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The effect of nozzle type on clodinafop-propargyl potency against winter wild oat

Akbar Aliverdi, Goudarz Ahmadvand*

Department of Agronomy and Plant Breeding, Faculty of Agriculture, Bu-Ali Sina University, Hamadan, Iran

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ABSTRACT

In rational herbicide application technique, a critical management decision to minimize exo- and/or endo-drift is the optimal nozzle selection to spray at wind speed authorized (< 1.5 m s^{-1}) and unauthorized (> 1.5 m s^{-1}). Two studies were conducted simultaneously to select the optimal nozzles for two windy conditions. In bioassay study, six doses of clodinafop-propargyl (0, 8, 16, 32, 48, and 64 g a. i. ha^{-1}) were sprayed with 10 types of yellow color-coded polymer spray nozzle having a 110° spray angle against winter wild oat at 0.5 and 7.5 m s^{-1} wind speeds. In drift and deposition study, only the recommended dose of clodinafop-propargyl (64 g a. i. ha^{-1}) was sprayed in the same manner above on the water sensitive papers which were installed in different positions. On the ground under the nozzle trajectory, the highest and lowest droplet density were observed with the Twin Fan Standard (45.0 droplet cm^{-2}) and Turbo TeeJet Induction (11.0 droplet cm^{-2}) nozzles at 0.5 m s^{-1} wind speed, respectively. With the exception of the Turbo TeeJet, Turbo Twin Jet and Air Induction Turbo Twin Jet nozzles, a significant droplet density was exo-drifted up to 10 m distance when other nozzle types were used to spray at 7.5 m s^{-1} wind speed. The highest and the lowest ED_{50} values were obtained with the Turbo TeeJet Induction (9.84 g a. i. ha^{-1}) and Twin Fan Standard (3.26 g a. i. ha^{-1}) nozzles when clodinafop-propargyl was sprayed at 0.5 m s^{-1} wind speed, respectively. While, the highest and the lowest ED_{50} values were obtained with the Turbo TeeJet Induction (12.35 g a. i. ha^{-1}) and Turbo Twin Jet (9.23 g a. i. ha^{-1}) nozzles when clodinafop-propargyl was sprayed at 7.5 m s^{-1} wind speed, respectively. The Twin Fan Standard nozzle having the lowest endo-drift at wind speed authorized and the Turbo Twin Jet nozzle having almost low exo-drift at wind speed unauthorized were found to be an optimal nozzle to obtain an optimal clodinafop-propargyl potency against winter wild oat.

1. Introduction

Herbicides can secure global food security provided that the rational herbicide application technique is taken into consideration (Cobb and Reade, 2010). The principal elements of rational herbicide application technique include the selectivity of herbicide, the application of appropriately timed herbicide and the accuracy of application equipment (Wilson, 2003). In some popular types of herbicide application equipment, the hydraulic spray nozzle is a key component to influence on the accuracy of spraying (Meyer et al., 2016). For this reason, the nozzle technology is always improving. Therefore, the manufactures have introduced more than 60 nozzle types that all are available to apply in different situations. Among the four functions of a nozzle, the main function is to atomize the spray solution into droplets which are necessary to evenly and effectively deposition the spray solution on the target (Creech et al., 2014). The atomization quality is a function of formulation (Contiero et al., 2016), adjuvant (Sasaki et al., 2013), operating pressure (Hewitt et al., 2009), nozzle size (Ferguson et al., 2016), and nozzle type (Creech et al., 2014). All hydraulic spray nozzles produce a wide range of droplet sizes having a normal distribution. The fate of each droplet after its formation depends on its size to deposit on target or drift to non-target areas (Monaco et al., 2002). Both small (< 100 μm) and large (> 500 μm) droplets often have the highest drift potential. The former is most likely to exo-drift (Wilson, 2003), particularly when wind speed at time of application is greater than 1.5 m s^{-1} (Monaco et al., 2002). The latter is most likely to endo-drift (Wilson, 2003), particularly when the target is a grass such as wild oat having a leaf surface with hard wettability due to its upright leaves (Aliverdi et al., 2009).

A systemic post-emergence herbicide such as clodinafop-propargyl, an acetyl coenzyme A carboxylase inhibitor, should be sprayed when the wind speed is lower than 1.5 m s^{-1} (Monaco et al., 2002). In such a

* Corresponding author.
E-mail addresses: a.aliverdi@basu.ac.ir (A. Aliverdi), gahmadvand@basu.ac.ir (G. Ahmadvand).

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Table 1
The technical information of nozzles at 300 kPa.

Nozzle type	Abbreviation	Spray geometry	VMD range (μm)	Droplet category	Symbol	Manufacturer
Standard Fan	SF	Single flat	144–235	Fine	F	ASJ, Italy
Low Drift	LD	Single flat	144–235	Fine	F	ASJ, Italy
Compact Fan Air	CFA	Single flat	341–403	Coarse	C	ASJ, Italy
Turbo TeeJet	TT	Single flat	236–340	Medium	M	TeeJet, USA
Turbo TeeJet Induction	TTI	Single flat	> 665	Ultra Coarse	UC	TeeJet, USA
Twin Fan Standard	TFS	Dual flat	61–144	Very Fine	VF	ASJ, Italy
Twin Fan Low Drift	TFLD	Dual flat	404–502	Very Coarse	VC	ASJ, Italy
Twin Fan Air	TFA	Dual flat	503–665	Extremely Coarse	XC	ASJ, Italy
Turbo Twin Jet	TTJ	Dual flat	341–403	Coarse	C	TeeJet, USA
Air Induction Turbo Twin Jet	AITTJ	Dual flat	404–502	Very Coarse	VC	TeeJet, USA

All nozzles are made of molded polymer with a 110° spray angle. Nozzle flow rate is 0.8 L min^{-1} at 300 kPa (0.2 gallon min^{-1} at 40 PSI). The angle between each spray pattern in dual flat nozzles is 60° forward and back. Volume median diameter (VMD) is a value where 50% of the spray volume is composed of droplets smaller than the VMD and 50% of the spray volume is in larger droplets.

situation, the spray nozzle manufacturers have recommended that it can be sprayed at a given pressure with a nozzle type that can produces the Very Fine (VF: 61–105 μm), Fine (F: 106–235 μm), Medium (M: 236–340 μm), or Coarse (C: 341–403 μm) droplets to obtain the minimum endo-drift. In a situation that the wind speed at time of application is greater than 1.5 m s^{-1}, this herbicide should be sprayed at a given pressure with a nozzle type that can produces the C, Very Coarse (VC: 404–502 μm), Extremely Coarse (XC: 503–665 μm), or Ultra-Coarse (UC: > 665 μm) droplets to obtain the minimum exo-drift (AST, 2017). This recommendation has already confirmed in previous studies. For instance, Bueno et al. (2017) reported that a nozzle with VC atomization quality presented the lowest percentage of drift at 1.8 m s^{-1} wind speed in relation to other nozzles with F, C, and M atomization qualities. A similar result was observed by Stainier et al. (2006) at 5.0 m s^{-1} wind speed. Gil et al. (2014) showed an interesting effect of air injection nozzles with VC atomization quality on drift reduction, in comparison with conventional flat fan nozzles with F atomization quality at 0.69 m s^{-1} wind speed.

The American Society of Agricultural Engineers (2009) categorized the atomization quality of nozzles from VF to UC using a series of tests in which water plus a nonionic surfactant at 0.25% *v/v* with a surface tension of ~32 mNm^{-1} was sprayed at 20 °C. As confessed by the spray nozzle manufacturers, the recommendations mentioned above cannot be wholly true for all formulations and under all climatic conditions (AST, 2017). Therefore, there is a major concern leading this experiment was conducted. The recommendations mentioned above to select the nozzle type can be true under temperate climatic conditions. However, in cool climates (Kottek et al., 2006) such as Hamedan (34°48′N, 48°31′E, 1850 m a.s.l.) in Iran, clodinafop-propargyl is often sprayed in wheat fields to control winter wild oat (*Avena sterilis* ssp. *ludoviciana*) (Moss, 2015) during winter or spring at a low air temperature. It is well established that there is a negative relation between temperature with either surface tension or viscosity of spray solution (de Ruiter et al., 2003). However, the temperature can decrease the metabolism of herbicide in the plant into a nonlethal metabolite (Olson et al., 2000), allowing herbicide to remain in the parent form for a longer time. At this point, the cold air temperature can enhance indirectly herbicide selectivity, especially when the formulation was included with a safener (Robinson et al., 2015). Selectivity of clodinafop-propargyl is based on the difference in the speed of its breakdown in wheat versus wild oat which obtained with adding a safener, cloquintocet-mexyl, to the formulation (Environmental Protection Agency, 2000). Therefore, if clodinafop-propargyl can be used at cold air temperature it represents indirectly an opportunity for reducing the dose of clodinafop-propargyl.

The present study aims to compare 10 nozzle types in relation to the potency of clodinafop-propargyl against wild oat and the drift and deposition potential of droplets at two wind speeds authorized and unauthorized for spraying under a low air temperature condition.

2. Materials and methods

2.1. Bioassay study

On 25 June 2016, the seeds of winter wild oat were collected from wheat fields in Hamedan, Iran. They were treated in the same manner which was already described by Aliverdi et al. (2009) to break their dormancy. Then, nine wild oat seedlings with 1 cm coleoptile stem length were planted with a quadrangular planting pattern at 1 cm depth within each square brown plastic pot (256 cm^2 area × 20 cm deep) filled with 3 Kg soil (28.91% clay, 47.01% silt, 23.65% sand and 0.43% organic matter with a pH 7.2). The seedlings were grown in the Research Greenhouse of Bu-Ali Sina University, Hamedan, Iran with day/night temperatures of 18/10 ± 2 °C during a natural photoperiod of 11–13 h. The seedlings were firstly sub-irrigated after plantation and then irrigated every five days. They were thinned to six plants pot^{-1} at the one-leaf stage.

The experiment was repeated two times. With an interval of one week, the first experiment was planted on 15 February 2017 and then the second experiment was planted on 22 February 2017. But with an interval of ten days, those experiments were sprayed on 8 and 18 April 2017, respectively. There were four replications of each treatment. In both experiments, when winter wild oats were at the five-leaf stage they were treated with clodinafop-propargyl at 0, 8, 16, 32, 48, and 64 g a. i. ha^{-1} (Tapik 8% EC) using 10 nozzle types at two wind speeds of 0.5 and 7.5 m s^{-1} which were adjusted with the rotation round of fans within a designed wind tunnel (2 × 2 × 12 m). The pots were rowed under the nozzle trajectory which was perpendicular to the wind direction. The atmospheric conditions on the days of spraying were 11 ± 2 °C and 58 ± 3% relative humidity. A standard 210 L ha^{-1} carrier volume was sprayed at a pressure of 300 kPa with 10 types of yellow color-coded polymer spray nozzle having a 110° spray angle. The technical information of nozzles is shown in Table 1. On the days of spraying, the untreated plants within four pots were separately harvested, oven-dried at 70 °C for 48 h, and then weighed to obtain the dry weight (result: 0.15 g plant^{-1}).

The treated plants were harvested four weeks after spraying and treated in the same manner above to obtain the dry weight. The date from each pot were divided by 6 (plant pot^{-1}) and subtracted from 0.15 (dry weight plant^{-1} on the day of spraying). Then, they were fitted to analyze using the following four-parameter log-logistic model (Ritz et al., 2015) to estimate the effective doses for clodinafop-propargyl against winter wild oat:

$$Y = \frac{C + (D - C)}{\{1 + exp[B(logX - logED)]\}}$$

Where, Y is the dry weight plant^{-1}; C and D are lower and upper limits, respectively; B is curve slope around ED; X is the dose of clodinafop-propargyl; ED is effective dose (g a. i. ha^{-1}) which can be replaced by