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Jin, Na Young
Department of Applied Biology, College of Agriculture and Life Sciences, Chungnam National University | Laboratory of Insect Pathology and Microbial Control, Institute of Biological Control, Faculty of Agriculture

Lee, You Kyoung
Department of Applied Biology, College of Agriculture and Life Sciences, Chungnam National University | Laboratory of Insect Pathology and Microbial Control, Institute of Biological Control, Faculty of Agriculture

Kim, Yu Seop
Department of Applied Biology, College of Agriculture and Life Sciences, Chungnam National University | Laboratory of Insect Pathology and Microbial Control, Institute of Biological Control, Faculty of Agriculture

Kim, Hee Ji
Department of Applied Biology, College of Agriculture and Life Sciences, Chungnam National University | Laboratory of Insect Pathology and Microbial Control, Institute of Biological Control, Faculty of Agriculture

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The Optimal Dose and Spraying Method of Chemical Pesticides for Pest Control Effects in Apple Orchards

Na Young JIN[1], You Kyoung LEE[1], Yu Seop KIM[1], Hee Ji KIM[1], Young A HUR[1], Young Shin KIM[2], Chi Hwan LIM[2], Young Nam YOUN[1], Chisa YASUNAGA–AOKI* and Yong Man YU[1]*

Laboratory of Insect Pathology and Microbial Control, Institute of Biological Control, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
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In this study, three apple orchards in Chungnam were selected to review pesticide sprayings conditions, pesticide deposit amounts, and pest control effects while spraying different spray water volumes by the customary methods. In the first orchard, the spray water volume of acetamiprid 8% WP targeting moths used in 2014 was 372 L/10 a and the one used in 2015 was 302 L/10 a, i.e. by about 70 L smaller as compared to the previous year; however, no difference in the control value was observed. Meanwhile, for control of *A. citricola*, acetamiprid 2.5% wettable powder was used; the spray water volume used in 2014 was 453 L/10 a and the one used in 2015 was 378 L/10 a, i.e. by about 70 L smaller as compared to the previous year. The well–sprayed sections showed pest control effects not lower than 95%, while the poorly sprayed sections showed pest control effects of about 78%. In the second and third orchards, the control target pest was *G. molesta* and the spraying pesticide used was acetamiprid 8% WP. The spray water volumes used in the second and third orchards were about 349 L and 378 L, respectively, and there was no problem in the control values. For control of *A. citricola*, imidacloprid 10% wettable powder and flonicamid 10% water–dispersible granules were used as spraying pesticides. The spray water volumes of these two pesticides were 355 L and 380 L per 10 a, respectively, i.e. smaller than the reference volumes; however, no problem in the overall pest control was observed. Therefore, our results suggest that pesticide deposit amounts on water–sensitive papers are proportional to increases in the dose; however, the dose exceeding the appropriate concentration is not related to the deposit amounts.

Key words: Amount of active ingredient, Apple orchards, Pesticide reduction, Spray water volume, Water–sensitive paper

INTRODUCTION

In apple orchards in South Korea, due to the shortage of labor following the aging of domestic agricultural population, the closing of orchards, rather than planting of new young trees, has increased and the cultivation area of apples amounted to 30,449 ha as of 2013 (Statistics Korea, 2013). In the process of cultivation of apples, the most serious problem in apple orchards is the occurrence of diverse diseases and insect pests, as well as the difficulties in controlling these diseases and insect pests. In addition, the insect pests' resistance to pesticides has been developing. Park *et al.* (1977) and Choi *et al.* (2004) reported *Phyllonorycter ringoniella*, peach leaf–miners, and *Lyonetia prunifoliella* (Hübner), which are leaf–miners, as three species of problematic pests in apple orchards; in particular, the occurrence of *Phyllonorycter ringoniella* was reported to be the most frequent. In addition, since, due to the effect of global warming, apple cultivation regions have been gradually moving northwards, diverse tiny insects, such as *Aphis citricola* and red spider mites, have been occurring.

To control these pests, pesticides such as synthetic pyrethroids, organophosphosphates, and carbamates have been continuously used (Lee *et al.*, 2010). Due to such continuous pesticide sprays, resistance to successively applied pesticides has rapidly developed; in order to solve this problem, farmers have started to continuously increase the concentration of used pesticides or to increase the number of treatments (Jin *et al.*, 2014; Seo *et al.*, 2015).

Optimal pesticide control effects vary greatly according to accurate diagnoses of diseases and insect pests, selection of pesticides, spraying tools, spraying method, and cropping systems. Among these factors, the characteristics of pesticide deposits to target points show clear differences according to users' skill levels and, although the efficacy of pesticides is proportional to deposited doses, deposit amount increases beyond the appropriate concentration are not reported to influence the efficacy of pesticides (Jeong *et al.*, 2004). Therefore, disease and insect pest control effects cannot be expected from increases in the concentration of pesticides used or spray water volumes.

According to the results reported by Kwon *et al.* (2001), each fruit farm was spraying pesticides 11 to 15.8 times per year and, in the case of apples, the number of times of spraying germicide showed a tendency to decrease with the passage of time. The authors reported that, among agricultural chemicals for different purposes, germicides were used the most frequently, followed by pesticides and herbicides in order of prece-

[1] Department of Applied Biology, College of Agriculture and Life Sciences, Chungnam National University, Daejon 305–764, Korea

[2] Department of Bio Environmental Chemistry, College of Agricultural Biology and Life Sciences, Chungnam National University, Daejeon, 305–764, Korea

* Joint corresponding authors (E–mail: ymyu@cnu.ac.kr and yasunaga@grt.kyushu–u.ac.jp)

dence. Kwon *et al*. (2001) also reported that the amount of pesticides used for apple per the unit area in South Korea was 27.1 kg a.i./ha, which was larger than the corresponding amount used in the US. In their analysis of actual states of the use of pesticides in apple orchards in the Geochang region, Jang *et al*. (2015) reported that germicides, pesticides, and acaricides were annually sprayed 13.9 ± 3.5 times, 12.6 ± 3.2 times, and 2.6 ± 1.3 times, respectively. However, thus far, relevant studies of pesticides investigated only control effects or the number of times of sprays and none of previous studies focused on the pesticide spray methods that would exert optimal effects on diseases/pests. In particular, no such data have been standardized for education of farmers. Although standards for safe use of pesticides (0 times from 00 days before harvest) have been set, no standard has been set for spray water volumes and even the spray method in the crop protection guidelines just reads, "spray evenly so that the pesticide can be sufficiently deposited on the leaves of the crop". Although the pesticide testing staff education booklet (Rural Development Administration, 2011) indicates spray water volumes by kind of crops, no appropriate spray water volume that would show the optimal pest control effects has been defined. However, the pesticide spray dose per unit area sprayed to crops in South Korea amounting to 11.6 kg a.i./ha is much larger than the one in other countries in the world, such as the US (2.2 kg a.i./ha), Germany (2.3 kg a.i./ha), and Italy (5.6 kg a.i./ha). However, Asian countries where agricultural cropping systems and climates are quite similar to those of South Korea show similar values to the value in Korea, such as Japan with the value of 13.1 kg a.i./ha and China with the value of 10.3 kg a.i./ha; however, there is a global trend to reduce pesticide doses to pursue environmentally–friendly fruit–growing (FAO, 2013).

Therefore, in the present study, to relieve farmers' anxiety factors resulting from the reduction in pesticides through the optimal use of pesticides necessary for pest control, the following related factors were comprehensively reviewed: (1) minimization of blind areas using water–sensitive paper; (2) pesticide spray conditions according to the types of sprayers; (3) identification of blind areas made by the habits of pesticide spraying persons; (4) pest control effects by carry–over effects of pesticides; (5) the production of incongruent agricultural products due to pesticide residues, and (6) pest control effects.

MATERIALS AND METHODS

Test materials

Four chemicals; Acetamiprid wettable powder (Acetamiprid 8% WP, brand name: Mothpiran), one of the chemicals registered as control chemicals for moths (*Grapholita molesta*, *Phyllonorycter ringoniella*) and three *Aphis citricola* control chemicals; Acetamiprid wettable powder (Acetamiprid 2.5% + Etofenprox 8% WP, brand name: Manjangilchi), Imidacloprid wettable powder (Imidacloprid 10% WP, brand name: Konido), and Flonicamid water–dispersible granules (Flonicamid 10% WG, brand name: Setis) diluted to safely usable multiples were used. Using an SS sprayer (HANSUNG T&I Co., Ltd.) installed with a 500 L tank as a sprayer, apple cultivating farmers firsthand sprayed the chemicals.

For the investigation of pesticides spray patterns and SS sprayer spray conditions of apple farms, the cultivating farmers firsthand sprayed the chemicals using an SS sprayer installed with a 500 L tank and the differences according to spray conditions, such as sprayed chemicals, spray water volume, spraying time, jet velocity, and pressure and apple cultivation periods were investigated.

Test place

An apple experimental field was a about 6,600 m^2 wide slope land located in Sinpung–myeon, Gongju–si, Chungcheongnam–do (hereinafter field–1) with 120 trees of 18–year–old Fuji cultivar and 90 trees of 7–year–old Fuji cultivar per 10 a. Another experimental field was a about 4,300 m^2 wide flatland located in Yeon–ri, Yesan–si, Chungcheongnam–do (hereinafter field–2) with 140 trees of 3–year–old Hongno and Fuji cultivars had been planted; the third experimental field was a about 6,600 m^2 wide flatland located in Daedeok–ri, Yesan–si, Chungcheongnam–do (hereinafter field–3) with 150 trees of 7–year–old Fuji cultivar. Field–1 is currently under the second year test. In the first year, the possibility of pesticide reduction was checked with adjusted spray water volumes. Thereafter, two fields were added for field application tests and the apple farms of fields–1, 2, and 3 treated their apple trees with the low water volumes per unit area using SS sprayers. The test period lasted from April 2014 to September 2015 and the tests were conducted in the farms' customary method.

Pest occurrence forecasting

In the field test, pheromone delta traps of six species of fruit trees, which are materials for insect pest control of Green Agrotech Company Limited, were installed at the end of March (Fig. 1A). Moth pests in the apple orchards were periodically monitored to forecast the time of occurrence of pests and captured *G. molesta* and *P. ringoniella* were identified from early April (Fig. 2C, 2D).

To improve the capture efficiency, the flypapers of the pheromone traps were replaced at 2–week intervals and the lures were replaced at 1–month intervals. The occurrence of tiny pests, such as Aphids, was identified through visual investigations; chemical spray tests were conducted from end of May, since *A. citricola* occurred in the number that satisfied the standard for pesticide tests (Fig. 2).

Water–sensitive paper and pesticide deposit amount patch analyses according to spray water volumes

To check whether sprayed pesticides evenly reached the targeted regions, water–sensitive papers (52 × 76 mm, TeeJet Tech. Swizerland) and patches were used (Fig. 1C, 1D). The water–sensitive papers were used to

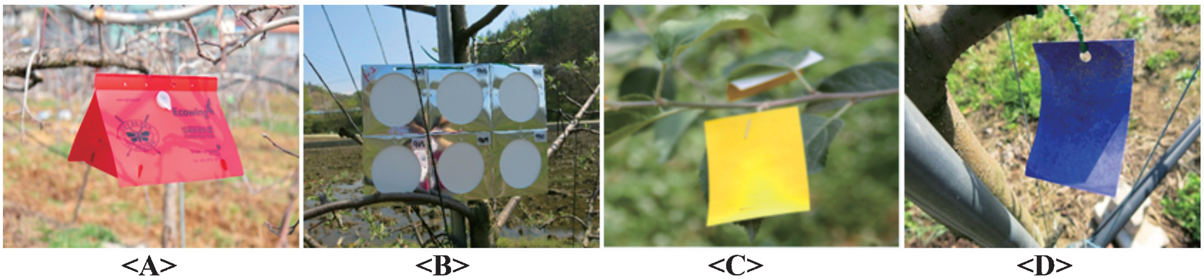

Fig. 1. Pheromone trap (A), α–cellulose paper patch (B), water–sensitive paper (C, D).

Fig. 2. Occurrence pest, *Panonychus ulmi* (A), *Aphis citricola* (van der Goot) (B), *Grapholita molesta* (C), *Phyllonorycter ringoniella* (D).

examine whether the sprayed pesticides were evenly deposited on the upper and lower leaves, front and back sides of the leaves of the crops, and the out–of–the–way areas in the farms in the method studied in advance (Chung *et al.*, 1997; Koo, 2007; Jin *et al.*, 2014). To evaluate the amounts of active ingredients of pesticides sprayed to the crops deposited per the unit area, patches were made by making pockets with aluminum foil and fixing α–cellulose paper (Whatman 17CHR, 46 × 57 cm, Cat. No.3017–915) for the skin exposure measurement cut to pieces in a 10 cm wide and 10 cm long size in the pockets (Kim *et al.*, 2011). Each patch was made to have a 50 cm^2 wide exposed area in its front and six patches connected together were installed on each apple tree (Fig. 1B). After the pesticides were sprayed, the patches were collected and preserved at –20°C with the minimized exposure to sunlight until the amounts of active ingredients were analyzed. The amounts of active ingredients were analyzed using HPLC Hewlet Packard 1090 (USA) and LC/MS Shimadzu 2020 (Japan) after removing the aluminum foil pockets and measuring the weights of the patches by the Department of Bio Environmental Chemistry of Chungnam National University (Kim *et al.*, 2015).

Control effects according to spray water volumes

For biological assay of moths, flypapers of the pheromone traps were collected to check whether the density of moths changed between before and after pesticide spraying. Insecticidal effects were checked by the comparison and review of the amounts of active ingredients per unit area and the trap densities of the pheromone traps through patch analyses. In the case of *A. citricola*, the correlations between the calculated control values on the 1st and 3rd days after chemical spraying and the results obtained by the degree of coating on water sensitive papers and patch analyses were checked.

RESULTS AND DISCUSSION

Recently, with the diversification and increase of the export and import of agricultural products following the FTA, etc., the importance of safe use of pesticides on agricultural products for export has become more pronounced. In South Korea, relevant guidelines for safe use of pesticides on agricultural products that comply with international standards have been continuously prepared and observed. However, evidentiary materials for the total amounts of pesticides used per unit area recently required in Europe, etc. are necessary. Therefore, in order to prepare accurate evidence of the total amounts of pesticides used per unit area in South Korea, relevant studies that would optimize the use of pesticides for pest control become necessary. However, the largest source of anxiety of field farmers has been the reduction of the used amounts of pesticides necessary for optimization, because, as assumed by farmers, this could reduce biologically active effects and spraying pesticides until the pesticides flow in drops from leaves has been a common practice. In this context, elaborating relevant methods for pest control using appropriate amounts of pesticides while minimizing such anxiety has become necessary. The factors that affect the control of those diseases and insect pests that occur in apple orchards include apple cultivating methods, tree ages, the kinds of diseases and insect pests occurring, selection of pesticides, the kind and specification of the sprayer used for spraying, spraying methods, and spraying person's habits.

Therefore, a review of relevant factors that affect the reduction of pesticide spray water volumes per unit area in farmlands where crops are cultivated is necessary. However, most previous studies for disease and insect pest control in South Korea examined only the efficacy of pesticides for registration and use of pesticides. Notwithstanding, spraying pesticides so that no blind area occurs has been found to be an important factor for methods of reducing the amounts of pesticides used in apple orchards while enabling the optimal pest control (Jin *et al.*, 2014).

Spray patterns of SS sprayers used in apple orchard

The spray water volumes by kind of crops generally presented as references for pesticide registration tests for safe use of pesticides are 1,600 L/ha for rice, 3,000 L/ha for grapes, and 4,500 L/ha (Table 1). Lee *et al.* (2007) reported that about 60% of apple farms were spraying 300–400 L of pesticides per 10a using SS sprayers and that the average spray water volume per unit area was about 360 L/10 a. Therefore, to obtain accurate test results, we selected an apple farm made using a slope land on a hill, an apple farm with young trees on a general flatland, and an apple farm with moderately old trees on a flatland as experimental fields to investigate spray patterns (Fig. 3). The conditions that affect the control of pests occurring in apple orchards include the kinds of pesticides, spray patterns made by the character of the spraying person, kinds of sprayers and nozzles, and cropping patterns; these conditions lead to clear differences. First, the spray patterns of the spraying persons that use a SS sprayer are the pesticide spraying methods of the farmers of the three fields (Fig. 3).

The three farmers' spraying methods did not show any particular difference and the farmers sprayed the pesticides according to their cropping systems or terrains. According to the results of the preliminary tests of blind areas conducted to identify potential differences among the spraying methods, the cases where the farm-

Table 1. Spray water volumes per ha for various crops in the 2011 pesticide test personnel training booklet

Crops	Spray water volume
Rice plant	**1,600 L**
Apple, Pear, Citrus, Peach, Persimmon	4,500 L
Grape	3,000 L
Mulberry tree	2,000 L
Cucumber, Watermelon	1,800 L
Bean, Pepper, Tobacco, Peanut, Garlic, Chives, Onion, White radish, tomato, Potato, Herb, Corn, Sesame	1,500 L
Strawberry	1,200 L
Other crops	Follow the farm practices

(2011 Pesticide Test Personnel Training Booklet, p. 177)

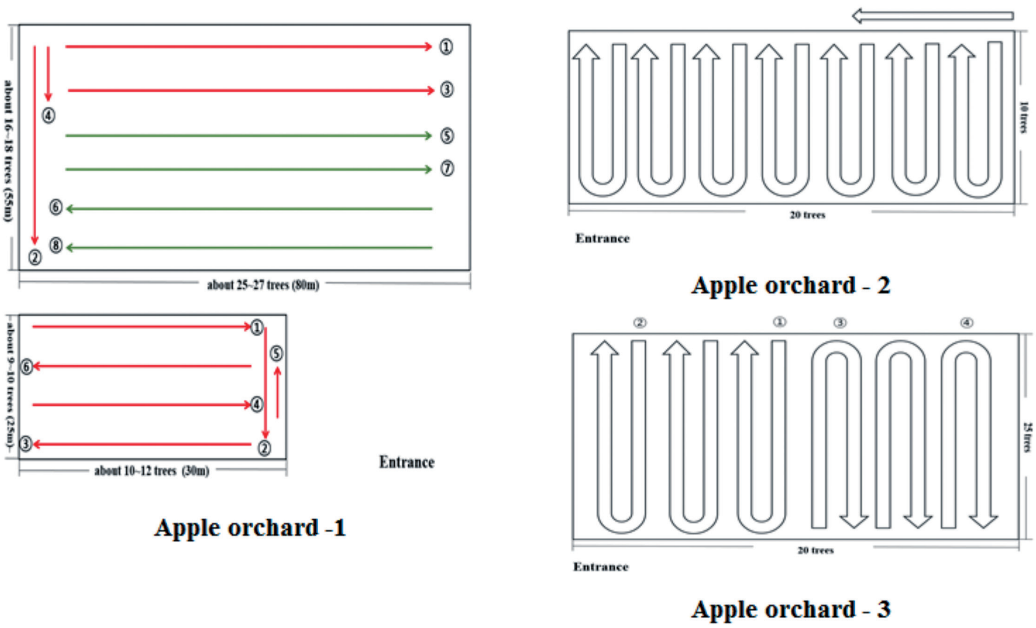

Fig. 3. Apple orchard shape and pesticide application patterns.

ers stopped pesticide spraying for a while when they were going around the corners frequently occurred. In the case of field–1, since the apple orchard was made on a slope land and steep slopes caused difficulties in the travel of an SS sprayer, pesticides were not accurately sprayed. However, in the case of fields–2 and 3, no problem occurred in the travel of SS sprayers, as these fields were farmlands on flatlands. The results of the evaluation of the effects of the kinds, speed, pressure, and nozzles of sprayers on pesticide spraying suggest that the users tended to use SS sprayers bought relying on users' experience, without changing the specifications of SS sprayers as presented according to situations. Therefore, these results suggest that the SS sprayers used in most apple farms in South Korea are used under the same conditions, including speed, pressure, and kind of nozzles for all diseases and insect pests. Considering that pesticides cannot be sprayed according to the biological characteristics of diseases and insect pests, so that the target pests survive instead of dying as a result of exposure to appropriate effective doses leading to the development of resistance, such methods of use may be a major cause of decreases in control values. Furthermore, it was shown that cropping patterns with large effects on disease and insect pest control were not considered yet. In particular, in the case of domestic methods of using pesticides, only the effects of pesticides that effect target disease and insect pest control values have been intensively reviewed. Consequently, relevant review data on the kinds of crops, cultivation methods, as well as the kinds, nozzles, pressure, or speed of sprayers, and spraying persons' spraying methods that affect control are scarce.

SS sprayer conditions and moth control effects in customary spraying

For optimal pesticide spraying methods for pest control, throughout the study conducted in field–1 during the first year (2014), pest control was performed customarily under natural conditions in the field. During the period of the study conducted for pest control, control effects on *G. molesta* and *P. ringoniella* occurring from April through June were reviewed. To forecast the occurrence of pests in the apple orchard, traps were installed and periodically investigated. To control *G. molesta* and *P. ringoniella*, chemicals were sprayed in the methods described in Table 2; biological assays were conducted observing the pesticide test methods of the Rural Development Administration.

In apple field–1, to examine the control effects in the field, the farmer's customary spray method, including the conditions such as the spraying time, spray velocity, and spraying pressure of the SS sprayer and spray water volumes, was closely investigated (Table 2). The initial pesticide spraying in the apple orchard was conducted before apple tree leaves germinated under the following conditions: a spraying time of 18 min/10 a, spray speed at levels 2–3 levels, 2000 rpm, and 20 bar. The control target pests were *G. molesta* and *P. ringoniella* and the treating chemical was acetamiprid 8% wettable powder.

As a general notion thus far, the effects of pesticides have been thought to be the most important factor for pest control. However, as pesticides and sprayers that can act as control factors have been used as the same condition, the cases where different control effects would appear depending on spraying persons have not been studied. Therefore, we judged that spraying persons' inappropriate habits during pesticide spraying could lead to pesticide blind areas. Water–sensitive papers that enable for identifying the formation of such blind areas were attached to apple trees unnoticeable to spraying persons and then checked. Whether appropriate amounts of effective pesticides were deposited was judged based on the degree of coating on the water–sensitive papers attached to here and there of apple orchards. Those pests that live in blind areas where control effects cannot appear due to the small amounts of pesticides deposited on water–sensitive papers would develop into resistant pests. Water sensitive papers not completely coated were identified in five out of 10 experimental areas in the apple experimental field where blind areas were forecasted. These areas were corners or slopes that were shown to be poorly sprayed sections due to the spraying persons' spraying habits. When evaluated based on the results of deposits on water–sensitive papers, blind areas always appeared in the corners where the spraying persons that operate the sprayer turned and areas where there were slopes. Since the information on this phenomenon was not provided to the spraying persons, almost

Table 2. Moths (*G. molesta*, *P. ringoniella*) and Aphids (*A. citricola*) control effect of the customary spray water volume (2014) of pesticides in the apple orchard–1

Tree condition	No leaf, fruit	Leaf, fruit small
Target pest control	*G. molesta, P. ringoniella*	*A. citricola*
Pesticide	Acetamiprid 8% WP	Acetamiprid 2.5% WP
Date	April 15, 2014	June 16, 2014
Spraying speed (level) and Pressure (rpm)	Low speed level 2–3, 2,000 rpm, 20 bar	Low speed level 2–3, 2,500 rpm, 20 bar
Actual spray water volume (L/10 a)	372	453
Standard spray volume (kg a.i. in 450 L/10 a)	0.018	0.011
Actual amount of active ingredient (kg a.i./10 a)	0.015	0.011
Actual spraying time (min/10a)	18	25

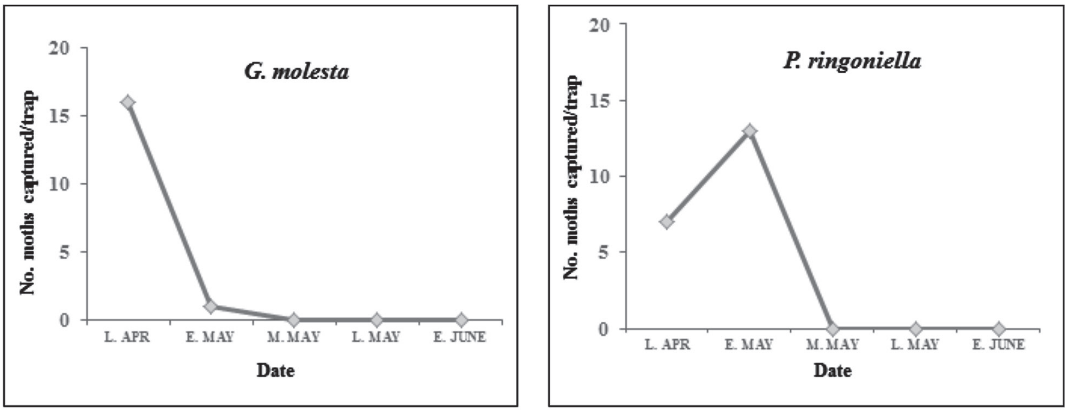

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Fig. 4. *G. molesta* and *P. ringoniella* control effect of customary spray water volume (2014) of acetamiprid 8% WP of the pesticide in the apple orchard–1. <A>: Control effect of *G. molesta* from the end of April until early June; <B>: Control effect of *P. ringoniella* from the end of April until early June.

the same blind areas appeared even when the chemicals were sprayed two or three times.

To accurately understand and analyze field situations, in the present tests of chemicals' control effects, the control effects were reviewed relying on farmers' general customary methods. In the present tests, poorly sprayed sections based on water–sensitive papers continuously appeared and chemicals for moth control were sprayed two more times at 10–day intervals. The present tests were conducted based on the assumption that the pests surviving in blind areas where the exposure to pesticides could be avoided would develop into resistant pests as potential pests; the results could not be derived due to the characteristics of the outdoor experimental fields and the physiological and ecological characteristics of the pests occurred. In other words, although the pests with low mobility, such as aphids, may involve a high possibility of the development of resistance in blind areas, the pests with high mobility could not be evaluated. Since each blind area was normally several branches or one apple tree, the pests that were hiding there moved to other places after chemical spraying, causing difficulties in measurement. The apple orchard spraying persons in the field sprayed chemicals three times between the end of April and early June to control the pests *G. molesta* and *P. ringoniella* occurring in the test period and 100% control effects were shown (Fig. 4).

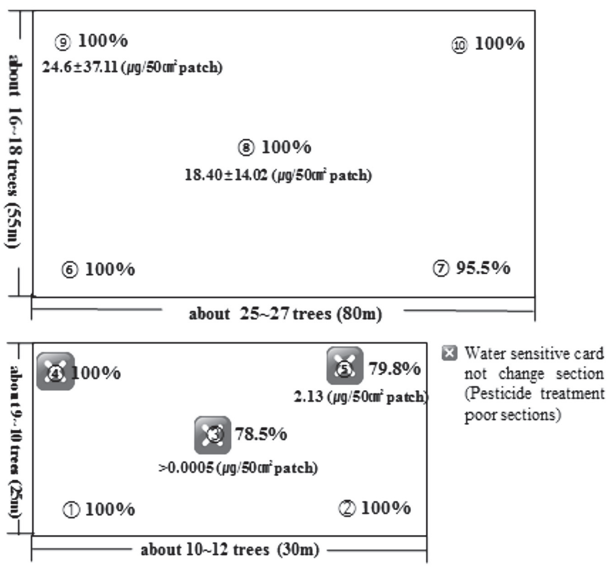

Fig. 5. Water–sensitive card discoloration results, amount of acetamiprid (μg/50 cm^2 patch) and *A. citricola* control effect of customary spray water volume (2014) of acetamiprid 2.5% WP of the pesticide in the apple orchard–1.

SS sprayer conditions and aphids control effects in customary spraying

The cases where pests that cannot move quickly when the pesticides are sprayed in outdoor fields such as aphids are not exposed to pesticides in blind areas were tested. These are the results of a customary chemical spraying experiment for *A. citricola* in the first year (2014) conducted in apple field–1 in Gongju. This test was conducted in June, i.e. when the leaves and fruits existed on the apple trees. The sprayed pesticide was acetamiprid 2.5% wettable powder and the SS sprayer conditions were low speed level 2–3, 2,500 rpm, and 20 bar. The spray water volume was 453 L per 10 a, which was sufficient. In order to identify whether blind areas would be formed while the pesticide was sprayed, water–sensitive papers were installed in 10 areas and three of those 10 areas were shown to be poorly sprayed areas. As for the pest control effects, seven areas showed death rates not lower than 95%, while the poorly sprayed areas, which were blind areas, showed control effects of about 79% (Fig. 5, Plots 3–5). Therefore, in the case of tiny insects with low mobility, such as aphids, control effects should decrease when blind areas have been formed and the pests minimally exposed to pesticides as a result will appear as a cause of resistance development.

Meanwhile, in order to measure the effective residual concentration of sprayed pesticides that can kill pests, the tests were performed after attaching patches.

Pesticides were prepared observing the criteria for safe use and sprayed using an SS sprayer after attaching the patches at locations similar to those of water–sensitive papers. Thereafter, the patches were removed and the residual pesticides were examined. According to the results of residual pesticide analyses, the mean residual amount of pesticides was about 21.3 μg/50 cm^2 patch in the sections where deposits of pesticide sprayed were good and 1.06 μg/50 cm^2 patch in the sections where deposits of pesticide sprayed were poor.

SS sprayer conditions and moth control effects with reduced spray water volumes

Tests of customary use of pesticides on pests with high mobility in the cases where blind areas were formed during pesticides spraying in outdoor experimental fields were performed in the first year (2014) in field–1. Although blind areas were formed in corners and slopes during pesticide spraying, the test results could not be expected due to the characteristics of the pests with high mobility. However, all the moths in the apple orchards were considered to have been controlled by the two times of customary sprays by the farmer. Therefore, in the second year (2015), field verification tests were performed in fields–1, 2, and 3 with the reduced amounts of pesticides; attention was paid to prevent the formation of blind areas.

In field–1, *G. molesta* and *P. ringoniellapests* occurred from about end of April to early June as with the first year (2014). Therefore, chemicals were sprayed and the results were examined. The SS sprayer conditions were set to low speed at level 2, 1,800 rpm, and 20 bar and the spray water volume was reduced by 70 L to 302 L. The amount of active ingredients of Acetamiprid 8% wettable powder per unit area was 0.018 kg a.i./10 a based on the standard spray volume of 450 L per 10 a. In 2015, the amount sprayed was reduced to 0.015 kg a.i./10 a. As a result, water–sensitive papers were not coated in three out of 10 experimental areas and, of these three areas, two areas were found to be corner areas. When compared to the first year (2014), the number of poorly sprayed sections was reduced by 2 (data not shown). Although the spray water volume was reduced by about 70 L/10 a as compared to the previous year, pest control was not much different and the number of poorly sprayed sections decreased (Fig. 6).

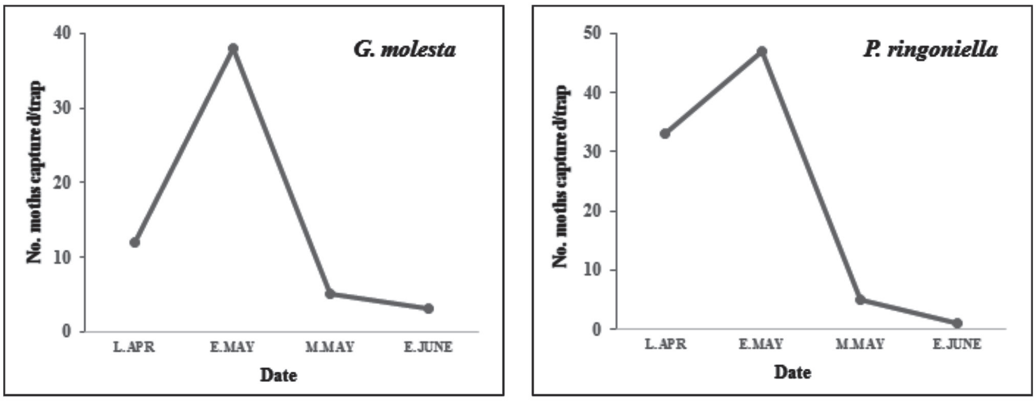

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Fig. 6. *G. molesta* and *P. ringoniella* control effect of low spray water volume (2015) of acetamiprid 8% of the pesticide in the apple orchard–1. <A>: Control effect of *G. molesta* from late April to early June; <B>: Control effect of *P. ringoniella* from late April to early June.

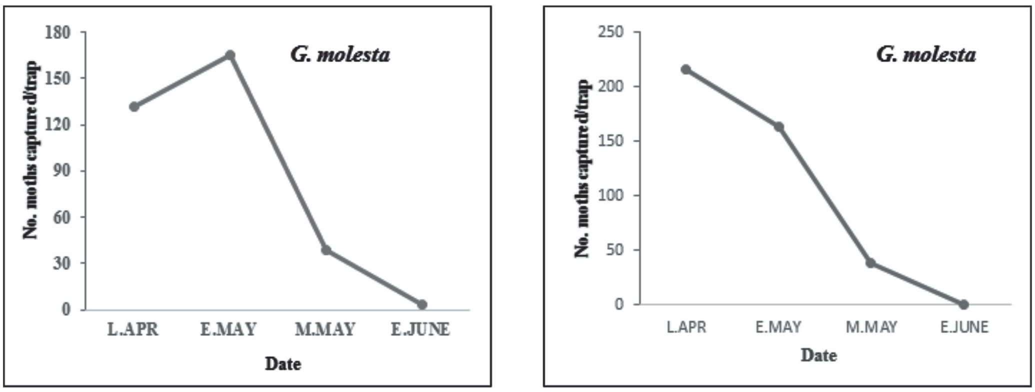

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Fig. 7. Control effect of *G. molesta* from late April to early June of low spray water volume (2014) of acetamiprid 8% WP of the pesticide in the apple orchards–2, 3. <A>: Apple orchard–2; <B>: Apple orchard–3.

In field–2, the date of the experiment was around April and the trees had no leaves or fruits. The control target pest was *G. molesta* and the sprayed pesticide was acetamiprid 8% wettable powder. The conditions of the SS sprayer were low speed level 2, 2,500 rpm, and 25 bar. The spray water volume was 349 L, i.e. about 100 L smaller than the standard amount. The amount of active ingredients of Acetamiprid 8% wettable powder per unit area was 0.018 kg a.i./10 a based on the standard spray volume of 450 L per 10 a; however, the sprayed amount was 0.014 kg a.i./10 a, which was smaller. As a result, water–sensitive papers were found to have not been coated at all in two out of nine experimental areas and it could be seen that poorly sprayed sections were formed in the corner areas in the field due to the spraying person's spraying habit. However, the *G. molesta* control effect was shown to be at least 95% (Fig. 7A). In field–3, the date of experiment was also around April and the trees had no leaves or fruits. The control target pest was *G. molesta* and the sprayed pesticide was acetamiprid 8% wettable powder. The conditions of SS sprayer were low speed level 2, 2,000 rpm, and 20 bar. The spray water volume was 378 L, i.e. about 70 L smaller than the standard amount. The amount of active ingredients of Acetamiprid 8% wettable powder per unit area was 0.018 kg a.i./10 a based on the standard spray volume of 450 L per 10 a; however, the sprayed amount was 0.015 kg a.i./10 a, which was smaller. As a result, water–sensitive papers were found to have not been coated completely in one out of nine experimental areas; nonetheless, the spraying person in this field showed a general habit of even spraying. The G. molesta control effect was shown to be at least 95% (Fig. 7B).

SS sprayer conditions and aphids control effects with reduced spray water volumes

The tests of *A. citricola* with the reduced amounts of sprayed pesticides were conducted in field–1. As shown in Table 3, the date of experiment was around June and the trees had both leaves and fruits. The control target pest was *A. citricola* and the sprayed pesticide was acetamiprid 2.5% wettable powder. The SS sprayer conditions were low speed level 2, 2,000 rpm, and 20 bar (Table 3). The spray water volume was 378 L, i.e. about 70 L smaller than in the first year (2014). Although the spray water volume was larger than the one used in the experiment conducted around April when the trees had no leaves or fruits, it was smaller than the standard volume, i.e. 450 L per 10 a.

As a result, water–sensitive papers in two out of 10 areas were not coated and one of the two areas was found to be a corner region (Fig. 8, Plots 3, 6). The areas where the sprays were good showed pest control effects not lower than 96%, while the areas where the sprays were poor showed pest control effects of about 54% (Fig. 8). The mean amount of pesticides attached to the patches was about 24.82 $\mu g/50\,cm^2$ patch in the areas with good spray and 5.5 $\mu g/50\,cm^2$ patch in the areas with poor sprays. It could be seen that, although a spray water volume smaller than that in the first year (2014) was

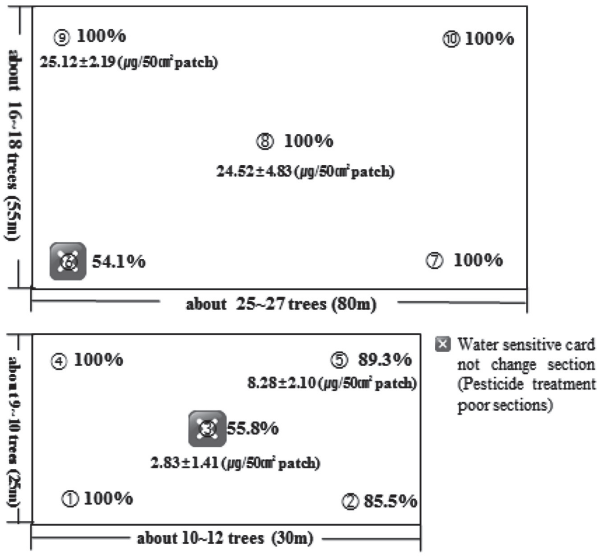

Fig. 8. Water-sensitive card discoloration results, amount of acetamiprid ($\mu g/50\,cm^2$ patch) and *A. citricola* control effect of low spray water volume (2015) of acetamiprid 2.5% WP of the pesticide in the apple orchard–1.

Table 3. Aphids (*A. citricola*) control effect of the low spray water volume (2015) of pesticides in three apple orchards

Apple orchard	Apple orchard–1	Apple orchard–2	Apple orchard–3
Tree condition		leaf, fruit smal	
Target pest control		*A. citricola*	
Pesticide	Acetamiprid 2.5% WP	Imidacloprid 10% WP	Flonicamid 10% WG
Date	June 1, 2015	May 29, 2015	June 9, 2015
Spraying speed (level) and pressure (rpm)	Low speed level 2 2,000 rpm 20 bar	Low speed level 2 2,500 rpm 25 bar	Low speed level 2 2,000 rpm 20 bar
Actual spray water volume (L /10 a)	378	355	380
Standard spray volume (kg a.i. in 450 L /10 a)	0.011	0.02	0.02
Actual amount of active ingredient (kg a.i./10 a)	0.009	0.016	0.017
Actual spraying time (min/10 a)	20	14	15

sprayed; the amount of deposited pesticides was larger. Based on the results of spraying a chemical spray water volume smaller than the standard volume in this year following the last year in field–1, it could be expected that, if the poorly sprayed sections due to the spraying person's spraying habit would be identified to improve spraying, there should be no problem in pest control effects.

The date of experiment in field–2 was around end of May and the trees had both leaves and fruits. The control target pest was *A. citricola* and the sprayed pesticide was imidacloprid 10% wettable powder. The SS sprayer conditions were low speed level 2, 2,500 rpm, and 25 bar. The spray water volume was 355 L, i.e. about 100 L smaller than the standard volume. The amount of active ingredients of imidacloprid 10% wettable powder per unit area was 0.02 kg a.i./10 a based on the standard spray volume of 450 L per 10 a; however, the sprayed amount was 0.016 kg a.i./10 a, which was smaller (Table 3). As a result, water–sensitive papers were found to have not been coated completely in two out of nine experimental areas (Fig. 9, Plots 3, 7). Well–sprayed sections showed pest control effects of 100%, while poorly sprayed sections showed pest control effects of about 88.3% (Fig. 9). The average amount of pesticides deposited in the entire experimental sections was 20.47 μg/50 cm^2 patch and it could be observed that the pesticide was sprayed relatively evenly.

The date of experiment in field–3 was around June

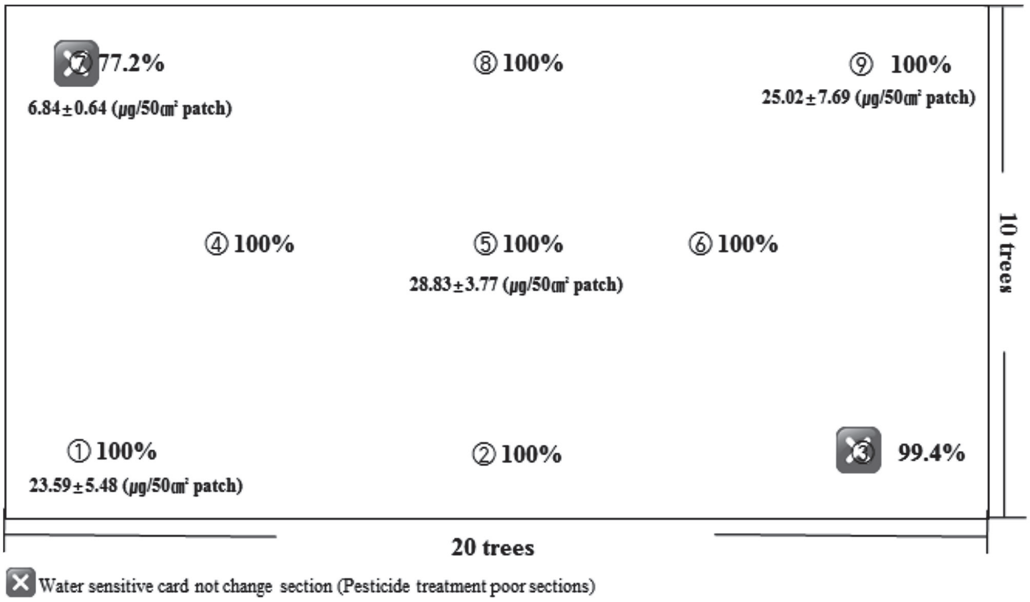

Fig. 9. Water-sensitive card discoloration results, amount of imidacloprid (μg/50 cm^2 patch) and *A. citricol*a control effect of low spray water volume (2015) of imidacloprid 10% WP of the pesticide in the apple orchard–2.

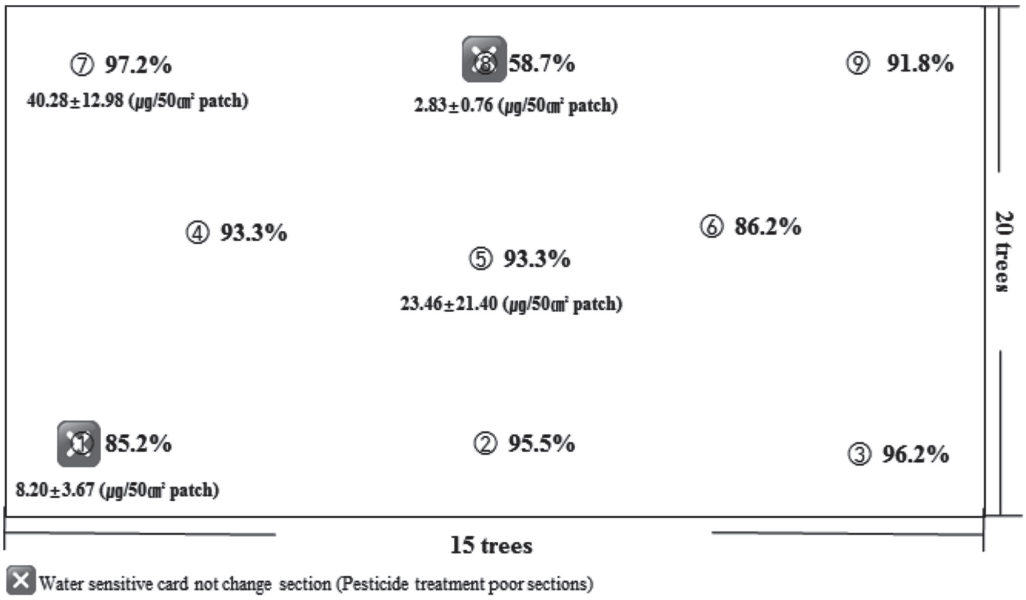

Fig. 10. Water-sensitive card discoloration results, amount of flonicamid (μg/50 cm^2 patch), and *A. citricola* control effect of low spray water volume (2015) of flonicamid 10% WG of the pesticide in the apple orchard–3.

and the trees had both leaves and fruits. The control target pest was *A. citricola* and the sprayed pesticide was flonicamid 10% wettable powder. The SS sprayer conditions were low speed level 2, 2,000 rpm, and 20 bar. The spray water volume was 380 L, i.e. about 70 L smaller than the standard volume. The amount of active ingredients of flonicamid 10% wettable powder per unit area was 0.02 kg a.i./10 a based on the standard spray volume of 450 L per 10 a. However, the sprayed amount was 0.017 kg a.i./10 a, which was smaller (Table 3). As a result, water–sensitive papers were not completely coated in two out of nine experimental areas; however, the experimental areas generally showed control effects not lower than 80% (Fig. 10, Plots 1, 8). The average amount of pesticides deposited was 31.87 μg/50 cm^2 patch in well–sprayed sections and 5.5 μg/50 cm^2 patch in the poorly sprayed sections; in addition, it could be seen that, although a r water volume smaller than the standard water volume was sprayed, the amount of deposited pesticides increased further.

The spray water volume in fields–1 and 3 was 380 L, which was by about 70 L smaller than the standard spray water volume and the spray water volume in field–2 was 350 L, which was by about 100 L smaller than the standard spray water volume. Therefore, even if the water volumes (350–450 L) smaller than 450 L per 10 a (the standard spray water volume per unit area) are sprayed, the optimal control effects can be shown if the spraying person evenly sprays the spray water to all areas.

AUTHOR CONTRIBUTIONS

Na Young Jin designed the study, performed the apple orchards experiments, analyzed the data and wrote the paper. You Kyoung Lee performed the water sensitive card experiments. Yu Seop Kim and Hee Ji Kim participated in the pest control experiments. Young A Hur conducted the control value analyses. Young Shin Kim and Chi Hwan Lim conducted the total active ingredients of pesticides analyses. Young Nam Youn edited the paper. Chisa Yasunaga–Aoki participated in the design of the study and discussed on the experiments and the results. Yong Man Yu supervised the work and wrote the paper. All authors assisted in editing of the manuscript and approved the final version.

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