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Weed management using chemical and mechanical hoes in maize cultivation

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ABSTRACT

Maize cultivation is affected by weed interference due to competition for nutrients, light, water, and space. In addition, both chemical and mechanical management can compromise crop productivity. This study aimed to determine whether the superficial soil disturbance caused by the use of a manual mechanical hoe interferes with maize plant development and grain yield, according to different weed competition periods throughout the crop cycle, compared to chemical control using a chemical hoe with the herbicide glyphosate. The experiment was conducted under a no-tillage system in the municipality of Jataí, Goiás, during the 2021/22 growing season. A randomized block design in a 2×4 factorial scheme was adopted, in which treatments consisted of combinations of management methods (mechanical hoe and chemical hoe) and different weed management times (10, 20, 30, and 60 days after sowing – DAS). In the chemical hoe treatment, glyphosate was applied at a 5:1 ratio. The evaluated variables included plant height, stem diameter, number of rows per ear, number of kernels per row, ear length and diameter, and grain yield. Chemical management reduced stem diameter and ear length and diameter; however, no significant difference in grain yield was observed compared to the use of the manual hoe. It can be concluded that mechanical weeding does not harm the crop's agronomic characteristics. Grain yield decreases with delayed weed control timing.

Keywords: Glyphosate, Weed interference period, Productivity, Weed competition.

Manejo de plantas daninhas com uso de enxada química e mecânica na cultura do milho

RESUMO

A cultura do milho é afetada pela interferência das plantas daninhas devido a competição por nutrientes, luz, água e espaço. Além disso, o manejo químico ou mecânico também pode comprometer a produtividade da cultura. O objetivo deste trabalho foi determinar se o revolvimento superficial do solo com uso de enxada mecânica manual interfere no desenvolvimento das plantas de milho e na produção de grãos, de acordo com os períodos de matocompetição ao longo do ciclo, quando comparado ao controle químico das plantas daninhas realizado com enxada química com o herbicida glyphosate. O experimento foi instalado no sistema de plantio direto no município de Jataí-GO no ano agrícola 2021/22. Foi adotado o delineamento de blocos casualisados em esquema fatorial 2x4, no qual os tratamentos foram constituídos pela combinação dos métodos de manejo (enxada mecânica e enxada química) em diferentes épocas de manejo (10, 20, 30 e 60 dias após a semeadura - DAS) Na enxada química foi utilizado o herbicida glyphosate na proporção 5:1. As variáveis avaliadas foram: altura de plantas, diâmetro de colmo, número de fileiras por espiga, número de grãos por fileira, comprimento e diâmetro de espigas e produtividade de grãos. O manejo químico reduziu o diâmetro de colmo, comprimento e diâmetro das espigas de milho, contudo não houve diferença de produtividade em relação ao uso da enxada manual. Pode-se concluir que a capina mecânica não traz prejuízos às características fitotécnicas da cultura. A produtividade de grãos diminui com o atraso na época de controle das plantas daninhas.

Palavras-chave: Glyphosate, Período de convivência, Produtividade, Matocompetição.

1. Introduction

Maize (*Zea mays*) is one of the most economically significant crops in Brazilian agriculture (Pereira et al., 2024). In the 2024/25 growing season, the cultivated area reached approximately 21.6 million hectares, producing 137 million tons (CONAB, 2025).

Weeds are responsible for substantial yield losses in grain production worldwide. In maize, they can host insects and diseases, as well as reduce grain quality and productivity, causing losses exceeding 80% (Galon et al., 2018; Basso et al., 2018). This occurs due to competition for natural resources such as water, light, and nutrients, particularly by plants with extensive root systems (Santos et al., 2017). To maintain cultivated areas, chemical management using herbicides is commonly adopted (Landau et al., 2021). However, in experimental fields and/or family farming systems, mechanical control with hoe weeding is still practiced.

Maize plants have a C4 photosynthetic metabolism (Bergamaschi and Matzenauer, 2014; Costa Neto, 2023), which provides anatomical and physiological advantages that enhance their competitiveness compared with C3 plants (Santos et al., 2017). Despite this physiological advantage, grain yield can be significantly reduced depending on the intensity of weed competition (Basso et al., 2018; Galon et al., 2018; Melo et al., 2019).

Since the approval of transgenic maize in Brazil, the use of these hybrids has increased substantially (Farias et al., 2014). The market offers hybrids tolerant to glyphosate, glufosinate ammonium, and combinations of both herbicides. Consequently, the adoption of such hybrids enables the post-emergence use of glyphosate, a broad-spectrum herbicide, thus providing alternative management strategies for farmers. Additionally, these tolerant cultivars bring economic benefits by reducing losses caused by herbicide drift and soil-persistent herbicides (López-Ovejero et al., 2003; Silva et al., 2020).

Glyphosate (N-phosphonomethyl glycine) plays a key role in global weed management as an alternative control method across various crops (Brito et al., 2018; Santos et al., 2022). In plants, this herbicide inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), disrupting the synthesis of essential aromatic amino acids (phenylalanine, tyrosine, and tryptophan). These amino acids are precursors of other important compounds such as lignin, alkaloids, flavonoids, and benzoic acids, leading to plant death (Radwan and Fayez, 2016).

In maize, weed control can be performed either mechanically or chemically. However, it remains unclear whether the superficial cutting or disruption of maize roots caused by the blade of a mechanical hoe could impair crop development and yield, as reported for other crops (Muliele, 2020).

The chemical hoe represents an alternative to the manual mechanical hoe for chemical weed control (Pereira et al., 2019). Its principle involves the use of contact-type herbicide applicators without spraying, consisting of tubes that store the herbicide solution, which - by gravity - moistens a polyester cord. The saturated cord enables contact application without the need for spraying (Peres, 2008).

In experiments involving herbicide use, it is common to include a treatment in which maize is kept free from weed interference throughout its growth cycle. To achieve this, manual mechanical weeding is typically used to keep the plots free from competition. Given this context, the present study aimed to evaluate whether weed management at different stages, using mechanical hoeing and/or a chemical hoe, affects maize crop development.

2. Material and Methods

The experiment was conducted in the experimental area of the Federal University of Jataí (UFJ), located at 17°51’53” S and 51°42’52” W, at an average altitude of 675 m above sea level, in the western region of the state of Goiás, approximately 320 km from the state capital. The soil in the experimental area was classified as a dystroferric Red Latosol (Santos et al., 2018). Climatic data on rainfall and temperature recorded during the experiment are presented in Figure 1. From February 1 to July 31, 2020, total rainfall was 488.8 mm, with an average temperature of 21.95 °C, a maximum of 37.4 °C, and a minimum of 13.1 °C, according to INMET (2020) (Figure 1).

Soil samples were collected from the 0–20 cm layer for physical and chemical characterization, yielding the following results: pH (H2O) = 5.8; P (mg dm^{-3}) = 4.9; K^+ (cmolc dm^{-3}) = 119.1; Ca^{2+} (cmolc dm^{-3}) = 2.2; Mg^{2+} (cmolc dm^{-3}) = 1.0; V (%) = 38.8; organic matter (g dm^{-3}) = 35.2; sand (g kg^{-1}) = 172; silt (g kg^{-1}) = 408; and clay (g kg^{-1}) = 420. The area remained fallow after soybean harvest, favoring the enrichment of the weed seed bank. A visual survey indicated a predominance of *Digitaria horizontalis* (crabgrass), with lesser occurrences of *Commelina benghalensis* (dayflower), *Urochloa ruziziensis* (brachiaria), and *Cenchrus echinatus* (sandbur).

The experiment was carried out under second-season conditions, following a randomized complete block design in a 2 × 4 factorial arrangement. Treatments combined two weed control methods (mechanical hoe and chemical hoe) at four different timings (10, 20, 30, and 60 days after sowing – DAS), with four replications, as shown in Table 1.

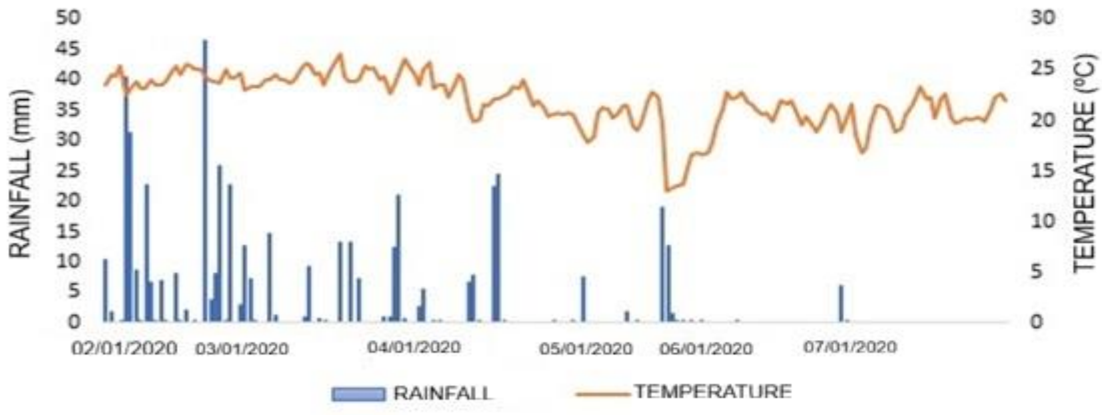

Figure 1. Weekly averages of rainfall and mean temperatures recorded during the trial conducted in Jataí, GO. Source: INMET, 2020.

Table 1. Treatments with different management times and types of weeding.

DAS	Weeding Method	Product (dilution v/v)
10	Manual	Hoe
	Chemical	Glyphosate 5:1
20	Manual	Hoe
	Chemical	Glyphosate 5:1
30	Manual	Hoe
	Chemical	Glyphosate 5:1
60	Manual	Hoe
	Chemical	Glyphosate 5:1

*Days after sowing (DAS).

The maize hybrid MG545PW was sown on February 17, 2020, at a density of three seeds per meter, with 0.45 m row spacing, targeting a final stand of 65,000 plants per hectare. Basal fertilization consisted of 380 kg ha^{-1} of NPK 08-20-18 plus 0.3% micronutrients (FTE), applied in the sowing furrow. Topdressing was performed using 220 kg ha^{-1} of urea (45% N), distributed manually with a wheel-driven applicator when plants reached the four fully expanded leaf stage.

Weed management using both the chemical and mechanical hoes was performed on the same day. The herbicide used in the chemical hoe was glyphosate (Roundup Transorb R, 480 g a.e. L^{-1}), diluted at a 1:5 v/v ratio, and applied in the morning (08:00 h). The chemical hoe is an instrument made of PVC tubing, in which the herbicide solution is stored inside the handle. The solution flows by gravity to a polyester-cotton segment (rope section) that remains saturated, enabling contact-based herbicide application without spraying (Figure 2).

Figure 2. Hoes used in conducting the experiment: mechanical hoe (left) and chemical hoe (right) used in the research.

At the tasseling stage, maize morphological traits such as plant height and stem diameter were evaluated. Plant height was measured on ten randomly selected plants per experimental unit using a ruler graduated in centimeters, from the soil surface to the ligule of the flag leaf. Stem diameter was measured with a digital caliper (in millimeters) at the first internode, 0.05 m above the soil surface. Harvesting was carried out manually, collecting all ears from an 8-meter row segment per plot. The following yield components were measured: number of grain rows per ear, number of grains per row, ear length, ear diameter, and grain yield. Grain yield was extrapolated to kg ha^{-1} and adjusted to 14% moisture content.

The data were subjected to analysis of variance (ANOVA), and when significant differences were detected, means were compared using the Scott-Knott test at a 5% significance level, employing the AGROESTAT software (Barbosa and Maldonado Jr., 2015).

3. Results and Discussion

Maize plant growth was not affected by the weed control method (Table 2). However, hoeing performed chemically with glyphosate reduced stem diameter compared with plots where weeds were managed only by mechanical hoeing.

The reduction in stem diameter caused by herbicide application is an important physiological factor, since in addition to providing structural support, the maize stem serves as a storage organ for nutrients and water used throughout different growth stages (Carmo et al., 2012; Silva et al., 2024).

According to Rockenbach et al. (2017), stem diameter correlates positively with crop yield because the maize stem accumulates a large portion of the starch destined for grain formation during the vegetative stage.

Studies have shown that transgenic maize exhibits significant changes in enzymatic activity related to glycolysis and the citric acid cycle, leading to imbalances in the plant’s energy metabolism (Mesnage et al., 2016; Liu et al., 2015; Zanatta et al., 2020). In addition, increases in oxidative stress-related compounds such as polyamines and alterations in glutathione metabolism have been reported (Mesnage et al., 2016; Zanatta et al., 2020). These changes suggest that the expression of EPSPS under glyphosate exposure induces metabolic adjustments, possibly increasing the plant’s energy expenditure to maintain cellular homeostasis (Mesnage et al., 2016; Zanatta et al., 2020; Chen et al., 2025).

Therefore, the reduction in maize stem diameter in treatments receiving herbicide application was likely due to the additional metabolic cost associated with detoxification processes. Moreover, mechanical hoeing immediately removes all weeds from the area, promptly reducing competition with the crop, whereas chemical control requires some time for full weed suppression.

Weed management timing significantly influenced maize development (Table 2). Weed competition reduced stem diameter from 30 DAS onward and plant height from 60 DAS onward. These differences indicate that delayed control and prolonged coexistence with weeds resulted in reduced metabolic performance due to competition for nutrients, light, and water, directly leading to yield loss.

These findings align with those of Melo et al. (2019), who reported that weed control in maize should be performed early in the crop’s development to minimize productivity losses.

Table 2. Morphological characteristics of corn grown under different weed management methods and timings, Jataí, GO, 2020.

	Variables	**Morphological Characteristics**	
		Plant height (cm)	Stem diameter (mm)
F (Calculated)	Types of Weeding (TW)	0.10^{ns}	11.69*
	Weeding Timings (WT)	13.08*	4.17*
	TW × WT	2.87^{ns}	1.99^{ns}
Types of Weeding (TW)	Mechanical Hoe	174.57 a	22.96 a
	Chemical Hoe	174.16 a	21.68 b
Weeding Timings (WT)	10 DAS	178.51 a	22.99 a
	20 DAS	176.26 a	22.91 a
	30 DAS	175.05 a	21.98 b
	60 DAS	167.65 b	21.40 b
CV%	---	4.48	4.09

^{ns} Not significant; *Significant; **Means followed by the same letter in the same column do not differ from each other, according to the Scott & Knott test (p<0.05); DAS – days after sowing.

Ear length (EL) and ear diameter (ED) were affected by both the type and timing of weed management (Table 3). Higher values were observed under mechanical hoeing. Ear development was reduced when management was performed from 30 DAS onward.

Ear length is an important trait as it correlates with the number of kernels per row (Kappes et al., 2009), directly influencing maize productivity.

The reductions in EL and ED were attributed to longer periods of competition between maize and weeds, which decreased water and nutrient availability, particularly due to the inefficiency of controlling *Commelina benghalensis* (dayflower), a species tolerant to glyphosate (Monquero et al., 2004; Dias et al., 2013).

Table 3. Productive characteristics of corn grown under different weed management methods and timings. Jataí, GO, 2020.

	Variables	Corn Plant Production Traits				
		EL (mm)	ED (mm)	NGR	NGPR	Productivity (kg ha^{-1})
F (Calculated)	Types of Weeding (TW)	38.79**	37.0**	6.00^{ns}	0.07^{ns}	0.89^{ns}
	Weeding Timings (WT)	7.77**	7.98**	1.78^{ns}	0.38^{ns}	25.84**
	TW × WT	2.58^{ns}	2.49^{ns}	0.67^{ns}	0.77^{ns}	0.30^{ns}
Types of Weeding (TW)	Mechanical Hoe	123.08 a	122.50 a	15.53 a	32.23 a	7496 a
	Chemical Hoe	114.66 b	114.93 b	15.08 a	32.07 a	7370 a
Weeding Timings (WT)	10 DAS	122.00 a	120.87 a	15.33 a	32.31 a	7696 b
	20 DAS	122.16 a	122.37 a	15.66 a	32.54 a	8231 a
	30 DAS	116.50 b	116.62 b	15.33 a	32.11 a	7147 c
	60 DAS	114.83 b	115.00 b	15.00 a	31.64 a	6657 d
CV%	---	2.78	2.93	3.26	4.68	5.09

^{ns} Not significant; *Significant (p<0.05); **Highly significant (p<0.001); Means followed by the same letter in the same column do not differ from each other, according to the Scott & Knott test; DAS – days after sowing; EL – ear length; ED – ear diameter; NGR – number of grain rows; NGPR – number of grains per row.

The number of kernel rows per ear and the number of kernels per row were not influenced by the weed control method or management timing (Table 3). Although these yield components are key determinants of maize productivity, the crop's yield potential is established well before the reproductive stage (Magalhães and Durães, 2006). Therefore, even in treatments where weed management was delayed, there was no impairment in the number of rows or kernels per row in maize ears.

The type of hoeing did not influence maize grain yield (Table 3), indicating that, in the short term, the superficial soil disturbance caused by mechanical hoeing does not harm the crop. Therefore, the use of mechanical hoeing in experimental plots kept weed-free can be adopted without detrimental effects on maize performance. These results corroborate those of Antuniassi and Furlani Júnior (1994), who reported no differences in yield between mechanical and chemical hoeing.

Weed management timing significantly affected maize grain yield. The highest yield (8,231 kg ha^{-1}) was obtained when management was performed at 20 DAS. Early weed control (10 DAS) reduced maize yield by 6.5% compared with the highest-yielding treatment (20 DAS); however, no morphological changes were observed in plant development (Table 1), indicating that initial weed suppression was effective. Nonetheless, the existing soil seed bank and the absence of herbicide residual activity allowed the emergence of new weed seedlings that later competed with the crop during the reproductive stage, negatively impacting grain yield.

In general, delayed weed management between 30 and 60 DAS caused greater yield losses of 13.17% and 19.12%, respectively. Therefore, both early and late interventions, outside the optimal 20 DAS window, resulted in reduced maize productivity, demonstrating that the timing and duration of weed competition directly affect grain yield. These findings are consistent with those reported by Pitelli (1985) and Galon et al. (2021).

4. Conclusions

Mechanical hoeing does not impair the grain yield of the maize hybrid compared with chemical hoeing;

Chemical hoeing affects morphological traits of the crop but does not compromise yield;

Maize grain yield decreases with delayed weed management.

Authors' Contribution

Conceptualization and methodology: Guilherme Alves Ferreira, Paulo César Timossi. Data collection and curation: Guilherme Alves Ferreira, Luís Antônio de Sousa Lima, Eduardo Helder Horácio, Paulo César Timossi. Statistical analysis: Guilherme Alves Ferreira.

Data interpretation and writing: Guilherme Alves Ferreira, Fenelon Lourenço de Sousa Santos, Paulo César Timossi. Original draft preparation and reviewing: Fenelon Lourenço de Sousa Santos, Paulo César Timossi. Review and editing: Fenelon Lourenço de Sousa Santos, Paulo César Timossi. All authors read and approved the final version ofthe manuscript.

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