Influence of application equipment on deposition of spray droplets in wheat canopy

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Summary

Fungicides manufactured to control various diseases in wheat are effective; however, successful control of diseases will mostly depend on proper application methods. The ability to provide protection across the wheat plant is important because different infections may occur on different parts of the plant canopy depending on the pathogen. The objective of this work was to identify effective application parameters to apply adequate amount of fungicides for protection against spike and foliar diseases of wheat. Field trials were conducted in 2009, 2010 and 2011 to evaluate the effect of different nozzle types and spray qualities on spray coverage at three levels within the wheat canopy: at the height of the spike, flag leaf, and 30 cm below the flag leaf. Nozzles selected for this three-year study included two single flow pattern nozzles (XR 8003 and XR11003) with respectively Medium and Fine spray qualities, and three twin-flow pattern nozzles (TJ, TTJ, TT Duo) with spray qualities of Fine, Medium and Coarse. Water Sensitive Paper cards placed vertically at spike level (vertical), at the height of the flag leaf (horizontal top), and 30 cm below the flag leaf (horizontal middle). In all three years, the mean percent spray coverage on vertical, horizontal top, and horizontal middle targets varied from 5–15\%, 18–35\%, and 8–28\%, respectively, across all five treatments. The three nozzles with double spray patterns outperformed the two single-flow pattern nozzles in deposition on vertical targets representing wheat spike. However, single-flow pattern nozzles produced higher coverage on middle horizontal targets than the twin-flow nozzles.

Key words: Wheat head scab, spray coverage, spraying equipment, nozzles

Introduction

The ability to provide fungicide protection of different parts of the wheat plant is important because different infections may occur on different parts of the plant canopy, depending on the pathogen. For instance, Fusarium head blight (\textit{Fusarium graminearum} Schwabe) and Stagonospora glume blotch (\textit{Stagonospora nodorum}) result from fungal infection of the wheat spike during heading and grain development. Wheat stem rust, on the other hand, is caused by an airborne fungus (\textit{Puccinia graminis} f. sp. \textit{tritici}) that primarily infects the stem but can also cause infection of...
the leaves. A similar disease, leaf rust, is caused by a fungus (*Puccinia triticina*) that primarily infects leaves. In the case of wheat stem rust, there are new virulent races of the fungus for which there is no natural disease resistance. This makes the use of protectant fungicides an extremely important management strategy for this disease. Moreover, most of the fungicides registered for use in wheat are effective against all of the aforementioned diseases; therefore a single application is often made in an effort to provide protection against multiple diseases.

Fusarium head blight, or head scab as it is commonly known, is an important disease of small grains such as wheat, oats, barley when warm, wet weather persists during the heading and blossoming period of these cereal crops. Head scab not only reduces yield significantly, it also reduces the quality and feeding value of the grain. The fungi causing head scab may produce mycotoxins, especially deoxynivalenol (also known as of Vomitoxin) in the infected grain which are toxic to both livestock and humans. Such contamination has been a problem in wheat in Ohio during years when wheat scab is widespread. In Ohio, during years of favourable weather, the incidence of infected heads may be as high as 100 percent in some fields (Lipps, 1996). Fungicides developed to provide protection against this disease and its associated toxins are effective if applied at early anthesis (Paul et al., 2007, 2008). After selection of the best fungicide and timing of application, the third most important factor affecting efficacy of fungicides is the application equipment and techniques used. Maximum deposition and uniform coverage on spikes will likely result in maximum efficacy.

Treating weed, insect and disease problems that occur on horizontally oriented parts of a plant, such as leaves, is relatively easier than the same problems that occur on vertically oriented parts of a plant, such as the spike (Tu et al., 1986; Wirth et al., 1991; Xie et al., 1995). In addition, crop canopy conditions such as density and height may also play a key role in selection of the appropriate spray equipment and technique to increase fungicide efficacy. For example, research conducted in Ohio has shown that while a nozzle with two spray patterns (one forward and one backward) may work well in providing deposition in lower parts of soybean canopy equal to that obtained from a nozzle with single vertical spray pattern if the canopy is not dense and tall, the same double pattern configuration produced the least amount of deposition in the same area of the canopy when the canopy was tall and dense (Derksen et al., 2008; Ozkan, 2005). Miller et al. (2002) reported that crop canopy conditions and application equipment related parameters should be taken into account to maximise efficacy when spraying fungicides in cereal crops. Jensen (2007) indicated that the projected coverage of vertically oriented targets increases when the spray angle is not vertically oriented. He found that efficacy of a foliar-acting herbicide on perennial rye grass at the two-to-three-leaf stage, when the leaves are relatively vertical, generally increased when angling the spray either forward or backward relative to the direction of travel. Wolf & Caldwell (2004) also demonstrated that increasing the angle of spray delivery between double nozzles increased spray deposits.

Other factors, which influence spray deposition and coverage on targeted parts of plant canopy includes nozzle type and configuration, spray pressure, the droplet size, the distance between the nozzle and the target area, and application volume per hectare. All of these factors also play a key role in creation of spray drift, which not only causes loss of spray material, it also creates problems for the environment and for the safety and health of the applicators and people living nearby the application site. Smaller droplets generally produce better coverage, assuming deposition is successful. However, they are highly susceptible to drift (Zhu et al., 1994). A study conducted by Wolf & Caldwell (2004) showed that Coarse sprays from air induction nozzles and double nozzle arrangements (one forward and one back) increased deposition on vertical and horizontal artificial targets representing orientation and specific parts of a cereal canopy. Halley et al. (2008) used a combination of treated wheat spikes and water sensitive paper to compare various application parameters for treating wheat spikes. They found that 93.5 L ha$^{-1}$ applications produced higher fungicide deposits on the wheat spikes than either applications made at 187 or 46.8 L ha$^{-1}$. They also found that spray quality between Fine and Medium classifications produced higher deposits and higher spray coverage.
In an aerial application study, Fritz et al. (2006) demonstrated through spray deposit and spray coverage results that a combination of low application volume (19 or 47 L ha$^{-1}$) and large droplet size (VMD=350 μm) produced the greatest deposits on wheat spikes. North Dakota State University (NDSU) Extension (Halley et al., 2010) recommends orienting the air/spray discharge on an air-assist sprayer to be 30° down from horizontal and forward in the direction of travel. The recommended air stream velocity is 22 m s$^{-1}$. NDSU also recommends using nozzles that produce a Fine or Medium spray quality delivering spray at 93.5 L ha$^{-1}$ to maximise spike deposits.

The objective of this research was to determine the influence of spray quality, nozzle type, and nozzle configuration on wheat canopy penetration and more importantly the coverage on wheat spike which could aid in selection of efficacious means for delivering fungicides to wheat head for protection against wheat head scab and other spike diseases.

**Materials and Methods**

Field trials were conducted on Ohio State University’s research farms near Hoytville, Ohio, in June of 2009, 2010 and 2011. The wheat (var. Hopewell) was planted in the fall at a rate of 100.8 kg ha$^{-1}$ with a row spacing of 18 cm. Field plots were arranged in a randomised complete block design, with five treatments randomly assigned to plots with four replications for each treatment. Each plot was 28 m long and 3 m wide, with a 1 m border between plots. Applications were made when the wheat reached early anthesis (Feekes 10.5.1) (Large, 1954), which is the growth stage at which the wheat crop is most susceptible to infection by *F. graminearum*.

Table 1 shows the five spray treatments evaluated, including application rate, spray pressure, nozzle height above the canopy, travel speeds, and droplet size distribution. The Hagie Model 254 self-propelled agricultural sprayer (Hagie Manufacturing Co., Clarion, IA, USA) with a 15-m-long boom was used for spraying plots. Only the central 3 m section of the boom, containing six nozzles spaced 50 cm apart, were turned on when spraying plots. All nozzles used on the sprayer were manufactured by Spraying Systems Co. (Wheaton, IL, USA). Manufacturer’s reported spray quality data were used to select nozzles that would provide Fine (XR11003 and TJ11003), Medium (XR8003) and Coarse (TTJ-11003 and TT110 015) spray qualities as described by ASABE nozzle classification standard S327.2 (ASABE, 2004).

<table>
<thead>
<tr>
<th>Treatment/Number</th>
<th>Application Rate (L ha$^{-1}$)</th>
<th>Spray Pressure (kPa)</th>
<th>Nozzle Height (cm)</th>
<th>Travel Speed (km h$^{-1}$)</th>
<th>D$_{v0.1}$</th>
<th>D$_{v0.5}$</th>
<th>D$_{v0.9}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) XR8003</td>
<td>140</td>
<td>276</td>
<td>56</td>
<td>9.66</td>
<td>90</td>
<td>213</td>
<td>415</td>
</tr>
<tr>
<td>(2) XR11003</td>
<td>140</td>
<td>276</td>
<td>51</td>
<td>9.66</td>
<td>84</td>
<td>183</td>
<td>346</td>
</tr>
<tr>
<td>(3) TwinJet 11003</td>
<td>140</td>
<td>276</td>
<td>46</td>
<td>9.66</td>
<td>77</td>
<td>160</td>
<td>292</td>
</tr>
<tr>
<td>(4) Turbo TwinJet</td>
<td>140</td>
<td>276</td>
<td>46</td>
<td>9.66</td>
<td>124</td>
<td>250</td>
<td>574</td>
</tr>
<tr>
<td>(5) Turbo TeeJet Duo</td>
<td>140</td>
<td>159</td>
<td>30</td>
<td>9.66</td>
<td>104</td>
<td>218</td>
<td>434</td>
</tr>
</tbody>
</table>

Application rate and travel speed were kept constant at 140 L ha$^{-1}$ and 9.66 km h$^{-1}$, respectively, for all treatments. Nozzle height above the canopy was set at values recommended by the sprayer.
manufacturers as shown in Table 1 prior to each application. Applications were made using tap water. Droplet sizes for the treatments listed in Table 1 were measured with the Malvern 2600 Laser Particle size analyzer (Worcestershire, United Kingdom). Droplet size distributions were determined 51 cm below the nozzle orifice across the entire spray pattern width. Each measurement was repeated three times. Detailed information on the equipment and the procedures used for measuring droplet sizes are given by Ozkan et al. (1992). Mean values for $D_{V0.5}$ (Volume Median Diameter) as well as for $D_{V0.1}$ and $D_{V0.9}$ are shown in Table 1.

Before each plot was sprayed, three fibreglass rods were placed in each plot within the canopy to support water sensitive paper (WSP) targets (52 mm × 76 mm) (Syngenta Crop 132 Protection AG, Basle, Switzerland) to measure vertical and horizontal spray deposit characteristics. Fig. 1 shows how WSP targets were positioned within the wheat canopy. WSP targets were supported on three different rods located approximately 0.61, 1.22, and 1.83 m from the edge of each plot along the drive row and at 15, 23, and 30 m from the starting edge of each plot. The vertical WSP targets were wrapped around wooden dowels (10 cm × 1.0 cm diameter) with the overlapped point facing down the row toward the end point of each plot. The vertical target was positioned at approximately the height of the head. Horizontal WSP targets were held with electrical clips fastened to the support rod. A pair of WSP targets was located on opposite sides of the support rod at each sampling height. The long axis of each Top Canopy target was oriented parallel to the row direction. The height of the Top Canopy WSP targets was approximately the height of the flag leaves. The Middle Canopy WSP targets were positioned approximately 30 cm below the Top Canopy (close to the second leaf from top) WSP targets with the long axis of each target perpendicular to the row direction. After the WSP targets had dried following each treatment, they were collected and stored in paper bags.

Spray deposit characteristics on WSP was measured with a portable scanning system as described in detail by Zhu et al., 2011. The system includes a handheld business card scanner (NeatReceipts, NEAT Business Cards colour scanner, Philadelphia, PA), a desktop computer, and a custom-designed program “DepositScan” which can be downloaded from the following web site: http://www.ars.usda.gov/mwa/wooster/atru/depositscan. The resolution of the scanned images was 600 dpi. Vertical (Head) WSP targets were removed and flattened before being scanned. Only areas on the WSP that was exposed to spray were used for spray deposit characteristics measurements. After spray deposit images on the WSP were scanned the program reported percentage area covered by the spots.

Fig. 1. Position of five water sensitive paper targets within canopy.
The spray coverage measured on WSP targets in the three different sections of the canopy (vertical, representing head; horizontal top and middle) are shown in Figs 2, 3 and 4 for years 2009, 2010 and 2011, respectively.

**Coverage on vertical targets**

In all 3 years, the mean percent spray coverage on vertical targets varied from 5–15% across all five treatments. The two single-flow pattern nozzles (XR8003, Medium spray; XR11003, Fine spray) produced somewhat similar coverage on vertical targets. Nozzles with twin-flow spray patterns (TJ, TTJ, TT Duo) outperformed the two single-flow pattern nozzles (XR 8003 and XR11003) regardless of spray quality (Fine, Medium, Coarse). When using twin-flow nozzles the coverage increased by 50–100%. Two out of three years, the standard TwinJet TJ nozzle, which produces Fine droplets, outperformed the other two twin-flow nozzles, TTJ and TT Duo, producing Coarse and Medium droplets, respectively.

**Coverage on top horizontal targets**

Across all 3 years, the mean percent spray coverage on top horizontal WSP targets varied from 18% to 35% across all five treatments. In general, as shown on Figs 2, 3 and 4, the single-flow pattern nozzles (XR8003 and XR11003) produced higher coverage on top horizontal targets than the twin-flow nozzles. There was no significant difference in coverage obtained from these two nozzles. There was not a clear-cut winner among the three twin-flow pattern nozzles in terms of coverage on top targets. In 2 of the 3 years (2009 and 2010), the standard TwinJet nozzle (TJ) producing Fine droplets provided the highest coverage. The Turbo Teejet Duo (TTDuo) nozzle, which has the widest angle between spray streams (120 degrees) and produces Medium quality droplets, produced the highest coverage (about 25%) in 2011.

**Coverage on middle canopy horizontal targets**

In all 3 years, the mean percent spray coverage on middle canopy horizontal WSP targets varied from 8% to 28% across all five treatments. Spray coverage on middle WSP targets followed the same trend as the coverage on top horizontal WSP targets. In general, as shown on Figs 2, 3 and 4, the single-flow pattern nozzles (XR 8003 and XR11003) produced higher coverage on middle horizontal targets than the twin-flow nozzles. There was no significant difference in coverage obtained from these two nozzles. There was not a clear-cut winner among the three twin-flow
Fig. 3. 2010 Mean percent spray coverage treatment and canopy location and standard error bars for each location (Bars identified by different uppercase letters, lowercase letters, and symbols are significantly different within each groups of treatments; $P < 0.05$).

Fig. 4. 2011 Mean percent spray coverage treatment and canopy location and standard error bars for each location (Bars identified by different uppercase letters, lowercase letters, and symbols are significantly different within each groups of treatments; $P < 0.05$).

... pattern nozzles in terms of coverage on middle horizontal targets in 2010 trials. However, in 2009 and 2011 the conventional TwinJet nozzle (TJ) producing Fine quality droplets provided the highest coverage among the twin pattern nozzles. The Turbo Teejet Duo (TTDuo) nozzle, which has the widest top angle (120 degrees) and produces Medium droplets, produced the highest coverage (about 25%) in 2011.

**Discussion**

Effective spray delivery is important when relying on protectant fungicides to help manage wheat diseases that may infect the head, leaves, or stem sections. Different pathogens tend to cause infection on different plant parts. Field trials were conducted in 2009, 2010 and 2011 to evaluate the effect of different nozzle types and spray qualities on spray coverage on artificial WSP targets positioned at three sections (vertical at wheat spike level, horizontal at flag leaf and 30 cm below the flag leaf) of wheat plant. In all 3 years, the mean percent spray coverage on vertical, horizontal top, and horizontal middle targets varied from 5–15%, 18–35% and 8–28%,...
respectively, across all five treatments. Nozzles with twin-fan spray patterns (TJ, TTJ, TT Duo) had higher spray coverage than the two single flow pattern nozzles (XR 8003 and XR11003) on vertical targets representing wheat spike. However, single-flow pattern nozzles produced higher coverage on middle horizontal targets than the twin-flow nozzles. There were no statistically significant differences in coverage obtained from nozzles producing Medium and Fine spray quality droplets. Results from this study also showed that, as far as coverage is concerned, Turbo TwinJet (TTJ11003), known as a drift reduction nozzle, did perform as well as some of the other nozzles which produce higher drift losses during field application. For this reason, when drift is a concern, wheat growers may be better off choosing TTJ nozzles over the other nozzles with much higher drift potentials.

Based on the factors evaluated in these trials, application parameters can be selected to increase protection of horizontal and vertical wheat plant sections as required for the management need. Greater spray angles may be needed to significantly improve application performance (coverage and deposition) but this may reduce penetration into the canopy.

It should be noted that final recommendations on the type of nozzle and the spray quality best suited for protection against various diseases of small grains such as wheat should be done when the spray coverage data presented in this paper is accompanied with the spray deposit and efficacy data.

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References


