Quantitative and economical assessment of effectiveness of electrostatic pesticide spraying

Ryo Nishimura1*, Satoko Fujita1, Shota Michihara1, Takashi MaSuoka2, Toshihiro Kimura2, Shinji Yatsuzuka2 and Shinobu Anaguchi2
1 Graduate School of Engineering, Tottori University, 4-101 Koyama-minami, Tottori 680-8552, Japan
2 Arimitsu Industry Co., Ltd., 1-3-7 Fukae-kita, Tousei-ku, Osaka 537-0001, Japan

E-mail: ryo@ele.tottori-u.ac.jp

Abstract. Electrostatic pesticide spraying (EPS) improves the adhesion characteristics of the pesticide solution to agricultural crops. If the adhesion characteristics are improved, the requisite amount of the pesticide to be sprayed can be reduced in comparison with the conventional spraying method that uses non-charged pesticide. In this research, disease (rust) control experiments were carried out to substantiate the effectiveness of the EPS from a statistical point of view. We sprayed pesticide to potted Japanese pear trees under calm condition. The numbers of the rust lesions on the pear leaves were counted at fixed intervals after spraying to investigate the difference of the results of the disease control. The t-tests were carried out for the populations of the various spraying times and applied voltages. It was statistically-derived that EPS can reduce the amounts of pesticide to be sprayed by 50% in comparison with the non-EPS method. It is also estimated from the results that about 55,000 kL year⁻¹ of pesticides can be reduced for the Japanese pear cultivation in Tottori prefecture. Also, this means that the expense of the pear cultivation can be reduced by about 240 million yen (3 million USD) every year in Tottori prefecture by introducing EPS.

1. Introduction

Electrostatic pesticide spraying (EPS) improves the adhesion characteristics of the pesticide solution to agricultural crops. If the adhesion characteristics are improved, the requisite amount of the pesticide to be sprayed can be reduced in comparison with the conventional spraying method that uses non-charged pesticide. Some agricultural implement and sprayer manufacturers sell various kinds of EPS nozzles. In order to investigate the effectiveness of EPS, in comparison with the conventional spraying method, Yamane et al. [1, 2] investigated the adhesion of the sprayed water to crops such as cabbages and melons using pieces of water-sensitive paper attached to the target. Also, they compared the numbers of the insect pests that inhabit the crops and insect damages of the crops between EPS and the conventional spraying method.

In this research, disease (rust) control experiments were carried out to substantiate the effectiveness of the EPS from a statistical point of view. The experiments were carried out for the Japanese pears (Pyrus pyrifolia), one of the signature agricultural products of Tottori prefecture, to estimate the cost-cutting in the disease control for the pear cultivation.

* To whom any correspondence should be addressed.
2. Experiments

2.1. Spraying nozzle and test trees

In this research, we sprayed the pesticide solution that controls rust to potted Japanese pear trees (test trees) by using a battery-driven sprayer that is usually sold at Do-It-Yourself stores. The average values of width $D$ and height $H$ are 58 cm and 87 cm, respectively. Each of the trees was cultivated in a pot of which height is 31 cm. A grounding rod was put in the soil of the pot when the spraying experiments were carried out. The nominal spraying rate and pressure of the sprayer are $269 \text{ cc min}^{-1}$ (4.48 cm$^3$ s$^{-1}$) and 2.7 atm (2735 hPa), respectively. Figure 1 shows the distribution of the diameter of the droplets from spraying nozzle. 55% of the droplets have the diameter of less than 0.1 mm. The pesticide droplets were charged by contacting charging. The voltages applied to the nozzle were -40 kV and 0 kV. The sprayer was fixed on the insulator during the experiments.

![Figure 1. Distribution of the diameter of the droplets from spraying nozzle.](image)

The spraying pressure of the sprayers usually used in agricultural field is 1 ~ 1.5 MPa. The spraying rate and pressure of the sprayer used in this research were rather smaller than those of the field-use sprayers. Also, the EPS nozzles sold in Japan for such sprayers are induction-charging type. In this research, as described below, the pesticide was sprayed to a single test tree for a trial spraying. The amounts of pesticide to be sprayed were controlled by changing the spraying time. If a sprayer with large spraying rate is used, it is concerned that too much pesticide is sprayed even for short spraying time and the amounts of sprayed pesticide will vary widely for small fluctuation of the spraying time. Because of these concerns, a battery-driven sprayer with not-so-large spraying rate was used for the research. The contacting charging method was adopted because an induction-charging electrode for the small sprayer was not able to be built.

2.2. Experimental conditions and procedures

Figure 2 show the arrangement of the spraying nozzle and a test tree. The nozzle height from the ground was fixed at 75 cm. The distance between the nozzle orifice and a pear trunk is 50 cm or 80 cm. The experimental condition was shown in table 1. The pesticide of the specified concentration was sprayed as follows:

(i) A grounded plate, which blocks the flow of the pesticide, was placed between the nozzle and a test tree.
(ii) The sprayer was activated.
(iii) The charging voltage was applied to the nozzle.
(iv) When the pesticide was stably sprayed and the nozzle voltage reached the setup value, the grounded plate was removed.
(v) After the pesticide was sprayed for a set time (4 s, 8 s, 12 s, 16 s and 20 s), the grounded plate was placed again between the nozzle and the test tree.

**Table 1.** Experimental conditions.

| Date       | Apr. 26, 2010 |
|------------|---------------|
| Temperature| 27 °C         |
| Humidity   | 24%           |
| Wind       | Calm          |

The numbers of the rust lesions on the leaves were counted after 5, 11 and 17 days after spraying. For this number counting, 150 leaves were selected randomly from a single test tree. Fifty of them were selected permitting overlaps from the area lower than 65 cm from the bottom of the pot, others 50 were from 65 ~ 85 cm and the others 50 were from upper than 85 cm.

**Figure 2.** Arrangement of the spraying nozzle and a test tree.

2.3. Rust

Rust on pear leaves is one of fungi developed by Basidiomycetes (*Gymnosporagnium asaticum*). As shown in figures 3, this disease develops yellow lesions on pear leaves. These lesions are not curable and become holes. The leaves with a lot of lesions will defoliate. Rust was one of the important diseases of Japanese pears. Recently, some pesticides that work wonders have been developed and easily control the disease [3]. This disease develops after a rainfall in late of April or beginning of May in Japan. In this paper, this disease is adopted as the experimental object because the developing time is easily predictable.

**Figure 3.** Rust lesions on Japanese pear leaves.
3. Results

3.1. Experimental results

Average lesion number of a test tree $N_{\text{ave}}$ was calculated by the following equation.

$$N_{\text{ave}} = \frac{N_{\text{lesion}}}{N_{\text{leaf}}} \quad (1)$$

where $N_{\text{lesion}}$ is the number of the counted lesions of the tree and $N_{\text{leaf}}$ is the number of the sample leaves.

Figure 4. Time variation of the numbers of rust lesions after spraying (spraying time = 8 s).

Figure 4 shows the time variation of the average numbers of the rust lesions on a leaf for various spraying conditions for the case that the spraying time is 8 s. Comparing the changes of the average lesion numbers from 5 days to 11 days after spraying (Time (i)) with those from 11 days to 17 days (Time (ii)), the numbers in Time (ii) change at a slower rate overall than those in Time (i) and most of them vary within one during Time (ii). From the above consideration, it is assumed that the lesion numbers converged at 17 days after the spraying and, in this paper, the effects of the disease control will be discussed using the data of “17 days after the spraying”. The previous research [4] also shows that the numbers of the rust lesions converged at around 16 days after pesticide spraying. Though the rust lesions are not curable, the lesion numbers for some spraying conditions decrease with time in figure 3. One of the reasons of this phenomenon is that more than one closely-developed lesions became larger with time and united as a large single lesion and was counted as a “one” lesion.

3.2. Data analyses using t-tests

As described in section 2.2, 150 leaves were selected permitting overlaps from a single test tree. The lesion numbers of each leaf was recorded. So, a raw data for statistical analyses consists of 150 numbers. T-tests [5, 6] were carried out for the samples of the various spraying times and applied voltages to determine if a significant difference between two samples (e.g. -40 kV and 0 kV) exists. In t-tests, the researchers’ hypothesis and the hypothesis that opposes “the researchers’ hypothesis” are called the alternate hypothesis and the null hypothesis, respectively. The tests are carried out
calculating the test statistic based on an assumption that the null hypothesis is correct. However, if the test statistics belongs to the rejection region, the null hypothesis is considered to be erroneous and rejected. The probability that null hypothesis is rejected is called significance level $\alpha$. In this research, Welch’s test is adopted and $\alpha$ is set at 0.05 (5%), a commonly-used probability. The Welch’s test is a kind of t-tests used when two samples are assumed to have different dispersions.

3.2.1. Relation between spraying distance and disease control
All the raw data, except for “Hand spraying” and “Not sprayed”, are categorized according to the spraying distance (50 cm and 80 cm) into two samples without considering the nozzle voltage and the spraying time. Table 2 shows the result of a significance test for the spraying distance. This table was automatically obtained by using one of the analytical tools of Microsoft Excel [7]. The alternate hypothesis for this tests is that “the number of lesions was changed (increased or decreased) by changing the spraying distance from 50 cm to 80 cm” and the two-tailed test should be adopted. If the alternate hypothesis is that “the number of lesions was increased (or decreased) by changing the spraying distance”, the one-tailed test would be adopted. If $P(T \leq t) < \alpha$ or $t_{\text{boundary}} < |t|$, the null hypothesis is rejected [7]. We can see that $P(T \leq t) > \alpha$ and $t_{\text{boundary}} > |t|$ for two-tailed test and no significant difference between the two samples is obtained. In the following discussions, for the same nozzle voltage and the same spraying time, the data for the two spraying distances will be merged into a single sample.

| Table 2. Significance test for spraying distances. |
|-----------------------------------------------|
| Spraying distance | 50 cm | 80 cm |
| Average lesion number | 3.375 | 3.559 |
| Dispersion | 10.96 | 13.70 |
| $t$ for two-tailed test | -1.212 | |
| $P(T \leq t)$ for two-tailed test | 0.2256 | |
| $t_{\text{boundary}}$ for two-tailed test | 1.961 | |

3.2.2. Relation between nozzle voltage and disease control
For various spraying time, except for “Hand spraying” and “Not sprayed”, the raw data are categorized according to nozzle voltage (-40 kV and 0 kV), without considering the spraying distances. The Welch’s tests are carried out for two samples for each spraying time. The alternate hypothesis for these tests is that “the number of lesions was decreased by adopting EPS” and the one-tailed tests are carried out.

| Table 3. Significance test for nozzle voltage. |
|-----------------------------------------------|
| Spraying time | 20 s | 16 s | 12 s | 8 s | 4 s |
| Nozzle voltage | 0 kV | -40 kV | 0 kV | -40 kV | 0 kV | -40 kV | 0 kV | -40 kV |
| Average lesion number | 3.443 | 3.763 | 3.286 | 3.505 | 2.825 | 2.621 | 4.219 | 3.204 | 4.258 |
| Dispersion | 9.785 | 13.61 | 13.71 | 12.99 | 7.505 | 11.79 | 11.23 | 22.51 | 11.68 |
| $t$ | -0.9767 | -0.7086 | 0.6767 | 3.003 | 1.960 |
| $P(T \leq t)$ | 0.1646 > $\alpha$ | 0.2395 > $\alpha$ | 0.2495 > $\alpha$ | 0.001422 < $\alpha$ | 0.025 < $\alpha$ |
| $t_{\text{boundary}}$ | 1.649 > |t| | 1.649 > |t| | 1.649 > |t| | 1.649 < |t| | 1.649 < |t| |
As shown in table 3, for the spraying times of 12 s ~ 20 s, the null hypothesis is not rejected. This means that the significant differences between EPS and non-EPS for these spraying times are not observed. On the other hand, for the spraying times of 4 s and 8 s, the significant differences between the two spraying methods are observed. For the spraying time of 12 s, though the significant difference between EPS and non-EPS is not observed, the average lesion number was decreased by adopting EPS. These results mean that even for the non-EPS case, some amounts of pesticide, which gave little difference in the disease control in comparison with the EPS case, adhered to the test trees when the spraying time is longer than 12 s. For the spraying time shorter than 12 s, non-EPS could not control the disease well in comparison with the EPS. This difference was significant for the spraying time of 4 s and 8 s.

4. Discussions

4.1. Estimation of pesticide reduction adopting EPS

Figure 5 shows the average numbers of the rust lesions for various spraying time obtained 17 days after spraying. Spraying excessive amount of pesticide usually does not decrease the control ability. Because of this, the lesion number will monotonically decrease as the spraying time and ideally be zero for a long enough spraying time if the pesticide is sprayed evenly all over a test tree. In this research, it is concerned that the pesticide did not reach some leaves even for the EPS cases because the positions of the spraying nozzle and the test trees were fixed. For such spraying conditions, the average lesion number will not decrease to zero for a long spraying time. From figure 5, it seems that the average lesion number converged at the spraying time of about 12 s and the longer spraying times did not improve the control ability for non-EPS cases. For EPS cases on the other hand, the average lesion number did not decrease so much as the spraying time and little difference was in the average lesion numbers between the spraying times of 4 s and 20 s is obtained. This means that it is expected that the convergence average lesion number was obtained even for the 4-s-spraying. In other words, the disease was sufficiently controlled by the 4-s-spraying for the adopted experimental conditions. For the non-EPS cases, the average lesion number too rapidly decreased at the spraying times of 12 s. It is concerned that some unknown factors affected this rapid decrease. So, we assume that the average lesion numbers converged and the disease was sufficiently controlled by the 16-s-spraying for the non-EPS cases. We carried out the Welch’s tests for the sample of 16-s-spraying for the non-EPS case and those of 4- and 8-s-spraying for the EPS cases. The alternate hypothesis was that “the number of lesions was decreased or increased by adopting EPS” and the two-tailed tests were adopted. The results (table 4) show that there are not significant differences between the non-EPS-16-s-spraying case and the both of EPS-4-s- and 8-s-spraying cases. These results mean that the amounts of pesticides to be sprayed can potentially be reduced by 50 % ~ 75 % by adopting EPS because the amounts of sprayed pesticides are proportional to the spraying time.

Figure 5. Average numbers of rust lesions for various spraying time (17 days after spraying).
Table 4. EPS can reduce the amounts of pesticide to be sprayed.

|                | (a) Reduced by 50% | (b) Reduced by 75% |
|----------------|--------------------|--------------------|
|                | 0 kV, 16 s         | -40 kV, 8 s        | 0 kV, 16 s         | -40 kV, 4 s        |
| Average lesion number | 3.286              | 3.204              | 3.286              | 3.496              |
| Dispersion     | 7.826              | 11.23              | 7.826              | 11.68              |
| \( t \)        | 0.2570             | -0.6952            |                    |                    |
| \( P(T \leq t) \) | 0.7973 > \( \alpha \) | 0.4873 > \( \alpha \) |                    |                    |
| \( t_{boundary} \) | 1.967 > |\( t \)| | 1.966 > |\( t \)| | |

4.2. Estimation of pesticide reduction adopting EPS

Assuming that the adopting EPS can reduce 50% of pesticides to be sprayed, the reduction of the pesticide cost in the pear cultivation in Tottori prefecture is estimated as follows.

The area for the pear cultivation in Field Science Center (FSC), a Tottori university’s experiment farm, is 960 m². The total amounts and costs of all pesticides to be sprayed without adopting EPS in this area are 8,600 L year⁻¹ and 37,600 yen year⁻¹ (470 USD year⁻¹), respectively. The area for the pear cultivation, including for young trees, in Tottori prefecture is 1,230 ha [8]. Assuming that the planting density of the pear trees in all the pear farms in Tottori prefecture is the same as that in FSC and required amounts of pesticides are proportional to the planting area, the estimated total amounts and costs of all pesticides to be sprayed for the pear cultivation in Tottori without adopting EPS are (8,600[L y⁻¹] • 1,230[ha] • 10,000[m² ha⁻¹]) • (960[m²])⁻¹ = 110,000 kL y⁻¹ and 480 million yen y⁻¹ (6 million USD y⁻¹), respectively. By adopting EPS, it is estimated that 55,000 kL y⁻¹ (240 million yen y⁻¹ or 3 million USD y⁻¹) of the pesticides can be reduced in the pear cultivation in the entire Tottori prefecture.

5. Conclusions

The spraying experiments described in this paper were carried out when calm. Because of this, the pesticide reduction discussed above can be applied for the real pear cultivation if the pesticides are sprayed only when calm or in greenhouses. However, the result that the amounts of pesticides to be sprayed can potentially be reduced by about 50% means that excess pesticides are sprayed. Considering this result, EPS is effective not only for the cost saving but also for the environmental protection and food safety.

References

[1] Yamane S, Miyazaki M and Ohmura K 2010 J. Jpn. Soc. Agric. Mach. 316 54
[2] Yamane S, Miyazaki M, Saito H, Ohmura K, Aono M and Ohsuka R 2010 J. Jpn. Soc. Agric. Mach. 321 570
[3] Sakagami Y and Kudo A 2003 A Handb. of Dis. and Insect Pests of Fruit Trees Vol. 2 Pears, Grape, Persimmon, Chestnut and Fig (Revised Edition) (Tokyo: Japan Plant Protection Association) (in Japanese)
[4] Michihara S, Nishimura R, Ishihara N, Masuoka T, Kimura T, Yatsuzuka S and Anaguchi S Proc.2010 Spring-time Meeting of Inst. Electrostat. Japan (Tokyo: IESJ) p 35 (in Japanese)
[5] Katatani N and Matsutou T 2003 Kankyo Toukeigaku Nyuuron (Tokyo: Ohm-sya) (in Japanese)
[6] http://www.aoni.waseda.jp/abek/document/t-test.html
[7] http://www1.tcue.ac.jp/home1/abek/htdocs/stat/Excel/t-test/t-test.html
[8] Ministry of Agriculture, Forestry and Fisheries of Japan 2008FY 57th Annu. Rep. of Stat. on Agric., For. and Fish.