Improving Spray Deposition and Reducing Drift in Almond Orchards

Project No.: **12-WATER3-Giles/Markle**

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Objectives:

1. Build a retro-fit kit that adds a thin mast and hydraulically- powered fans to a conventional axial fan airblast sprayer that will allow spray delivery from below and above the canopy.
2. After preliminary testing of the retrofit and tuning the ground speeds, spray volumes and nozzle arrangements, determine hull-split spray deposition and navel orange worm control efficacy within lower and upper sections of trees for the modified sprayer and the same sprayer operating without the modification.
3. Determine spray drift from hull-split spray application of both modified and unmodified sprayer.
4. Conduct an initial pilot study into the effects of pruning on sprayer performance and spray deposition.

Interpretive Summary:

Spray deposition in the upper regions of almond trees is often difficult to obtain when spraying mature or dense canopied orchards. Typical air blast or “speed” sprayers are designed with a single large axial flow fan that is positioned near ground level and usually with its center line directly aligned with the towing tractor’s PTO shaft. While the low profile allows sprayers to easily transit the orchard, the releases of all spray droplets and the air carrier in the lowest regions of the trees results in non-uniform spray deposition in the trees. As found in earlier ABC-funded field tests of spray efficiency, the lower regions have greater pesticide deposit and pest control while the upper regions have less deposit and can suffer greater pest damage.

Without changes to spray equipment, the only potential solutions to improving upper tree deposit and pest control have been: 1) To increase the spray application rate of liquid, which does not necessarily improve the uniformity of deposition but instead may only increase the

overspraying of the lower tree parts and may increase ground deposit, or 2) To reduce the ground speed while keeping the spray application rate the same, this allows the air jet to increase the penetration into the tree canopy and carry more of the spray droplets into the upper regions of the tree. However, this reduces the productivity, i.e., the “acres per day”, of the spraying.

Equipment design changes can include the use of towered sprayers that include an air duct, often rectangular in cross section, through which a portion of the blower air is directed upward and outward toward the target trees. While tower sprayers generally improve the uniformity of spray deposition in the trees, they can be limited in that the towers must be large in order to accommodate significant airflow within them. This can make them difficult to pass through mature, unpruned orchards. Also, tower designs can provide limited ways to direct and control the airflow.

Materials and Methods:

The Retrofit Sprayer Design and Construction

The approach taken in this project was to modify an existing, typical orchard sprayer with the specific goal of increasing upper canopy spray deposit. The approach was to add air and liquid sources at the top of the canopy. This was accomplished by adding a single mast to the rear of the sprayer and on the mast, mounting hydraulically-powered axial flow fans with spray nozzles. The entire system was designed for ease of use in existing orchard settings.

A conventional axial flow orchard sprayer (Oma TR1500) was modified by adding two hydraulically-powered axial flow fans (Vinetech, Inc., Pasco, WA, the distributor for SARDI of Australia). The fans were driven by the tractor remote hydraulic system. Each fan had standard disc-core spray nozzles installed radially around the outside the fan housing. The existing spray plumbing system on the sprayer was retained for the conventional fan nozzles; a parallel plumbing system was added for the upper fans. The pressure could be controlled individually. The supporting mast for the fans could be lowered by rotation on a mounting shaft at the rear of the sprayer. This rotation was done by a hydraulic cylinder, powered by the tractor hydraulic system. The design concept for the sprayer is shown in **Figure 1**.

Key design features of the design include a slender fan structure support (i.e., 4 inch diameter steel tube) that minimizes interference with the trees as the sprayer passes down the middle of the row and the routing of all hydraulic power, electrical control and spray liquid hoses and cables within the tube in order to minimize damage to the sprayer and the orchard. The powered fans are mounted in a manner that allows them to be repositioned vertically along the tower mast and also for their angles, both outward and forward, to be adjusted (**Figure 2**). Additionally, the rotational speed of the fans and the spray liquid pressure at the nozzles mounted on the fans are fully adjustable. The fans are controllable from the tractor seat, using an electrical control panel.

The physical sprayer deployed for sprayer testing is shown in **Figure 3**. Detailed design specifications, including engineering drawings and construction details are available from the Project Leader at contact address above.

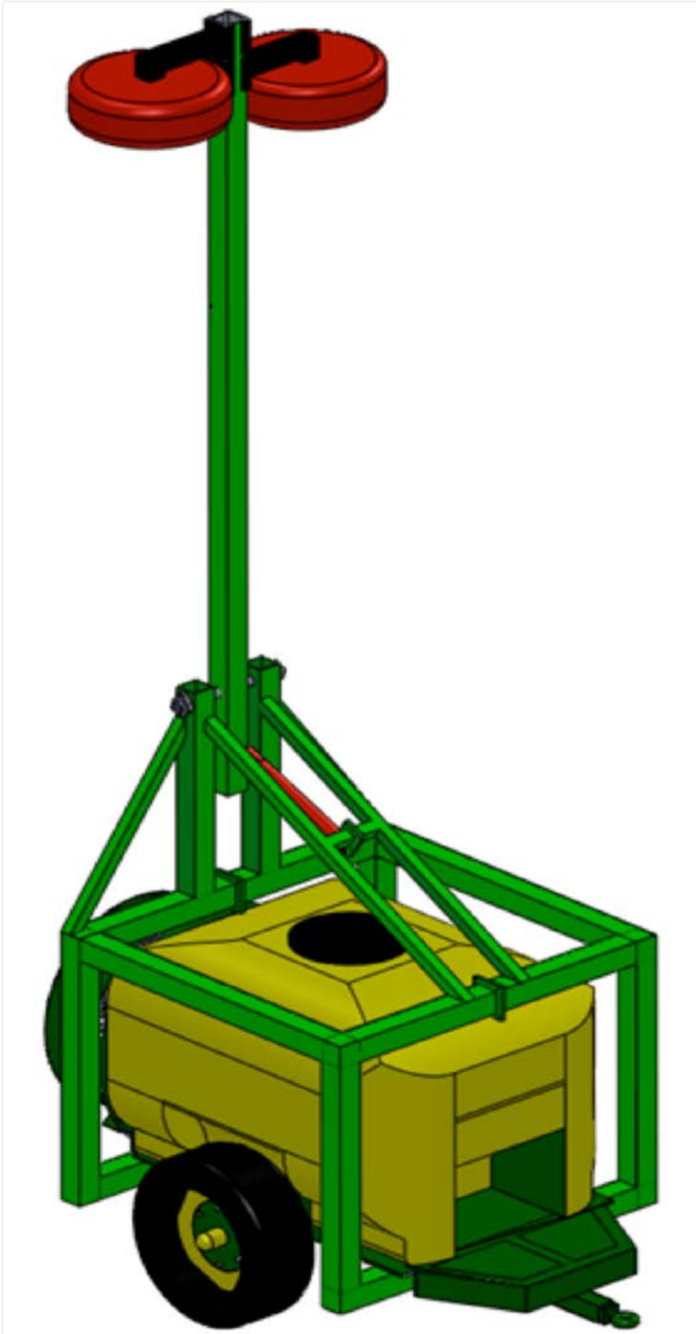

Figure 1. Conceptual design for retro-fit orchard sprayer.

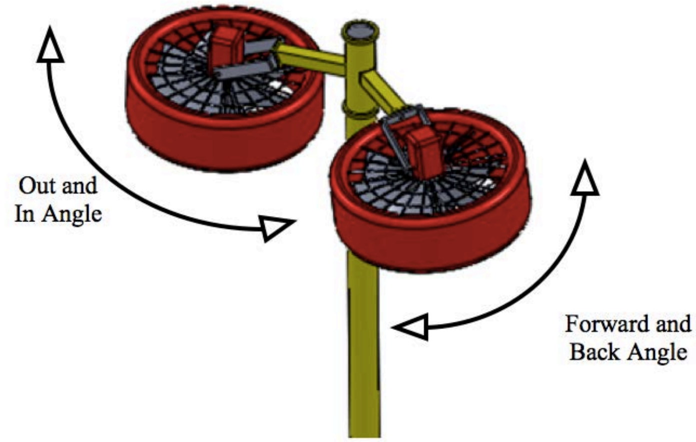

Figure 2. Fan adjustment angles possible with fan interface design on mast.

Figure 3. Completed retrofit sprayer design as deployed for field testing.

After construction of the prototype sprayer, the sprayer was placed into operation at the Nickels Field Station. The trees were 7 years old (or on their seventh leaf) and ranged between 15 and 20 feet tall. Because the trees had not grown to their full size yet, there were no limbs protruding into the middle of the row that would interfere with the sprayer as it traveled down the row. The trees were on 22 feet by 16 feet plantings. The terrain was moderately flat with slight undulations going down the rows. Testing was done at hull split time in the season.

The sprayer was evaluated for spray deposition by using water sensitive cards to record the spray liquid deposited in the trees. All testing was conducted at 2 mph ground speed and with a constant application rate of 100 gallons / acre. What was varied over the test was the speed of the top fans (in a relative scale of 0 to 100% of the manufacturer's suggested operating range) and the relative application rate from the bottom spray manifold of the sprayer and the top fans. The test conditions are shown in **Table 1**. Control trial was with only the conventional (bottom) fan and nozzles operating. Trial 1 was with the bottom fan operating and with bottom nozzles operating and the top fans used only to produce air in order to "push" any overspray back into the trees. Trial 2 was a 50%/50% division of spray liquid between the top fans and the bottom axial fan with both top and bottom fans operating for air flow. The "70/30" trial was with both top and bottom fans operating and the fluid mix of 70% (i.e., 70 gal/acre) from the top fans the 30% (30 gal/acre) from the bottom spray manifold. The "70/30" trial conditions had been developed from a series of preliminary tests in which the air flow and liquid flow distribution between the upper and lower regions was optimized using the water sensitive paper. A comparison of the deposition from the two application conditions appears in **Figure 4**. The improvement in deposition in the upper tree can be easily seen. Based on the results, the efficacy trial, using procedures developed by Joel Siegel of USDA, was conducted to compare the conventional sprayer design (Control) and the best multifan configuration (70/30).

Table 1: Sprayer settings for each trial.

Trial	Axial Fan Speed (Low/High/Off)	Upper Fan Nozzle Count	Axial Fan Nozzle Count	Upper Fans Speed (%)	Upper Fan Fluid (%)	Axial Fans Fluid (%)
Control	Low	0	8	0	0	100
1	Low	0	8	70	0	100
2	Low	8	8	70	50	50
70/30	Low	8	8	70	70	30

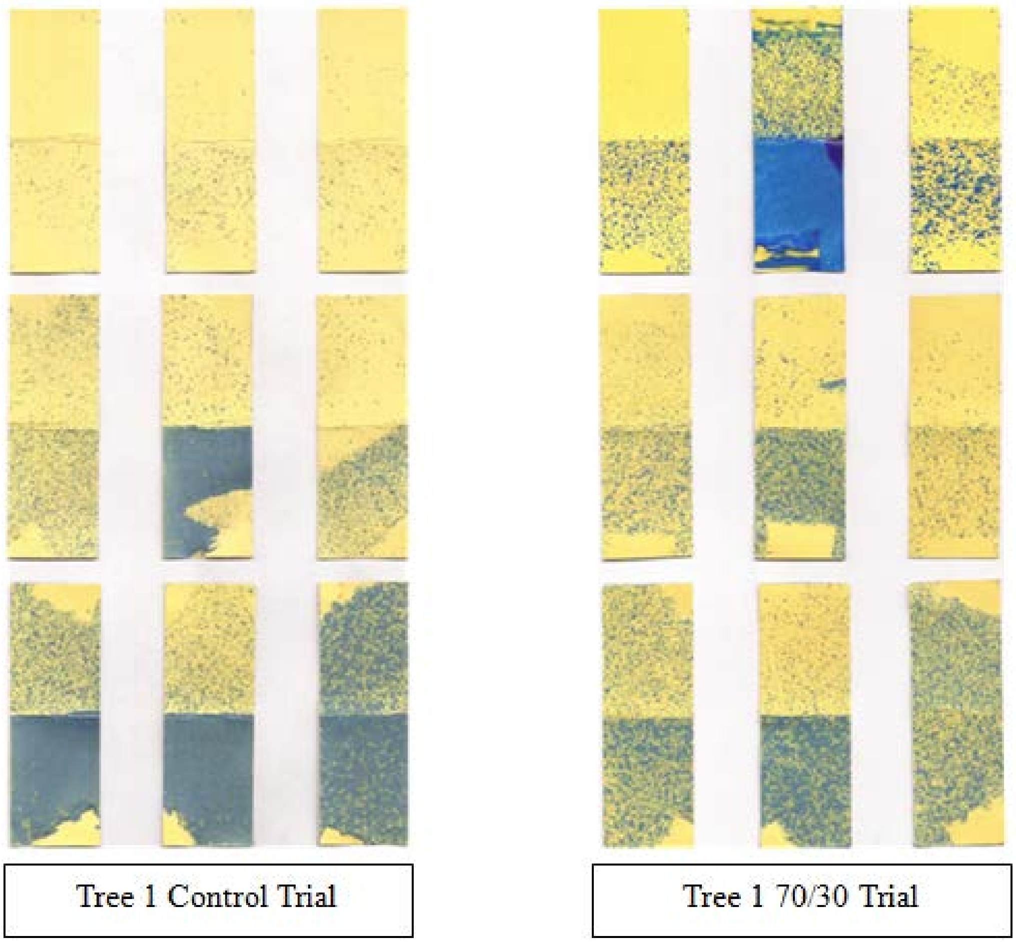

Figure 4. Observed spray deposition from a conventional (axial fan at ground level) application, left, and a multi-fan application, right.

Using the sprayer configuration conditions described above, sample blocks of trees were treated with Altacor® (4 oz/acre) plus non-ionic spreader (R-11®, 8 oz/100 gallons). At 1 and again on 14 days after treatment (DAT), nuts from four unpruned and four standard-pruned trees were sampled for NOW bioassay in Dr. Siegel's USDA lab in Parlier, CA. On the first sampling date, nuts were also sampled from untreated trees in the same block. No "control" samples were taken on the last sampling date. At each sampling date, 50 nuts from the tops of each tree (15-20' above the orchard floor) and 50 nuts from the lower part of the canopy (5-8' above the orchard floor) were pulled from the tree and placed in paper bags, stored on ice and shipped that day to Dr. Siegel's lab. In the lab, nuts were placed in 5 gallon buckets and exposed to a known number of NOW eggs. After incubation, the surviving larvae were counted and control presented as percentage survival and percentage NOW reduction, corrected for percentage survival on control nuts.

Pruning Test.

Reduced pruning in almond orchards can save growers money in pruning costs without harming yield in many varieties. However, the increased canopy density of unpruned trees may reduce spray coverage and pest control, especially hard-to-reach areas of the canopy such as the tree tops. Navel orangeworm (NOW) is a key pest in almonds, and excellent spray coverage is needed for the best possible pest control, especially with reduced risk pesticides [Intrepid®, Delegate®, Altacor®, Belt™, Dipel® (B.t.), etc.]

To test if pruning treatments can affect pest control in almonds, a field study was conducted in the pruning trial at the Nickels Soil Lab (NSL) near Arbuckle in the Sacramento Valley. This trial was planted in 1997. For more details on the pruning trial at (NSL), please see the report on this trial elsewhere in the annual report of the Almond Board of California (12-HORT6 Niederholzer).

The Nonpareil (NP) trees in the pruning trial at Nickels Soil Lab were sprayed with Altacor® (4 oz/acre) plus non-ionic spreader (R-11®, 8 oz/100 gallons) using a John Bean axial fan airblast sprayer (2 mph and 100 psi). Spray volume was 100 gallons per acre and the sprayer fan gear box was set to "high". Both sides of the NP tree rows were sprayed using nozzles on one side of the sprayer on each pass. Spray was not directed at the pollinizer varieties. A miticide plus nutrient spray (18 oz Envidor®, 1 gallon 415 oil, 3 lbs Solubor®, and one quart Tri-fol® organic acidifier per acre) was applied to the entire orchard within a week of hull split application.

At 1 and again on 14 days after treatment (DAT), nuts from four unpruned and four standard-pruned trees were sampled for NOW bioassay in Dr. Siegel's USDA lab in Parlier, CA. On the first sampling date, nuts were also sampled from untreated trees in the same block. No "control" samples were taken on the last sampling date. At each sampling date, 50 nuts from the tops of each tree (15-20' above the orchard floor) and 50 nuts from the lower part of the canopy (5-8' above the orchard floor) were pulled from the tree and placed in paper bags, stored on ice and shipped that day to Dr. Siegel's lab. In the lab, nuts were placed in 5 gallon buckets and exposed to a known number of NOW eggs. After incubation, the surviving larvae were counted and control presented as percentage survival and percentage NOW reduction, corrected for percentage survival on control nuts.

Spray Drift Testing for Multi-fan Sprayer.
Due to constraints and the spray test set up and conditions with the multi-fan sprayer field evaluations, no drift sampling was possible in 2012. An alternate evaluation method is in development as an interim evaluation method.

Results:

1. *Multifan Sprayer Efficacy*

There are two obvious statistical interactions in this experiment, Height and Time. One expects that spray efficacy will differ by height and if so, the effects will diverge at 14 days. Therefore, the analysis was conducted as a series of one-way ANOVA. In addition, there was a third interaction in this study, which is a consequence of the infestation technique. Some of the almonds were infested by tucking the egg papers into the suture; this provides the easiest entry of the neonate into the nut and may provide a more humid environment for the eggs while they mature, boosting survival. Additionally, depending on the width and length of the suture, there may be fewer droplets of insecticide in this suture zone. The remaining almonds were infested by pinning the egg paper on the exterior of the hull, forcing the neonates to wander along the hull before entering the suture; this increased the likelihood that they would encounter insecticide. In addition, the development of the eggs on the hull occurred in a less humid environment, which may have increased egg mortality. There is one additional finding worth noting: In previous years, Dr. Siegel noticed a difference in maturity between the high and low control nuts. In this analysis the High Control nuts are used to contrast the treatments in the High nuts and the Low Control nuts are used to contrast the treatments in the Low nuts. The outcome variable was survival assessed 30 days after the eggs were placed in the nuts.

Control, Pin vs. Tuck: Overall, there was no difference in survival between the pinned and tucked eggs in the controls. However, there was a large difference in survival between the High Control: 709/2,130 or 33.29% survival and Low Control: 317/1,990 or 15.9% survival. Survival in the High Control nuts was 2.09X the survival in the Low nuts. This difference is quite significant; Chi Square is 164.8, $P < 0.0001$. Consequently, as previously stated, the high treatments will be compared to the High controls, the low treatments to the Low controls. Overall survival is 24.90%.

Upper tree samples:

Conventional Sprayer

Pin: 293/1,600 or 18.31% survival. Reduction compared to Control: 45.0%

Tuck: 570/2,330 or 24.46% survival. Reduction compared to Control: 26.5%

Navel orangeworm was 1.34X more likely to survive when eggs were placed in the suture than when pinned on the hull, Chi Square = 20.59, $P < 0.001$. This is perhaps because the likelihood of encountering insecticide is greater when the neonates must traverse the hull. If this relationship does not occur in the Low nuts, these data may reflect a lower deposition rate into the suture. When the data were pooled, overall survival was 21.96%; overall reduction in survival compared to control nuts is 34.0%.

MultiFan sprayer

Pin: 34/540 or 6.30% survival. Reduction compared to Control: 81.9%

Tuck: 282/2,000 or 11.49% survival. Reduction compared to Control: 65.5%

Navel orangeworm was 2.24X as likely to survive when eggs were placed in the suture compared to pinned eggs, Chi Square = 23.06, $P < 0.001$. This is perhaps because the likelihood of encountering insecticide is greater when the neonates must traverse the hull. These results support the hypothesis that the insecticide coverage of the hull was greater than in the suture. Overall survival is 12.44%; overall reduction compared to control is 62.6%.

MultiFan vs. Conventional Sprayer-High Nuts

Pin: Conventional Sprayer treatment was 2.91X more likely to yield larvae than MultiFan Sprayer treatment, Chi Square = 44.11, $P < 0.001$

Tuck: Conventional Sprayer treatment was 1.74X more likely to yield larvae than MultiFan Sprayer treatment, Chi Square = 72.48, $P < 0.001$

Pooled Pin and Tuck: Navel orangeworm survival in nuts sprayed with a Conventional Sprayer was 1.77X greater than MultiFan Sprayer treatment, Chi Square = 93.16, $P < 0.001$.

Both treatments are noteworthy because they were less effective than in the previous years. MultiFan Sprayer was clearly superior in the high zone.

Lower tree samples:

<u>Conventional Sprayer</u>
In the lower nuts, there is a reversal in survival between Pinned and Tucked egg papers

Pin: 25/1,000 or 2.05% survival. Reduction compared to Control: 87.1%
Tuck: 13/1,250 or 1.00% survival. Reduction compared to Control: 93.7%

Survival when the eggs were pinned into the hull was 2.40X greater than when tucked, Chi Square = 6.28, $0.025 > P > 0.01$. This is the reverse of the Upper Canopy situation. Overall survival is 1.69%; overall reduction compared to control is 89.4%.

<u>MultiFan Sprayer</u>
Pin: 75/1,000 or 7.50% survival. Reduction compared to Control: 52.8%
Tuck: 78/930 or 8.39% survival. Reduction compared to Control: 47.2%

There was no difference in larval recovery between pinned and tucked eggs. This may indicate that there was ample insecticide deposition in the suture. Overall survival is 7.93%; overall reduction compared to control is 62.6%.

<u>MultiFan vs. Conventional Sprayer</u>
Pin: Survival in the MultiFan Sprayer treatment was 3.00X greater than survival in the Conventional Sprayer treatment, Chi Square = 25.3, $P < 0.001$
Tuck: Survival in the MultiFan Sprayer treatment was 8.07X greater than Conventional Sprayer treatment, Chi Square = 70.14, $P < 0.001$
Combined: Survival in the MultiFan Sprayer Treatment was 4.69X greater than survival in the Conventional Sprayer treatment, Chi Square = 91.30, $P < 0.001$.

Both treatments are noteworthy because they were less effective than the previous years. The Conventional Sprayer was clearly superior in the Low zone.

In the conventional treatment, survival was 13X greater High than Low, Chi square = 470, $P \ll 0.001$ and in the multifan treatment, survival was 1.57X greater High than Low, Chi Square = 23.3, $P < 0.001$. Results are summarized in **Table 2**.

Table 2. Overall Summary of Survival, Day 1 after spray – multifan sprayer.

Treatment	Survival	Reduction	Eggs
High			
Control	33.30% ± 47.10 A		2,130
Conventional	22.00% ± 41.40 B	33.93%	3,930
Multifan	12.40% ± 33.00 C	62.76%	2,540
Low			
Control	15.90% ± 36.60 A		1,990
Conventional	1.70% ± 12.90 B	89.31%	2,250
Multifan	7.90% ± 27.00 C	50.31%	1,930

Means within a height separated by a different letter differ at $P < 0.0001$.

2. *Efficacy in the Pruning Trial*

As in previous work using this system, NOW larvae survival on untreated nuts was less than 50% -- 40% for nuts from the upper canopy and 22% for nuts from the lower canopy (**Table 3**). The explanation for these differences is complicated by the difference in hull split between upper and lower nuts, with the nuts from high in the canopy being more advanced than those in the lower canopy. Nuts from the upper canopy were 1.83x more likely to support NOW than nuts from the lower canopy.

At 1 DAT, results from the two treatments were pooled for high and low nuts. Larvae survival for the eggs placed on nuts from high in the canopy was 11%, while survival on nuts from the lower canopy was 4%. When NOW numbers were corrected for survival on the control nuts, spraying with Altacor® plus surfactant resulted in 73% and 81% reduction in NOW survival in the upper and lower tree canopy, respectively. Nuts from high in the canopy were 2.62x as likely to support NOW as nuts from the lower canopy.

At 14 DAT, significant differences between treatments were measured in the upper but not the lower canopy. In the lower canopy, NOW survival was 8.2% in the unpruned and 7.3% in the pruned treatments (no real difference). In the upper canopy, more NOW larvae survived in nuts from the unpruned treatment (4.5%) compared with the standard pruning treatment (0.8%). Nuts from high in the unpruned tree canopies were 4.5x more likely to support NOW than nuts in the standard pruned trees.

NOW survival in the tree tops at 14 DAT was less than in the lower canopy on the same date, a reversal of the survival trend at 1 DAT and in previous studies, where less NOW control was measured in nuts from higher in the canopy than in the lower canopy at 14 DAT. We cannot explain this shift between sampling dates, which occurred in both trials conducted at Nickels Soil Lab in 2012.

Table 3. Comparison of navel orangeworm (NOW) survival under pruned and "unpruned" 16th leaf Nonpareil almond trees at two different heights in the canopy at two times after treatment with Altacor® insecticide. Survival values followed by the same letter are not significantly different. Nickels Soil Lab, Arbuckle, CA. 2012.

Treatment	Surviving NOW	Total Eggs	% Survival
Unpruned High Control	697	1,760	39.60 a
Unpruned Low Control	398	1,840	21.63 b
Day 1 High Pruned Treat	383	3,581	10.70 a
Day 1 Low Pruned Treat	143	3,500	4.09 b
Day 14 Unpruned High	82	1,820	4.51 a
Day 14 Pruned High	28	3,600	0.78 b
Day 14 Unpruned Low	111	1,360	8.16 a
Day 14 Pruned Low	221	3,030	7.29 a

Conclusions:

In general, the results of the field studies continue to confirm and illustrate the challenges with achieving control of insect pests in the upper regions of tree. The challenge of reaching the tops of trees and depositing sufficient pesticide to control NOW and other pests is complex, especially when considered in the light of the need for higher ground speeds and lower volumes in order to maximize time and machinery for pest control. The multi-fan, towered sprayer produced promising results, not only in improved spray deposition and pest control in upper tree regions but also in practical deployment and design. However, the sprayer also revealed and confirmed the challenge of improving upper tree deposition while maintaining lower tree deposition and timelines of spray operations.

Research Effort Recent Publications (also cited within this report):

Dasso, Andrew. 2012. Design, construction and evaluation of an improved orchard sprayer. M.E. Project Report (Thesis). Department of Biological & Agricultural Engineering, University of California, Davis. Davis, CA 95616.

References Cited: