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Can spraying tip and tank mix affect weed control and herbicide selectivity in onion culture?

A ponta de pulverização e a mistura em tanque podem afetar o controle de plantas daninhas e a seletividade dos herbicidas para a cultura da cebola?

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RESUMO

O objetivo do trabalho foi avaliar o controle de plantas daninhas na cultura da cebola, em função da ponta de pulverização e mistura de herbicidas em tanque. O experimento foi conduzido em área comercial, no município de Imbuia, SC, em delineamento de blocos casualizados com tratamentos organizados em esquema fatorial (2 x 4) + 2 e quatro repetições. Os fatores estudados foram os modelos de pontas de pulverização, TT 110 015 e ADIA 110 02, e os herbicidas: ioxynil + flumioxazin (IO + FL; 250 + 75 g i.a. ha^{-1}), ioxynil + pendimethalin (IO + PE; 250 + 1.200 g i.a. ha^{-1}), diuron + flumioxazin (DI + FL; 500 + 75 g i.a. ha^{-1}) e diuron + pendimethalin (DI + PE; 500 + 1.200 g i.a. ha^{-1}). Adicionalmente, manteve-se duas testemunhas, com e sem capinas. As variáveis avaliadas foram controle de *Amaranthus deflexus*, *Sonchus oleraceus*, *Polygonum persicaria* e *Coronopus didymus,* fitointoxicação, estande de plantas, diâmetro e peso médios de bulbos, produtividade comercial e produtividade total. Todos os tratamentos controlaram as espécies *A. deflexus*, *S. oleraceus* e *P. persicaria*. Para o *C. didymus,* o controle foi inferior a 81% ao se usar DI + PE aplicado com a ponta ADIA 110 02. A fitointoxicação foi superior a 18 e 8% aos 7 e 14 dias após a aplicação (DAA), respectivamente envolvendo os herbicidas IO + FL e DI + FL. As pontas de pulverização e as misturas em tanque de herbicidas não influenciaram nos componentes de produção e na produtividade de bulbos. As misturas em tanque avaliadas foram eficientes no controle das plantas daninhas e seletivos para cultura da cebola, independentemente da ponta de pulverização.

PALAVRAS-CHAVE: *Allium cepa*; inibidores do fotossistema II; pontas de jato plano; tecnologia de aplicação.

ABSTRACT

This paper aimed the evaluation of weed control in onion crop regarding spray tips and herbicide tank mixture. It was conducted in a commercial area in Imbuia municipality, in SC, Brazil. Randomized block experimental design was used, with treatments organized in factorial scheme (2 x 4) + 2, and four repetition. The treatments consisted in two spraying tips models: TT 110 015 and ADIA 110 02, and four herbicide mixtures: ioxynil + flumioxazin (IO + FL; 250 + 75 g i.a. ha^{-1}), ioxynil + pendimethalin (IO + PE; 250 + 1.200 g i.a. ha^{-1}), diuron + flumioxazin (DI + FL; 500 + 75 g i.a. ha^{-1}) e diuron + pendimethalin (DI + PE; 500 + 1.200 g i.a. ha^{-1}). Additionally, two controls, with and without deweeding were kept. Assessed variables were *Amaranthus deflexus*, *Sonchus oleraceus*, *Polygonum persicaria* and *Coronopus didymus* control; phytotoxicity, plant stand, bulb's diameter and average weight and, commercial and total yield. All treatments were effective controlling *A. deflexus*, *S. oleraceus* and *P. persicaria*. *C. didymus* controls were lower than 81% for DI + PE treatment applied with ADIA 110 02 spraying tip. The phytotoxicity was higher than 18% and 8 % at 7 and 14 Days After Spraying (DAS) respectively, involving herbicides IO + FL and DI + FL. Spraying tips and herbicide tank mixtures did not influence yield components or bulb productivity. All tank mixtures were efficient to controlling weed plants, and selective for onion crop, regardless the spraying tip.

KEYWORDS: *Allium cepa*; inhibition of photosynthesis; flat fan spraying tip; spraying technology.

INTRODUCTION

In 2022, Brazil's onion production reached 1.65 million tons, harvested from an area of 48,9 hectares. Of these, the state of Santa Catarina accounts for 29.7% of production and 35.4% of the area, with 492,000 tons harvested from 17,3 hectares, making it the main onion producer in the country (IBGE 2023). Onions have slow initial growth, so competition with weeds hinders their development, either through direct competition for resources or indirectly by hosting pests or diseases (MENEZES JÚNIOR & SGROTT 2016). EPAGRI studies (2013) showed a 57.4% yield loss when weeds competed with onions for up to 60 days after transplanting. Coexistence with weeds during the first 98 days reduced onion crop yields by up to 95% (SOARES et al. 2003).

Conventional weed control in onion cultivation, often done manually or mechanically, is extremely labor-intensive, costly, and inefficient, and may even damage the crop's bulbs. This makes chemical control an important tool in onion production (KUMAR et al. 2022). The effectiveness of chemical control, in turn, is determined by factors such as the amount of active ingredient deposited on the target and the uniformity of coverage, which are directly influenced by the spray nozzles (GRELLA et al. 2020). The choice of spray nozzle plays a crucial role in the effectiveness of pest management, as it influences pesticide droplet size, transfer, deposition on the target, and spray drift during application (WANG et al. 2023). Nozzles that produce fine droplets improve product deposition and coverage on the target, but are more susceptible to losses through evaporation or drift, especially in hot and windy conditions. Tips that generate thicker droplets are less retained on the target, but reduce the potential for losses as they are heavier and carry greater kinetic energy (PRADO et al. 2024, PRIVITERA et al. 2023). In air-induction nozzles, air is drawn into the hydraulic channels through induction holes and mixes with the spray solution. By injecting air into the sprayed liquid, larger droplets less prone to drift are created, which produce smaller droplets upon impact with the target, improving coverage (DE CAUWER et al. 2023).

Tank mixing is defined by Decree No. 4074/2002 as: "the combination of pesticides and related products in the applicator equipment tank, immediately before application" (BRAZIL 2002). When done correctly, it offers operational benefits such as fewer applications, efficient water use, reduced applicator exposure, and potential cost savings. Furthermore, interactions between active ingredients can enhance herbicidal action or broaden the treatment's control spectrum (GAZZIERO 2015, GALON et al. 2021) The recommendation for tank mixtures is regulated by Normative Instruction No. 40 of October 11, 2018 (BRASIL/MAPA 2018), and is permitted in agronomic prescriptions when signed by an Agronomist. Nevertheless, farmers and technicians lack information on physicochemical incompatibilities and the impact of mixtures on pest control, and many questions remain due to the countless possible combinations (OLIVEIRA et al. 2021).

The technology of pesticide application in onion cultivation is an understudied topic in Brazil. In a study, OLIVEIRA NETO et al. (2018) showed that reducing the application rate is a viable alternative for the crop and does not compromise spray deposition or herbicide efficacy. AMLER et al. (2021) showed that the choice of spray nozzle affects product deposition on onions and soil, with air-induction flat fan nozzles and single impact nozzles outperforming standard flat fan and pre-orifice flat fan nozzles.

Based on the hypothesis that the choice of spray nozzle and tank-mixed herbicides can affect weed control and onion crop yield, this study aimed to evaluate weed control in onion cultivation, considering the spray nozzle and herbicide tank mixtures.

MATERIALS AND METHODS

The experiment was conducted in a commercial onion field located in the municipality of Imbuia, Santa Catarina (27°29'17''S, 49°23'16''W, elevation 824 m) from August 2019 to January 2020. The soil in the area was classified as Cambissolo Háplico Tb Distrófico (SANTOS et. al. 2018). The chemical analysis of the soil, carried out in the 0 to 0.2 m layer, had the following characteristics: pH in water of 5.3; clay of 47%; MO of 0.9%; P of 13.1 mg dm^{-3}; K of 213.8 mg dm^{-3}; Al of 0.5 cmol$_c$ dm^{-3}; CTC 19.03 cmol$_c$ dm^{-3} and V% of 72.7. The region's climate was classified as humid subtropical (Köppen-Geiger climate classification: Cfa), with an average annual temperature of 19.1°C and average annual precipitation of 1530 mm (CATONI et al. 2012).

The experimental design used was a randomized complete block design (RCBD) in a factorial arrangement (2 x 4 + 2), with four replications. Two application nozzles (ADIA 110 02 - air-induction flat fan nozzle and TT 110 015 - wide-angle flat impact nozzle) and four tank mixtures of herbicides were evaluated: ioxynil + flumioxazin (250 + 75 g a.i. ha^{-1}), ioxynil + pendimethalin (250 + 1,200 g a.i. ha^{-1}), diuron + flumioxazin

(500 + 75 g a.i. ha^{-1}), and diuron + pendimethalin (500 + 1,200 g a.i. ha^{-1}), applied post-emergence. The commercial herbicides used were Totril®, Diuron Nortox 500®, Flumizyn 500 SC® and Herbadox®. Simultaneously, two control plots were maintained: one with manual weeding to assess potential phytotoxic effects of treatments, and another without weeding to evaluate weed control efficiency on onion productivity. The experimental units consisted of 6 m^2 (2 x 3 m) plots.

Juporanga cultivar seedlings were manually transplanted at a spacing of 0.25 cm between rows and 0.1 cm between plants, resulting in a density of 400,000 plants ha^{-1}. Fertilization was based on recommendations for onion cultivation in the states of Rio Grande do Sul and Santa Catarina (SBCS 2016). Nitrogen was applied at a rate of 120 kg/ha^{-1} (urea - 20 kg at planting + three topdressings of 25, 50, and 25 kg); 160 kg/ha^{-1} of P_2O_5 was applied at planting; and 150 kg/ha^{-1} of K_2O (50 kg/ha^{-1} applied at planting + two topdressings of 50 kg/ha^{-1} each). Pest and disease control was carried out following the farmer's management practices, based on research-backed technical recommendations for onion crop protection (WORDELL FILHO et al. 2006).

The treatments were applied using a CO_2-pressurized backpack sprayer 15 days after transplanting, when the onion seedlings had 3 to 4 leaves. Two spray booms were used for the application, one equipped with four ADIA 110 02 nozzles and the other with four TT 110 015 nozzles. The working pressure was 208 kPa, monitored by a pressure gauge on the spray boom, with a travel speed of 1.0 m s^{-1}, achieving application rates of 210 L ha^{-1} for the ADIA 110 02 nozzle and 145 L ha^{-1} for the TT 110 015 nozzle. Weather conditions during treatment application were monitored using a digital thermo-hygro-anemometer, showing: air temperature of 23°C, relative humidity of 66%, and wind speed of 2.5 km/h^{-1}. The soil was moist at the time of application.

Weed control assessments and phytotoxicity in onion crops were conducted at 7, 14, and 28 days after treatment application (DAT) using visual evaluation based on a percentage scale, where 0% represents no control or phytotoxicity, and 100% represents plant death (KUVA et al. 2016). The weed species whose control was measured were: caruru (*Amaranthus deflexus* - 77 plants m^{-2} and 2 true leaves), serralha (*Sonchus oleraceus* - 13 plants m^{-2} and 2 true leaves), erva-de-bicho (*Polygonum persicaria* - 7 plants m^{-2} and 2 true leaves) and mastruz (*Coronopus didymus* - 100 plants m^{-2} and 1 true leaf). Before harvest, the following parameters were evaluated: plant stand (PS: plants m^{-1}), average bulb diameter (BD: mm), average bulb weight (BW: g), yield of bulbs classified as "box 3" or higher (CY: t ha^{-1}), and total bulb yield (TY: t ha^{-1} - sum of bulbs of all diameters).

The pre-harvest plant stand count was conducted on 1 linear meter of two central rows in each plot. The harvested bulbs were naturally cured for 30 days in a dry, well-ventilated shed without direct sunlight exposure. After curing, the dried bulbs were cleaned and graded as above or below size 3, which has an equatorial diameter of ≥ 51 mm, as recommended (CEAGESP 2021). The weight of the harvested bulbs in the sample was divided by the number of plants to obtain the average bulb weight. The average bulb diameter was determined by measuring the equatorial diameter of 10 randomly selected bulbs per plot. Bulb productivity was estimated by class and presented in tonnes per hectare (t ha^{-1}).

After analysis of variance, no interaction was observed between application tip and tank mixture factors, so the factors were considered separately for statistical analyses. Weed control (%) at 7, 14, and 28 DAA were subjected to Tukey's test ($p>0.05$), as well as the effect of spray nozzle and tank mixture on onion phytotoxicity (%) at 7 and 14 DAA and on onion yield parameters. Additionally, Dunnett's test ($p>0.05$) was used to compare the productive parameters with the unweeded control, to observe potential effects of weed control on productivity; and with the weeded control, to observe possible phytotoxic effects on the onion crop.

RESULTS AND DISCUSSION

At 7 DAA, control was above 92% for caruru and serralha, rising to 100% from 14 DAA and maintained until 28 DAA for all the treatments tested (Table 1). Regarding smartweed, treatments with diuron + pendimethalin (DI + PE) were statistically different from the others, including the weeded control, at 7 DAA, achieving only 56% and 80% control with TT 110 015 and ADIA 110 02 nozzles, respectively.

At 14 DAA, control reached 100% for all treatments, remaining so until 28 DAA. This effect can be attributed to the mode of action of the herbicide pendimethalin (HRAC group 3), which acts more slowly and almost exclusively on the root system, inhibiting microtubule formation and halting cell mitosis during metaphase (MENDES et al. 2022). A similar effect was observed by GUERRA et al. (2020) when using pendimenthalin (1600 g ha^{-1}) on garlic, achieved satisfactory weed control (<80%) at 17 DAA, evolving to excellent control (<95%) by 45 DAA.

Table 1. Control (%) of caruru, serralha, mastruz and erva-de-bicho at 7, 14 and 28 days after treatment (DAA). Imbuia, SC, 2019.

Tip	Herbicide	caruru (%)			serralha (%)		
		7DAA	14DAA	28DAA	7DAA	14DAA	28DAA
TT110015	IO+FL	98 a	100	100	98 a	100	100
TT110015	IO+PE	93 a	100	100	94 a	100	100
TT110015	DI+FL	96 a	100	100	99 a	100	100
TT110015	DI+PE	99 a	100	100	97 a	100	100
ADIA11002	IO+FL	98 a	100	100	98 a	100	100
ADIA11002	IO+PE	92 a	100	100	86 a	100	100
ADIA11002	DI+FL	99 a	100	100	99 a	100	100
ADIA11002	DI+PE	95 a	100	100	97 a	100	100
Weeded witness		100 a	100	100	100 a	100	100
Witness without weeding		0 b	0	0	0 b	0	0
CV (%)		5,6	-	-	7,8	-	-
Tip	Herbicide	mastruz (%)			erva-de-bicho (%)		
		7DAA	14DAA	28DAA	7DAA	14DAA	28DAA
TT110015	IO+FL	92 ab	100 a	100 a	99 a	100	100
TT110015	IO+PE	84 b	91 a	100 a	99 a	100	100
TT110015	DI+FL	89 ab	100 a	100 a	98 a	100	100
TT110015	DI+PE	85 b	100 a	100 a	56 c	100	100
ADIA11002	IO+FL	93 ab	100 a	100 a	98 a	100	100
ADIA11002	IO+PE	87 ab	93 a	97 a	97 a	100	100
ADIA11002	DI+FL	96 ab	100 a	100 a	98 a	100	100
ADIA11002	DI+PE	65 c	78 b	81 b	80 b	100	100
Weeded witness		100 a	100 a	100 a	100 a	100	100
Witness without weeding		0 d	0 c	0 c	0 d	0	0
CV (%)		6,7	5,3	4,1	8,7	-	-

Averages followed by the same letter do not differ according to Tukey's test ($p>0.05$). IO = ioxynil 250 g a.i. ha^{-1}, FL = flumioxazin 75 g a.i. ha^{-1}, PE = pendimethalin 1,200 g a.i. ha^{-1} and DI = diuron 500 g a.i. ha^{-1}.

The lowest control rates were observed for the mastruz weed, particularly with the DI + PE combination applied using the ADIA 110 02 nozzle, which resulted in control levels of 65, 78, and 81% at 7, 14, and 28 DAA, respectively. This treatment was the only one that did not match the hand-weeded control at 28 DAA. This finding corroborates the data obtained by PEZENTI et al. (2020), where mastruz control was not efficient for any of the herbicides tested (ioxynil + clethodim and ioxynil + fluazifop). These same authors demonstrate that the sequential application of pendimethalin significantly improved control, though effectiveness did not exceed 86%. Matruz is a species that is difficult to control in onion growing and has ruderal characteristics, with a short development cycle, rapid diaspore production and a high distribution of resources for reproduction structures (SOARES et al. 2003).

For the tip factor, a statistical difference was observed only for phytotoxicity at 7 DAA, where the ADIA 110 02 nozzle showed greater phytotoxicity than the TT 110 015 nozzle (Table 2). Similarly, AMLER et al. (2021) when comparing four spray tips (MF 110 015, AD 110 015, TT 110 015 and ADIA 110 02), observed that the TT 110 015 and ADIA 110 02 model tips showed higher average spray deposition on the onion and on the ground compared to the other treatments, but they did not differ from each other. The phytotoxicity observed for the tip factor (≤ 12%) can be classified as mild injuries and growth reduction with rapid recovery, with insufficient effects to cause yield reductions, according to the methodology for evaluating phytotoxicity in cultivated plants (SBCPD 1995).

Table 2. Average values of the effect of the spray tip and the herbicide applied on phytointoxication at 7 and 14 DAA (F7 and 14: %), plant stand (EP: plants m^{-1}), average bulb diameter (DB: mm), average bulb weight (PB: g), commercial bulb yield (CO: t ha^{-1}) and total bulb yield (TO: t ha^{-1}). Imbuia, SC, 2019.

Tip	F7	F14	EP	DB	PB	CO	TO
TT 110.015	10,6 b	5,3 a	10,5 a	60,3 a	112,6 a	30,5 a	34,0 a
ADIA 110.02	12,0 a	6,1 a	10,2 a	59,9 a	114,1 a	29,9 a	33,2 a
Herbicide	F7	F14	EP	DB	PB	CO	TO
IO+FL	27,3 a	14,3 a	10,3 a	59,4 a	108,4 a	28,2 a	31,9 a
IO+PE	0,0 c	0,0 c	10,1 a	59,4 a	112,7 a	29,9 a	32,6 a
DI+FL	18,0 b	8,6 b	10,4 a	60,4 a	117,9 a	31,0 a	35,0 a
DI+PE	0,0 c	0,0 c	10,7	61,1 a	114,2 a	31,8 a	34,9 a
CV (%)	15,5	21,4	7,1	4,1	12,2	18,3	13,3

Averages followed by the same letter do not differ according to Tukey's test ($p>0.05$). IO = ioxynil 250 g a.i. ha^{-1}, FL = flumioxazin 75 g a.i. ha^{-1}, PE = pendimethalin 1,200 g a.i. ha^{-1} and DI = diuron 500 g a.i. ha^{-1}.

For the herbicide factor, treatments with ioxynil + flumioxazin (IO + FL) and diuron + flumioxazin (DI + FL) caused phytotoxicity of 27.3 and 18.0% at 7 DAA and 14.3 and 8.6% at 14 DAA, respectively. The comparison of herbicide treatments showed that flumioxazin caused more damage than pendimethalin, which proved to be more selective for onion crops. For all treatments used, productivity indices did not differ, showing that phytotoxicity did not affect the crop's yield potential, regardless of the tip used.

These findings partially support the results observed by HERRMANN et al. (2017) when evaluating three doses of flumioxazin and five tank mixtures for weed control in onions, they observed phytotoxicity of 33% after application of flumioxazin (72 g ha^{-1}) alone and up to 70% after application of flumioxazin in tank mixtures. These same authors report that, despite the injuries, the treatments were effective in controlling pigweed and smartweed, and the variation in onion crop selectivity to flumioxazin may be related to the applied product dose and the crop's developmental stage at the time of use.

OLIVEIRA et al. (2018) observed that doses of 2.5, 5.0, 7.5, and 10 g ha-^{1} of flumioxazin, WP formulation, reduced the yield parameters of seed-propagated onions when applied at the "whip" stage (10 days after emergence). Doses of 7.5 and 10 g ha^{-1} also caused reductions when applied at the 1st and 2nd true leaf stages, while applications from the 3rd true leaf stage onwards did not cause yield reductions, regardless of the dose.

In Table 3, a comparison was made between the treatments and the weeded control (means followed by the same lowercase letter), where the crop was kept weed-free, and the unweeded control (means followed by the same uppercase letter), where the onion remained under weed interference. For all analyzed variables, the treatments showed similar behavior to the weeded control, demonstrating the control efficiency and selectivity of the herbicides used. On the other hand, the observed values differed statistically from the unweeded control, which showed lower averages for all productive variables. Losses of up to 40% in productivity were witnessed by SOUZA et. al. (2020), when weeds were not controlled until 24 days after onion emergence, highlighting the potential for losses due to interference and reinforcing the importance of weed control in onion cultivation.

Table 3. Comparisons between treatments and controls for the variables plant stand (PS: plants m^{-1}), average bulb diameter (BD: mm), average bulb weight (BW: g), marketable bulb yield (MY: t ha^{-1}), and total bulb yield (TY: t ha^{-1}). Imbuia, SC, 2019.

Tip	Herbicide	EP	DB	PB	CO	TO
TT110015	IO+FL	10.3 aA	61.2 aA	111 aA	29.9 aA	32.9 aA
TT110015	IO+PE	10.3 aA	59.8 aA	111 aA	30.7 aA	33.2 aA
TT110015	DI+FL	10.6 aA	59.3 aA	114 aA	29.0 aA	34.5 aA
TT110015	DI+PE	11.0 aA	60.8 aA	113 aA	32.5 aA	35.3 aA
ADIA11002	IO+FL	10.2 aA	57.6 aA	105 aB	26.5 aA	30.8 aA
ADIA11002	IO+PE	9.8 aA	59.1 aA	113 aA	29.0 aA	31.9 aA
ADIA11002	DI+FL	10.2 aA	61.5 aA	121 aA	32.9 aA	35.5 aA
ADIA11002	DI+PE	10.5 aA	61.4 aA	115 aA	31.1 aA	34.4 aA
Weeded witness		9,8 a	61,3 a	128 a	34,1 a	36,0 a
Witness without weeding		9,3 A	48,8 B	79 B	13,4 B	21,3 B

Averages followed by the same lowercase letter do not differ from the weeded control according to Dunnett's test (p>0.05). Averages followed by the same capital letter do not differ from the no-weeding control by Dunnett's test (p>0.05). IO = ioxynil 250 g a.i. ha^{-1}, FL = flumioxazin 75 g a.i. ha^{-1}, PE = pendimethalin 1,200 g a.i. ha^{-1} and DI = diuron 500 g a.i. ha^{-1}.

Although treatments containing flumioxazin showed higher phytotoxicity, no reductions in onion yield parameters were observed, demonstrating that these treatments were selective for onion in the seedling transplant system.

CONCLUSION

Weed control for caruru, serralha, and erva-de-bicho in onion crops was effective regardless of tank mixing or application nozzle type. For mastruz, only the application of diuron + pendimethalin with the ADIA 110 02 nozzle did not achieve 100% control at 28 DAA.

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