https://doi.org/10.17221/39/2023-PPS

Particle drift potential of mesotrione and rimsulfuron plus thifensulfuron-methyl tank mixture in a low-speed wind tunnel

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Citation: Brankov M., Alves G.S., Vieira C.B., Zaric M., Kruger R.G. (2023): Particle drift potential of mesotrione and rimsulfuron plus thifensulfuron-methyl tank mixture in a low-speed wind tunnel. Plant Protect. Sci., 59: 284–291.

Abstract: Particle drift happens during herbicide application when droplets travel outside the intended site. Different nozzles produce various range of droplets, so they play a very important role in coverage and drift occasions. When nozzles produce small droplets, the potential for off-target movement is very high. Another important factor determining particle drift is the distance between crops. Wind velocity gives the energy to herbicide particles to move away from the target place. Therefore, a drift simulation of herbicide (mesotrione and rimsulfuron plus thifensulfuron-methyl mixture) was done in a wind tunnel, using different nozzles Extended Range (XR) and Turbo TeeJet Induction (TTI). The wind speed was set at 4.4 m/s, representing the least favourable conditions where applications are possible. In the wind tunnel, eight crops (cantaloupe, cotton, green bean, pumpkin, soybean, sunflower, wheat, and watermelon) were positioned at 4, 6, 9, and 12 m downwind distances from the nozzle, and drift was simulated. Following treatments, plants were returned to a greenhouse for 28 days, and biomass reduction was recorded. Artificial collectors (Mylar cards) and water sensitive cards were positioned alongside plants. According to obtained results, spraying with XR nozzle influences higher injuries than TTI nozzle. Tracer deposition was higher at all distances when XR nozzle was used. Accordingly, droplet numbers, covered area, Volume Median Diameter (VMD), and deposition were higher on water sensitive cards when spraying were done using XR nozzle. As a consequence, higher biomass reduction occurred using the XR nozzle. The most sensitive crops were cantaloupe, pumpkin and sunflower, while the most tolerant were soybean and wheat.

Keywords: off-target movement of application; crop injuries; deposition

Awareness regarding pesticide off-target movement exists all the time, and in the last few years, research on herbicide drift has been investigated more than ever. The implications with auxin herbicides include very high susceptibility to non-GM crops, tank contamination or volatility issues (McCown et al. 2018; Alves et al. 2020; Soltani et al. 2020). Due to this fact, all applications regarding these kinds of herbicides are regulated with strict application guidelines, including restrictions on nozzle type, and applications are labelled requiring the use of extremely coarse or ultra-coarse sprays

This research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-47/2023-01/200040).

https://doi.org/10.17221/39/2023-PPS

(Anonymous 2019). With a growing concern about herbicide off-target movement and respect for new label standards, farmers are adopting drift-reducing nozzles to increase herbicide droplet size and reduce their likelihood of spray drift.

Nozzles are some of the most important parts of spraying equipment, determining all spray characteristics (amount of spray solution, uniformity, coverage, drift). They are designed to produce droplets from liquid solution, and according to droplet size characterization (diameter), they can vary from extremely fine (diameter < 60 μm) and ultra-coarse (diameter > 650 μm) (American Society of Agricultural and Biological Engineers). Drift reduction nozzle types are constructed to increase droplet size, which reduces off-target movement. Those nozzles use a Venturi process [the reduction in fluid pressure that results when a fluid flows through a constricted section (or choke) of a pipe], which regulates the herbicide flow, and produces lower drop velocity (Dorr et al. 2013). Due to the process, the pressure drop in the nozzle causes air to be drawn in, which mixes into the spray solution in the nozzle, creating larger, air-entrained droplets. Specified nozzles have a pre-orifice insert or chamber, which produces the Venturi effect, leading to larger droplets being delivered.

With the adoption of drift-reducing nozzles for application, the issue regarding herbicide efficacy becomes interesting since coarse droplets provide lower coverage, and large droplets could easily slip from the leaves (Legleiter & Johnson 2016). Therefore, studies were conducted to investigate the influence of droplet size's effects on herbicide efficacy. Based on the literature source, spraying with nozzles that produce coarse droplets could be mainly used for translocate herbicides (Butts et al. 2018; Butts et al. 2019), while adding adjuvants and their interaction with herbicide solution plays a very important role in obtaining the maximum efficacy (Bunting et al. 2004).

In addition to nozzle selection, several options exist to mitigate or reduce spray drift. One way is to provide a physical barrier to eliminate possible damage to the surrounding vegetation (Vieira et al. 2018). Providing an optimal distance between crops also helps to mitigate herbicide drift. Since the literature evaluated drift mostly followed by glyphosate or dicamba application, it is necessary to evaluate other herbicides of interest and show their possible negative effect on drift. This research sought to present simulated particle drift from mesotrione and rimsulfuron plus thifensulfuron-methyl mixture in a wind tunnel, using two nozzle types: Extended Range (XR), which produces fine droplets, and Turbo TeeJet Induction (TTI) which produces coarse droplets. Eight crops [cantaloupe (*Cucumis melo* L.), cotton (*Gossypium hirsutum* L.), green bean (*Phaseolus vulgaris* L.), pumpkin (*Cucurbita pepo* L.), soybean (*Glycine max* L. Merril.), sunflower (*Helianthus annuus* L.), wheat (*Triticum vulgare* L.), and watermelon (*Citrulus vulgaris* S.)] were positioned at four distances away from the nozzles. The least favourable conditions for applications were simulated (4.4 m/s).

MATERIAL AND METHODS

Eight crops: cantaloupe, cotton, green bean, pumpkin, soybean, sunflower, watermelon, and wheat were grown in a greenhouse, and then plants (height of 15–20 cm) were moved into a wind tunnel, where they were exposed to herbicide drift. The research was carried out at the Pesticide Application Laboratory, West Central Research and Extension Center of the University of Nebraska-Lincoln, North Platte, Nebraska, USA. The experiment was conducted and repeated as a complete randomized design with a split-split plot arrangement, where crops were the main plot, nozzles were the subplot, and downwind distance (4, 6, 9, and 12 m) was the sub-sub plot.

In this research, a herbicide mixture of mesotrione (Callisto®, 480 SC g ai/L, Syngenta Crop Protection LLC, Greensboro, NC, USA) and rimsulfuron plus thifensulfuron-methyl (Resolve Q®, 184 g/kg rimsulfuron plus 40 g/kg thifensulfuron-methyl WG, DuPont Co., Wilmington, DE, USA) were used. This tank-mix combination was applied at rate 105.6 g/ha and 6.1 plus 3.5 g/ha for mesotrione and rimsulfuron plus thifensulfuron-methyl, respectively at carrier volume of 200 L/ha. Herbicide applications in the wind tunnel were performed using two nozzle types: Extended Range (XR110015) and Turbo TeeJet® Induction (TTI11015) (Spraying Systems Co., Wheaton, IL, USA). Both nozzles were evaluated at 276 kPa. Wind speed was set at 4.4 m/s, representing the least favourable conditions for application. Wind velocity is the most important factor influencing

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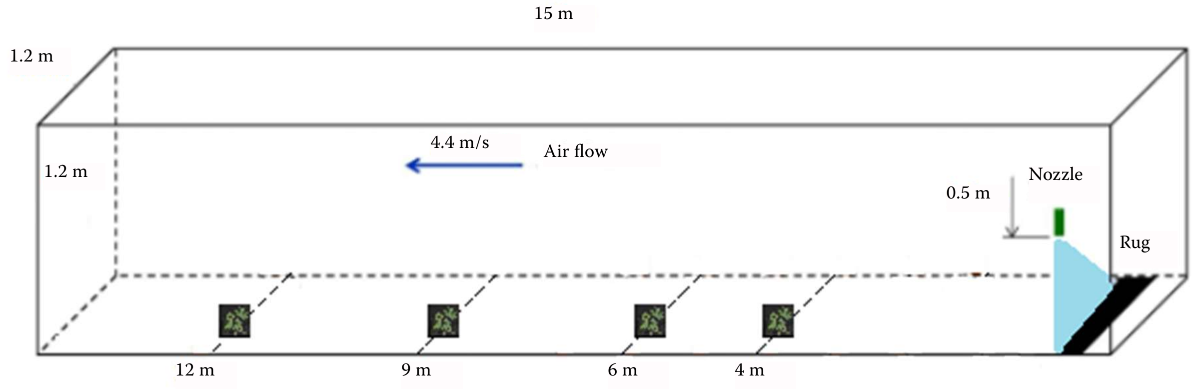

Figure 1. The wind tunnel facility

application by catching droplets that have not yet settled on the target. The higher the potential for spray drift, the higher the wind velocity will be and otherwise (Alves et al. 2017).

Crops were grown in plastic cones (Stuewe and Sons, Inc., Corvallis, OR, USA) filled with ProMix General Purpose growing medium (Premier Tech, Quakertown, PA, USA). Plants were watered with an incorporated UNL 5–1–4 at 0.2% v/v fertilizer. Greenhouse was maintained at 30/20 °C day/night and 16 h photoperiod (supplemental light – LED growth lights 520 µmol/s, Philips Lighting, Somerset, NJ, USA). Plants were returned to the greenhouse after being exposed to herbicide drift, maintained, and at 28 days, dry biomass was measured after drying, and data were presented as a percentage of biomass reduction compared to the untreated control.

All treatments were applied in a low-speed wind tunnel with a 1.2 m wide, 1.2 m high, and 15 m long working section (Figure 1). The wind tunnel uses an axial fan (Hartzell Inc., Piqua, OH, USA) to generate airflow and move air from the fan into an expansion chamber in front of the tunnel. The airspeed was fixed at 4.4 m/s at the nozzle height measured using a portable anemometer (Nielsen-Kellerman Inc., Kestrel® 4 000, Boothwyn, PA, USA).

Artificial collectors (Mylar cards, 10 × 10 cm; Grafix Plastics, Cleveland, OH, USA) and water-sensitive cards (TeeJet Technologies, Glendale Heights, IL, USA) were positioned alongside every plant (Figure 2). The water-sensitive cards (Figure 2) were subjected to Flat-bed Scanner and DropletScan (University of Nebraska-Lincoln), and coverage (%), total number of droplets, Volume Median Diameter (VMD), and deposition volume (L/ha).

A fluorescent tracer [PTSA (1, 3, 6, 8 – pyrenetetrasulfonic acid tetra-sodium salt, Spectra Colors Corp., Kearny, NJ, USA)] was added to the herbicide solution at 3 g/L (Hoffmann et al. 2010). After applications, the Mylar cards were collected and placed individually into plastic bags and then placed in a dark container to prevent tracer photo degradation. Samples were kept in the dark until fluorometric analysis was conducted. In the laboratory, 50 mL of 10 : 90 (v : v) isopropyl alcohol: distilled water solution was added to each plastic bag using a bottle top dispenser (LabSciences Inc., 60000-BTR, Reno, NV, USA). Samples were then swirled and shaken to release the fluorescent mate-

Figure 2. The position of Mylar and water sensitive card

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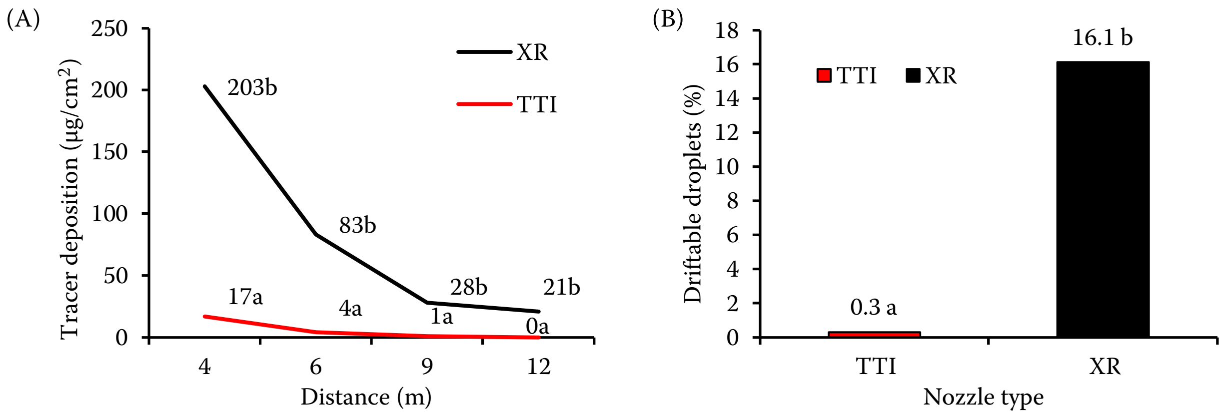

Figure 3. Tracer deposition is influenced by distance and nozzle type (A) and percentage of driftable droplets (droplets < 150 µm); (B) Letters in the figures indicate significant differences between nozzle types

XR – Extended Range, TeeJet Technologies, Glendale Heights, IL, USA; TTI – Turbo TeeJet Induction, TeeJet Technologies, Glendale Heights, IL, USA

rial. After the tracer was suspended in the liquid, a 1.5 mL aliquot was drawn from each sample bag to fill a glass cuvette. The cuvette was placed in a PTSA module inside a fluorimeter (Turner Designs, Trilogy 7 200.000, Sunnyvale, CA, USA) that uses ultraviolet light to collect fluorescence data. The fluorimeter was initially calibrated in relative fluorescence units (RFUs), and the data was then converted into nL/cm^2.

All comparison of the crop biomass, tracer deposition, droplet fines, coverage, number of droplets, VMD, and deposition volume was done using ANOVA [Sisvar Statistical Software, version 5.6 (Ferreira 2011)] and differences between means were tested by Tukey's test (α = 0.05). A regression analysis was done to estimate the relationship between coverage and total droplet with dry biomass reduction.

RESULTS

According to obtained results, the tracer deposition was higher at all distances 4, 6, 9 and 12 m when for applications, the XR nozzle was 91% higher deposited tracer was measured at a 4 m distance (203 µg/cm^2) using the XR nozzle. At the 12 m distance, no deposition was recorded using the TTI nozzle (Figure 3A). Furthermore, the percentage of driftable droplets was only 0.3% using the TTI nozzle, compared with the XR, where the percentage of droplets was 16% (Figure 3B).

Based on the estimations done on water-sensitive cards (Figure 4), droplet number, covered area, and herbicide volume had the same trend: decreasing the amount of droplets and covered area going the further distance, while larger values were obtained using the XR nozzle (Table 1). Droplet number varied for the XR nozzle from 6 285, 4 835, 2 747, and 1 510 to 4, 6, 9, and 12 m respectively. On the other hand, the highest droplet number using the TTI nozzle was at 4 m (334), while 71 was at 12 m from the nozzle. The covered area was less than 1% using the TTI nozzle, while up to 14% (at 4 m) using the XR nozzle. Deposition volume was more than 50 L/ha for the XR, while only 2 L using the TTI nozzle. No consistent results were observed for VMD for each nozzle.

The biomass reduction, expressed in percentages, significantly depends on coverage, but in

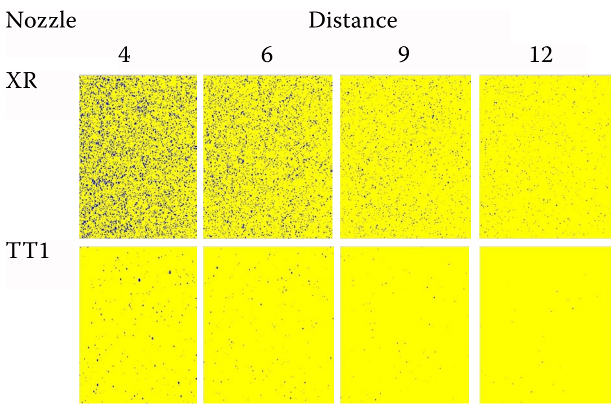

Figure 4. Water-sensitive cards show herbicide deposition depending on nozzle type and distance

XR – Extended Range, TeeJet Technologies, Glendale Heights, IL, USA; TTI – Turbo TeeJet Induction, TeeJet Technologies, Glendale Heights, IL, USA

https://doi.org/10.17221/39/2023-PPS

Table 1. Droplet number, covered area (%), volume median diameter (VMD), and deposition volume (L/ha) based on estimations from water-sensitive cards as influenced by Extended Range (XR) and Turbo TeeJet Induction (TTI) nozzles and distance

Distance (m)	Nozzle[1]	Parameter			
		Droplet number	Covered area (%)	VMD	Deposition volume (L/ha)
4	XR	6 285.6^{aA}	14.33^{aC}	256.0^{aB}	51.40^{aC}
	TTI	334.2^{bA}	0.63^{bC}	203.0^{bB}	2.02^{bC}
6	XR	4 835.8^{aA}	6.79^{aC}	190.2^{aB}	20.90^{aC}
	TTI	259.8^{bA}	0.32^{bC}	172.4^{bC}	0.93^{bC}
9	XR	2 745.0^{aA}	2.41^{aC}	149.6^{aB}	6.30^{aC}
	TTI	145.8^{bA}	0.13^{bB}	160.2^{bA}	0.34^{bB}
12	XR	1 509.8^{aA}	0.97^{aC}	120.0^{aB}	2.27^{aC}
	TTI	71.4^{bB}	0.04^{bC}	128.4^{bA}	0.10^{bC}

Means followed by the same letter, lowercase in the row and uppercase in the column within distance, do not differ according to Tukey's test at $\alpha = 0.05$; [1]TeeJet Technologies, Glendale Heights, IL, USA

a higher degree, it depends on drop size (Figure 5). In particular, soybean, cotton, watermelon and green bean expressed greater biomass loss with increased drop numbers ($R2 > 0.9$). When coverage was considered, the greater biomass loss was detected in soybean and watermelon ($R2 = 0.8852$ and 0.9574, respectively). Even at lower values of drops number (2 000) and coverage (5 000), biomass reduction was greater in the case of sunflower, pumpkin, green bean, and cantaloupe, and then it mainly remains constant, while for soybean and watermelon, biomass reduction almost linearly followed the increase in drops number, i.e. coverage. Only wheat maintained the greater biomass with the progression of drops number, i.e. coverage, i.e. dependence was the lowest.

DISCUSSION

This research confirms the existing knowledge about nozzle effects on droplet characteristics. Depending on nozzle types, drift can be higher when nozzles produce larger amounts of small, driftable droplets and otherwise (Al Heidary et al. 2014; Torrent et al. 2017). According to Gill et al. (2014) drift potential of any solution depends on droplet size. Herbicide drift is common during application, and economic losses might be very high if a sensitive crop is very close (Brain et al. 2017). The adoption of dicamba-tolerant crops in the USA, together with glyphosate-tolerant crops, influenced research, and most of recently available papers discuss those two herbicides, either for efficacy or off-target movement. However, no previous research tested the herbicide mixture of mesotrione and rimsulfuron plus thifensulfuron-methyl on selected crops, while those herbicides can be used as alternatives for controlling glyphosate-resistant weeds (Brankov et al. 2023). Using alternative herbicides to glyphosate and dicamba is needed for successful weed control (Costa et al. 2019), while the literature reported no results on the drift of those herbicide mixtures to nearby crops. Restriction for dicamba applications in the USA influenced those herbicide applications only possible with nozzles producing coarse and ultra-coarse droplet spectrum for avoiding an off-target movement (Alves et al. 2017), directly lowering any potential for damage on susceptible crops, while our core idea was to test in those nozzles could result in other alternative herbicides, especially tank-mixed. Yet, the literature reported no consistent results on herbicide efficacy of those nozzles to different weeds, since a lot of factors may directly or indirectly influence the efficacy (Moraes et al. 2021).

Furthermore, our research reported intensive crop damage, especially when the XR nozzle was used in simulated drift scenarios. Cantaloupe, pumpkin, and sunflower were very sensitive to the simulated drift, especially using the XR nozzle. However, significantly lower injuries occurred using the TTI nozzle. On the contrary, lower injuries were noticed when spraying using the TTI nozzle (Table 2). In the study, it can be seen that crops were differently affected by the herbicide mixture drift. The highest biomass reduction was noticed in pumpkins and cantaloupes, while soybean and wheat were the most tolerant. However, going further downwind from the nozzles, injuries significantly decreased. An optimal distance between crops (more than 6 m) and a barrier can reduce off-target movement, enabling crop safety (Vieira et al. 2018). According to the obtained data, selecting appropriate nozzles when spraying herbicides is crucial. Still, it is very important that chosen nozzles do not influence herbicide efficacy.

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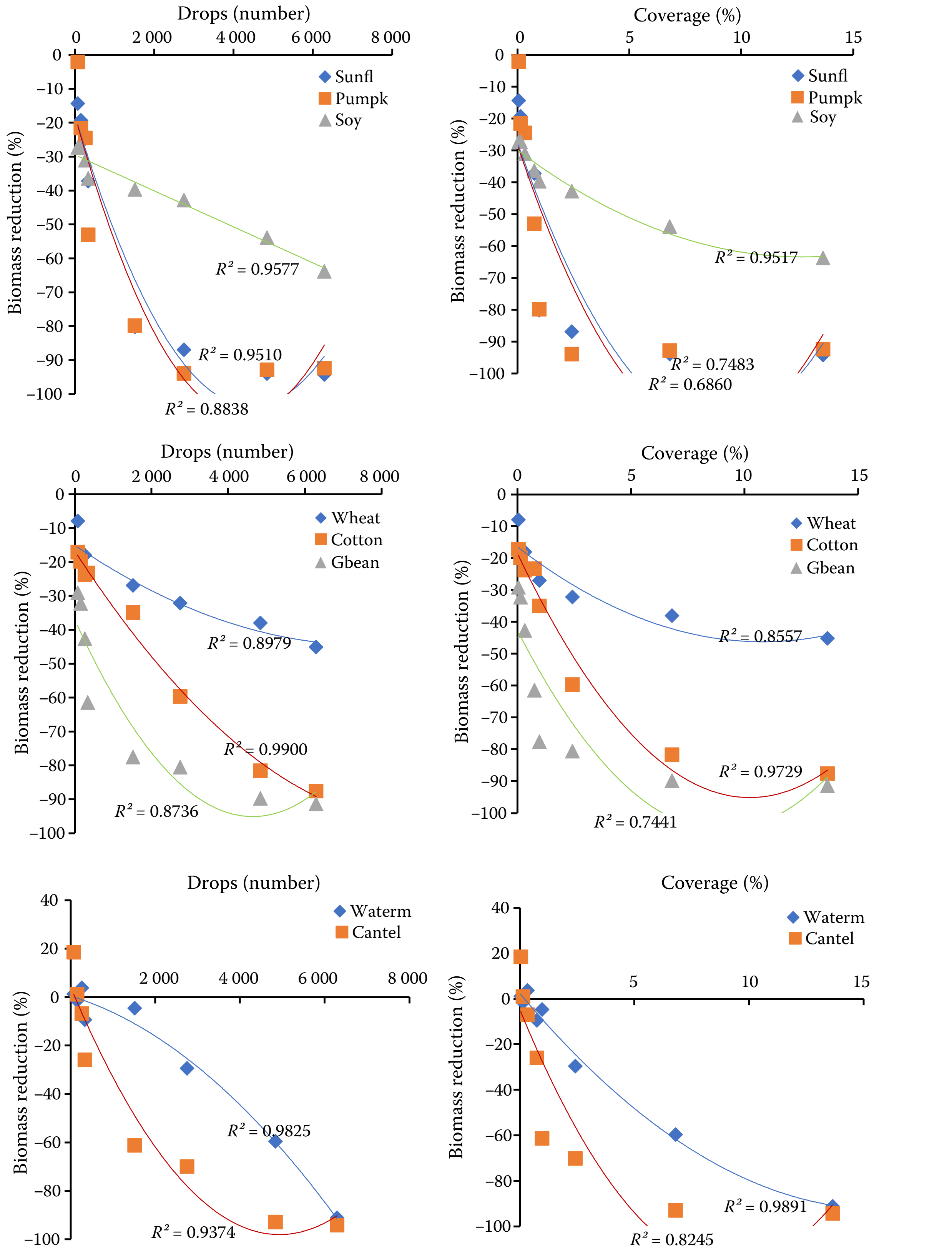

Figure 5. Regression analyses of total drops and coverage on biomass reduction (data combined across both nozzle type)

Sunfl – sunflower; Pumpk – pumpkin; Soy – soybean; GBean – green bean; Waterm – watermelon; Cantel – cantaloupe

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Table 2. Percentage of dry biomass reduction (g) of each crop species 28 days after being exposed to drift of mesotrione plus rimsulfuron plus thifensulfuron-methyl using two nozzles in a wind tunnel

Distance (m)	Nozzle*	Crop species							
		Cantaloupe	Cotton	Green bean	Pumpkin	Soybean	Sunflower	Wheat	Watermelon
4	XR	94.2^{cB}	87.6^{bB}	91.3^{cB}	93.8^{cB}	63.9^{bB}	94.2^{dB}	44.9^{aB}	91.3^{cB}
	TTI	26.1^{bA}	23.7^{bA}	61.5^{cA}	53.0^{cA}	36.4^{bA}	37.5^{bA}	23.0^{bA}	10.0^{aA}
6	XR	92.8^{cB}	81.6^{cB}	88.9^{cB}	93.1^{cB}	56.1^{bB}	93.9^{cB}	38.5^{aB}	59.9^{bB}
	TTI	7.1^{aB}	23.3^{aB}	42.7^{cB}	24.4^{bB}	31.1^{aB}	21.5^{aB}	18.9^{aB}	2.3^{aB}
9	XR	70.0^{cB}	59.7^{bB}	80.7^{cB}	92.3^{dB}	42.1^{aB}	87.1^{aB}	32.8^{aB}	30.1^{bB}
	TTI	0.0^{*aA}	19.9^{aA}	32.3^{bA}	21.5^{bA}	27.6^{aA}	19.5^{aA}	17.7^{aA}	0.0^{*aA}
12	XR	61.2^{cB}	34.9^{bB}	77.6^{dB}	79.9^{dB}	39.7^{dB}	79.9^{dB}	27.5^{bB}	5.1^{cB}
	TTI	0.0^{*aA}	17.3^{aA}	29.1^{bA}	16.0^{bA}	27.6^{aA}	14.6^{aA}	8.3^{aA}	0.0^{*aA}

Means followed by the same letter, lowercase in the row and uppercase in the column within distance, do not differ according to Tukey's test at α = 0.05

*no biomass reduction; XR – Extended Range, TeeJet Technologies, Glendale Heights, IL, USA; TTI – Turbo TeeJet Induction, TeeJet Technologies, Glendale Heights, IL, USA

The literature does not report clear and uniform efficacy results using different nozzles. Therefore, using nozzles producing coarser droplets is necessary in windy conditions, while nozzles producing smaller droplets could be used when there is no wind because those nozzles provide larger coverage of the target.

This pointed out that an optimal distance between crops is needed to protect surrounding vegetation from injuries (Aguiar et al. 2015). Besides nozzle selection and herbicide use, a buffer zone is very important in drift mitigation (Moore et al. 2022). Furthermore, it can contain a barrier which, even to a higher degree, reduces potential off-target movement (Vieira et al. 2018). The highest possible injuries to the neighbour crops come from herbicides because they can act at very low micro rates compared to other pesticides (insecticides or fungicides). Literature reported a significant reduction in off-target movement by a three-meter buffer zone between two crops (de Snoo & Wit 1998). Furthermore, Burn (2003) recommends a six-meter zone as an important factor in reducing the negative effects of drift. The results from our study clearly indicated that a distance between crops and nozzle selection can protect crops when meteorological conditions are not ideal for spraying.

CONCLUSION

Optimizing herbicide application is needed to improve efficacy and reduce off-target movement, disabling agricultural losses and saving the environment. Our study clearly showed the advantage of nozzles producing coarse droplet spectrum when field meteorological conditions are not ideal. Using those nozzles can mitigate spray particle drift in a higher percentage than standard flat-fan nozzles. Besides that, establishing an optimal buffer zone between crops is also essential, according to our findings. Furthermore, all other available tools can be used to reduce the negative impact of herbicides on the environment.

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Recieved: April 11, 2023
Accepted: June 14, 2023
Published online: August 17, 2023