^{-1} + standard fertilization at corn silage.

Figure 3: Effect of the treatment x evaluation period interaction on weed dry weight (gm^{-2}).

(2008), plants of the families Asteraceae and Poaceae have a large diaspore production capacity, facilitating the propagation and occupation of the ecological niche in different environments, especially under unfavorable conditions for their development.

The constant presence of the species *C. benghalensis* during the evaluation periods in the study area (Table 5) may be related to the biology of the plant and the management methods used in the area, such as the use of the herbicide glyphosate for weed control in the 2019/20, 2020 and 2020/21 harvests and tools used in soil preparation, such as the brush cutter and harrow. According to Faden (1992) and Sarmento *et al.* (2015), *C. benghalensis* is a species of considerable relevance since it has high reproductive capacity (seeds or vegetative parts of the stem), is able to survive in various environments, is tolerant to glyphosate



Means followed by the same lowercase letter in the same treatment do not differ by Tukey's test at 5%. (Fallow = area without any crop; CsV_4 = corn silage at V_4 stage; Cs harvest = harvest at corn silage; M+K_2O= millet at different doses of K_2O; Rec = standard fertilization). The first line in the legend of the x-axis indicates the treatments applied in the evaluation period, and the second line indicates the evaluation period.

Figure 4: Effect of the evaluation period x treatment on weed dry weight (gm^{-2}).

and is an herbicide widely used in agricultural production systems. The tolerance to glyphosate of the species *T. procumbens* and *R. brasiliensis* (Cerdeira *et al.,* 2011) and the resistance of the species *B. pilosa* (Cruz *et al.,* 2016) may also be a factor that justifies the occurrence of these plants in most of the evaluation periods, depending on the appropriate management.

The IVI is an index that determines which species are most important within a plant community (Lima *et al.,* 2014). Thus, plants with the highest IVI should have priority in management to reduce interference in crop yield (Batista *et al.,* 2016). In general, we observed a change in the most important weed species (IVI) during the evaluation periods, which shows the relevance of phytosociological studies in different periods, in addition to the need to understand the biology of these plants. According to Silva *et al.* (2018), the occurrence of a given species and the diversity of plants in a given area can be influenced by the types and intensity of crop treatments used during the management practices used, thus causing changes in the populations and distribution of plant species in a community. Therefore, for the present study, the occurring species (Table 5) as well as the lower density (Figure 1) and number of plant species (Figure 2) found in 2019 (Fallow) in relation to the other cultivation periods may be explained by the conditions of the experimental area that was in fallow, without soil preparation two years after successive Cs cultivation under conventional planting. According to Colbach *et al.* (2005), soil tillage modifies its properties and seed distribution, in addition to directly affecting the germination and emergence of weeds. Soil tillage increases aeration, exposes the seeds of some species to the surface near light or buries the seeds of others that need different conditions to germinate (Blanco & Blanco, 1991), in addition to causing the spread of rhizomes, bulbs and tubers due to the fragmentation of its subterranean parts, causing breakage of dormancy and regrowth and thus increasing the infestation of the area (Silva *et al.,* 2005).

Higher plant density (Figure 1) and plant species (Figure 2) values found for the 2020/21 evaluation period (CsV_4) may be related to the climatic conditions and the fertilizations previously performed in the winter crop of 2020 ($M+K_2O$) added to the planting fertilizations and the highest water availability. According to Ochoa-Huesto & Manrique (2010), soil moisture affects nutrient availability and seed germination and contributes to seedling survival and establishment. For Yang *et al.* (2011), water is one of the main limiting factors not only for the development but also for the diversity of weeds. In turn, the levels of nutrients present in the soil influence the community composition, density, and diversity of weed (Tang *et al.,* 2014; Than *et al.,* 2017; Baker *et al.,* 2018).

The differences in DW of weeds observed among the treatments for the evaluations performed in 2019 (Fallow) (Figure 3) may be associated with the different species found and their different stages of development within the plots, considering that during this evaluation period, there was no variability between treatments. However, we also observed that the soil preparation (mowing + harrowing) performed for the implementation of the 2019/20 Cs harvest and the weed control with the combination of the herbicides glyphosate + atrazine was efficient for standardizing the occurrence of weed in the plots, as observed in the evaluation periods 2019/20 (CsV_4) and 2019/20 (Cs harvest). According to Silva *et al.* (2020), the use of herbicides with different mechanisms of action helps in the control of tolerant species, keeping the crop free of weed in its initial period of development.

In the evaluations performed in 2020 (Fallow), the highest mean in the FCFCRec treatment (143.0 gm^{-2}) that was fallow at the time of sampling in relation to the other treatments shows that the efficacy of the millet crop remains in the off-season of Cs in the control of weed, even after 120 days of management. Similar results were obtained by Sodré Filho *et al.* (2008), Castro *et al.* (2011) and Araújo *et al.* (2021), who observed a reduction in DW of weed in areas cultivated with cover crops in the off-season. According to Ferreira *et al.* (2018), pearl millet is one of the main cover crop species used as a component of integrated management of weed in the Brazilian Cerrado region due to its large biomass production in a short period. However, according to Pereira *et al.* (2011), in areas covered with straw from cover crops, the increase in accumulated DW of weed occurs with the increase in the composition of crop remains. For these same authors, the greater the interval between the management of cover crops and the sowing of the crop in sequence, the greater the weed infestation.

With a significant effect observed between the evaluation periods for the FCMC30, FCMC0, and FCMC treatments (Figure 4), it was possible to infer that potassium fertilization doses above 90 kg ha^{-1} applied in advance in millet cultivated in the off-season caused an increase in the DW of weed in the 2020 (M+K_2O) and 2020/21 (CsV_4) harvests. However, the DW values obtained in 2020 (M+K_2O) were lower than those observed for the FCFCRec treatment for this same harvest (Figures 3 and 4), which is currently under fallow conditions (2020 (Fallow). Khan *et al.* (2013) evaluated the effect of fertilization with N, P and K, alone or in combination, on corn yield with and without weed infestation and observed that the lowest DW values of weed were obtained for the treatments containing K and PK. Everaarts (1992) also found no responses to the application of K in relation to the DW of weed in two different sites and in acidic and low-fertility soils; however, the number of plants increased with the application of K. The author attributed the result to high amounts of K available in the soil. According to Bajwa *et al.* (2014), weeds have different responses when subjected to different doses of fertilizers under different cultivation systems, rates, and application methods. To authors, the changes in soil fertility and physics caused by conservation cultivation systems promote a distinct environment for germination, emergence, growth, and competition for weeds; thus, variations in fertilizer doses, methods and types of application that occur in these systems should be performed according to the responses of the weeds. However, in this work, considering to be the first year of implementation of the no-till system and that changes in soil attributes occur with the time of adoption of the system, it is suggested that more striking changes in the weed community in this area may occur with the implementation time of the no-till system.

CONCLUSIONS

The management used in a given crop, as well as soil preparation, fertilization and water availability, alters the weed community, as well as the occurrence of the most important species.

The density and number of weed species increased in the first year of implementation of the no-tillage system of Cs grown in succession with early fertilization in the cover crop. However, studies are needed to verify the effect of these variables in the long term.

Early potassium fertilization with doses of 90, 120 and 150 kg ha^{-1} applied in advance in the winter crop (millet) increased the DW of weeds before planting and during vegetative stage V_4 of Cs grown in sequence. However, the increase in weed DW values is considerably lower before planting than in an area kept in fallow.

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