Evaporation Time and Spread Area of Adjuvant-amended Droplets on Waxy and Hairy Leaves

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Abstract

Understanding the evaporation of pesticide droplets and wetting of leaf surfaces can increase foliar application efficiency and reduce pesticide use. Evaporation time and wetted area of single pesticide droplets on hairy and waxy geranium leaf surfaces were measured under the controlled conditions for five droplet sizes and three relative humidity levels. Stereoscopic sequential images of the droplet evaporation processes were taken for five droplet sizes, three relative humidity (RH) conditions and 9 different sprays. The sprays were combinations of water, an alkyl polyoxyethylene surfactant, a fungicide and three insecticides. The evaporation time and wetted area of droplets were significantly changed by adding the surfactant to the sprays, but not by adding the fungicide or insecticide. Droplet evaporation times on waxy leaves were longer than those on hairy leaves. Evaporation times increased exponentially as droplet diameter and RH increased with limited variability of regression coefficients independent of spray type and leaf surface. The wetted area of droplets also increased exponentially as droplet diameter increased but it was not significantly affected by RH. On the waxy geranium leaf surfaces, the contact area of pesticide droplets decreased throughout the evaporating process and at all RH conditions, while, on hairy leaf surfaces for the same size droplets and at the same RH conditions, the contact area continued to spread until evaporation was nearly completed. Therefore, droplet size, surface characteristics of the target, relative humidity, and chemical composition of the spray mixtures (water alone, pesticide, additives) should be included as important factors that affect the efficacy and efficiency of pesticide applications.

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1. Introduction

Pesticide application has ensured high quality of floral and nursery crops, but the increased use of chemicals has brought public concerns about worker exposure, environmental contamination, and adverse impacts on vulnerable ecosystems. Nursery and floriculture crops in California, Florida, Michigan, Oregon, Pennsylvania, and Texas consumed a total of 2.54 million kilograms of pesticide active ingredients in 2006, about 17% increase from the amount applied in 2003 [1].

Pesticide application is complicated by the use of a variety of delivery equipment and methods, varied physical properties of chemical sprays, diverse crops and their growth habits, numerous pests and diseases, disparity of operator skills, uncontrollable weather conditions, extensive worker safety and environmental regulations, and economics related to the benefits of pesticide applications.

Several studies have investigated the role of leaf surface microstructure in relation to pesticide or herbicide spread and absorption with scanning electron micrographs of leaf surfaces [2, 3, 4]. In general, the amount of wax and the spray droplet coverage has been found to be inversely related. Long-chain hydrocarbons are highly hydrophobic, whereas alcohols and acids are relatively hydrophilic. The density of trichomes (the fine outgrowths of hair on leaves) has been found to have a greater influence on droplet coverage than the trichome length because closely spaced trichomes appear to produce air pockets beneath the droplets that prevent leaf surface contact [5]. The presence of a large number of glandular trichomes may result in increased micro-roughness and hence the greater spreading of droplets[6].

Spray additives such as alkyl polyoxyethylene surfactants are widely used in foliar applications to reduce spray drift and to increase leaf wetness. Spray deposition, adhesion, droplet coverage, and retention on leaves were found to be enhanced when non-ionic surfactants were added into spray mixtures [7, 8, 9]. With surfactants, it was found that smaller droplets had improved retention and spread more efficiently on leaves than larger droplets [9]. When surfactants are used, the foliar uptake of pesticides from droplets and the biological efficacy of the active ingredients were improved [10, 11, 12]. Reports also indicated that surfactants altered the size of droplets produced in sprays [13, 14, 15, 16]. However, the amount of surfactants to be added to sprays should be carefully monitored because residue patterns of droplets on surfaces vary with the concentration of added surfactants [17].

During the past several decades, research in pesticide spray application technologies mostly concentrated on methods and equipment to improve the accuracy of spray delivery on targets. These included air-assisted sprays, electrostatic sprays, nozzle selections, optimizing application rates, etc. However, there are few reports on how droplets react on targets after delivery. Reaction of droplets on the plant surface contributes to controlling physiological and biological processes. Absorption and uptake of active ingredients by leaves can be increased when the duration of sprays remain as on leaves increased [18, 19]. The absorption of chemicals may stop after droplet evaporation on leaves [20]. Also, chemical residues may form crystals which have low retention on leaves if droplets evaporate too fast and do not spread out on leaves. On the other hand, longer lifetimes of water droplets on leaves may accelerate germination of certain pathogens [21, 22]. Therefore, information on the evaporation time and spreading area of pesticide droplets on plant leaf surfaces can assist pesticide formulators to develop better products that can maximise uptake by leaves. It can also help spray applicators to maximise efficacy and minimise chemical use by selecting optimal droplet sizes and chemical formulations for the specific crops under specific environmental conditions.

Droplet size, RH, leaf surface fine structure and spray formulation are well known factors that influence droplet evaporation and spread on leaves. However, quantitative information on the influences is lacking. The objectives of this research are: to investigate effects of spray mixture additives, droplet sizes, and relative humidity on the evaporation and wetted area of droplets deposited on waxy and hairy leaf surfaces. We want to provide useful information for end users to maximize pesticide spray application efficiency and reduce pesticide use. The wetted area of a droplet in this paper is defined as the observed maximum contact area of a droplet on the target surface. Experiments were conducted under the controlled conditions to avoid interferences among these variables that could not be controlled under the field conditions.

2. Materials and Methods

This study examined the droplet evaporation and wetted area on two different surface leaves (hairy and waxy surfaces) with three RH conditions (30, 60 and 90%), five droplet sizes (246, 343, 575, 762, and 886 µm) and 9 liquid sprays formed by combinations of three insecticides, a fungicide, an alkyl polyoxyethylene surfactant, and distilled water.

A custom-built, experimental system (Figure 1) was constructed for the study. The system mainly consisted of a RH control unit, a target holding chamber, a stereoscope fitted with a high definition digital camera, and a single droplet generator [23, 24]. With this system, individual factors such as droplet diameter, RH, spray formulation and leaf surface structure were controlled separately.

The droplet generator was a microprocessor-based timed mode, air-powered fluid dispenser (Model 2405, EFD Inc., East Providence, RI, USA) that could produce a single droplet with diameters ranging from 200 µm to 2,000 µm. The RH control unit consisted of a humidifier, a dehumidification unit, an air mixing tank, two RH probes, a micro data-logger, and associated electronics which provided the target holding chamber with air at a constant RH ranging from 10 to 90%. The target holding chamber was insulated from the environment and was used to position targets and single droplets in X-Y directions along the plane of the leaf surface. The image acquisition assembly was a stereoscope and an Insight Firewire©, high-definition digital camera mentioned above. With this system, individual factors such as droplet diameter, RH, spray formulation and leaf surface structure were controlled separately.

Details of the 9 liquid sprays with the three insecticides, one fungicide and one surfactant are listed in Table 1. These materials are examples of chemicals commonly used in foliar spray applications. Each of the materials contained a different active ingredient, and was presented either as a powder or liquid formulation. They were mixed with distilled water to form 9 sprays for the tests (Table 2). Surface tension and viscosity of the sprays were also reported in Table 2.

A plant with waxy leaves and another plant with hairy leaves were selected from the *Pelargonium* collection of the Ornamental Plant Germplasm Centre (OPGC), Columbus, OH, USA. The waxy plant was *Pelargonium Stenopetalum* (OPGC accession number 566), and the hairy plant was *Pelargonium tomentosum* (OPGC accession number 521). Both plants were provided by the Ornamental Plant Germplasm Center (OPGC) of Columbus, OH, USA. This selection provided an opportunity to select genetically related plant material with widely varying leaf phenotypes. Contact angles of a 343 µm diameter droplets on the waxy leaf surfaces were 84.5° for the water-only spray, and 30° for the surfactant spray, respectively. Contact angles of droplets on hairy leaf surfaces were not available because long hairs blocked side view of droplets for the contact angle measurement. The abaxial side of freshly cut leaf samples (20 mm by 20 mm) was secured onto a glass plate with double-sided adhesive tape and then placed into an environmentally-controlled chamber for tests. For each measurement, only one droplet was deposited on the leaf by direct contact. This was followed by the process of taking sequential images of the droplet spreading and evaporation process.

The evaporation time (T) of the droplet on the leaf sample was calculated based upon the total number of sequential images starting from the first picture of droplet disposition to the final picture of the evaporation completion stage, as well as the interval time of each image. For example: the time t = 0 s indicates the moment when the first photo of a droplet evaporation process was taken during a section of sequential images after droplet was landed on the leaf surface.

The wetted area was obtained with the Polygonal Hand-trace feature of Image-Pro Plus software (Version 6.1, Media cybernetics, Bethesda, MD, USA) to trace the marked outline of the deposit contact area on the leaf surface. The measurement of the wetted area was calibrated with a Zeiss 0.01 mm micrometer slide. For each treatment, five leaves representing five replications were used. Only one droplet was discharged on the top of the leaf surface for each replication.

The same group of data was first analysed using a one-way analysis of variance (ANOVA) to test null hypothesis that all treatments had equal means with Duncan's methods using ProStat version 3.8 (Poly Software International, Inc., Pearl River, NY, USA). If the null hypothesis was rejected, the multiple comparison procedure was used to determine differences among means. All differences were determined at the 0.05 level of significance.

3. Results and Discussion

3.1. Droplet spreading process

For droplets containing surfactant, the evaporation process and the coverage pattern formation with time performed differently on hairy and waxy leaves. Compared to the droplet deposited on the waxy leaves (Figure 2), the droplet contact area spread greatly after it was deposited on the hairy leaves (Figure 3). For example, the wetted area increased from 1.50 mm^2 to 1.59 mm^2 at 7 s after deposition on the waxy leaves (only 0.08 mm^2 increase during 7 s), while the wetted area of the same-sized droplet increased from 0.64 mm^2 to 1.68 mm^2 at 7 s (1.04 mm^2 increase during 7 s) after deposition on the hairy leaves. The wetted area became 2.38 mm^2 (or 4.7-time increase) at 20 s after deposition on the hairy leaves and then shrank to 0.23 mm^2 at 48 s before complete evaporation. The wetted area of a 343 μm water droplet containing insecticide No. 3 and the surfactant on the waxy leaf surface was 2.4 times the wetted area of the same-sized droplet on the hairy leaf surface when first deposited, but by the time the droplets completely evaporated, the droplet on the hairy leaves spread to cover an area 2.4 times larger than the area covered on the waxy leaves. Consequently, the addition of surfactant to the spray mixtures could enhance the performances of applications requiring adequate coverage on surfaces.

Droplets containing the surfactant spread rapidly and then evaporated rapidly after deposited on hairy leaves. Visual observation found that a droplet containing the surfactant penetrated between the hairs and spread along the path between hairs, perhaps through capillarity, after landing on the leaf surface. However, the same-sized droplet without surfactant stayed on top of the hairs and did not spread out readily.

3.2. Evaporation time

At 0.05 level of significance, the type and concentration of pesticides (fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3 did not significantly influence the evaporation time of droplets from sprays of water only, or water mixed with surfactant. This trend was also true for the wetted area. Because of this matter, the results from the fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3 were unified and simply defined as pesticide. Their droplet evaporation times and wetted areas for each treatment were averaged as a group.

The evaporation time of droplets on hairy and waxy geranium leaf surfaces was greatly influenced by droplet size, RH and surfactant (Tables 3 and 4). Figure 4 illustrates the comparison of evaporation time of droplets containing water and insecticide No. 3 on hairy leaf and waxy leaf surfaces for droplet sizes ranging from 246 μm to 886 μm at 60% RH. Droplets had a longer evaporation time on the waxy leaf than that on the hairy leaf. For a 343 μm water droplet containing insecticide No. 3 at 60% RH, the evaporation time was 80 s on the waxy leaf and 47 s on the hairy leaf. Droplet evaporation times for all sprays varied greatly with the fine structure of the target surface.

Evaporation time decreased when the surfactant was added into the sprays. For example, the average evaporation time of 343 μm water droplets containing pesticides (Table 3) at 60% RH on the hairy geranium surface decreased 56% (i.e., from 48 s to 21 s) after the surfactant was added into the spray.

The relative percent change in evaporation time for droplets with surfactant varied with the structure of the target surface. Figure 4 illustrates the relative percent reduction in evaporation time due to addition of the surfactant at 60% RH for different size droplets containing the mixture of water and insecticide No. 3 on the waxy and hairy surfaces. The relative percent reduction varied considerably with the type of target surfaces, but did not vary with droplet size. The average relative percent reduction in evaporation time due to addition of the surfactant for the five droplet sizes was 57% on hairy leaf surface while only 29% on waxy leaf. After a surfactant was added, the relative percent reduction of droplet evaporation time on hairy leaves was nearly twice as great as on waxy leaves.

The evaporation time increased as droplet size and RH increased (Tables 3 and 4), and their relationship could be expressed as an exponential function.

$$T = a_0 e^{0.0038X + 0.0134Y} \qquad (1)$$

Where, T is the evaporation time (s), X is droplet diameter (μm) and Y is RH (%). a_0 is the regression coefficient, and its values for all the sprays on hairy and waxy leaves are shown in Table 5.

On waxy leaves, the evaporation time of 343 μm water droplets containing the pesticide increased from 52 s to 115 s when RH increased from 30% to 90% (Table 4). Hence, it is important to include RH in allocation guidelines for applications such as formulation preparations and best pesticide management programs to assure that a longer droplet evaporation time is incorporated for systemically active chemicals.

3.3 Wetted area

As mentioned before, the type of pesticides (fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3 did not make a significant difference to the wetted area. The wetted areas of droplets of five different sizes containing different additive sprays on hairy and waxy leaves are presented in Tables 6 and 7. These data illustrate that the wetted area significantly increased after the surfactant was added to the sprays. For example, the wetted area of 343 μm droplet containing insecticide No. 3 at 60% RH increased 4.2 times (from 0.42 mm^2 to 1.76 mm^2) on the hairy leaf and increased 5 times (from 0.25 mm^2 to 1.24 mm^2) on the waxy leaf after the surfactant was added. However, changing RH did not change the wetted area significantly ($p<0.05$) because the wetted area was reached shortly after deposition.

The wetted area on hairy and waxy geranium leaf surfaces increased as droplet diameter increased for all the sprays and RH conditions (Tables 6 and 7). For the insecticide No. 3 solution on hairy leaves at 60% RH, the wetted area increased from 0.13 mm^2 to 2.59 mm^2 (or 19.6 times) when droplet diameter increased from 246 μm to 886 μm (or 3.6 times) or droplet volume increased 46.7 times (Figure 4). For the same range of droplet sizes, the wetted area increased from 0.16 mm^2 to 1.08 mm^2 (6.9 times) on waxy leaves.

The wetted area varied greatly with the type of fine structures of target surface (Tables 6 and 7). Droplets without surfactant had smaller wetted area on the hairy leaf than on the waxy leaf (Figure 4). For example, the wetted area of a 343 μm droplet containing water and insecticide No. 3 at 60% RH was 0.66 mm^2 on the waxy leaf surface and 0.15 mm^2 on the hairy leaf surface. However, when the surfactant was added to the sprays, the wetted area on the hairy leaf had much greater increase than that on the waxy leaf. Within the range of relative humility from 30% to 90% and droplet diameter from 246 μm to 886 μm, the wetted area increased 4.5 to10.1 times on the hairy geranium leaf (calculated from Table 6) and 3.4 to 4.9 times on waxy geranium leaf (calculated from Table 7) after the surfactant was added to the spray.

4. Conclusions

Droplet evaporation times were longer on the waxy geranium leaves than on the hairy geranium leaves for all droplet diameters, spray types and RH conditions. Addition of the alkyl polyoxyethylene surfactant to the spray significantly reduced the evaporation times of droplets on waxy and hairy leaves. Addition of the surfactant to the spray affected the evaporation times of droplets on hairy leaves more than they did on waxy leaves.

Droplet evaporation times increased exponentially as droplet diameters and RH increased. For water droplets containing pesticides without additives on the waxy geranium leaf at 60% RH, the mean evaporation time increased from 40 s to 453 s when the droplet diameter increased from 246 µm to 886 µm. For the 343 µm water droplets containing pesticides on the waxy geranium leaf, the mean evaporation time increased from 52 s to 115 s when RH increased from 30% to 90%.

Adding the surfactant increased the wetted area 4.5 to 10.1 times on the hairy leaves and 3.4 to 4.1 times on the waxy leaves under the conditions in this study. For the same size droplets without the surfactant, the wetted area on waxy leaves was greater than on hairy leaves but the result was quite the opposite for droplets with the surfactant. Droplets with the surfactant on hairy leaves continued to spread until they nearly evaporated, demonstrating a different behavior from similarly treated droplets on waxy leaves.

The wetted areas increased exponentially as droplet diameters increased; however, the wetted area was not significantly affected by the addition of insecticide, or fungicide, or the change in RH.

Droplet size, leaf surface structures (waxy or hairy), and addition of the surfactant greatly influenced evaporation time and wetted area, suggesting that these factors are critical for the development of future spray strategies to improve efficacy and efficiency of foliar pesticide applications.

Acknowledgments

The authors gratefully acknowledge Adam Clark and Barry Nudd for setting up the experimental system, Mollie Sheron for analysing images, and the Ornamental Plant Germplasm Centre (OPGC; Columbus, OH, USA) for providing plants.

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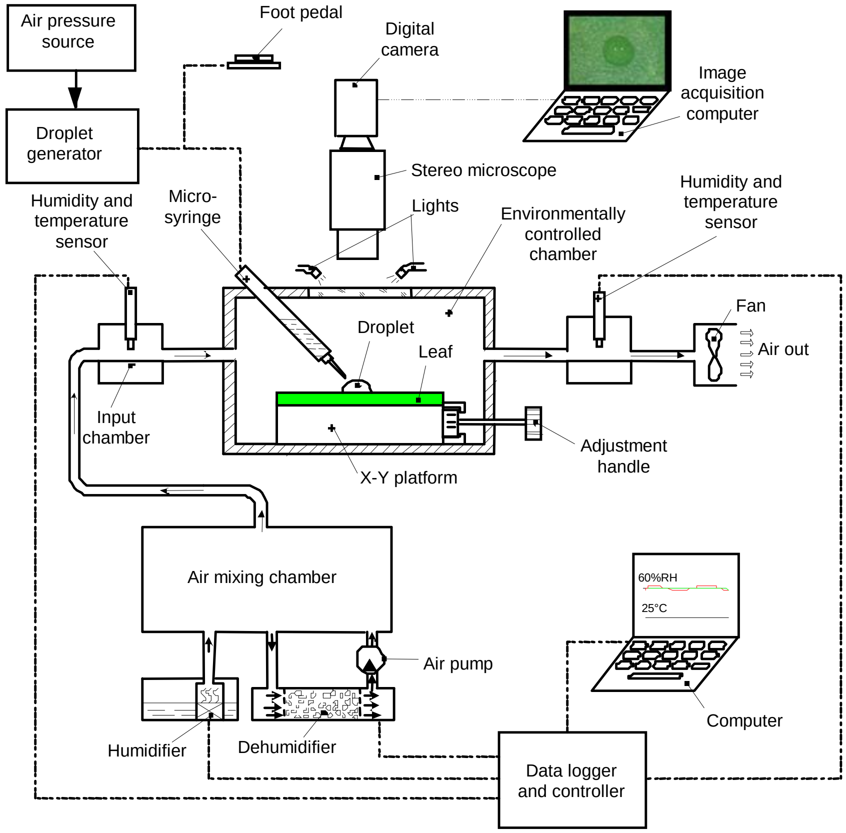
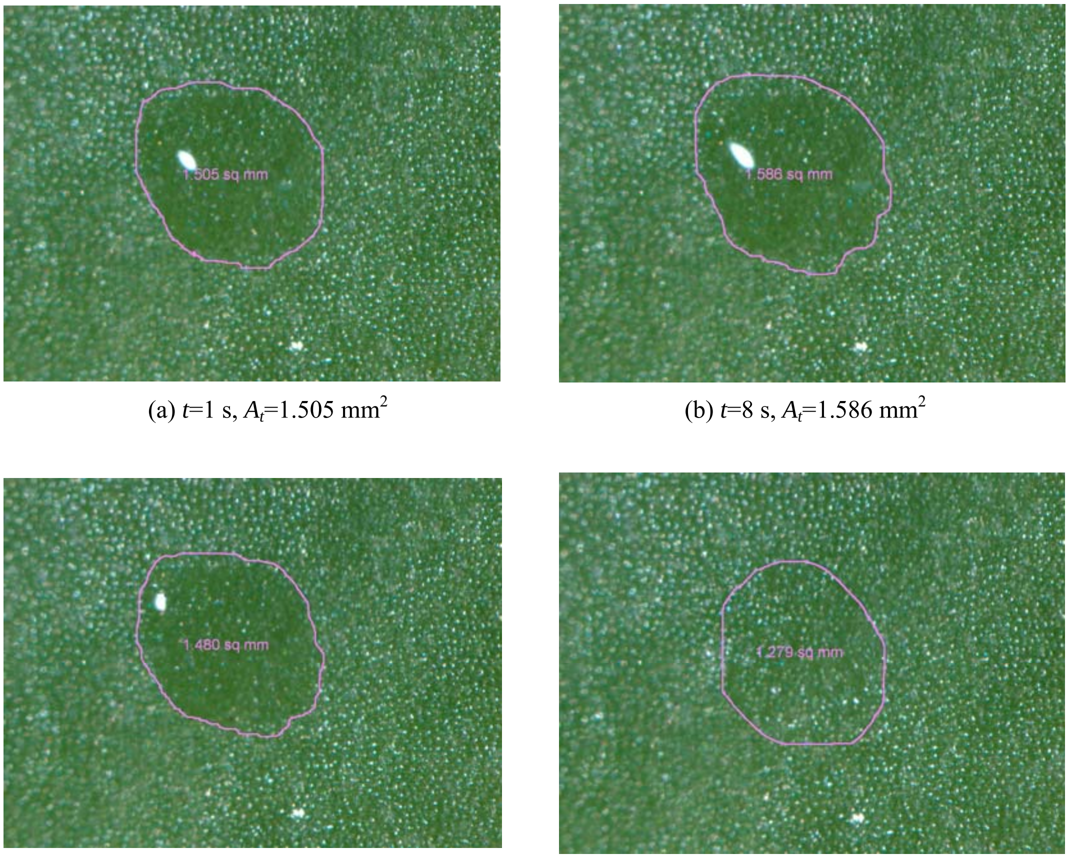


Figure 1. Experimental system to determine droplet evaporation and spreading on waxy and hairy leaves in an environmentally controlled chamber.



(a) t=1 s, A_t=1.505 mm^2

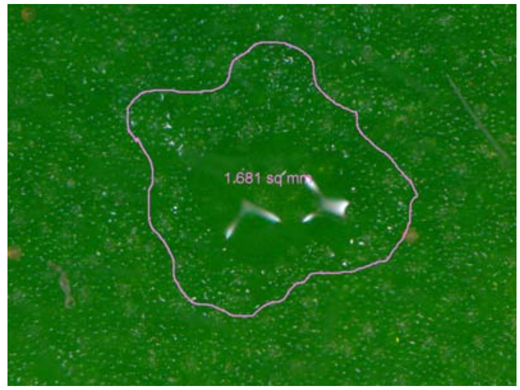
(b) t=8 s, A_t=1.586 mm^2

(c) t=16 s, A_t=1.480 mm^2

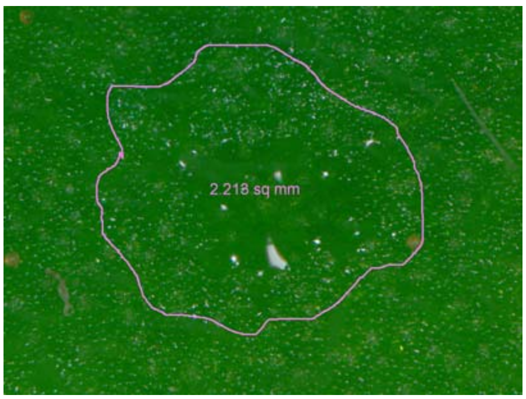
(d) t= 48 s, A_t=1.260 mm^2

Figure 2. Wetted area of a 343 µm droplet containing insecticide No. 3 + surfactant mixture at different times after deposited on waxy geranium leaf at 60% RH. t is the time after droplet is deposited on target surface, and A_t is the deposition coverage area on the target surface at the time t.

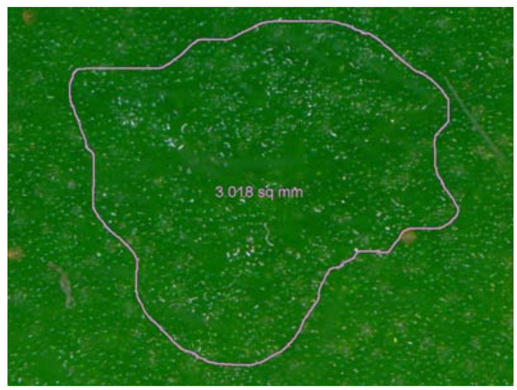
(a) t=1 s, A_t=0.637 mm^2



(b) t= 8 s, A_t=1.681 mm^2



(c) t=16 s, A_t=2.213 mm^2



(d) t=21 s, A_t=3.018 mm^2

Figure 3. Contact area of a 343 µm droplet containing insecticide No. 3 + surfactant mixture at different times after deposited on hairy geranium leaf at 60% RH. t is the time after droplet is deposited on target surface, and A_t is the deposition contact area on the target surface at the time t.

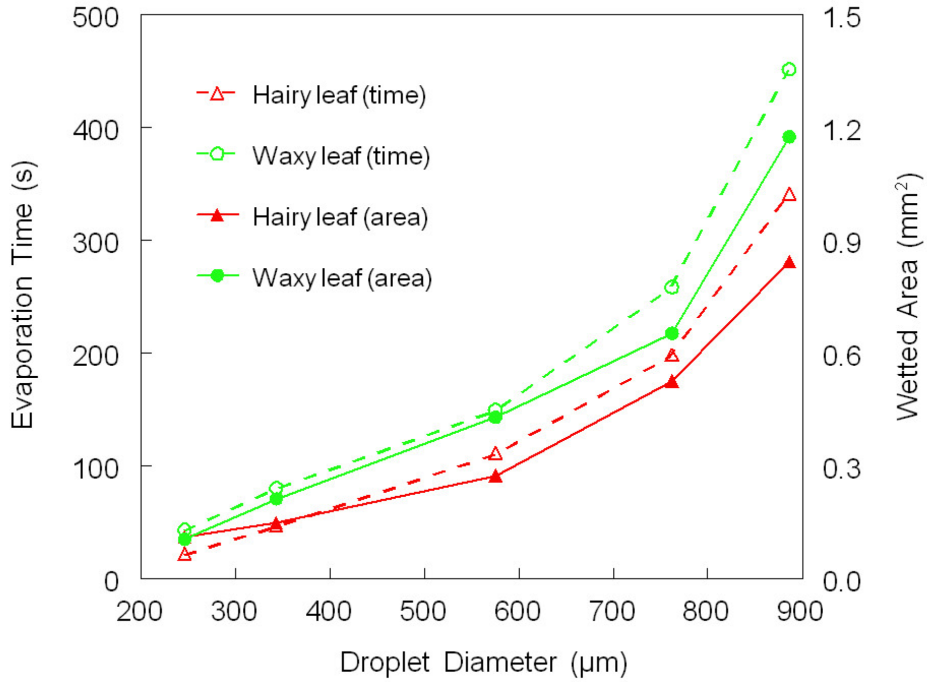


Figure 4. Evaporation time of different size droplets containing water and insecticide No. 3 on hairy leaf and waxy leaf surfaces at 60% relative humidity.

Table 1. Formulation, active ingredient and concentration of chemicals used to form mixtures in tests.

Chemicals	Trade name	Formulation	Active Ingredient	Concentration[a]
Surfactant	X-77[b]	Liquid	90% Alkyl Polyoxyethylene and 10% Constituents ineffective as adjuvants.	7.52 mL/L
Fungicide	Banner Max[c]	Powder	14.3% Propiconazole and 85.7%Others.	1.5 g/L
Insecticide No. 1	Celero 16 WSG[d]	Powder	16% Clothianidin and 84%Intert ingredients.	0.23 g/L
Insecticide No. 2	Marathon II[e]	Liquid	21.4% Imidacloprid and 78.6% Others.	0.13 mL/L
Insecticide No. 3	Safari 20 SG[f]	Powder	20% Dinotefuran and 80% Others.	0.45 g/L

[a] Concentration of the chemical in distilled water

[b] From Loveland Industries Inc., Greeley, CO, USA

[c] From Syngenta Crop Protection, Inc., Greensboro, NC, USA

[d] From Arysta Lifescience North America Corporation, San Francisco, CA, USA

[e] From Olympic Horticultural Products Company, Mainland, PA, USA

[f] From Valent USA Corporation, Walnut Creek, CA, USA

Table 2. Surface tension and viscosity of spray mixtures used in tests. Standard deviations are presented in the parentheses.

Spray No.	Spray type[a]	Surface Tension (mN m^{-1})	Viscosity (mPa s)
1	Water only	71.7(0.3)	0.97(0.06)
2	Fungicide	67.8(0.1)	0.99(0.04)
3	Insecticide No. 1	69.3(0.4)	0.99(0.07)
4	Insecticide No. 2	64.3(0.2)	0.97(0.09)
5	Insecticide No. 3	68.3(0.2)	0.97(0.07)
6	Fungicide + Surfactant	39.7(0.2)	1.84(0.25)
7	Insecticide No. 1 + Surfactant	35.5(0.1)	1.25(0.03)
8	Insecticide No. 2 + Surfactant	39.1(0.4)	1.91(0.15)
9	Insecticide No. 3 + Surfactant	40.6(0.1)	1.40(0.14)

[a] All sprays used water as the carrier.

Table 3. Mean evaporation time (s) of droplets containing different spray mixtures on hairy geranium leaf at three values of relative humidity (RH). Standard deviations are presented in the parentheses.

Sprays[a]	RH (%)	Droplet Diameter (μm)				
		246	343	575	762	886
Water only	30	12(1)	25(3)	73(13)	166(7)	277(12)
Water only	60	19(6)	41(10)	109(10)	220(9)	357(17)
Water only	90	40(3)	71(9)	157(12)	292(21)	480(58)
Pesticide[b]	30	15(3)	36(6)	83(8)	165(13)	280(19)
Pesticide	60	23(4)	48(7)	112(12)	212(12)	359(44)
Pesticide	90	42(8)	80(9)	157(19)	286(20)	444(31)
Pesticide + Surfactant	30	6(1)	14(2)	31(5)	58(10)	92(20)
Pesticide + Surfactant	60	10(2)	21(4)	43(9)	81(8)	134(29)
Pesticide + Surfactant	90	17(3)	39(5)	72(13)	123 (23)	199(32)

[a] All sprays used water as the carrier.

[b] Evaporation time for pesticide was averaged from values of fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3.

Table 4. Mean evaporation time (s) of droplets containing different spray mixtures on waxy geranium leaf at three values of relative humidity (RH). Standard deviations are presented in the parentheses.

Sprays[a]	RH (%)	Droplet Diameter (μm)				
		246	343	575	762	886
Water only	30	23(2)	45(3)	99(6)	196(3)	315(12)
Water only	60	35(7)	64(5)	156(4)	302(12)	448(21)
Water only	90	58(8)	116(16)	249(8)	500(9)	768(32)
Pesticide[b]	30	26(3)	52(6)	105(7)	201(10)	337(22)
Pesticide	60	40(9)	72(9)	150(15)	275(15)	453(37)
Pesticide	90	64(6)	115(13)	235(16)	441(26)	734(22)
Pesticide + Surfactant	30	13(2)	31(5)	65(7)	126(15)	242(17)
Pesticide + Surfactant	60	26(3)	53(4)	111(6)	201(14)	324(31)
Pesticide + Surfactant	90	42(6)	78(8)	165(15)	304(28)	490(35)

[a] All sprays used water as the carrier.

[b] Evaporation time for pesticide was averaged from values of fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3.

Table 5. Regression coefficient a_0 for the exponential function shown in Eq. (1) for different spray droplets on hairy and waxy leaf surfaces.

Sprays[a]	Regression coefficient a_0	
	Hairy Leaf	Waxy Leaf
Water only	3.67	6.32
Fungicide	5.70	7.85
Insecticide No. 1	5.59	8.55
Insecticide No. 2	5.48	8.13
Insecticide No. 3	5.24	8.35
Fungicide + Surfactant	2.10	3.89
Insecticide No. 1 + Surfactant	1.74	4.00
Insecticide No. 2 + Surfactant	2.02	4.02
Insecticide No. 3 + Surfactant	1.81	4.93

[a] All sprays used water as the carrier.

Table 6. Mean wetted area (mm^2) of droplets containing different mixtures on hairy geranium leaf at three values of relative humidity (RH). Standard deviations are presented in the parentheses.

Sprays[a]	RH	Droplet Diameter (μm)				
	(%)	246	343	575	762	886
Water only	30	0.08(0.005)	0.15(0.03)	0.26(0.05)	0.54(0.05)	0.64(0.01)
Water only	60	0.09(0.02)	0.12(0.02)	0.23(0.04)	0.42(0.03)	0.71(0.02)
Water only	90	0.15(0.02)	0.23(0.03)	0.35(0.06)	0.66(0.17)	1.22(0.23)
Pesticide[b]	30	0.13(0.02)	0.18(0.03)	0.34(0.05)	0.63(0.06)	1.10(0.21)
Pesticide	60	0.13(0.02)	0.29(0.06)	0.52(0.08)	0.92(0.12)	1.52(0.27)
Pesticide	90	0.16(0.03)	0.23(0.04)	0.38(0.06)	0.68(0.07)	0.98(0.09)
Pesticide + Surfactant	30	0.78(0.25)	1.03(0.53)	2.32(0.82)	3.18(0.67)	6.34(2.12)
Pesticide + Surfactant	60	1.27(0.21)	1.99(0.55)	2.85(0.77)	4.94(1.49)	6.86(2.11)
Pesticide + Surfactant	90	1.27(0.27)	1.59(0.31)	3.16(0.67)	4.88(0.84)	7.60(1.21)

[a] All sprays used water as the carrier.

[b] Wetted area for pesticide was averaged from values of fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3.

Table 7. Mean wetted area (mm^2) of droplets containing different mixtures on waxy geranium leaf at three values of relative humidity (RH). Standard deviations are presented in the parentheses.

Sprays[a]	RH	Droplet Diameter (μm)				
	(%)	246	343	575	762	886
Water only	30	0.12(0.01)	0.21(0.02)	0.36(0.02)	0.79(0.01)	1.20(0.02)
Water only	60	0.20(0.05)	0.23(0.03)	0.44(0.002)	1.05(0.12)	1.40(0.07)
Water only	90	0.12(0.01)	0.19(0.01)	0.40 (0.10)	0.65(0.06)	1.00(0.06)
Pesticide[b]	30	0.14(0.03)	0.26(0.04)	0.45(0.02)	0.78(0.07)	1.19(0.13)
Pesticide	60	0.16(0.03)	0.26(0.04)	0.54(0.05)	0.94(0.09)	1.37(0.11)
Pesticide	90	0.15(0.02)	0.26(0.07)	0.44(0.06)	0.80(0.07)	1.23(0.12)
Pesticide + Surfactant	30	0.48(0.03)	0.99(0.10)	2.00(0.12)	3.82(0.16)	5.85(0.39)
Pesticide + Surfactant	60	0.69(0.13)	1.11(0.06)	2.14(0.11)	3.94(0.15)	5.61(0.38)
Pesticide + Surfactant	90	0.54(0.12)	0.95(0.04)	1.77(0.09)	3.12 (0.25)	4.28(0.29)

[a] All sprays used water as the carrier.

[b] Wetted area for pesticide was averaged from values of fungicide, insecticide No. 1, insecticide No. 2 and insecticide No. 3.