Shielding of Drifting Pesticide Particles by Electrostatic Pesticide Spraying and Grounded Conducting Net for Compliance with Positive List System

Ryo Nishimura, Yoshifumi Hashimoto, Yuusuke Tsutsui, Katsumi Nishimori and Naganori Ishihara

Abstract— **It is well known that electrostatic pesticide spraying (EPS) is effective to improve the adhesion performance of pesticide to agricultural crops. On May 29, 2006 the Ministry of Health, Labour and Welfare introduced the positive list system for agricultural chemicals remaining in foods. The system prohibits the distribution of foods that contain agricultural chemicals, such as pesticides, above a certain level if maximum residue limits have not been established. Because of this, pesticides should be sprayed only on the target plants. Also, the drifting pesticide particles should be shielded not to reach the other plants. In this paper, we show that charged droplets can be shielded by using grounded conducting net. EPS is also effective to prevent drift hazard of pesticides.**

.

***Index Terms*— charged particle, electrostatic pesticide spraying, food safety, particle shielding**

I. Introduction

IT is well known that when pesticides are sprayed to agricultural crops, some pesticide particle do not reach the crops (target). It is reported that 80% of pesticide sprayed from the nozzle did not reach the target [1]. The pesticide that does not reach the target pollutes the soil and rivers. Moreover, such "drifting" pesticide may cause health problem. Also, it is not desirable from the viewpoint of the cost performance. In Japan, especially, the suppression of the drift of the pesticide is strictly required these days because of the introduction of the Positive List System.

This work was supported by KAKENHI (Grant-Aid for Scientific Research (C)) (19580293).

R. Nishimura is an associate professor of the Department of Information and Electronics, the Graduate School of Engineering, Tottori University, 4-101, Koyama-minami, Tottori 680-8552, JAPAN (corresponding author to provide phone:+81-857-31-5237;fax:+81-857-31-0880;e-mail:ryo@ele.tottori-u.ac.jp).

Y. Hashimoto is a student of the Department of Information and Electronics, the Graduate School of Engineering.

Y. Tsutsui is a student of Department of Electrical & Electronic Engineering of Tottori University.

K. Nishimori is a professor of the Department of Information and Electronics, the Graduate School of Engineering, Tottori University. (e-mail: nisimori@ele.tottori-u.ac.jp)

N. Ishihara is a technician of the Department of Information and Electronics, the Graduate School of Engineering, Tottori University. (e-mail: ishi@ele.tottori-u.ac.jp)

II. Positive List System

A. Necessity to Suppress the Pesticide drifting

On May 29, 2006 the Ministry of Health, Labour and Welfare in Japan introduced the Positive List System for agricultural chemicals remaining in foods. The system prohibits the distribution of foods that contain agricultural chemicals, such as pesticides, above a certain level (0.01 ppm) if maximum residue limits have not been established [2]. For example, assume that farms of crops A and B adjoin each other. If a pesticide sprayed on crop A, which is not allowed to use to crop B, is detected from crop B, the shipping of crop B is prohibited. The cause of this trouble is the drift of the pesticide sprayed on A and the drifting pesticide adheres to B. Because of this, pesticides should be sprayed only on the target crops. Also, the pesticides, which do not reach the targets, should be shielded not to adhere to the other crops.

The conventional methods for drift-suppression are, for example:

・The smallest amount of pesticide needed to produce the desired effect should be used for required area.
・Spray pesticide when calm.
・Spray pesticide near the target crops.
・Spray pesticide with large particle diameter.
・Spray pesticide by an appropriate pressure.
・Shield the drifting pesticide by windbreak net.

However, it is very difficult to suppress the pesticide drifting effectively.

B. Application of Electrostatic Pesticide Spraying for Drift-suppression

Electrostatic pesticide spraying (EPS) is known as an effective spraying method to reduce the amount of pesticide to be sprayed. The charged pesticide droplets move along the electrical flux lines to the crops. Because the electrical flux lines reaches all over the crops, the pesticide can be sprayed on all over the crops. Because of this, some of the pesticide droplets which fall onto the ground and do not reach the crops when a conventional spraying method is adopted are also attracted to the crops. This means that the amount of the required pesticide can be reduced and it is expected that the drift of the pesticide can be suppressed at some level.

The charged pesticide particles are attracted to not only crops but also other grounded objects. This means that it is expected that the drifting pesticide can be shielded by grounded conducting net if the pesticide is charged. In this research, we applied the principle of electrostatic pesticide spraying (EPS) to the drift-suppression.

III. Fundamental Principle

Figure 1 shows the schematic illustration of pesticide shielding by using the principle of ESP. Charged pesticide is sprayed from the nozzle. It is expected that the pesticide is effectively attracted to the target crops. However, some of the pesticide particles do not adhere to the target and drift in the air. If such "drifting" pesticide adheres to the not-target crops, it will cause a problem. If grounded conducting net is placed between the target and not-target crops, the charged drifting pesticide is attracted to the net. So, it is expected that the amount of pesticide that adheres to the not-target crops can be reduced. Though the not-target crops also attract the charged pesticide, it is expected that the amount of drifting pesticide can be reduced by adjusting the arrangement of the nozzle, the target crops, the net and the not-target crops.

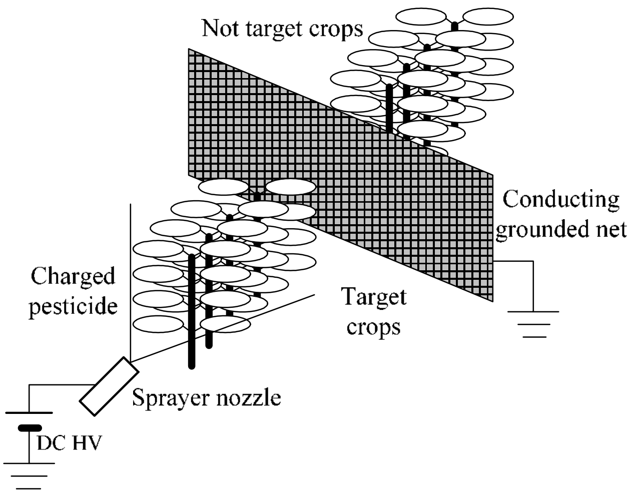

Fig. 1. Schematic illustration of pesticide shielding by using the principle of electrostatic pesticide spraying.

IV. Experiments

A. Experimental Apparatus

A metal dummy tree shown in Fig.2, which imitates cultivated crop, consists of a brass rod with 1.2 m length and 6 mm diameter as a trunk and 28 piece of thin ellipse metal plate with 10 cm and 8 cm radii as leaves.

In this research, we used water-diluted black ink for an ink-jet printer instead of pesticide. The 10cm^3 of the black ink (OM Inc., Item No.01-0133) is diluted by adding 3000 cm^3 of ion-exchanged water. We pasted white filter paper with the same size of the metal leaves on both sides of the leaves of the dummy tree. In this research, we estimated the amount of the ink adhered to the leaves as the area of the ink on the filter paper.

The conducting net is an ordinary metal net with about 2.2 m length (height) and 1.8 m width. The diameter of wire of the net is about 1 mm. The mesh size of the net is shown in Fig. 3.

Fig. 2. Metal dummy tree.

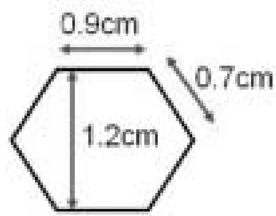

Fig. 3. Mesh size of the conducting net.

We used a battery-powered sprayer IR-3000 (IRISOHYAMA Inc.), which is commonly sold at Do-It-Yourself stores in Japan, for this experiment. The rated pumping rate and pressure are 4.48 cm^3/s (269 cc/min) and 2735 hPa (2.7 atm), respectively. The distribution of diameters of the water droplets sprayed from the nozzle is shown in Fig. 4. The diameters of the droplets are smaller than 0.5 mm and about 55 % of them are smaller than 0.1 mm. This sprayer is placed on an insulator. A high-voltage DC power supply is connected directly to the sprayer nozzle to charge the diluted ink.

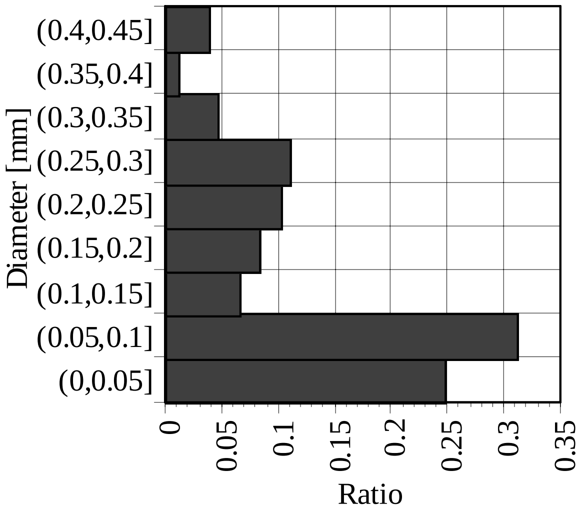

Fig. 4. Droplet-diameter distribution.

B. Nozzle-voltage Dependence of Shielding Characteristic

In order to confirm the effectiveness of grounded conducting net for shielding the drifting charged droplets, we compared the amount of adhered droplets for the case when the net is placed between the sprayer nozzle and the dummy tree (with-net case) with that for without-net case for various nozzle voltages. Figure 5 shows the arrangement of the experimental apparatus. The height of the nozzle is 80 cm from the ground. A high-voltage source is connected to the sprayer nozzle and charges the droplets. A grounded metal dummy tree corresponds to the “not-target crops” in Fig. 1 to which pesticide should not adhere. Though target crops should be placed between the nozzle and the conducting net, they are omitted in this research. Because of this, the droplets sprayed from the nozzle correspond to the “drifting” droplets that do not adhere to the target crops. These charged “drifting” droplets are attracted to the grounded conducting net and can be shielded not to adhere to the dummy tree. Though the dummy tree also attracts the charged droplets, it is expected that the amount of drifting pesticide particles can be reduced by adjusting the distances between the nozzle and the net and between the net and the dummy tree. For with-net case, the distance between the nozzle and the net L_1 is 80 cm and that between the net and the trunk of the dummy tree L_2 is 60 cm. The distance between nozzle and the dummy tree L is 140 cm for the both with-net and without-net cases.

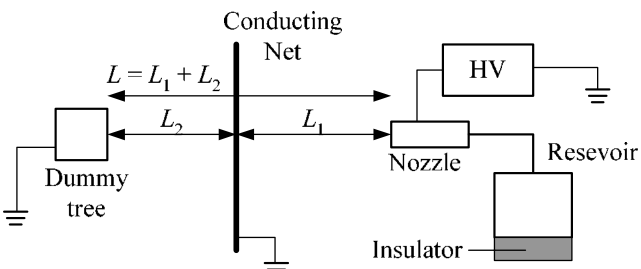

Fig. 5. Arrangement of experimental apparatus.

We pasted the filter paper on both sides of all (28) leaves of the dummy tree. Then, the water-diluted ink was sprayed for 20s under calm condition. After spraying, the total area of the ink that adhered to the paper is measured by the following procedures.

(1) The area of a piece of the filter paper pasted on the leaves is 62.8 cm^2.
(2) After spraying, the ink stain on each piece of the filter paper is taken by a scanner against black background and saved inside a PC as a gray-scale-image file. The resolution of the scanner is 75 dpi.
(3) The level adjustment is carried out by using Adobe Photoshop Element 5 to distinguish black and white areas. The shadow, demitint and highlight values are 120, 0.10 and 223, respectively for the adjustment. An example of the level-adjusted image of the filter paper is shown in Fig. 6.

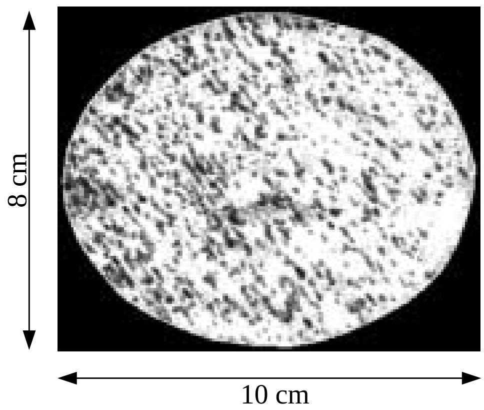

Fig. 6. Example of scanned filter paper

(4) The number of the pixels corresponds to white area N_w is counted.
(5) For 75 dpi, 1 in^2 corresponds to 5625 (= 75 x 75) pixels and 6.4516 cm^2 (2.54 cm x 2.54 cm). The white area of the paper A_w[cm^2] is calculated by

$$A_w = \frac{6.4516}{5625} \times N_w . \qquad (1)$$

(6) The black area corresponding to the adhered ink A_b[cm^2] is obtained by

$$A_b = 62.8 - A_W . \qquad (2)$$

Figure 7 shows the total area of the ink on the 28 leaves for various nozzle voltages. The area of ink that adhered to the leaves is reduced by placing the grounded conducting net between the nozzle and the dummy tree. The shielding factor a[%] is defined by the following equation.

$$a = \frac{c-b}{b} \times 100 , \qquad (3)$$

where b is the total area of the ink on the leaves for the with-net case and c is that for without-net case. Figure 8 shows the shielding factor for various nozzle voltages. As the nozzle voltage becomes higher, the shielding factor becomes larger. The maximum value of the shielding factor is obtained when the nozzle voltage is -40 kV. The particle can be shielded more than 40 % when the nozzle voltage is -40 kV. On the other hand, the shielding factor is less than 5 % when the voltage is not applied.

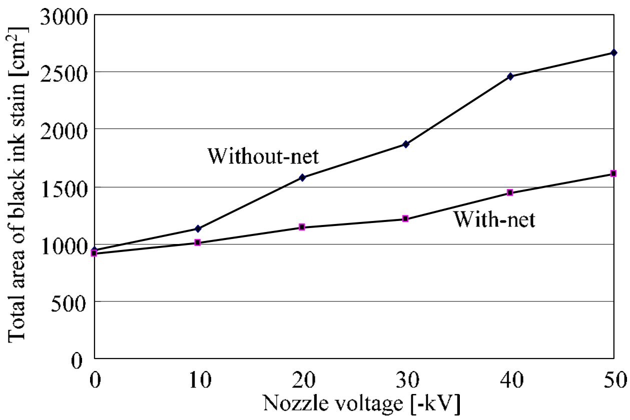

Fig.7. Total area of the ink on the 28 leaves for various nozzle voltages.

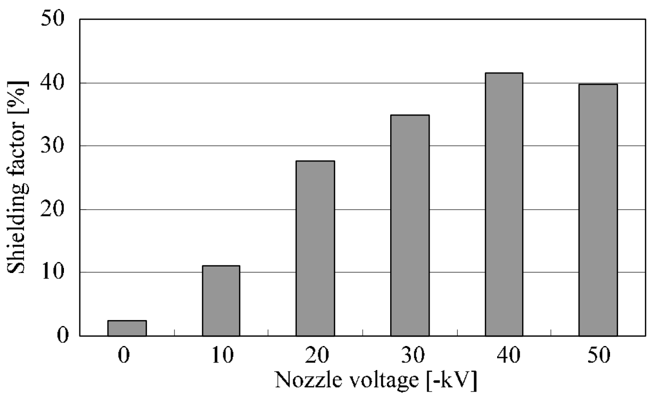

Fig. 8. Shielding factor for various nozzle voltages.

C. Spraying-distance Dependence of Shielding Characteristics

We carried out the experiments for changing the distances between the nozzle and the net and between the net and the dummy tree. The nozzle voltage is fixed at -40 kV for these experiments. Figure 9 shows the total area of the ink on the 28 leaves for the cases that the distances between the nozzle and the net L_1 are 40 cm, 60 cm and 80 cm. The distance between the net and the dummy tree L_2 is fixed at 60 cm. Figure 10 shows the result for the case that L_2 are 40 cm, 60 cm and 80 cm. The distance L_1 is fixed at 60 cm. The shielding factors for Fig. 9 and 10 are shown in Table 1 and 2, respectively. We can see that when the distance between the net and the nozzle is fixed at 60 cm (Fig. 10 and Table 2), the shielding factor reduces (improves) only 5 % by changing the distance between the net and the dummy tree from 40 cm to 80 cm. However, when the distance between the net and the dummy tree is fixed at 60 cm (Fig. 9 and Table 1) the shielding factor reduces 25 % by changing the distance between the net and the nozzle from 40 cm to 80 cm. This means that it is effective to suppress the drift of the pesticide that the conducting grounded net should be placed near the crops to which pesticide should not adhere.

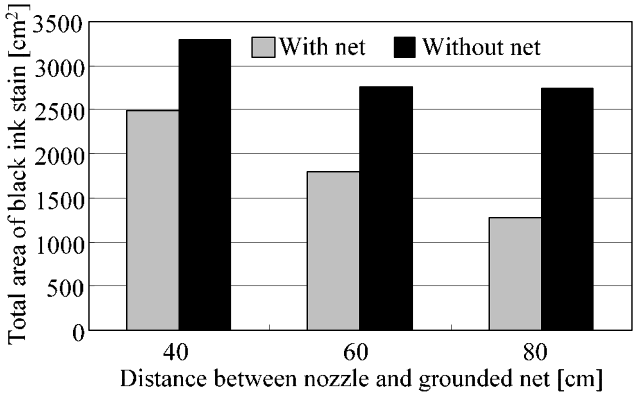

Fig. 9. Total area of the ink on the leaves. The distances between the nozzle and the net are 40 cm, 60 cm and 80 cm. The distance between the net and the dummy tree is fixed at 60 cm.

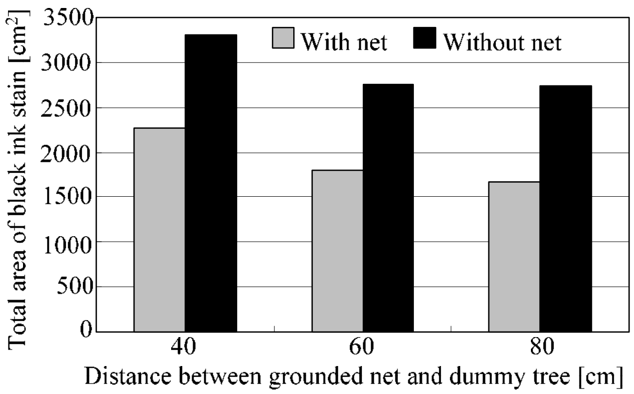

Fig. 10. Total area of the ink on the leaves. The distances between the net and the dummy tree are 40 cm, 60 cm. and 80 cm. The distance between the nozzle and the net is fixed at 60 cm.

Table 1. Shielding factor for various distance between the nozzle and the grounded net. The distance between the net and the dummy tree is fixed at 60 cm.

Distance between nozzle and net [cm]	Shielding factor [%]
40	22.4
60	31.4
80	47.6

Table 2. Shielding factor for various distance between the grounded net and the dummy tree. The distance between the nozzle and the nozzle is fixed at 60 cm.

Distance between net and dummy tree [cm]	Shielding factor [%]
40	28.8
60	31.4
80	33.9

Because of the viscosity of the air, the kinetic energy of a particle sprayed from the nozzle becomes smaller as the distance from the nozzle becomes larger. If the distance between the nozzle and the net is too short, the charged particles have enough kinetic energy to escape the grounded net.

D. Shielding Characteristics for Various Waveform of Nozzle Voltage

In order to investigate the effect of the waveform of the nozzle voltage on the shielding characteristics, we apply the voltage with various waveforms to the spraying nozzle listed in Table 3. The nozzle voltage is controlled by the signal with a rectangular waveform from the function generator (FG) connected to the HV power supply. An example of the waveform is shown in Fig. 11. The waveforms of voltages Type A, B and C are quasi-rectangular. The Type D is a DC voltage that corresponds to the average value of Type A. The Type E corresponds to the average values of Type B and C. The type F and G are the cases that the voltage is not applied to the nozzle for comparison.

Table 3. Nozzle voltages with various waveforms.

Type	Control signal: Duty ratio [%]	Control signal: Frequency [Hz]	Nozzle voltage [kV]: Maximum [kV]	Nozzle voltage [kV]: Average [kV]
A	20	0.25	-50	-28.6
B	50	0.5	-50	-41.9
C	20	0.25	-50	-41.5
D			DC -28.6	
E			DC -41.7	
F			0 (with net)	
G			0 (without net)	

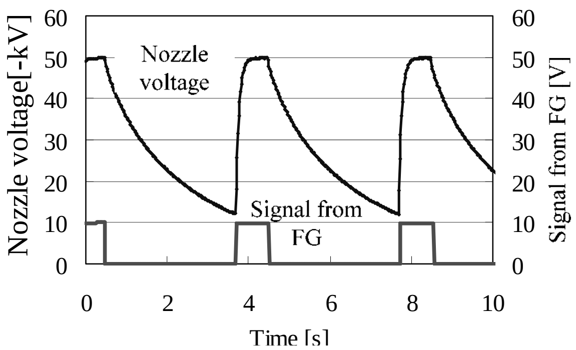

Fig. 11. Nozzle voltage waveform of Type A.

The shielding characteristics depend on both the electric field and the charges of the droplets. If the amounts of droplet charge become larger, the droplets are attracted to the grounded object more strongly. The droplet current, which corresponds to the droplet charges, are measured by using the apparatus shown in Fig. 12. The diameter and the depth of the metal vessel are 36 cm and 18 cm, respectively. The ion-exchanged water is sprayed from the same sprayer used in the previous experiments. The internal impedance of the voltage logger is 1 MΩ. The sampling frequency for this measurement is 50 Hz.

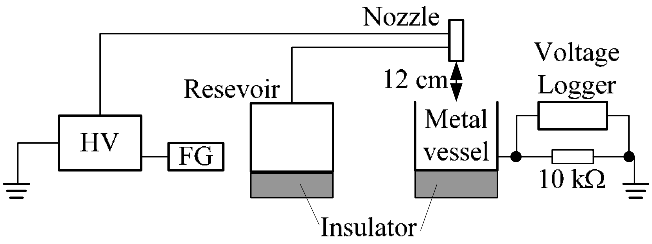

Fig. 12. Apparatus for droplet current measurement.

Figures 13 and 14 are the waveform of the currents that flow from the metal vessel to the ground. The currents in Fig. 13 are obtained when the voltage Type A is applied to the nozzle. Those in Fig. 14 are obtained when nozzle voltage Type D is applied. The current I_1 (gray line) is obtained when the water is sprayed. On the other hand, I_2 (black line) is obtained when the water is not applied. The droplet current can be estimated by I_1-I_2. It is obvious from Fig. 13 and 14 that:

(1) The droplet current is about 3 μA DC at most for Type D (DC) nozzle voltage.

(2) The droplet current for Type A (quasi rectangular) nozzle voltage is larger than that for Type D.

(3) The current for Type A increases steeply as the nozzle voltage rises.

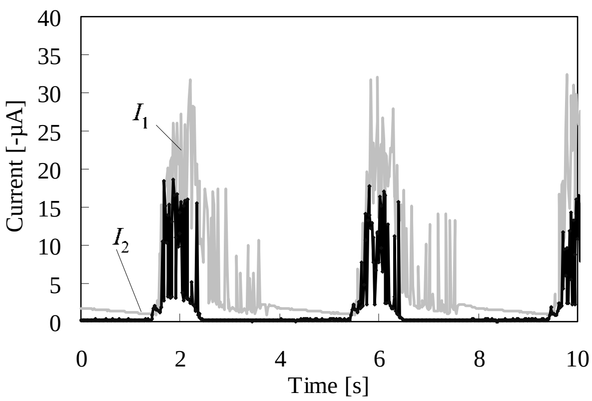

Fig. 13. Waveform of the currents that flow from the metal vessel to the ground obtained when nozzle voltage Type A is applied. The current I_1 is obtained when the water is sprayed. I_2 is obtained when the water is not sprayed.

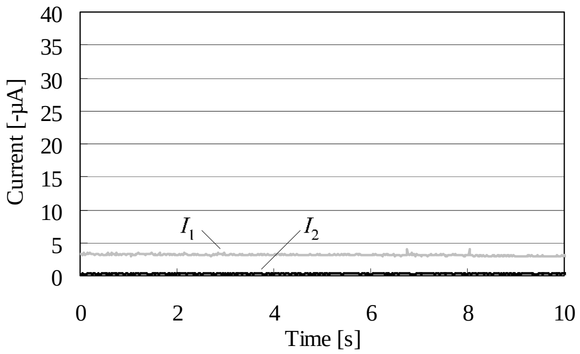

Fig. 14. Waveform of the currents that flow from the metal vessel to the ground obtained when nozzle voltage Type D is applied. The current I_1 is obtained when the water is sprayed. I_2 is obtained when the water is not sprayed.

Figure 15 shows the arrangement of apparatus for this experiment. We used four dummy trees shown in Fig. 2 for this experiment. The nozzle height from the ground is 80 cm. We pasted the filter paper on both sides of six leaves of each dummy tree.

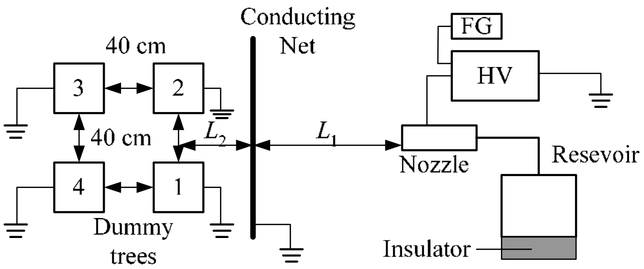

Fig. 15. Arrangement of experimental apparatus.

Figure 16 shows the total areas of the ink on the 24 leaves (6 leaves/tree x 4 = 24) for the case that distance between the nozzle and the net L_1 is 120 cm and the distance between the net and the "front" dummy trees L_2 is 60 cm.

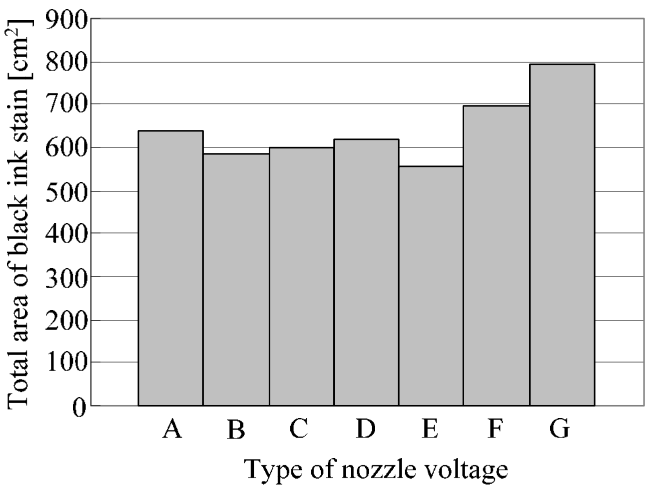

Fig. 16. Total area of the ink on the leaves. Distance between the nozzle and the net is 120 cm and the distance between the net and the "front" dummy trees is 60 cm.

V. Discussions

A. Nozzle-voltage Dependence of Shielding Characteristic

In the experiment in IV-B, the maximum value of shielding factor is obtained when the nozzle voltage is -40 kV. From this result, if an arrangement of the nozzle and the dummy tree(s) is given, it seems that an appropriate nozzle voltage that maximizes the shielding factor exists. We frame a hypothesis to explain this result as follows.

Assuming that a charged droplet is move along the electric flux line A, which reaches to the grounded conducting net, and comes to the point α as shown in Fig. 17, the direction of the inertia force of the droplet F_1 is the same direction of its velocity. The direction of the Coulomb force F_2 is the same direction of the tangential-line of the electric flux line A. The total force acts on the droplet is the summation of F_1 and F_2. If the electric field is too strong, i.e, the nozzle voltage is too high, not only F_2 but also F_1 becomes large because the droplet is accelerated by the electric field. When the droplet just goes through the point where the curvature radius of the electric flux line A is small, the droplet cannot move along the flux line if F_1 is too strong. In this case, the droplet flies out of the line A to another point (β) and then move along another flux line B. If the flux line B reaches the dummy tree, the droplet cannot be shielded and adhere to the dummy tree. The number of such droplet increases as the nozzle voltage is higher.

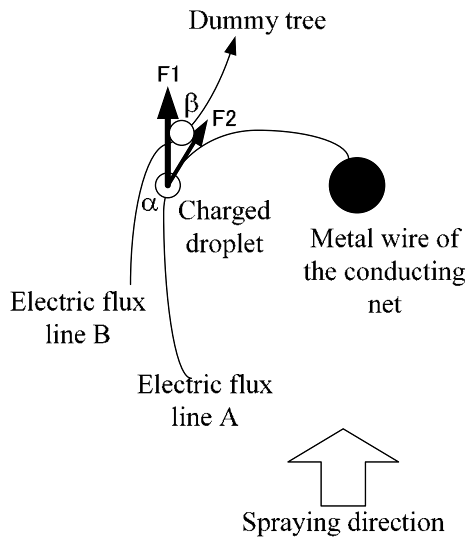

Fig. 17. Trajectory of a charged droplet.

B. Spraying-distance Dependence of Shielding Characteristics

It is shown that when the distance between the nozzle and the net is fixed, the shielding factor does not reduce so much as the distance between the net and the dummy tree becomes larger. This means that it is necessary that the kinetic energies of the droplets should be weakened by the viscosity of the air before they reach to the grounded net.

C. Shielding Characteristics for Various Waveform of Nozzle Voltage

As shown in Fig. 16, the total area of ink stain is reduced when the nozzle voltage with various waveforms is applied. However, the distinct differences of shielding characteristics among the waveforms were not observed. For example, the areas for the nozzle voltages Type A and D are almost the same.

We can see from Fig. 11 and 13 that large droplet current is obtained at the moment when nozzle voltage rises. This means that the droplets sprayed at that moment are strongly charged. On the other hand, the droplets sprayed when the nozzle voltage decays are not charged well. Such droplets cannot be shielded so much by the grounded net. Because of these droplets that cannot be shielded, the adhesion area of the ink is not reduced. If a high frequency pulsating DC voltage with precipitous waveform is applied to the nozzle, different shielding characteristics will be obtained.

The above hypothesis does not contradict the one described in the previous section if the nozzle voltage is not too high.

VI. Conclusions

In Japan, the suppression of the drift of the pesticide is strictly required these days because of the introduction of the Positive List System. The drifting pesticide particle can be effectively shielded by charging the pesticide and the grounded net. For this pesticide shielding, we show that it is necessary that:

1) The appropriate nozzle voltage should be applied to maximize the shielding factor.

2) The spraying nozzle, the grounded net and the crops should be appropriately arranged.

We will carry out further investigations of the nozzle-voltage waveform dependence on the shielding characteristics. The HV power supply used in the experiments cannot change the generate voltage rapidly. The practical frequency is at most 1 Hz because of the time constant of the circuit of the power supply. If a high frequency pulsating DC voltage with precipitous waveform is applied to the nozzle, different shielding characteristics will be obtained.

A voltage commonly applied to an induction-charging type EPS nozzle is much lower (~5 kV) than that to a contact-charging type nozzle which is used in this research. We will also investigate the shielding characteristics for the case when the pesticide is charged by induction charging.

References

[1] Law S. E. “Electrostatic Pesticide spraying: Concepts and Practice”, *IEEE Trans. Industrial Application*, 19, 2, 160-168, 1983.

[2] Introduction of the Positive List System for Agricultural Chemical Residues in Foods [Online]. Available: http://www.mhlw.go.jp/english/topics/foodsafety/positivelist060228/introduction.html