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WEED SCIENCE

The Application Time-of-Day Effect for Trifloxysulfuron Against Velvetleaf as Affected by Nozzle Type

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ABSTRACT

All previous studies reporting the application time-of-day effect for herbicides have been conducted with a single-orifice, flat fan nozzle. Whether an increased number of flat fans in the nozzle could affect the application time-of-day effect is unknown. A replicated outdoor pot experiment was conducted to determine the best application time for trifloxysulfuron from 05:00 (before sunrise), 07:00 (after sunrise), 09:00, 11:00, 13:00, 15:00, 17:00, 19:00 (before sunset), and 21:00 (after sunset) against velvetleaf when sprayed with a single-, dual-, or triplet-orifice flat fan nozzles. Trifloxysulfuron sprayed with the single-orifice flat fan nozzle at 05:00 was the least effective treatment reducing velvetleaf fresh weight by 51%. When the single-orifice flat fan nozzle was used, velvetleaf fresh weight, expressed as a quadratic polynomial function with a parabola opening upward, decreased as the application time changed from 05:00 to 11:00 (70% control); thereafter, it increased until 21:00. When the dual- and triplet-orifice flat fan nozzles were used, velvetleaf fresh weight, expressed as a quadratic polynomial function with a parabola opening downward, increased from 05:00 to 07:00; thereafter, it increased as the application time changed until 19:00 (the best application time, reducing velvetleaf fresh weight by 82%). Foliar nyctinasty in velvetleaf is responsible for decreased efficacy of trifloxysulfuron sprayed with the single-orifice flat fan nozzle before sunset. This obstacle can be overcome using the dual- or triplet-orifice flat fan nozzles.

Trifloxysulfuron is a systemic herbicide belonging to the inhibitors of acetolactate synthase (group B/2), the key enzyme in the branched-chain amino acid biosynthesis pathway. In cotton (*Gossypium hirsutum* L.), it can selectively control velvetleaf (*Abutilon theophrasti* Medic.) (O'Berry et al., 2008; Salimy et al., 2008), a weed causing cotton yield loss up to 80% at a density of 12 plants m^{-2} (Ghorbanpour et al., 2014). Trifloxysulfuron is not rapidly degradable, resulting in carryover injury on succeeding crops (Dvorkin et al., 2012; Minton et al., 2008; Porterfield et al., 2006; Rector et al., 2020). Moreover, the strong selection pressure it exerts on sensitive biotypes leads to the evolution of trifloxysulfuron resistance in some species (Brosnan et al., 2015; Francischini et al., 2014a, b), but that has not happened in velvetleaf yet. The application of trifloxysulfuron at reduced rates to decrease the carryover effect can occur if it is rationally applied. An herbicide is rationally used if three principles are followed: selectivity of herbicide in the crop, application of appropriately timed herbicide, and accuracy of application equipment (Wilson, 2003).

Previous studies have shown that the application of herbicides at different times of day can influence their activity. This is referred to as the application time-of-day effect reported for: aciflurofen (Carter and Prostko, 2019; Lee and Oliver, 1982), atrazine (Stewart et al., 2009), bentazon (Carter and Prostko, 2019; Doran and Andersen, 1976; Stopps et al., 2013), bromoxynil (Stewart et al., 2009), carfentrazone (Wersal et al., 2010), chlorimuron (Miller et al., 2003; Stopps et al., 2013), dicamba (Johnston et al., 2018; Montgomery et al., 2017;Stewart et al., 2009), diflufenzopyr (Stewart et al., 2009), diquat (Wersal et al., 2010), fluazifop (Fausey and Renner, 2001; Friesen and Wall, 1991), flumiclorac, fluthiacet (Fausey and Renner, 2001), fomesafen (Cieslik et al., 2014; Miller et al., 2003; Stopps et al., 2013), glufosinate (Martinson et al., 2002; Miller et al., 2003; Montgomery et al., 2017; Sellers et al., 2003; Stewart et al., 2009), glyphosate (Belbin et al., 2019; Martinson et al., 2002; Miller et al., 2003; Mohr et al., 2007; Norsworthy et al., 1999; Sellers et al., 2003; Stewart et al., 2009; Stopps et al., 2013; Waltz et al., 2004;), imazapic (Carter and Prostko, 2019), imazethapyr (Stopps et al., 2013), ioxynil (Skuterud et al., 1998), lactofen (Carter and Prostko, 2019; Ferreira et al., 1998;), linuron (Kraatz and Andersen, 1980),

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nicosulfuron (Stewart et al., 2009), paraquat (Carter and Prostko, 2019; Montgomery et al., 2017; Norsworthy et al., 2011; Preston et al., 2005), quizalofop (Stopps et al., 2013), saflufenacil (Montgomery et al., 2017), 2,4-D (Johnston et al., 2018; Montgomery et al., 2017), and 2,4-DB (Carter and Prostko, 2019). Application time-of-day effect on the activity of trifloxysulfuron has not been studied. In general, review of the literature revealed that with contact herbicides, weed control is better at nighttime than daytime, particularly after sunset. Whereas the reverse is true for systemic herbicides. Moreover, only a single-orifice flat fan nozzle was used to spray the herbicides in all previous studies although dual- and triplet-orifice flat fan nozzles are available (Fig. 1; MagnoJet, 2015) and the performance of dual-orifice flat fan nozzle has been reported as better than that of single-orifice flat fan nozzle (Aliverdi and Ahmadvand, 2018; Peng et al., 2005; Vallet and Tinet, 2013). No information is available on the performance of triplet-orifice flat fan nozzle in comparison to single- and dual-orifice flat fan nozzles. Whether nozzle type could influence the application time-of-day effect for an herbicide is unknown.

The objective of this study was to determine the best application time for trifloxysulfuron when was sprayed with the single-, dual-, and triplet-orifice flat fan nozzles against velvetleaf.

MATERIALS AND METHODS

Velvetleaf seeds were collected from a field in Gorgan, Iran (36°49′ N, 54°28′ E, 155 m asl) in summer 2017 and stored in a cool, dry room. They were hydro-primed in hot water at 60°C for 1 h (Ravlić et al., 2015). Twenty hydro-primed seeds were planted at a depth of 0.5 cm in each 2-L brown plastic pot containing a clay loam soil with 0.4% organic matter and pH of 7.2. The pots were placed in the open air at Bu-Ali Sina University, Hamedan, Iran (34°52′ N, 48°32′ E, 1850 m asl). After the seedlings emerged, they were thinned to five plants pot^{-1}. The plants were irrigated every 2 d and fertilized every week with 30 ml of a solution containing 3 g L^{-1} of an N:P:K (20:20:20) fertilizer.

The experiment was arranged in a randomized, complete block design with a 3 × 9 factorial arrangement of treatments using two factors and four replications. The experiment was repeated at 1-d intervals at all stages. The first experimental run was planted on 31 May 2019, sprayed on 11 July 2019, and harvested on 2 August 2019. The first factor was the type of nozzle: single-, dual-, or triplet-orifice flat fan nozzles (Fig. 1; all are anti-drift 11002VK). The second factor was the application time: 05:00 (before sunrise, which occurred at 06:10), 07:00 (after sunrise), 09:00, 11:00, 13:00, 15:00, 17:00, 19:00 (before sunset, which occurred at 20:32), and 21:00 (after sunset). In all treatments, 12 g ha^{-1} trifloxysulfuron (16 g ha^{-1} Envoke® %75 WG, Syngenta) were applied with 210 L ha^{-1} at 3 bar using a compressed-air sprayer at the four-leaf stage of velvetleaf. A non-treated control was included for comparison purposes. A medium spray quality ranging from 236 to 340 μm with the single- and dual-orifice flat fan nozzles and a fine spray quality ranging from 106 to 235 μm with the triplet-orifice flat fan nozzle can be provided at 3 bar (MagnoJet, 2015). The angle between two flat fans in the dual- and triplet-orifice flat fan nozzles is 40°. The angle of the fourth leaf of one plant pot^{-1} to the ground was measured with a protractor at application time (Table 1). Foliar nyctinasty in velvetleaf depends on daylight and has been reported by Aliverdi and Sharifi (2020). Air temperature, relative humidity, and wind speed at each application time were recorded (Table 1).

Figure 1. Single-, dual-, and triplet-orifice flat fan nozzles used in the study, all anti-drift 11002VK.

Table 1. The leaf angle of velvetleaf to the ground, air temperature, relative humidity, and wind speed at the application times of day.

Application time of day	Air temperature (°C)	Relative humidity (%)	Wind speed (km h^{-1})	Leaf angle (°)
05:00	17	39	0.0	-78
07:00	23	35	2.3	-5
09:00	27	19	0.0	-13
11:00	31	18	0.0	-12
13:00	36	19	0.7	-20
15:00	37	17	1.1	-10
17:00	32	17	1.4	-24
19:00	27	21	1.2	-65
21:00	26	21	0.6	-81

Data were averaged over two experimental runs. No dew was seen.

Three weeks after treatment, the plants in each pot were harvested and weighed to obtain the fresh weight. The fresh weight of treated plants was converted to a percentage of non-treated plants. A normal distribution of data was stabilized (Shapiro-Wilk test > 0.97). The data were subjected to analysis of variance using SAS software. No significant run-by-treatment interactions occurred. Hence, the data were pooled to give eight replications, then re-analyzed. For separating the means, Fisher's least significant difference (LSD) was used at the 5% probability level. Further to this analysis, the R^2 values indicated that the trend of the fresh weight of treated plants (% of the non-treated control) over different times of day was best fitted by a non-linear model (quadratic) on each nozzle type.

RESULTS AND DISCUSSION

The dose of 12 g ha^{-1} trifloxysulfuron chosen for this study was based on a pre-test dose-response of approximately 80% control achieved when sprayed with a single-orifice flat fan nozzle at 9:00. Complete control with the label rate was achieved (data not shown).

The ANOVA showed that velvetleaf fresh weight, as a percentage of the non-treated control, was significantly affected by the two-way interaction between the main effects (*F* value = 89.32, *p*-value < 0.001). This interaction was fitted best by a quadratic polynomial function with a parabola opening upward for the single-orifice flat fan nozzle, but by a quadratic polynomial function with a parabola opening downward for the dual- and triplet-orifice flat fan nozzles (Fig. 2).

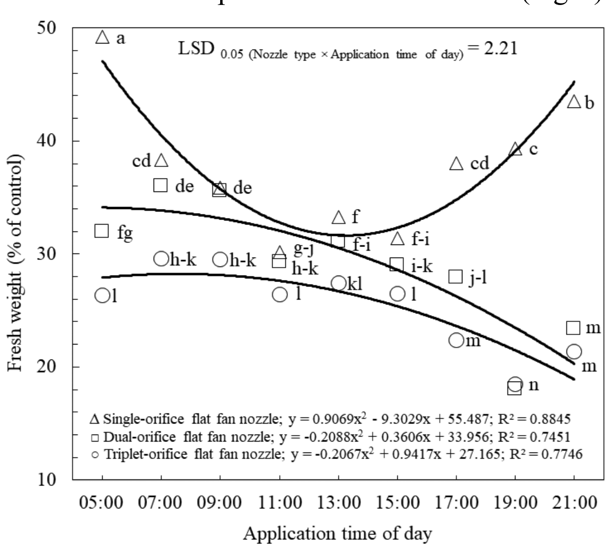

Figure 2. Mean fresh weight (% of control) of velvetleaf when trifloxysulfuron was applied with the anti-drift 11002VK single-, dual-, and triplet-orifice flat fan nozzles at different times during the day. Data points are means of eight replicates from two experimental runs. The means followed by same letter are not significantly different according to Fisher's Protected LSD at the 5% probability level.

Trifloxysulfuron sprayed with the single-orifice flat fan nozzle at 05:00 reduced velvetleaf fresh weight 51% compared to the non-treated control. It was the least effective treatment in this study. When trifloxysulfuron was sprayed with the single-orifice flat fan nozzle, velvetleaf fresh weight was decreased as the application time of day changed from 05:00 to 11:00 (the best application time providing 70% reduction in velvetleaf fresh weight); thereafter, it increased until 21:00. This result indicated that there was an application time-of-day effect on the activity of trifloxysulfuron against velvetleaf: trifloxysulfuron was more active at the daytime applications than the nighttime applications. Many researchers have found similar results with other systemic herbicides when sprayed with a single-orifice flat fan nozzle. Better efficacy of trifloxysulfuron at daytime applications can be related to the occurrence of foliar nyctinasty in velvetleaf (Table 1). In general, the leaf angle of velvetleaf was less at the nighttime applications (5:00 and 21:00) than at the daytime applications (7:00 to 19:00). Norsworthy et al. (1999) and Sellers et al. (2003) sprayed glyphosate with a single-orifice flat fan nozzle and reported that as the leaf angle decreased, the interception area for spray droplets decreased. As a result, the spray droplets most likely will endo-drift without impacting the target, resulting in reduced glyphosate efficacy.

The best application time for trifloxysulfuron sprayed with the dual-orifice flat fan nozzle was achieved at 19:00 (82% control). When the application time coincided with a velvetleaf leaf angle of more than -20° (07:00-15:00), there was no significant difference between the performance of single- and dual-orifice flat fan nozzles. When the application time coincided with a velvetleaf leaf angle of less than -20° (05:00, 17:00, 19:00, and 21:00), the performance of dual-orifice flat fan nozzle was better than single-orifice flat fan nozzle. Differences in the performance of single and dual-orifice flat fan nozzles increased as the leaf angle of velvetleaf decreased. A possible reason for this observation is that as the leaf angle of velvetleaf decreased, it likens to a grassy species having vertically oriented leaves. As a result, the interception area can be increased for the non-vertical sprays from the dual-orifice flat fan nozzle producing two flat fans: one angled 40° forward and the other angled 40° backward (Fig. 1). When spraying a dye solution on artificial vertically and horizontally oriented targets, Wolf and Peng (2011) reported that the angling of spray from a single-orifice flat fan nozzle increased the spray deposition on a vertically oriented target but not on a horizontally oriented target. It is possible that the spray angle from a single-orifice flat fan nozzle can improve the efficacy of herbicides on grassy species having vertically oriented leaves, but not on broadleaved species having horizontally oriented leaves (Aliverdi and Zarei, 2020). Although the single and dual-orifice flat fan nozzles are classified as having the same spray quality (MagnoJet, 2015), the latter has a smaller droplet size due to atomizing through two orifices. It is possible that as the leaf angle of velvetleaf decreased, the efficacy of trifloxysulfuron sprayed with the dual-orifice flat fan nozzle increased because the smaller droplet sizes resulted in greater coverage on vertical plant surfaces (Butts et al., 2018).

Like the dual-orifice flat fan nozzle, the best application time for trifloxysulfuron sprayed with the triplet-orifice flat fan nozzle was achieved at 19:00 (82% control). At all application times, the performance of triplet-orifice flat fan nozzle was better than that of single-orifice flat fan nozzle. For seven of nine application times (05:00-17:00), the performance of triplet-orifice flat fan nozzle was better than that of dual-orifice flat fan nozzle. There are two reasons for the better performance of triplet-orifice flat fan nozzle. Firstly, the spray droplets of triplet-orifice flat fan nozzle are smaller than that of dual-orifice flat fan nozzles (MagnoJet, 2015) due to atomizing through three orifices. It is accepted that the smaller the droplet size, the better the spray retention, resulting in improved herbicide activity (Aliverdi and Ahmadvand, 2018; Ferguson et al., 2018), although increased carrier volume can buffer the droplet size effect (Butts et al., 2018). Secondly, the triplet-orifice flat fan nozzle produces three flat fans: one angled 40° forward, one perpendicular to the ground, and the third angled 40° backward (Fig. 1). Presumably, better targeting can occur with an increased number of flat fans in the nozzle. More research is required to corroborate this issue.

When the leaf angle of velvetleaf decreased, the activity of trifloxysulfuron sprayed with the dual- and triplet-orifice flat fan nozzles against velvetleaf improved. Nonetheless, the efficacy of trifloxysulfuron sprayed with the dual- and triplet-orifice flat fan nozzles at 19:00 was significantly higher than at 21:00. Higher photosynthetic rate in velvetleaf before sunset than after sunset can increase the transport of a systemic herbicide (Waltz et al., 2004). This finding confirmed that trifloxysulfuron is more active at daytime applications than the nighttime applications.

CONCLUSIONS

Velvetleaf control with trifloxysulfuron varied diurnally, with daytime applications generally being more effective. The occurrence of foliar nyctinasty and photosynthesis in velvetleaf in response to light availability were recognized the main reasons for the application time-of-day effect observed on the activity of trifloxysulfuron. However, the type of nozzle used altered the application time-of-day effect for trifloxysulfuron. For the single-orifice flat fan nozzle, trifloxysulfuron was most effective when applied mid-day, whereas with dual- and triplet-orifice flat fan nozzles, trifloxysulfuron was most effective when applied late-day. In conclusion, foliar nyctinasty in velvetleaf is responsible for less efficacy of trifloxysulfuron sprayed with the single-orifice flat fan nozzle before sunset. This obstacle can be overcome using the dual- or triplet-orifice flat fan nozzles.

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