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THE EFFECT OF DESIGN AND THE ACCELERATED WEAR TEST OF AGRICULTURAL NOZZLES ON THE RESULTING DROPLET SIZE

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ABSTRACT

The change in the size of the droplets during the pesticide application process could have a negative impact on the percentage of drift or the losses of pesticides to the environment. One of the factors that could affect the droplet size produced from a single nozzle is the internal design of the nozzle itself, in addition to the wear of the nozzle orifice as a result of the usage time. In this research, three types of nozzles with different internal designs were used (Turbo TeeJet (TT), Turbo TwinJet (TTj 6011003), and Drift Guard (DG 11003)). The nozzles were subjected to an accelerated wear test for one hundred hours, and different droplet size parameters (Dv 0.1, Dv 0.5, Dv 0.9), relative span (RS), and Sauter mean diameter (SMD) were measured during and after this test. The measurements were made using the Sympatec HELOS-VARIO/KR device in fifteen positions along the spray swath. The results of the study showed that the droplet size (Dv 0.5) generally increased for the DG 11003 and TTj 6011003 nozzles after the accelerated wear test (worn nozzles), while there was a decrease in Dv 0.5 for the TT 11003 nozzles. The DG 11003 nozzles (before and after the wear test) had the highest percentage of droplets with a size smaller than 150 μm (%< 150 μm) compared to the TT 11003 and TTj 6011003 nozzles. Moreover, the %< 150 μm was higher in the middle position of the spray swath for the three types of nozzles and the new and worn nozzles.

Introduction

Droplet size has an influence on the spray application process (Milanowski et al., 2022a; Parafiniuk et al., 2017) and it affects the deposition, canopy penetration, and spray drift (Subr et al., 2019). Selecting an appropriate nozzle can produce coarser droplets, reducing spray drift (Ferguson et al., 2016). Bueno et al. (2017) also pointed out that increasing the droplet size of the spray will reduce the drift percentage especially near the crop regions. Creech et al. (2016) study recommended using a large droplet size to control weed using the dicamba herbicide with the aim of reducing drift. However, excessively large droplets reduced weed control efficacy. This decrease in the control efficacy was also reported by Meyer et al. (2016) study results. The study showed that using nozzles that produce coarser droplet size accompanied by low application rate could decrease the herbicide efficacy in controlling the weed. Carter et al. (2017) reported similar findings, i.e., that a coarser droplet size could cause a decrease in the spray coverage and efficacy (taking into account the herbicide and weed type). However, Ferguson et al. (2018) reported that using coarse droplet size (produced by nozzles with drift reduction technologies) resulted in the most herbicide efficacy, and at the same time reduced the drift potential compared with fine droplet size. On the other hand, Ferguson et al. (2019) study results showed no effect of the droplet size produced from different type nozzles on the herbicide efficacy on the control of Chloris spp grasses.

There are different parameters that affect the droplet size produced from a certain type of nozzle. found that the nozzle type affected soybean biometrics and the yield of seeds. Subr et al. (2020) found that the nozzle type had a significant effect on the droplet size. Al-Taie and Kadhim (2023) mentioned that the nozzle type and size influence the spray distribution uniformity and the coverage, which impact the efficacy of the pesticide spray. Dorr et al. (2013) study results showed that the droplet size is influenced by the nozzle design, parameters of operation, and spray formulation. The other factors that have an influence on the droplet size were the spray pressure, herbicide type, application rate, and nozzle orifice size. Increasing the last factor (orifice size) from 03 to 05 resulted in an increase in the droplet size (Creech et al., 2015). Li et al. (2021) also reported a positive relationship between the droplet size and the orifice size at fixed spray angle and pressure.

However, Liao et al. (2020) study indicated that the size of the droplet is not always related to the nozzle orifice size. For example, a large orifice size does not always produce a large droplet size, and it could produce a smaller droplet size percentage more than expected for its orifice size. The orifice size could be changed (enlarged) due to the nozzle wear after a certain number of usage hours. Yao et al. (2020) reported that the nozzles wear due to the long usage could affect the nozzle performance and could make the deviation of the droplet size measurement higher. It should be mentioned that the design of the nozzle affects its resistance to wear (Milanowski et al., 2022b).

Creech et al. (2015) indicated that the nozzle type has the main effect on the droplet size. Lafferty and Tian (2013) indicated that the droplet size spectrum could be affected by the nozzle's internal geometry, where the nozzle orifice size, pre-orifice design, and the air intake design can cause an increase in the droplet size. The decrease in pressure due to the pre-orifice design, besides a possible influence of the turbulent intensity, can cause this increase in the droplet size. The pre-orifice design also influenced the flow rate of spray due to the increased loss in energy inside the nozzle body. Moreover, this design has energy losses due to the friction through the upstream orifice. McGinty et al. (2016) reported the same findings in their study of nozzles with pre-orifice design, where this type of nozzle produced larger droplet size and less fine size droplets. Moreover, their study found that nozzles with air induction and pre-orifice design resulted in a decrease in the potential drift percentage of the spray. Farias et al. (2020) reported that TTj 6011003 nozzle type provided a medium droplet size leading to reducing the possibility of non-target drift occurrence. Moreover, the double jet of the TTj 6011003 nozzle provided better penetration of the spray inside the plants' canopy. Xiao et al. (2018) study results showed that the type of the TT110 nozzle registered the highest values of the relative spans, and the widest spray pattern width compared with flat-fan (XR110), TwinJet (TJ 110), and air-induction (AI 110) nozzles. Lafferty and Tian (2013) pointed out that the new design of the drift reducing nozzles, which changed the size of droplets to a coarser size, did not enhance the uniformity of the droplet size.

Increasing the nozzle orifice size due to the wear will lead to an increase in the amount of pesticide applied to the crops. This has a negative impact on the economic efficiency of the pesticide control process, besides its negative impact on human and animal health, food safety, and the preservation of the environment. In addition, the changes in the nozzle orifice dimensions could lead to a change in the droplet size spectrum and its uniformity across the spray swath of the nozzles. Therefore, this study aims to investigate the effect of using different design nozzles before and after subjecting them to the accelerated wear test on the droplet size spectrum produced from these nozzles.

Materials and Methods

Nozzles

Three types of nozzles were used in the study, Turbo TeeJet (TT 11003), Turbo TwinJet (TTj 6011003), and Drift Guard (DG 11003) produced by TeeJet manufacturer (Spraying Systems Co., Illinois USA). These nozzles feature a pre-orifice design, and the TTj 6011003 nozzle has twin flat spray patterns with a 60° angle between the streams. According to the manufacturer's catalog (Spraying Systems Co., 2014), the main features of the TTj 6011003 nozzle include excellent chemical and wear resistance, better canopy coverage, and penetration than the TT 11003 nozzle with the same capacity. It also produces a slightly larger droplet size than the TT 11003 nozzle for drift reducing. The main features of the TT 11003 nozzle were firstly it provides uniform coverage in broadcast spraying. Secondly, it has resistance to corrosive solutions. Thirdly, less clogging because of its rounded and large internal passage. Fourthly, it has superior resistance to wear, and finally, it produces large droplets for less drift. The DG 11003 nozzle has two orifices placed in sequence, the first one (pre-orifice) is to reduce the liquid pressure inside the inner chamber of the nozzle body before discharging it through the second orifice (exit orifice). The main features of the DG 11003 nozzle according to the manufacturer catalog where it provides uniform coverage and large droplets for drift reduction.

Nozzles were subjected to an accelerated wear test for one hundred hours using an abrasive material (Kaolin KOM). The abrasive mixture consisted of 300 litre water (tap water) mixed with 18.2 kg Kaolin KOM. The nominal flow rate for the nozzles was 1.18 $l \cdot min^{-1}$, (for details see Table 1) and the flow rate after finishing the wear test became 1.28, 1.27, and 1.19 l·min^{-1} for DG 11003, TT, and TTj 6011003, respectively.

Droplet size measurements

The droplet size classifications at different operating pressure for the three types of nozzles provided by the manufacturer are listed in Table 1.

Table 1.
Nominal flow rate, spray angle, and the droplet size classifications (VMD) at different operating pressures for the three types of nozzles (Spraying Systems Co., 2014)

Nozzles	Nominal flow rate, (l·min^{-1}), (at 3.0 bar pressure)	Spray angle, (at 3.0 bar pressure)	Operating pressure, (bar)					
			1.0	2.0	3.0	4.0	5.0	6.0
TT 11003	1.18	110	VC	C	M	M	M	M
TTj 6011003	1.18	110	-	C	C	C	C	M
DG 11003	1.18	110	-	C	M	M	M	-

VC: Very Coarse, C: Coarse, M: Medium.

Droplet size classifications are based on BCPC specifications and in accordance with ASABE Standard S572.1.

Droplet size and the distribution of droplet size were measured using a Sympatec HELOS-VARIO/KR (Sympatec Inc., Clausthal, Germany) laser diffraction device. Measurements were controlled by WINDOX 5.7.0.0 software provided with the laser diffraction device. The examined nozzle was fixed inside a holder, and the assembly of the nozzle, its holder, and the solenoid valve were moving horizontally across the laser beam using a moving trailer and rail. This process, moving the nozzle assembly and activating the solenoid valve, was controlled using controlling software.

The droplet size measurements were taken after every 10 hours of the accelerated wear test. All measurements were done at 3.0 bar pressure and 50 cm under the nozzle tip along the longer axis of the spray swath. Measurements were taken at 10 cm intervals, and since the long axis of the spray swath was 140 cm, then there were fifteen measurements positions (Figure 1). Some of the reported results were averaged for those fifteen positions (three repetitions in every position). Moreover, graphs showing the change in the measured traits in every position were included. Traversing the nozzle fan through the laser beam, and combining the readings from several samples, which are representative of the spray fan, is an acceptable method according to ASABE (2009).

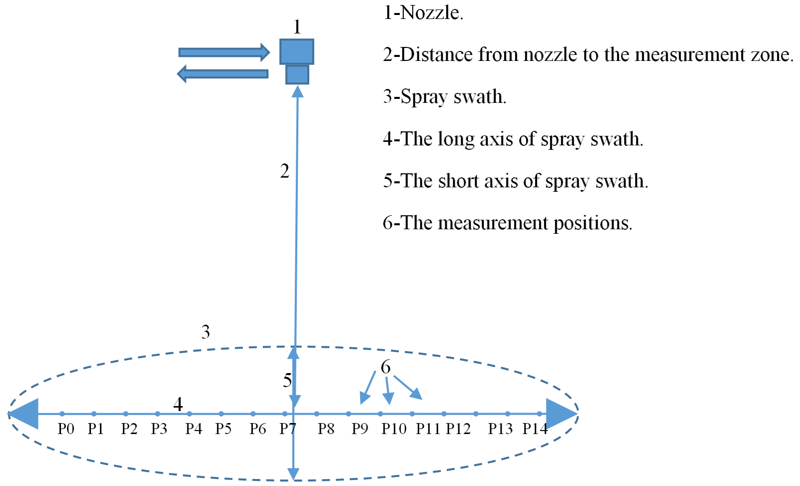

Figure 1. The setting for the droplet size measurement (the nozzle was moving perpendicular to the laser beam).

The measured parameters were: Dv 0.1, Dv 0.5, Dv 0.9, Relative span (RS), and the Sauter Mean Diameter (SMD). The Dv 0.1, Dv 0.5, or volume median diameter (VMD), and Dv 0.9 represent the droplet size (diameter, µm) at which 10, 50, and 90% of the spray volume are comprised of droplets of smaller or equal size, respectively. Relative span (RS), which is a non-dimensional parameter, is an indicator of the variation in the size distribution and the droplet spectrum homogeneous (value close to zero is preferable); it can be calculated as follows:

$$RS = \frac{D_{v0.9} - D_{v\,0.1}}{D_{v\,0.5}} \quad (1)$$

The Sauter Mean Diameter (SMD or D32) is the mean diameter of spray droplets having the same volume to surface area ratio of the total spray volume and it is an indicator of the droplets surface area.

Percentage of droplets volume with a diameter less than 150 µm (%< 150 µm) from the total spray volume was also calculated. This parameter refers to the droplets that have a tendency to drift (Ferreira et al., 2020; Liao et al., 2019; Vieira et al., 2018; Yates et al., 1985).

Results and Discussion

According to the manufacturer catalog, the three types of nozzles (DG 11003, TT, and TTj 6011003) were designed and introduced to reduce the drift percentage by providing a larger droplet size. This aim was sought to be achieved by designing those nozzles with a pre-orifice part, which is located before the exit orifice that emits the spray. This pre-orifice will divide the nozzle internal space into two chambers separated by this pre-orifice part. The liquid pressure in the second chamber (near the exit orifice) will be lower than the pressure of the liquid entering the nozzle in the first chamber because of the pre-orifice presence. This drop in the liquid pressure near the exit orifice will make the produced droplets larger. After the accelerated wear test, droplet size was expected to change due to alterations in the exit orifice's dimensions and shape caused by wear. Figure 2 shows the Dv 0.1, Dv 0.5, and Dv 0.9 for DG 11003, TT, and TTj 6011003 nozzles before and after the accelerated wear test.

The Dv 0.5 or volume median diameter (VMD) for the TTj 6011003 nozzle before the wear test was 372 µm, and it becomes 694 µm after the test (the highest value comparing with DG 11003 and TT 11003 nozzles). While the new nozzle DG 11003 had the lowest value of Dv 0.5 (281 µm) before the wear test (comparing with TT 11003 and TTj 6011003 nozzles), and it becomes 303 µm after the test. The same trend was observed concerning the Dv 0.9 values. For the Dv 0.1, the lowest value was registered for the TT 11003 nozzle after the accelerated wear test (162 µm), while the worn TTj 6011003 nozzle also gave the highest value (334 µm). The new TT 11003 nozzle had a higher value of Dv 0.5 than the worn nozzle; this trend was observed only for this nozzle type. The nozzles can be classified into different droplet size categories (coarse, medium, fine, etc.) based on their Dv 0.5 values (ASABE, 2009). Figure 2 demonstrates a possibility that the TTj 6011003 nozzle was shifted from one size category to another category due to the wear of the nozzle tip.

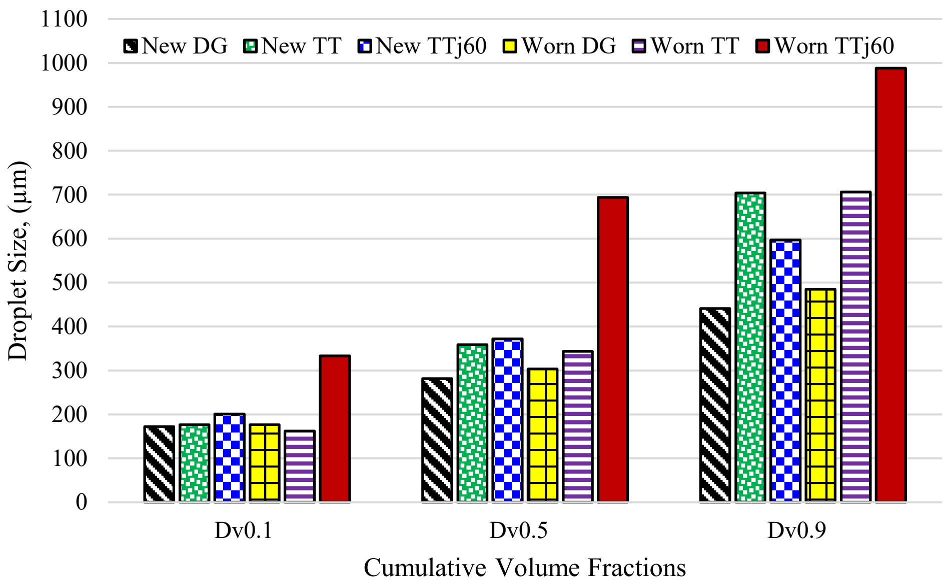

Figure 2. Values of Dv $0_{.1}$, Dv $0_{.5}$, and Dv $0_{.9}$ for three nozzle types (DG 11003, TT, and TTj 6011003) before and after the accelerated wear test

The Dv 0.5 for the three types of nozzles (DG 11003, TT 11003 and TTj 6011003) before and after the accelerated wear test along the long axis of the spray swath are presented in Figure 3. Dv 0.5 values were lower at the center of the spray swath than at its edges for the new TTj 6011003 nozzle and both new and worn DG 11003 nozzles. These results agree with the findings of Bissell et al. (2014) which indicated that larger size droplets were observed at the edges of the spray pattern. Li et al. (2021) also reported the same findings, attributing it to the difference in the droplet velocities at the center and the edge positions of the spray pattern. The new and worn TT 11003 nozzle and the worn TTj 6011003 nozzle did not show a clear trend of Dv 0.5 changing across the spray swath.

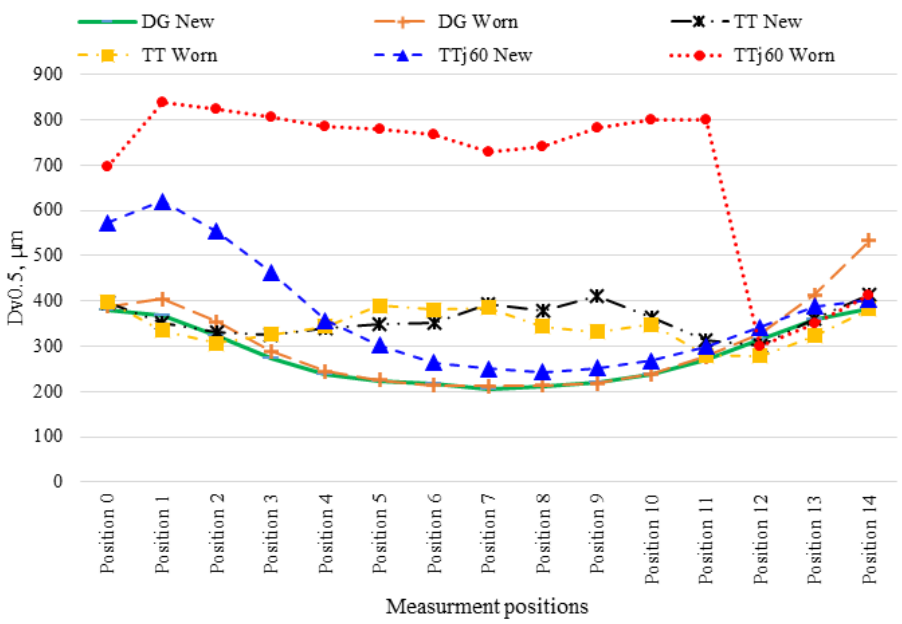

Figure 3. The Dv $0_{.5}$ values along the long axis of the spray swath for the three nozzle types before and after the accelerated wear test

The DV $0_{.1}$, DV $0_{.5}$, DV $0_{.9}$, SMD, and RS measurement results for the three types of nozzles after the different periods of the accelerated wear test are listed in Table 2 (averaged for fifteen measurements positions). As the accelerated wear test progressed, the Dv $0_{.1}$ was decreased for the TT 11003 nozzles, while there was an increase in the Dv $0_{.1}$ values for the TTj 6011003 nozzles. The DG 11003 nozzles did not show a clear trend. As for the results of Dv $0_{.5}$ measurement, as the accelerated wear test progressed, for the DG 11003 and TTj 6011003 nozzles there was generally an increase observed, while for TT 11003 nozzles there was a decrease observed. Generally, there was an increase in the Dv $0_{.9}$ value for the DG 11003 and TTj 6011003 nozzles as the accelerated wear test progressed, while there was not a clear trend for the TT 11003 nozzles. Concerning the SMD results, there was a decrease for the TT 11003 nozzles and an increase in the SMD values for the TTj 6011003 nozzles, while DG 11003 nozzles did not show a clear trend. The DG 11003 nozzles did not show a clear trend concerning the RS values, the same situation was observed for the TTj 6011003 nozzle. The relative span (RS) parameter is a non-dimensional indicator of the variation and spread in the droplets size distribution, smaller values (closer to zero) refer to homogeneity (tightest distribution) of the size of the droplets across the spray pattern. Generally, TT 11003 nozzles have the least homogeneity across their spray pattern during the whole wear test compared with DG 11003 and TTj 6011003 nozzles.

Table 2.
Droplet size parameters for the DG 11003, TT 11003and TTj 6011003 nozzles after increasing duration of wear test (from 0 to 100 hours – step 10 hours)

Duration of wear test	Nozzle	DV $0_{.1}$, μm	DV $0_{.5}$, μm	DV $0_{.9}$, μm	SMD, μm	RS
After 0 hours of wear (new)	DG 11003	172.1	281.6	441.2	214.8	0.96
	TT 11003	176.9	358.3	703.9	289.6	1.47
	TTj 6011003	200.4	371.8	596.8	286.5	1.07
After 10 hours of wear	DG 11003	138.0	280.9	494.0	213.8	1.27
	TT 11003	181.0	377.1	740.4	301.5	1.48
	TTj 6011003	202.2	391.8	689.4	291.6	1.24
After 20 hours of wear	DG 11003	151.3	297.6	503.0	211.1	1.18
	TT 11003	179.2	389.0	733.9	294.2	1.43
	TTj 6011003	203.1	387.9	661.1	296.3	1.18
After 30 hours of wear	DG 11003	171.4	292.7	477.5	244.2	1.05
	TT 11003	176.0	378.1	706.0	294.0	1.40
	TTj 6011003	189.6	308.0	449.4	244.3	0.84
After 40 hours of wear	DG 11003	156.7	294.4	503.6	229.6	1.18
	TT 11003	176.8	386.6	717.2	296.8	1.40
	TTj 6011003	198.2	342.2	588.7	276.3	1.14
After 50 hours of wear	DG 11003	175.5	302.6	493.5	246.2	1.05
	TT 11003	174.7	362.5	688.9	272.5	1.42
	TTj 6011003	208.3	332.4	556.8	281.1	1.05
After 60 hours of wear	DG 11003	175.0	294.2	507.0	223.7	1.13
	TT 11003	162.4	330.3	704.7	275.1	1.64
	TTj 6011003	200.9	326.4	587.4	300.4	1.18
After 70 hours of wear	DG 11003	178.1	293.0	513.3	257.2	1.14
	TT 11003	167.0	349.5	722.3	281.8	1.59
	TTj 6011003	207.3	336.7	538.1	294.5	0.98
After 80 hours of wear	DG 11003	177.3	297.4	526.6	247.7	1.17
	TT 11003	168.5	341.8	701.1	282.1	1.56
	TTj 6011003	244.5	457.4	682.9	352.3	0.96
After 90 hours of wear	DG 11003	171.7	291.2	481.0	239.3	1.06
	TT 11003	165.0	328.2	651.3	261.4	1.48
	TTj 6011003	260.3	478.7	695.1	383.2	0.91
After 100 hours of wear	DG 11003	176.8	303.4	484.6	239.7	1.01
	TT 11003	162.2	343.5	706.1	272.1	1.58
	TTj 6011003	333.5	694.0	988.2	485.1	0.94

Percentage of droplets smaller than 150 µm (%< 150 µm), which are mostly responsible for the drift, was higher in the middle position of the spray swath for the three types of nozzles and during the whole period of the accelerated wear test as well as for the new nozzles (0 hours of wear). The wear progress resulted in an increase in the percentage of droplets smaller than 150 µm at the edges of the spray swath (position 13 and 14) especially during the first 50 hours of wear and after 100 hours of wear, this trend was observed for the three types of nozzles (Table 3).

Table 3.
Percentage of droplets smaller than 150 µm in the total spray volume for DG 11003, TT 11003 and TTj 6011003 nozzles across the spray measurement positions and during different wear duration hours.

Nozzle	Wear duration (h)	Positions of measurement														
		Pos. 0	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6	Pos. 7	Pos. 8	Pos. 9	Pos. 10	Pos. 11	Pos. 12	Pos. 13	Pos. 14
		Percentage of droplets smaller than 150 µm, (%)														
DG 11003	0	5.7	1.8	2.3	7.4	15.6	21.8	25.6	29.7	26.7	22.5	16.2	8.4	3.0	2.1	3.7
	20	10.6	7.1	4.5	4.7	12.6	19.7	23.5	26.6	22.5	19.5	12.4	4.6	4.9	6.3	10.1
	40	10.6	3.6	1.3	2.9	12.3	20.3	24.4	28.0	24.8	21.1	12.6	3.6	2.9	4.3	11.8
	60	3.3	1.7	1.3	7.0	16.3	21.8	24.6	26.2	25.2	22.6	17.7	8.6	3.0	1.4	3.6
	80	2.2	1.7	1.3	7.1	16.4	23.4	25.6	27.6	25.4	21.8	15.2	4.6	0.6	1.2	3.8
	100	7.4	1.7	1.0	5.3	14.8	21.5	26.6	28.4	26.0	22.4	14.1	2.7	0.2	1.5	2.9
TT 11003	0	1.3	1.8	6.1	10.3	11.6	12.2	12.4	11.6	11.4	10.3	10.8	9.9	5.2	1.1	0.7
	20	2.4	1.5	4.7	9.3	10.8	11.2	11.0	12.0	9.8	9.0	9.2	8.7	5.9	2.5	2.5
	40	3.6	0.9	5.0	8.9	10.7	10.8	10.8	12.1	10.9	12.0	10.2	9.0	4.3	1.8	2.7
	60	0.4	2.8	7.1	12.7	12.7	7.3	11.2	12.2	11.0	14.2	12.9	11.8	7.2	2.4	0.8
	80	1.1	2.6	8.4	12.9	11.8	9.1	12.6	12.2	12.2	12.0	12.0	11.4	6.4	1.7	0.8
	100	4.8	2.9	6.5	10.8	11.5	10.9	9.5	11.2	12.1	12.6	12.4	13.1	8.7	3.5	4.9
TTj 6011003	0	1.6	0.8	0.9	1.5	7.5	14.5	18.9	19.1	20.5	17.1	9.8	3.9	5.0	5.9	8.2
	20	2.1	0.7	0.3	1.0	5.1	12.9	17.1	17.1	17.4	15.2	10.3	2.2	3.1	4.6	6.8
	40	3.2	0.7	0.0	1.3	9.6	16.2	19.4	18.5	18.0	14.8	7.4	2.2	1.4	2.1	5.8
	60	0.1	0.0	0.1	1.8	5.0	13.5	17.9	20.9	20.9	19.3	8.7	1.4	0.1	0.0	0.1
	80	0.4	0.2	0.3	0.5	6.4	12.9	16.1	20.9	20.6	17.8	9.2	2.6	4.6	4.3	1.8
	100	1.6	0.1	0.1	0.7	3.4	8.0	9.7	10.6	11.1	8.8	4.8	1.2	1.1	2.1	1.9

Generally, and regardless of the measurements position (results were averaged), DG 11003 nozzles had the highest %< 150 µm. The new nozzles (0 hours of wear) of DG 11003 and TTj 6011003 nozzles had higher %< 150 µm than the same nozzles after finishing the accelerated wear test (100 hours of wear), while for the TT 11003 nozzles the opposite trend of the test data was observed (Table 4).

Table 4.
The percentage of droplets smaller than 150 µm averaged for fifteen measurement positions along the long axis of spray swath for DG 11003, TT 11003and TTj 6011003 nozzles after from 0 to 100 hours of wear test (step 20 hours).

Wear duration, (hours)	Percentage of droplets, (%)		
	Nozzles		
	DG 11003	TT 11003	TTj 60 11003
new	12.8	7.8	9.0
20	12.6	7.4	7.7
40	12.3	7.6	8.0
60	12.3	8.4	7.3
80	11.9	8.5	7.9
100	11.8	9.0	4.4

The results presented on this study would suggest the need for further studies to investigate the effect of tested DG 11003, TT 11003and TTj 6011003 nozzles (new and worn) and the droplets size spectrum produced by it on the spray deposition on natural and artificial targets.

Conclusions

Based on the study results and circumstances, the following can be concluded:

1. The droplet size (Dv 0.5) in general increased for the DG 11003 and TTj 6011003 nozzles as the accelerated wear test progressed, while the opposite happened for TT 11003 nozzles. Moreover, TT 11003 nozzles exhibited the least spray homogeneity (highest relative span values) across the spray pattern throughout the wear test, compared to DG 11003 and TTj 6011003 nozzles.
2. Lower values of Dv 0.5 were observed at the center of the spray swath more than at the edge's positions for the new TTj 6011003 nozzle, and the new and worn DG 11003 nozzle.
3. The %< 150 µm value was measured as higher in the middle position of the spray swath for the three types of nozzles and both new and worn nozzles. Additionally, after the first 50 hours of wear and after 100 hours of wear, an increase in the %< 150 µm was observed clearly at the edges of the spray swath (positions 13 and 14).
4. Regardless of the position of the measurements, new and worn DG 11003 nozzles had the highest %< 150 µm. Moreover, new DG 11003 and TTj 6011003 nozzles had higher

%< 150 μm than the same nozzles after finishing the accelerated wear test (100 hours of wear); while an opposite trend happened to the TT 11003 nozzles.

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References

Al-Taie, H. A. H. & Kadhim, N. S. (2023). The Effect of Power Sources in the Agricultural Tractor and the Developed Sprayer System on the Performance of the Electrical and Mechanical Sprayer System and some Performance Indicators of the Engine. *IOP Conference Series: Earth and Environmental Science*, *1262*(9). https://doi.org/10.1088/1755-1315/1262/9/092005.

ASABE. (2009). Spray nozzle classification by droplet spectra. *ANSI/ASAE S572.1 W/Corr.1*, *2009*.

Bissell, D., Lai, W., Stegmeir, M., Troolin, D., Pothos, S. & Lengsfeld, C. (2014). An approach to spray characterization by combination of measurement techniques. *In ILASS Americas 26th Annual Conference on Liquid Atomization and Spray Systems*. Portland.

Bueno, M. R., Cunha, J. P. A. R. da & de Santana, D. G. (2017). Assessment of spray drift from pesticide applications in soybean crops. *Biosystems Engineering*, *154*. https://doi.org/10.1016/j.biosystemseng.2016.10.017.

Carter, O. W., Prostko, E. P. & Davis, J. W. (2017). The Influence of Nozzle Type on Peanut Weed Control Programs. *Peanut Science*, *44*(2). https://doi.org/10.3146/ps17-4.1.

Creech, C. F., Henry, R. S., Fritz, B. K. & Kruger, G. R. (2015). Influence of Herbicide Active Ingredient, Nozzle Type, Orifice Size, Spray Pressure, and Carrier Volume Rate on Spray Droplet Size Characteristics. *Weed Technology*, *29*(2). https://doi.org/10.1614/wt-d-14-00049.1

Creech, C. F., Moraes, J. G., Henry, R. S., Luck, J. D. & Kruger, G. R. (2016). The Impact of Spray Droplet Size on the Efficacy of 2,4-D, Atrazine, Chlorimuron-Methyl, Dicamba, Glufosinate, and Saflufenacil. *Weed Technology*, *30*(2). https://doi.org/10.1614/wt-d-15-00034.1.

Dorr, G. J., Hewitt, A. J., Adkins, S. W., Hanan, J., Zhang, H. & Noller, B. (2013). A comparison of initial spray characteristics produced by agricultural nozzles. *Crop Protection*, *53*. https://doi.org/10.1016/j.cropro.2013.06.017.

Farias, M. A. G. L., Raetano, C. G., Chechetto, R. G., Ferreira-Filho, P. J., Guerreiro, J. C., Bonini, C. S. B., Prado, E. P. (2020). Spray nozzles and droplet size effects on soybean canopy deposits and stink bugs control in west region of São Paulo state - Brazil. *Phytoparasitica*, *48*(2). https://doi.org/10.1007/s12600-020-00786-8.

Ferguson, J. C., Chauhan, B. S., Chechetto, R. G., Hewitt, A. J., Adkins, S. W., Kruger, G. R. & O'Donnell, C. C. (2019). Droplet-size effects on control of chloris spp. with Six POST herbicides. *Weed Technology*, *33*(1). https://doi.org/10.1017/wet.2018.99.

Ferguson, J. C., Chechetto, R. G., Adkins, S. W., Hewitt, A. J., Chauhan, B. S., Kruger, G. R. & O'Donnell, C. C. (2018). Effect of spray droplet size on herbicide efficacy on four winter annual grasses. *Crop Protection*, *112*. https://doi.org/10.1016/j.cropro.2018.05.020.

Ferguson, J. C., Chechetto, R. G., Hewitt, A. J., Chauhan, B. S., Adkins, S. W., Kruger, G. R. & O'Donnell, C. C. (2016). Assessing the deposition and canopy penetration of nozzles with different spray qualities in an oat (Avena sativa L.) canopy. *Crop Protection*, *81*, 14-19. https://doi.org/10.1016/j.cropro.2015.11.013

Ferreira, P. H. U., Thiesen, L. V., Pelegrini, G., Ramos, M. F. T., Pinto, M. M. D. & da Costa Ferreira, M. (2020). Physicochemical properties, droplet size and volatility of dicamba with herbicides and adjuvants on tank-mixture. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-75996-5.

Lafferty, C. L. & Tian, L. F. (2013). *The impacts of pre-orifice and air-inlet design features on nozzle performance*. https://doi.org/10.13031/2013.7343.

Li, S., Chen, C., Wang, Y., Kang, F. & Li, W. (2021). Study on the atomization characteristics of flat fan nozzles for pesticide application at low pressures. *Agriculture (Switzerland)*, *11*(4). https://doi.org/10.3390/agriculture11040309.

Liao, J., Hewitt, A. J., Wang, P., Luo, X., Zang, Y., Zhou, Z., O'donnell, C. (2019). Development of droplet characteristics prediction models for air induction nozzles based on wind tunnel tests. *International Journal of Agricultural and Biological Engineering*, *12*(6). https://doi.org/10.25165/j.ijabe.20191206.5014.

Liao, J., Luo, X., Wang, P., Zhou, Z., O'Donnell, C. C., Zang, Y. & Hewitt, A. J. (2020). Analysis of the influence of different parameters on droplet characteristics and droplet size classification categories for air induction nozzle. *Agronomy*, *10*(2). https://doi.org/10.3390/agronomy10020256

McGinty, J., Baumann, P., Hoffmann, W. & Fritz, B. (2016). Evaluation of the Spray Droplet Size Spectra of Drift-reducing Agricultural Spray Nozzle Designs. *American Journal of Experimental Agriculture*, *11*(3). https://doi.org/10.9734/ajea/2016/23785.

Meyer, C. J., Norsworthy, J. K., Kruger, G. R. & Barber, T. L. (2016). Effect of Nozzle Selection and Spray Volume on Droplet Size and Efficacy of Engenia Tank-Mix Combinations. *Weed Technology*, *30*(2). https://doi.org/10.1614/wt-d-15-00141.1.

Milanowski, M., Subr, A., Combrzyński, M., Różańska-Boczula, M. & Parafiniuk, S. (2022a). Effect of Adjuvant, Concentration and Water Type on the Droplet Size Characteristics in Agricultural Nozzles. *Applied Sciences (Switzerland)*, *12*(12), 5821. https://doi.org/10.3390/app12125821.

Milanowski, M., Subr, A. & Parafiniuk, S. (2022b). Evaluation of Different Internal Designs of Hydraulic Nozzles under an Accelerated Wear Test. *Applied Sciences (Switzerland)*, *12*(2). https://doi.org/10.3390/app12020889.

Parafiniuk, S., Milanowski, M., Subr, A. & Krawczuk, A. (2017). *Influence of surface tension of water on droplet size produced by flat jet nozzles*. 295–300. https://doi.org/10.24326/fmpmsa.2017.53.

Spraying Systems Co. (2014). *TeeJet technologies, Catalogue 51A-M. Wheaton*. Wheaton, Illinois USA.

Subr, A., Al-Ahmadi, A. & Abbas, M. (2020). Effect of nozzle type and some locally used surfactants on the spray quality. *Iraqi Journal of Agricultural Sciences*, *51*(3), 856-864. https://doi.org/10.36103/ijas.v51i3.1040

Subr, A. K., Alheidary, M. H. R. & Al-Ahmadi, A. H. (2019). The informatics adequacy on the spraying technology in Iraqi agricultural researches: A literature review. *Journal of Physics: Conference Series*, *1294*(9), 092007. https://doi.org/10.1088/1742-6596/1294/9/092007.

Vieira, B. C., Butts, T. R., Rodrigues, A. O., Golus, J. A., Schroeder, K. & Kruger, G. R. (2018). Spray particle drift mitigation using field corn (Zea mays L.) as a drift barrier. *Pest Management Science*, *74*(9). https://doi.org/10.1002/ps.5041.

Xiao, L., Zhu, H., Wallhead, M., Horst, L., Ling, P. & Krause, C. R. (2018). Characterization of biological pesticide deliveries through hydraulic nozzles. *Transactions of the ASABE*, *61*(3). https://doi.org/10.13031/trans.12698.

Yao, W., Lan, Y., Hoffmann, W. C., Li, J., Guo, S., Zhang, H. & Wang, J. (2020). Droplet size distribution characteristics of aerial nozzles by Bell206L4 helicopter under medium and low airflow velocity wind tunnel conditions and field verification test. *Applied Sciences (Switzerland)*, *10*(6). https://doi.org/10.3390/app10062179.

Yates, W. E., Cowden, R. E. & Akesson, N. B. (1985). Drop size spectra from nozzles in high-speed airstreams. *Transactions of the American Society of Agricultural Engineers*, *28*(2). https://doi.org/10.13031/2013.32268.

WPŁYW KONSTRUKCJI ORAZ TESTU PRZYSPIESZONEGO ZUŻYCIA ROZPYLACZY ROLNICZYCH NA WIELKOŚĆ POWSTAJĄCYCH KROPEL

Streszczenie. Zmiana wielkości kropel podczas procesu aplikacji pestycydów może mieć negatywny wpływ na znoszenie rozpylonej cieczy lub ociekania z roślin na ziemię. Jednym z czynników, które mogą wpływać na wielkość kropli wytwarzanych przez pojedynczą dyszę jest wewnętrzna konstrukcja samej dyszy, a także zużycie jej otworu w wyniku użytkowania. W badaniu wykorzystano trzy typy dysz o różnych konstrukcjach wewnętrznych (Turbo TeeJet (TT 11003), Turbo TwinJet (TTj 6011003) i Drift Guard (DG 11003)). Dysze zostały poddane testowi przyspieszonego zużycia przez sto godzin, a podczas i po zakończeniu testu zmierzono parametry: wielkości kropli (Dv 0,1, Dv 0,5, Dv 0,9), względną rozpiętość (RS) i średnią średnicę Sautera (SMD). Pomiary wykonano za pomocą urządzenia Sympatec HELOS-VARIO/KR w piętnastu pozycjach w strudze wachlarza rozpylonej cieczy. Wyniki badania wykazały, że po teście przyspieszonego zużycia rozmiar kropli (Dv 0,5) ogólnie wzrósł dla rozpylaczy DG 11003 i TTj 6011003, a zmalał dla rozpylaczy TT 11003. Dysze DG 11003 (przed i po teście zużycia) miały najwyższy odsetek kropel o rozmiarze mniejszym niż 150 μm (%< 150 μm) w porównaniu do dysz TT 11003 i TTj 6011003. Co więcej, %< 150 μm był wyższy w środkowej pozycji strugi rozpylonej cieczy dla wszystkich trzech typów dysz, zarówno nowych, jak i zużytych.

Słowa kluczowe: test zużycia dyszy, typ dyszy, dysza płaskostrumieniowa, parametry wielkości kropli, metoda dyfrakcji laserowej. aplikacja pestycydów