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Effect of chemical weed control in the soybean and maize production system in the floristic community in the Cerrado regions of central Minas Gerais state

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Abstract: Background: The study of the effects of different chemical management practices on the floristic composition of weeds in soybean and maize crops in succession is essential for understanding the population dynamics of the main species present in these cultivated areas. **Objective:** This study evaluated the impact of different weed control programs on the floristic community in a soybean-maize succession system, in the Cerrado regions of central Minas Gerais state. **Methods:** Five management systems were compared, ranging from low to high technology levels, including different combinations of herbicides, manual weeding, and winter fallow. The frequencies, densities, dominance, and Importance Value Index (IVI) of weeds were calculated. The similarity index between treatments in the two soybean crops was calculated. Dry biomass (DB) data and total plant density of *Commelina benghalensis* L. were analyzed at the end of the experiment using geostatistical methods. **Results:** In all phytosociological surveys, 31 weed species were identified. A predominance of weeds from the Poaceae and Asteraceae families was observed. The highest weed density was observed in the low technology system. Regardless of the technology level adopted, the greatest weed control occurred in the maize crop, reducing the total biomass of the species. In the spatial distribution mapping of *C. benghalensis* DB, the highest concentration occurred in the low technology system. **Conclusions:** The greater diversification of herbicides with different mechanisms of action provides less similarity between the weed population in different agricultural crops.

Keywords: *Glycine Max*; *Zea Mays*; Herbicides; Phytosociology

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1. Introduction

The national maize production in 2021/22 season was 114.7 million tons, with an increase of 31.7% compared to the 2020/21 and an average yield of 5,314 kg per hectare (Companhia Nacional de Abastecimento, 2022). in 2021/22 season, soybean production was 124 million tons, with reduction of 10.2% compared to the previous season and yield of 3,029 kg per hectare (Companhia Nacional de Abastecimento, 2022).

Among the factors that interfere with productivity and final product quality, there is weed competition. This is because weeds can compete with crops for water, light, nutrients and space, and even harbor host pests and diseases (Silva et al., 2021).

Among the direct losses, the losses in productivity, is what stands out. In soybean the interference by species of *Urochloa plantaginea* (Link) R. D. Webster, *Digitaria horizontalis* Willd., *Ipomoea triloba* L., *Euphorbia heterophylla* L., *Amaranthus deflexus* L., *Commelina benghalensis* L., *Richardia brasiliensis* Gomes, *Bidens pilosa* L. and *Raphanus raphanistrum* L. resulted in 52% yield reduction (Silva et al., 2015). Weed management is a necessary practice in the crop production system, and technical knowledge is essential to define management strategies. Thus understanding the dynamics and interaction of the weed community in the area is of paramount importance and to carry out the phytosociological survey is necessary to identify and quantify the composition of weed populations (Mueller-Dombois, Ellenberg, 1974). Population dynamics which refers to changes in the composition of the weed community over time, considers the number and relative dominance of each species as well as the variation in edaphic and climatic characteristics of the agronomic practices adopted (Zelaya et al., 1997).

Another reason for conducting phytosociological surveys is the possibility of evaluating the degree of weed interference on agricultural crops. This evaluation that is variable and depends on the species density and spatial distribution of the weeds, the period of coexistence between the crop and the weed community and the edaphoclimatic conditions in the cultivation region (Costa et al., 2021). In this context, analyzing the floristic composition of weeds is important, especially for the identification of the most problematic weed species in the study area to use specific mechanisms of action for the chemical management of these species.

The phytosociological survey provides knowledge about the weed community, important for management recommendations especially in early stages of the plant, creating a favorable environment for crop development and herbicide economy.

Phytosociological studies are important to optimize the management, through choices of efficient control methods for weed species in the area (Oliveira, Freitas, 2008).

Over the years, due to the recurrent use of reactive management in which weed management is done to control a species that is already with a high index of importance in the production area, there was an increase in the density of several weed species. However, for this, studies in several production systems and in several regions is important to evaluate the differences and trends of the weed community. Given the above, the objective of this study was to evaluate the floristic community of weeds in a system where soybeans and maize are grown in succession under different chemical control programs in the Cerrado of the central region of the Minas Gerais State, in Brazil.

2. Material and Methods

The phytosociological surveys were carried out in the 2019/20 and 2020/21 seasons at the time of harvest of soybean (*Glycine max* L. Merril) and maize (*Zea mays* L.) at *Embrapa Milho e Sorgo* in Sete Lagoas, Minas Gerais. The climate is Aw (Koppen), with dry winter and average air temperature of the coldest month exceeding 18 °C. Annual rainfall in the 2019/2020 agricultural year was 1,360 mm and in the 2020/2021 agricultural year 1,100 mm, with a higher incidence between the months of October and March (Instituto Nacional de Meteorologia, 2022).

Table 1 - Mechanisms of action of herbicides applied at five different technological levels in the soybean/maize second crop system. Agricultural year 2019/2020 in Cerrado in center region of the Minas Gerais state

System (technology level)	Nº MOAs for system	MOAs	Additional management
Low	2	EPSPs + FSII	
Medium	4	EPSPs + FSII + ACCase + HPPD	
High	6	EPSPs + FSII + ACCase + HPPD + ALS + FSI	
High +	6	EPSPs + FSII + ACCase + HPPD + ALS + FSI	Hand-weeding
Medium +	4	EPSPs + FSII + ACCase + Auxin	Fallow

MOAs: mechanisms of action of herbicides; EPSPs: inhibitor of the enzyme Enol-pyruvil-chiquimate-phosphate synthetase; FSII: photosystem II inhibitor; ACCase: enzyme inhibitor Acetyl CoA Carboxylase; ALS: Acetolactate synthase inhibitor; HPPD: carotenoid synthesis inhibitor; FSI: photosynthesis inhibitor in photosystem I; Auxin: auxin-mimetic

Table 2 - Systems with different herbicides application in the soybean/maize second crop system. Agricultural year 2019/2020 in Cerrado in center region of the Minas Gerais state

System (technology level)	Dose (kg ha^{-1})				
	Soybean				Maize
	Burndown (09/11/2019)	Pre[1] (23/11/2019)	Post[2] (13/12/2019)	Post S[3] (02/01/2020)	Post (01/04/2020)
Low	gly (1,440 g e.a. ha^{-1})		gly (1,440 g e.a. ha^{-1})	gly (1,440 g a e.a. ha^{-1})	gly (720 g e.a. ha^{-1}) + atz (1000 g ha^{-1})
Medium	gly (1,440 g e.a. ha^{-1})		gly (1,440 g e.a. ha^{-1}) + fen (110 g ha^{-1}) + Ast (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + clt (96 g ha^{-1}) + Ast (0.5% v/v)	atz (1,000 g ha^{-1}) + tmb (100 g ha^{-1}) + Ast (0.5% v/v)
High	gly (1,440 g e.a. ha^{-1}) + chl (20 g ha^{-1})	diq (600 g i.a. ha^{-1}) + mtz (384 g ha^{-1}) + Veg (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + fen (110 g ha^{-1}) + Ast (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + clt (96 g ha^{-1}) + Ast (0.5% v/v)	atz (1,000 g ha^{-1}) + tmb (100 g ha^{-1}) + Ast (0.5% v/v)
High+	gly (1,440 g e.a. ha^{-1}) + chl (20 g ha^{-1})	diq (600 g ha^{-1}) + mtz (384 g ha^{-1}) + Veg (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + fen (110 g ha^{-1}) + Ast (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + clt (96 g ha^{-1}) + Ast (0.5% v/v)	atz (1,000 g ha^{-1}) + tmb (100 g ha^{-1}) + Ast (0..5% v/v)
Medium+	gly (1,440 g e.a. ha^{-1}) + 2,4-D (670 g e.a. ha^{-1})		gly (1,440 g e.a. ha^{-1}) + clt (96 g ha^{-1}) + Ast (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + clt (96 g ha^{-1}) + Ast (0.5% v/v)	gly (1,440 g e.a. ha^{-1}) + 2,4-D (670 g e.a ha^{-1})

gly: glyphosate; atz: atrazine; chl: chlorimuron-ethyl; diq: diquat; mtz: metribuzin; veg: Veget Oil; fen: fenoxaprop-P-ethyl; ast: assist; clt: clethodim; atz: atrazine; tmb: tembotrione. Low: two mechanisms of action; medium: four mechanisms of action; high: six mechanisms of action; high +: six mechanisms of action + mechanical control; Medium +: three mechanisms of action and fallow in winter. [1] application in pre-emergence; [2] application in post-emergence; [3] application in sequential post-emergence.

In all soybean crops, the cultivar used was KWS 6813 sown on November 22, 2019 and November 5, 2020. The maize cultivars used were RB 9006 PRO2 and KWS 8774 PRO3, sown on March 18, 2020 and March 3, 2021, respectively with the technology developed by the Brazilian Agricultural Research Company (Embrapa) which allows the early intercropping of maize between soybean rows 20 days before the oilseed harvest (Karam et al., 2020). In all crops, crop spacing was 0.5 m between rows. In the soybean crop had a stand of 360,000 plants ha^{-1} and in the maize crop 60,000 plants ha^{-1}. The study was conducted in a no-till system and fertilization was carried out according to good agricultural practices.

The five management systems with low, medium and high technology using herbicides with different mechanisms of action and combinations for soybean and maize crops are described in Table 1. Herbicides were applied both in pre-plant, pre-emergence and post-emergence of weeds and at different doses. The systems were defined based on the level of technology adopted for each management program as described in Tables 2 and 3 for the agricultural years 2019/2020 and 2020/2021, respectively.

With the exception of the year 2020, the medium-tech+ system, with application of herbicides inhibitors of epsps and auxin mimetizers, remained fallow during the maize growing seasons. The applications were performed using a self-propelled sprayer equipped with TT 110.02 fan tips (*Tecnologia* Teejet®), spaced 0.50 m, with working pressure during application of 3.0 bar and displacement speed of 6.0 km h^{-1}, with slurry volume of 150 L ha^{-1}.

Before starting the experiment, the predominant species were D. insularis and Amaranthus spp. The phytosociological survey of the weed community was carried out in the harvest of the crops. The weed species were identified, quantified and collected with the method of square leaked inventory with 0.25 m^2 released 36 times in each system with spacing between points of 10 m in the experimental area. The weed species identified were collected, cut close to the ground, packed in paper bags and taken to drying oven for 72 h and regulated at 65 °C. After this process, the dry biomass for each weed species collected was determined. The phytosociological parameters: absolute and relative frequency (FRE and FR), absolute and relative density (DEN and DR), absolute and relative dominance (DOM and DOR) and the importance value index (IVI) of weeds were determined as proposed by Mueller-Dombois and Ellenberg (1974), using equations:

FRE = Number of squares containing the species / total number of squares

DEN = Total number of individuals of the species / total area sampled

DOM = Dry biomass in the species / total area sampled

$FR = FRE \times 100 / \sum FRE$

$DR = DEN \times 100 / \sum DEN$

$DOR = DOM \times 100 / \sum DOM$

$IVI = FR + DR + DOR$

The collected data were submitted to phytosociological analysis and the IVI data of each species within each management system were quantified. The figures with the IVI's of the main species were plotted using Microsoft Office Excel 2016. The floristic similarity indexes between

Table 3 - Systems with application of different herbicides in the soybean/maize crop system. Agricultural year 2020/2021 in Sete Lagoas, Minas Gerais

System (technology level)	Dose (kg ha⁻¹)					
	Soybean				Maize	
	Burndown (22/10/2020)	Pre[1] (06/11/2020)	Post[2] (25/11/2020)	Post S[3] (03/12/2020)	Burndown (22/03/2021)	Post (09/04/2021)
Low	gly (1,440 g e.a. ha⁻¹)		gly (1,440 g e.a. ha⁻¹)	gly (1,440 g a e.a. ha⁻¹)		gly (720 g e.a. ha⁻¹) + atz (1,000 g i.a. ha⁻¹)
Medium	gly (1,440 g e.a. ha⁻¹)		gly (1,440 g e.a. ha⁻¹) + fen (110 g ha⁻¹) + Ast (0.5% v/v)	gly (1,440 g e.a. ha⁻¹) + clt (96 g ha⁻¹) + Ast (0.5% v/v)		atz (1,000 g ha⁻¹) + tmb (100 g ha⁻¹) + Ast (0.5% v/v)
High	gly (1,440 g e.a. ha⁻¹) + chl (20 g ha ha⁻¹)	diq (600 g ha⁻¹) + mtz (384 g ha⁻¹) + Veg (0.5% v/v)	gly (1,440 g e.a. ha⁻¹) + fen (110 g ha⁻¹) + Ast (0.5% v/v)	gly (1,440 g e.a. ha⁻¹) + clt (96 g ha⁻¹) + Ast (0.5% v/v)		atz (1,000 g ha⁻¹) + tmb (100 g ha⁻¹) + Ast (0.5% v/v)
High+	gly (1,440 g e.a. ha⁻¹) + chl (20 g ha⁻¹)	diq (600 g ha⁻¹) + mtz (384 g ha⁻¹) + Veg (0.5% v/v)	gly (1,440 g e.a. ha⁻¹) + fen (110 g ha⁻¹) + Ast (0.5% v/v)	gly (1,440 g e.a. ha⁻¹) + clt (96 g ha⁻¹) + Ast (0.5% v/v)	atz (1,000 g ha⁻¹) + tmb (100 g ha⁻¹) + Ast (0.5% v/v)	
Medium+	gly (1,440 g e.a. ha⁻¹) + 2,4-D (670 g e.a. ha⁻¹)		gly (1,440 g e.a. ha⁻¹) + clt (96 g ha⁻¹) + Ast (0,5% v/v)	gly (1,440 g e.a. ha⁻¹) + clt (96 g ha⁻¹) + Ast (0,5% v/v)	gly (1,440 g e.a. ha⁻¹) + atz (1,000 g ha⁻¹) + 2,4-D (670 g e.a ha⁻¹)	

gly: glyphosate; atz: atrazine; chl: chlorimuron-ethyl; diq: diquat; mtz: metribuzin; veg: Veget Oil; fen: fenoxaprop-P-ethyl; ast: assist; clt: clethodim; atz: atrazine; tmb: tembotrione. Low: two mechanisms of action; medium: four mechanisms of action; high: six mechanisms of action; high +: six mechanisms of action + mechanical control; medium +: three mechanisms of action and fallow in winter. [1] application in pre-emergence; [2] application in post-emergence; [3] application in sequential post-emergence.

the collection periods were calculated using the Similarity Index (SI) of Sorensen (1972) based on the equation:

$$IS = (2a / (b + c) \times 100$$

Where:

a = number of species in common between areas;

b = total number of species area 1;

c = total number of species area 2.

The level of total infestation of the area was determined by control through visual estimation performed by two evaluators on a scale of 0 to 100%, assigning 0 when there is no infestation and 100 when the area is completely infested. A similarity dendrogram built by the group average clustering method (UPGMA) on the level of infestation in the five management systems at the end of the experiment was processed using the statistical software R (R Development Core Team, 2020).

The dry biomass (DB) and total plant density (DEN) data of the *C. benghalensis* were analyzed at the end of the experiment by geostatistical methods and the maps were generated by the ordinary Kriging method using the QGis software version 3.22 with Smart-Map: Decision Support System for Precision Agriculture. The data were interpolated on a 1 x 1m grid.

3. Results and Discussion

According to the phytosociological survey, 31 weed species were identified in the pre-harvest soybean/maize

Table 4 - Relationship of weeds by family present in Cerrado in center region of the Minas Gerais state.

Family	Scientific Name	Common Name	Season			
			Soybean		Maize	
			2019/20	2020/21	2020	2021
Amaranthaceae	*Alternanthera tenella* Colla	Perroleaf	P	A	A	A
	Amaranthus spp.	Pigweed	P	P	P	P
Asteraceae	*Ageratum conyzoides* L.	Tropic ageratum	P	A	A	A
	BiDEN pilosa L.	Hairy beggarticks	P	P	P	A
	Blainvillea dichotoma (Murray) Stewart	Erva-palha	A	A	P	A
	Conyza spp.	Hairy fleabane	A	P	P	A
	Melampodium perfoliatum (Cavanilles) Kunth	Perfoliate blackfoot	P	A	P	A
	Parthenium hysterophorus L.	Ragweed parthenium	P	P	P	A
	Sonchus oleraceus L.	Annual Sowthistle	A	A	P	A
	Tridax procumbens L.	Coat buttons	P	A	A	A
Commelinaceae	*Commelina benghalensis* L.	Benghal dayflower	P	P	P	P
Convolvulaceae	*Ipomoea* spp.	Morning glory	P	A	P	A
Euphorbiaceae	*Euphorbia heterophylla* L.	Wild poinsettia	P	A	P	A
	Chamaesyce hirta (L.) Millsp.	Garden spurge	P	A	P	A
Fabaceae	*Glycine max* L. Merril	Voluntary soybean	A	A	A	P
	Senna spp.	Sicklepod	P	A	A	A
Lamiaceae	*Leonotis nepetifolia* L. R. Br	Bald busch	P	A	A	A
Malvaceae	*Sida* spp.	Buffpetal	P	A	P	A
Poaceae	*Cenchrus echinatus* (L.) Pers.	Southern sandbur	A	P	P	P
	Digitaria horizontalis Willd.	Large crabgrass	A	P	P	A
	Digitaria insularis (L.) Fedde	Sourgrass	P	P	A	P
	Echinochloa spp.	Barnyard grass	A	A	P	A
	Eleusine indica (L.) Gaertn	Goosegrass	A	A	P	P
	Panicum maximum Jacq.	Guineagrass	P	P	P	P
	Rhynchelytrum repens (Willd.) C.E. Hubb.	Fairy grass	A	P	A	P
	Sorghum arundinaceum (Desv.) Stapf	Wild sorghum	P	P	A	A
	Sorghum bicolor L. Moench	Voluntary sorghum	A	A	P	A
	Urochloa decumbens (Stapf) R.D. Webster	Signal grass	P	A	A	A
	Zea mays L.	Voluntary maize	P	A	P	A
Portulacaceae	*Portulaca oleracea* L.	Purslane	A	A	P	A
Rubiaceae	*Richardia brasiliensis* Gomes	Brazil pusley	P	P	P	A

Source: adapted from Lorenzi (2014). P: the species is present in the season; A: the species is absent in the season systems evaluated (Table 4). Weed species were distributed in 11 families and 36% of the species found belong to the family Poaceae and 26% to Asteraceae. In a survey of weed flora carried out on grain crops in the Center-South region of Brazil, there was a predominance of species of the family Poaceae (Bordin et al., 2021).

Poaceae and Asteraceae are among the families with the highest number of species in the studies conducted in Brazil, due to the climatic characteristics that favor the development of these species (Silva, Coelho, Medeiros, 2008). In the soybean crop, species of the families Poaceae and Asteraceae were also the most important according to work carried out by Benedetti et al. (2009). Corroborating with these results, Oliveira and Freitas (2008) affirm that the families Poaceae and Asteraceae are the main families of weeds existing in Brazil.

The Poaceae family has a high number of perennial species with production of large numbers of seeds and morphophysiological structures that facilitate dispersion through environmental factors such as wind, man, animals and water (Holm et al., 1991). The Asteraceae family is also quite widespread because it has high capacity for environmental adaptation predominant in the Center-South region of the country (Correia et al., 2021).

The DEN, DB of weeds and total number of species of each experimental unit are described in Table 5. In the low technology system, despite the increase in the number of species, the DB and DEN decreased over time. For the three variables analyzed, compared to the soybean crops, the maize crop showed lower values. One of the reasons for the decrease in these values is the lower rainfall during the two maize crops compared to the rainfall in the soybean crops, hindering the development of weeds.

The IVI of the weed species varied with the systems applied. For the low-technology system (Figure 1), in the soybean crop 2019/20, volunteer maize accounted for 42% of the IVI and with DOR of 95% followed by *C. benghalensis* with an IVI of 19% and DOR of 2%. In the same year, in the maize crop, *C. benghalensis* was also the most important species, with an IVI of 69.3%, followed by *Amaranthus* sp. with an IVI of 30.7%. In the soybean harvest 2020/21 the volunteer maize had an IVI de 29% also followed by *C. benghalensis*. In the 2021 crop cultivated with maize, the *Digitaria insularis* (L.) Fedde presented high DOR, when compared to the other species (8%).

In the medium-tech system (Figure 2), the species with the highest IVI in all seasons was *C. benghalensis* except for maize grown in 2020 in which *D. insularis* had the highest IVI (44%). The IVI of *C. benghalensis* was 52, 46, 23 and 45 in the 2019/2020 and 2020/2021 soybean crop, and the 2020, and 2021 maize crop, respectively. The DOR of the C. benghalensis reached 17% in the 2019/2020 soybean crop.

In the high-tech system (with six mechanisms of action) (Figure 3), IVI increased from the 2019/2020 soybean crop to the 2020/2021 crop, from 33% to 65%. In maize crops, species of the family Poaceae stood out. In the 2020 harvest, *Panicum maximum* Jacq. presented IVI of 75% while in the 2021 harvest, *Cenchrus echinatus* (L.) Pers. presented IVI of 50%.

In the high-tech system + hand-weeding and also in the high-tech system (six mechanisms of action), *C. benghalensis* showed higher IVI's in soybean crops while the grasses stood out in maize crops (Figure 4). However, when comparing the two soybean crops, in the high-tech system + hand weeding, the IVI of *C.benghalen* decreased from 49% to 43%. In maize crops of the maximum IVI values were 49% for P. maximum in 2020 and 58% for *C. echinatus* in the 2021 maize crop

Table 5 - Total weed density (DEN), dry weed biomass (DB) and total number of weed species in the four harvests in each of the technology levels, always in the same experimental area. Cerrado in center region of the Minas Gerais state.

System (technology level)	Soybean 2019/2020			Maize 2020			Soybean 2020/2021			Maize 2021		
	DEN (plantas m²)	DB (g m²)	Total number of species	DEN (plants m²)	DB (g m²)	Total number of species	DEN (plants m²)	DB (g m²)	Total number of species	DEN (plants m²)	DB (g m²)	Total number of species
Low	28	168,4	10	1	1,8	3	21	121,9	14	3	12,3	5
Medium	19	85,5	10	3	6,5	4	16	18,1	13	2	9,0	4
High	9	5,2	7	2	1,9	4	4	1,4	6	0,56	9,5	3
High+	13	4,8	7	1	0,47	4	2	2,1	9	0,4	2,6	2
Medium+	13	61,0	11	19	8,9	10	16	15,9	6	0,7	4,1	3

Low technology system (two mechanisms of action) - gly in soybean and gly + atz in maize; Medium- gly + fen + clethodim in soybean and gly + atrazine + tembotrione in maize; High- gly + phenoxaprop-P-ethyl + clethodim + diquat + metribuzin in soybean and gly + atrazine + tembotrione in maize; High+- gly + phenoxaprop-p-ethyl + clethodim + diquat + metribuzin + chlorimuron-ethyl for soybean and gly + atrazine + tembotrione for maize; Medium+- gly + 2,4-D + clethodim for soybean and gly + 2,4-D for maize

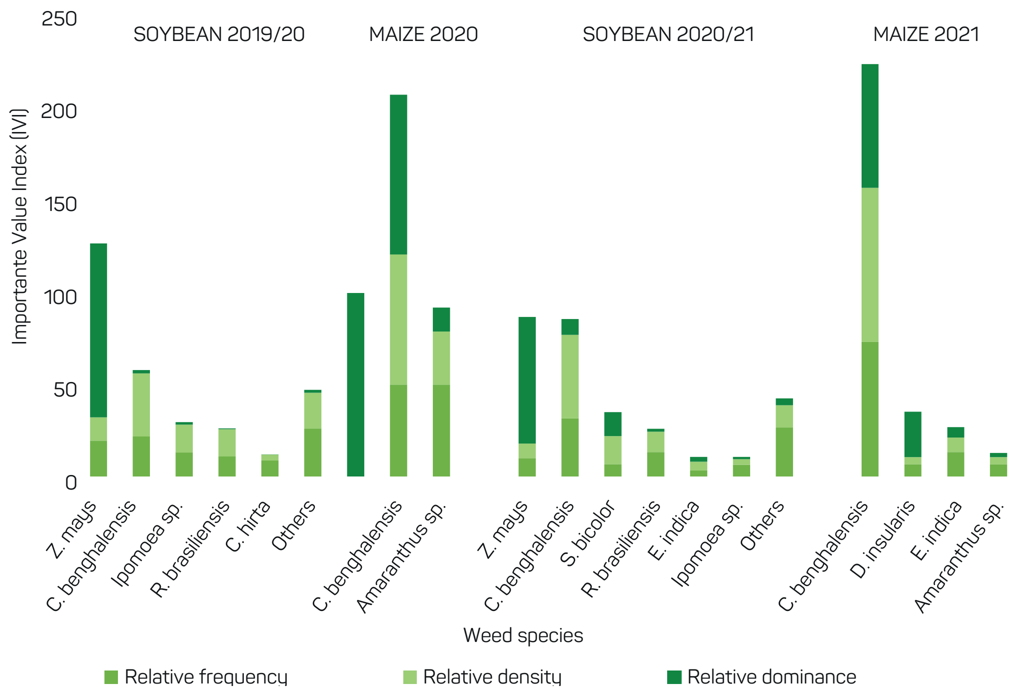


Figure 1 - Weed importance value index in the low-tech system (two mechanisms of action), with glyphosate application only in all crops

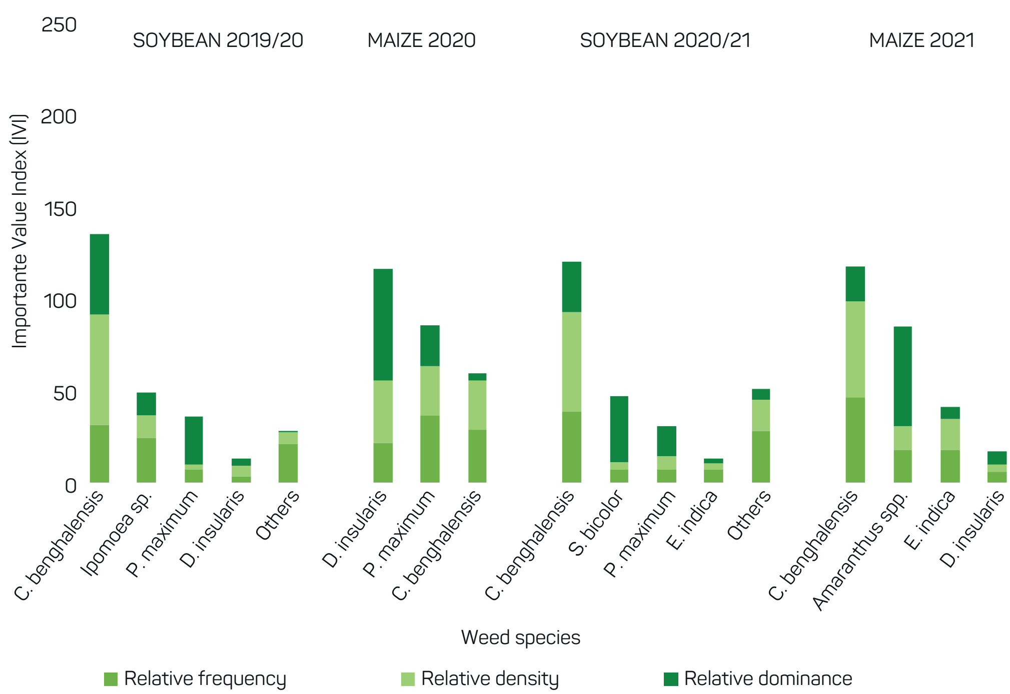


Figure 2 - Value index of importance of weeds in the medium technology system (four mechanisms of action), with application of the herbicides glyphosate + fenoxaprop-p-ethyl + clethodim in soybean crops and glyphosate + atrazine + tembotrione in maize crops

In the system of medium technology + fallow in winter, the difference between the IVI's in the course of the harvests increased (Figure 5). In the soybean crop in the 2019/2020 and maize 2020, *B. pilosa*, and *C. echinatus* species had the highest IVI's with values of 23% and 19% in the soybean crop and 31% and 34% in the maize crop, respectively. On the other hand, in the subsequent soybean and maize crops, the species with the highest IVI's were *C. benghalensis* with 60% and *P. maximum* with 54% in soybean and maize crops, respectively.

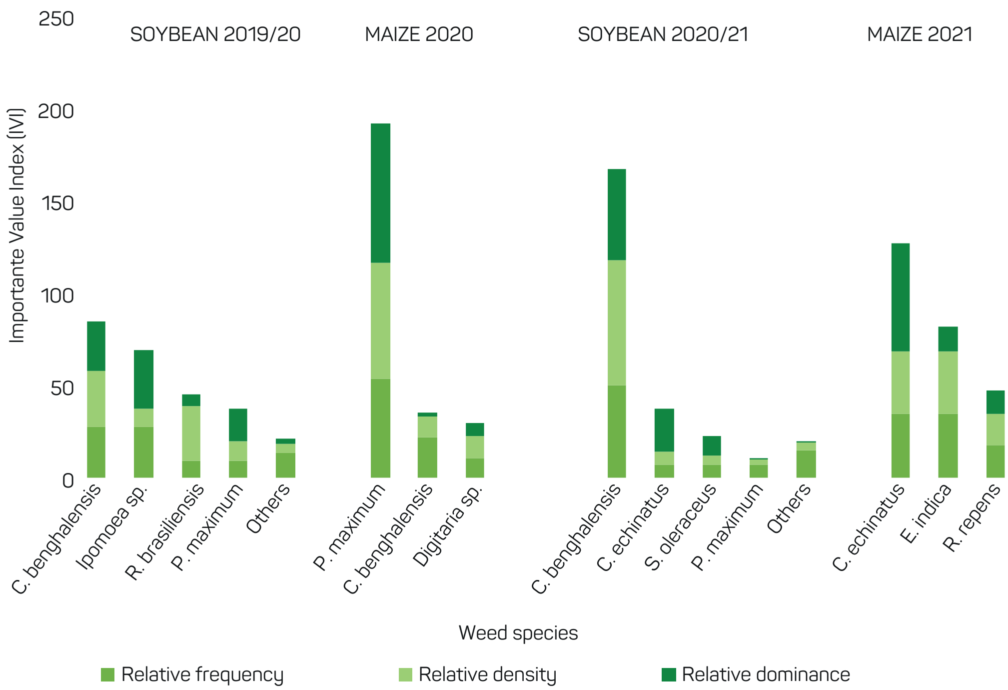


Figure 3 - Value index of importance of weeds in the high-tech system (six mechanisms of action), with application of glyphosate + phenoxaprop-p-ethyl + clethodim + diquat + metribuzin in soybean and glyphosate + atrazine + tembotrione crops

Figure 4 - Value index of importance of weeds in the high-tech system (six mechanisms of action) + manual weeding, with application of the herbicides glyphosate + phenoxaprop-p-ethyl + clethodim + diquat + metribuzin + chlorimuron-ethyl in soybean crops and glyphosate + atrazine + tembotrione in maize crops

The analysis of phytosociological parameters in the four harvests revealed that the difference in IVI between species over time indicates the selection of species more adapted to the soybean/maize second crop production system. The species *C. benghalensis* stood out the most in terms of DO and showed the greatest increase in IVI over the years, especially in management systems without the application of herbicides in the pre-emergence application of the soybean crop.

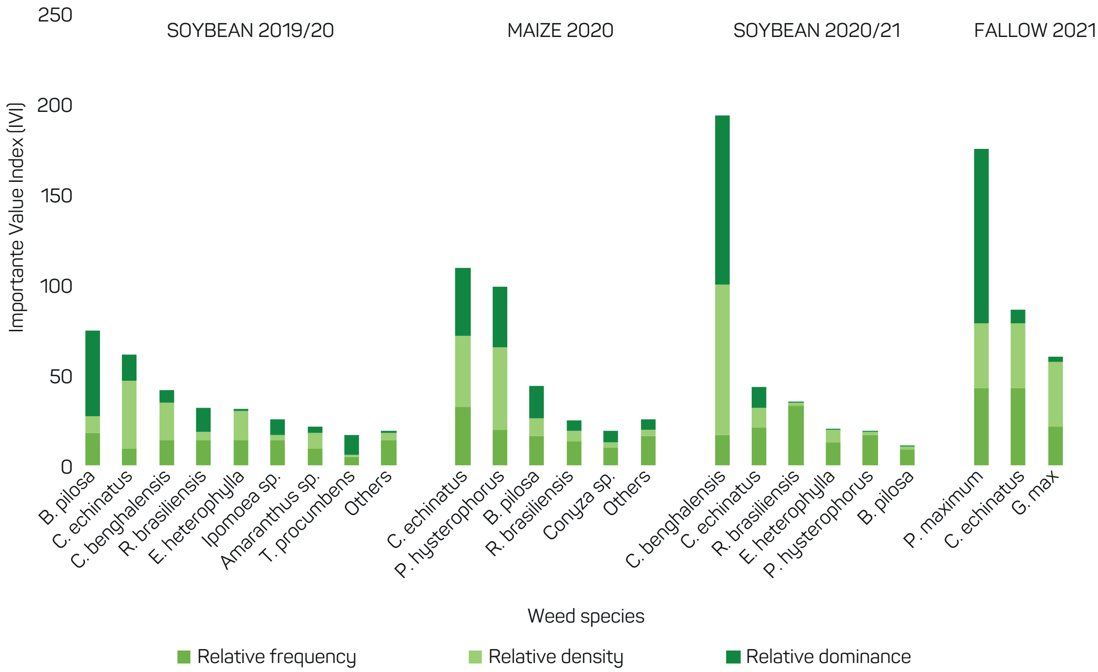


Figure 5 - Value index of importance of weeds in the system of medium technology (three mechanisms of action) + fallow in winter with application of glyphosate + 2,4-D + clethodim in soybean crops and glyphosate + 2,4-D in maize crops

For, a weed that is difficult to control due to a double mechanism of reproduction (seeds and rooting of nodes), herbicides applied in pre-emergence are important for the management of this species (Wilson, 1981). Still, when analyzing the phytosociological parameters, the increase of DOR may indicate the late control of this species and tolerance to glyphosate. The use of different mechanisms of action and the application of herbicides in the pre-emergence treatment of weeds is an important technique for management, as it reduces the seed bank of the species (Dias et al., 2013).

In a phytosociological survey carried out in production systems with maize in succession to soybean in the north of the state of Paraná, the species that presented the highest IVI was the *C. benghalensis* due to the good adaptation to the coexistence conditions provided by the maize crop (Pasqualetto et al., 2001).

In the soybean crop, within the low-tech system, an analysis of the phytosociological parameters from the 2019/20 and 2020/21 growing seasons in Sete Lagoas revealed a significant presence of volunteer maize with a high Importance Value Index (IVI). This was attributed to the exclusive use of glyphosate and the previous cultivation of Roundup Ready (RR®) maize, which is resistant to this herbicide. The broad-spectrum action of glyphosate, its low cost, and the absence of residual effects on the soil are factors that have driven the increased use of this herbicide and, consequently, glyphosate-resistant cultivars in Brazil (Silva et al., 2018). As a management alternative, the herbicide clethodim has been used for the effective control of volunteer maize due to its efficacy against this species (Braz et al., 2018).

The presence or absence of weed species when launching a sampling frame in an area is quantified by frequency (Marinho et al., 2017). When analyzing this parameter, it was noticed a lower frequency of weeds in the maize crop due to the period with higher water deficit, as described data.

In the last phytosociological survey (2020/2021), it was observe that chemical control reduced the incidence of weeds. In addition, the use of herbicides in the pre-emergence of weeds reduced the IVI for *C. benghalensis*, demonstrating efficiency in the control of this species.

To define the level of similarity between two or more communities, the SI was calculated and there was change between the management systems in the two soybean crops over time (Tables 6 and 7). When comparing the weed flora of the high-tech systems with and without hand weeding with low- and medium-tech systems, hand weeding increased the similarity of this system with low- and medium-tech systems. On the other hand, the high-tech system, when comparing with other systems, the similarity over time decreased.

From the dendrogram, the level of weed infestation on the low and medium technology systems were not similar to the high-tech systems, at the time of harvest of the 2020/2021 soybean crop (Figure 6).

Weed control with glyphosate without the use of complementary weed management practices has contributed significantly to the selection of tolerant weed species (Monquero et al., 2001). When this happens, the population dynamics of the main species present in the area undergoes changes that influence the management of these weeds. Linked to this, the system of cultivation in succession of soybean and maize second crop can also favor the selection of more adapted species. Therefore, establishing new strategies for chemical weed management is essential to increase the effectiveness of control.

Kriging is an interpolation technique that, through estimates of regionalized variables, uses parameters of semi-variograms and the values of samples made and georeferenced (Trangmar et al., 1985). When observing the spatial distribution of DB (Figure 7A) and DEN (Figure 7B) of *C. benghalensis* at the end of the experiment, in the low-tech system, the dominance rates for were higher (Figure 7A), indicating inefficient management of this species. For the density (Figure 7B) the total distribution in the area was higher, indicating a greater distribution of the species in the analyzed variable. However, in the mapping, despite the high variability in DEN, DB is concentrated in the system with the use of only two mechanisms of herbicide action, consequently increasing the importance of this species in this management system.

Weed species can be dispersed in total area or in windrows, due to aspects of weed biology and, for this, the mapping of their distributions in the field is performed (Shiratsuchi et al., 2003). The spatial distribution of *C. benghalensis* showed that the highest concentration of DB occurred in the low technology system (two mechanisms of action), indicating a high IVI for the species. This highlights the relevance of weed mapping and phytosociological surveys for the application of weed control methods.

The data of this study showed the difference in effectiveness in weed management and the importance of joining different mechanisms of action. However, it is expected that, over the years, to maintain the same control effectiveness, integrated weed management (IWM) using chemical weed control in association with other practices must be employed.

Table 6 - Phytosociological similarity index (SI) between the systems in the harvest of 2019/2020 soybean crop in the Cerrado in the central regions of the Minas Gerais state

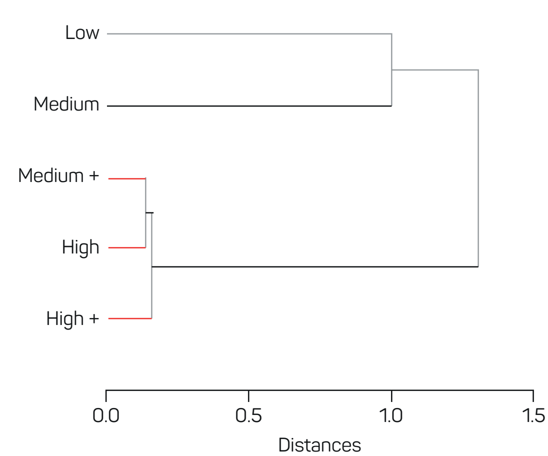
Similarity Index (%)					
System (technology level)	**Low**	**Medium**	**High**	**High+**	**Medium+**
Low	100,00	72,73	50,00	40,00	50,00
Medium		100,00	50,00	50,00	60,00
High			100,00	42,86	44,44
High+				100,00	55,55
Medium+					100,00

Low: two mechanisms of action; medium: four mechanisms of action; high: six mechanisms of action; high +: six mechanisms of action + mechanical control; Medium +: three mechanisms of action and fallow in winter

Table 7 - Phytosociological similarity index (SI) between systems in soybean harvest of 2020/2021 soybean crop in the Cerrado in the center regions of the Minas Gerais state.

Similarity Index(%)					
System (technology level)	**Low**	**Medium**	**High**	**High+**	**Medium+**
Low	100,00	74,07	40,00	60,87	40,00
Medium		100,00	31,58	63,63	44,44
High			100,00	40,00	33,33
High+				100,00	53,33
Medium+					100,00

Low: two mechanisms of action; medium: four mechanisms of action; high: six mechanisms of action; high +: six mechanisms of action + mechanical control; medium +: three mechanisms of action and fallow in winter



Low: two mechanisms of action; medium: four mechanisms of action; high: six mechanisms of action; high +: six mechanisms of action + mechanical control; medium +: three mechanisms of action and fallow in winter

Figure 6 - Similarity dendrogram constructed by the grouping method by the group average (UPGMA) of the level of weed infestation in the five systems at the end of the experiment, in the harvest of the 2020/2021 soybean in Sete Lagoas (R Development Core Team, 2020). Low = two mechanisms of action; medium = four mechanisms of action; high = six mechanisms of action; high + = six mechanisms of action + mechanical control; medium + = three mechanisms of action and fallow in winter.

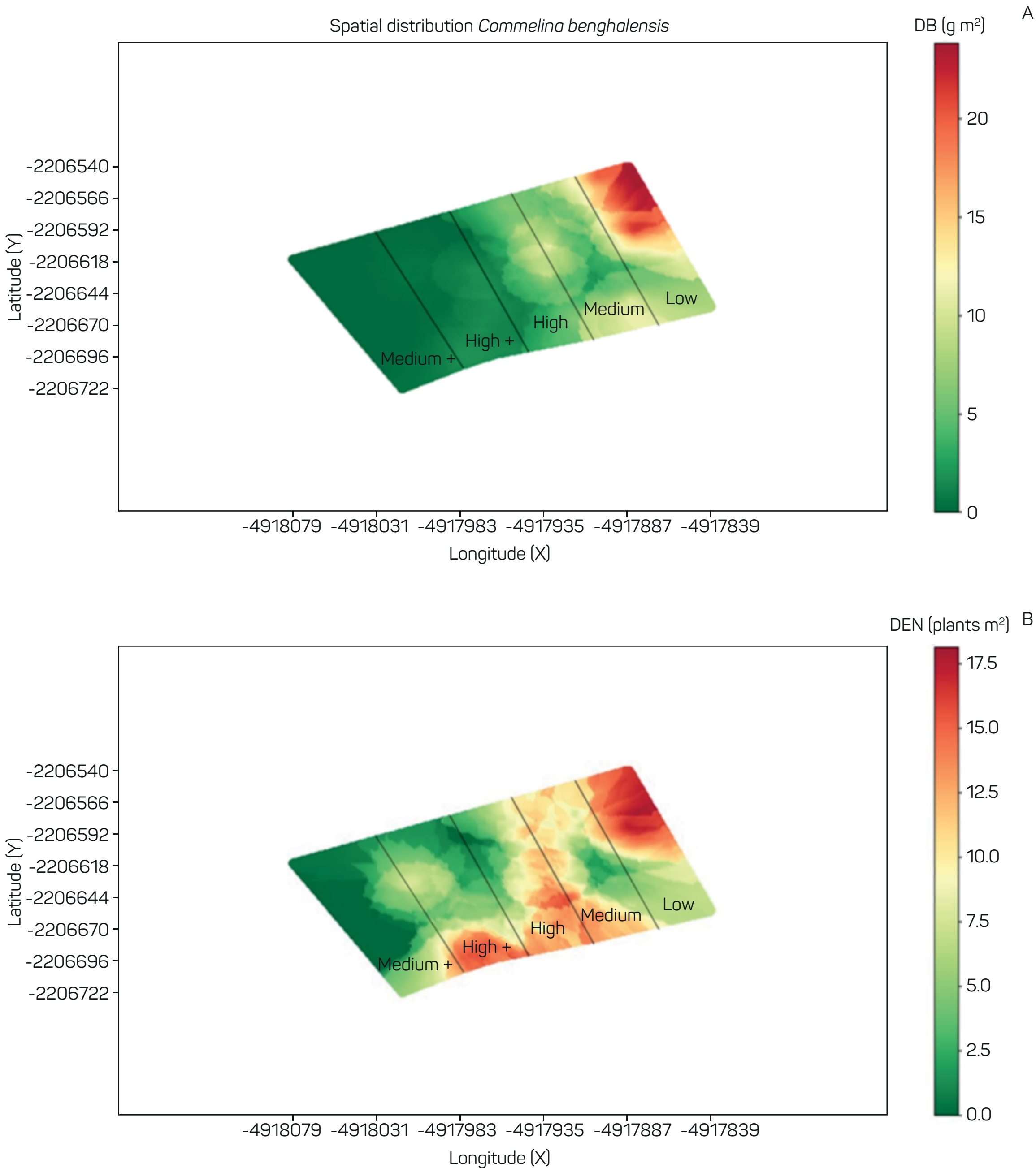


Figure 7 - Map of spatial distribution of biomass (DB - g m²) and total density (DEN - plants m²) of *Commelina* benghalensis L. in the 2020/21 soybean crop. The green color gradient indicates lower concentration of the variables studied and, when the red color approaches, the highest concentration of these variables is observed. Low = two mechanisms of action; medium = four mechanisms of action; high = six mechanisms of action; high + = six mechanisms of action + mechanical control; medium + = three mechanisms of action and fallow in winter.

4. Conclusions

The phytosociological survey obtained for the soybean/ maize second crop system indicates the predominance of the families Poaceae and Asteraceae.

The greater rotation of herbicides with different mechanisms of action results in species with l ower IVI's.

The highest concentration in the spatial distribution of the DB of *Commelina benghalensis* L. was in the low-tech system.

Author's contributions

All authors read and agreed to the published version of the manuscript. JROS, DK, and KFM: conceptualization of the manuscript and development of the methodology. JROS, DK, and KFM: data collection and curation. JROS, DK, and KFM: data analysis. JROS, DK, and KFM: data interpretation. DK: funding acquisition and resources. DK: project administration. KFM, and DK: supervision. JROS: writing the original draft of the manuscript. DK, and KFM: writing, review and editing.

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