Research Article

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Liquid atomization and spray drift measurement in a wind tunnel for a twin fluid system with a deflector nozzle

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Abstract: The objectives of this research were to inspect the drop production of a twin fluid system with the Floodjet TK SS 10 042 deflector nozzle and to identify the drift of the droplets produced by the nozzle in a wind tunnel when using the nozzle with the individual settings provided by the company that enlisted our institute to do the described research task. The results of the inspection of drop production, done using a particle sizer, showed that the values of volume diameter D_{v10} were low, the percentage of drops smaller than 100 µm in size was considerable, and the drop sizes varied widely in each setting. It was concluded that the risk of drift and, therefore, the risk of placing an unnecessary load on the environment existed when using the nozzle with the given settings. The application of the nozzle that was tested may cause problems in various aspects of practical spraying techniques. Based on the results of the drift measurements performed in a wind tunnel, the material deposition reported as relative coverage decreased significantly only when the recommended settings were changed at wind velocities of 2.0 m s^{-1} and 4.0 m s^{-1}. At wind velocities of 4.0 m s^{-1} and 6.0 m s^{-1}, detectable (≥1%) relative coverage values were recorded for each setting, even at the measurement limit. It was concluded that the inspected twin fluid system with the Floodjet TK SS 10 042 deflector nozzle does not provide the expected decrease in drift when using the given settings at wind velocities of 4.0 m s^{-1} and 6.0 m s^{-1}.

Key words: Drift, drop production, droplet size, wind tunnel

Introduction

Grown plants can only be effectively protected against the negative effects of pests, pathogens, and furrow weed if expertly selected pesticides are evenly applied in the necessary quantity to the target surfaces over an optimum period of time. Farmers may often suspect that the pesticides are inefficient if the expected results are not obtained. However, another obvious cause may be that the spray was not appropriately applied to the plants. One of the basic requirements of effective plant protection is the use of appropriate machinery and technology. The application system, machinery layout, and technical solutions (namely the system, type, and size of the nozzles) used during plant protection greatly influence the degree to which the agents escape the target area and endanger the environment (Cooke et al. 1990; Rietz et al. 1997; Kutcher and Wolf 2006; Wolters et al. 2008; Nuyttens et al. 2009). Requirements concerning the machinery and technology for applying pesticides have recently become stricter. There have been more professional and social demands placed on using lower quantities

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of chemicals to protect plants and on using the chemicals in an environmentally safe manner without reducing the work quality of the machines or the treatment efficiency (Tuck et al. 1997; Balsari et al. 2007; Vanella et al. 2011).

Many field crop sprayers (boom sprayers) use conventional (standard) flat fan spray nozzles. Because the spraying process with these nozzles creates fine drops, the spray quality may be preferred for the application of pest management products, but the major disadvantage is the risk of drift to nontarget areas (Nordbo et al. 1995; Combellack et al. 1996; Matthews 2004; Bayat and Bozdogan 2005).

Several technical solutions help to considerably increase the drop size of the field crop sprayers and reduce the degree of drift of the spread liquid, thereby moderating the load on the environment (Miller and Hadfield 1989; Wicke et al. 1999; Hewitt 2000; Matthews 2004; Lešnik et al. 2005; Nuyttens et al. 2007).

One possible way to increase the drop size is by using air induction nozzles, in which the liquid flow sucks air into the nozzle in order to create larger drops with increased energy (Piggott and Matthews 1999; Butler Ellis et al. 2002; Matthews 2004; Delele et al. 2007; Jamar et al. 2010).

Another possibility for increasing drop size is using a twin fluid system. Air is actively supplied into the nozzles by a compressor during system operation, and the drop size created by the nozzles can be changed by altering the operating pressure of the liquid and air flowing into the nozzles from the hydraulic spray system (Combellack et al. 1996; Nguyen and Rhodes 1998; Kufferath et al. 1999).

Deflector nozzles may also be used to create larger drops. During the operation of these nozzles, the spray jet ejected through the cylindrical borehole does not collide with another jet of liquid. Instead, it collides with a curved or flat solid surface, spreads, and changes its direction. The liquid film that is subsequently created disintegrates into larger drops according to commonly known principles (Matthews 2004; Silva 2006).

The objectives of this research were to inspect the drop production of a twin fluid system with the Floodjet TK SS 10 042 deflector nozzle and to identify the drift of the droplets produced by the nozzle in a wind tunnel when using the nozzle with the individual settings recommended by the company that enlisted our institute to do the described research work.

Materials and methods

Inspection of drop production

Measurements were performed at the Hungarian Institute of Agricultural Engineering (HIAE) in Gödöllő. The drops produced by the Floodjet TK SS 10 042 nozzle were inspected using a Malvern 2600 C laser particle sizer. The measurements were taken by scanning the spray fan (the total spray fan was scanned while moving the nozzle holder on a straight track at a speed of 0.01 m s^{-1}) at a distance of 0.5 m from the nozzle (the center of the nozzle orifice was located exactly over the laser beam that transmitted through the spray fan). The drops were produced by the nozzle using special settings provided by the company that requested the inspections (Table). These settings include air and liquid pressure settings necessary to produce drops classified as “very fine”, “fine”, “medium”, and “coarse” according to their sizes. The given classification according to drop size does not comply with the specifications set by the British Crop Production Council or with those set in standard no. S572.1 of the American Society of Agricultural and Biological Engineers. Drop distribution according to droplet size was characterized by volume diameter (D_{vx}), by the percentage of drops with sizes smaller than 100 µm, and by droplet size spectra. D_{vx} is the volume diameter (µm) below which smaller droplets constitute x% of the total spray volume (Nuyttens et al. 2010). D_{v10} and the percentage of drops with sizes smaller than 100 µm have an outstanding role from the aspect of the drift inclination of the drops (Ganzelmeier and Rautmann 2000; Murphy et al. 2000; Nuyttens et al. 2007; Nuyttens et al. 2009). Tap water was used to perform the measurements, which were repeated 3 times for each setting, and the mean of the 3 measurements was reported.

Drift measurements in a wind tunnel

The drift inspections were performed in a wind tunnel at the HIAE. The wind tunnel (length: 8.0 m; width: 2.0 m; height: 1.5 m; max. wind velocity: 10.0 m s^{-1}) was built by the Department of Fluid Mechanics at the

Budapest University of Technology and Economics. The inspections were performed according to the given settings mentioned above. Sheets of water-sensitive paper sized 52 × 76 mm (Hill and Inaba 1989; Fox et al. 2001) were fixed to the floor of the measurement area at 0.5-m intervals from the nozzle, which was located at a height of 0.5 m from the floor of the wind tunnel. The longitudinal axis of the spray fan was located across the flow direction of the wind tunnel. Tap water was sprayed using different wind velocities (2.0, 4.0, and 6.0 m s^{-1}) during the measurements. The completely dried sheets of water-sensitive paper were collected and photographed using a digital camera (resolution: 2260 dpi) joined to a stereomicroscope (type: Wild M7A; magnification range: ×6-×31) for the proper magnification, and the images were recorded electronically. Drift was characterized by the relative coverage values (%) calculated by an image-processing program using measurements that were repeated 3 times. The origin of the horizontal axis on the subsequent graphs was 1 m away from the nozzle ("0 point"). A relative coverage of 100% indicates that the water-sensitive papers, located under the middle point of the fan created by the nozzle, were fully colored.

Statistical analyses

All statistical tests were performed using SPSS 14.0 for Windows (SPSS Inc., Chicago, Illinois, USA).

The Kolmogorov-Smirnov test, completed on the results of the drop inspection (values of volume diameter D_{v10} and the percentage of drops with sizes smaller than 100 µm) as well as on the results of drift measurements (relative coverage values), showed a normal data distribution ($P > 0.05$).

The differences between the drop inspection results belonging to the provided individual settings (as groups) and the data from drift measurements belonging to the settings (as groups), wind velocity, and distance were determined by analysis of variance (ANOVA). Duncan's post hoc test was used to compare pairs of settings. The confidence interval for all statistical tests was set at $\alpha = 0.05$.

Results

Results from the drop inspection

The settings and results of the drop inspection are given in the Table, and the drop distribution curves are shown in Figure 1.

The values of volume diameter D_{v10} were recorded in the range of 59.5-97.4 µm (Table).

The results of the comparison of individual settings ("very fine", "fine", "medium", and "coarse") as groups showed significant differences in D_{v10} values ($F_{3,8} = 15.113$, $P \leq 0.001$) between each setting (Table).

The pairwise comparison represented nonsignificant differences in D_{v10} values ($P > 0.05$) between the "very fine" and "fine" settings, and between the "medium" and "coarse" settings (Table). All the other pairs of settings ("very fine" ↔ "medium", "very fine" ↔ "coarse", "fine" ↔ "medium", and "fine" ↔ "coarse") showed significantly differently sized droplets ($P < 0.05$) characterized by their D_{v10} values (Table).

The percentage of drops smaller than 100 µm in size, as shown in Figure 1, was almost identical for the settings "very fine" and "fine" (>25%), nearly 14% for "medium", and higher than 11% for the "coarse" setting.

Table. Drop distribution of the Floodjet TK SS 10 042 nozzle.

Setting	Liquid pressure (bar)	Air pressure (bar)	D_{v10} (µm)	D_{v50} (µm)	D_{v90} (µm)
"Very fine"	2.0	1.5	63.1 ± 3.4 µm	161.3 ± 4.3 µm	283.2 ± 22.5 µm
"Fine"	2.5	1.25	59.5 ± 5.4 µm	176.1 ± 10.3 µm	351.6 ± 14.6 µm
"Medium"	1.5	0.75	86.3 ± 9.4 µm	256.1 ± 6.1 µm	509.8 ± 18.1 µm
"Coarse"	1.5	0.5	97.4 ± 11.6 µm	288.9 ± 28.0 µm	564.6 ± 40.3 µm

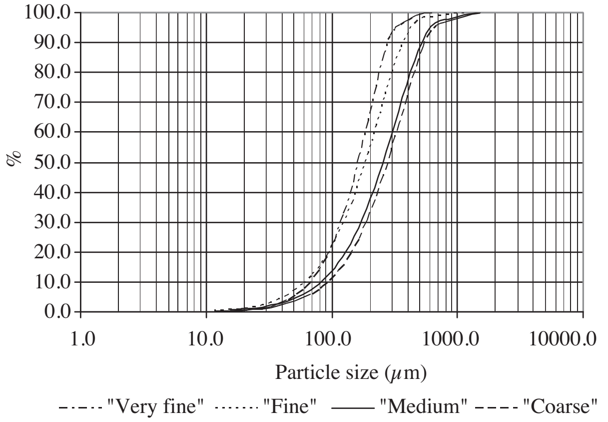

Figure 1. Drop size distribution of the Floodjet TK SS 10 042 nozzle.

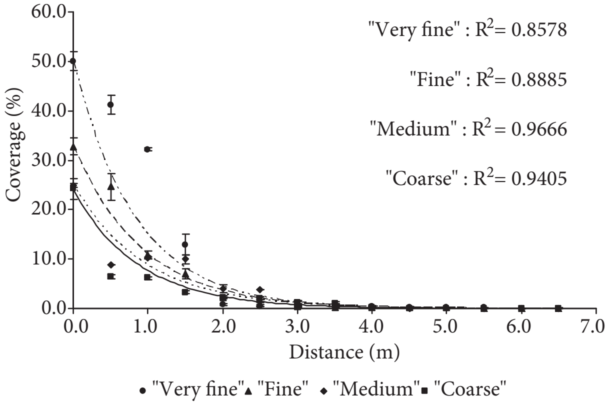

Figure 2. Drift measurements with the Floodjet TK SS 10 042 nozzle at a wind velocity of 2.0 m s^{-1}.

The results of comparing settings as groups showed significant differences in the percentage of drops smaller than 100 μm ($F_{3,8} = 37.966$, $P < 0.001$) between each setting (Figure 1). The differences were nonsignificant ($P > 0.05$) between the pair of "very fine" and "fine" and between the pair of "medium" and "coarse". The other pairs showed significantly differently sized droplets ($P < 0.05$) characterized by the percentage of drops smaller than 100 μm (Figure 1).

As shown in Figure 1, the size of the largest drops rarely exceeded 600 μm for the setting "very fine", and the setting "fine" created drops of up to 850 μm. For the setting "medium", drops larger than 1000 μm appeared, and even drops larger than 1500 μm were found. The setting "coarse" formed a higher ratio of larger- to smaller-sized drops. The occurrence of drops larger than 1000 μm increased relative to the setting "medium". The size of the largest drops exceeded the measurement range of the particle sizer, which was 0.5-1800 μm.

Drift measurements in a wind tunnel

Figures 2-4 show the results of the drift measurements carried out in the wind tunnel.

For the settings "very fine" and "fine" at a wind velocity of 2.0 m s^{-1} (Figure 2), relative coverage on the floor of the wind tunnel was detectable (≥1.0%) up to a distance of 2.5 m away from the "0 point". At a wind velocity of 4.0 m s^{-1} (Figure 3), the relative coverage was 4.0% and 3.0% for the settings "very fine" and "fine", respectively. At a wind velocity of 6.0 m s^{-1} (Figure 4), the relative coverage values at the measurement limit were 7.0% ("very fine") and 4.0% ("fine").

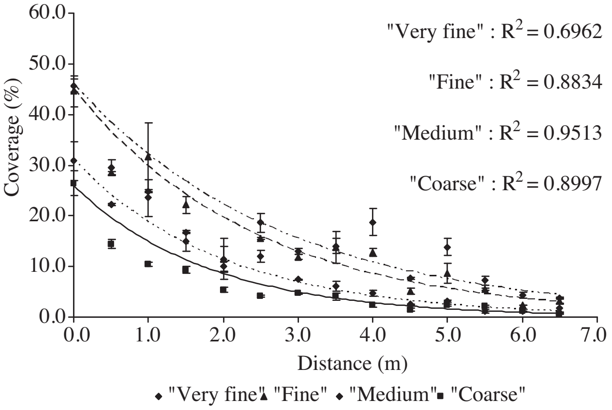

Figure 3. Drift measurements with the Floodjet TK SS 10 042 nozzle at a wind velocity of 4.0 m s^{-1}.

As shown in Figure 2, detectable coverage up to a distance of 3.5 m away from the "0 point" was recorded for the setting "medium" at a wind velocity of 2.0 m s^{-1}. At wind velocities of 4.0 m s^{-1} (Figure 3) and 6.0 m s^{-1} (Figure 4), the relative coverage at the measurement limit decreased to 2.0%.

Detectable relative coverage was measured on the floor of the wind tunnel also up to a distance of 3.5 m away from the "0 point" for the setting "coarse" at a wind velocity of 2.0 m s^{-1} (Figure 2). The relative coverage at the measurement limit decreased to 1.0% in the cases of both higher wind velocities (Figures 3 and 4).

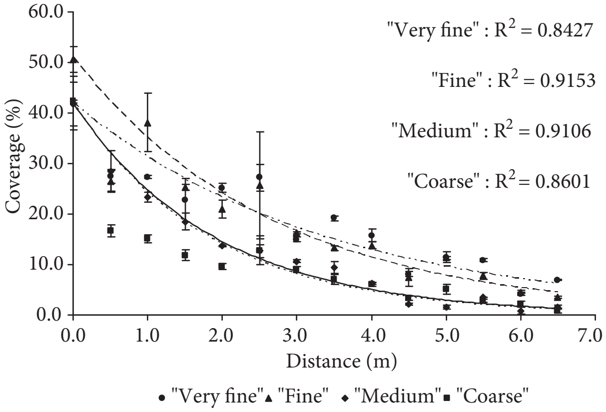

Figure 4. Drift measurements with the Floodjet TK SS 10 042 nozzle at a wind velocity of 6.0 m s^{-1}.

The results of the comparison of specific settings ("very fine", "fine", "medium", and "coarse") as groups showed significant differences in values of total relative coverage (the sum of relative coverage values from the "0 point" to the measurement limit) at all wind velocities (Figure 2: 2.0 m s^{-1}, $F_{3,8} = 800.409$, $P < 0.001$; Figure 3: 4.0 m s^{-1}, $F_{3,8} = 1113.007$, $P < 0.001$; Figure 4: 6.0 m s^{-1}, $F_{3,8} = 1170.545$, $P < 0.001$) between each setting.

The pairwise comparison of settings represented significant differences in total relative coverage values ($P < 0.05$) between each setting at lower wind velocities (Figure 2: 2.0 m s^{-1}, Figure 3: 4.0 m s^{-1}). At a wind velocity of 6.0 m s^{-1} (Figure 4), the difference was nonsignificant ($P > 0.05$) between the settings "very fine" and "fine", but all other pairs ("very fine" ↔ "medium", "very fine" ↔ "coarse", "fine" ↔ "medium", "fine" ↔ "coarse", and "medium" ↔ "coarse") showed significant difference ($P < 0.05$) in total relative coverage.

At a distance of 2.5 m from the "0 point", significant differences were found in the values of relative coverage at all wind velocities (Figure 2: 2.0 m s^{-1}, $F_{3,8} = 232.407$, $P < 0.001$; Figure 3: 4.0 m s^{-1}, $F_{3,8} = 92.593$, $P < 0.001$; Figure 4: 6.0 m s^{-1}, $F_{3,8} = 5.827$, $P < 0.05$) between each setting.

According to the results of the pairwise comparison, significant differences were found in relative coverage values ($P < 0.05$) between each setting at lower wind velocities (Figure 2: 2.0 m s^{-1}, Figure 3: 4.0 m s^{-1}). The differences were nonsignificant ($P > 0.05$) between the settings "very fine" and "fine", as well as between the settings "medium" and "coarse", at a wind velocity of 6.0 m s^{-1}, but all of the other pairs produced significantly different ($P < 0.05$) relative coverage values at a distance of 2.5 m (Figure 4).

Discussion

Inspection of drop production

Based on the drop inspection results, it was concluded that the sizes of drops created by the inspected nozzle increased/decreased nonsignificantly as 2 pairs of individual drop production settings ("very fine" ↔ "fine" and "medium" ↔ "coarse") were changed. It was found that the values of volume diameter D_{v10} were low for all settings (Table). In addition, drops smaller than 100 µm were present in a considerable percentage for each setting (Figure 1).

According to several related references cited above, the twin fluid system and deflector nozzles are effective technical solutions for increasing drop size (increasing D_{v10} and the percentage of drops with sizes smaller than 100 µm), and thus for decreasing drift inclination (Combellack et al. 1996; Nguyen and Rhodes 1998; Kufferath et al. 1999; Matthews 2004; Silva 2006). Despite these references, it was concluded that the inspected twin fluid system with a Floodjet TK SS 10 042 deflector nozzle, using the settings given by the company enlisting our institute to do the described research, was only partly able to ensure the mentioned beneficial properties. Therefore, the risk of drift exists, which may add unnecessary load to the environment.

According to the results of drop inspection, there was a considerable size difference between the drops produced at each setting (Figure 1). Previously, it was reported that differently sized drops show different drift, deposition, spreading, and flowing characteristics, which may increase the risk of burning, escape, and loss of chemicals (Tuck et al. 1997; Balsari et al. 2007; Vanella et al. 2011). In agreement with the related references, it was concluded that the inspected twin fluid system with a Floodjet TK SS 10 042 deflector nozzle, using the specified settings, might cause problems in various aspects of practical spraying techniques.

Drift measurements in a wind tunnel

Based on the results of drift measurements, the material deposition reported as total relative coverage produced by the inspected nozzle increased/decreased nonsignificantly as 1 of the pairs of given drop production settings ("very fine" ↔ "fine") was changed by a wind velocity of 6.0 m s^{-1} (Figure 4). At a wind velocity of 6.0 m s^{-1}, the differences were nonsignificant between 2 pairs of settings ("very fine" ↔ "fine" and "medium" ↔ "coarse") in relative coverage values at a distance of 2.5 m from the "0 point" (Figure 4).

However, at higher wind velocities (Figure 3: 4.0 m s^{-1}, Figure 4: 6.0 m s^{-1}), detectable (≥1%) relative coverage values were recorded for all settings, even at the measurement limit.

According to prior research, the inspected technical solutions are also able to ensure the decrease of drift disposition at higher wind velocities. Despite this statement, it was concluded that the inspected twin fluid system with a Floodjet TK SS 10 042 deflector nozzle did not provide the expected decrease in drift when using the recommended settings at wind velocities of 4.0 m s^{-1} and 6.0 m s^{-1} (Figures 3 and 4). The research results given in this paper and the conclusions drawn on the basis of these results do not support any reasoning for the effective practical use or commercial trade of the combined technical solution inspected.

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