J. Crop Prot. 2021, 10 (4): 659-667

Research Article

Soil settled on velvetleaf *Abutilon theophrasti* affects optimal carrier volume for trifloxysulfuron

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Abstract: Whether a soil is settled on velvetleaf *Abutilon theophrasti* (Malvaceae) or not, it was not clear if the concentration of spray droplets could influence the effectiveness of trifloxysulfuron. In an experiment, 12 g ha^{-1} trifloxysulfuron was sprayed at 135 l ha^{-1} on velvetleaf treated with 0, 4, 8, 12, 16, and 20 kg soil ha^{-1} through two soil treatment methods, one within a soil dust chamber and the other with a simulated muddy rain. In another experiment, velvetleaf was treated with 20 kg soil ha^{-1} and exposed to the airflow of 0 and 10 km h^{-1}. Then 12 g ha^{-1} trifloxysulfuron was sprayed at 135, 180, 225, 270, 360, and 450 l ha^{-1}. The effectiveness of trifloxysulfuron was negatively correlated with the rate of soil settled on velvetleaf. When the source of soil was a simulated muddy rain, compared to the soil dust chamber, it had a more negative effect on the effectiveness of trifloxysulfuron. Besides, it was not removed from velvetleaf by the airflow before spraying. The effectiveness of trifloxysulfuron was correlated with carrier volume. Correlation type was affected by soil settled on velvetleaf. A positive correlation was observed in soil-treated velvetleaf, especially within the soil dust chamber. Therefore, larger, more diluted droplets were needed to obtain the best trifloxysulfuron efficacy. Unlike in non-treated velvetleaf, a negative correlation was observed. Therefore, larger, more diluted droplets were required to get the best trifloxysulfuron effectiveness.

Keywords: cotton, herbicide, muddy rain, soil dust

Introduction

Trifloxysulfuron is a selective herbicide used postemergence to control certain emerged weeds in cotton. This herbicide inhibits the enzyme acetolactate synthase (ALS) (Molin *et al.*, 2016; Annabestani *et al*., 2020; Sarani *et al*., 2021). ALS catalyzes the first step in synthesizing the branched-chain amino acids of leucine, isoleucine, and valine necessary for plant growth (Binder, 2010). In cotton, it can effectively control velvetleaf *Abutilon theophrasti* Medicus (Salimy *et al*., 2008), the weed causing cotton yield loss up to 80% at a density of 12 plants m^{-2} (Ghorbanpour *et al*., 2014). It is not rapidly degradable, resulting in a carryover injury on succeeding crops such as soybean (Porterfield *et al*., 2006), corn, rice (Minton *et al*., 2008) sorghum, (Minton *et al*., 2008; Dvorkin *et al*., 2012), and crimson clover (Rector *et al*., 2020). Moreover, the intense selection pressure on sensitive biotypes has led to herbicide resistance evolution in some species (Francischini *et al*., 2014a, 2014b; Brosnan *et al*., 2015). Of course, it has not happened in velvetleaf yet.

The application of trifloxysulfuron at lower doses (12 g a.i. ha^{-1}), reducing the risk of side-

Handling Editor: Eshagh Keshtkar

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Received: 15 January 2021, Accepted: 24 November 2021
Published online: 08 December 2021

effects mentioned above, can occur if applied with an optimal carrier volume. An optimal carrier volume selection can be considered a simple method to optimize the effectiveness of foliage-applied herbicides (Aliverdi and Borghei, 2021). However, the ALS inhibitors have shown different behavior with carrier volume. In foramsulfuron (Lesnik *et al*., 2012), nicosulfuron (Green and Cahill, 2003), imazapic, and imazethapyr (Grichar and Dotray, 2015), the effectiveness of herbicide increased as carrier volume reduced. Carrier volume does not affect herbicide effectiveness in imazamox (Ramsdale and Messersmith, 2001) and rimsulfuron (Green, 1996). In nicosulfuron (Brown *et al*., 2007) and imazapyr (Patten, 2002), the effectiveness of herbicide increased as carrier volume increased. Whether the effectiveness of trifloxysulfuron could be affected by the carrier volume has not been examined so far.

The effectiveness of some ALS inhibitors can be decreased due to soil settling on the surfaces of a weed. For example, the effectiveness of mesosulfuron plus iodosulfuron plus diflufenican (Shahbazi *et al*., 2015), foramsulfuron, nicosulfuron (Naghib-Alsadati *et al*., 2020), diquat (Rytwo and Tropp, 2001), paraquat, glyphosate, 2,4-D plus MCPA (Asadi-Sabzi *et al*., 2020), oxyfluorfen, and glufosinate (Aliverdi *et al*., 2020) may decreased by soil cover on weeds. However, some exceptions have been reported. For example, mesosulfuron plus iodosulfuron (Naghib-Alsadati *et al*., 2020) and sulfosulfuron (Asadi-Sabzi *et al*., 2020). The soil settled on the surfaces of weeds can ensue from field cultivation, farm roads (Zhou *et al*., 2006), dust phenomenon (Asadi-Sabzi *et al*., 2020), and muddy rain (Aliverdi and Ahmadvand, 2020).

The number and severity of dust phenomenon are increasing in Iran (Shahsavani *et al*., 2012) and the world (Schweitzer *et al*., 2018). Moreover, the number of rainfalls less than 1 mm is probably rising in Iran (Rezayee-Banafshe *et al*., 2012). Although not documented, the number of muddy rains is perhaps increasing based on these two reports.

Previous researches have proposed three methods to decrease the adverse effect of soil settling on weeds against the effectiveness of foliage-applied herbicides. The first method is adding an adjuvant in the spray solution, which is helpful in the bipyridylium herbicides of paraquat and diquat (Rytwo and Tropp, 2001). It does not become beneficial to other herbicides (Aliverdi *et al*., 2020). The second method is shaking the weeds with a stream of air before spraying, which is applicable if the soil has settled on the surfaces of weeds through a soil dust chamber (Zhou *et al*., 2006). However, according to our observations (Aliverdi and Ahmadvand, 2020), if the soil has settled on the surfaces of weeds through a muddy rain, shaking cannot remove the soil. The third method is increasing carrier volume (Zhou *et al*., 2006; Aliverdi *et al*., 2020), which is relatively simple.

The purpose of this study was to answer some questions: 1) Can the effectiveness of trifloxysulfuron be affected by the source and rate of soil settled on the surfaces of velvetleaf? and 2) What is the optimal carrier volume for trifloxysulfuron whether the soil is settled on velvetleaf or not?

Materials and Methods

By the same method described by Ravlić *et al*. (2015), the velvetleaf seeds were hydro-primed and planted in 2 kg pots at 0.5 cm depth. Soil texture was a Eutric Cambisol (Lomic) with 23.6% sand, 47.0% silt, 28.9% clay, 0.7% organic matter, and 7.2 pH. The pots were placed in the Research Greenhouse of Bu-Ali Sina University, Hamadan, Iran. The seedlings were thinned to five plants pot^{-1} after emergence, irrigated every two days, and fed every seven days with 30 ml of a fertilizer solution containing 3 g l^{-1} of a water-soluble NPK (20-20-20).

Two experiments were conducted. In the first experiment, trifloxysulfuron (Envoke® %75 WG, Syngenta) at 12 g a.i. ha^{-1} was applied at carrier volume of 135 l ha^{-1} at the four-leaf stage of velvetleaf that had already been treated with 0, 4, 8, 12, 16, and 20 kg soil ha^{-1} through two soil treatment methods, one within a soil dust chamber (Fig. 1) and the other with a simulated muddy rain. Treatments were arranged in a completely randomized-factorial design (6 soil rates × 2 soil treatment methods) with four replications, and the experiment was repeated. In the second experiment, after velvetleaf was treated with and without 20 kg soil ha^{-1} through two soil treatment methods, one within a soil dust chamber and the other with simulated muddy rain, they were exposed to the airflow speeds at 0 and 10 km h^{-1}. Then, trifloxysulfuron was applied at 12 g a.i. ha^{-1} at carrier volumes of 135, 180, 225, 270, 360, and 450 l ha^{-1}. Treatments were arranged in a completely randomized-factorial design (3 soil treatment methods × 2 wind speeds × 6 carrier volumes) with four replications, and the experiment was repeated. In each experiment, four non-treated pots were included for comparisons. Two airflow speeds were supplied with a home fan turning on and off. Six carrier volumes were provided with a hand compressor sprayer equipped with an anti-drift single flat fan nozzle (MagnoJet, Brazil) at 11001, 110015, 11002, 11003, 11004, and 11005 sizes at a pressure of 3 bar. The first nozzle size can create droplets of 106-235 µm, and the other nozzle sizes can create droplets of 236-340 µm (MagnoJet, 2021). The soil to settle on the surfaces of velvetleaf was the same as that used in the pots. It was milled and then passed through a 200 mesh screen. With such a mesh, soil particles of less than 75 µm were obtained. The soil dust chamber, made of a 5 mm transparent plastic sheet, was a rectangular cube with 45 cm length, 45 cm width, and 120 cm height. A spring was fixed on the underside of the chamber lid. Four 50 cm mesh screens, which have been connected using the wire, were connected using rubber bands to the chamber walls. A rope was attached to the center of the spring and passed through the chamber lid. By pulling and releasing the rope, the spring could be vibrated; as a result, the screens would also shake, pouring the soil onto a rayon cloth attached at the bottom of each screen. Therefore, even the soil could be evenly distributed (Fig. 1). The plants in pots were dusted after being placed at the bottom of the soil dust chamber. The soil was added to water to simulate muddy rain and sprayed with a hand compressor sprayer equipped with a twin symmetrical fan flat nozzle 11005. A 0.04 mm muddy rain (400 l ha^{-1}) was simulated.

Figure 1 Soil dust chamber designed in this study to dust the plants. The rayon cloth attached at the bottom of each screen helped distribute the soil evenly.

Three weeks after herbicide treatment, the plants were cut above the soil surface. Then, the fresh weight was recorded and expressed as a percent reduction from the fresh weight of non-treated plants. The data were subjected to analysis of variance using SAS 9.4 software. There was no need for data transformation. In both experiments, no significant run-by-treatment interactions occurred. Hence, the data were pooled to give eight replications, then re-analyzed. The means were separated with Fisher's least significant difference (LSD) procedure at the 5% level for significance.

Results

In the first experiment, the analysis of variance of data revealed that the fresh weight of velvetleaf was significantly influenced by both simple effects (soil treatment method and soil rate) and their interaction ($P < 0.05$). The fresh weight of velvetleaf strongly indicated that the decreased effectiveness of trifloxysulfuron was correlated with the rate of soil settled on velvetleaf (Table 1). The significance of trifloxysulfuron was not affected when velvetleaf was dusted with a soil rate less than 4 kg ha^{-1} through the simulated muddy rain or with a soil rate less than 8 kg ha^{-1} through the soil dust chamber. With a soil rate of more than 12 kg ha^{-1}, the adverse impact of soil on the effectiveness of trifloxysulfuron against velvetleaf was more significant when the soil was applied with the simulated muddy rain than when the soil was used within the soil dust chamber.

In the second experiment, the analysis of variance of data revealed that the fresh weight of velvetleaf was significantly influenced by all simple effects (airflow speed before spraying, carrier volume, and soil treatment method) and their interaction ($P < 0.05$). In the absence of soil on velvetleaf, the best effectiveness of trifloxysulfuron (96.6% control) was obtained with the carrier volume of 135 L ha^{-1}. In the absence of soil on velvetleaf, the fresh weight of velvetleaf was continually increased with increasing the carrier volume, indicating a decrease in the effectiveness of trifloxysulfuron. So, the fresh weight of velvetleaf was reduced 62.6% compared to non-treated plants when trifloxysulfuron was applied at the carrier volume of 450 L ha^{-1}. Moreover, the results revealed that the airflow before spraying did not affect this relationship (Table 2).

When the velvetleaf was dusted with 20 kg soil ha^{-1} through both soil treatment methods but not exposed to airflow before spraying, at all carrier volumes (except at 450 L ha^{-1}), the effectiveness of trifloxysulfuron was significantly decreased as compared with 0 kg soil ha^{-1} (Table 2). These results showed that soil settling on velvetleaf affected the optimal carrier volume for trifloxysulfuron. So that, when the velvetleaf was not treated with the soil, a lower carrier volume; while, when it was dusted, a higher carrier volume is necessary to obtain higher effectiveness of trifloxysulfuron.

Except at the carrier volume of 450 L ha^{-1}, at all carrier volumes, the adverse impact of soil on the effectiveness of trifloxysulfuron against velvetleaf was more remarkable when the soil was applied through the simulated muddy rain than when the soil was spread through the soil dust chamber. For example, when trifloxysulfuron was used at the carrier volume of 135 L ha^{-1}, the fresh weight of velvetleaf dusted through the soil dust chamber, and the simulated muddy rain was reduced 45.8 and 27.9% in comparison to non-treated plants, respectively.

Table 1 The efficacy of trifloxysulfuron when the different soil rates settle on velvetleaf *Abutilon theophrasti* through a soil dust chamber and simulated muddy rain.

Treatment method	Fresh weight reduction (%)					
	Soil (kg ha^{-1})					
	0	4	8	12	16	20
Soil dust chamber	96.6 a	88.4 a	86.8 ab	85.3 b	66.5 c	48.7 d
Simulated muddy rain	94.1 a	91.2 ab	79.3 bc	73.9 c	47.1 d	33.5 e

The means with the same letter are not sigificantly different ($LSD_{0.05} = 9.1$).

Table 2 The effect of carrier volume, soil treatment method, and airflow speed before spraying on trifloxysulfuron effectiveness against velvetleaf *Abutilon theophrasti*.

Airflow speed before spraying (km h^{-1})	Carrier volume (l ha^{-1})	Fresh weight reduction compared to control (%)		
		Control without soil (0 kg ha^{-1})	Soil dust chamber (20 kg ha^{-1})	Simulated muddy rain (20 kg ha^{-1})
0	135	96.6 a	45.8 g	27.9 i
	180	88.3 b	50.2 g	37.1 h
	225	88.1 b	51.5 g	57.9 f
	270	78.4 cd	73.5 d	56.7 fg
	360	71.3 de	74.4 cd	65.3 e
	450	62.6 ef	82.3 bc	79.6 cd
10	135	94.1 a	62.2 ef	26.4 i
	180	86.2 b	77.3 cd	32.1 hi
	225	84.6 bc	83.0 bc	56.4 fg
	270	80.6 c	74.7 cd	51.6 g
	360	68.5 de	71.9 d	60.8 ef
	450	53.5 fg	61.2 ef	83.8 bc

The means with the same letter are not statistically different ($LSD_{0.05}$ = 6.4).

In the method of soil dust chamber, the airflow before spraying increased the effectiveness of trifloxysulfuron against velvetleaf at all carrier volumes (except at 450 L ha^{-1}). When the soil was applied on velvetleaf within the soil dust chamber and then exposed to the airflow before spraying, a carrier volume of 225 L ha^{-1} was optimal for trifloxysulfuron (83.0% control). While, in the method of simulated muddy rain, the airflow before spraying did not alter the effectiveness of trifloxysulfuron against velvetleaf at all carrier volumes (Table 2).

Discussion

In this work, we explored the effectiveness of trifloxysulfuron against velvetleaf dusted with different soil rates. This work provides the finding that the effectiveness of trifloxysulfuron is negatively correlated with the rate of soil settled on velvetleaf. Already, a similar correlation has been reported by Zhuo *et al*. (2006) and Aliverdi and Ahmadvand (2020). However, at low soil rates settled on velvetleaf, trifloxysulfuron efficacy was not affected. Similarly, Zhuo *et al*. (2006) reported that the effectiveness of glyphosate against nightshade dusted within the soil dust chamber cannot be adversely affected by a soil rate of less than 4 kg ha^{-1}. Moreover, Aliverdi and Ahmadvand (2020) reported that the effectiveness of paraquat against winter wild oat could not be adversely affected by a soil rate of less than 2 kg ha^{-1}.

In this work, moreover, we explored optimal carrier volume for trifloxysulfuron in the presence and absence of soil on the surfaces of velvetleaf. In the absence of soil, a decrease in the effectiveness of trifloxysulfuron occurred when the carrier volume was increased. Decreased effectiveness of trifloxysulfuron when carrier volume was increased can be due to some reasons. Firstly, as mentioned above, the nozzle size of 11001 can create the droplets with a range of 106-235 µm, and the nozzle size of 110015 can create the droplets with a range of 236-340 µm. As a result, the smaller the size nozzle, the smaller the droplet size. Smaller droplets may deposit better over the leaf surface, improving herbicide efficacy. Such a negative relationship between droplet size and herbicide efficacy has been reported with glyphosate (Kogan and Zuniga, 2001), glufosinate (Butts *et al*., 2018), dicamba (Meyer *et al*., 2016), and 2,4-D (Lesnik *et al*., 2012). Secondly, the lower the carrier volume, the higher the herbicide concentration. More concentrated herbicide may create a more significant concentration gradient for herbicide between the spray solution and leaf, increasing the diffusion of herbicide into leaf, resulting in improved herbicide efficacy (Buhler and Burnside, 1984). Although the size of droplets in the nozzle sizes of 110015 to 11005 is equal (a range of 236-340 µm), there was still a negative relationship between the carrier volume and effectiveness of trifloxysulfuron on velvetleaf. Therefore, the decreased effectiveness of trifloxysulfuron by increasing the carrier volume can be related to the spray solution's dilution. Although diluting the spray solution improves the point of contact herbicides (Butts *et al*., 2018), it enhances the effectiveness of trifloxysulfuron, a systemic herbicide. Therefore, smaller, more concentrated droplets can improve the effectiveness of trifloxysulfuron on velvetleaf than larger, more diluted droplets. A similar result has been reported for foramsulfuron (Lesnik *et al*., 2012), nicosulfuron (Green and Cahill, 2003), imazapic, and imazethapyr (Grichar and Dotray, 2015). While, a different result has been reported for imazamox (Ramsdale and Messersmith, 2001), rimsulfuron (Green, 1996), nicosulfuron (Brown *et al.*, 2007), and imazapyr (Patten, 2002).

In the presence of soil on velvetleaf (without airflow before spraying), an increase in trifloxysulfuron effectiveness occurred when the carrier volume was increased. Current results showed that soil settling on velvetleaf affected the optimal carrier volume for trifloxysulfuron. So, when the velvetleaf was not treated with the soil, a lower carrier volume; while, when the velvetleaf was treated with the soil, a higher carrier volume was necessary to obtain higher effectiveness trifloxysulfuron. On the other hand, smaller, more concentrated droplets were needed to get the best trifloxysulfuron effectiveness. These results agree with results published by Zhuo *et al*. (2006), who reported that the relationship between carrier volume and glyphosate efficacy depends on the presence or absence of soil dust on the leaves of black nightshade. So that, there is a positive relationship in the presence of soil dust.

Our results showed that the adverse impact of soil settled on velvetleaf against the effectiveness of trifloxysulfuron was more when the soil was applied through the simulated muddy rain than when the soil was spread through the soil dust chamber. This result may be because the soil used through the simulated muddy rain can firmly adhere to the surfaces of velvetleaf (personal observations) and is not likely affected by the collision energy of spray droplets. As a result, the soil, in part, cannot be removed, unlike the soil applied through the soil dust chamber that can flabbily settle on the surfaces of velvetleaf and is likely affected by the collision energy of spray droplets. As a result, the soil in part can fall. Therefore, the soil-applied through the simulated muddy rain can cause more adverse effects on the effectiveness of trifloxysulfuron than the soil used through the soil dust chamber. The removal of soil dust settling on black nightshade by the airflow and its effect on the effectiveness of glyphosate has already been reported (Zhou *et al*., 2006).

Conclusion

The source and rate of soil settled on the surfaces of velvetleaf influenced the effectiveness of trifloxysulfuron. When the source of the soil was a simulated muddy rain, compared to the soil dust chamber, it had a more negative effect on the effectiveness of trifloxysulfuron. Besides, it was not easily removed from velvetleaf by the airflow before spraying. The activity of trifloxysulfuron was negatively correlated with the rate of soil settled on velvetleaf. The relationship between carrier volume and trifloxysulfuron efficacy depended on the presence or absence of soil on the surfaces of velvetleaf. When velvetleaf was treated with the soil, a positive relationship was observed. While, when velvetleaf was not treated with the soil, a negative relationship was observed.

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خاک نشست کرده روی گاوپنبه بر حجم حامل بهینه برای تریفلوکسی‌سولفورون تأثیرگذار است

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دریافت: ۲۶ دی ۱۳۹۹؛ پذیرش: ۳ آذر ۱۴۰۰

چکیده: خواه روی گاوپنبه خاک نشسته باشد یا نباشد، این‌که غلظت قطرات پاشش می‌تواند کارایی تریفلوکسی‌سولفورون را تحت تأثیر قرار دهد مشخص نبود. در آزمایش اول، ۱۲ گرم تریفلوکسی‌سولفورون در هکتار با ۱۳۵ لیتر آب در هکتار روی گاوپنبه تیمار شده با صفر، ۴، ۸، ۱۲، ۱۶ و ۲۰ کیلو گرم خاک در هکتار با دو روشِ اتاقک گرد و خاک ساز و باران گل‌آلود پاشیده شد. در آزمایش دیگر، ابتدا گاوپنبه با و بدون ۲۰ کیلوگرم خاک در هکتار با دو روشِ مذکور تیمار شد و در معرض وزش بادی با سرعت صفر و ۱۰ کیلومتر بر ثانیه قرار گرفت. سپس، ۱۲ گرم تریفلوکسی‌سولفورون در هکتار با ۱۳۵، ۱۸۰، ۲۲۵، ۲۷۰، ۳۶۰ و ۴۵۰ لیتر آب در هکتار به‌کار برده شد. کارایی تریفلوکسی‌سولفورون به‌طور منفی با مقدار خاک نشست کرده روی گاوپنبه ارتباط داشت. وقتی منبع خاک از طریق باران گل‌آلود بود، در مقایسه با اتاقک گرد و خاک‌ساز، تأثیر منفی بیش‌تری بر کارایی تریفلوکسی‌سولفورون داشت. هم‌چنین، خاک نمی‌توانست از گاوپنبه به‌وسیله جریان هوای قبل از پاشش حذف شود. کارایی تریفلوکسی‌سولفورون با حجم حامل هم‌بستگی داشت. نوع هم‌بستگی بستگی به خاک نشست کرده روی گاوپنبه داشت. روی گاوپنبه با خاک تیمار شده، به‌خصوص درون اتاقک گرد و خاک‌ساز، نوع هم‌بستگی مثبت مشاهده شد. از این‌رو، قطرات پاشش رقیق‌تر و بزرگ‌تر برای کسب کارایی بهتر تریفلوکسی‌سولفورون لازم بود. برعکس، روی گاوپنبه با خاک تیمار نشده، نوع هم‌بستگی منفی مشاهده شد. از این‌رو، قطرات پاشش غلیظ‌تر و کوچک‌تر برای کسب کارایی بهتر تریفلوکسی‌سولفورون لازم بود.

واژگان کلیدی: پنبه، علف‌کش، باران گل‌آلود و گرد و خاک