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Research Article

Efficacy of bio-surfactants and spray volume on performance of fenoxaprop-p-ethyl against *Avena sterilis* subsp. *ludoviciana*

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Abstract: Whether fenoxaprop-p-ethyl activity could be affected by the carrier volume and whether this relationship can be affected by two types of bio-surfactants, rhamnolipid and surfactin, was assessed under greenhouse conditions. Treatments consisted of herbicide dose (0, 18.75, 37.5, 56.25, 75, and 93.75 g ha^{-1}), spray volume (60, 120, 240, and 480 L ha^{-1}), surfactant type above, and surfactant concentration (0, 0.125, 0.25, 0.5, 1, 2, 4, and 8x critical micelle concentration (CMC). The dry matter of sterile oat was regressed over the doses of fenoxaprop-p-ethyl to obtain a dose causing 50% sterile oat control (ED_{50}). Without surfactant, a 38% increase in the ED_{50} with increasing the spray volumes from 60 to 480 L ha^{-1} (44.7 and 72.1 g ha^{-1}, respectively) revealed a negative relationship between fenoxaprop-p-ethyl activity and spray volume. In other words, a low-volume spray solution, creating smaller, more concentrated spray droplets, is necessary to get the optimal action of fenoxaprop-p-ethyl. This relationship could also be observed when both surfactants were used at 0.125 to 1x CMC. At 2 to 8x CMC, the relationship mode changed from negative to neutral for rhamnolipid, while it did not change for surfactin. This study shows that, unlike surfactin, rhamnolipid worked better at a low concentration in a low-volume spray solution to get the optimal action of fenoxaprop-p-ethyl.

Keywords: adjuvant, herbicide, nozzle size

Introduction

The aryloxyphenoxypropionate (APP) herbicide fenoxaprop-p-ethyl is labeled for use in wheat and barley to control grassy species, e.g., the genus oat, *Avena* (Poaceae). In such a susceptible species, the enzyme Acetyl-CoA carboxylase in the fatty acid biosynthesis pathway is inhibited by the APP herbicides, disrupting cell division and growth and leading to their death (Zhang *et al.*, 2017). In soil and crop, the ester bond of fenoxaprop-p-ethyl can hydrolyze to its corresponding acid (fenoxaprop) by non-enzymatic reactions. Then, fenoxaprop acid is re-hydrolyzed to form some metabolites. As a result, no residues of the parent herbicide and its corresponding acid are detectable when the crop is harvested (Tandon, 2019). However, Badawi *et al.* (2015) reported that fluazifop-butyl metabolites in soil could leach faster than fluazifop-butyl. Toxicologically, the hydrolytic products

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derived from fenoxaprop-p-ethyl have higher toxicity to the aquatic organism (*Daphnia magna*) than fenoxaprop-p-ethyl (Jing *et al*., 2016). Similarly, Cai *et al*. (2007) reported that the hydrolytic products derived from diclofop-methyl have higher toxicity to the freshwater microalga *Chlorella pyrenoidosa* than diclofop-methyl. Therefore, the aim should be to optimize the dose of fenoxaprop-p-ethyl, reducing its visible and hidden costs.

Commonly, water is always used as a carrier in spraying herbicides. At a preliminary step, it should be determined how much spray volume is suitable to apply an APP herbicide because it is considered a simple way to achieve and use the reduced doses of foliage-applied herbicides. The response of APP herbicides to spray volume is different. In some studies, decreasing the spray volume increased the activity of clodinafop-propargyl (Gauvrit and Lamrani, 2008), fluazifop-butyl (Chandrasena and Sagar, 1989), and haloxyfop-r-methyl (Aliverdi and Borghei, 2021). In other studies, it reduced diclofop-methyl activity (Knoche, 1994) and quizalofop-p-ethyl (Sikkema *et al*., 2008). Sometimes, no interaction has been observed between the activity of APP herbicide and spray volume, for example, fenoxaprop-p-ethyl (McMullan, 1995) and fluazifop-p-butyl (Creech *et al*., 2015). After determining a suitable spray volume for a foliage-applied herbicide, the next step is to adjust it. The spray volume can be adjusted by two methods: the change in application speed or nozzle size. If less spray volume is necessary to apply an herbicide, it is also needed to increase application speed. It causes the spray droplets to be more bounced or shattered from the waxy leaf surface (Jensen, 2012), causing the herbicide not to achieve optimal efficacy. Therefore, a smaller orifice nozzle is more applicable if the spray drift is controlled. The findings mentioned above from McMullan (1995) confirm such a situation because the spray volume for fenoxaprop-p-ethyl has been adjusted by changing application speed. In general, advances in nozzle technology have made the nozzle size change method more feasible to adjust spray volume.

Tank-mixing a surfactant into the spray solution of APP herbicides can be considered another way to reduce their dose. The surface tension of water, which is used to spray herbicides, can be slightly reduced after adding the formulation of APP herbicides (Gauvrit and Lamrani, 2008). Therefore, the relatively high surface tension of the spray solution poses three main problems. First, the spray droplets can quickly be bounced off the waxy leaf surface, particularly when sprayed on a grassy species having upright-growing leaves (Jensen, 2012) or ones having leaves with dense trichrome (Xu *et al*., 2010). Second, those remaining on the waxy leaf surface after impact have a relatively spherical shape, resulting in a relatively low wetted leaf area. That means they are not effectively successful in wetting the leaf surface, reducing the absorption efficacy of herbicide into the leaf tissues (Xu *et al*., 2011). Third, the crystalline wax in the cuticles, particularly in grassy species (Knoche, 1994), is considered an essential barrier to penetrating herbicides into the leaf tissues (Schönherr *et al*., 2000). In such situations, the herbicide does not achieve optimal efficacy. It is well-established that the three main problems mentioned above may be overcome if a synthetic surfactant is selected to add to the spray solution, causing the herbicide to achieve optimal efficacy.

However, the public perceptions of synthetic surfactants are also ruined due to their low biodegradation potential, leading to side effects on non-target organisms, water pollution, and crop surfactant residues. Therefore, there is an increasing demand for access to natural surfactants produced by microorganisms, known as bio-surfactants, which have high biodegradation potential in soil. Furthermore, they are considered a cost-effective and long-term sustainable way to bioremediate the herbicides from the environment. The chemical structure and microbiological derivation of numerous bio-surfactants identified have been listed (Raj *et al*., 2021). However, only the compatibility of rhamnolipid has been checked with glyphosate (Liu *et al*., 2016). Therefore, testing their performance and compatibility with other agrochemicals is necessary.

This study aims to assess whether the effect of spray volume adjusted by changing nozzle size on fenoxaprop-p-ethyl herbicidal activity could be affected by two bio-surfactants: rhamnolipid and surfactin.

Materials and Methods

A greenhouse experiment was performed as a dose-response relationship at the Bu-Ali Sina University, Hamedan, Iran. The seeds of sterile oat (*Avena sterilis* subsp. *ludoviciana* (Durieu) Gillet and Magne) were de-hulled by hand, immersed in 0.2% KNO_3 solution, placed inside the Petri dishes, incubated at 4 °C for 48 h, and re-incubated at 20/10 °C with a 16/8 h regime for 48 h. Five germinated seeds with 1 cm root length were planted at 1 cm soil depth within 1-liter plastic pots filled with clay loam soil containing 0.7% organic matter. The soil surface of pots was moistened at least once a day until the seedlings started to emerge. After that, the plants were evenly irrigated as required and treated in the three-leaf stage. Greenhouse environmental conditions were 21 ± 6 °C air temperature with 40% ± 12% relative humidity. Outdoor environmental conditions were 16 ± 5 °C air temperature with 32% ± 9% relative humidity.

The experiment was designed as a completely randomized four-factor (6 by 4 and 2 by 8) design. The first factor was the dose of fenoxaprop-p-ethyl, including 0, 18.75, 37.5, 56.25, 75 (labeled dose), and 93.75 g ha^{-1}. The formulation of Puma Super® EW 7.5% (Aventis, France) was used. It contains 18.8 g L^{-1} crop safener mefenpyr-diethyl. The second factor was spray volume, including 60, 120, 240, and 480 L ha^{-1}, which were adjusted using 1100075, 110015, 11003, and 11006 flat fan nozzle, respectively. Based on the catalog, the 61 to 105-µ droplets with 1100075 flat fan nozzle (HARDI, 2022), the 106 to 235-µ droplets with 110015 and 11003 flat fan nozzles, and the 236 to 340-µ droplets with 11006 flat fan nozzle (AGROTOP, 2022) can be created at 300 kPa spray pressure. The third factor was two types of bio-surfactants, rhamnolipid (90% $C_{32}H_{58}O_{13}$, Shanghai Send Pharmaceutical Technology Co., Ltd., China) and surfactin (98% $C_{53}H_{93}N_7O_{13}$, Sigma-Aldrich, USA). In a pre-test conducted, the critical micelle concentration (CMC), a concentration above which micelles form and the surface tension of distilled water is not affected, was determined to be 50 mg L^{-1} for both bio-surfactants. At the CMC, the surface tension of distilled water was measured to be 29.6 and 27.9 mN m^{-1} using a force tensiometer model TM-TN-555, respectively. The concentrations above CMC could not affect the surface tension of distilled water (data not shown). The fourth factor was surfactant concentration, including 0, 0.125, 0.25, 0.5, 1, 2, 4, and 8x CMC (a range from ⅛ to 8 CMC, respectively). A portable spray test chamber with a constant nozzle travel speed was used to apply the treatments at 300 kPa spray pressure. The shoots of plants were cut four weeks after treatment, kept inside an oven at 75 °C for 48 h, and then weighted to obtain the dry matter. Each treatment had four replicates.

The normality of data was checked for each measured variable (1 > Shapiro-Wilk test > 0.9). The data were averaged across the two runs and analyzed based on the methodology described by Knezevic *et al*. (2007). Accordingly, a nonlinear regression analysis was conducted using the software R after installing the extension package *'drc'* version 3.5.1 in which the following four-parameter model was applied to regress the dry matter of sterile oat, *Y*, over the doses of fenoxaprop-p-ethyl, *X*.

$$Y = C + \frac{D - C}{1 + \exp(B(\log X) - logE)}$$

The four parameters of the model above are D, C, B, and E, which were estimated using the function *'summary'*. *D* and *C* are the maximum and minimum asymptotes of *Y*, respectively; *E* is where *Y* is halfway between *D* and *C*, donating an effective dose for 50% sterile oat control (ED_{50}); and *B* is the slope of the fitted nonlinear-regression line around *E*. The standard error of ED_{50}s was estimated at a 5% significance level and used to evaluate the inferences among the ED_{50}s (Ritz *et al*., 2015). At each spray volume, the horizontal displacement between the fitted nonlinear regression line related to *'no bio-surfactant'* and the one related to *'with bio-surfactant'* was estimated using the ratio of ED_{50} without bio-surfactant to ED_{50} with bio-surfactant. This ratio is called relative potency. A relative potency equal to one denotes the ineffectiveness of adding the bio-surfactant to the spray solution on fenoxaprop-p-ethyl activity. A bigger or smaller relative potency than one means the positive and negative effect of adding the bio-surfactant to the spray solution on fenoxaprop-p-ethyl activity, respectively.

Results

The fitted nonlinear-regression lines shifted to the right as the spray volume increased (Fig. 1). When the parameter of ED_{50} for each line was estimated separately, it was found that by increasing the spray volume, the ED_{50} value increased (Table 1). No significant difference was observed between the ED50 values of fenoxaprop-p-ethyl applied with 60 and 120 L ha-1. However, when applied at other spray volumes, a significant difference could be observed among the ED50 values of fenoxaprop-p-ethyl. A 38% increase in the ED_{50} value occurred with increasing the spray volumes from 60 to 480 L ha^{-1} (44.7 and 72.1 g ha^{-1}, respectively), indicating a negative relationship between fenoxaprop-p-ethyl activity and spray volume.

At each of the four spray volumes, adding both bio-surfactants at 0.125x ($^1/_8$) CMC could not affect the ED_{50} value of fenoxaprop-p-ethyl (Table 1). At each of the four spray volumes, except at 60 L ha^{-1} with rhamnolipid (ED_{50} = 38.3 g ha^{-1}), when the surfactants were added at 0.25x ($^1/_4$) CMC to the spray solution, the ED_{50} value decreased significantly.

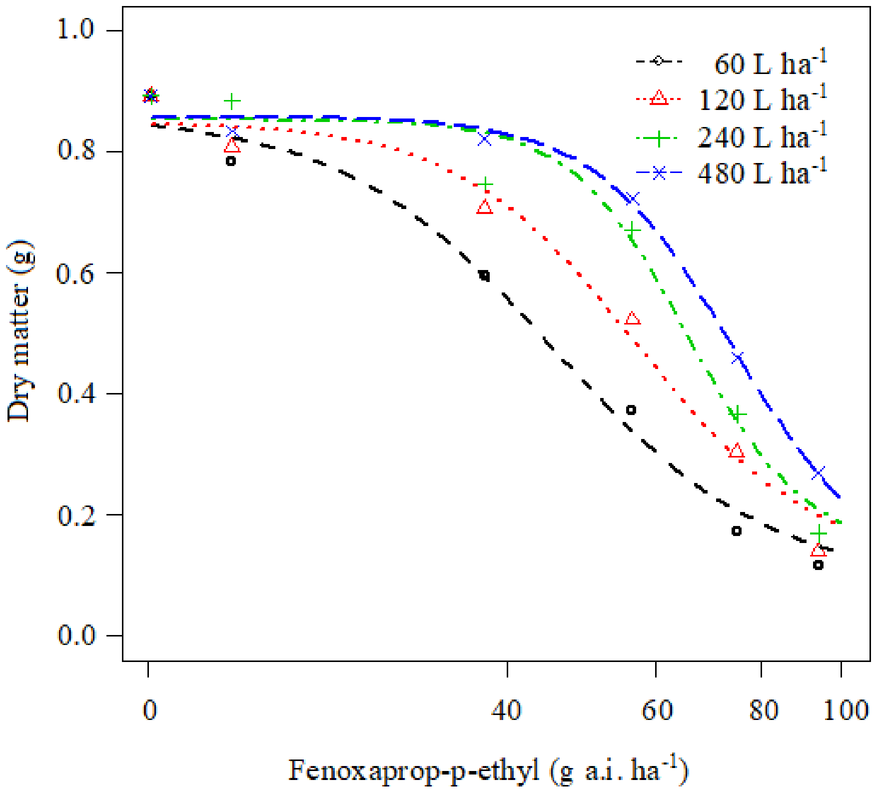

Figure 1 The fitted nonlinear-regression lines for the dry matter of sterile oat over the doses of fenoxaprop-p-ethyl (without bio-surfactant) spraying with 60, 120, 240, and 480 L ha^{-1} spray volumes adjusted by nozzle size.

Table 1 The effective dose (ED_{50}) values of fenoxaprop-p-ethyl against sterile oat when it was applied with different spray volumes, bio-surfactant types, and bio-surfactant concentrations.

Surfactant	Concentration (x CMC)	Spray volume (L ha^{-1})			
		60	120	240	480
Control	0	44.7 ± 4.4 (1.00)	51.6 ± 2.6 (1.00)	66.8 ± 4.1 (1.00)	72.1 ± 3.7 (1.00)
Rhamnolipid	0.125	45.3 ± 1.6 (0.98)	52.4 ± 3.2 (0.98)	61.2 ± 3.9 (1.09)	69.0 ± 4.1 (1.04)
	0.25	38.3 ± 2.3 (1.16)	15.6 ± 0.8 (3.31)	32.7 ± 1.9 (2.04)	33.8 ± 1.3 (2.13)
	0.50	31.5 ± 2.1 (1.41)	13.1 ± 0.9 (3.93)	25.7 ± 3.7 (2.59)	34.0 ± 2.9 (2.12)
	1	22.0 ± 0.8 (2.03)	12.1 ± 0.4 (4.26)	14.1 ± 1.2 (4.73)	17.4 ± 1.0 (4.14)
	2	23.4 ± 3.8 (1.91)	12.5 ± 1.6 (4.13)	15.0 ± 1.5 (4.45)	18.8 ± 2.2 (3.83)
	4	38.9 ± 3.7 (1.14)	37.4 ± 2.8 (1.37)	38.0 ± 4.2 (1.75)	32.3 ± 2.4 (2.23)
	8	47.1 ± 2.5 (0.94)	48.9 ± 3.9 (1.05)	49.3 ± 5.1 (1.35)	55.2 ± 3.9 (1.30)
Surfactin	0.125	47.3 ± 2.7 (0.94)	48.4 ± 2.2 (1.06)	55.9 ± 3.4 (1.19)	73.8 ± 1.9 (0.97)
	0.25	32.0 ± 3.6 (1.39)	38.9 ± 4.9 (1.32)	49.8 ± 2.5 (1.34)	60.2 ± 5.8 (1.19)
	0.50	15.4 ± 0.9 (2.90)	34.4 ± 3.0 (1.50)	41.3 ± 3.8 (1.59)	58.6 ± 6.2 (1.23)
	1	12.5 ± 0.5 (3.57)	23.2 ± 2.1 (2.22)	38.7 ± 1.4 (1.72)	59.3 ± 3.7 (1.21)
	2	12.4 ± 0.5 (3.60)	19.7 ± 1.4 (2.61)	38.1 ± 3.3 (1.75)	80.7 ± 5.2 (0.89)
	4	13.1 ± 0.7 (3.41)	24.4 ± 1.5 (2.11)	55.0 ± 4.8 (1.21)	81.4 ± 7.1 (0.88)
	8	11.9 ± 0.7 (3.75)	25.6 ± 2.3 (2.01)	58.9 ± 6.9 (1.13)	93.4 ± 5.2 (0.77)

Notes. The ED_{50} is a dose of fenoxaprop-p-ethyl (g h^{-1}) causing 50% sterile oat control. The critical micelle concentration (CMC). The spray volumes were adjusted using 1100075, 110015, 11003, and 11006 flat-fan nozzles, respectively. The ED_{50} value ± standard error (relative potency; estimated using the ratio of ED_{50} without bio-surfactant to ED_{50} with bio-surfactant).

Adding rhamnolipid at 0.25x CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 1.16, 3.31, 2.04, and 2.13-fold decrease in the ED_{50} value compared with no surfactant at their corresponding spray volumes, respectively. Meanwhile, adding surfactin at 0.25x CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 1.39, 1.32, 1.34, and 1.16-fold decrease in the ED_{50} value compared with no surfactant at their corresponding spray volumes, respectively. Adding rhamnolipid at 0.5x ($^1/_2$) CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 1.41, 3.93, 2.59, and 2.12-fold decrease in the ED_{50} compared with no surfactant at their corresponding spray volumes, respectively. While, adding surfactin at 0.5x CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 2.90, 1.50, 1.56, and 1.23-fold decrease in the ED_{50} value compared with no bio-surfactant at their corresponding spray volumes, respectively. Adding rhamnolipid at 1x CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 2.03, 4.26, 4.73, and 4.14-fold decrease in the ED_{50} compared with no surfactant at their corresponding spray volumes, respectively. Meanwhile, adding surfactin at 1x CMC to 60, 120, 240, and 480 L ha^{-1} spray volumes caused a 3.57, 2.22, 1.72, and 1.21-fold decrease in the ED_{50} value compared with no surfactant at their corresponding spray volumes, respectively. The results in the range of $^1/_4$ to 1 CMC showed that adding surfactin to 60 L ha^{-1} spray volume caused more relative potency than adding rhamnolipid (1.39 vs. 1.16 at 0.25x CMC, 2.9 vs. 1.41 at 0.5x CMC, and 3.57 vs. 2.03 at 1x CMC, respectively). While at 120 to 480 L ha^{-1} spray volumes, the relative potency value has changed in favor of rhamnolipid. On the other hand, the lowest ED_{50} value was obtained by adding rhamnolipid at 0.05, 0.1, and 0.2% v v^{-1} to 120 L ha^{-1} spray volume (13.1, 12.1, and 12.5 g ha^{-1}, respectively) or by adding surfactin at 0.1, 0.2, 0.4, and 0.8% v v^{-1} to 60 L ha^{-1} spray volume (12.5, 12.4, 13.1, and 11.9 g ha^{-1}, respectively).

The negative relationship between fenoxaprop-p-ethyl activity and spray volume can still be observed well when both surfactants were added at 0.125 to 1x CMC; of course, if 60 L ha^{-1} is not being considered for rhamnolipid at 0.1% v v^{-1}. However, at 2 to 8x CMC, the mode of relationship between fenoxaprop-p-ethyl activity and spray volume changed from negative to neutral for rhamnolipid while it was still in place for surfactin.

Discussion

The negative relationship between fenoxaprop-p-ethyl activity and spray volume can be attributed to two reasons. First, the spray volumes were adjusted by nozzle size in the current study (1100075, 110015, 11003, and 11006; all flat fan nozzle). As mentioned above, the atomization quality of the nozzle is affected by its size; as the nozzle size increases, the droplet size increases (HARDI, 2022; AGROTOP, 2022). It is well established that larger droplets bounce off the leaf surface easier than smaller droplets (Butts *et al*. 2018), resulting in decreased activity of fenoxaprop-p-ethyl against sterile oat. Second, as the spray volume decreases, the concentration of spray droplets increases, creating a concentration gradient for fenoxaprop-p-ethyl to diffuse better from the spray droplet to the leaf tissue (Aliverdi and Borghei, 2021), resulting in increased activity of fenoxaprop-p-ethyl against sterile oat. Combining the above two arguments, smaller and more concentrated spray droplets are needed to get better action of fenoxaprop-p-ethyl. However, McMullan (1995) found that if the spray volume for fenoxaprop-p-ethyl has been adjusted by changing application speed (not by changing nozzle size), it cannot affect the activity of fenoxaprop-p-ethyl. Although the findings from these studies (McMullan and I) are different, they show that the effect of spray volume on herbicide's activity depends not only on the herbicide but also on how it is adjusted - by changing application speed or nozzle size.

Previously, the ineffectiveness of surfactants applied at $^{1}/_{25}$ to $^{1}/_{5}$ CMC on herbicide activity has been observed (Green, 1996). A reduced ED_{50} by adding the bio-surfactants indicates an improved activity of fenoxaprop-p-ethyl against sterile oat, which can be due to a reduction in the surface tension of the spray solution, leading to increased retention (Jensen 2012) and/or spreading area (Schönherr *et al*., 2000) of the spray droplets on the leaf surface, leading to increased herbicide penetration into the leaf tissue. The study findings indicate that rhamnolipid works better when added to a low-volume spray solution at a low concentration. In contrast, surfactin works better when added to a low-volume spray solution at high concentrations. It can be attributed to the difference in the wetting properties of surfactants. However, no remarkable difference was observed between the surface tension of distilled water containing both surfactants at the CMC (24.1 vs. 22.6 mN m^{-1}). It is well-established by Gaskin and Murray (1997) that at each concentration of a super wetting trisiloxane surfactant (Silwet® 408), as the spray volume increases, the spray retention on the leaf surface of wheat increases, but the capture efficiency of spray decreases due to spray run-off. Moreover, they reported that in a spray volume less than 280 L ha^{-1}, spray run-off does not occur. As a result, the capture efficiency of spray is higher in lower spray volume and higher concentration of a super wetting trisiloxane surfactant. While with a non-super wetting trisiloxane surfactant, there is still the capacity to increase the stomatal absorption by increasing the spray volume without the danger of spray run-off (Gaskin *et al*., 2000). However, this capacity seems limited partly due to the adverse effect of spray volume on fenoxaprop-p-ethyl activity.

The natural relationship between fenoxaprop-p-ethyl activity and spray volume at higher concentrations of rhamnolipid may be related to its phytotoxic effect, resulting in an antagonism effect on fenoxaprop-p-ethyl activity against sterile oat (Table 1). Similarly, the antagonism of the activity of rimsulfuron (Green, 1996) and glyphosate (Liu, 2004) against grassy species has already been reported by increasing the concentration of non-silicone surfactants. Moreover, it has been reported that a super wetting trisiloxane surfactant (Silwet® L-77) at high concentration has an antagonism effect on the activity of glyphosate against wheat (Gaskin and Stevens 1993). When surfactant at high concentrations is used, the cells placed under the spray droplets may be injured, resulting in reduced herbicides' absorption, translocation, and activity. However, it is believed that the surfactant at high concentrations can create a concrete environment for the droplets, reducing herbicides' absorption, translocation, and activity (Green, 1996). In the case of surfactin, the relationship between fenoxaprop-p-ethyl activity and spray volume was not affected by surfactant concentration, indicating that this surfactant lacks a phytotoxic effect. Therefore, an increased ED_{50} occurred by adding surfactin at a high concentration to a high-volume spray solution can be related to a combination of the adverse effect of spray volume on fenoxaprop-p-ethyl activity and spray run-off.

The current study revealed a negative relationship between fenoxaprop-p-ethyl activity and spray volume, adjusted by nozzle size. Although these findings differ from a previous study in which spray volume has been adjusted by application speed, they show that the effect of spray volume on the herbicide's activity depends not only on the herbicide but also on how it is adjusted. The smaller, more concentrated spray droplets are necessary to get a better action of fenoxaprop-p-ethyl against sterile oat. The negative relationship between fenoxaprop-p-ethyl activity and spray volume could also be due to adding bio-surfactants at 0.125 to 1x CMC to the spray solution. At 2 to 8x CMC, rhamnolipid changed the correlation mode from negative to neutral due to its phytotoxic and/or concrete effects. However, it was still in place with surfactin due to the adverse impact of spray run-off and volume on fenoxaprop-p-ethyl activity. Bio-surfactant type can alter surfactant concentration-spray volume interaction on herbicide activity.

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References

AGROTOP. 2022. Catalog. https://www.agrotop.com/Katalog_109E/mobile/index.html. [Accessed 8 September 2022]

Aliverdi, A., and Borghei, S. M. 2021. The effect of spray pattern and volume on haloxyfop-r-methyl efficacy against wild barley (*Hordeum spontaneum*). Journal of Plant Protection, 35(2): 265-278.

Badawi, N., Rosenbom, A. E., Olsen, P., and Sørensen, S. R. 2015. Environmental fate of the herbicide fluazifop-p-butyl and its degradation products in two loamy agricultural soils: a combined laboratory and field study. Environmental Science and Technology, 49(15): 8995-9003.

Butts, T. R., Samples, C. A., Franca, L. X., Dodds, D. M., Reynolds, D. B., Adams, J. W., Zollinger, R. K., Howatt, K. A., Fritz, B. K., Clint, H. W., and Kruger, G. R. 2018. Spray droplet size and carrier volume effect on dicamba and glufosinate efficacy. Pest Management Science, 74(9): 2020-2029.

Cai, X., Liu, W., and Lin, K. 2007. Relation of diclofop-methyl toxicity and degradation in algae cultures. Environmental Toxicology and Chemistry, 26(5): 970-975.

Chandrasena, N. R., and Sagar, G. R. 1989. Fluazifop toxicity to quackgrass (*Agropyron repens*) as influenced by some application factors and site of application. Weed Science, 37](6): 790-796.

Creech, C. F., Henry, R. S., Werle, R., Sandell, L. D., Hewitt, A. J., and Kruger, G. R. 2015. Performance of postemergent herbicides applied at different carrier volume rates. Weed Technology, 29(3): 611-624.

Gaskin, R. E., and Stevens, P. J. G. 1993. Antagonism of the foliar uptake of glyphosate into grasses by organosilicone surfactants. part 1: effects of plant species, formulation, concentrations and timing of application. Journal of Pesticide Science, 38(2-3): 185-192.

Gaskin, R. E., Elliott, G., and Steele, K. D. 2000. Novel organosilicone adjuvants to reduce agrochemical spray volumes on row crops. New Zealand Plant Protection, 53: 350-354.

Gaskin, R. E., and Murray, R. J. 1997. Effect of surfactant concentration and spray volume on retention of organosilicone sprays on wheat. 50th New Zealand Plant Protection Conference: 139-142.

Gauvrit, C., and Lamrani, T. 2008. Influence of application volume on the efficacy of clodinafop-propargyl and fenoxaprop-P-ethyl on oats. Weed Research, 48(1): 78-84.

Green, J. M. 1996. Interaction of surfactant dose and spray volume on rimsulfuron activity. Weed Technology, 10(3): 508-511.

HARDI. 2022. Catalog. https://myhardi.com.au/index.php/manuals/931-parts-and-components/file [Accessed 8 September 2022].

Jensen, P. K. 2012. Increasing efficacy of graminicides with a forward angled spray. Crop Protection, 32: 17-23.

Jing, X., Yao, G., Liu, D., Liu, M., Wang, P., Zhou, Z. 2016. Environmental fate of chiral herbicide fenoxaprop-ethyl in water-sediment microcosms. Scientific Reports, 6: 26797.

Knoche, M. 1994. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Protection, 13(3): 163-178.

Knezevic, S. Z., Streibig, J. C., and Ritz, C. 2007. Utilizing R software package for dose-response studies: the concept and data analysis. Weed Technology, 21: 840-848.

Liu, H., Shao, B., Long, X., Yao, Y., and Meng, Q. 2016. Foliar penetration enhanced by biosurfactant rhamnolipid. Colloids and Surfaces B: Biointerfaces, 145: 548-554.

Liu, Z. 2004. Effects of surfactants on foliar uptake of herbicides - a complex scenario. Colloids and Surfaces B: Biointerfaces 35(3-4): 149-153.

McMullan, P. M. 1995. Effect of spray volume, spray pressure and adjuvant volume on efficacy of sethoxydim and fenoxaprop-p-ethyl. Crop Protection, 14(7): 549-554.

Ritz, C., Baty, F., Streibig, J. C., and Gerhard, D. 2015. Dose-response analysis using R. PLoS One, 10: e0146021.

Raj, A., Kumar, A., and Dames, J. F. 2021. Tapping the role of microbial biosurfactants in pesticide remediation: an eco-friendly approach for environmental sustainability. Frontiers in Microbiology, 12: 791723.

Schönherr, J., Baur, P., and Uhlig, B. A. 2000. Rates of cuticular penetration of 1-naphthylacetic acid (NAA) as affected by adjuvants, temperature, humidity and water quality. Plant Growth Regulation, 31: 61-74.

Sikkema, P. H., Brown, L., Shropshire, C., Spieser, H., and Soltani, N. 2008. Flat fan and air induction nozzles affect soybean herbicide efficacy. Weed Biology and Management, 8(1): 31-38.

Tandon, S. 2019. Degradation of fenoxaprop-p-ethyl and its metabolite in soil and wheat crops. Journal of Food Protection, 82(11): 1959-1964.

Xu, L., Zhu, H., Ozkan, H. E., and Thistle, H. W. 2010. Evaporation rate and wetted area of water droplets with and without surfactant at different locations on waxy leaf surfaces. Biosystems Engineering, 106(1): 58-67.

Xu, L., Zhu, H., Ozkan, H. E., Bagley, W. E., and Krause, C. R. 2011. Droplet evaporation and spread on waxy and hairy leaves associated with type and concentration of adjuvants. Pest Management Science, 67(7): 842-851.

Zhang, P., Wu, H., Xu, H., Gao, Y., Zhang, W., and Dong, L. 2017. Mechanism of fenoxaprop-p-ethyl resistance in Italian ryegrass (*Lolium perenne* ssp. *multiflorum*) from China. Weed Science, 65(6): 710-717.

تاثیر مویان‌های زیستی و حجم پاشش بر کارایی فنوکساپروپ-پی-اتیل علیه یولاف وحشی *Avena sterilis* subsp. *ludoviciana*

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چکیده: این‌که آیا فعالیت فنوکساپروپ-پی-اتیل می‌تواند تحت تأثیر حجم حامل قرار گیرد و این که آیا این رابطه می‌تواند توسط دو نوع مویان زیستی، رامنولیپید و سورفاکتین، تحت تأثیر قرار گیرد، مشخص نبود؛ لذا در شرایط گلخانه‌ای این موضوع مطالعه شد. تیمارها شامل مقدار علف‌کش (۰، ۱۸/۷۵، ۳۷/۵، ۵۶/۲۵، ۷۵ و ۹۳/۷۵ گرم ماده مؤثره در هکتار)، حجم پاشش (۶۰، ۱۲۰، ۲۴۰ و ۴۸۰ لیتر در هکتار)، نوع مویان‌ها که در بالا ذکر شد و غلظت مویان (۰، ۰/۱۲۵، ۰/۲۵، ۰/۵، ۱، ۲، ۴ و ۸ برابر غلظت بحرانی میسل مویان‌ها). ماده خشک یولاف وحشی روی مقادیر فنوکساپروپ-پی-اتیل رگرسیون شد تا مقدار علف‌کشی که باعث کنترل ۵۰ درصدی می‌شود (ED_{50}) استخراج شود. بدون کاربرد مویان، یک افزایش ۳۸ درصدی در ED_{50} با افزایش حجم پاشش از ۶۰ به ۴۸۰ لیتر در هکتار مشاهده شد (به‌ترتیب ۴۴/۷ و ۷۲/۱ گرم ماده مؤثره در هکتار) که وجود رابطه منفی بین فعالیت فنوکساپروپ-پی-اتیل و حجم پاشش را نشان داد. به عبارت دیگر، یک حجم پاشش کم، که ایجادکننده قطرات پاشش کوچک‌تر و غلیظتر است، برای کسب عملکرد بهینه از فنوکساپروپ-پی-اتیل ضروری است. این رابطه زمانی که هر دو مویان در غلظت‌های ۰/۱۲۵ تا ۱ برابر غلظت میسل بحرانی استفاده شدند نیز قابل مشاهده است. در غلظت‌های بالاتر، حالت رابطه فوق برای رامنولیپید از منفی به خنثی تغییر کرد؛ درحالی‌که برای سورفاکتین تغییر نکرد. این مطالعه نشان می‌دهد که برخلاف سورفاکتین، رامنولیپید باید در غلظت کم همراه با حجم پاشش کم به‌کار برده شود تا به عملکرد بهینه فنوکساپروپ-پی-اتیل دست یافت.

واژگان کلیدی: مواد افزودنی، علف‌کش، شماره نازل