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Sensitivity of conventional corn hybrids to simulated drift of glyphosate

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Abstract

Sharing agricultural areas with genetically modified corn, conventional corn is subject to drift of glyphosate applied to adjacent areas, requiring evaluation of consequences from this intoxication. Thus, this work was developed in order to evaluate the sensitivity of two conventional corn hybrids to subdoses of glyphosate herbicide. Three similar experiments were conducted in a greenhouse, between November 2023 and May 2024. The first and second experiments assessed the Biomatrix BM3051 conventional hybrid corn; the third experiment evaluated the Semeali XB8018 hybrid corn. All experiments used five subdoses of the glyphosate herbicide, at a highest dose applied of 144 g ha^{-1}. Plants were sprayed at a vegetative stage of three to four leaves. Qualitative (description of anatomical and morphological changes) and quantitative symptoms were evaluated using a visual scale of phytotoxicity and dry matter mass. Glyphosate doses equal to or greater than 36 g ha^{-1} led to significant intoxication of corn plants, possibly reducing dry matter. Biomatrix BM3051 had greater sensitivity to glyphosate intoxication compared with Semeali XB8018 corn. Most common phytotoxic symptoms observed included (in increasing order of intensity): slight reduction in size, yellowish streaks, wrinkling of the leaf blade, chlorosis or bleaching of young leaves, purplish leaf blade, curled leaves similar to drought damage, excessive formation of adventitious roots, necrosis of older leaves, generalized necrosis, tillering and meristematic damage. For the hybrid Semeali XB8018, glyphosate-induced hormetic effect occurred at doses below 36 g ha^{-1}. Considering 1,440 g ha^{-1} of glyphosate as a maximum dose, the 36 g ha^{-1} subdose equals 2.5 %. Thus, the severe toxic symptoms observed in the field may result from improper applications rather than from glyphosate drift into adjacent areas.

Keywords: Biomatrix BM3051. Semeali XB8018. Hormesis. Phytotoxicity.

Introduction

Corn (*Zea mays* L.) constitutes the most important agricultural crop originating from the Americas. Its economic importance stems from its use in animal feed and the food industry. corn is considered the world's largest agricultural crop with a total production over one billion tons, surpassing traditional competitors like rice and wheat (CONTINI *et al.*, 2019). corn production is led by the United States of America, with 377.63 million tons equivalent to 31 % of the world production, followed by China, with 294.92 million (24 %), and Brazil, with 135 million tons (11 %) (USDA, 2025).

Animal feed accounts for most consumption of corn grain (DUARTE, MATTOSO, GARCIA, 2016). In the 2023/24 harvest alone, Brazilian corn production yielded approximately 114 million tons from 20.8 million cultivated hectares (CONAB, 2024). These figures justify the intensive studies aimed at further improving corn productivity, especially in search of new technologies for weed control (MANÇANARES *et al.*, 2018).

One obstacle for farmers is the competition between corn and weeds, which can reduce crop yield when not managed properly and efficiently. Weeds use the same resources required by the crop for their development—that is, water, light, nutrients and space—, establishing a competitive process when crop and weeds grow in the same place (VASCONCELOS, SILVA, LIMA, 2012).

Corn is unable to achieve high soil cover rates in the early stages of development, thus contributing to the growth and infestation of weed species (SILVA *et al.*, 2008). In such cases, productivity losses may range from 15 to 87 % influenced by different cultivation conditions (CARVALHO *et al.*, 2007; KOZLOWSKI, KOELER, PITELLI, 2009; FIELDS *et al.*, 2016).

Negative effects induced by the presence of weeds are related to several factors, including type of soil, climatic conditions, period of interference, allelopathy, type of control performed, and not only to competition (KARAM, MELHORANÇA, OLIVEIRA, 2006). Weeds can also reduce product quality, both by hindering its development and processing and by altering its characteristics, besides making agricultural practices more expensive and serving as hosts for pests and diseases (KARAM, CRUZ, RIZZARDI, 2008).

Weed control is an indispensable practice to ensure productivity in modern agriculture. Chemical weed control by means of herbicides is the most used technology given the balance between costs, effectiveness, speed and spectrum of action (CIUBERKIS *et al.*, 2010; SCHNEIDER *et al.*, 2022; FOLONI *et al.*, 2024). In this perspective, glyphosate has been considered the most important herbicide worldwide and used for many years to control annual or perennial weeds in various production systems (FAIRCLOTH *et al.*, 2001; BLACKSHAW, HARKER, 2002).

With the advent of soybean cultivars and corn hybrids genetically modified for glyphosate tolerance, this product has become one of the most widely used molecules in crops, which includes the possibility of drift to adjacent, non-resistant crops. According to Gavrilescu (2005), of the total pesticides applied to crops, approximately 55 % do not reach the target, being dispersed to biotic and abiotic components of the ecosystem. Regarding glyphosate, the drift of small doses to adjacent areas can lead to qualitative and quantitative changes in plant development (CODOGNOTO *et al.*, 2023).

Although the cultivation of glyphosate-tolerant genetically modified hybrids is more significant in terms of land area, there are still demand for conventional corn production, serving different market niches such as popcorn (FREITAS *et al*., 2009). Growing conventional corn in refuge areas is also important for preserving *Bt* technology and for meeting the demands of specific markets with higher added value for the grains. Thus, research focused on chemical weed control should also continue to be directed towards conventional corn hybrids (ROSA *et al.*, 2025). Glyphosate drift over conventionally cultivated areas can harm plant development and, consequently, grain productivity since green leaf area is the main source of photoassimilates for corn crops (MAGALHÃES *et al.*, 2001).

As such, this work was developed in order to evaluated the sensitivity of two conventional hybrid corns (Biomatrix BM3051 and Semeali XB8018) to glyphosate herbicide subdoses.

Material and methods

Three similar experiments were conducted at a greenhouse in the municipality of Machado/MG (21º 40’ S; 45º 55’ W; 850 m altitude), between November 2023 and May 2024. For this purpose, pots with a 4 L capacity were used, duly filled with sieved clay soil, which chemical analysis is presented in Table 1. Each pot received four corn seeds, homogeneously spaced and arranged according to the vertices of an imaginary square, at a depth of 3.0 cm. After sprouting, the seedlings were thinned, maintaining a final density of two corn plants per pot. Whenever necessary, topdressing fertilization was performed in the pots with monoammonium phosphate, ammonium sulfate, and potassium chloride to ensure the full development of the plants without nutritional deficiencies.

Table 1. Chemical attributes of the soil used in greenhouse work. Machado/MG, 2024

pH	O.M	Pres	K	Ca	Mg	H+Al	SB	CEC	V	m
$CaCl_2$	g kg^{-1}	mg dm^{-3}	mmolc dm^{-3}	mmolc dm^{-3}					%	%
5.6	28.5	77.0	5.22	35.9	18.0	22.2	59.1	81.3	73.0	0.0

Textural class – clayey; O.M – organic matter; CEC – Cation exchange capacity; V% – base saturation; m% – aluminum saturation.

Source: authors (2024).

The first and second experiments assessed the Biomatrix BM3051 conventional hybrid corn; the third experiment evaluated the Semeali XB8018 hybrid corn. Both genetic materials are considered conventional hybrids without tolerance against glyphosate. All experiments adopted five subdoses of glyphosate. The first experiment used doses at 0.7, 1.4, 3.6, and 7.2 g ha^{-1} and a checkplots without application. The second experiment used doses at 14.4, 36.1, 72.2, and 144.0 g ha^{-1} and a checkplots without application. The highest dose used, 144.0 g ha^{-1}, equaled 10 % of the maximum desiccation dose, considering a possible recommendation of 1,440.0 g ha^{-1} of glyphosate.

All experiments adopted a randomized block design, with seven (first and second experiments) or eight (third experiment) replications and five treatments. All sprays were performed when the corn plants reached a phenological stage of three to four leaves. Spraying used a precision backpack sprayer, pressurized by CO2, coupled to a bar containing two XR 110.02 tips, spaced 0.5 m apart, working at 2.5 bar, properly calibrated for a mixture volume proportional to 200 L ha^{-1}.

After each application, the pots were kept for at least 12 hours without irrigation to ensure herbicide absorption. They were then submitted to automated daily irrigation, without water deficit. Corn phytotoxicity evaluations were performed at 7, 14, 21 and 28 days after application (DAA), and residual dry matter mass analysis at 28 DAA. During phytotoxicity assessments, qualitative and quantitative observations were made for corn plants. Qualitative evaluations consisted of morphological descriptions of the symptoms observed in the accumulated repetitions of each applied dose. Quantitative observations used a scale with variable scores between 0 and 100 %, in which 0 represented fully healthy plants and 100 % represented dead plants (FRANS, 1972; SBCPD, 1995). For residual dry matter, at the end of the experiments, all plant material present in the plots was harvested and dried in a forced-air oven at 65ºC until a constant dry matter mass was obtained.

Data underwent F-test for analysis of variance and, when significant, data were compared using Tukey's test. All tests adopted a 5 % significance. Quantitative data referring to the dry matter mass of the third experiment were adjusted using nonlinear regression models, assuming the hormetic effect of the herbicide glyphosate.

Results and discussion

Glyphosate doses used in the first experiment were not sufficient to cause significant intoxication in the Biomatrix BM3051 conventional hybrid corn. Slightly yellowish leaf streaks and a small size reduction occurred only at the highest dose. At 14 DAA, slight yellowing and a small size reduction were observed on random plants, but did not justify quantitative assessments by scores. These observations were confirmed by dry matter mass analysis, the statistics of which showed no significance for all treatments (Table 2).

Table 2. Residual dry matter of the Biomatrix BM3051 corn hybrid after application of glyphosate subdoses. Machado/MG, 2024

Glyphosate (g ha^{-1})	Dry matter (g share^{-1})
0.0	33.75
0.7	32.32
1.4	30.70
3.6	30.23
7.2	29.34
F_{trat}	1.68^{NS}

^{NS}F-test not significant at 5 % probability.

Source: authors (2024).

Given these findings, a second experiment was conducted with increased glyphosate doses to intensify the symptoms. All treatments were differentiated in the second experiment, with the most intense symptoms observed at the highest doses, reaching up to 85 % intoxication (Table 3). At lower doses, symptoms included a slight size reduction, the appearance of yellowish streaks on younger leaves, wrinkling of the leaf blade, delayed development, and some whitish spots. With increasing doses, the reductions in plant size became more intense, evolving into necrosis of older leaves, larger yellowish streaks, purplish discoloration at the base of the leaves, and curled new leaves (similar to water deficit). At higher doses, observable symptoms include severe reduction in plant size, excessive production of adventitious roots, curling and necrosis of young leaves, streaked yellowing, drying of new leaves, progressing to generalized necrosis of the plants (Figure 1).

Notably, the mechanism of action of glyphosate is quite unique since it is the only herbicide currently on the market capable of specifically inhibiting the enzyme 5-enolpyruvylshikimate 3-phosphate (EPSP), which catalyzes the condensation of shikimic acid and phosphoenolpyruvate, thus preventing the synthesis of three essential amino acids—tryptophan, phenylalanine, and tyrosine (JAWORSKI, 1972; ZABLOTOWICZ, REDDY, 2004; AZEVEDO *et al.*, 2023). The absence of these amino acids in plant metabolism helps to explain the various symptoms observed, particularly tryptophan (a precursor of indole-3-acetic acid, which is the growth hormone) and tyrosine (related to the production pathway of pigments, including chlorophyll).

Productive potential of corn is defined when the plant has between four and five leaves, at which point floral differentiation begins. (RITCHIE, HANWAY, BENSON, 1993). Intoxication at this stage is of great importance, as

Table 3. Phytotoxicity and residual dry matter of the Biomatrix BM3051 hybrid corn after application of glyphosate subdoses. Machado/MG, 2024

Glyphosate	Phytotoxicity			Dry matter
(g ha^{-1})	7 DAA	14 DAA	21 DAA	(g share^{-1})
0.0	0.00 A	0.00 A	0.00 A	36.26 A
14.4	7.28 B	10.43 B	11.28 B	36.33 A
36.1	23.00 C	31.43 C	27.86 C	22.38 B
72.2	44.71 D	52.14 D	52.86 D	9.17 C
144.0	64.28 E	72.14 E	85.00 E	3.93 C
CV (%)	12.12	13.43	11.64	17.72
F_{trat}	435.04*	307.36*	479.88*	107.23*

*Significant F-test at 1 % probability; averages followed by equal letters in the columns do not differ from each other according to the 5 % probability Tukey's test.

Source: authors (2024).

Figure 1. Detail of some symptoms caused by glyphosate in conventional Biomatrix BM3051 hybrid corn. Machado/MG, 2024

Source: authors (2024).

it can trigger physiological effects on plant growth and development, meristematic alterations, and consequently impact crop productivity.

In the third experiment, the Semeali XB8018 conventional hybrid was less sensitive to glyphosate compared with the Biomatrix BM3051 hybrid, but acute symptoms were also observed (Table 4). At 28 DAA and the highest dose, an average phytotoxicity effect of 81 % was observed, with generalized necrosis, stimulation of tillering, chlorosis, purpling, and severe reduction in plant size. Overall, the symptoms observed were consistent with previous experiments, beginning with a slight size reduction, yellowish streaks on the leaf blade, and purplish discoloration of the edges. At higher doses, a significant reduction in

Table 4. Phytotoxicity of the Semeali XB8018 corn hybrid after application of glyphosate subdoses. Machado/MG, 2024

Glyphosate	Phytotoxicity			
(g ha^{-1})	7 DAA	14 DAA	21 DAA	28 DAA
0.0	0.00 A	0.00 A	0.00 A	0.00 A
14.4	7.13 B	4.38 A	8.25 AB	3.62 AB
36.1	8.00 B	7.25 A	12.38 B	8.25 B
72.2	19.13 C	23.12 B	22.63 C	14.75 C
144.0	31.25 D	53.12 C	56.25 D	81.25 D
CV (%)	25.34	35.87	32.28	20.67
F_{trat}	108.76*	94.85*	92.94*	460.08*

*Significant F-test at 1 % probability; averages followed by equal letters in the columns do not differ from each other according to the 5 % probability Tukey's test.

Source: authors (2024).

size, purplish midrib, and interveinal yellowing were observed (Figure 2).

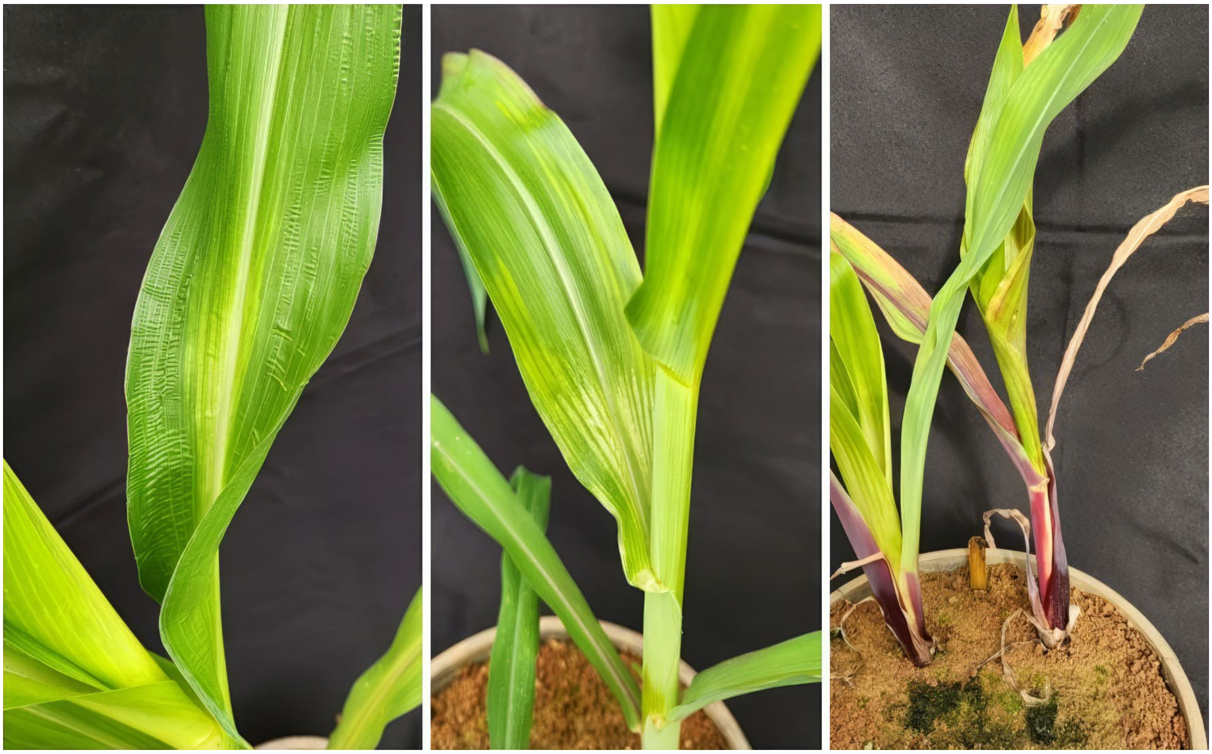
Regarding dry matter mass, this hybrid corroborated the hypothesis of a hormetic effect of glyphosate, in which doses of 14.4 and 36.1 g ha^{-1} contributed to greater dry matter mass, with the 36.1 g ha^{-1} dose being superior to checkplots according to Tukey's test (Figure 3). Hormesis describes a positive response in plant development after the application of reduced doses of a substance known to be toxic at commercial doses (CALABRESE, BALDWIN, 2002; SILVA *et al.*, 2012).

Although uncommon, the literature reports on the hormetic effect of glyphosate in corn (WAGNER, KOGAN, PARADA, 2003), common beans (SILVA) *et al.*, 2012), sugarcane (SILVA *et al.*, 2009), guinea grass (GALLARDO *et al.*, 2021), eucalyptus (PEREIRA *et al.*, 2013) and *Urochloa* cultivars (CODOGNOTO *et al.*, 2023). Frequently, doses lower than 36 g ha^{-1} have been associated with hormesis effects (PEREIRA *et al.*, 2013; VELINI *et al.*, 2008; GALLARDO *et al.*, 2021), but the explanations for this phenomenon are still unclear.

The shikimic acid pathway (in which glyphosate acts) contributes to the assimilation of approximately 20 % of the carbon dioxide absorbed by plants. Less activity in this pathway may result in CO_2 being available for other metabolic pathways, leading to greater growth. Additionally, the amino acid phenylalanine is a precursor to the phenol pathway in plants, including lignin synthesis. The reduced synthesis and deposition of lignin may contribute to the cell wall remaining elastic for longer, resulting in greater longitudinal cell growth (DUKE *et al.*, 2006; GALLARDO *et al.*, 2021).

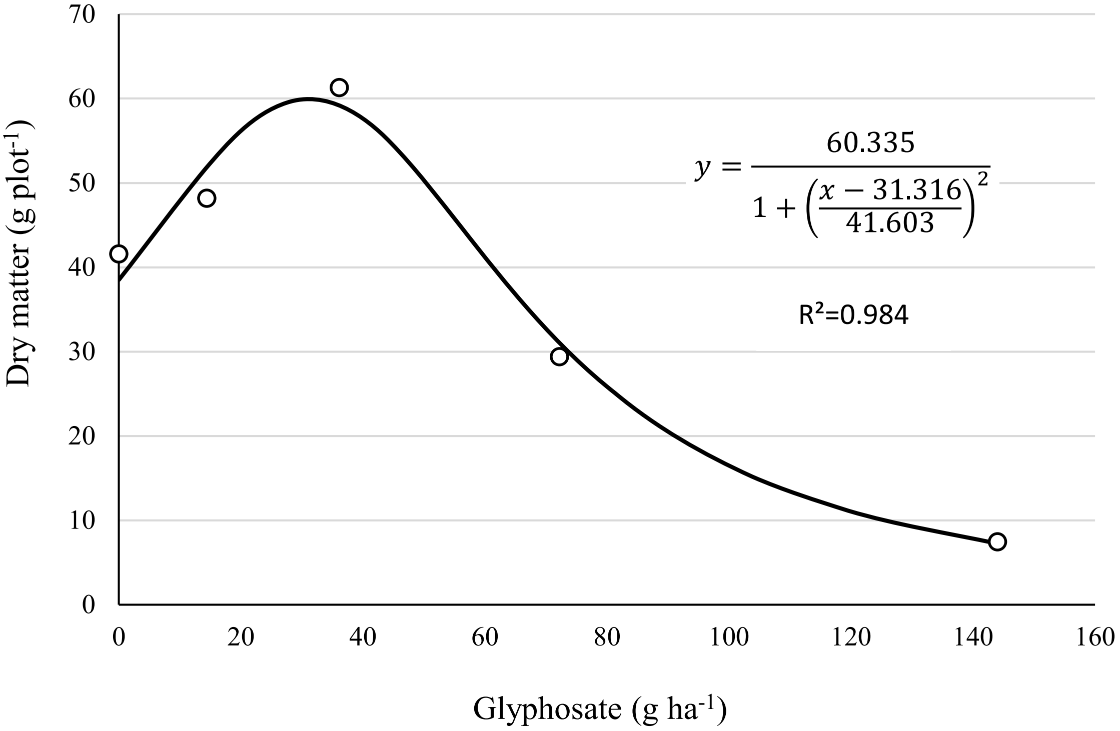
Finally, it is important to validate these data under field conditions, evaluating the effects of

Figure 2. Detail of some symptoms caused by glyphosate in Semeali XB8018 conventional corn hybrid. Machado/MG, 2024



Source: authors (2024).

Figure 3. Residual dry matter of the Semeali XB8018 hybrid corn after application of glyphosate subdoses. DMStrat = 11.98. Machado/MG, 2024



Source: authors (2024).

glyphosate drift on the productivity of conventional corn hybrids. Considering this important market niche, the occurrence of application failures and drifts to adjacent areas can compromise the productivity of conventional crops.

Conclusions

Glyphosate doses greater than 36 g ha^{-1} led to significant intoxication of corn plants, reducing dry matter. Biomatrix BM3051 showed greater sensitivity to glyphosate effects compared with Semeali XB8018 corn.

When present, most common toxic symptoms observed included (in increasing order of intensity): slight reduction in size, yellowish streaks, wrinkling of the leaf blade, chlorosis or bleaching of young leaves, purplish leaf blade, curled leaves similar to drought damage, excessive formation of adventitious roots, necrosis of older leaves, generalized necrosis, tillering and meristematic damage.

For the hybrid Semeali XB8018, glyphosate-induced hormetic effect occurred at doses below 36 g ha^{-1}. Considering 1,440 g ha^{-1} of glyphosate as a maximum dose, the 36 g ha^{-1} subdose equals 2.5 %. Thus, the phytotoxic symptoms observed in the field may result from improper applications rather than from glyphosate drift into adjacent areas.

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