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Effect of spray nozzle type and crop canopy on spray deposition

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ABSTRACT
A study was carried out to investigate if the interaction between nozzle type and crop canopy has an effect on spray deposition and come up with ways of improving spray deposition during chemical applications to crops. The overall goal of the study was to optimize chemical use in crop production and minimize chemical pollution of the environment resulting from off-target spray deposition. Three nozzle types; disc-core hollow cone, disc-core full cone and extended range flat spray, and five crop canopy types; maize, soybean, tomato, mung bean and carrot were investigated. Two tracer solution application rates of 150 and 600 litres/ha were used in the study at a pump delivery pressure of 3 bars. Manganese sulphate monohydrate was used as a deposition tracer. Spray deposition on crop canopies was quantified using the Periodate Oxidation method. Results from the study indicated that nozzle-canopy interaction significantly affected spray deposition at 5% level of significance. It was also found out that spray deposition could be improved by up to 189% and 355% at tracer solution application rates of 150 and 600 litres/ha, respectively, if nozzles are selected based on crop canopy type.
Keywords: Spray deposition, nozzle-canopy interaction, environmental pollution, spectrophotometry, periodate oxidation.

INTRODUCTION

Chemical application process by spraying is inherently inefficient. This is more so with the application of foliar pesticides. Matthews (1982) indicated that up to one third of the spray applied to a crop might be lost to the soil at the time of application. Studies by (Pergher and Gubiani, 1995) in vineyards recorded losses to the ground of up to 94% in the first growing stages of the vines due to low canopy density. Ozkan *et al.*, (1997) reported that sometimes, particularly under windy conditions, only a small portion of the intended chemical dose actually reaches the target and contribute to the desired biological effect. The chemicals that miss their target are not only a waste to crop production but also find their way into the environment thereby polluting it.

Off-target deposition of chemical spray is one of the problems that contribute to inefficient application of foliar pesticides (Gan-Mor and Matthews, 2003; Farooq and Salyani, 2002; Pergher *et al.*, 1999; Hoffmann and Salyani, 1996). Nozzle and crop canopy characteristics are some of the major factors that affect spray deposition. The nozzle is the major factor in determining the amount of spray liquid applied to an area, the coverage obtained on the target and the amount of potential drift. Nozzles break the spray liquid into droplets, form a spray pattern, and propel the droplets in the proper direction (Daum and Reed, 2002; Johnson and Swetnam, 2002; Wilkinson and Oberti, 1999; Waxman, 1998; Matthews, 1982). Crop canopy, on the other hand, affects spray penetration and distribution, droplet collection efficiency and spray retention (Altman, 1993; Zhou *et al.*, 1996; Matthews, 1982). Many studies on the independent effects of these factors on spray deposition have been carried out over the years (Zhu *et al.*, 2002; Franz *et al.*, 1998; Hoffmann and Salyani, 1996; Bouse *et al.*, 1994) and the results indicate significant effect of the factors on spray deposition. However, considering the importance of interaction between variables in biological systems and the fact that factors rarely act independently of each other, the results from the studies, though very useful, might have given an incomplete picture. Thus, the contribution of the studies to the improvement of spray deposition might have been limited.

Many variations exist between nozzles. Some of the variations are solely due to differences in nozzle type while others are a result of nozzle design parameters. The differences that occur among various nozzles are the spray pattern shapes, spray angle, spray liquid atomization and hence droplet size spectra, uniformity of application and coverage, droplet penetration of crop canopy, and flow rates. There are three basic nozzle types that are used in crop production; the flat fan, the hollow cone and the solid cone. At a given pressure, flow rate and spray angle, fan nozzles produce a more uniform distribution of spray and are thus used for uniform coverage of surfaces, for example applying herbicides or fertilizers to the soil. Cone nozzles, on the other hand, provide better penetration and coverage of plant canopy and are mainly used to apply fungicides and insecticides to plant foliage (Kepner *et al.*, 1978).

Variations also exist in canopy characteristics and architecture between and among crops. These variations are due to biological and environmental factors hence there exist both intra-specific and inter-specific differences in crop canopy characteristics and architecture (Altman, 1993; Matthews, 1982). Differences can also be present on an individual plant depending on the stage of crop growth and micro-environmental factors. Purseglove, (1988) and Purseglove, (1969) gave an account of all the angiosperms that are grown as crops in the tropics together with their botany and agronomy. Maize (*Zea mays* L.) is a stout annual crop with a solid stem and clearly defined nodes and internodes. It has 8 – 21 leaves that are borne alternately on either side of the stem at nodes. The leaves are more numerous on the lower side of the stem. The leaf blade is linear-lanceolate and acuminate measuring 30 – 150 x 5 – 15 cm. Soybeans (*Glycine max* L.) are erect, bushy, pubescent annuals, 20 – 180 cm tall. The leaves are alternate, trifoliate, with long, narrow and cylindrical petioles. The leaflets are ovate to lanceolate, variably pubescent and measure 3 – 10 x 2 – 6 cm. Tomato *(Lycoperscon esculentum)* is a variable herb, 0.7 – 2 m tall. The leaves are imparipinate and spirally arranged with 2 or 5 phyllotaxy and measure 15 – 30 x 10 – 25 cm. The petiole is 3 – 6 cm long. It has 7 to 9 major pinnae that are opposite or alternate, incurled, ovate to oblong, 5 to 10 cm long, irregularly toothed and sometimes pinnafid at the base. Mungbean *(Phaseolus aureus)* is an erect, much branched, rather hairy, annual herb measuring 0.5 – 1.3 m tall. It has alternate trifoliate leaves. It has long petioles and ovate stipules. The leaflets are 1.5 – 12 x 2 – 10 cm. Carrot *(Daucus carota)*, on the other hand, is an erect biennial 30 – 100 cm in height with a solid stem. Leaves are 3-pinnate, segments pinnafid, lobes lanceolate; petioles usually long; umbels 3 – 7 cm in diameter, becoming concave in fruit.

A good understanding of nozzle-canopy interaction can prove very useful in improving spray deposition. The aim of the study was to optimize chemical use in crop production and minimize chemical pollution of the environment. The objectives of the study were; (i) to determine if the interaction between nozzle type and crop canopy has an effect on spray deposition, and (ii) to come up with ways of improving spray deposition during chemical applications to crops.

MATERIALS AND METHODS

The study was carried out at the Asian Institute of Technology, Pathumthani, Thailand, approximately 14° 4' North and 100° 35' East. The study involved two 3 x 5 factorial experiments arranged in split-plot randomized complete block design with three replications. The first experiment was carried out at a tracer solution application rate of 150 litres/ha while 600 litres/ha was used in the second experiment. Nozzle type was the main plot factor while crop canopy type was the subplot factor. Three nozzle types namely:

disc-core hollow cone, disc-core full cone, and extended range flat spray, constituted the three levels of the main plot factor. Five crops namely: (i) maize, (ii) soybean, (iii) tomato, (iv) mungbean and (v) carrot were the five levels of crop canopy. Potted plants grown outdoors under sprinkler irrigation were used in the experiment. Recommended agronomic practices (Acquaah, 2005; Yayock *et al.*, 1988) were followed in growing the crops. The crops were forty-five days old during the time of experimentation, this being the growing stage when all the five crops are susceptible to attacks by pests and/or diseases. A total of 90 plants were used in the study with 45 plants assigned to each of the two tracer solution application rates. At each tracer solution application rate, three plants from each of the five crops were assigned to each of the three nozzles.

The plants were individually sprayed with an aqueous tracer solution of manganese sulphate monohydrate, $MnSO_4.H_2O$, at two application rates of 150 and 600 litres/ha using an OSATU® STAR 16 GREEN knapsack sprayer at a pump delivery pressure of 3 bars. A tracer rate of 15 kg/ha $MnSO_4.H_2O$ (4.8 kg/ha Mn) was used in all the two experiments. Spraying was done inside a spraying chamber to counteract the fluctuation of weather variables. A spray height of 1.15 m was used for disc-core hollow cone and disc-core full cone nozzles while 0.6 m was used for the extended range flat spray nozzle. The spray heights were chosen so as to obtain a ground spray area of 1 m^2. Each test plant was placed in the sun after the spraying exercise to allow the tracer solution to dry. After the tracer solution had sufficiently dried, six leaf samples were collected from each test plant; two leaves each, from the top, middle and bottom of the canopy. The sample leaves at the top of the canopy had no leaves above them, those in the middle had leaves both above and below them, while those at the bottom had no leaves below them. Each leaf sample was placed in an individual sealable plastic bag and stored in an ice box to prevent leaf wilting.

Recovery of $MnSO_4.H_2O$ deposits from the leaf samples was done following the procedure by Hoffmann and Salyani (1996) which is reported to have an Mn recovery rate of 99.3%. The amount of manganese, Mn, deposited on each leaf sample was quantified using the Periodate Oxidation method (Hoffmann and Salyani, 1996). Manganese high range (0 - 20 mg/l in 10 ml sample solution) reagent set and a JENWAY® UV/Vis 6305 spectrophotometer with a resolution of 0.001 units were used for taking the Mn deposition readings. Leaf area measurements (top and bottom) were taken after quantifying the amount of Mn deposited on the leaf samples using a LI-COR® LI-3100 area meter system with a resolution of 0.01 mm^2. The leaf area measurements and the amount of Mn deposited on each leaf sample were used to calculate spray deposition ($\mu g/cm^2$) which is described as the amount of Mn deposited per unit area of crop canopy.

Data analysis was done using STATISTIX® for Windows analytical software version 7. Analysis of variance was done at 5% level of significance ($P < 0.05$). Separation of means was done using the least significant differences. The maximum improvement in spray deposition on a particular crop canopy was calculated using the following Equation:

$$I_{D-max} = \left(\frac{D_{max} - D_{min}}{D_{min}} \right) \times 100 \qquad (1)$$

where I_{D-max} is the percentage maximum improvement in spray deposition on a particular crop canopy type at a given tracer solution application rate, D_{max} is maximum spray deposition on a particular crop canopy type at a given tracer solution application rate, and D_{min} is the minimum spray deposition on a particular crop canopy type at a given tracer solution application rate.

RESULTS

Nozzle-canopy interaction significantly ($P < 0.05$) affected spray deposition (Table 1). The interaction effects were higher at tracer solution application rate of 600 litres/ha (F-value = 19.85) than at 150 litres/ha (F-value = 1.56).

Table 1: Analyses of variance of the spray deposition results.

Source of variation	**df	150 litres/ha		600 litres/ha	
		P-value	F-value	P-value	F-value
Replication	2				
Nozzle type (A)	2	0.15	3.14*	0.01	26.07*
Error (a)	4				
Subtotal	8				
Crop canopy type (B)	4	0.04	4.07*	0.00	18.21*
Interaction (AB)	8	0.21	1.56*	0.00	19.85*
Error (b)	24				
Total	44				

*Significant at 5% level of significance; **df, degrees of freedom.

Table 1 also shows significant (P < 0.05) independent effects of nozzle type and crop canopy. Figure 1 shows spray deposition on five crop canopies at a tracer solution application rate of 150 litres/ha, using the three types of nozzles. The highest spray deposition in maize and soybeans was obtained by using the disc-core hollow cone nozzle. Disc-core full cone nozzle produced the highest spray deposition in mungbean and carrot while in tomatoes the extended range flat spray tip nozzle produced the highest spray deposition. Figure 2 shows spray deposition on the five crop canopies at a tracer solution application rate of 600 litres/ha. The highest spray deposition in maize, soybeans, tomato, mungbean and carrot were produced using disc-core full cone, disc-core hollow cone, disc-core hollow cone, disc-core hollow cone and disc-core full cone nozzles, respectively. It is evident from Figures 1 and 2 that no single nozzle type gave the highest spray deposition in all the five crop canopy types.

Table 2 shows the percentage maximum improvements in spray deposition on the five crop-canopies. Improvements in spray deposition ranged from 24 to 189% at tracer solution application rate of 150 litres/ha and 163 to 355% at 600 litres/ha.

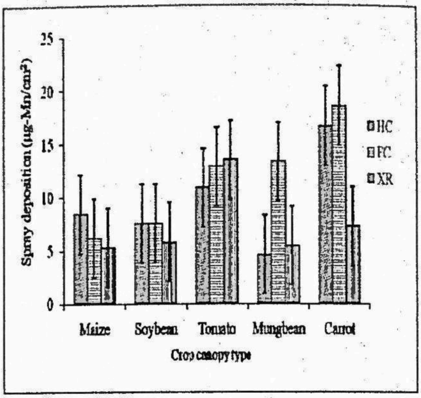

Figure 1. Spray deposition at 150 litres/ha by three nozzle types; disc-core hollow cone (HC), disc-core full cone (FC), and extended range flat spray tip (XR), separated by 95% confidence interval error bars.

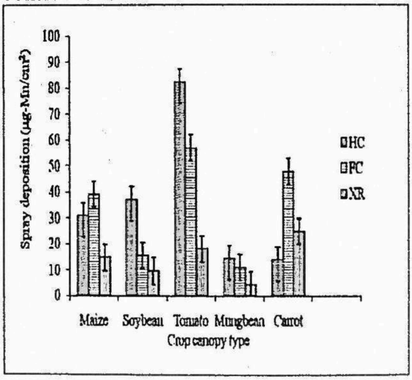

Figure 2. Spray deposition at 600 litres/ha by three nozzle types; disc-core hollow cone (HC), disc-core full cone (FC), and extended range flat spray tip (XR), separated by 95% confidence interval error bars.

DISCUSSION

Results of the study indicate that nozzle type and crop canopy significantly (P <0.05) affect spray deposition (Table 1). This is in agreement with the results from numerous

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