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Residual herbicides applied to common bean cultivars on maize yield in succession

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Abstract

Crop rotation is one of the key strategies for sustainable production, as it helps to reduce the need for pesticides by minimizing problems with pests, diseases, and weeds. However, in Brazil, crop succession remains predominant, particularly with maize being grown following soybean or common bean. Given the introduction of increasingly productive and early maturing maize cultivars over the past decade, coupled with the restricted availability of herbicides for controlling eudicots weeds in common bean crops, leading producers have resorted to using mixtures of active ingredients. Consequently, there arises a necessity for studies to assess the carryover effects of these mixtures in succession crops. This work was developed with the objective of evaluating the residual effect of herbicides applied in common bean cultivars on maize, during two cultivation periods. The split-plot statistical design with four replications was adopted. In the main plots, the common bean cultivars BRS Pérola, IPR Tuiuiú, and BRSMG Marte were planted in the summer season of 2016/2017 and in the winter season of 2017. In the subplots, post-emergence herbicides were applied, isolated or mixed, at the following rates [g a.i. ha^{-1}]: fomesafen [250]; fomesafen [375]; bentazon + imazamox [600+28]; bentazon + imazamox + fomesafen [(600+28)+125]; bentazon + imazamox + fomesafen [(600+28)+87.5]; and hand weeded plots without herbicide. DKB 390PRO maize was planted in the winter season and summer season, after the common bean harvest. The herbicides did not cause negative effects on maize yield, regardless of the sowing period and common bean cultivar.

Key words: *Zea mays* L. Carryover. Sowing period

Introduction

Crop rotation is the practice of growing a sequence of plant species on the same land and has been used for thousands of years (BULLOCK, 1992). Crop rotation plans involve land-use decisions and encompass, at the very least, selecting crops to be grown, determining their acreage and allocation within a particular farmland (DURY et al., 2012). The adoption of crop rotation has primarily been driven by the increase in crop yields attributed to improved agroecosystem function, such as enhanced soil fertility (especially when leguminous plants are included in rotation) (BOWLES et al., 2022), preservation of soil structure (McDANIEL; GRANDY, 2016; TIEMANN et al., 2015) and disruption of pest cycles and weed suppression (DOMINSCHEK et al., 2021; RUSCH et al., 2013). Thus, the adoption of this cropping system, along with other management practices such as the use of technologies, improved cultivars, and irrigation, has contributed to increase the productivity of the agricultural systems.

Several crops may be incorporated into this crop rotation system, including soybean, maize, sorghum, oat, wheat, and common bean, among others. Crop diversification in the rotation system has yielded numerous benefits (BOWLES et al., 2020). For instance, maize yields have shown significant improvements when grow in rotation with other crops compared to monoculture (BOWLES et al., 2020). However, in a cropping system that involves multiple crops within a year, careful attention must be paid to herbicide management and usage, as well as its effects on succession crops, due to the potential residues of these products lingering in the soil (VAN ACKER, 2005; LORENZON et al., 2016; PALHANO et al., 2018). Example this, Cornelius and Bradley (2017) reported findings from experiments suggesting that several commonly used herbicides in maize and soybean cultivation have the potential to impede cover crop establishment. However, the severity of such damage is contingent upon factors such weather conditions, cover crop species, and the specific combination of herbicides.

In Brazil, common bean has been extensively utilized in rotation and succession systems with other crops. However, there is a scarcity of specific herbicide molecules for controlling broadleaf weeds (eudicots) in common bean crops (MAPA, 2023). Consequently, due to the limited control efficacy of certain isolated molecules (SILVA et al., 2013a), many farmers have turned to herbicide mixtures for broadleaf weed control in common bean, particularly with active ingredients such as fomesafen, imazamox and bentazon. Nonetheless, there remains a crucial need for investigating the dynamics of these mixtures in the environment and their residual effects on crops in succession.

Although studies were performed in the 1990s to assess the residual effects of herbicides used in bean crops on maize, it's important to note both bean and maize cultivars have evolved since then. They are now earlier maturing and more productive genetic materials. Additionally, when summer crops follow winter crops in succession, there is a possibility of increased exposure to herbicide residues in the soil. Considering the above, this research was developed with objective of evaluating the residual effects of herbicides applied to common bean cultivars in maize crops in succession.

Material and methods

The experiment was carried out at the Muquém Farm of the Federal University of Lavras (UFLA), in the State of Minas Gerais, Brazil (21°14'S 45°00'W, 918 m latitude), from 2016 to 2018. The region falls under Cwa climate type, as per the Köeppen climatic classification system, with dry climate from April to September and a rainy season from October to March. The average annual temperature hovers around 20.4 °C, with an annual rainfall of 1460 mm. Total evaporation amounts to 1034.3 mm, and the average relative humidity stands at 76 %. The maximum and minimum temperatures observed during the experiment are presented in Figure 1, along with the average monthly rainfall.

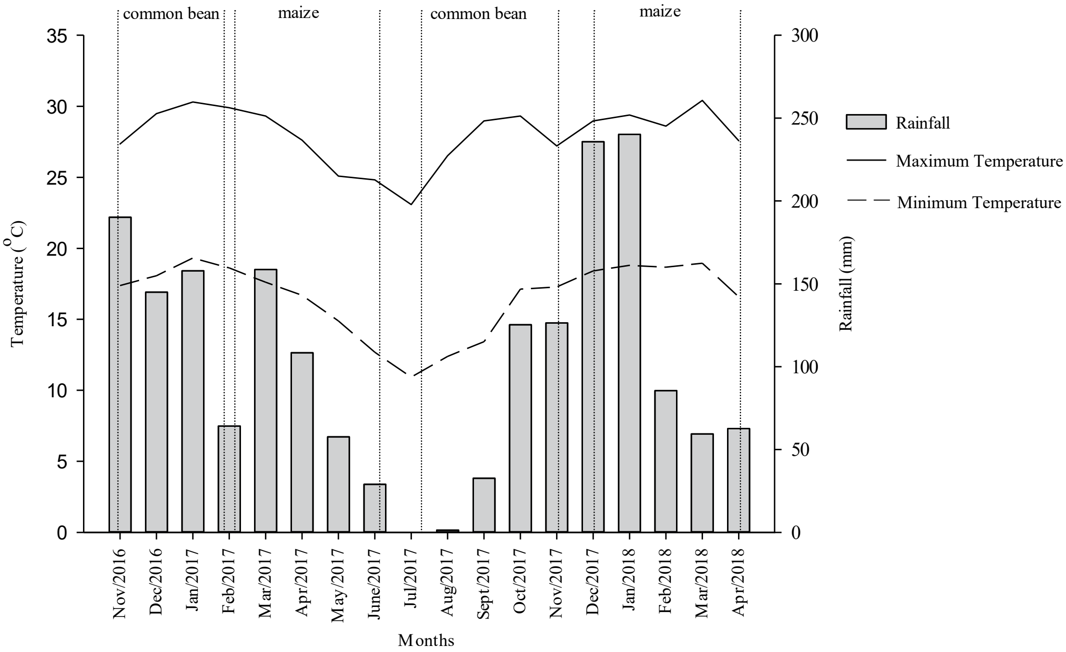
The experiment involved three common bean cultivars followed by maize crop. The sequence was as following: crop 1 - common bean (November 2016 to February 2017); crop 2 – maize (February to June 2017), referred to as the winter season; crop 3 - common bean (July to November 2017); and crop 4 - maize (December 2017 to April 2018), referred summer season.

The experimental areas feature a typical Dystrophic Red Latosol, with 53 % clay, 26 % sand and 21 % silt. Chemical characterization of the 0-0.20 m deep layer was conducted prior to the maize crops and is detailed in Table 1.

Split-plot statistical design with was adopted four replications. The main plots consisted of a common bean cultivar, being three in the total (BRS Pérola, IPR Tuiuiú and BRSMG Marte), planted at a density of 220,000 plants per hectare. The subplots consisted of five herbicides (applied either in isolation or as mixed), which were used at different rates, including checkplots without herbicide (Table 2).

The herbicides were applied at 26 and 25 days after common bean crop emergence in each season, respectively. At that time, cultivar Pérola and IPR Tuiuiu plants were in stage V4.4 (fourth trifoliate leaf) and cultivar BRSMG Marte in V4.3 (three trifoliate leaves). For the application of the treatments, a CO_2 pressurized backpack sprayer with a syrup volume of 200 L ha^{-1} as equipped

Figure 1. Average rainfall, maximum, and minimum monthly temperatures recorded during the years 2016 and 2018



Source: Lavras' Main Climatologic Station, situated at the State UFLA campus in the State of Minas Gerais, in accordance with the National Institute of Meteorology (INMET)

Table 1. Chemical characterization of soil samples from the experiment areas at a depth of 0-0.20 m Federal University of Lavras (UFLA), State of Minas Gerais, Brazil

Attributes	pH	OM	P	K	Ca	Mg	Al	H+Al	BS	t	T	V	m
	H_2O	dag kg^{-1}	---- mg dm^{-3} --		------------------- cmol$_c$ dm^{-3} ------------------							------ % ----	
Sample 1 – Feb. 2017	5.6	2.3	3.7*	61.4	1.0	0.3	0.3	3.6	1.5	1.8	5.1	29.4	16.7
Sample 2 – Nov. 2017	5.9	2.0	22.8**	141.8	3.8	0.8	0.1	3.4	5.0	5.1	8.5	59.5	2.0

pH - pH in water (1:2.5 soil/solution); OM: soil organic matter ($Na_2Cr_2O_7$ 4 mol L^{-1} + H_2SO_4 5 mol L^{-1}); P (Mehlich-1* and resin** extraction); K (Mehlich-1), Ca, Mg e Al (KCl 1 mol L^{-1}); H + Al: potential acidity (SMP); BS: sum of basis (Ca+Mg+K); T: cation exchange capacity (CEC) at pH 7.0 (BS+(H+Al)); t: effective CEC (SB+Al); V: base saturation ((BS/T)x100); m: aluminum saturation ((Al/t)x100).

Source: Elaborated by the authors (2018)

Table 2. Herbicides applied to common bean cultivars during both seasons

Comercial product (c.p.)	Active Ingredient (a.i.)	Rates	
		c.p. (L ha^{-1})	(g a.i ha^{-1})
Flex®	fomesafen	1.0	250
Flex®	fomesafen	1.5	375
Amplo®	bentazon + imazamox	1.0	600 + 28
Amplo® + Flex®	(bentazon + imazamox) + fomesafen	1.0 + 0.5	(600 + 28) + 125
Amplo® + Flex®	(bentazon + imazamox) + fomesafen	1.0 + 0.35	(600 + 28) + 87.5
Manual weeding	-	-	-

Source: Elaborated by the authors (2018)

with a bar with four spray nozzles type DG 110 02 that produced medium droplets at an average pressure of 200 kpa.

Each experimental plot was composed of six rows, each measuring ten metres in length, with a spacing of 0.6 m between rows. This arrangement resulted in a total experimental area of 36 m^2, with a usable area of 12 m^2 (corresponding to the two central rows), as described in Costa et al. (2020).

For both the winter season and summer season, the maize cultivar DKB 390PRO was evaluated as a succession crop. For the maize crop, sowing was performed using a no-tillage system, with 4.6 seeds per linear meter and a spacing of 0.6 m between rows.

The recommended fertilization for the maize crop followed the guidelines proposed by Souza e Lobato (2004). The fertilization in the sowing furrow was composed by 29.5, 98.4 and 54.7 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Nitrogen cover fertilizer composed by 200 kg ha^{-1} of urea (90 kg of N) was applied by throwing in stage V4 (four developed leaves). For weed management in both maize crops, a mixture of tembotrione (84 g a.i. ha^{-1}) and atrazine (1500 g a.i. ha^{-1}) was applied, along with an agricultural adjuvant. This application occurred during stage V3. As part of phytosanitary management, monitoring and necessary applications were carried out.

On the seventh and fourteenth day after sowing, phytotoxic symptoms were evaluated, following the grading scale proposed by European Weed Research Council (1964). During stage R1, which marks the completion of vertical development in the maize crop, two parameters were evaluated: ear insertion height (IE) and plant height (AP). IE and AP evaluations measured the average distance between the ground, the insertion of the first productive ear and the insertion of the sheath of the last leaf from 10 competitive plants, respectively. After harvest and threshing, the weight of 100 grains (P100G) and grain yield (PG) were assessed by weighing the grains, and these values were corrected to 13 %.

Data obtained were submitted to analysis of variance using the F test, and the Scott-Knott test at 5 % probability level was employed to group the means. This analysis was facilitated using SISVAR software (FERREIRA, 2011). The evaluation of yield, plant height, ear insertion height, and weight of 100 grains data was conducted for both the winter and summer seasons. These assessments were performed individually and jointly to compare the effects of herbicide treatments applied to common bean cultivars on the maize crop.

Results and discussion

None of the herbicide treatments applied to the common bean cultivars resulted in phytotoxicity symptoms in the maize crop during both seasons. In other study fomesafen + bentazon + imazamox mixture applied on common bean did not cause intoxication on maize cultivated in succession and only the fomesafen herbicide residue caused very mild symptoms in the plants (SILVA et al., 2013a). Due to the reduced effectiveness of isolated herbicide molecules in weed control, producers tend to increase the recommended dosage specified on the product label. In order to illustrate what we have observed in the field, this study utilized a dose of fomesafen above the recommended level (375 g a.i. ha^{-1}) in common bean cultivation, which also did not cause any injury to the maize crop.

Based on the analysis of variance, significant differences were observed only between the two seasons ($p < 0.05$) for plant height, ear insertion height and weight of 100 grains (Table 3).

Contrary to expectations, higher plant height and ear insertion height were observed in maize grown during the winter season rather than the summer season (Table 4). This unexpected outcome can be attributed to environmental conditions (Figure 1). During the summer season, elevated day, and night temperatures, associated with the occurrence of more cloudy days, can potentially compromise photosynthesis rates, and increase respiration. As consequence, there is greater energy expenditure by the plant, and reduced accumulation of photoassimilates (HATFIELD; PRUEGER, 2015; ADHIKARI; BARAL; SHRESTHA, 2016) which may have compromised the plant's height growth. Conversely, during the winter season, the milder temperatures may have favoured the vegetative growth of maize.

To achieve maximum maize yields, water supply of 500 to 800 mm is necessary throughout the growth cycle (SANS; SANTANA, 2002). Maize's water demand can be influenced by hybrid characteristics, sowing season, crop development stage, and overall climate conditions (ALBUQUERQUE, 2010).

Table 3. Survey on the analysis of variance for the set of characteristics relative to plant height, ear insertion, weight of 100 grains and yield in both winter and summer season maize

Variance factor	G.L.	Plant height	Ear insertion height	Weight of 100 grains	Yield
		Value-p			
Season (S)	1	0.0000*	0.0000*	0.0000*	0.0000*
Block (season)	6	0.8516ns	0.3076ns	0.6620ns	0.0066*
Cultivar (C)	2	0.1959ns	0.1774ns	0.1336ns	0.0055*
S x C	2	0.5195ns	0.8785ns	0.2214ns	0.0059*
Error1	12				
Herbicide (H)	5	0.4535ns	0.2330ns	0.9254ns	0.0625ns
H x S	5	0.4516ns	0.7080ns	0.1222ns	0.1728ns
Error 2	30				
H x C	10	0.5042ns	0.0665ns	0.1330ns	0.0770ns
H x C x S	10	0.5568ns	0.0914ns	0.0970ns	0.0124*
Error 3	60				
Total	143				
C.V. 1 (%)		7.6	7.6	5.8	12.1
C.V. 2 (%)		6.4	7.1	5.2	12.1
C.V. 3 (%)		6.4	6.4	4.7	13.9

C.V.: Coefficient of variance; G.L.: Degree of freedom; QM.: Average condition, nsnot significant; *significant at 5 % probability.

Source: Elaborated by the authors (2018)

Table 4. Average values of plant height, ear insertion, weight of 100 grains and maize yield in the two seasons

Season	Plant height (m)	Ear insertion height (m)	Weight of 100 grains (gram)	Yield (kg ha^{-1})
Summer	2.04 B	1.23 B	29.49 A	7554 A
Winter	2.45 A	1.36 A	22.04 B	4653 B
C.V. (%)	7.6	7.6	5.8	12.1

Averages followed by the same uppercase letter within the column are same according to the F Test.

Source: Elaborated by the authors (2018)

For the summer season, the entire growth cycle of the experiment had 624.1 mm of available water for the maize crop, whereas during the winter season, the water availability was 417.6 mm (Figure 1). Additionally, a dry spell occurred during the grain-filling stage of the winter season cultivation. As a result, maize grown in the summer season had higher weight of 100 grains and yield compared to the winter season maize (Table 4).

The critical stages for water demand in maize typically occur approximately 15 days before and 15 days after flowering (R1). This explains the lower yields obtained from maize grown during the winter season because the water deficit began during stage R1 (FANCELLI; DOURADO NETO, 2007).

The interaction among seasons, herbicides, and common bean cultivars was found to be significant ($p < 0.05$) (Table 3). However, due to the practical difficulty associated with analysing and interpreting triple interactions, separate analysis of variance was performed for each season. Consequently, significant differences were observed only during winter season (Table 5), primarily influenced by the interaction between herbicides and common bean cultivars.

With the unfolding of the dual interaction, it was possible to study the effect of herbicides on each common bean cultivar and verify the impact of the common bean cultivar within each herbicide treatment. The maize yield was not reduced due to the treatments (Table 6). Except for maize crop in succession to the cultivar BRSMG Marte, maize yield was not affected by the herbicides in other common bean cultivars.

For the study of the effect of common bean cultivars in each herbicide treatment, the maize cultivated in plots where the herbicide bentazon + imazamox + fomesafen ((600+28)+125 g a.i. ha^{-1}) was applied on the BRSMG Marte exhibited the highest yield compared to the maize cultivated after the other common bean cultivars (BRS Pérola and IPR Tuiuiú) (Table 6).

The presence of plant residues from the previous crop may influence the residual effects of herbicides. Fontes et al. (2002) reported that these residues have a significant herbicide sorption capacity. In the current study, BRS

Table 5. Summary of the analysis of variance for maize yield for each season.

Variance factor	G.L.	Summer season	Winter season
		---------------- **Value-p**	----------------
Block (season)	3	0.0239*	0.6606^{ns}
Cultivar (C)	2	0.0112*	0.6609^{ns}
Error1	6		
Herbicide (H)	5	0.0820^{ns}	0.6336^{ns}
Error 2	15		
H x C	10	0.0674^{ns}	0.0157*
Error 3	30		
Total	71		
C.V. 1 (%)		12.2	10.5
C.V. 2 (%)		12.0	11.0
C.V. 3 (%)		14.0	12.3

C.V.: Coefficient of variance; G.L.: Degree of freedom; QM.: Average condition, ^{ns}not significant; *significant at 5 % probability.

Source: Elaborated by the authors (2018)

Table 6. Average yield of maize (kg ha^{-1}) in the winter season, in succession to bean cultivars

Treatments	Rate (g a.i. ha^{-1})	BRS Pérola	IPR Tuiuiú	BRSMG Marte
manual weeding	-	4959 aA	4763 aA	4304 aB
fomesafen	250	4722 aA	5226 aA	4325 aB
fomesafen	375	4072 aA	4388 aA	4921 aA
bentazon + imazamox	600 + 28	5146 aA	4386 aA	4403 aB
(bentazon + imazamox) + fomesafen	(600 + 28) + 125	4718 bA	4177 bA	5513 aA
(bentazon + imazamox) + fomesafen	(600 + 28) + 87.5	4692 aA	4570 aA	4474 aB

Averages followed by the same lowercase letter within a line and an uppercase letter within the column do not statistically differ at a 5 % probability in the Scott-Knott test.

Source: Elaborated by the authors (2018)

Pérola, IPR Tuiuiú, and BRSMG Marte bean cultivars reached high yield (COSTA et al., 2020). This yield suggests substantial dry matter production by the plants, considering a harvest index of 50 % (MOREIRA et al., 2023); consequently, a considerable amount of plant residues remained in the soil after harvest. This residue presence likely contributed to herbicide sorption, which could explain why maize grown after these bean cultivars remained unaffected by the herbicides.

The dynamics of herbicides in the soil are directly influenced by cropping systems, rate, mixtures, climatic conditions, as well as soil attributes and physicochemical properties of the molecules (SILVA et al., 2013a; 2013b; SILVA et al, 2014a; 2014b). When herbicides enter the in contact with soil, they are subject to retention, transformation, and transport processes, which can interfere with their persistence in the soil and their residual activity for the next harvest.

The molecules imazamox and bentazon are considered non-persistent, while fomesafen is classified as moderately persistent in soil (PPDB, 2024). Consequently, fomesafen is more likely to cause carryover problems in succession crops. Additionally, all three molecules exhibit mobility in the soil and can be leached (PPDB, 2024).

The application of fomesafen at rates of 250 g ha^{-1} in bean and soybean cultivation did not affect maize yield after 65 and 60 days of application, respectively (COBUCCI; SILVA; PRATES, 1997; ARTUZI; CONTIERO, 2006). Fomesafen is known to persist in the Brazilian soils with a half-life ranging from 60 to 114 days (COSTA et al., 2015). Thus, it is advisable to allow a minimum interval of 150 days for the cultivation of maize after fomesafen application (COBUCCI; SILVA; PRATES, 1997; MAPA, 2023)

Based on the results obtained in this work, it can be considered that the environmental conditions influenced the persistence the herbicides in the soil, since the application of all herbicides did not cause phytotoxicity to the maize crop and did not reduced the maize yield. In addition, there was no effect of the herbicides applied to the common bean crop on the maize crop when maize was grown during the summer. It is possible that the higher rainfall during the summer (Figure 1), compared to other seasons, may have reduced herbicide residue in the soil, even before the deepening of the root system. Cornelius e Bradley (2017) also verified a reduction in the carryover effects of maize and soybean residual herbicides on the establishment of autumn cover crops in the years of higher rainfall.

Similar results of low residual activity of the herbicides bentazon + imazamox and fomesafen, isolated or mixed, and absence of carryover on maize cultivated in succession to common bean were obtained by Silva et al. (2013a). The herbicide mixture broadens the weed control spectrum, enabling a reduction in the application rate of the active ingredient. In our current study, the mixture of bentazon + imazamox + fomesafen allowed for a 50 to 75 % reduction in the fomesafen rate without causing injuries or negatively impacting maize yield during succession.

Conclusion

Fomesafen and bentazon + imazamox herbicides, both in isolated and mixed applications, did not caused carryover effect on maize in succession to common bean cultivars during the summer and winter seasons.

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