

SENSITIVITY OF POTATO CULTIVARS TO FOMESAFEN AND METRIBUZIN

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ABSTRACT: The objective of this research was to evaluate the sensitivity of 3 potato cultivars (different ripening periods) to fomesafen (300 g/ha a.i.) and metribuzin (980 g/ha a.i.) herbicides applied preemergence (PRE). The experiments were conducted during 2020 and 2021 in the Leningrad region of the Russian Federation. The application of herbicides at all three potato cultivars caused slight yellowing of tips of the leaves (less than 5%). This symptom of phytotoxicity was more noticeable in the early season cultivars Udacha (ripening time from 65 days) and Nevsky (ripening time from 75 days). The negative effect of herbicides on plant height was demonstrated in arid conditions (in 2021), when after applying fomesafen and metribuzin there was a significant delay in plant growth in two cultivars (Udacha and Avrora) at 7 and 14 days after emergence (DAE). By 28 DAE, the plant height of all three cultivars after herbicide treatments and in the nontreated check were equalized (differences did not exceed 10%). Despite the observed symptoms of phytotoxicity, none of the herbicide treatments in both years didn't show a statistically significant negative effect of herbicides on potato yield, indicating the high regenerative capacity of potatoes.

KEYWORDS: herbicide, phytotoxicity, crop injury, *Solanum tuberosum*

INTRODUCTION

Potato is an integral part of the diet in countries of the Nordic region (such as Sweden, Norway, Finland, Russia). Climatic conditions in these countries contribute to the wide spread of the crop (relatively short and intense seasons with long day length), as well as specific consumer preferences. At the same time, potato has the highest yield potential of all crops in the Nordic region (Eriksson *et al.*, 2016). One of the important factors limiting potato yields is the presence of weeds on agricultural land (Barbas and Sawicka 2020). Weeds compete for nutrients and negatively effect on plant growth and crop yield (Mondani *et al.*, 2011; Dhaliwal *et al.*, 2021).

Weeds should be controlled in the early growth stages of the crop, when they are most harmful (Karimmojeni *et al.*, 2014). Besides, control of some weeds in the later growth stages is difficult due to their morphological

characteristics, such as deep root system or underground shoots in perennial weeds (Siblani and Haidar 2017). Experiments conducted by Isik *et al.* (2015) showed that the critical period of weed control on potatoes is from 8 to 66 days after emergence. Ignoring weeds during this period can lead to a significant reduction in potato yield and tuber quality.

Weeds can be eliminated from potato plantings at the beginning of the crop's vegetation period by using herbicides, which have become an indispensable and permanent element in potato cultivation technologies. One of the most commonly used herbicides on potatoes is metribuzin. However, despite its high effectiveness against weeds, it can have a negative effect on some potato cultivars (Friesen and Wall 1984; Arsenault and Ivany 1996; Arsenault and Ivany 2001; Alebrahim *et al.*, 2012). Because of this negative effect, there is a search for active ingredients that can improve the existing assortment of herbicides. One of the ways of such improvement is to

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expand the range of protected crops for well-known products.

Fomesafen (PPO Inhibitor (Group 14)), which has residual action, is an effective means to control dicotyledonous weeds in crops (Wu *et al.*, 2018). This herbicide is most widely used in soybean crops, but attempts are being made to use it in other crops as well, including: bean, vegetable soybean, cotton, corn, rice, tomatoes (Wilson 2005; Williams and Nelson 2014; Oliveira Neto *et al.*, 2015; Galon *et al.*, 2018; Sperry *et al.*, 2019; Lawrence *et al.*, 2021; Yu *et al.*, 2021). However, in practice the use of fomesafen in addition to reducing the number of weeds, can also have an adverse effect on protected crops and even on succession crops (Barkley *et al.*, 2016; Li *et al.*, 2018; Schmitt *et al.*, 2019; De Souza Cruz *et al.*, 2020; Chen *et al.*, 2021; Hand *et al.*, 2021). At the same time, fomesafen may be less toxic to crops than other herbicides (chlorimuron-ethyl, glyphosate, paraquat, atrazine) (Do Amaral *et al.*, 2018). Researches have shown that potato resistance to herbicides can be directly related to the characteristics of some cultivars (Wilson *et al.*, 2002; Pszczółkowski *et al.*, 2020). In this regard, the commercial use of fomesafen on potatoes should be preceded by a study of the sensitivity of potato cultivars to this active ingredient. It is important to evaluate such sensitivity compared to metribuzin. The aim of this research was to evaluate the response of three of potato cultivars (different ripening periods) to fomesafen and metribuzin applied preemergence (PRE). Accordingly, the objective of the trials was to assess the effect of herbicides on potato germination, plant height, number of stems and leaves, and crop yield.

MATERIALS AND METHODS

Trials were conducted in 2020 and 2021 in the Leningrad region of the Russian Federation

(59.74 'N, 30.42 'E) on the experimental field of the All-Russian institute of plant protection (VIZR).

Characteristics of the experimental site

The soil of the experimental site was sod-podzolic, with 3.5% organic matter in the arable layer, pH=6.3. Previous crop in both trial years was potato.

Soil treatment included disking, plowing, cultivation, cutting furrows. In spring NPK fertilizer at the rate of 200 kg/ha was applied into the soil before planting potato.

Measures for the maintenance of experimental site

Two hilling and applying 2.5 kg/ha fungicide Ridomil Gold MC, WG (mancozeb, 640 g/kg + mefenoxam, 40 g/kg) against late blight (*Phytophthora infestans* (Mont.) de Bary) were made during the trials.

Weather conditions

According to the data presented in the Table 1, the weather in both years of the experiment was generally hotter and drier compared to the average long-term data. In general, the air temperature in the growing season of 2020 was 7% higher than the average long-term value, and the humidity was 8% lower. The 2021 data differed more: the temperature was 21% higher than the long-term average, the humidity was 16% lower, and the amount of precipitation was 23% lower. All this had a direct impact on the results obtained in the experiments. Due to more arid conditions and, as a consequence, stress for potato plants, the expression of phytotoxicity in the second year of the study was more intense.

Conditions for conducting experiments

The experiments were based on the method of randomized blocks in three

Table 1. Weather conditions during the experiments (2020, 2021)

Indicators	Months and decades											
	May			June			July			August		
	1	2	3	1	2	3	1	2	3	1	2	3
Air temperature, °C long-term average	8.5	11.1	12.3	14.3	15.7	16.6	17.3	17.8	17.9	17.2	16.0	14.4
2020	9.1	6.5	11.8	16.1	19.8	20.1	17.1	17.4	16.6	18.2	16.0	16.1
2021	5.7	17.6	11.4	18.0	19.8	24.2	23.4	24.2	19.6	17.3	18.0	13.9
Precipitation, mm long-term average	10.3	12.2	14.7	13.8	17.0	24.5	22.1	21.2	22.7	24.2	20.4	24.8
2020	7.0	27.6	8.8	13.6	8.5	10.0	17.6	5.3	43.9	15.5	0.3	78.7
2021	45.0	40.9	38.1	0	5.8	19.6	7.9	10.1	25.9	87.4	51.6	27.2
Air humidity, % long-term average	67	73	71	66	68	71	72	74	76	77	79	82
2020	58	68	52	68	62	56	70	67	75	73	67	77
2021	73	60	69	51	55	61	52	54	59	74	71	80

replications. The plot size was 2 m². The herbicides were applied with Resistent 3610 backpack sprayer. To prepare the working liquid, 250 l/ha of water were used. The scheme of the experiments included the use of the following herbicides before the germination of potato plants (PRE) (Table 2.).

We have selected three cultivars of table potatoes, differing in terms of maturation and the size of the bushes: 1. Cv. Udacha. Ripening time from 65 days. The plant is medium-height, semi-spreading. Leaves with large lobes, dark green. The corolla is white. The tuber is light beige. 2. Cv. Nevsky. Ripening time from 75 days. The plant is semi-erect, of medium height. The leaf is medium-sized, wavy margin is weak. The corolla is white. The tuber is light beige. 3. Cv. Avrora. Ripening time from 85 days. The plant is tall, semi-erect. The corolla is large, red-purple.

In order to eliminate the negative effect of weeds on potatoes, all plots of the experiments (with herbicides and nontreated check) were regularly weeded manually until harvest.

In accordance with PP 1/135 (4) EPPO (2014), we planned following counts: 1. Evaluation of possible delayed emergence of plants with preemergence herbicide treatment was performed by counting the number of plants on the plot after the appearance of mass seedlings. Since the shoots appeared unevenly, the date when the area of the plots was filled with shoots by 50% was considered the day of the emergence of seedlings; 2. Visual assessment of herbicide selectivity separately for each type of damage (where 0% – without damage, 100% – complete death of plants) at 2, 7, 14 and 28 days after the emergence (DAE); 3. Observation of the stages of crop growth at 2, 7, 14 and 28 DAE; 4. Determination of the density of the crop,

Table 2. Herbicides information

Products name	Active ingredients (a.i.)	Content	Formulation	Application rates	
				products	a.i.
Nexus	Fomesafen	24%	Water solution (WS)	1.25 l/ha	300 g/ha
Lazurit	Metribuzin	70%	Wettable powder (WP)	1.4 kg/ha	980 g/ha

as well as the height, number of stems and leaves at 2, 7, 14 and 28 DAE; 5. Counting the crop yield from each plot of the experiment.

Harvesting was carried out manually, by digging out bushes from 1 linear meter. The data obtained in the experiments were analyzed using ANNOVA F test.

RESULTS AND DISCUSSION

Visual signs of phytotoxicity

Potato injury caused by fomesafen and metribuzin herbicides occurred on potato plants in both years of the study. The application of fomesafen caused yellowing of the edges of potato leaves (Fig 1). Metribuzin, in addition to yellowing, caused “marbling” of leaves.

In 2020, injuries caused by herbicide were observed in all cultivars, but the number of potato seedlings with these injuries was different. After 2 days after the appearance of mass shoots (DAE) an average of 1.7 plants Udacha cultivar with injuries from both herbicides were noted (Table 3). At that time, the number of plants Nevsky cultivar injured by herbicides was lower: 1 plant – with fomesafen and 1.3 – with metribuzin. On the Avrora cultivar, the values were the lowest:

0.3 and 0.7 plants with injuries on average on the plot. Visual signs of phytotoxicity were observed within a week. Subsequently, potato plants of all cultivars recovered and two weeks after the mass emergence of seedlings (14 DAE), all potato plants were without any injury. It should be noted that the number of sprouted potato plants in the experimental plots varied significantly during the counts, but statistically these differences were insignificant in both years of research.

In 2021, statistically significant injury from fomesafen to potatoes cultivar Udacha was observed at the 2 DAE (in average 2 injured plants per plot). During the next count, potato injury two cultivars was observed from both fomesafen and metribuzin herbicides. On the Udacha cultivar, plants with injuries were on average 1.0 and 0.7, and on the Nevsky cultivar – 0.3 and 0.7, respectively. As in the first year of studies, all injured potato plants recovered in 2 weeks after emergence.

Plant height

In 2020, the height of potato plants of all three cultivars with herbicide application was generally not inferior to the height of the nontreated check.



A. *fomesafen* – 300 g/ha a.i. (PRE)



B. nontreated check

Figure 1. Visual injuries of the potato cultivar Udacha caused by fomesafen one week after emergence (2021)

Table 3. Visible injury on potato after herbicides treatments (2020, 2021)

Treatments (g/ha a. i.)	2020						2021					
	2 DAE		7 DAE		14 DAE		28 DAE		2 DAE		7 DAE	
	TNOP	PWI	TNOP	PWI	TNOP	PWI	TNOP	PWI	TNOP	PWI	TNOP	PWI
Udacha												
fomesafen (300) PRE	10.5**	1.7 ^b	15.0**	0.7 ^b	15.0**	0 ^a	15.0**	0 ^a	16.3**	2.0 ^b	21.3**	1.0 ^a
metribuzin (980) PRE	8.6**	1.7 ^b	14.7**	1.3 ^b	14.7**	0 ^a	14.7**	0 ^a	17.0**	0 ^a	20.7**	0.7 ^a
nontreated check	8.0**	0 ^a	14.3**	0 ^a	14.3**	0 ^a	14.3**	0 ^a	15.7**	0 ^a	19.0**	0 ^a
Nevsky												
fomesafen (300) PRE	11.1**	1.0 ^b	16.7**	2.0 ^b	16.7**	0 ^a	16.7**	0 ^a	13.3**	0 ^a	18.7**	0.3 ^a
metribuzin (980) PRE	11.7**	1.3 ^b	16.7**	0.3 ^b	16.7**	0 ^a	16.7**	0 ^a	15.7**	0 ^a	17.0**	0.7 ^a
nontreated check	10.1**	0 ^a	16.0**	0 ^a	16.0**	0 ^a	16.0**	0 ^a	14.7**	0 ^a	18.3**	0 ^a
Avrora												
fomesafen (300) PRE	7.1**	0.3 ^b	16.3**	0.3 ^b	16.3**	0 ^a	16.3**	0 ^a	6.3*	0 ^a	14.7**	0 ^a
metribuzin (980) PRE	11.4**	0.7 ^b	18.0**	0.7 ^b	18.0**	0 ^a	18.0**	0 ^a	11.3**	0 ^a	16.7**	0 ^a
nontreated check	9.2**	0 ^a	15.3**	0 ^a	15.3**	0 ^a	15.3**	0 ^a	10.3**	0 ^a	16.3**	0 ^a

TNOP - total number of plants on the plot; PWI - plants with injury on the plot. **insignificant differences at $p=0.05$ level; means followed by distinct letters differ from each other by the F test, respectively.

Potato plants of the Udacha cultivar after using fomesafen grew even faster than the nontreated check: during the first accounting, the excess height values were 39% (Fig 2). When metribuzin was applied, the height of the plants was at the nontreated check level, and the range of variation was from 2 to 5%.

The height of potato plants of the Nevsky cultivar did not depend on the application of both herbicides: the range of changes in height relative to the nontreated check was within the interval of 1 to 15%.

On the Avrora cultivar, application of metribuzin led to a significant (23%) delay in plant height compared to nontreated check at the first accounting. Next count values were in the range from 1 to 10%.

In 2021, potato injury caused by the application of herbicides was significantly stronger.

Thus, on the cultivar Udacha there was a delay in the height of potato plants after the application of both herbicides. On the 7 DAE, this delay was 35% (with fomesafen) and 23% (with metribuzin). Subsequently, the differences leveled off and at the 14 DAE the delay in height was significant after applying metribuzin (14%). On the Nevsky cultivar in the initial period (7 DAE), there was a delay plant height after application of fomesafen (by 16%). After next 7 days, the situation changed and, conversely, the height of plants treated with herbicides was higher, and the range was from 1 to 12%.

On the Avrora cultivar, the delay in height of plants after herbicides treatments was the strongest. After fomesafen treatment, it was 44% (7 DAE) and 24% (14 DAE). After using metribuzin: 31% and 14%, respectively. Thus, the height of plants of this cultivar after all treatments was leveled only at 28 DAE.

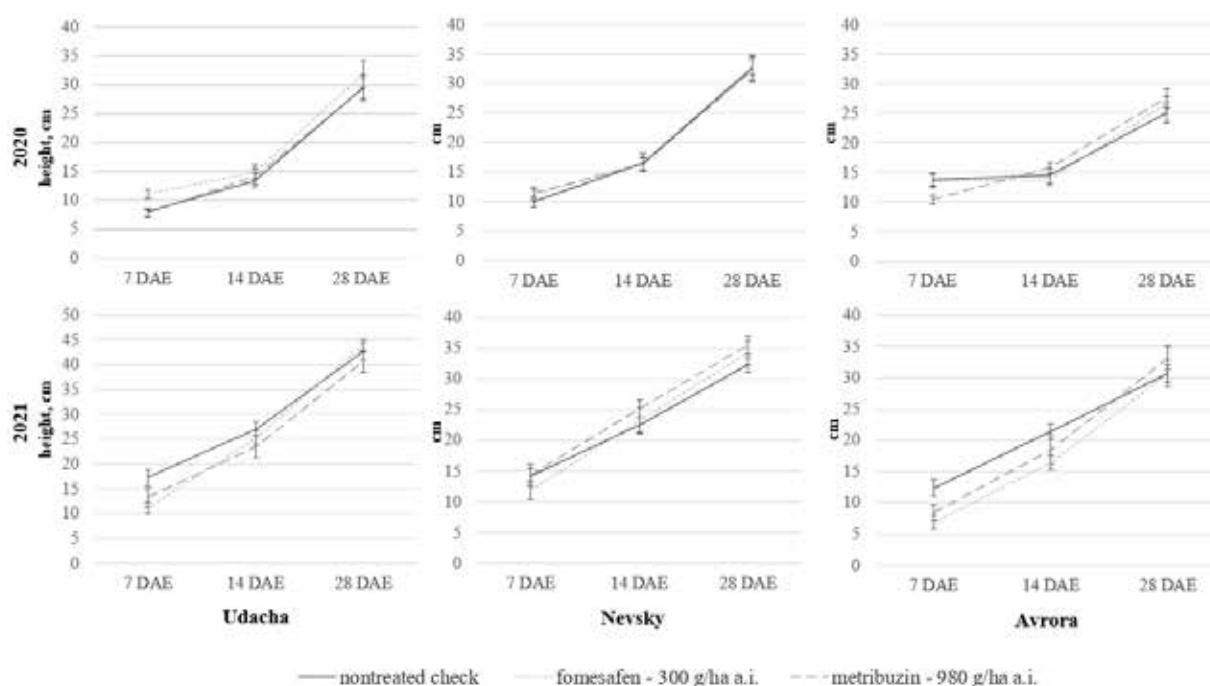


Figure 2. Height of potato after herbicides treatments (2020, 2021)

Potato tuber yield

In 2020, the yield of all three potato cultivars was at the same level – from 24.1 (for the Avrora cultivar) to 25.5 t/ha (for the Udacha cultivar). In 2021, the yield of the cultivars Udacha and Nevsky was noticeably higher – 28.0 and 30.2 t/ha, respectively. And the potato cv. Avrora did not increase – 22.8 t/ha.

Despite the high variety of the results, none of the herbicide's treatments lead a significant reduction in crop yields (Table 4). The only significant difference was recorded

in 2020: after metribuzin treatment the yield was significantly higher than the nontreated check, but this trend was not confirmed the following year.

The results of the experiments allow us to state that the application of fomesafen and metribuzin can cause lightening and yellowing of the leaf tips of all studied potato cultivars. At the same time, the degree of such impact varies depending on the cultivar.

Although plant injuries were observed at all three cultivars in 2020, the number of injured plants of the cultivars Udacha

Table 4. Potato yield after herbicides treatments (2020, 2021)

Treatments (g/ha a.i.)	Yield of potato cultivars, tons per hectare					
	Udacha		Nevsky		Avrora	
	2020	2021	2020	2021	2020	2021
fomesafen (300) PRE	24.0	34.9	25.4	36.7	21.2	25.9
metribuzin (980) PRE	30.7	29.8	24.7	37.0	19.4	21.4
nontreated check	25.5	28.0	24.8	30.2	24.1	22.8
LSD ($p=0.05$)	2.1	9.4	4.0	14.2	7.3	10.7

and Nevsky was greater compared to the cultivar Avrora. In 2021, injuries of potato plants were observed mainly at the cultivar Udacha and only in the second count their insignificant number was observed at the cultivar Nevsky.

It should be noted that visual signs of injuries in both years of the research were shown for a short period of time, not exceeding one week. These results are compatible with the data obtained by other authors who have studied herbicide phytotoxicity. It was shown that, clomazone presented phytotoxicity symptoms at 10 days after emergence (DAE) and the plants recovered from these symptoms at 30 DAE (Luz *et al.*, 2018; Abdallah *et al.*, 2021). Another author also reports that the crop can recover from the injury caused by fomesafen: minimal crop injury was observed 7 and 14 DAT and none crop injury at 42 DAT (Mohseni-Moghadam *et al.*, 2017).

In 2020, the height of potato plants of all three cultivars with application of herbicides was generally not inferior to the height of plants in the nontreated check. And the negative effect was noted in 2021: after application of both metribuzin and fomesafen herbicides a significant delay in plant growth of two cultivars (Udacha and Avrora) was observed at 7 and 14 DAE.

As already noted, the weather conditions during the experiments in 2020 and 2021 were drier and hotter compared to the average long-term conditions. At the same time, the weather observed directly during the beginning of experiment, treatments and the first counts (4 decades, starting from the second decade of June) was even more extreme. Thus, the average temperature during this period was 10% higher than the long-term average in 2020 and 36% higher in 2021; the amount of precipitation in both

years was twice lower than the average long-term value; and the humidity in 2020 was 11% lower, and in 2021 – 22%.

In this context, it can be assumed that the hot and arid conditions of 2021 caused stronger phytotoxicity symptoms in the form of stunted plant growth. This is compatible with the results of other authors. In general cases, tolerance or susceptibility of a plant to herbicides varies depending on the product, application time (pre or postemergence), dose used, characteristics of soil and plant (related to absorption, translocation and metabolism of herbicide, alteration of plant of action) and environmental conditions (Correia and Carvalho 2019; Colquhoun *et al.*, 2021). In particular, it has been shown that environmental conditions that have a direct effect on crop plants (such as rainfall, or on the contrary, arid conditions) contribute to a strong phytotoxicity of fomesafen (Main *et al.*, 2012; Cieslik *et al.*, 2014).

It should be emphasized that as a result, the range of variability in plant height of all three cultivars when both herbicides were applied as well as in the nontreated check, did not exceed 10% by 28 DAE (all values were statistically at the same level).

This fact, along with the absence of a significant effect of herbicides on the number of stems and leaves, which is also confirmed by Fonseca *et al.* (2018) data, indicates a great regenerative ability of potatoes, regardless of their cultivar characteristics.

Visual observations of potato growth stages showed no significant signs of potato stunting in the plots with herbicide application compared to the nontreated check. The growth of potato plants of all three cultivars in both years after herbicides applied was in accordance with their biological characteristics.

The regenerative abilities of potatoes, we revealed in experiments, are reflected in the analysis of such an integral indicator as crop yield. Despite the appearance of yellow spots on the leaves, as well as a decrease in potato height in the early growth stages of potato compared to the nontreated check; no statistically significant negative effect of herbicides was detected in both years of research.

These data correlate with the data obtained by scientists conducting experiments with metribuzin and fomesafen on soybean. Also, as in our experiments, soybean injury resulting from fomesafen and metribuzin treatments can be observed in the initial period, but no yield loss occurred with any herbicide application (Priess *et al.*, 2020; Arsenijevic *et al.*, 2021).

CONCLUSION

The preemergence application of fomesafen – 300 g/ha a.i. and metribuzin – 980 g/ha a.i. can cause symptoms of phytotoxicity in the form of yellowing of leaf tips in all three studied potato cultivars (especially Udacha and Nevsky cultivars). The negative effect of herbicides on plant height was most demonstrated under arid conditions (in 2021), when after the application of both herbicides there was a significant delay in plant growth of two cultivars (Udacha and Avrora) at 7 and 14 DAE. By 28 DAE, the height of plants of all three cultivars with herbicide application and in the nontreated check was leveled (the differences did not exceed 10%). Despite the observed signs of plant injuries, no statistically significant negative herbicides effects at yield were detected in both years of the study, which indicates a great regenerative ability of potatoes.

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CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

LITERATURE CITED

- Abdallah IS, Atia MAM, Nasrallah AK, El-Beltagi HS, Kabil FF, El-Mogy MM and Abdeldaym EA (2021) Effect of new pre-emergence herbicides on quality and yield of potato and its associated weeds. *Sustainability* 13(17): 9796
- Alebrahim M, Majd R, Rashed Mohassel M, Wilkakson S, Baghestani M, Ghorbani R and Kudsk P (2012) Evaluating the efficacy of pre and post-emergence herbicides for controlling *Amaranthus retroflexus* L. and *Chenopodium album* L. in potato. *Crop Protection* 42: 345–50
- Arsenault W and Ivany J (1996) Response of three potato cultivars to metribuzin. *Journal of Production Agriculture* 9(1): 86–88
- Arsenault W and Ivany J (2001) Response of several potato cultivars to metribuzin and diquat. *Crop Protection* 20(7): 547–52
- Arsenijevic N, De Avellar M, Butts L, Arneson N and Werle R (2021) Influence of sulfentrazone and metribuzin applied preemergence on soybean development and yield. *Weed Technology* 35(2): 210–15
- Barbas P and Sawicka B (2020) Dependence of potato yield on weed infestation. *Agronomy Research* 18(2): 346–59
- Barkley S, Chaudhari S, Jennings K, Schultheis J, Meyers S, and Monks D (2016) Fomesafen programs for palmer amaranth (*Amaranthus palmeri*) control in sweetpotato. *Weed Technology* 30(2): 506–15
- Chen Z, Qiao Y, Zhang N, Liu J and Yang H (2021) Insight into metabolism pathways of pesticide fomesafen in rice: Reducing cropping and environmental risks. *Environmental pollution (Barking, Essex: 1987)* 283: 117128
- Cieslik L, Vidal R and Trezzi M (2014) Fomesafen toxicity to bean plants as a function of the time of application and herbicide dose. *Acta Scientiarum. Agronomy* 36(3): 329–334

- Colquhoun J, Heider D, and Rittmeyer R (2021) Potato injury risk and weed control from reduced rates of PPO-inhibiting herbicides. *Weed Technology* **35**(4): 632–37
- Correia N and Carvalho A (2019) Herbicide selectivity for potato crop. *Horticultura Brasileira* **37**(3): 302–08
- De Souza Cruz A, Alves de Albuquerque J, Rocha P, Souza L, Cruz D, Soares M, Castro T, Santos T and da Silva E (2020) Effect of the use of pre- and post-emergence herbicides on nodulation and production of cowpea (*Vigna unguiculata* L.) in the Amazonian savannah. *Agronomia Colombiana* **38**(2): 280–86
- Dhaliwal SS, Sharma S, Shukla AK, Sharma V, Bhullar MS, Dhaliwal TK, Alorabi M, Alotaibi SS, Gaber A and Hossain A (2021) Removal of biomass and nutrients by weeds and direct-seeded rice under conservation agriculture in light-textured soils of North-Western India. *Plants* **10**(11): 2431
- Do Amaral U, Ferreira L, De Souza K, Vieira E and Barcelos M (2018) Phytotoxicity of herbicides in seedlings of sweet passion fruit. *Journal of Agricultural Science* **10**(9): 423–29
- Eriksson D, Carlson-Nilsson U, Ortíz R and Andreasson E (2016) Overview and breeding strategies of table potato production in Sweden and the Fennoscandian region. *Potato Research* **59**(3): 279–94
- European and Mediterranean Plant Protection Organization (EPPO) (2014) PP 1/135 (4) Phytotoxicity assessment. *EPPO Bulletin* **44**(3): 265–73
- Fonseca L, Luz J, Duarte I and Wangen D (2018) Weeds control with herbicides applied in pre-emergence in potato cultivation. *Bioscience Journal* **34**(2): 279–86
- Friesen G, and Wall D (1984) Response of potato (*Solanum tuberosum*) cultivars to metribuzin. *Weed Science* **32**(4): 442–44
- Galon L, Castoldi C, Forte C, De David F, Perin G and Radunz A (2018) Weed management in beans using subdoses of fluazifop-p-butyl + fomesafen. *Planta Daninha* **36**: e018174070
- Hand L, Carter O and Prostko E (2021) Peanut response to preemergence applications of metribuzin. *Peanut Science* **48**(1): 1–5
- Isik D, Akca A, Kaya Altop E, Tursun N and Mennan H (2015) The critical period for weed control (CPWC) in potato (*Solanum tuberosum* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **43**(2): 355–60
- Karimmojeni H, Barjasteh A, Mousavi RS and Bazrafshan AH (2014) Determination of the critical period of weed control in potato (*Solanum tuberosum* L.). *New Zealand Journal of Crop and Horticultural Science* **42**(3): 151–60
- Lawrence B, Bond J, Golden B, Allen T, Reynolds D, and Bararpour T (2021) Rice response to sublethal rates of paraquat, metribuzin, fomesafen, and cloransulam-methyl at different application timings. *Weed Technology* **35**(5): 681–89
- Li X, Grey T, Vencill W, Freeman J, Price K, Cutts G, and Price A (2018) Evaluation of cotton responses to fomesafen-based treatments applied preemergence. *Weed Technology* **32**(4): 431–38
- Luz J, Fonseca L and Duarte I (2018) Selectivity of pre-emergence herbicides in potato cv. Innovator. *Horticultura Brasileira* **36**(2): 223–28
- Main C, Faircloth J, Steckel L, Culpepper A and York A (2012) Cotton tolerance to fomesafen applied preemergence. *The Journal of Cotton Science* **16**(1): 80–87.
- Mohseni-Moghadam M and Doohan D (2017) Fomesafen crop tolerance and weed control in processing tomato. *Weed Technology* **31**(3): 441–46
- Mondani F, Golzardi F, Ahmadvand G, Ghorbani R and Moradi R (2011) Influence of weed competition on potato growth, production and radiation use efficiency. *Notulae Scientia Biologicae* **3**(3): 42–52
- Oliveira Neto A, Constantin J, Oliveira Jr R, Barroso A, Braz G, Guerra N and Gheno E (2015) Selectivity of fomesafen to cotton. *Planta Daninha* **33**(4): 759–70
- Priess G, Norsworthy J, Roberts T and Gbur E (2020) Impact of postemergence herbicides on soybean injury and canopy formation. *Weed Technology* **34**(5): 727–34
- Pszczołkowski P, Barba P, Sawicka B and Krochmal-Marczak B (2020) Biological and agrotechnical aspects of weed control in the cultivation of early potato cultivars under cover. *Agriculture* **10**(9): 373
- Schmitt J, Jochem W, de Mello G, Schiessel J, Demartini S, Fioreze S, de Oliveira Neto A and Guerra N (2019) Application of pyraclostrobin as an alternative to reduce phytotoxicification of fomesafen in common bean. *Communications in Plant Sciences* **9**: 29–35

- Siblan W and Haidar M (2017) Reduced rates of metribuzin and time of hilling controlled weeds in potato. *American Journal of Plant Sciences* **8**(12): 3207–217
- Sperry B, Lawrence B, Bond J, Reynolds D, Golden B and Edwards H (2019) Corn (*Zea mays* L.) response to sublethal rates of paraquat and fomesafen at vegetative growth stages. *Weed Technology* **33**(4): 595–600
- Williams M and Nelson R (2014) Vegetable soybean tolerance to bentazon, fomesafen, imazamox, linuron, and sulfentrazone. *Weed Technology* **28**(4): 601–07
- Wilson D, Nissen S and Thompson A (2002) Potato (*Solanum tuberosum*) variety and weed response to sulfentrazone and flumioxazin. *Weed Technology* **16**(3): 567–74
- Wilson R (2005) Response of dry bean and weeds to fomesafen and fomesafen tank mixtures. *Weed Technology* **19**(1): 201–06
- Wu X, Zhang Y, Du P, Xu J, Dong F, Liu X and Zheng Y (2018) Impact of fomesafen on the soil microbial communities in soybean fields in Northeastern China. *Ecotoxicology and Environmental Safety* **148**: 169–76
- Yu J, Boyd N, Schumann A and Sharpe S (2021) Tomato tolerance to preemergence herbicides in plasticulture using narrow bands and precision technology. *Crop Protection* **146**: 105680

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