Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Pre and post-emergency management of the dicamba herbicide in *Xtend* soybeans and its reflexes on morphological aspects and productivity components

Manejo em pré e pós emergência do herbicida dicamba na soja xtend e seus reflexos nos aspectos morfológicos e componentes da produtividade

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Submission: March 05th, 2025 | Acceptance: April 24th, 2025

ABSTRACT

The increasing use of soybean cultivars (*Glycine max*) with *Xtend*® technology facilitates the management of weeds that are resistant to some herbicides, through the use of auxin-mimicking herbicides in post-emergence soybean. However, the use of these herbicides on the crop is still uncertain for farmers due to the consequences on the plants. The objective of the study was to evaluate the effects of the Dicamba molecule on the morphological and productive characteristics of *Xtend*® soybean. The experiment was carried out in Augusto Pestana - RS, in the 2022/2023 harvest. Eight treatments were carried out, including pre- and post-emergence Dicamba application times for soybean cultivars with *Xtend*® technology. After each treatment, evaluations of the herbicide's phytotoxicity symptoms and plant development were carried out on days 0, 3, 5, 7, and 15 after application. At harvest, all soybean productivity components of each plot were evaluated. Dicamba applications in the vegetative stage of soybean reduced the leaf area of the plants, but with immediate recovery. Applications of the herbicide in the reproductive stages of soybean compromised the number of viable flowers in the plants, being an irreversible damage.

KEYWORDS: Weeds. Resistance. Phytotoxicity. Vegetative. Reproductive.

RESUMO

O crescente uso de cultivares da soja (*Glycine max*) com a tecnologia *Xtend*® facilita o manejo de plantas daninhas que apresentam resistência a alguns herbicidas, através da utilização de herbicidas mimetizadores de auxinas em pós emergência da soja. Porém o emprego destes herbicidas sobre a cultura ainda é uma incerteza por parte dos agricultores perante as consequências nas plantas. O objetivo do estudo foi avaliar os efeitos da molécula Dicamba sobre os caracteres morfológicos e produtivos da soja *Xtend*®. O experimento foi realizado em Augusto Pestana – RS, na safra 2022/2023. Foram realizados oito tratamentos, sendo eles momentos de aplicação do Dicamba em pré e pós emergência da soja de cultivares com a tecnologia *Xtend*®. Posteriormente a cada tratamento, foram realizadas avaliações dos sintomas de fitotoxicidade do herbicida e o desenvolvimento das plantas nos dias 0, 3, 5, 7 e 15 após a aplicação. Na colheita, avaliou-se todos os componentes de produtividade da soja de cada parcela. As aplicações de dicamba no estádio vegetativo da soja reduziram a área foliar das plantas, porém com imediata recuperação. Aplicações do herbicida nos estádios reprodutivos da soja comprometeram o número de flores viáveis nas plantas, sendo um dando irreversível.

PALAVRAS-CHAVE: Plantas daninhas. Resistência. Fitotoxicidade. Vegetativo. Reprodutivo.

INTRODUCTION

Soybean (*Glycine max* L.), is considered the main agricultural commodity in Brazil, it is characterized by being a versatile crop, due to its wide purposes such as the production of oils, bran, biodiesel, chemical industry for making paints, varnishes, in addition to of its consumption in grains for human or animal consumption. Although Brazil is the world's largest soybean producer, crop productivity is interrelated to several biotic and abiotic factors, such as climatic conditions, soil and fertilization management, and other phytosanitary management (SCARTON et al. 2023).

Brazil had an average productivity of 3201 kg ha^{-1} of soybeans in the 2023/2024 harvest, and for the 2024/2025 harvest an increase of 9.6% in the productivity of this oilseed grain is predicted (CONAB 2025). However, this productivity is limited, according to SILVA et al. (2024) soybeans have a productivity potential of 5854 kg ha^{-1} of grains, where approximately 42% of the productivity potential is lost due to management failures. Among these limiting factors, we can mention the occurrence of weeds, according to ALBRECHT et al. (2018), in an experiment carried out in the field in two consecutive harvests, soybean productivity was reduced by 14%, around 560 kg ha^{-1} of grains, with the presence of only one *Conyza bonariensis* plant per square meter.

Given this scenario, new technologies have been developed over the years, aiming to minimize losses caused by weeds. The *Xtend*® technology was recently approved in Brazil, through the insertion of the *ODM* gene, DI-6 strain of *Stenotrophomonas maltophilia*, in addition to the *cp4 epsps* gene (aroA:CP4), conferring tolerance to the herbicides dicamba and glyphosate (DUMITRU et al. 2009, ISAAA 2025).

The herbicide dicamba (3,6-dichloro-2-moxybenzoic acid) belongs to the class of auxin-mimicking herbicides, belonging to the chemical group of benzoic acids. Dicamba, widely used in corn, wheat and pasture cultivation, is active on a range of dicotyledonous weed species. It is also recommended for use in pre-sowing soybean and cotton crops. According to UNDERWOOD et al. (2017), in plant cells, the Dicamba molecule binds to the auxin receptor and deregulates several important physiological processes in plants, through deformations of veins, abnormal growth and paralysis, with subsequent death of the plant.

The symptoms of auxin herbicides in soybeans can present themselves in different ways, such as chlorosis of terminal meristems, wrinkling of canopy leaves and epinasty of leaves or stems, the latter being the most immediate symptom of the phytotoxicity of hormonal herbicides. In high concentrations of Dicamba, for example, it can cause thickening and cracking of the stem, terminal death and even death of the plant (FOSTER MR & GRIFFIN JL. 2019). According to NARDINO et al. (2015), Dicamba and 2,4-D caused injury symptoms such as leaf drop and stem twisting, also known as epinasty. These symptoms develop quickly after exposure to 2,4-D (between 60 to 120 minutes); however, it may take several hours for these symptoms to develop

DOI: 10.5965/223811712422025298

after exposure to Dicamba. Given the increasing use of technology in soybean cultivation in Brazil and the lack of knowledge of the possible consequences of using this herbicide on the crop with tolerance, we sought to evaluate the effects of the Dicamba molecule on the morphological characters of soybeans *Xtend*®.

MATERIALS AND METHODS

The experiment was carried out in the experimental area of the Escola Fazenda of the Universidade Regional do Noroeste do Estado do Rio Grande do Sul – UNIJUÍ, in the municipality of Augusto Pestana- RS (28º 00'14" S, 52º 0' 22" W, 328m). The soil in the experimental area is classified as a Typical Dystroferic Red Oxisol and the climate is characterized by Köppen as *Cfa* (humid subtropical).

The experimental design was randomized blocks, in a factorial scheme, with eight treatments (times of application) on five soybean cultivars with *Xtend*® technology (BMX Torque (57IX60 I2X), M5710 I2X, FT 4426 I2X, BMX Nexus (64IX66 I2X), FT 4664 I2X), arranged in three replications, totaling 120 experimental units. Soybean sowing was carried out on December 21, 2023, with a sowing density of 16 seeds m^{-1} and fertilization of 250 kg ha^{-1} of formula 05-35-12 (NPK). The experimental units were composed of 14 sowing rows, spaced 0.45 m apart. The treatments (table 1) were always carried out under favorable conditions with relative air humidity above 60%, air temperature below 30 °C and wind speed below 10 km h^{-1}, with equipment adjusted for a spray volume of 150 L ha^{-1}.

Table 1. Moments of application of each treatment during the soybean cycle.

Treatment	Time of application	Number of applications	Dose of Xtendicam + Xtend Protect
AB	No application of the molecule	0	0
PS	Pre-Seeding	1	1 L ha^{-1} + 1 L ha^{-1}
PS+V4	Pre-Seeding + V4 stage	2	1 L ha^{-1} + 1 L ha^{-1}
PS+R2	Pre-Seeding + R2 stage	2	1 L ha^{-1} + 1 L ha^{-1}
PS+R3	Pre-Seeding + R3 stage	2	1 L ha^{-1} + 1 L ha^{-1}
V4	Stage V4	1	1 L ha^{-1} + 1 L ha^{-1}
R2	Stage R2	1	1 L ha^{-1} + 1 L ha^{-1}
R3	Stage R3	1	1 L ha^{-1} + 1 L ha^{-1}

In each experimental unit, three plants were selected at random, on which evaluations were carried out throughout the experiment. For all moments of post-emergence application of the culture, evaluations were carried out at 0, 3, 5, 7 and 15 days after application (DAA). The variables measured were:

Plant height (PH, cm), considered the distance from the soil surface to the end of the terminal meristem; number of nodes (NN, units); number of leaflets (NLEA, units); number of flowers (NFLO, units), number of developing pods (NDP, units); number of pods on the plant (NPP, units); total chlorophyll index (CHL, %); symptoms of herbicide phytotoxicity (based on chlorosis, necrosis, epinasty, leaf wrinkling, leaf curling, leaf narrowing and death of the apical meristem), with identification of presence or absence.

In the evaluations of 0, 7 and 15 DAP, a representative leaf was collected from three random plants from each experimental unit, measuring the percentage of healthy and symptomatic leaf area (%) and the leaf area (cm²), using phenomic techniques through of the RStudio software, using the data analysis packages *AgroR* (SHIMIZU et al. 2024) and *Metan* (OLIVOTO & LÚCIO 2020).

At the time of harvest, eight plants were selected in each experimental unit, where the following were evaluated: insertion height of the first pods (IHFP, cm); number of pods on the main stem (NPMS, units); number of pods on branches (NPB, units); number of pods with one grain (NP1G, units); number of pods with two grains (NP2G, units); number of pods with three grains (NP3G, units); number of pods with four grains (NP4G, units); number of grains per plant (NGP, units); grain weight per plant (GWP, grams) and grain yield (GY, ton ha^{-1}) adjusted for grain moisture at 13%.

Data relating to meteorological variables, maximum air temperature (T max., ºC), mean air temperature (T mean, ºC), minimum air temperature (T min, ºC) and precipitation (Prec., mm), later descriptive analysis of the data was used to understand the distribution and trend of the data.

The data were subjected to the assumptions of normality of errors using the Shapiro Wilk test and homogeneity of residual variances using Bartlett, then analysis of variance at 5% probability was used using the F test, where the interaction of cultivars x treatments was tested. The variables that showed a significant interaction were decomposed into simple effects at 5% probability using the Tukey and Dunnett matrix. The Dunnett test compared all assessments of 3, 5, 7 and 15 DAA with the assessment of 0 DAA, which was performed on the same day of each application. The estimated value, when positive for the variables plant height (cm), number of nodes (unit), number of leaflets (unit), number of flowers (unit), number of developing pods (unit), number of pods on the plant (unit), leaf area (cm²), percentage of total plant chlorophyll (%) and healthy leaf area (%), the normal development of the plant was considered in each DAA.

Subsequently, the Pearson's linear correlation was used in order to understand the association between variables with significance based on the t test at 5% probability, stratified by treatments.

DOI: 10.5965/223811712422025298

RESULTS AND DISCUSSION

According to the average variations in air temperature throughout the experiment (Figure 1a), it was noticed that the mean was 28 ºC. The maximum air temperature averaged 32 ºC, and maximum temperatures were observed in the month of February, with maximum temperatures above 35 ºC (Figure 1b). Therefore, it can be inferred that temperatures were not a limiting factor for the development of the culture, according to ZANON et al. (2018), the optimal air temperature for soybean cultivation throughout the vegetative and reproductive period is 25 to 31 ºC, an air temperature range that can be observed throughout the crop cycle.

During the entire crop cycle in the experiment, the accumulated precipitation was only 274 mm (Figure 1d). The highest accumulations were observed between February and April, with a volume of 180 mm, a period that was from stage R1 (flowering), to R5 (grain filling), an average of 3 mm day^{-1}, that is, lower than water demand required in these stages, which, under normal environmental conditions, range from 7 mm to 9 mm per day (TAGLIAPIETRA et al. 2022).

The analysis of variance (Table 2), at 5% probability of error using the F test, revealed significant effects for all measured variables. For the cultivar x treatments interaction, significance was observed for the variables plant height, number of pods with three grains and grain yield, indicating a possible difference in plant behavior and grain yield of some cultivars under the applied treatments. The coefficients of variation presented values between 6.58 and 36.71, demonstrating the reliability of the data. According to CARVALHO et al. (2003), the classification of coefficients of variation in experiments with soybean depends on the character evaluated. In this same study, the authors classified that CVs of up to 16% for grain productivity and 12% for soybean height are acceptable, values close to those inferred in the present study.

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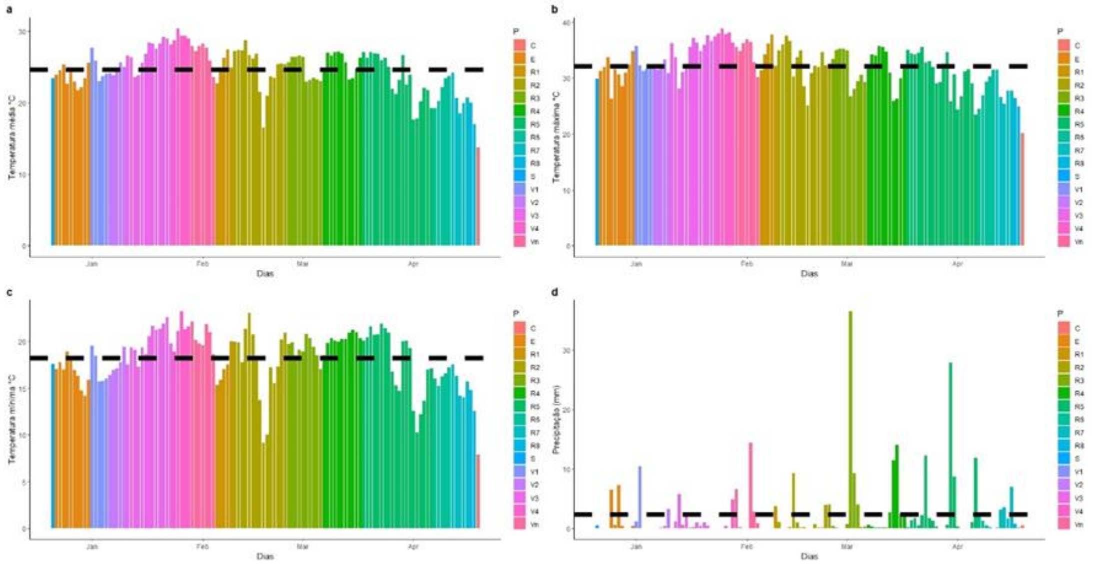

Figure 1. Mean air temperature (a, ºC), minimum air temperature (b, ºC) and maximum air temperature (c, Cº) and precipitation (d, mm) during the phenological stages of soybean at the Escola Fazenda of the Universidade Regional do Northwest of the State of Rio Grande do Sul – UNIJUÍ, located in the municipality of Augusto Pestana - RS. Treatments: AB: absence; PS: pre-sowing application; PS+R2: pre-sowing application + R2; PS+R3: pre-sowing application + in R3; PS+V4: pre-sowing application + V4; R2: application in R2; R3: application in R3; V4: application in V4.

In the interaction between cultivars and treatments (Figure 2A), it was found that the BMX Nexus cultivar presented greater plant height. The smallest plant heights were found for cultivar M5710 I2X. In the BMX Torque cultivar, all treatments with herbicide application resulted in plants with lower height compared to the absence treatment. These results are in line with those observed by FOSTER et al. (2019), and FOSTER & GRIFFIN (2019), where it was shown that there was a reduction in soybean plant height when subjected to treatments with dicamba.

The BMX Torque and M5710 I2X cultivars showed a reduced number of pods with three grains (Figure 2B) with the application of the herbicide at all times, being higher in the absence treatment in both cultivars. The BMX NEXUS I2X cultivar showed superior performance, in all treatments, for this variable, over the other cultivars. The lowest number of pods with three grains occurred in the absence treatment, in the cultivar FT4664 I2X, being the cultivar that presented this variable reduced for all treatments, in relation to the other cultivars. Study by FOSTER et al. (2019), found that applications during the soybean reproductive period showed greater reductions in the number of grains per legume, as well as the number of grains per legume. In another study ROBINSON et al. (2013) reported that the soybean yield components most affected by dicamba application were number of main stem nodes, number of main stem reproductive nodes, number of pods and seeds m^{-2}.

Table 2. Joint variance analysis for the variables plant height (PH, cm); insertion height of the first vegetable (IHFV, cm); grain weight per plant (GWP, gr); number of pods on the main stem (NPMS, unit); number of grains per plant (NGP, unit); number of pods with one grain (NP1G, unit); number of pods with two grains (NP2G, unit); number of pods with three grains (NP3G, unit); number of pods with four grains (NP4G, unit); number of total pods (NTP, unit); and grain yield (GY, kg ha^{-1}).

FV	DF[1]	MS[2]									
		PH	IHFV	GWP	NPMS	NGP	NP1G	NP2G	NP3G	NTP	GY
Cultivar (C)	4	845.31*	50.79*	25.23*	419.79*	2525.94*	20.83*	249.80*	259.44*	535.85*	0.67*
Treat-ment (T)	7	5.75	7.50	1.40	7.46	60.21	1.00	5.96	4.48	10.95	0.05
Block	2	22.05	18.34*	1.89	4.31	86.81	0.14	2.03	3.99	10.15	0.16
C x T	28	18.20*	4.91	1.67	14.55	117.77	0.65	4.04	10.34*	19.85	0.23*
Residual	78	9.32	3.56	1.26	18.69	126.38	1.12	4.76	5.94	26.42	0.09
CV[3] (%)		6.58	12.24	17.91	18.53	20.38	36.71	20.46	23.56	21.01	18.16

1Degrees of freedom (DF); 2Mean square (MS); 3Coefficient of variation (CV). *Significant at 5% probability of error by F test.

The higher grain yield (Figure 2 C), with 2.20 ton ha^{-1}, occurred in the cultivars BMX NEXUS I2X AND FT4426 I2X, for the PS+R3 and PS treatments, respectively. In the BMX TORQUE I2X cultivar, the treatment without herbicide application was superior for grain yield compared to the other treatments, in which all applications were carried out.

Reductions in grain yield were observed for the cultivars BMX TORQUE I2X, FT4426 I2X and M5710 I2X for the PS+R2, PS+R3 and PS+R2 treatments, respectively, compared to the absence of application. According to BEHRENS et al. (2007), a study carried out over three years in the United States of America, showed that transgenic plots, tolerant to the dicamba molecule, treated with application of up to 1.5 kg ha^{-1} of dicamba in pre-sowing and in the V3 stages did not reveal no compromise in yield, flowering date, plant height. However, a study by SPERRY et al. (2022), suggests that dicamba applications at the R1 stage reduce soybean grain productivity by 2.8 to 3.5 times compared to applications throughout the reproductive period. These results are in line with those observed by FOSTER & GRIFFIN (2019).

In the analysis of the simple effect for the cultivar factor (Figure 3), it was observed that the genotype BMX Nexus I2X was superior to the other cultivars for the variables insertion height of the first pods, number of pods on the main stem, number of total pods, number of grains per plant and grain weight per plant. The BMX Torque I2X cultivar showed lower performance for the variables number of pods on the main stem, number of total pods, number of pods with one grain and number of pods with two grains. The number of grains per plant and the grain weight per plant were lower in the cultivar FT4664 I2X. The number of pods on the main stem coincides with the number of total pods, indicating low branching and/or few pods, when present, on the plants. For SZARESKI et al. (2015), smaller soybean cultivars that express a low number of branches directly depend on an increase in the number of pods on the main stem, and consequently grains per plant, to achieve high productivity.

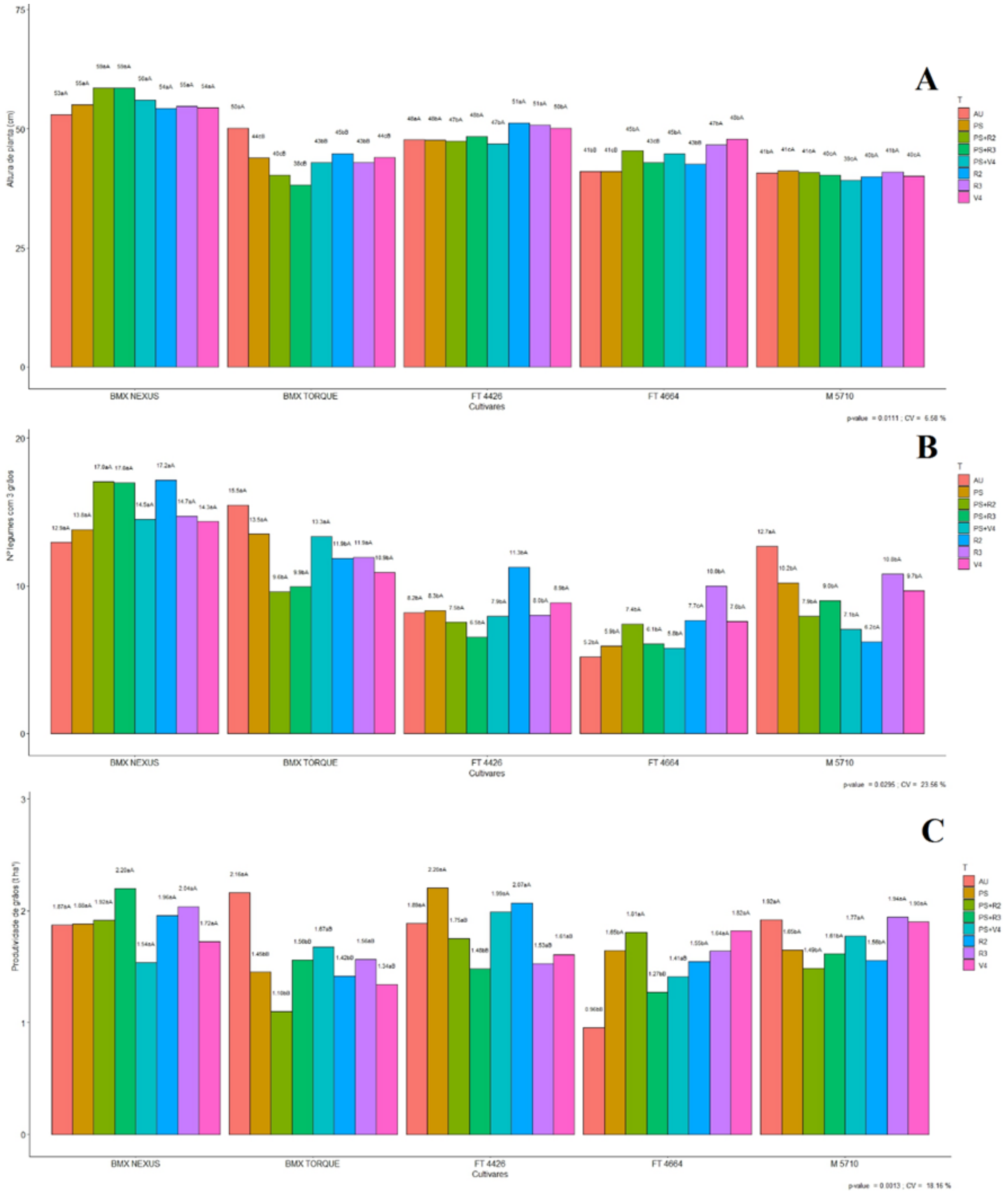

Figure 2. Interaction between cultivars and treatments for the variables: A- plant height (cm); B- number of pods with three grains (unit); and C- grain yield (ton ha^{-1}). Treatments: **AB**: absence; **PS**: pre-sowing application; **PS+R2**: pre-sowing application + R2; **PS+R3**: pre-sowing application + in R3; **PS+V4**: pre-sowing application + V4; **R2**: application in R2; **R3**: application in R3; **V4**: application in V4.

For all treatments, in the five *Xtend* cultivars, symptoms of chlorosis, necrosis, epinasty, leaf wrinkling, leaf curling, leaf narrowing and death of the apical meristem were not observed in the plants of each plot, caused by the phytotoxicity of the dicamba molecule, at the times 0, 3, 5, 7 and 15 DAA, in agreement with UNDERWOOD et al. (2017), where no symptoms of herbicide phytotoxicity were observed in dicamba applications on *Xtend* soybeans.

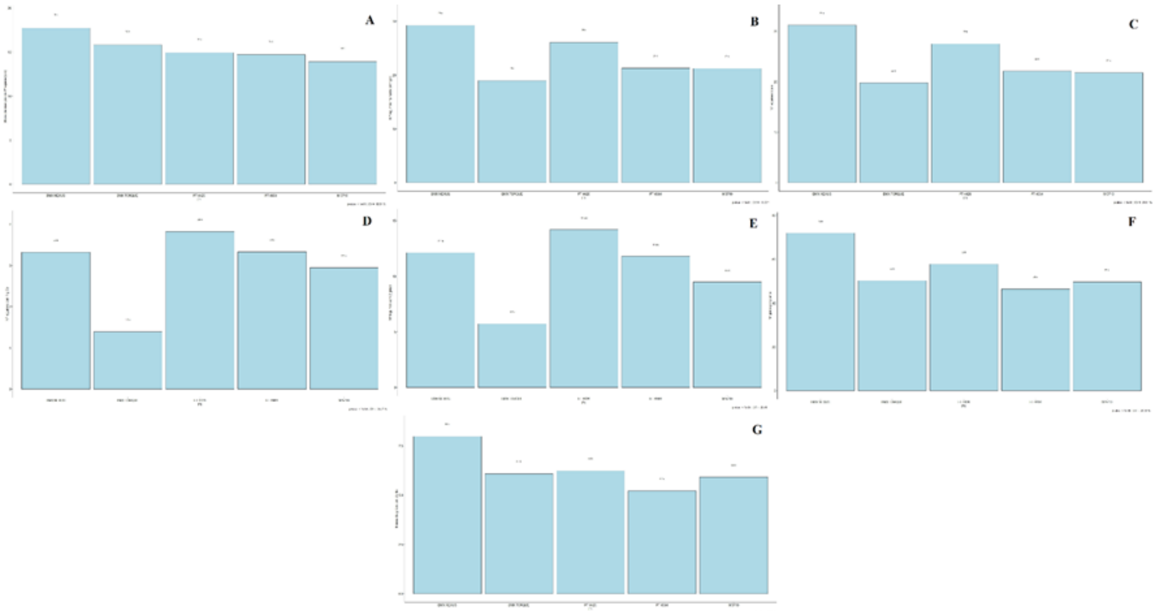

Figure 3. Effects of cultivars for the variables: A- insertion height of the first pods (cm); B- number of pods on the main stem (unit); C- number of total pods (unit); D- number of pods with one grain (unit); E- number of pods with two grains (unit); F- number of grains per plant (unit); and G- grain weight per plant (gr).

In treatments with applications at the V4 stage (Table 3), plant height was reduced to 3 DAA in cultivars M5710 I2X (-7,400 cm), FT4426 I2X (-5,067), BMX Nexus I2X (-9,067 cm) and FT4664 I2X (-4.667), and the cultivar M5710 I2X showed a reduction in leaf area healthy (-1.44%) and increase in symptomatic leaf area (1.45%) at 7 DAA. Likewise, in the pre-sowing application + V4 stage (PS+V4), plant height was reduced to 3 DAA in cultivars M5710 I2X (-6,400 cm), FT4426 I2X (-5,067), BMX Nexus I2X (- 7,733 cm) and FT4664 I2X (-6,000) and there were changes in leaf quality, where the cultivar M5710 I2X showed a reduction in healthy leaf area (-1.15%) and an increase in symptomatic leaf area (1.16%) at 7 DAA, cultivar FT4664 I2X at 15 DAA also reduced healthy leaf area (-3.33 %) and increased symptomatic leaf area (3.32%).

In the evaluations of 5, 7 and 15 DAA, plant height was positive for all cultivars in the V4 and PS+V4 treatments, indicating the plants' ability to recover immediately. According to SILVA et al. (2018), simulating the drift of 2,4-D and dicamba in vegetative and reproductive stages of soybeans not tolerant to these herbicides, found the greatest damage in height reduction with the application of dicamba in the vegetative stages. This more significant damage is motivated by the rapid growth and greater absorption of plant leaf meristems in the initial stages, compared to the final stages of growth and development (NARDINO et al., 2015).

Table 3. Dunnett's test to compare evaluations 3, 5, 7 and 15 days after application (DAA) on day 0, of treatments V4 and PS+V4.

TREATMENT V4								
Cultivar	**Variables**	**DAA**	**Estimate**	**IC-lwr**	**IC-upr**	**t value**	**p-value**	**sig**
BMX TORQUE I2X	Chlorophyll (%)	7	7.167	0.623	13.711	3.283	0.026	*
	Number of nodes (un.)	3	1.667	0.034	3.300	3.062	0.043	*
	Plant height (cm)	3	13.333	9.387	17.279	10.127	0.000	*
	Healthy leaf area (%)	15	4.983	1.546	8.420	4.257	0.003	*
	Symptomatic leaf area (%)	15	-4.983	-8.418	-1.548	-4.257	0.003	*
M 5710 I2X	Number of nodes (un.)	5	1.600	0.413	2.787	4.000	0.003	*
	Plant height (cm)	3	-7.400	-12.341	-2.459	-4.445	0.001	*
	Healthy leaf area (%)	7	-1.440	-2.324	-0.556	-4.725	0.002	*
	Symptomatic leaf area (%)	7	1.450	0.566	2.334	4.761	0.001	*
FT 4426 I2X	Number of nodes (un.)	5	2.067	0.481	3.652	3.868	0.005	*
	Plant height (cm)	3	-5.067	-9.930	-0.203	-3.092	0.037	*
		5	5.600	0.736	10.464	3.417	0.016	*
	Healthy leaf area (%)	7	2.013	0.266	3.760	3.344	0.023	*
	Symptomatic leaf area (%)	7	-2.013	-3.761	-0.266	-3.344	0.023	*
BMX NEXUS I2X	Number of nodes (un.)	3	-1.400	-2.644	-0.156	-3.340	0.019	*
	Plant height (cm)	3	-9.067	-14.500	-3.633	-4.952	0.000	*
FT 4664 I2X	Number of nodes (un.)	3	-1.133	-2.204	-0.062	-3.141	0.032	*
		5	1.200	0.129	2.271	3.326	0.020	*
	Plant height (cm)	3	-4.667	-9.001	-0.332	-3.195	0.028	*
		5	5.000	0.665	9.335	3.423	0.016	*
TREATMENT PS+V4								
BMX TORQUE I2X	Number of nodes (un.)	3	2.667	1.034	4.300	4.899	0.001	*
	Number of leaflets (un.)	3	1.100	3.928	18.072	4.661	0.001	*
	Plant height (cm)	7	6.667	2.721	10.613	5.064	0.001	*
		15	8.667	4.721	12.613	6.583	0.000	*
		3	16.000	12.054	19.946	12.153	0.000	*
	Healthy leaf area (%)	15	4.930	1.493	8.367	4.211	0.003	*
	Symptomatic leaf area (%)	15	-4.930	-8.365	-1.495	-4.211	0.004	*
M 5710 I2X	Number of nodes (un.)	3	-1.733	-2.920	-0.546	-4.333	0.001	*
		5	1.267	0.080	2.454	3.167	0.030	*
	Plant height (cm)	3	-6.400	-11.341	-1.459	-3.844	0.005	*
	Healthy leaf area (%)	7	-1.150	-2.034	-0.266	-3.774	0.011	*
	Symptomatic leaf area (%)	7	1.160	0.276	2.044	3.809	0.010	*
FT 4426 I2X	Number of nodes (un.)	5	1.733	0.148	3.319	3.244	0.025	*
	Plant height (cm)	3	-5.067	-9.930	-0.203	-3.092	0.037	*
BMX NEXUS I2X	Plant height (cm)	3	-7.733	-13.167	-2.300	-4.224	0.002	*
	Leaf area (cm²)	15	5.593	0.058	11.128	2.852	0.048	*
FT 4664 I2X	Plant height (cm)	3	-6.000	-10.335	-1.665	-4.108	0.002	*
	Healthy leaf area (%)	15	-3.323	-5.407	-1.240	-4.627	0.003	*
	Symptomatic leaf area (%)	15	3.323	1.240	5.406	4.627	0.003	*

(DAA: Days After Application); (IC-lwr: lower confidence interval); (CI-upr: upper confidence interval); (t value: calculated value); (p-value: probability); (sig: significance); (ns: not significant); (*: significant).

In applications carried out in the pre-sowing stage + R2 stage (PS+R2), in which

DOI: 10.5965/223811712422025298

R2 stands out with the reduction in the number of flowers at 5 DAA for the cultivars FT 4426 I2X (-12.26 un.) and FT4664 i2x (-13.26 un.), with no immediate recovery of the plant being identified, with a possible significant increase in this variable, in these cultivars, in the following evaluations, 7 and 15 DAA (Table 4). For both treatments, there was a reduction in healthy leaf area and an increase in symptomatic leaf area at 7 DAA in the cultivars FT 4426 I2X (R2: -11.00% / +11.09%) and BMX Nexus I2X (PS+R2: -2.70% / +2.70).

Table 4. Dunnett's test to compare evaluations 3, 5, 7 and 15 days after application (DAA) on day 0, of treatments R2 and PS+R2.

TREATMENT R2								
Cultivar	**Variables**	**DAA**	**Estimate**	**IC-lwr**	**IC-upr**	**t value**	**p-value**	**sig**
BMX TORQUE I2X	Number of nodes (un.)	3	2.000	0.328	3.672	3.586	0.012	*
	Plant height (cm)	3	6.667	1.194	12.139	3.652	0.010	*
M 5710 I2X	Plant height (cm)	5	8.600	1.439	15.761	3.564	0.011	*
	Healthy leaf area (%)	7	15.803	9.599	22.008	7.398	0.000	*
		15	19.703	13.499	25.908	9.224	0.000	*
FT 4426 I2X	Chlorophyll (%)	5	5.557	0.311	10.783	3.144	0.032	*
	Number of nodes (un.)	5	3.400	0.727	6.073	3.776	0.006	*
	Number of leaflets (un.)	5	36.133	12.402	59.865	4.519	0.001	*
	Plant height (cm)	5	13.733	4.726	22.741	4.525	0.001	*
	Number of flowers (un.)	5	-12.267	-24.515	-0.019	-2.972	0.049	*
	Healthy leaf area (%)	7	-11.003	-17.707	-4.300	-4.757	0.002	*
	Symptomatic leaf area (%)	7	11.093	4.378	17.809	4.797	0.002	*
BMX NEXUS I2X	Chlorophyll (%)	5	4.380	0.425	8.335	3.287	0.022	*
	Number of nodes (un.)	5	2.333	0.331	4.335	3.460	0.014	*
	Plant height (cm)	5	9.000	1.084	16.916	3.374	0.018	*
FT 4664 I2X	Chlorophyll (%)	5	7.520	3.527	11.514	5.589	0.000	*
	Number of leaflets (un.)	5	17.400	3.281	31.519	3.658	0.008	*
	Plant height (cm)	5	6.533	0.124	12.942	3.025	0.043	*
	Number of flowers (un.)	5	-13.267	-25.101	-1.432	-3.327	0.020	*
TREATMENT PS+R2								
BMX TORQUE I2X	Number of nodes (un.)	3	2.667	0.994	4.339	4.781	0.001	*
	Plant height (cm)	3	13.333	7.861	18.806	7.303	0.000	*
M 5710 I2X	Number of nodes (un.)	3	-2.067	-3.818	-0.315	-3.502	0.012	*
	Healthy leaf area (%)	7	13.527	7.322	19.731	6.332	0.001	*
		15	19.943	13.739	26.148	9.336	0.000	*
FT 4426 I2X	Healthy leaf area (%)	7	-8.063	-14.767	-1.360	-3.486	0.018	*
	Symptomatic leaf area (%)	7	8.063	1.348	14.779	3.487	0.018	*
BMX NEXUS I2X	Number of nodes (un.)	5	2.667	0.665	4.669	3.954	0.003	*
	Number of leaflets (un.)	5	19.800	1.882	37.718	3.280	0.023	*
	Plant height (cm)	5	10.000	2.084	17.916	3.749	0.006	*
	Healthy leaf area (%)	7	-2.703	-4.924	-0.482	-3.531	0.016	*
	Symptomatic leaf area (%)	7	2.703	0.480	4.926	3.531	0.016	*
FT 4664 I2X	Chlorophyll (%)	5	6.787	2.793	10.780	5.044	0.001	*
	Number of nodes (un.)	5	2.933	0.682	5.185	3.866	0.005	*
	Plant height (cm)	5	10.200	3.791	16.609	4.723	0.001	*

(DAA: Days After Application); (IC-lwr: lower confidence interval); (CI-upr: upper confidence interval); (t value: calculated value); (p-value: probability); (sig: significance); (ns: not significant); (*: significant).

With application at stage R3 (R3), cultivar M5710 I2X showed a reduction in the number of leaflets (-12.53 units), at 15 DAA (Table 5). This same cultivar presented,

DOI: 10.5965/223811712422025298

in the treatment with pre-sowing application + R3 stage (PS+R3), reduction in the number of leaflets on days 3 DAA (-15.53 un.), remaining with this loss until 7 DAA, in addition to the reduction of plants (-5.20 cm) and in the number of pods (-15.60 units) on day 3 DAA. In the BMX Nexus I2X cultivar, for both treatments, a decrease in the chlorophyll variables was identified on day 3 DAA (R3:-4.76%; PS+R3:-5.73%) and leaf area on days DAA 15 (R3: -10.87 cm^2) and 7 (PS+R3: -10.33 cm^2).

Table 5. Dunnett's test to compare evaluations 3, 5, 7 and 15 days after application (DAA) on day 0, of treatments R3 and PS+R3.

TREATMENT R3								
Cultivar	Variables	DAA	Estimate	IC-lwr	IC-upr	t value	p-value	sig
M 5710 i2x	Number of nodes (un.)	5	2,133	0,752	3,514	4,585	0,001	*
	Number of leaflets (un.)	15	-12,533	-24,671	-0,395	-3,065	0,039	*
	Plant height (cm)	5	4,800	0,382	9,218	3,224	0,026	*
	Number of pods (un.)	5	13,267	0,113	26,420	2,993	0,047	*
	Healthy leaf area (%)	7	10,573	4,358	16,789	4,935	0,001	*
		15	9,317	3,101	15,532	4,349	0,004	*
	Symptomatic leaf area (%)	7	-10,573	-16,784	-4,362	-4,941	0,002	*
		15	-9,317	-15,528	-3,106	-4,354	0,004	*
FT 4426 i2x	Chlorophyll (%)	5	7,247	1,026	13,468	3,457	0,014	*
	Number of pods (un.)	5	29,200	10,307	48,093	4,587	0,001	*
BMX NEXUS i2x	Chlorophyll (%)	3	-4,767	-9,506	-0,027	-2,985	0,048	*
		5	10,100	5,360	14,840	6,324	0,000	*
	Number of nodes (un.)	5	2,200	0,240	4,160	3,332	0,020	*
	Number of developing pods (un.)	15	33,400	5,443	61,357	3,546	0,011	*
	Leaf area (cm²)	15	-10,873	-20,153	1,593	-3,401	0,021	*
FT 4664 i2x	Chlorophyll (%)	5	3,933	1,776	6,091	5,409	0,000	*
	Plant height (cm)	15	7,667	1,149	14,185	3,491	0,013	*
		5	10,000	3,482	16,518	4,553	0,001	*
	Number of flowers (un.)	3	8,933	3,173	14,694	4,602	0,001	*
	Number of pods (un.)	5	26,733	11,590	41,877	5,239	0,000	*
	Number of developing pods (un.)	15	27,600	3,977	51,223	3,467	0,014	*
TREATMENT PS+R3								
BMX TORQUE i2x	Number of nodes (un.)	3	2,000	0,452	3,548	3,873	0,006	*
M 5710 i2x	Chlorophyll (%)	5	7,847	2,715	12,978	4,538	0,001	*
	Number of nodes (un.)	3	-1,867	-3,248	0,486	-4,012	0,003	*
		15	1,467	0,086	2,848	3,152	0,032	*
	Number of leaflets (un.)	3	-15,533	-27,671	-3,395	-3,798	0,006	*
		7	-15,533	-27,671	-3,395	-3,798	0,006	*
	Plant height (cm)	3	-5,200	-9,618	-0,782	-3,493	0,013	*
		15	4,800	0,382	9,218	3,224	0,026	*
	Number of developing pods (un.)	3	-15,600	-27,482	-3,718	-3,897	0,004	*
	Healthy leaf area (%)	7	10,467	4,251	16,682	4,886	0,002	*
		15	10,880	4,665	17,096	5,079	0,001	*
	Symptomatic leaf area (%)	7	-10,587	-16,798	-4,376	-4,947	0,002	*
		15	-10,880	-17,091	-4,669	-5,085	0,001	*
FT 4426 i2x	Number of pods (un.)	5	25,533	6,641	44,426	4,011	0,003	*
BMX	Chlorophyll (%)	3	-5,733	-10,473	-0,994	-3,590	0,010	*

NEXUS i2x	Number of nodes (un.)	5	3,200	1,240	5,160	4,846	0,000	*
	Number of flowers (un.)	3	14,333	1,089	27,577	3,212	0,027	*
	Healthy leaf area (%)	7	1,630	0,679	2,581	4,979	0,001	*
	Symptomatic leaf area (%)	7	-1,630	-2,658	-0,602	-4,607	0,002	*
	Leaf area (cm²)	7	-10,133	-19,413	-0,853	-3,169	0,031	*
FT 4664 i2x	Chlorophyll (%)	15	2,600	0,442	4,758	3,576	0,010	*
		5	2,267	0,109	4,424	3,118	0,034	*
	Plant height (cm)	15	8,333	1,815	14,851	3,794	0,006	*
		5	7,667	1,149	14,185	3,491	0,013	*
	Number of flowers (un.)	3	9,933	4,173	15,694	5,117	0,000	*
	Number of pods (un.)	5	24,733	9,590	39,877	4,847	0,001	*
	Number of developing pods (un.)	15	27,600	3,977	51,223	3,467	0,014	*

(DAA: Days After Application); (IC-lwr: lower confidence interval); (CI-upr: upper confidence interval); (t value: calculated value); (p-value: probability); (sig: significance); (ns: not significant); (*: significant).

Using Pearson's linear correlation, it is possible to determine patterns of associations between the variables that make up grain yield, and which significantly influence the variable grain weight per plant. In this way, it was inferred that in the absence treatment (AB), the grain weight per plant showed positive correlations of strong magnitude (r= > 0.70), with the number of grains per plant, number of total pods, number of pods in the main stem and number of pods with three grains (Figure 4). However, when dicamba management was carried out only in pre-sowing (PS) it was evident, for the variable grain weight per plant, strong positive associations with the number of grains per plant, number of total pods, number of pods in stem, number of pods in the branches and number of pods with two and three grains.

When applied to the V4 stage of soybean cultivation, the grain weight per plant showed strong positive correlations with the number of grains per plant, number of pods with three grains, number of total pods, number of pods in branches and plant height. In pre-sowing applications and at the V4 stage (PS+V4), the number of grains per plant, the number of total pods and the number of pods on the main stem had a strong positive influence on the grain weight per plant; number of pods with three and four grains.

When applied only at the R2 stage, strong correlations were found between the number of grains per plant and the number of total pods, and between the number of pods on the main stem and number of pods with three grain. In contrast, with pre-sowing applications and at the R2 stage (PS+R2), the grain weight per plant correlated only moderately, positively and significantly, with the number of grains per plant, the number of total pods and the number of pods on the main stem, with a value of 0.68 for both, and in the same magnitude with the number of pods with three grains and plant height.

In the treatment applied at stage R3, the grain weight per plant showed a positive and strong association, with the number of grains per plant (0.94), number of total pods (0.90), number of pods in branches (0.83), plant height (0.82), number of pods with four grains (0.77) and number of pods in the main stem (0.73). Similarly, applications

DOI: 10.5965/223811712422025298

in pre-sowing and at the R3 stage (PS+R3), on the same plot, a strong positive and significant correlation was observed between grain weight per plant and the number of grains per plant, plant height, the number of pods with three grains and the number of pods on the main stem and number of total pods.

Analyzing the standards established in each treatment, which influence the grain weight per plant, and comparing them, it is observed that in treatments with applications in pre-sowing (PS) and in pre-sowing + V4 stage (PS+V4) Plant height did not show a significant correlation with grain weight per plant, indicating a possible reduction in plant height in plots with these applications. Similarly, only in the treatments of application in pre-sowing + stage V4 (PS+V4) and application in V4 (V4) did the grain weight per plant correlate with the total leaf area of the plant.

DOI: 10.5965/223811712422025298

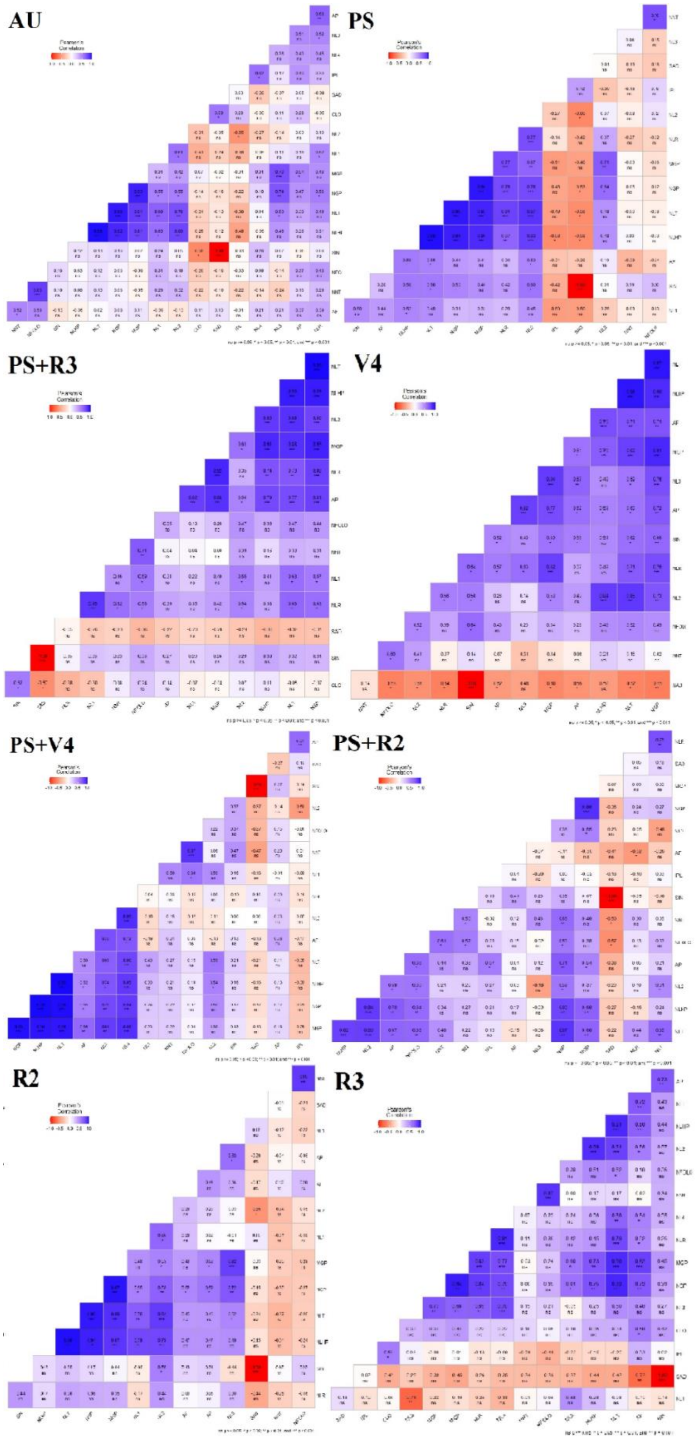

Figure 4. Pearson Linear Correlations of treatments AB: absence; PS: pre-sowing application; PS+R2: pre-sowing application + R2; PS+R3: pre-sowing application + in R3; PS+V4: pre-sowing application + V4; V4: application in V4; R2: application in R2; R3: application in R3. Plant height (PH, cm); insertion height of the first pods (IHFP, cm); number of pods on the main stem (NPMS, un.); number of pods on branches (NPB, unit); number of pods with one grain (NP1, un.); number of pods with two grains (NP2, un.); number of pods with three grains (NP3, un.); number of pods with four grains (NP4, un.); number of total pods (NPV, un.); number of grains per plant (NGP, un.); grain weight per plant (GWP, gr); number of total nodes (NTN, un.); Total plant chlorophyll (CHL, %); number of leaflets (NFOLO, un.); healthy leaf area (HEA, %); symptomatic leaf area (SYM, %) and leaf area (LA, cm²).

DOI: 10.5965/223811712422025298

CONCLUSION

Applications of dicamba at pre-sowing, at the V4 stage and at pre-sowing + V4 stage caused a reduction in the height and healthy leaf area of the plants. Applications in the R2 stage and in the pre-sowing + R2 stage reduced the number of flowers with reflection on the fifth day after application.

In the event of future government authorization for the use of dicamba herbicide in post-emergence of soybean crops, in *Xtend* cultivars, carry them out in the vegetative stages of the plants (V4), for immediate recovery in the event of the occurrence of morphological and agronomic changes.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis**, Gabriel Mathias Weimer Bruinsma**; software and validation**, Ivan Ricardo Carvalho;** investigation**, Leonardo Cesar Pradebon**; resources and data curation,**Murilo Vieira Loro**; writing-original draft preparation**, Felipe da Rosa Foguesatto**; supervision, **Eduardo Ely Foleto**; project administration, **Adriano Dietterle Schulz**; **Ivan Ricardo Carvalho**. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

We would like to thank CNPq and the Regional University of the Northwest of the State of Rio Grande do Sul.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

ALBRECHT AJP et al. 2018. Interference of buva population densities on soybean productivity. In: XXXI Brazilian congress on weed science: challenges and sustainability in weed management. Rio de Janeiro: CBCPD.

BEHRENS MR et al. 2007. Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. Science 316: 1185-1188.

CARVALHO CGP et al. 2003. Proposal for classifying coefficients of variation in relation to soybean plant productivity and height. Brazilian Agricultural Research 38: 187-193.

CONAB. 2025. Companhia Nacional de Abastecimento. Grains: grains harvest 2022/23 3rd survey harvest 2024/2025. Available in: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos>. Accessed on: Jan 9, 2025.

DUMITRU R et al. 2009. Crystal Structure of Dicamba Monooxygenase: A Rieske Nonheme Oxygenase that Catalyzes Oxidative Demethylation. Journal of Molecular Biology 392: 498-510.

FOSTER MR et al. 2019. Development of a model to predict soybean yield loss from dicamba exposure. Weed Technology 33: 287-295.

FOSTER MR & GRIFFIN JL. 2019. Changes in soybean yield components in response to dicamba. Agrosystems, Geosciences & Environment 2: 1-6.

ISAA. 2025. International Service for the Acquisition of Agri-biotechnology. Genetically modified approval database. Available in: <https://www.isaaa.org/gmapprovaldatabase/default.asp>. Accessed on: Jan 10, 2025.

NARDINO M et al. 2015. Artificial defoliation in vegetative stages and its implications for soybean cultivation. Magistra 27: 199-207.

OLIVOTO T & LÚCIO AD. 2020. metan: An R package for multi-environment trial analysis. Methods in Ecology and Evolution 11: 783-789.

ROBINSON AP et al. 2013. Response of glyphosate-tolerant soybean yield components to dicamba exposure. Weed Science 61: 526-536.

SCARTON VDB et al. 2023. Influence of meteorological variables and geographic factors in the selection of soybean lines. Revista de Agricultura Neotropical 10: e7246-e7246.

SHIMIZU G et al. 2024. AgroR: Experimental Statistics and Graphics for Agricultural Sciences_. R package version 1.3.6, https://CRAN.R-project.org/package=AgroR.

SILVA DROD et al. 2018. Drift of 2, 4-D and dicamba applied to soybean at vegetative and reproductive growth stage. Rural Science 48: e20180179.

SILVA EHFM et al. 2024. Exploring avenues for tropical soybean intensification: how much water and nutrients are demanded to achieve exploitable yield?. Scientia Agricola 81: e20230168.

SPERRY BP et al. 2022. Soybean dose–response to 2, 4-D and dicamba at vegetative and reproductive growth stages. Pest Management Science 78: 2759-2766.

SZARESKI VJ et al. 2015. Cultivation environment and its effects on the morphological and bromatological characteristics of soybean. Brazilian Magazine of Sustainable Agriculture 5: 79-88.

TAGLIAPIETRA EA et al. 2022. Soybean ecophysiology aiming for high productivity. 2.ed. Santa Maria: Palloti. 432p.

UNDERWOOD MG et al. 2017. Weed control, environmental impact, and net revenue of two-pass weed management strategies in dicamba-resistant soybean. Canadian Journal of Plant Science 98: 370-379.

ZANON AJ et al. 2018. Soybean ecophysiology aiming for high productivity. 1st ed. Santa Maria: [n.s.], 136p.

DOI: 10.5965/223811712422025298