Evaluation of the spray generated by a greenhouse spraying robot

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Abstract: In this study, characterization of an automatic greenhouse spraying system containing a full cone spray nozzle is presented. Spray flow rate of the nozzle as a function of incoming pressure to the nozzle, together with distribution of mean drop size, two components of drop velocity and uniformity of the generated spray are given in this study. Based on the results obtained, mean droplet size at the centreline of the spray is much smaller than dose in the outer side of the full cone spray. Uniformity of the generated spray by a given nozzle should be examined before application, especially if the nozzle is not new. The average generated drop size by the examined nozzle is less than 60 μm which is suitable for the insecticide or fungicide applications.

Keywords: spray, nozzle, full-cone nozzle, insecticide, uniformity

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1 Introduction

Recent studies have been confirmed that spraying operations have hazardous effects on the human in conditions of high temperature and poor ventilation inside the greenhouse (Gan-Mor et al., 1997). An automatic spraying system could be set to begin operation at night ensuring that the plants are sprayed in conditions that cause the least amount of damage to the human and plants (Sammons et al., 2005). In some applications, it is desirable to eliminate the deposited film on the wall as far as possible, e.g. in internal combustion engines, whereas in some cases the maximum deposition is required, e.g. in agricultural sprayers (Kalantari and Tropea, 2007; Sommerfeld and Qiu, 1995).

Practically nozzle selection in a hydraulic sprayer is the most influencing factor in reducing pesticide drift. In application of a hydraulic sprayer, atomizing pressure, chemical product being sprayed and pest type should be considered. As an example, very fine spray is needed for insecticide or fungicide application, whereas coarser sprays are suitable for many herbicide applications. However, for some applications including Gramoxone, Buctril, and Cobra maximum coverage using a fine spray is required. These herbicides are known as "contact-type herbicides" (Pringnitz et al., 2010).

Hollow cone nozzles are generally used to apply insecticides or fungicides to field crops when foliage penetration and complete coverage of leaf surfaces are required. Spray drift potential is higher than the other conventional nozzles due to the small droplet generations.

Full cone nozzles produce relative large droplets which are suitable for soil incorporated herbicides. For a full cone hydraulic nozzle, optimum uniformity is achieved by angling the nozzles 30 rage and overlapping the spray coverage by 100%.

Entrained air and droplet velocities produced by agricultural flat-fan nozzles was experimentally studied by Miller et al (1996). Their results indicated that sprays formed from liquids based on emulsions generally have a coarser droplet size distribution compared with

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sprays formed from surfactant solutions.

Previous researches indicate that droplets smaller than 150 μm mostly drift away from the target surface and will not deposit on the target. Due to the light weight of very small droplets, they take much longer to deposit and wind speed will affect their trajectories. Mostly droplets smaller than 50 μm remains suspended in air until they evaporate (Miller and Hadfield, 1989; Holterman et al., 1997).

Sammons, Tomonari, and Bulgin (2005) described an autonomous spraying robot with navigation control based on inductive sensors which detect metal pipes buried on the ground. Mandow et al. (1996) described an autonomous vehicle (*Aurora*) for spraying tasks. Subramanian et al. (2005) and Singh et al. (2005) also described a mini-robot to perform spraying activities, for which navigation is controlled by algorithms based on fuzzy logic. Some of researcher presented the *Agrobot Project*, a robotic system for greenhouse cultivation of tomatoes (Dario et al., 1994; Shariati, 2004).

In this study, characterization of a full cone spray nozzle is presented. Spray flow rate of the nozzle is obtained as a function of incoming pressure to the nozzle. Meanwhile distribution of mean drop size, two components of drop velocity and uniformity of the generated spray are given in this study.

2 Methods and materials

A photograph of the designed and constructed robot is presented in Figure 1a. The spray system consists of a large tank for holding the pesticides, vertical spray booms with several nozzles, two pumps and four valves to direct the generated spray to the sections of plant either side of the robot as it moves past the desired spray area. The valves are electronically controlled by the on-board microprocessor which receives input signals from micro switch on the underside of the robot. As the robot passes over reflective markers placed on the ground, the pump is turned on and off to enable selective spraying of the greenhouse plants. During spraying, micro switches can shut down the right or left side of the vertical spray boom by actuating solenoid valves. This allows the robot to spray rows next to walls without wasting chemicals. In this experimental study, the spray was created using a full-cone nozzle from Spraying System Co., (SS.Co.F.J.-TG.SS0.3) operated at pressures between 2 and 7 bar and flow rate between 27 and 40 L h^{-1}. Both flow rate and pressure during the experiments were variable and measured.

a

b

Figure 1 Photograph of the constructed greenhouse sprayer (a), and full cone spray pattern generated by a nozzle (b)

To characterise the spray, a dual-mode phase Doppler instrument from Dantec Dynamics was used, comprising a transmitting optics with a 310 mm focal length, a receiving optics with a 310 mm focal length, and an "A" type mask at a 36° scattering angle. By using a dual-mode configuration both normal and tangential velocity components of each individual droplet and its diameter were measured. Coordinate system used for the nozzle characterization is illustrated in Figure 2.

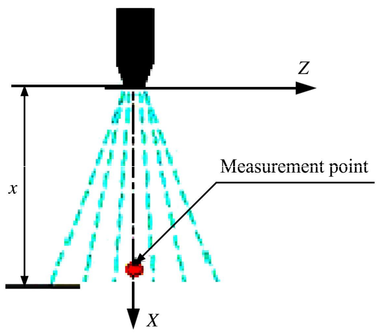


Figure 2 Coordinate system used for the nozzle characterization

Summary of the measured range of quantities including mean droplet diameter (d10) and two component of normal and tangential velocities are given in Table 1.

Table 1 Summary of the measured range of quantities

Measured quantity	Unit	Numerical value
Mean droplet size/d_{10}	μm	20-50
Normal component of velocity/u	m s^{-1}	0.5-16
Tangential component of velocity/v	m s^{-1}	0-5
Spray cone angle/θ	o	70
Weber	-	2-167
Reynolds	-	10-560

3 Results and discussions

In general, nozzle flow rate varies with spraying pressure. In theory, using the Bernoulli's equation, nozzle flow rate is proportional to the square of nozzle inlet pressure, i.e., $Q\sim(\Delta P)^{0.5}$. Nozzle flow rate of the examined nozzle is presented in Figure 3. In this experiment, a correlation in the form of $Q\sim(\Delta P)^{0.46}$ was obtained for the tested full cone nozzle, which the power is slightly deviates from theory, maybe due to the internal frictions and irreversibility. In practice, increasing the nozzle pressure decreases the mean droplet size, but potentially spray drift and nozzle wear increases. Meanwhile by increasing the atomizing pressure, spray angle and spray coverage increases. For decreasing the potential drift and nozzle damages, the maximum operational pressures should be avoided.

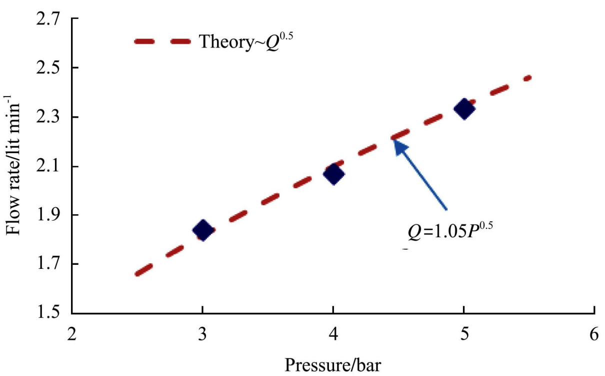
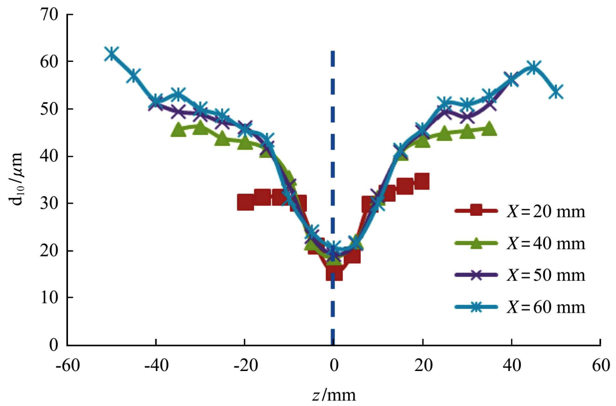


Figure 3 Nozzle flow rate as a function of spraying pressure

Some typical measurement results of drop size distributions are presented in Figure 4a. Based on the results presented in this figure, mean droplet size at the centerline of the spray (z=0) is much smaller than dose in the outer side of the full cone spray, e.g., in z=20. This result is schematically illustrated in Figure 4b. Meanwhile the mean droplet size increases with increasing the spray height measured from the nozzle tip as illustrated in Figure 4a.



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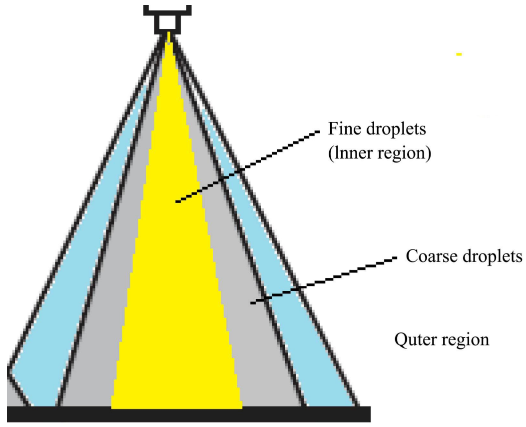


b

Figure 4 Drop size distributions as a function of nozzle height (a), and a sketch for the fine and coarse region of droplets inside the spray (b)

Small droplets at higher environment temperatures and low relative humidity are more prone to drift and also evaporation. Low application rates normally need smaller nozzles which operate in greater pressures. The overall effect is decreasing the mean droplet size and consequently increasing the risk of drift. In considering the spray drift, also the wind velocity must be taken into account which has the most influencing effect on the smaller droplets. For reducing the influence of wind velocity on drift, the distance between the nozzle tip and the plant area should be decreased. An exemplary result presented in Figure 5 indicates that the drop size distribution in the outer region of the spray is coarse, whereas in the inner region more fine droplets presents. Results of this figure can be compared with the schematically illustrated results in Figure 4b.

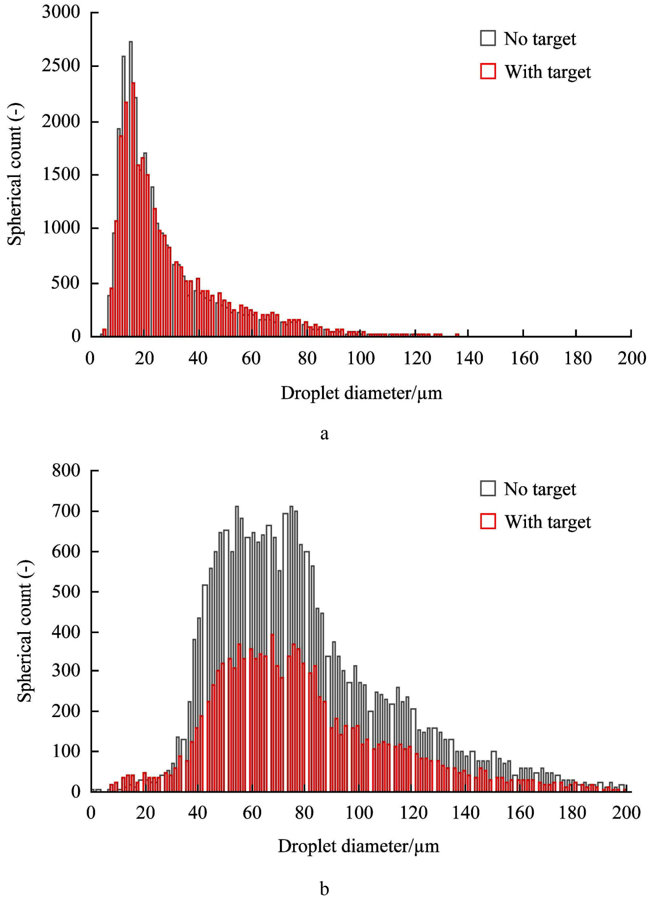


Figure 5 Drop size distributions at the inner region of the full cone spray (a), and at the outer region of the full cone spray (b)

Combined measurements of particle velocities, size distributions and concentration first was performed by Durst (1982). In Figure6 the velocity of droplets inside the spray is presented for the normal and tangential components, albeit very representative of other operational conditions. These velocities are shown as a function of measurement radial position inside the spray. The results indicate clearly that the normal component of velocity for ejected droplets is the maximum at the spray centerline for the full cone spray (Figure 6a). As illustrated in this figure, the normal component of velocity vanishes with increasing the radial position inside the spray. On the other hand, the tangential component of ejection velocity behaves quite differently. Positive and negative values for the tangential component of velocity in this figure represent the right and left sides of the spray.

The ejection angle of the droplets depends strongly on the radial position of the droplets, as shown in Figure 7. Droplets at the centerline of the spray move vertically, whereas the outer droplets follow the flow streamline inside the spray cone.

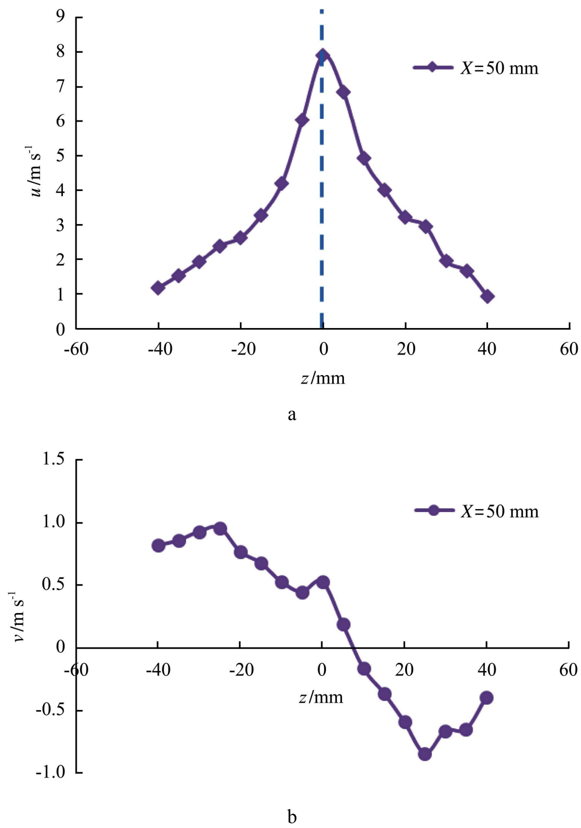


Figure 6 The normal (a) and tangential (b) components of the droplet velocity inside the spray

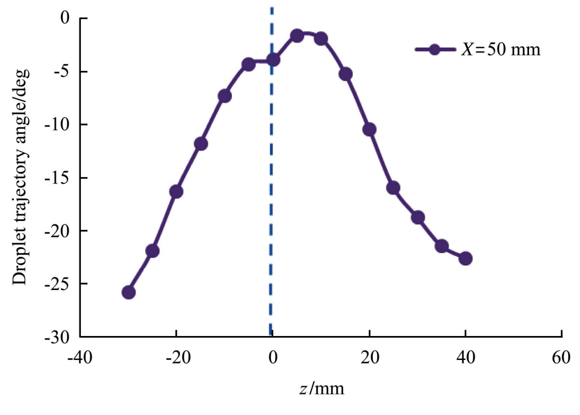
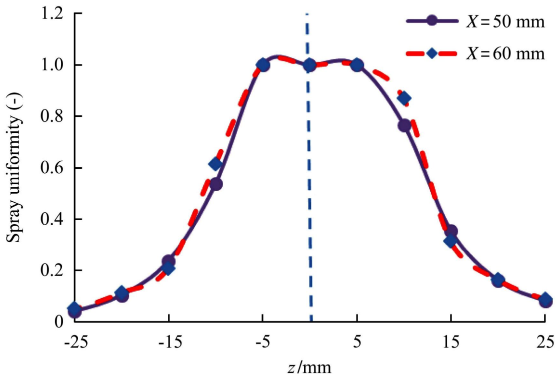


Figure 7 The ejection angle of the droplets as a function of the radial position inside the spray

Uniformity of the spray generated by the examined nozzle is presented in Figure 8a. As shown in this figure, the generated spray is completely uniform. Uniform distribution of the generated spray is very important for a uniform coverage of the sprayed surface. Uniformity of the generated spray by a given nozzle should be examined before application, especially if the nozzle is not new. Meanwhile water sensitive paper (which turns from yellow to blue when water contacts it) was placed in three locations under the spray to qualitatively observe the generated spray. An exemplary result is shown in Figure 8b.



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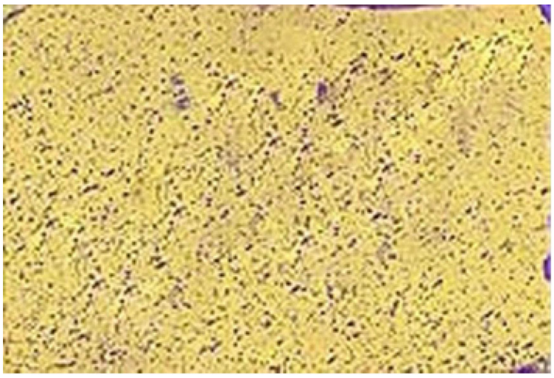

b

Figure 8 Drop concentrations uniformity as a function of radial position inside the spray (a), and water sensitive paper to qualitatively observe the spray uniformity (b)

4 Conclusions

From these experiments some general conclusions can be drawn about the operation of the examined full cone nozzle.

- The average drop size decreases with increasing the injection pressure.
- The average drop size increases with increasing the nozzle height from the sprayed surface.
- The average drop size is minimum at the spray centreline.
- Uniform distribution of the generated spray is very important for a uniform coverage of the sprayed surface and must be examined before the application.
- The average generated drop size by the examined nozzle is less than 60 μm which is suitable only for the insecticide or fungicide applications.
- Drift of the generated spray by the examined nozzle can be significant in practice, except using this nozzle in the closed environments like greenhouse.

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