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Residual effects of grass-selective herbicides applied for millet desiccation prior to corn sowing

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Abstract
Background: Corn is a major crop in the world, and weed interference limits yield. While glyphosate-resistant cultivars have improved control, the selectivity and safety of pre-sowing desiccation—especially when tank-mixing glyphosate with grass-selective herbicides—remain concerns.
Objective: To evaluate the optimal interval between desiccation with glyphosate plus haloxyfop or clethodim and corn sowing under no-till system with millet cover (NTCS) and a conventional system (CS).
Methods: A greenhouse trial was conducted in a completely randomized design (four replications) in a 2×4 factorial: soil cover (with millet vs. without) and herbicides (untreated control, glyphosate, glyphosate+clethodim, glyphosate+haloxyfop). Applications occurred 1, 5, 10, and 15 days before sowing (DBS). Plant height, phytotoxicity, and shoot dry mass (SDM) were assessed 28 days after emergence.
Results: Shorter plant-back intervals increased injury and reduced growth. Mixtures with haloxyfop or clethodim caused the greatest damage, mainly at 1 and 5 DBS. No-till with cover (NTCS) benefited most from the longest interval.
Conclusions: Planting at least 15 days after desiccation minimized negative effects, particularly under NTCS.

Keywords: Corn, pre-sowing desiccation, glyphosate, ACCase inhibitors, cover crops

Introduction

Maize plays a central role in global food security and the world economy, with production spread across multiple planting windows and broad adoption of high-yield technologies. Yet average worldwide yields remain below the crop's potential, largely due to weed interference and the rise of herbicide-resistant biotypes driven by intensive, repeated herbicide use in conservation systems. Among the most impactful perennial grasses is sourgrass (*Digitaria insularis*), whose aggressiveness—rhizome formation, tussock growth, and prolific propagule dispersal—complicates control and favors regrowth after applications, especially where starch reserves in underground organs hinder translocation (Lorenzi, 2000; Kissmann and Groth, 1997; Machado *et al*., 2008) [1, 2, 3]. In no-till settings, synchronizing pre-sowing desiccation with maize establishment is critical: staged/early desiccation programs consistently outperform applications made close to sowing, reducing the risk of injury from residual activity (Constantin *et al*., 2009) [4].

For glyphosate-resistant biotypes, ACCase inhibitors—particularly clethodim and haloxyfop, from the cyclohexanedione and aryloxyphenoxypropionate groups—have shown high efficacy, alone or in mixture, but they require careful plant-back intervals to preserve maize selectivity (Gemelli *et al*., 2013; Spader and Lopes, 2012; Mendes *et al*., 2020) [5, 6, 7]. The literature also underscores that diversifying modes of action within integrated weed management is essential to slow resistance evolution at a global scale (Agostinetto *et al*., 2002) [8]. Moreover, indirect effects such as root exudation and rhizosphere transfer can exacerbate phytotoxicity in adjacent or succeeding crops, as demonstrated for glyphosate (Rodrigues *et al*., 1982; Coupland and Lutman, 1982) [9, 10].

Against this global backdrop—where selection pressure and carryover/transfer risks coincide with the need for tight operational windows, this study evaluated plant-back intervals for glyphosate tank-mixed with haloxyfop or clethodim under two soil-cover systems to identify

safer practices for corn establishment.

Materials and Methods

The experiment was carried out in a greenhouse at the Federal University of Viçosa - Rio Paranaíba campus, Minas Gerais, Brazil. A completely randomized design with four replications was used; each pot (8 L) constituted one experimental unit filled with a dystrophic Red-Yellow Latosol. Treatments followed a 2×4 factorial: soil cover (millet straw present—no-till with cover, NTCS; or absent—conventional system, CS) and herbicides (untreated control, glyphosate, glyphosate+clethodim, glyphosate+haloxyfop). To simulate straw, millet was sown in staggered dates every five days for NTCS treatments. Herbicides were applied 1, 5, 10, or 15 days before sowing (DBS) using an electric backpack sprayer with a single flat-fan nozzle delivering 200 L ha^{-1}. Application rates were 3 kg ha^{-1} glyphosate, 0.8 L ha^{-1} haloxyfop, and 0.8 L ha^{-1} clethodim. Four corn seeds were sown per pot and thinned to two plants after emergence. Base fertilization used 450 kg ha^{-1} NPK (08-28-16). Plant height, visual injury (0-100%), and shoot dry mass (SDM) were assessed 28 days after emergence (DAE). Samples were dried at 68 °C for 48 h and weighed to two decimal places. The data were subjected to normality and homoscedasticity tests, followed by analysis of variance ($p<0.05$). The means were compared by the Student-Newman-Keuls test ($p<0.05$) using the SPEED Stat program (Carvalho *et al*., 2020) [11].

Results and Discussion

Mean plant height decreased as the interval between treatment application and sowing shortened. The effect was more pronounced when glyphosate was combined with haloxyfop, especially under CS, where at 15 DBS the reduction reached 97% relative to the control; under NTCS, the same mixture limited height by 50%, indicating attenuation by the straw (Table 1).

Table 1: Corn plant height (cm) at 28 days after emergence under NTCS and CS across plant-back intervals (1, 5, 10, 15 DBS) and herbicide treatments

	Milllet							
	With	Without	With	Without	With	Without	With	Without
Treatments	**1DBS/²**		**5DBS/¹**		**10DBS**		**15DBS**	
Control	36.9 [1]Ba	44.1 Aa	37.3 Aa	44.2 Aa	44.3 Aa	46.8 Aa	44.7 Aa	47.8 Aa
Gly	14.7 Bb	39.0 Aa	25.9 Ab	26.9 Ab	24.8 Ab	30.2 Ab	48.6 Aa	47.2 Aa
Gly+hal	0.5 Bc	6.9 Ab	0.5 Ac	2.6 Ac	3.3 Ac	6.5 Ac	22.4 Ac	1.9 Bc
Gly+cle	0.0 Ac	0.0 Ac	0.0 Bc	22.5 Ab	10.8 Bc	39.8 Aa	28.6 Ab	24.5 Ab
F millet	85.54**		34.94**		24.56**		26.16**	
F herb	419.78**		101.64**		67.91**		229.26**	
F mil x herb	17.26**		16.31**		9.93**		20.83**	
CV (%)	12.96		20.12		22.11		9.6	

Note: /[1] and /[2] the transformation (arcsen√x100) was used

[1]Means followed by the same letter, uppercase in the row and lowercase in the column, do not differ from each other according to the SNK test at a 5% probability of error; DBS = days before sowing; DAE = days after emergence.

A similar trend was reported by Mendes *et al*. (2020) [7], who observed sharp decreases in corn growth at short intervals after applying ACCase inhibitors, and by Constantin *et al*. (2009) [4], who demonstrated higher productivity when desiccation is brought forward in stages.

Phytotoxicity increased as the interval between desiccation and sowing decreased. The glyphosate+haloxyfop mixture produced the greatest injuries, reaching 95% at several timings and complete plant death in CS at 1 DBS (Table 2).

Table 2: Phytotoxicity (%) of corn plants 28 days after emergence.

Treatments	Millet							
	With	Without	With	Without	With	Without	With	Without
	1DBS/⁴		**5DBS/³**		**10DBS/²**		**15DBS/¹**	
Control	0.0 [1] Ac	0.0 Ab	0.0 Ac	0.0 Ac	0.0 Ad	0.0 Ac	0.0 Bb	0.0 Ac
Gly	53.7 Ab	0.0 Bb	16.2 Ab	6.2 Bb	30.0 Ac	21.2 Bb	0.0 Ab	2.5 Ac
Gly+hal	97.5 Aa	95.0 Aa	97.5 Aa	83.7 Ba	92.5 Aa	93.7 Aa	53.7 Ba	97.5 Aa
Gly+cle	100.0 Aa	100.0 Aa	100.0 Aa	8.0 Bb	62.5 Ab	0.0 Bc	53.2 Aa	10.0 Bb
F millet	6.38**		49.20**		903.79**		2.8^{Ns}	
F herbicides	49.62**		110.53**		2832.99**		56.58**	
F mil x herb	3.89*		20.40**		741.79**		5.0*	
CV (%)	22.91		14.66		4.26		21.76	

Note: /[1], /[3] e /[4] the rank noise transformation was used. /[2] The cubic root transformation (x) was used. [1] Means followed by the same letter, uppercase in the row and lowercase in the column, do not differ from each other by the SNK test at a 5% probability of error. DBS = days before sowing; DAE = days after emergence.

This pattern aligns with evidence of a higher risk of injury when ACCase inhibitors are combined with glyphosate in early planting scenarios (Takano *et al*., 2020; Mendes *et al*., 2020) [14, 7].

Shoot dry mass (SDM) followed the same trend as height, with higher values at longer intervals (Table 3).

Table 3: Shoot dry mass (g) of corn plants at 28 days after emergence.

Treatments	Millet							
	With	Without	With Without		With	Without	With	Without
	1DBS/3		5DBS/2		10DBS/1		15DBS	
Control	0.96 [1]Aa	1.05 Aa	1.02 Aa	0.99 Aa	1.53 Aa	1.09 Ba	1.33 Ab	1.18 Aa
Gly	0.22 Bb	1.16 Aa	0.31 Ab	0.45 Ab	0.58 Ab	0.36 Bb	2.05 Aa	1.16 Ba
Gly+hal	0.00 Ac	0.01 Ab	0.01 Ac	0.02 Ad	0.01 Bd	0.12 Ac	0.70 Ac	0.00 Bb
Gly+cle	0.00 Ac	0.00 Ab	0.00 Bc	0.20 Ac	0.23 Bc	0.85 Aa	0.78 Ac	0.27 Bb
F millet	2.26[Ns]		26.08**		16.44**		52.83**	
F herbici	45.34**		113.51**		185.31**		58.63**	
F mil x herb	6.32**		12.98**		29.85**		4.01*	
CV (%)	23.18		19.74		8.5		23.5	

Note: /[1] e /[2] the cubic root (x) transformation was used.
/[3] The rank noise transformation was used.

[1]Means followed by the same letter, uppercase in the row and lowercase in the column, do not differ from each other by the SNK test at a 5% probability of error. DBS = days before sowing; DAE = days after emergence.

At 15 DBS under NTCS, means were 45% greater than under CS, attributed to the physical and microclimatic effects of straw, which favor early corn establishment and may accelerate microbial degradation of herbicides (Prata and Lavorenti, 2000) [12].

The behavior of haloxyfop is consistent with its low Koc (66 mL g^{-1}), implying moderate adsorption and greater persistence in the soil solution, with reports of activity lasting >30 days (Pesticide Properties DataBase, 2018) [13]. The association with glyphosate may also heighten risks due to root-mediated transfer in the rhizosphere, as shown for wheat and neighboring crops (Rodrigues *et al*., 1982) [9] and by movement to adjacent plants (Coupland and Lutman, 1982) [10]. Under NTCS conditions, greater injury with glyphosate was observed at the shortest windows, possibly due to the proximity and overlap of root systems; the literature reinforces the importance of this dynamic in areas with *Digitaria insularis* (Lucio *et al*., 2017) [15].

Short plant-back intervals with ACCase inhibitors mixed with glyphosate increased corn injury and reduced growth, corroborating prior reports on residual activity and crop sensitivity [6, 7]. The mitigating effect of NTCS (millet straw) at longer intervals likely reflects physical protection and microclimatic moderation that favors early corn establishment and may enhance microbial degradation of herbicides in surface residues and the soil matrix [12]. Greater injury with haloxyfop is consistent with physicochemical properties (e.g., low Koc) and documented persistence [13]. Additionally, rhizosphere transfer and root exudation phenomena may contribute to injury under close spatial and temporal proximity to treated vegetation [9, 10]. These findings reinforce recommendations for earlier, staged desiccation prior to sowing to balance weed control and crop safety [4].

Conclusion

Delaying corn sowing to at least 15 days after desiccation with glyphosate mixed with haloxyfop or clethodim minimized injury and supported better early growth, particularly under no-till with millet cover (NTCS). Longer plant-back intervals should be adopted when ACCase inhibitors are used near planting.

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