Air-Assisted Electrostatic Application of Pyrethroid and Endosulfan Mixtures for Sweetpotato Whitefly Control and Spray Deposition in Cauliflower

John Palumbo and Wayne Coates

Abstract

Pyrethroid and endosulfan mixtures applied at full and reduced rates with three application methods (air-assisted electrostatic, air-assisted hydraulic, and standard hydraulic sprayers) were evaluated in field studies in 1992 and 1993 for control of sweetpotato whitefly, Bemisia tabaci-strain B (Genn.), also known as silverleaf whitefly, Bemisia argentifolii Bellows and Perring, and spray deposition on cauliflower, Brassica oleracea L. Based on adult suppression, improved control of whiteflies was achieved with full and reduced rates of the air-assisted electrostatic sprayer following two applications in 1992, but percent reduction of adults did not differ significantly among the application methods when full rates of insecticide were applied in 1993. Control based on immature colonization indicated that the air-assisted electrostatic sprayer was the only spray method to significantly reduce nymph densities when compared with the control in 1992, but differences in numbers of eggs, nymphs and eclosed pupal cases varied among application methods and rates of active ingredient in 1993. Comparisons of cauliflower harvest dates indicated that the air-assisted electrostatic sprayer did not provide significantly better control than the other application methods when used at similar rates. Spray deposition with the air-assisted electrostatic application technique was variable throughout these studies with no clear trends being observed. Our results suggest the air-assisted electrostatic sprayer may offer a means to control sweetpotato whitefly with a 50% reduction in insecticide usage.

Introduction

The sweetpotato whitefly, Bemisia tabaci-strain B (Genn.), (also known as silverleaf whitefly, Bemisia argentifolii Bellows and Perring has become a serious threat to cauliflower, Brassica oleracea L., crops grown in the lower desert areas of Arizona, southern California and northern Mexico. Cauliflower is particularly susceptible to whitefly feeding injury during the fall when populations migrate onto young seedlings from surrounding cotton, Gossypium hirsutum L., and melon, Cucumis melo L., crops. Growers have attempted to suppress colonizing adult and immature populations by treating fields with foliar applications of pyrethroid, organophosphate and organochlorine insecticide mixtures at 4-7 d intervals. Control has only been moderately effective, even though several insecticide active ingredients are available that are efficacious against adults and immatures. The primary difficulty encountered with foliar applied insecticides is that droplet deposition occurs primarily on the upper surface of the leaves and whiteflies colonize the lower surface of leaves where they are largely protected from sprays. To date, application technology designed to improve canopy penetration and spray deposition on lower leaf surfaces has not been sufficiently developed.

Several methods of electrostatic charged spraying have been developed to improve pesticide deposition, and the principles and techniques have been extensively reviewed. These methods employ electrostatic forces of attraction that place a surface charge on the spray droplets and theoretically will cause a greater proportion of the spray to reach and remain on the target. Most methods apply a charge to the spray droplets during atomization through solid-cone nozzles, flat-fan nozzles or rotary atomizers. Under laboratory conditions, these systems have shown increased spray deposition on model targets and plant surfaces, but spray deposition under field conditions has been inconsistent. Although greater deposition of pesticides on leaf surfaces is generally observed with electrostatic charged spraying, control of insect and mites may not necessarily be improved. However, the combination of air-assisted spray delivery with electrostatic charging of spray droplets has been shown to improve insect control.
As the potential for improved spray coverage on under leaf surfaces, and increased efficacy on sweetpotato whitefly with reduced amounts of active ingredient appeared to exist, studies were conducted to evaluate electrostatic application of insecticides. The objectives were to determine the effects of full and reduced rates of insecticides applied with air-assisted electrostatic, air-assisted hydraulic, and standard hydraulic application equipment on control of sweetpotato whitefly; and the deposition of foliar sprays on adaxial and abaxial surfaces of cauliflower leaves under field conditions.

Materials and Methods

Field studies were conducted in 1992 and 1993 at the University of Arizona, Yuma Valley Agricultural Center at Yuma, AZ. Cauliflower seedlings 'Snowcrown' were grown from seed (planted on 10 Aug., 1992 and 2 Aug. 1993) in a greenhouse and transplanted (5 Sept. 1992 and 1 Sept. 1993) into raised beds. Plots were immediately irrigated with overhead sprinklers. After stand establishment, all plots were furrow irrigated until harvest. Plots were 4-beds wide by 22 m long, with a 0.9 m spacing between beds. A 12.2 m buffer was established between plots to minimize interplot migration of whiteflies and prevent contamination from spray drift. Several cotton and melon fields (10-25 ha), located within a 2 km radius of the test site, served as a source of whiteflies during the test. All other plot preparation and seasonal maintenance procedures were conducted following local agronomic practices.

Application Equipment. The three application techniques evaluated in the studies were air-assisted electrostatic sprayer (AAE), air-assisted hydraulic sprayer (AAH) and standard hydraulic sprayer (SH). The AAE sprayer was fabricated in the Office of Arid Land Studies Agricultural Engineering Laboratory, University of Arizona, Tucson using commercial components provided by the manufacturer (Electrostatic Spraying Systems, Inc., Watkinsville, GA). Spray atomization was achieved by air assist delivery (compressed air at 207 KPa) and then electrically charged as the droplets were hydraulically delivered through the spray charging nozzles (Law 1982) at 172 KPa. These operational pressures produced droplets having volume median diameters measuring from 40 to 50 µm. The embedded-electrode voltage for the spray cloud averaged -8.4 uA per nozzle. Each nozzle was calibrated to deliver 2.5 mils, and application volume for the AAE sprayer was 66.4 liters/ha at 8.3 km/h.

AAH applications were made with a commercially available sprayer, DeGanya (FMC Corp, Philadelphia, PA). The sprayer was calibrated and operated according to manufacturer recommendations. The spray was hydraulically delivered at 275 KPa through hollow-cone nozzles. Air-assist was provided by a 45 cm diameter air curtain which forced air vertically downward directly over the nozzles. Nozzles were arranged at 50 cm intervals along the boom with each nozzle calibrated to deliver 16 ml/s, yielding an application volume of 292 liters/ha at a ground speed of 8.3 km/h.

SH applications were made with standard commercial application equipment similar to that used by growers in the Yuma area. The boom contained Twin-Jet flat-fan nozzles (TJ 8004VS; Spray Systems Co., Wheaton, Il) spaced at 50 cm intervals. Each nozzle was calibrated to hydraulically deliver 22.0 ml/s, providing an application volume of 386 liters/ha at 207 KPa and 8.3 km/h.

In the 1992 study, the nozzles on each sprayer were pointed to the soil surface with a nozzle-to-plant elevation of 30 cm. In each case, the spray was directed vertically downward. In 1993, the booms of the AAE and SH sprayers were configured with two nozzles set 30 cm above the plant and directed vertically downward, and a single drop nozzle set 30 cm from either side of the plant and directed 45° toward the terminal of the plant. The arrangement of nozzles on the AAH boom was not modified in 1993. Wind speed at the time applications were made did not exceed 6.0 km/h.

Experimental Design and Treatments. A randomized complete block design with 4 replications was used both years. In 1992, treatments consisted of an untreated control; a soil drench application of imidacloprid (ISD) (Admire 2F®, Bayer Co., Kansas City, MO) at 0.04 g(AI) in 0.2 liters of solution per plant at transplanting that served as a positive control; and applications of a mixture of permethrin (Pounce 3.2EC®, FMC Corp, Philadelphia, PA) and endosulfan (Gowan Endosulfan 3EC®, Gowan Co., Yuma, AZ) at full (0.09 kg [AI]/ha and 1.1 kg [AI]/ha mixture, respectively) and reduced (0.045 kg [AI]/ha + 0.55 kg [AI]/ha, respectively) label rates using each of the application methods described above. The permethrin and endosulfan mixture was applied on 19, 30 Sep, 8, 15, Oct and 2 Nov. The treatments were the same in 1993 except that full (0.09 kg [AI]/ha) and reduced (0.045 kg [AI]/ha) rates of bifenthrin (Capture 2EC®, FMC Corp, Philadelphia, PA) were used in mixture with endosulfan instead of permethrin. The bifenthrin and endosulfan mixture was applied 22, 29 Sept, 6, 14, and 28 Oct. An organo-silicone based spreader-sticker, Kinetic® (Helens Chemical Co.; Memphis TN.) was applied with each treatment at a 0.25 % vol/vol solution.
Assessment of Whitefly Control. Measurement of adult suppression following applications involved estimation of adult numbers by direct visual counts on the undersides of leaves from ten randomly selected plants in the center two rows of each plot. The undersides of terminal leaves (3rd-4th fully expanded leaf from the terminal area of the plant) were carefully turned upward, and the total number of live adults on the surface was recorded. Counts were made in each treatment at sunrise between 0500-0700 hrs. A 1-d preapplication count was followed by a 4-d postapplication count. Percentage reduction of adults compared with the untreated control was calculated as the percentage of pretreatment numbers and adjusted for natural mortality and immigration from counts in the untreated control. Percentages were transformed to arcsine square root values to stabilize the variance and data for each application were analyzed as a one-way analysis of variance (ANOVA) using the Ryan-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences.

Colonization of sweetpotato whitefly immature stages was measured by estimating whitefly densities on leaves taken at 5 and 10 wk following transplanting. Ten plants were randomly selected in each plot, and a single leaf was collected from the terminal area (3rd fully expanded leaf from the terminal of the plant) and two leaves from the basal area (3rd and 6th leaf from the basal node) of each plant. The samples were immediately transported to the laboratory and the underside of each leaf was then divided into 4 sectors of equal size. The total number of eggs, nymphs, and eclosed pupal cases within a 2.5-cm² area of each sector were counted under a stereo microscope. Data were initially transformed (log10+ 1) to stabilize the variance. Means calculated at 5 and 10 wk after transplanting were analyzed as a one-way analysis of variance (ANOVA) using the Ryan-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences.

Seasonal control of sweetpotato whiteflies was also assessed from cauliflower yield estimates. Hand harvest of plots began 83 and 85 d following transplanting in 1992 and 1993 respectively, and continued 2-3 times weekly until all cauliflower heads were harvested. Heads larger than 12 cm diameter were removed from plants within a 20 m section of each plot. Weights of each harvested head and the date of harvest were recorded. The total number of cauliflower heads harvested from each plot were analyzed as a one-way analysis of variance (ANOVA) using the RYAN-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences. To quantify harvest maturity relative to treatment, an average weighted mean harvest date for each treatment was calculated similar to Palumbo et al. (1991). These average weighted mean harvest dates were analyzed with analysis of variance (ANOVA) using the Ryan-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences.

Measurement of Spray Deposition. Two methods were used to measure spray deposition on both adaxial (upper) and abaxial (lower) leaf surfaces. The first methods was a dual-side leaf wash technique. A collection device was employed that was clamped to the leaf and used to wash a 14.5 cm² area of the adaxial and abaxial surfaces simultaneously. By mixing a dye (FD & C #1 blue; Warren Jenkinson, St. Louis, MO) with the spray solution, the amount of material on each leaf surface was measured. A micro-spectrophotometer, model U-2000 UV/VIS, (Fisher Scientific, Pittsburg, PA) set to detect a 620 nm wavelength, was used to measure the dye concentration in the leaf wash samples. Prior to each application, a series of calibration trials was performed to establish baseline spectrophotometer values and to ensure that varying leaf surface characteristics and presence of honeydew or other contaminants did not confound the results during the trials. The calibration procedure consisted of applying drops of a water/dye mixture in varying amounts to adaxial and abaxial surfaces, allowing them to dry, and then performing leaf washing. Three sets of measurements were taken in each plot from terminal and base leaves (same leaf position that immatures were sampled from) following each application. The mean μl/cm² of dye recorded for each treatment was analyzed as a one-way analysis of variance (ANOVA) using the Ryan-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences. Because no differences in deposition were detected between half and full rate treatments for each application method, results from the full rate applications are presented.

In addition, water sensitive paper (Spray Systems Co.; Wheaton, Ill.) was used to measure spray coverage on abaxial and adaxial leaf surfaces. The 25 x 76 mm cards were stapled to the abaxial and adaxial leaf surfaces of three plants in each plot. After spraying, papers were collected and transported to the laboratory where a hand held scanner, Logitech Model-32 (Logitech Inc., Fremont, CA), was used to measure deposition on each card, with the data stored as a TIFF computer file. These files were subsequently analyzed using software developed to quantify percent coverage being determined for each paper. To ensure that the cards were properly located within the scan area, a jig was fabricated to hold them and guide the scanner. The mean % spray coverage per card for each application method was analyzed as a one-way analysis of variance (ANOVA) using the RYAN-Einot-Gabriel-Welsch multiple F test (P = 0.05) to distinguish treatment mean differences. Similar to the leaf wash techniques, no differences in deposition were detected between half and full rate treatments for the same application method and results from the full rate applications are presented.
Results and Discussion

Differences among the application methods in control of sweetpotato whiteflies were inconsistent from year to year, and varied depending on how control was evaluated. When based on adult suppression, a significant improvement in control was observed with the AAE sprayer following two applications in the 1992 where greater than 80% reduction of adults was achieved in the AAE plots receiving the full rates of the permethrin and endosulfan mixture (Table 1). Following the 30 Sep application, adult suppression in plots treated with the AAE at reduced rates of the insecticide mixture was similar to the full rate application. Following the 8 Oct application, the full rate AAE treatment provided significantly greater reduction of adults than any other spray treatment. Suppression of adults with AAH and SH treatments were similar throughout the test, regardless of rate used.

The use of the bifenthrin mixture in 1993 appeared to improve adult suppression following each application, but percent reduction of adults did not differ among application methods employed at full rates (Table 2). Following the 22 Sep application, reduction of whitefly adults (> 85%) did not differ among the three application methods at full rates and the AAE reduced rate treatment. Greater than 95% adult reduction was observed for all three application methods at full rates following the second application (Sep 29). Percent reduction of adults did not differ among the spray treatments following subsequent applications (6, 19 and 25 Oct).

The ISD treatment was not included in the analysis for adult suppression in either year because the imidacloprid was applied only at transplanting, and subsequently maintained adults at very low numbers throughout the season (2.9 ± 0.4 adults per leaf in 1992 and 2.5 ± 0.3 adults per leaf in 1993); whereas adult numbers in the untreated control averaged 62.6 ± 5.9 and 37.5 ± 3.2 per leaf in 1992 and 1993, respectively. Adult densities for each treatment were also reflected in the numbers of eggs measured at 5 and 10 wk after transplanting (Table 3 & 4). Egg densities have been shown to be highly correlated to numbers of adults per leaf in other annual cropping systems. Significant differences in mortality of eggs were not observed among the spray treatments.

Control based on densities of nymphs and eclosed pupal cases at 5 and 10 wk after transplanting varied among the application methods, ISD, and untreated control in both years. In 1992, all treatments had fewer eggs than the untreated check at 5 weeks after transplanting (Table 3). The AAE full rate treatment had significantly fewer eggs than any other spray method, but had more eggs than the ISD treatment. At 10 wk, egg densities were similar for all treatments. Among application methods, the AAE and SH at full rates had significantly fewer nymphs than the untreated check at 5 wk, but only the AAE full rate treatment had fewer nymphs than the check at 10 wk. Although the AAE full rate treatment had significantly more nymphs than ISD treatment at 5 wk, nymph densities at 10 wk were similar for the two treatments. The numbers of pupal cases at 5 and 10 wk did not differ among the application methods and the check, but were significantly lower in the ISD treatment when compared to all other treatments.

In the 1993 experiment, immature densities for all application methods and ISD were significantly lower than the check at 5 and 10 wk (Table 4). Numbers of nymphs were significantly lower in the AAE and AAH at full rates, AAE at reduced rates, and ISD than in all other treatments. Numbers of pupal cases at 5 wk were significantly lower in plots treated with the AAE at full and reduced rates, and the ISD treatment, than in the untreated plots. At 10 wk, densities of pupal cases did not differ among application methods at full rates, but were lower in AAE plots when compared with the other methods at reduced rates.

Because cultural and environmental factors remained constant for all treatments, yield responses provided a reliable measure of sweetpotato whitefly control among treatments. Results of multiple harvests indicated that there were no differences among treatments in the total number of heads per plot in either 1992 or 1993 (Table 5). However, this is not an appropriate parameter for assessing yield because whitefly feeding injury does not directly affect cauliflower head size, but rather delays plant growth and reproductive maturity. Consequently, control based on head maturity indicated that average harvest dates in the AAE plots did not differ from the other application methods at similar rates (Table 5). In 1992, only the AAE full rate treatment and the ISD treatment had shorter average harvest dates than the untreated check. In 1993, all treatments had a shorter average harvest date than the check. Harvest maturity in AAE reduced rate treatment did not differ from full rate spray treatments and the ISD treatment. These results are of practical significance because control decisions in commercial cauliflower production are usually based on the growers perception of the insects potential to delay harvest.

In general, populations of sweetpotato whiteflies appeared to be greater in 1992 than in 1993. However, comparisons of the application methods with the ISD treatment in each year suggests that the variability in control observed between the two years may be partly attributed to the different insecticide mixtures used. Based on whitefly densities and yield assessments in the ISD treatment, foliar applications of the permethrin mixture in 1992 did not provide
economic control, regardless of method used. Imidacloprid, a systemic insecticide highly efficacious against sucking insects, was included in the study as a comparison to provide control of whiteflies and prevent plant injury caused by whitefly colonization. Immature densities were minimal in the ISD plots and cauliflower was harvested on schedule 2-3 wk earlier. The lack of control resulting from the permethrin mixture prompted the use of bifenthrin in 1993 because it is highly efficacious on sweetpotato whitefly. Although the number of applications and spray timing were similar to 1992, full rate applications of the bifenthrin mixture with all application methods provided average harvest dates comparable to the ISD. Furthermore, harvest maturity occurred significantly sooner in the spray treatments than in the untreated check. Although direct comparisons between permethrin and bifenthrin mixtures were not made in either year, the results of this study suggest that the active ingredient used in foliar applications for whitefly control is as important as type of application equipment used.

Analysis of spray deposition on the terminal leaves of cauliflower indicated that more spray was deposited on the adaxial surfaces of leaves than on abaxial surfaces (Fig 1 and 2). The amount of deposition of active ingredient and percent coverage of sprays measured on the adaxial surface differed among the three spray methods throughout both years. None of the spray methods consistently provided significantly greater deposition of active ingredient, (Fig 1) and in most cases, there were no differences in adaxial leaf coverage among the methods (Fig 2). These data are consistent others who reported that spray deposited on the undersides of leaves was relatively low compared to spray deposited on the upper sides of leaves near the top of cotton plants.

Similarly, differences among the application methods in the amount of deposition and percent coverage of sprays measured on the abaxial leaf surface was not consistent following each application. Measurements of spray deposition with the leaf wash technique indicated that in 1992 (Table 1) the AAE method deposited more spray on the abaxial leaf surface on two application dates (8 and 15 Oct). In 1993, significantly more spray was deposited on the abaxial leaf surface with the AAE method when compared to AAH and SH on the first application (22 Sept). On the Oct 6 application, significantly less spray was deposited with the SH method when compared to the AAE and AAH methods. On the other application dates, no significant differences in spray deposition were detected among treatments. Measurements of percent coverage on abaxial leaf surfaces were more variable than the leaf wash data, as CV values exceeded 100% for most applications (Fig 2). Consequently, significant differences in spray coverage were not detected among the three application methods. Analysis of measurements taken from the lower base leaves on cauliflower plants with both methods indicated no differences among spray methods in the amount of spray deposited on either adaxial or abaxial leaf surfaces.

The failure of the three application techniques to show consistent differences in control of whitefly adults may have been associated with the lack of correlation between adult suppression and spray deposition. Increased adult suppression associated with greater abaxial spray deposition was observed with the AAE sprayer at full and reduced rates only once using the leaf wash technique in 1992 and once in 1993, respectively. Similar relationships between differences in mortality and deposition were not observed on other application dates in either year. The lack of correlation between differences in foliage spray deposition and differences in insect control has been reported in numerous studies. Although measurements with water sensitive cards indicated no statistical differences in % spray coverage on the abaxial leaf surface in either year, numerical differences were often similar for both techniques. However, the large variation in card measurements within plots and among treatments did not allow us to detect significant differences among spray methods.

In general, uniformity of deposition and coverage decreased with application date and plant size. The water sensitive papers yielded the greatest CV's overall, but this is expected since attaching paper to the leaf alters the plant architecture to some extent and does not represent the overall leaf. Conversely, the leaf wash technique more closely represents the actual amount of material deposited on the leaf surface. The contrasting results between the two measuring procedures can not be easily explained, but may reflect differences between the spray-surface interface on paper cards and cauliflower foliage. Furthermore, the failure to consistently detect improved deposition with the electrostatic system is not surprising. Electrostatic techniques have been shown to be very effective under controlled conditions, however in the field, the influence of plant charge, plant size, dust, humidity and wind can mask the advantages that electrostatic charging offers.

Greater deposition on the adaxial leaf surface than on the abaxial surface was anticipated because the nozzles were configured with the spray directed towards the upper surface of leaves. Consequently, adult mortality likely occurred to some degree from contact exposure to the insecticide on the adaxial leaf surfaces where *Bemisia* spp. often land and feed before walking to the underside to oviposit. Mortality to adults from direct contact with the spray cloud during applications may have been significant as well. We often observed increased interplant movement of adults as the spray equipment moved through the plots. This is consistent with reports that adults quickly take flight when plants are disturbed. The effects of pyrethroid and endosulfan repellency on whitefly flight activity and spatial distribution patterns may have also influenced our estimates of adult suppression.
On several occasions, the air-assisted electrostatic sprayer provided a significant improvement in control with reduced rates of active ingredient. Increased suppression of adults following AAE applications with reduced rates of active ingredients was observed each year when plants were relatively small. Furthermore, densities of immature whiteflies and harvest maturity were not different between the AAE full and reduced rate treatments when the bifenthrin mixture was applied in 1993, whereas control was not improved in plots treated with both the AAH and SH reduced rate treatments. These results concur with those published previously, reporting dose reductions by at least 50% without significant reductions in biological efficacy. It is unclear why reduced rates of pyrethroid/endosulfan mixtures were most effective with AAE applications, but may be associated with toxicity of active ingredients, smaller droplet size, reduced spray volume, and spray coverage on abaxial leaf surfaces.

In conclusion, the air-assisted electrostatic application technique appeared to provide little improvement in control of sweetpotato whitefly over hydraulic application equipment when the same rates of active ingredients were used. Differences in whitefly control among the application methods varied depending on whether adult suppression, immature colonization, or harvest maturity was considered as the measurement for control. Spray deposition with the air-assisted electrostatic application technique was variable throughout these studies with no clear trends being observed. However, based on reduced immature colonization and average harvest dates achieved with applications of bifenthrin and endosulfan, the air-assisted electrostatic sprayer may offer a means to reduce insecticide usage and spray volume required to economically control sweetpotato whitefly populations in cauliflower.

### TABLE 1. Effects of endosulfan and permethrin applied with three application methods on suppression of adult whiteflies on cauliflower at 4 d after application, 1992

<table>
<thead>
<tr>
<th>Application method</th>
<th>Rate</th>
<th>% reduction of adults compared with untreated control at 4 d after application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>19 Sep</td>
</tr>
<tr>
<td><strong>AAE</strong></td>
<td>Full</td>
<td>43.0 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>26.0 a</td>
</tr>
<tr>
<td><strong>AAH</strong></td>
<td>Full</td>
<td>29.5 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>16.3 a</td>
</tr>
<tr>
<td><strong>SH</strong></td>
<td>Full</td>
<td>37.5 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>41.8 a</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different (LSD_{0.05}). Application methods included: air-assisted electrostatic (AAE), air-assisted hydraulic (AAH), and standard hydraulic (SH). Rates of foliar sprays expressed as full (0.1 kg [Al]/ha of permethrin + 1.1 kg [Al]/ha endosulfan) and reduced (0.05 kg [Al]/ha permethrin + 0.55 kg [Al]/ha endosulfan).
### TABLE 2. Effects of endosulfan and bifenthrin applied with three application methods on suppression of adult whiteflies on cauliflower at 4 d after application, 1993

<table>
<thead>
<tr>
<th>Application method</th>
<th>Rate</th>
<th>22 Sep</th>
<th>29 Sep</th>
<th>6 Oct</th>
<th>19 Oct</th>
<th>25 Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAE</td>
<td>Full</td>
<td>95.8 a</td>
<td>98.5 a</td>
<td>83.5 a</td>
<td>81.6 a</td>
<td>68.8 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>89.5 a</td>
<td>70.0 b</td>
<td>81.5 a</td>
<td>82.7 a</td>
<td>60.0 a</td>
</tr>
<tr>
<td>AAH</td>
<td>Full</td>
<td>86.8 a</td>
<td>98.5 a</td>
<td>78.0 a</td>
<td>71.2 a</td>
<td>84.5 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>68.8 b</td>
<td>74.8 b</td>
<td>91.3 a</td>
<td>80.5 a</td>
<td>65.0 a</td>
</tr>
<tr>
<td>SH</td>
<td>Full</td>
<td>89.8 a</td>
<td>95.0 a</td>
<td>72.3 a</td>
<td>82.9 a</td>
<td>64.8 a</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>69.8 b</td>
<td>82.3 b</td>
<td>79.5 a</td>
<td>77.2 a</td>
<td>60.0 a</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different (LSD_{0.05}). Application methods included: air-assisted electrostatic (AAE), air-assisted hydraulic (AAH), and standard hydraulic (SH). Rates of foliar sprays expressed as full (0.09 kg [AI]/ha of bifenthrin + 1.1 kg [AI]/ha endosulfan) and reduced (0.045 kg [AI]/ha bifenthrin + 0.55 kg [AI]/ha endosulfan).

### TABLE 3. Effect of various methods of foliar application and rates of endosulfan + permethrin and soil treatment of imidacloprid on colonization of immature sweetpotato whiteflies on cauliflower, 1992

<table>
<thead>
<tr>
<th>Application method</th>
<th>Rate</th>
<th>5 wk</th>
<th>10 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Eggs</td>
<td>Nymphs</td>
</tr>
<tr>
<td>AAE</td>
<td>Full</td>
<td>11.9 d</td>
<td>14.5 b</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>27.2 bc</td>
<td>43.0 a</td>
</tr>
<tr>
<td>AAH</td>
<td>Full</td>
<td>45.9 bc</td>
<td>27.3 ab</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>51.0 b</td>
<td>33.0 a</td>
</tr>
<tr>
<td>SH</td>
<td>Full</td>
<td>24.3 c</td>
<td>15.7 b</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>31.7 bc</td>
<td>31.1 a</td>
</tr>
<tr>
<td>ISD</td>
<td>Full</td>
<td>2.1 e</td>
<td>0.7 c</td>
</tr>
<tr>
<td>Untreated</td>
<td>-</td>
<td>114.5 a</td>
<td>43.5 a</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different (LSD_{0.05}). Application methods included: air-assisted electrostatic (AAE), air-assisted hydraulic (AAH), and standard hydraulic (SH). Rates of foliar sprays expressed as full (0.1 kg [AI]/ha of permethrin + 1.1 kg [AI]/ha endosulfan) and reduced (0.05 kg [AI]/ha permethrin + 0.55 kg [AI]/ha endosulfan); imidacloprid soil drench applied at a rate of 0.04 gm ai/plant at transplanting.
TABLE 4. Effect of various methods of foliar application and rates of endosulfan/permethrin on colonization of immature sweetpotato whiteflies on cauliflower, 1993

<table>
<thead>
<tr>
<th>Application method</th>
<th>Rate</th>
<th>Eggs 5 wk</th>
<th>Nymphs 5 wk</th>
<th>Pupal cases 5 wk</th>
<th>Eggs 10 wk</th>
<th>Nymphs 10 wk</th>
<th>Pupal cases 10 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAE</td>
<td>Full</td>
<td>3.4 c</td>
<td>0.6 d</td>
<td>0.1 c</td>
<td>3.0 b</td>
<td>0.1 c</td>
<td>0.4 c</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>6.0 bc</td>
<td>1.2 d</td>
<td>0.1 c</td>
<td>3.8 b</td>
<td>0.3 c</td>
<td>0.2 c</td>
</tr>
<tr>
<td>AAH</td>
<td>Full</td>
<td>6.1 bc</td>
<td>4.0 cd</td>
<td>2.8 b</td>
<td>4.5 b</td>
<td>0.8 c</td>
<td>1.8 c</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>11.0 b</td>
<td>9.6 bc</td>
<td>2.1 b</td>
<td>4.4 b</td>
<td>3.5 b</td>
<td>8.8 b</td>
</tr>
<tr>
<td>SH</td>
<td>Full</td>
<td>6.5 bc</td>
<td>6.6 bc</td>
<td>3.2 b</td>
<td>2.3 b</td>
<td>4.5 b</td>
<td>1.9 c</td>
</tr>
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<td></td>
<td>Reduced</td>
<td>13.0 b</td>
<td>16.4 b</td>
<td>3.4 b</td>
<td>3.5 b</td>
<td>2.8 b</td>
<td>6.9 b</td>
</tr>
<tr>
<td>ISD</td>
<td>Full</td>
<td>7.6 bc</td>
<td>1.0 d</td>
<td>0.5 c</td>
<td>6.6 b</td>
<td>0.9 c</td>
<td>1.2 c</td>
</tr>
<tr>
<td>Untreated</td>
<td>-</td>
<td>50.8 a</td>
<td>56.4 a</td>
<td>10.2 a</td>
<td>31.0 a</td>
<td>26.6 a</td>
<td>14.3 a</td>
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</table>

Means followed by the same letter are not significantly different (LSD<sub>0.05</sub>). Application methods included: air-assisted electrostatic (AAE), air-assisted hydraulic (AAH), and standard hydraulic (SH). Rates of foliar sprays expressed as full (0.09 kg [AI]/ha of bifenthrin + 1.1 kg [AI]/ha endosulfan) and reduced (0.045 kg [AI]/ha bifenthrin + 0.55 kg [AI]/ha endosulfan); imidacloprid transplant drench applied at a rate of 0.04 gm (AI)/plant at transplanting.

TABLE 5. Effect of various application methods and rates of insecticides on average harvest dates and total yields of cauliflower, 1992 and 1993

<table>
<thead>
<tr>
<th>Application method</th>
<th>Rate</th>
<th>1992 Heads /20 m</th>
<th>Avg. harvest date&lt;sup&gt;a&lt;/sup&gt;</th>
<th>1993 Head /20 m</th>
<th>Avg. harvest date&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
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<tr>
<td>AAE</td>
<td>Full</td>
<td>67.1 a</td>
<td>106.5 b</td>
<td>59.5 a</td>
<td>92.4 c</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>64.4 a</td>
<td>109.4 ab</td>
<td>62.0 a</td>
<td>93.6 bc</td>
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<tr>
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<td>Full</td>
<td>68.9 a</td>
<td>109.8 ab</td>
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<td>94.3 c</td>
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<td>Reduced</td>
<td>71.0 a</td>
<td>110.6 a</td>
<td>61.5 a</td>
<td>94.9 b</td>
</tr>
<tr>
<td>SD</td>
<td>Full</td>
<td>67.8 a</td>
<td>109.6 ab</td>
<td>59.8 a</td>
<td>94.7 bc</td>
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<td>61.3 a</td>
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<tr>
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<td>62.5 a</td>
<td>92.1 c</td>
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<td>-</td>
<td>66.0 a</td>
<td>111.2 a</td>
<td>60.5 a</td>
<td>104.0 a</td>
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</tbody>
</table>
Figure 2

1992

AAE

19 Sep

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

Sh

100 75 50 25 0 50 100 150 200

1993

AAE

22 Sep

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1992

30 Sep

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1993

29 Sep

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1992

8 Oct

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1993

6 Oct

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1992

15 Oct

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1993

19 Oct

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1992

2 Nov

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

1993

28 Oct

AAE

AAH

SH

AAE

Abaxial

AAH

SH

AAE

Abaxial

AAH

SH

100 75 50 25 0 50 100 150 200

% Mean Coverage CV (%)

% Mean Coverage CV (%)

113