Depositional studies of a charged spray application in an orchard

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The experiment was carried out to find out the effect of electrostatic forces on plant canopy in an orchard with fluorescent tracer as a test liquid. A manganese (II) sulfate ($MnSO_4$) was selected as fluorescent tracer. Seven pressure-swirl nozzles were used to evaluate the depositional characteristics in charged and uncharged sprays in a semi-dwarf apple orchard. Fan speeds at 1000, 1500 and 2000 rpm were selected for the orchard sprayer. Spray deposit was analyzed for two varieties of semi-dwarf apple tress i.e. M9 and M26. The field experiment was performed with one-pass and two-passes of the sprayer at a constant ground velocity of 0.82 km/h. Analysis and comparison with the fan speed effect on spray deposition were made between the uncharged and charged sprays, and also at sampling locations by using the statistical method. No significant differences were observed between the uncharged and charged sprays on the M9 and M26 trees at fan speeds of 1000 and 1500 rpm at all tree levels with both passes. No significant difference in spray depositional ratio between the tree level sampling regions for each specific fan speed for M9. At 2000 rpm, a significant difference was observed at the top level for one pass and at the middle level for the two-passes. At a fan speed of 2000 rpm with both passes for M9 and M26 trees, it emerged that the charged spray proved superior to the uncharged one.

1. Introduction

The conventional sprayers for agricultural applications rely mainly on a combination of inertial and gravitational forces to control the spray drops towards the target. These forces are often unable to overcome the problems of poor deposition, poor penetration into the plant canopy and high drift susceptibility. It is known from previous experiences that, the upper part of the plant canopy and top leaf surfaces receive higher deposits than the lower part, where most pests are active [1]. With the existing problems, an improvement in spraying equipment and a modern spray atomization technology are needed to increase the efficiency of spray deposit on both sides of the leaf, penetration into plant canopy and overall pest control.

The application of pesticide is still one of the most frequently used methods to protect crops and trees against diseases and insects in orchards. Over dosage of the pesticide is common in most countries and its application leads to many problems such as chemical wastage and environmental pollution from spray drift. One of the current trends towards prevention of chemical wastage and environmental pollution is the application of electrostatic technique in the agricultural spray; of which the induction charging type [2] is known to be the best electrification method for aqueous liquid.

Nowadays, vineyards and orchards sprays are performed by using the air-carrier sprayer. This does not only serve as a means to transport the chemical from the sprayer to the target foliage, but also effects good penetration and deposition or coverage of the droplets. Technically, the orchard sprayer is designed such that, the nozzle can be oriented, to provide uniform distribution and deposition along the height and through the width of the tree profile. The transportation of droplets to the plant is greatly influenced by droplet size, velocity of droplet, dynamic of the sprayer, weather conditions, and physical properties of the plants. The best spray management method is to define the target and the selection of appropriate drop size.

Spray behaviours for orchard spray applications have been studied by many researchers [3-10]. A reduction of air transport from the sprayer could affect transport of spray material and deposition within the plant canopy. Atomizers that have been used in both conventional and electrostatics orchard sprayers were the flat [3, 5, 6]; twin-fluid [4]; spinning disc [7] and pressure-swirl nozzles [11]. Recently, a general review on agricultural electrostatic application has been described by Law [10]. There have been some studies including laboratory works on electrostatic pressure-swirl nozzles by using the induction and ionized-field charging methods [13-15]. The electrical phenomena governing the deposition of charged droplets are the electrical field gradient between the atomizer and the plant, space charge, and image charge effects.

This project is in collaboration with National Agricultural and Mechanization Research Institute (NAMRI), Paru, Taegu Apple Research Institute, Kyungpook National University and Chungbuk National University, Korea. The purpose of this paper is to evaluate the contribution of the electrostatic forces on spray deposition by using the traditional orchard sprayer and the effect of the sprayer fan speed on spray deposition.

2. Experimental Methods and Materials

The field experiment was conducted in a semi-dwarf apple orchard of two different varieties, East Malling Roots (M9 and M26) at Taegu, Korea. With the M9 trees, the distance between rows was 3.2 m; the tree spacing within rows was 1.2 m and average height of about 3.2 m. In the case of M26, the row of trees in this block was 4.8 m and tree spacing was 3m with average height of 3.5 m. There was no dense foliage formed among blocks.

The experiments were conducted in July, August and September 2002. The wind speed, temperature and relative humidity were recorded at 2 s interval for 2mins period before and after each treatment by anemometer TSI (Model No. 8360-M-GB, USA). The weather and experimental conditions have been illustrated in Table 1.

Table 1
Weather and experimental conditions

Date of test	11-7- 02	2-8-02	18-9-02
Weather conditions			
Temperature, °C	29	33	33
Relative humidity, %	60	57	67
Wind speed, m/s *			
Before spraying	0.55	0.38	0.7
After spraying	0.8	0.42	0.52
Experimental conditions			
Electrostatic nozzle (Pressure-swirl type)			
Number of nozzles	7		
Nozzle orifice diameter, mm	0.59		
Operating pressure, MPa	2.0		
Forward speed, km/h	0.82		
Liquid flow rate (per nozzle), l/min	0.56		
Volume rate, l/ha	183		
Fan speed, rpm	1000,	1500,	2000

* Measured outside the orchard at 2.5 m above the ground

2.1 Spray Deposit Evaluation

Three different kinds of salts ($ZnCl_2$, $MnCl_2$ and $MnSO_4$) were selected as candidates because they are not photo-degrading, and also, not normally found in high levels in apple leaves. The electrical conductivities of the salts were measured and $MnSO_4$ was found to be more conductive as presented in Fig. 1. The pH of the solution was not tested because it was assumed that it may not have effect on the charge. The treatment procedures are similar with one described by Dersken and Gray [6]. The treatment rows were separated by two trees (as buffer) rows to minimize the drift effect.

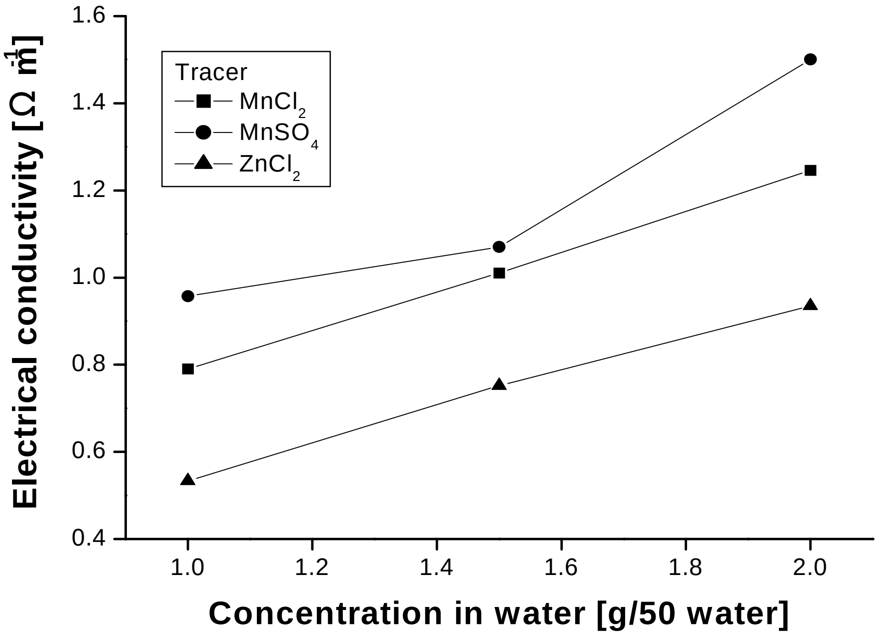

Fig. 1 Conductivity measurement for selecting a fluorescent tracer

A solution of 1.5 kg of the $MnSO_4$ per 100 L of water was prepared in the spray tank and used for the experiment. Precaution was taken as high level of concentration may be harmful to the plant. The tracers were used as a measure for the spray deposits on the apple leaves. The charge to mass ratio and the volume median diameter of the droplets were measured to be 0.28 mC/kg and 116 μm respectively. The high voltage power supply a pulse type with a power input of 12 V was connected from the orchard sprayer battery terminals. A regulated high voltage of 4 kV was applied to the nozzles with parallel connection.

Three leaves were plucked from each of the three locations of the trees (top, middle and bottom) before spraying and used as the baseline study of the analysis. These nine baseline leaves from individual trees were placed in plastic bags. The trees were then treated with only the right side of the spray (i.e. by front view of the sprayer as shown in Fig. 2) that was one pass. At the end of the spray, the sprayer went round the trees and the other side of the trees were also sprayed, thus two passes. Three variable fan speeds (i.e. 1000, 1500 and 2000 rpm) were used to evaluate their effectiveness for one pass and two passes of the spray deposition. The average distances from the center of the sprayer to that of the trees were 1.7 and 2.2 m for the M9 and M26 respectively as shown in Fig. 2. The spray solution was allowed to dry and ten leaves were collected from each of the locations per tree. Each group of ten leaves was placed in a separate bag for analysis.

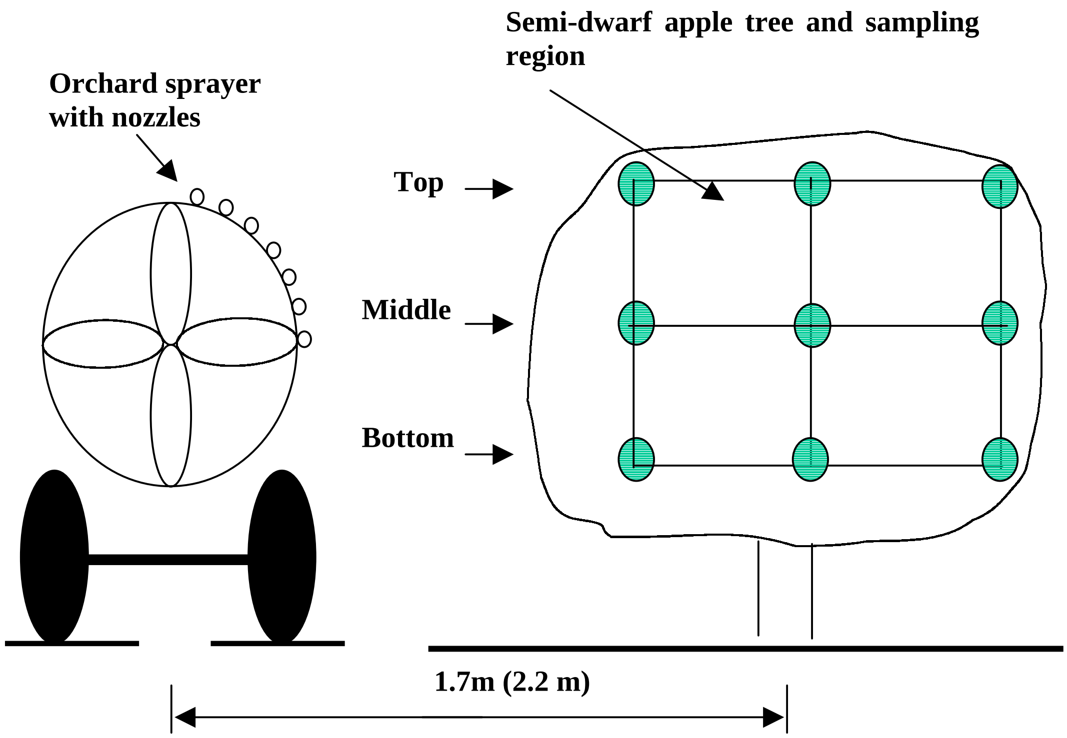

Fig. 2 Sampling location within a tree canopy

2.2 Tracer Analysis Process

All the leaf samples were placed in plastic bags and carried in an ice-box to the laboratory for tracer analysis. Samples were dried, ground, re-dried, cooled and 0.3 g of each sample was put into test-tubes as ash for the analysis. 10 ml of acid (Petchloric acid + Sulphuric acid) was added to each of the sample (as ash) in the test-tubes.

In all, forty pieces of test-tubes containing the solution were heated for 5 hours at 250 °C for the digestion process. They were left to cool overnight for filtration. Each sample was analyzed using argon plasma atomic absorption spectrometer (Perkin Elmer A. Analyst 100, USA). The leaf samples were analyzed in parts per million on a dry weight basis. No leaf area measurement was taken for spray deposition analysis. All test-tube samples were sub-samples of the original leaf samples and were of the same weight. Data were analyzed for spray deposit at top, middle and bottom levels of the trees. Depositional fold was expressed as the ratio of the charged to the uncharged sprays on the target. Statistical analysis (ANOVA) was performed to evaluate the effect of electrostatic forces as well as the fan speed.

3. Results and Discussion

The mean value of spray tracer deposits unto the East Malling Roots (M9 and M26) trees are given in Tables 2 and 3 at one pass and two passes respectively. The tables show comparisons that were made between spray treatments onto the targets. The deposit values represent the net deposit after accounting for the background levels of the metal manganese (Mn) in and on the leaves.

From Table 2, it was observed that the lowest spray deposit was obtained at a fan speed of 1000

Table 2. Mean tracer deposits from the orchard sprayer operated for M9 trees (ppm)

Fan speed (rpm)	Tree level	One pass Spray treatment Uncharged	One pass Spray treatment Charged	Ratio* C / U	Two passes Spray treatment Uncharged	Two passes Spray treatment Charged	Ratio C / U
1000	Top	961 (a)	778 (a)	0.80	2452 (a)	2014 (a)	0.82
	Middle	1716 (a)	1395 (a)	0.81	3345 (a)	3172 (a)	0.95
	Bottom	1827 (a)	1645 (a)	0.90	2195 (a)	2062 (a)	0.94
1500	Top	1609 (a)	2527 (a)	1.57	3148 (a)	2852 (a)	0.91
	Middle	2025 (a)	3961 (b)	1.96	3142 (a)	3614 (a)	1.15
	Bottom	2336 (a)	3706 (a)	1.59	2537 (a)	3051 (a)	1.20
2000	Top	1445 (a)	2484 (a)	1.72	1708 (a)	3023 (b)	1.77
	Middle	1455 (a)	3674 (b)	2.53	2207 (a)	4476 (b)	2.03
	Bottom	1861 (a)	4318 (b)	2.32	1740 (a)	4192 (b)	2.40

* C – Charged spray: U – Uncharged spray
** Means within row separated by both the DMRT and the Tukey methods of comparisons, common letter are not significantly different at the 5% level

Table 3. Mean tracer deposits from the orchard sprayer operated for M26 trees (ppm)

Fan speed (rpm)	Tree level	One pass Spray treatment Uncharged	One pass Spray treatment Charged	Ratio* C / U	Two passes Spray treatment Uncharged	Two passes Spray treatment Charged	Ratio C / U
1000	Top	740 (a)	480 (a)	0.68	1056 (a)	1562 (a)	1.48
	Middle	951 (a)	959 (a)	1.00	2570 (a)	2539 (a)	0.99
	Bottom	760 (a)	1042 (a)	1.37	2179 (a)	2719 (a)	1.25
1500	Top	692 (a)	645 (a)	0.93	2372 (a)	2160 (a)	0.91
	Middle	1678 (b)	489 (a)	0.29	2590 (a)	2854 (a)	1.10
	Bottom	2102 (a)	1139 (a)	0.54	3235 (a)	3471 (a)	1.07
2000	Top	784 (a)	1965 (b)	2.51	1404 (a)	2593 (a)	1.85
	Middle	1306 (a)	1343 (a)	1.03	1439 (a)	4016 (b)	2.79
	Bottom	825 (a)	1498 (a)	1.82	2106 (a)	2729 (a)	1.30

* C – Charged spray: U – Uncharged spray
** Means within row separated by both the DMRT and the Tukey methods of comparisons, common letter are not significantly different at the 5% level

and 1500 rpm and the greatest at fan speed of 2000 rpm for M9 with both one pass and two passes. This may be due to the effect of air transportation speed to the target. It can also be observed that there was no significant difference in spray deposition between the tree level sampling regions at each fan speed. This does not conform to the one as stated in the literature [1]. This can be attributed to the difference between the sprayer with air-assisted nozzle and the air-carrier with pressure-swirl nozzle, climate condition and the target. The field experimental analysis shows that, there was a uniform distribution of drops by the sprayer.
In Table 3 (M26), similar behaviour was observed as the greatest mean value was obtained at fan speed of 2000 rpm for both one pass and two passes. There was no significant difference in

spray deposition between the tree level sampling regions at individual fan speeds of 1000 and 1500 rpm for both passes. At 2000 rpm, a significant difference was observed at the top level for one pass and at the middle level for the two-passes. The result was in agreement with the experiment carried out in the literature [1] when the air injection pressure of 160 psi (1.1 MPa) was used. This showed that, at higher speeds the aerodynamic forces play a role in spray deposition.

During the analysis, comparison was not performed between the M9 and M26 trees due to the following reasons: 1) the trees were at different location of the site, 2) the tree and leaf surface area of the M9 was smaller than the M26.

4. Safety Considerations

The fan of the orchard sprayer blows the spray droplets away from the operator, making it unlikely for the operator to be exposed. However, for complete safety, it is advisable for the operator to wear protective clothing. Additionally, the sprayer should be well grounded to prevent any high voltage leakage that may cause shock and becomes hazardous to the operator.

5. Conclusions

Uncharged and charged sprays in a semi-dwarf apple orchard have been performed by using seven pressure-swirl nozzles. Fluorescent tracer manganese sulfate ($MnSO_4$) was used to evaluate the effect of electrostatic forces on the charged and the uncharged sprays. An induction charging method was used for the electrostatic nozzle design. The orchard sprayer was operated at fan speeds of 1000, 1500 and 2000 rpm. The study was performed with one-pass and two-passes of the sprayer at a constant velocity of 0.82 km/h. Spray deposit (ppm) was analyzed for two varieties of semi-dwarf apple tress (M9 and M26).

Statistical analysis (ANOVA) was used and comparisons were performed to evaluate the effect of electrostatic forces as well as the fan speeds of the orchard sprayer. From this study, the following conclusions have been made:

1. No significant difference was observed between the uncharged and charged sprays at fan speeds of 1000 and 1500 rpm for the M9 and M26 trees at both one pass and two passes.
2. The charged spray deposit increased by 1.72-2.32 times that of the uncharged spray at a fan speed of 2000 rpm at one pass and between 1.77-2.4 times at the same speed at two passes for M9 trees.
3. No significant difference in spray depositional ratio between the tree level sampling regions at individual fan speeds. It was concluded that, the spray was uniformly distributed by the sprayer for the M9 trees.
4. The charged spray deposit increased by 1.03-2.51 times that of the uncharged spray at a fan speed of 2000 rpm at one pass and between 1.30-2.79 times at the same speed at two passes for M26 trees.
5. No significant difference in spray deposition between the tree level sampling regions at individual fan speeds of 1000 and 1500 rpm for both passes for the M26 tree. At 2000 rpm, a significant difference was observed at the top level for one pass and at the middle level for the two-passes.
6. The charged spray proved superior to the uncharged spray at a fan speed of 2000 rpm, that showed the effect of the air transportation to the target on spray deposition

6. Acknowledgement

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