

Interference of post-emergent herbicides with wheat (*Triticum aestivum* L.) productivity parameters

Interferência de herbicidas pós-emergentes sobre parâmetros produtivos do trigo (*Triticum aestivum* L.)

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ABSTRACT

Wheat is the most important income-generating crop in southern Brazil during the cold season. It also contributes to the crop rotation system and increases the yield of successive crops. During its growth cycle, herbicides are used to control weeds, which are the main factor limiting wheat productivity. Further, high costs of weed control directly affect crop economic returns. The objective of this study was to evaluate the effect of the application of two herbicides, namely, 2,4-D and iodosulfuron-methyl, on the productivity of two wheat cultivars during the nine different stages of crop development. The most suitable crop stage for herbicide application, as described in the corresponding label on the package, is at the beginning of tillering. 2,4-D had a significant impact on productivity parameters, reducing the number of tillers, the number of ears, and the number of tillers without grains, while increasing the number of tillers without ears and ears without grains, indicating greater phytotoxicity and, ultimately, reducing crop productivity. Conversely, iodosulfuron-methyl showed greater selectivity to the wheat cultivars tested and caused a much lesser impact on the productivity parameters measured.

Keywords: phytotoxicit, 2,4-D, iodosulfuron-methyl, TBIO Sinuelo, TBIO Toruk

RESUMO

O trigo é a principal cultura geradora de renda no Sul do Brasil durante a estação fria, contribuindo ainda para o sistema de rotação de culturas e elevando o rendimento de culturas em sucessão. Durante seu ciclo de crescimento, os herbicidas são utilizados para controlar as ervas daninhas, que são o principal fator limitante da produtividade. Além disso, os altos custos para o controle de ervas daninhas afetam diretamente os retornos econômicos das culturas. O objetivo deste estudo foi avaliar o efeito da aplicação de dois herbicidas, o 2,4-D e o iodosulfuron-methyl, sobre a produtividade de duas cultivares de trigo durante nove diferentes fases de desenvolvimento da cultura. O estágio de aplicação mais indicado para a utilização dos herbicidas se assemelha ao descrito em bula, sendo no início do perfilhamento. O herbicida 2,4-D promove impactos mais significativos nos parâmetros produtivos, reduzindo o número de perfilhos, o número de espigas e o número de espigas sem grãos, aumentando o número de perfilhos sem espigas e espigas sem

grãos, ocasionando uma maior fitotoxicidade e, ocasionando a redução na produtividade da cultura. Em contrapartida, o iodosulfuron-methyl apresentou maior seletividade para as cultivares de trigo avaliadas e causou menor impacto sobre os parâmetros de produtivos avaliados.

Palavras-chave: fitotoxicidade, 2,4-D, iodosulfuron-methyl, TBIO Sinuelo, TBIO Toruk

1 INTRODUCTION

According to USDA data (CONAB, 2020), wheat (*Triticum aestivum* L.) was grown in over 220 million hectares worldwide and the global production exceeded 770 million tons in the last cropping season. Wheat contributes approximately 20% of the total calories and proteins in the global diet. Further, wheat demand is projected to increase worldwide by approximately 60% by 2050 (Shiferaw et al., 2013). In Brazil, the area under wheat cultivation is approximately 2.3 million hectares, for a total production of over 6 million tons year⁻¹, which is approximately 50% of the 12 million tons consumed annually (CONAB, 2021). Furthermore, the southern region of Brazil accounts for approximately 90% of the national production of this grain (CONAB, 2021b), contributing to the crop rotation system and increasing the yield of successive crops, which makes it one of the main income-generating crops during the cold season in the region (Lamego et al., 2013; Pereira et al., 2017).

During the wheat growth cycle, edaphic, biological, and climatic factors interfere with final crop yield. Among the biological factors, weeds constitute the most important limiting factor for high productivity, as they can reduce crop yield by up to 40% and significantly increase total production cost, thereby evidencing the need for weed control (Oerke, 2006; Jabran, 2017).

Chemical weed control is the most effective weed management strategy, as it reduces management costs, requires less labor, reduces damage to soil structure, and allows soil water conservation (Chauhan et al., 2012; Gianessi, 2013). Two herbicides, 2,4-D and iodosulfuron-methyl, are most commonly used for the control of magnoliopsids, and oats and ryegrass, respectively (Rodrigues & Almeida, 2011; Karpinski, 2018). However, the selective use of herbicides depends on variation in herbicide tolerance and on crop growth stage (Rosinger, 2014).

The objective of this study was to evaluate the effect of 2,4-D and iodosulfuron-methyl applied at nine different developmental stages in two wheat cultivars, namely,

TBIO Toruk and TBIO Sinuelo. Visual phytotoxicity and the main parameters used to estimate crop productivity were recorded.

2 METHODOLOGY

Two greenhouse experiments were conducted in 2018 and 2020 using cultivars TBIO Toruk and TBIO Sinuelo, respectively. The experimental units consisted in 2.3 gallon pots, (0.23 m high, 0.26 m upper diameter and 0.19 m lower diameter). Initially, 10 seeds were sown per pot and after seedling emergence, thinning was performed leaving five seedlings per pot. Each experiment was laid in a completely randomized blocks design with 19 treatments, including a control without herbicide application, nine 2,4-D, and nine iodosulfuron-methyl treatments, and four replications. Herbicides were applied at 7, 14, 21, 28, 35, 42, 49, 56, and 63 days after emergence (DAE).

According to the Zadoks' decimal scale, the developmental stages of both cultivars at 7, 14, 21, 28, 35, 42, 49, 56, and 63 DAE were: 10 (first leaf outside the coleoptile), 13 (third leaf unfurled), 21 (main stem plus one tiller), 23 (main stem plus 3 tillers), 25 (main stem plus 5 tillers), 27 (main stem plus 7 tillers), 31 (first detectable node), 37 (visible leaf banner), and 43 (beginning of budding), respectively.

A 502.5 g ae ha⁻¹ dose of 2,4-D was attained by applying 0.75 L ha⁻¹ of the commercial herbicide Aminol[®] 806, as indicated in the product label. Furthermore, 100 g ha⁻¹ (5 g ae ha⁻¹ of the active ingredient, iodosulfuron-methyl) of herbicide Hussar[®] was used for treatment. The two herbicides were applied using a 2-L CO₂ pressurized costal sprayer, with a sprayer volume of 150 L ha⁻¹. Cultivar TBIO Toruk was sown in 2018 and TBIO Sinuelo in 2020. Sowing and management, including fertilization, weed, pest, and disease control, followed the technical recommendations for the crop.

The evaluation of the phytotoxicity effect of herbicides was based on visual observation of characteristic symptoms, such as leaf chlorosis, leaf epinasty, stem burning, defective ears, curled leaves, retention of the ears in the stem after elongation, crooked ears, apex attached to the stem by spikes or leaves, and plant death. A scale of 0 to 100 was used for visual evaluation of phytotoxicity, where 0 indicated no visual phytotoxic effects and 100 indicated plant death.

Harvest was performed manually, as well as threshing of the ears and measurement of the yield components. The parameters evaluated were visual phytotoxicity at 7 days after the application of treatments, number of tillers per plant,

number of ears per plant, number of tillers without ears, number of grains per ear, number of grainless ears, 1000-grain weight, and total yield per unit area (kg ha^{-1}).

The data obtained were checked for homogeneity of variance and, subsequently, submitted to analysis of variance at 5% probability, using the software "Assistat 7.7 beta" (Silva & Azevedo, 2016); significant effects were verified for the evaluated parameters, and means were compared by the mean grouping test proposed by Skott-Knott.

3 RESULTS AND DISCUSSION

Phytotoxicity

Herbicide application causes crop toxicity and requires enzymatic metabolism for inactivation or hydroxylation of the herbicide molecules into non-toxic products before it reaches the site of action in the cell and causes damage to the plant. This herbicide inactivation is energetically costly, can compromise crop development and, consequently, reduce final productivity (Dias et al., 2017; Queiroz, et al., 2017; Rubenich et al., 2017). Phytotoxicity of 2,4-D and iodosulfuron-methyl at 7 days after treatment application (7 DAT) was less than 10%, consistently with results reported by Piasecki et al. (2017). Both herbicides can be considered selective for wheat; however, they promoted different results and had different phytotoxic effects (Table 1). Further, more pronounced phytotoxic were observed at 7 and 28 DAE (Table 2).

Table 1. Significance of the F-test, response of the evaluated productivity parameters in relation to cultivar, herbicide and growth stage

FACTORS	CULTIVAR TBIO TORUK (Exp. 1 - 2018)			CULTIVAR TBIO SINUELO (Exp. 2 - 2020)		
	HERBICIDE	DEVELOPMENT STAGE	HERBICIDE X STAGE	HERBICIDE	DEVELOPMENT STAGE	HERBICIDE X STAGE
Phytotoxicity	**	**	**	**	**	**
Number of tillers	ns	**	ns	ns	**	ns
Number of ears	ns	**	*	ns	**	ns
Tillers without ears	**	**	**	*	ns	ns
Grainless ears	**	**	**	**	**	**
1000-grain weight	ns	*	ns	*	**	**
Productivity (kg ha^{-1})	ns	ns	ns	**	**	**
Grains per ear	ns	**	ns	ns	**	**

** : 1% significance level; * : 5% significance level; ns: not significant

Table 2. Interaction of the different factors with the evaluated yield components

FACTORS	Phytotoxicity	Number of tillers	Number of ears	Tillers without ears	Grainless ears	Thousand seed weight	Productivity (kg ha ⁻¹)	Grains per ear
CULTIVAR TBIO TORUK (Exp. 1 – 2018)								
2,4-D	1,5 b	8,9 a	8,7 a	0,2 b	0,2 b	39,2 a	3425,2 a	34,2 a
Iodosulfuron	0,5 a	8,9 a	8,8 a	0,0 a	0,0 a	38,6 a	3596,2 a	35,8 a
Control	0,0 a	11,1 a	11,1 a	0,0 a	0,0 a	37,4 b	3565,0 a	32,8 b
7 DAE	3,2 c	8,6 b	8,5 b	0,1 a	0,1 a	40,1 a	3435,0 a	33,6 b
14 DAE	1,7 b	9,1 b	8,7 b	0,3 b	0,3 b	37,6 b	3360,0 a	34,0 b
21 DAE	1,2 b	8,2 b	8,0 b	0,1 b	0,2 b	38,6 b	3568,1 a	37,1 a
28 DAE	1,0 b	8,7 b	8,6 b	0,1 a	0,1 a	37,8 b	3555,0 a	36,6 a
35 DAE	0,7 a	9,0 b	8,9 b	0,1 a	0,1 a	38,4 b	4085,6 a	39,8 a
42 DAE	0,6 a	8,5 b	8,3 b	0,2 b	0,2 b	39,0 a	3390,0 a	35,0 b
49 DAE	0,6 a	9,1 b	9,0 b	0,1 a	0,1 a	39,1 a	3690,0 a	34,9 b
56 DAE	0,5 a	8,3 b	8,1 b	0,1 a	0,1 a	40,1 a	3307,0 a	33,8 b
63 DAE	0,3 a	8,1 b	8,1 b	0,0 a	0,0 a	40,6 a	3150,0 a	32,2 b
CULTIVAR TBIO SINUELO (Exp. 2 – 2020)								
2,4-D	2,9 b	14,8 a	13,1 a	1,7 b	1,1 b	43,1 a	3915,8 b	23,9 a
Iodosulfuron	1,6 a	14,8 a	13,6 a	1,1 a	0,5 a	41,8 b	4389,0 a	24,1 a
Control	0,0 a	17,9 a	16,7 a	1,0 a	0,6 a	37,0 c	4950,0 a	26,6 a
7 DAE	4,1 b	11,4 b	10,6 d	0,8 a	0,1 a	41,7 b	3356,8 c	24,6 a
14 DAE	7,0 c	14,0 b	12,6 c	1,4 a	0,3 a	44,3 a	3485,4 c	20,5 b
21 DAE	4,2 b	15,0 b	13,0 c	1,9 a	0,0 a	39,6 c	4237,9 b	25,7 a
28 DAE	1,9 a	13,8 b	12,3 c	1,4 a	0,3 a	42,1 b	4033,2 b	24,9 a
35 DAE	1,0 a	14,5 b	13,6 c	0,8 a	0,3 a	38,8 c	4083,1 b	25,3 a
42 DAE	1,3 a	13,9 b	12,7 c	1,2 a	0,6 a	44,3 a	4771,1 a	28,0 a
49 DAE	1,0 a	14,7 b	12,9 c	1,8 a	1,1 a	44,9 a	4132,7 b	22,8 b
56 DAE	1,0 a	16,4 a	14,6 b	1,8 a	2,1 b	47,0 a	4229,1 b	19,9 b
63 DAE	1,0 a	16,6 a	14,7 b	1,7 a	2,3 b	44,9 a	4244,6 b	21,6 b

CV: 14,37%

Means within columns followed by different lowercase letters and means within rows followed by different uppercase letters are significantly different, as per the Scott-Knott test for comparison of means (5% level of significance)

Both cultivars showed visual damage after 7 DAA in all treatments except the control; however, in subsequent evaluations, there was no evolution in phytotoxicity caused by the treatments. Cultivars TBIO Toruk and TBIO Sinuelo showed greater phytotoxic effects when herbicides were applied at 14 and 7 DAE, respectively. In general, the more advanced the vegetative wheat growth stage, the less the visual damage caused by herbicide application in both cultivars. Furthermore, 2,4-D caused more damage than iodosulfuron-methyl, and cultivar TBIO Toruk showed worse phytotoxic symptoms than cultivar TBIO Sinuelo (Table 2).

Number of tillers per plant

Tillering is an important agronomic trait that determines plant architecture and the number of ears produced from a single seed in a wheat crop (Zhao et al., 2019). Stem branching is regulated by several plant hormones, and its permanence, development, and fertility is related to the nitrogen supply to the plants (Ferrari et al., 2016). Genotypes with high tillering potential present a longer period of tiller production because of their longer developmental cycle, also characterized by a greater senescence of tillers, as shading and competition reduce the survival of these propagules (Valério et al., 2008).

In this study, no interaction between herbicides and no difference between herbicides for productivity parameters were observed (Table 1 and Table 2). Cultivar TBIO Toruk did not respond differently to the moment of application of herbicide treatments; however, it showed greater production of tillers when no herbicides were applied. In contrast, cultivar TBIO Sinuelo not only showed a higher average number of tillers per plant than TBIO Toruk but also an increase in the number of tillers per plant, with the most advanced stage of crop development at which herbicides were applied. Treatments with herbicide application at 56 and 63 DAE did not significantly differ from the control, thus indicating that herbicide application during the more advanced stages of growth did not interfere with the productivity parameters.

The difference in number of tillers per plant between the two cultivars is common and variable, as each wheat cultivar presents unique characteristics (Fioreze et al., 2019). With respect to the applied herbicides and their effect on the number of tillers, cultivar TBIO Toruk did not exhibit differences as to the period at which treatments were applied, and hence, it may be considered a cultivar with good plasticity, in agreement with the results of Piaseck et al. (2017), who used similar treatments. In contrast, herbicide application at 7 DAE interfered most negatively with the number of tillers per plant in cultivar TBIO Sinuelo, likely because the herbicide interferes during the period of tiller emission and because the inactivation or hydroxylation of the herbicide molecule implies a high energy cost (Mithila et al., 2011).

Number of ears per plant and number of tillers with ears

Compared to the control treatment, the number of ears per plant was reduced, regardless of cultivar and treatment; further, no difference between herbicides was observed (Table 1). In general, the number of ears per plant varied according to the number of tillers per plant, as the average number of tillers without ears was low. 2,4-D

promoted a greater variation in the number of ears per plant. Cultivar TBIO Sinuelo showed higher interference by herbicide treatments on the number of ears per plant than cultivar TBIO Toruk (Table 2).

Cultivar TBIO Sinuelo had more tillers but developed a greater number of tillers without ears. As tillers originate from the mother plant, they emerge late. Therefore, they have a lower capacity for competition and are less vigorous and more susceptible to senescence, such that they cannot compensate for a low plant population density, and may in fact interfere in harvest due to the irregularity of plant growth within the population (Fioreze et al., 2019).

Number of grains per ear, grainless ears, productivity and 1000-seed weight

The number of grains per unit area and the average grain weight are considered the most important determinants of crop productivity (Vesohoski et al., 2011). However, great variation can be observed among genotypes for the parameters that interfere with productivity in each case (Pimentel et al., 2015; Fioreze et al., 2019). In general, cultivar TBIO Toruk produced a smaller number of tillers but developed ears with higher average grain weight, which compensated for the low production, consistently with previous observations by Pires et al. (2011), who showed that this compensatory effect aims to maintain the final grain yield of the crop (Table 2). In contrast, cultivar TBIO Sinuelo produced a higher average number of tillers but a lower number of grains per ear, in the absence of herbicide treatment (Table 1), as well as a greater number of ears without grain under 2,4-D treatments, which reduced the number of ears with grain, especially if herbicide was applied closer to the reproductive stage (Table 2). Further, grain weight is influenced by the average amount of seeds in each ear, such that, a lower grain production in the ear promotes a higher weight of the individual grains. This is explained by the effect of the herbicide on the plant, which interferes with photosynthesis and reduces energy conversion, resulting in lower production of photoassimilate that is essential for grain filling (Dias et al., 2017).

The average yield was higher when iodosulfuron-methyl herbicide was used, possibly because of its lower influence on the productivity parameters of the crop. The best crop growth stage for the application of herbicides is the beginning of tillering, as described in the labels on herbicide packages. If herbicides are applied too early or closer to the reproductive period, they tend to have a greater impact on the parameters that determine crop productivity. Cultivar TBIO Sinuelo showed higher yield than TBIO

Toruk, however, it produced a lower average number of grains per ear and a lower 1000-grain weight, which was compensated by the larger number of ears per plant (Table 2).

4 CONCLUSIONS

Herbicide 2,4-D had a greater impact on wheat productivity parameters than iodosulfuron-methyl, as it reduced the number of tillers per plant, the number of ears per plant, and the number of grains per plant, ultimately reducing productivity, thus evidencing a greater phytotoxic effect. Furthermore, 2,4-D increased the number of tillers without ears and the number of empty ears, especially when the herbicide was applied after tillering. The treatments applied at 21, 35, and 42 DAE, as well as the control, demonstrated higher productivity than the rest of the treatments evaluated here.

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