



# A Road Map to Improve Chemical Delivery Technologies in Specialty Crops

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This document describes the priorities and future directions of research, extension, and manufacturing in pesticide delivery technology pertaining to tree fruit, grapes, and nuts.

Producers, researchers, extension and manufacturers contributed to the development of this document.

This effort was funded from 2009-2010 through a USDA-SCRI planning grant titled Development of a Smart Targeted Spray Application Technology Roadmap for Specialty Crops.



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## *Road Map to Improve Chemical Delivery Technologies in Specialty Crops*

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## 1. About this Roadmap:

This document describes the priorities and future directions of research, extension, and manufacturing in pesticide delivery technology pertaining to tree fruit, grapes, and nuts. Producers, researchers, extension and manufacturers contributed to the development of this document. Our long term goals are to 1) increase the economic, environmental, and social sustainability of the apple, cherry, pear, almond and grape industries by improving orchard and vineyard chemical delivery technologies, and 2) increase adoption of improved chemical delivery technologies by producers through effective educational products and outreach programs.

Improving chemical delivery technologies is a large and complex issue ranging from machinery to biological improvements. This document has organized the problems identified by the industry into three major categories or issues: drift/pesticide runoff, targeted deposition, and worker safety. An assessment of current practices and technologies is included as a perspective for why certain technologies are or are not adopted.

This effort was funded from 2009-2010 through a USDA-SCRI planning grant titled Development of a Smart Targeted Spray Application Technology Roadmap for Specialty Crops.

It is our hope that this roadmap will lead to a coordinate and collaborative national effort in improving pesticide delivery technology in relation to costs, drift, worker safety, and technology adoption.

## 2. Background

Tree fruit, nut and vine production in the U.S. relies on inefficient, economically and environmentally unsustainable spray application technology for delivery of crop inputs such as pesticides and plant growth regulators. Crop protection products (pesticides), plant growth regulators, and nutrients are essential inputs to economically sustainable tree and vine crop production. Application of these materials to tree and vine canopies by axial-fan air-blast sprayers has been an effective, yet often inefficient, means of delivery since the basic design was patented in 1949 (Fox et al., 2008). That design has not been significantly modified in 60 years and the majority of orchard and many vineyard sprayers in the US currently employ this delivery technology

Materials applied with axial-fan sprayers can be lost to the atmosphere above the canopy (Figure 1) or onto the ground via sedimentation. Spray material loss above the canopy as aerial drift can equal 45% of application materials (Landers, personal communication, 2008). Ground deposit of spray material can equal as much as half of total application per acre (Brown et al., 2008). Material costs for a single spray



Figure 1: Off-target drift from multiple air-blast

application can exceed \$100/acre, with additional costs for labor, fuel, and lubricants (Freeman et al., 2008). Consequently, aerial and/or ground losses of applied material result in significant economic losses to growers. From a market perspective, higher production costs equate to either less affordable fruits and nuts for the average consumer or, more likely, for reduce profit margins for producers.

Conventional air-blast sprayers deliver non-uniform spray coverage, as the spray solution must travel through much of the lower canopy to reach the topmost branches. Following passage of the Food Quality Protection Act, EPA began targeting organophosphate (OP) insecticides (e.g. azinphosmethyl) that were widely used and controlled pest populations in spite of poor coverage because they impacted multiple life stages and acted when pests contacted residues. The OP-alternatives and reduced risk products that have been registered to replace OPs are more selective, target a narrow pest spectrum, typically impact a single life stage, must be consumed to be most effective, and are much more expensive than the OP products they are designed to replace. Consequently, producers must precisely time products and achieve excellent coverage of the plant surface for effective pest control. Lastly, as both U.S. and foreign markets demand more sustainable products, US producers must reduce or modify their pesticide inputs to meet consumer preferences.

Off target applications of pesticides, plant growth regulators and nutrients is a well documented environmental concern. Pesticides applied to orchards can be found in unacceptable levels in surface water following applications or winter runoff events (Werner, et al, 2004). Social issues include on-farm worker safety and contamination, as well as off-site movement across an increasing extensive rural-urban interface.

There are several ongoing local research and extension efforts on delivery technology, worker safety, and drift reduction for deciduous tree and vine crops in the US. Researchers, extension faculty, applicators, producers and sprayer manufacturers have identified the need and desire to work collaboratively to improve application technology and increase the adoption of existing and novel delivery technologies.

### **3. Goals and Targets**

Voluntary adoption of an innovative agricultural technology is expected to be highly correlated with the perceived value of that technology to the end user (Kaine, et al., 2005). This roadmap was developed in collaboration with producers and manufacturers. The goals and vision for the future are heavily influenced by industry input.

The long term goals are to:

- 1) increase the economic, environmental, and social sustainability of the tree fruit, nut and grape industries by improving orchard and vineyard pesticide delivery technologies, and
- 2) increase adoption of improved pesticide delivery technologies by producers through effective educational products and outreach programs.

The suggested categories below reflect a priority list based on relative time as much or more than the defined years. More detailed information about the issues presented can be found in the section “Specific Research, Extension, and Manufacturing Needs”.

### **Short-term(3-5 years)**

For both research and extension, there needs to be a focus to solve problems associated with existing equipment or use commercially available technologies first.

*“Need to have the equipment we have now working better so that we stay competitive.”  
“Have to start on an airblast because 95% of the industry has it.”*

Initial research should focus on available technologies that can be modified or ones that can easily be developed. For example, work should be done on simplifying rate controllers and sensors (on/off canopy sensors) while making them adaptable to all machines. Modular or interchangeable solutions may have the greatest initial impact. Additionally, questions on current operation of machines should be examined. Answers about the interaction of chemicals and the environment, tree row volume, alternate row spraying, and technical issues with sprayers are researchable, or may there may already existing research knowledge, that could provide rapid solutions to existing practices.

Extension should focus on organizing the latest research and making it available in one place. There should be an effort to develop and deliver in multiple formats a unified message about best practices. Tactile or experiential learning should occur for calibration, comparison and optimization of machines, and assessment of coverage. There needs to be a deliberate effort to learn from other commodities and disciplines.

### **Medium-term (5-10 years)**

Medium term objectives were identified primarily as research or educational areas that would take longer to accomplish. Within ten years, significant progress should be made in four areas:

- precision agriculture,
- worker safety,
- biological control, and
- machinery guidelines.

Producers have indicated that they want more tools for precision agriculture like canopy density sensors and real time monitoring systems on sprayers.

Significant changes in worker safety should occur within ten years such as changes in bottling, mixing chemicals, direct injection, and the elimination of the driver through either autonomous vehicles or fixed spray system. This work must be done in collaboration with chemical companies and regulatory agencies.

Growers felt that methods to increase beneficial organisms (natural controls) are somewhat amorphous with loose guidelines. Systematic and deliberate methods should be developed on how to conserve, augment, increase, and maintain biological control agents in orchards systems.

The last area, machinery guidelines, is not regulatory but rather a step towards building consumer confidence and better machines. The concept is to develop baseline specifications for agricultural sprayers.

### Long-term (10-20 years)

Long term objectives are considered to be technologies or solutions that will take more than a decade to develop. These primarily focused around the elimination of pest control chemicals or their negative consequences, developing non-chemical pest control alternatives, such as different pheromone delivery systems, disruptive electric waves, and nano technologies.

## 4. Specific Research, Extension, and Manufacturing Needs

Besides limitations with specific machinery, there are three major areas that impact delivery technology; drift, targeted deposition, and worker safety. These problems and their solutions interact with each other. Clearly by reducing drift we have the potential to increase target deposition and possibly improve worker safety. Yet each of these areas of concern has its own distinct researchable problems and is discussed separately.

### Drift

The potential of drift, the off-target movement of a chemical, reduces as the sophistication of sprayers (the delivery technology) increases. Basic axial-fan sprayers generate too much drift, with very few ways of controlling the excessive amount of air, produced by sprayer, which carries the spray solution off site. Directed deposition sprayers, such as a tower or over-the-row, have the potential to reduce drift, while tunnel/recapture and electrostatic sprayers are supposed to be superior at drift reduction. However, growers have serious concerns about the more sophisticated machines. For example, directed deposition sprayers are sometimes marketed for alternate row spraying and growers sometimes rely on drift to improve coverage.

*“Drift and spray coverage are big issues, but work against each other.”*

There is a need to address the validity of alternate row spraying and drift as a means to increase coverage. There are serious concerns about tunnel and electrostatic sprayers that need to be addressed before widespread adoption of these machines (see Current Technologies).

Canopy sensors can be attached to most sprayers and seem like a good solution for reducing drift. Commonly when canopy sensors were discussed with growers responses were similar to:

*“[Canopy sensors] have been a bigger advantage to farms with more gaps and missing canopy. Better growers have a denser uniform canopy, so the savings goes down significantly”*

Canopy sensors are used in nut orchards where skip trees are common. Yet there are other successful uses not associated with missing trees/vines such as in grapes when sensors are used to detect and spray the trunk for cutworm control. Sensors would also be advantageous to turn off spray when not in the row and when spraying on hills and where canopy height can vary. However, in general growers are not yet convinced of the economic and environmental return on investment (ROI) for currently available canopy sensors.

There was also great interest in a sensor that detects canopy density and adjusts application based on density. ***Any sensor used or developed must be robust, easy to maintain/replace, and simple to operate.***

There are some drift reduction tools currently available, however, growers are unsure how to use them or if they impact their spray and coverage. For example, these are just some of the concepts that are unclear:

- How do drift adjuvants affect the efficacy of the chemicals used?
- What is the optimal droplet size to reduce drift?
- Do air induction nozzles really work at lower volumes?
- Can drift provide enough coverage to allow alternate row spraying?

Producers wanted to see tactile information of answers to these questions. Further any sensor work would have to be thoroughly demonstrated in situ to build confidence in the technology.

### *Summary*

- Need to assess the validity of alternate row spraying.
- Need to prove an economic benefit and reliability for currently available canopy sensors.
- A canopy density sensor could reduce drift and improve target deposition.
- The sophistication of a sprayer is positively correlated with drift reduction.
- Sophisticated sprayers are negatively correlated with growers' confidence and use.
- There needs to be more dissemination of information to producers and manufacturers to answer questions where research answers are already available.

### **Targeted Deposition**

The idea of getting 'good coverage' varies among growers. It should be our goal to apply all of the material to the desired target (i.e. canopy or fruit/nut). For economic, environmental, and control of the pest we should strive to deliver *every drop to the crop*. Feedback acknowledged the discrepancy in views among growers.

*“Change the way we think about targeted deposition. People like to see water on the crop. It is hard to convince people that you get coverage with little spray. Some growers still think that the spray needs to drip on the ground even if that is wrong thought.”*

Compounding this issue of establishing good coverage is that it appears some treatments work better at higher volumes than lower volumes and there may be differences in the efficacy of the material based on environmental factors (i.e. humidity, temperature). This leads to different practices in the East versus West. In Western states, growers felt that fungicides and plant growth regulators (PGRs) were more effective with higher volumes of water. The Washington Tree Fruit Research Commission has done extensive trials on thinning agents at different dilutions and sprayers. All of the results have been inconclusive so far. Nonetheless, growers in the west identified a need for sprayers that range from 50-400 gal/acre to accommodate the wide range of rates they perceive occurs from spraying insects and diseases to PGRs. There is a need to explore environmental and dilution rates on the efficacy of material.

Tree Row Volume (TRV) is the process of calculating the rate of spray based on the volume of the canopy rather than simply acreage. Using TRV with targeted deposition has the potential to

greatly decrease the amount of material applied, yet there are still uncertainties from growers about using TRV. The concerns included difficulty calculating the formulas, not being effective if drift occurs, and making sure the rate remains the same while applying less material. Growers viewed this as a moderately risky procedure in that if TRV spray does not hit the target, there is a great, negative economic impact. They felt that applying more material (i.e. not using TRV) is less risky because there is more room for error with drift or non-targeted deposition.

Improving deposition can also be addressed with improvements on the actual machines. Producers expressed an interest for a machine that has more functionality. At a minimum, they wanted easily adjustable machines that control airflow, volume and direction in real-time so that spray is better matched to the target canopy. Ultimately sprayers were seen as the ideal platform for numerous technologies because they are driven through the orchards/vineyards so frequently. Sprayers could carry sensors to measure canopy density, pest presence, wind flow and direction, drift, location and record keeping of sprays and horticultural factors like fruit size and yield. This would allow for increased monitoring and precision spraying. Realistically, some of these technologies exist and some do not. The adoption of them is going to depend on numerous factors ranging from manufacturers producing the sensors, cost, ROI, and confidence in the technologies.

The basic axial fan sprayer is the most commonly used sprayer, but it is not known for precise deposition. The spray is not directed at the canopies, but rather blown up into them. Axial fan sprayers lack the ability to automatically target spray for different canopy shapes and sizes. Additionally, they skew the air flow from the fan in the direction of the fan rotation creating non-uniform spray delivery. Growers do not often pay attention to the different patterns in airflow and deposition. Perceptions on coverage vary among growers. Some use axial fan sprayers for all low volume (50-80 gal/acre) sprays, while others believed that good coverage is not achieved with low pressure and low volume. Regardless of all these issues, growers consistently stated the need for modifications to this technology. There is an understanding that it will never be the 'ideal' machine as described above, but the majority of the industry owns at least one axial fan sprayer. Some engineering and education efforts must address problems with these machines that are currently so pervasive through the industry.

More sophisticated sprayers improve targeted deposition. Directed deposition sprayers (towers or similar designs) can spray in "zones" or specific parts of the canopy. However, they are not adaptable to all cropping systems (i.e. height, canopy shape, and terrain limitations) and there is confusion about how to 'fine tune' or change the machines to different blocks and canopy shapes. Tunnel/recapture sprayers would be a huge benefit early in the season when the canopies are small and much of the spray falls to the ground and there is a potential for wind to interrupt spray timing. In theory, an electrostatic sprayer has the greatest chance of achieving 'every drop to the crop'. The charged particles naturally attract each other and pull the spray to the target. However, with both the tunnel and electrostatic sprayers there are serious concerns about the machines that need to be addressed either through research or extension (see Current Technologies).

Rate controllers can be found on some newer directed spray systems. They work to improve deposition in that they adjust for differences in driving speed. Further, the ability to maintain a

precise calibration and get the appropriate rate on the canopy is extremely important with newer selective chemicals. However, many growers felt that they were not robust enough and they were too complicated with 16 buttons. In addition, growers wanted rate controllers that were adaptable to all machines like axial fan, hydraulic- sprayers.

Extension of the research is critical in improving targeted deposition. Yet, producers are concerned that their industries as a whole lacked basic information. There is a need to find, discuss and show tools that make calibration, nozzle output and machine maintenance easy. Some of the tools, like high volume flow meters, are either not manufactured or are too difficult to find. There is also a lack of confidence in some of the available technologies. Producers desire comparative tests of sprayers to assess coverage, pest/disease control, and thinning performance. Machines will vary in performance as horticulture and geography change. Comparative tests should be conducted in collaboration with growers and manufacturers so that machines are optimized and improvements are rapidly assimilated. Extension should showcase the available technologies through field days and workshops so that producers can see machines working. Practical demonstrations should include information like particle size, coverage, cost analysis and other relevant research. Some initial work in California, New York, Oregon and Washington with patternators to view vertical spray patterns has been well received. However, a patternator does not show coverage. Growers and extension demonstrations would greatly benefit from a tool that rapidly assesses coverage, other than water sensitive cards and Surround or other particle film technology. In the absence of this 'tool', patternators are an alternative but not a final solution.

#### *In summary*

- The idea of getting 'good coverage' varies among growers and there is a need to change the way the industries understand targeted deposition.
- There is a need to explore environmental and dilution rates on the efficacy of different materials.
- Tree row volume is a good technique, but there are too many uncertainties with the calculations, environmental factors, and targeted deposition.
- Axial fan sprayers are pervasive in the industry. There are numerous problems that could be addressed to improve deposition while using these machines.
- Directed deposition (tower type?), tunnel and electrostatic sprayers improve targeted deposition. However, each machine has problems that need to be addressed.
- Growers identified an ideal machine with sensors to measure canopy density, wind flow and direction, drift, location and record keeping of sprays and horticultural factors like fruit size and yield. Production and adoption of this machine will be a lengthy project.
- Simplify rate controllers and make them adaptable to more sprayers.
- Extension activities should include demonstrations of easy calibration methods, comparison of machines, and alternative ways to assess coverage.

#### **Worker Safety**

No operation should occur in a vineyard/orchard without worker safety being a top priority. Worker protection has improved over the past few decades but there are still exposure concerns for both a driver/mixer and a field worker. Producers felt that the use of protective gear greatly

reduced pesticide exposure during spray, but workers are still at risk and make the greatest mistakes while mixing a tank.

*“mixing is the number one time of pesticide exposure the weak link in safety”*

Direct injection (DI) systems is one alternative to eliminate worker exposure during tank mixing. There are many benefits of DI including improves worker safety, decreases the chance of phytotoxicity, no chemical is wasted or measured incorrectly, and no tank washing. With DI opportunities for spraying may be increased because the spray can be started or stopped without concern of a full tank mix going bad. There are however some issues with DI that prevent wide spread adoption. Perhaps the biggest issue is that there is no uniform container for pesticides so many of the materials are not in a DI container, thereby limiting a grower’s choice of chemical. Any sprayer can be modified with DI but it may be cost prohibitive if the operation performs a lot of tank mixes. For example if 6 materials are tank mixed, 6 pumps need to be installed and maintained. There is a tremendous amount of uncertainty on the ROI for growers so the cost expenditures and savings need to be examined.

Direct injection is not the solution for everyone. However, there are other changes in bottling and labeling that could reduce pesticide exposure. Pouring chemicals from large bottles or tanks into measuring devices is a primary source for waste and contamination. Changing the bottle and measuring devices so that they are one closed system would be an improvement. Changing labels to effective rates based on new technologies that target the canopy and fruit better also means less exposure and use of pesticide. For instances, in addition to volume/acre labels could also provide leaf or canopy volume/acre. All this work must be done in collaboration with chemical companies and regulatory agencies.

Another way to minimize pesticide exposure is to eliminate the driver. Growers identified autonomous or self propelled sprayers as a possibility in the future. They expressed a desire for a fleet of small machines with various sensors that could be controlled remotely, similar to an air traffic controller. Alternatively, some growers were intrigued by Dr. Andrew Landers’s work on fixed spray systems that basically run irrigation tube along trellis wires and apply materials without any external tractor or machine. With both of these technologies there are concerns about the effectiveness, cost, and regulations.

Growers also identified the elimination of chemicals or non chemical alternatives as a possible step towards improving worker safety. Increasing biological controls, puffers with pheromones or pesticide, electric disruptive waves, and nano technologies were all suggested. Growers also suggested working with formulation chemists to look at agents that will spread pesticides on leaves so that less will need to be sprayed. Growers felt that methods to increase predatory organisms are somewhat amorphous with loose guidelines. Systematic and deliberate methods should be developed on how to increase and maintain biological controls. All of these ideas are intriguing with the driving point being that we need to keep abreast of other technologies that may be adaptable to orchard pest control.

### *In summary*

- Direct injection systems would eliminate a major source of contamination and error, however, there are problems with both the availability of chemicals for this system and the maintenance of pumps.
- Changes in bottling, measuring, and labeling chemicals could improve worker safety and reduce pesticide use.
- Autonomous vehicles and fixed spray systems would eliminate the person from exposure, but the development and adoption of the technologies is not in the near future.
- Alternatives to chemicals should be explored and we should learn from other disciplines or non-agriculture methods.

## **5. Assessment of Current Technologies**

While application technologies can be categorized in one of the three major issues from the previous section, problems and solutions do not occur in isolation of the equipment. Current sprayers can be classified into four major categories—axial fan, directed spray, tunnel/recapture, and electrostatic. Growers identified advantages and disadvantages of each category of machine. No single machine satisfied the needs of a grower while minimizing drift and maximizing targeted deposition and worker safety.

The specifics here focus on the operation of the machines in the hopes that we can optimize the equipment and understand some of the limitations.

Producers proposed the concept of unbiased, third-party machinery guidelines. These are not regulatory but rather a step towards building consumer confidence and better machines. The concept is to develop baseline specifications for agricultural sprayers. Companies can advertise that they meet or exceed minimum standards. Admittedly this topic can be controversial if viewed as regulatory. However, if engineers work closely with manufacturers minimum guidelines for robustness can be determined without friction.

### **Axial Fan Sprayers**

Simple axial fan sprayers are the most used sprayers in perennial specialty crops. These sprayers include 1) axial fan, hydraulic nozzle sprayers and 2) centrifugal fan, air-shear sprayers. There are clear disadvantages to operation of this machine. However, many growers stated that they keep these sprayers because of a lack of capital to purchase a new one and the market does not yet have a satisfactory alternative that meets their needs and return on investment for their commodity. Manufacturers have stated that there are numerous highly sophisticated options available. Specific advantages and disadvantages of axial fan sprayers are found in table 1.

Table 1: Basic Axial Fan (ex. simple airblast design)

<b>Advantages</b>	<b>Disadvantages</b>
easy to operate and modify	excessive noise
simple to maintain and readily available parts	high horsepower
relatively robust	excessive amount of air and often an inability to adjust airflow other than high and low
inexpensive to buy and maintain	Commonly, no flow/rate control
familiarity	difficulty in adapting it to tree row volume
easy orchard access	lacks ability to automatically target spray for different canopy shapes and sizes
versatile, works in multiple commodities, row widths, and terrains	too much drift
	Hydraulic nozzles can get clogged with lower volume sprays, so tanks need agitators to eliminate a sludge build up
	axial fans can skew the air in the direction of fan rotation. These sprays do not often account for the different patterns in airflow and deposition
	Poor coverage is seen when using axial fans on low volume in large canopies (i.e. nuts or pears)

### Directed Deposition Sprayers

Directed deposition sprayers improve some of the disadvantages seen in axial fan systems, however, there are horticultural, height, terrain and safety limitations to these machines (Table 2). Growers stated the need for a robust machine that works like a directed sprayer, but needs less power and is self leveling.

Table 2: Directed deposition sprayers (ex. Tower and multi-headed fan sprayers)

<b>Advantages</b>	<b>Disadvantages</b>
most of above advantages of an axial fan plus the ability to direct airflow	excessive noise
some can apply very low rate/acre	Horticultural limitations: 1) grower needs to change their canopy to accommodate tower sprayers 2) limited access to non-trellised systems or systems with excessive inter-row branches
can spray 'zones' (ex. Top of tree with PGR or fruiting zone in grapes)	Height limitation: not appropriate for canopies taller than 12-14 feet.
improved control on insects that live in top	Terrain limitation: 1) maneuvering on hills require more power/bigger tractors 2) tip/Fall over easily on hills with fold down styles being very top heavy and the most likely to

	tip over 3) cannot spray the top of trees on hills 4) sprayer adjustments must be done before entering the field, which is impractical during an actual spray event
multiple row designs allow for more coverage in less time.	heavier machines with larger tractors cause more soil compaction and inability to use when ground is wet.
much less drift potential	capital cost
	changing and optimizing the spray volume to match the canopy size through the season is complicated and not intuitive
	too many hoses or external parts that get caught in the canopies.

### Tunnel or Recycling Sprayers

Tunnel or recycle sprayers are intriguing to growers because there is the potential for large cost savings, reduction of materials and almost no drift (Table 3). Savings would vary with the season (i.e. larger savings in early season when canopy is small) and farm operations. However, producers question the cost, robustness, ease of use, and effectiveness of these machines. Unlike the two previous machines discussed, few growers actually own one of these machines.

Therefore, many of the disadvantages are actually concerns expressed after seeing demonstrations of these machines. Producers are interested in more demonstrations and unbiased information on this type of sprayer.

Table 3: Tunnel or recycle sprayers

Advantages	Disadvantages
reduced drift possibly less material used	capital cost Maintenance concerns: 1) concerns about the availability of parts and down time during breakage 2) robustness is questionable with fiberglass designs that crack in the sun 3) no filtration system in some of the sprayers
fewer tank refills needed	Operation concerns: 1) uncertainty about maneuverability on a sloping terrain 2) need highly skilled driver
there is a feedback mechanism in that growers can assess the amount of spray used/recycle and adjust throughout the season	Coverage and chemical concerns: 1) uncertainty about coverage in dense canopies 2) some evidence that drift reducing chemicals can breakdown over multiple uses in the line 3) uncertainty about cross contamination of chemicals that have been 'recycled' 4) unknown if diseases can be spread through the

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recycling system

especially effective in the early season, where other machines apply too much adjustable to different row sizes

limited to shorter, trellised designs with uniform canopy

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### Electrostatic Sprayer

Electrostatic sprayers were tried 10-20 years ago. Their performance was variable in different environments and maintenance/repair was extremely difficult. Unfortunately, that has led to the negative perception of electrostatic sprayers, even though new designs exist and may solve some of the problems found in older models. There are some California grape producers with extensive use of electrostatic sprayers, but as a whole there are few perennial specialty crop producers that actually own these machines. Therefore, many of the disadvantages are actually concerns expressed after seeing demonstrations of these machines. Producers are interested in more demonstrations and unbiased information on this type of sprayer.

Table 4: Electrostatic sprayers (ex. ESS, Windmill, or AMS/On-Target)

Advantages	Disadvantages
extremely low application rate/acre	maintenance (keeping system clean)
TABLE GRAPES	re-sale value
Lower fuel costs	(lack) of familiarity
seems to be better efficacy, but don't cut pesticide rates	noise
Much less soil compaction in the vineyard because it uses so little water.	liquid flow limits
Really good at drift reduction	Coverage in heavy, thick canopies?
Small manufacturers = they will work to customize for your operation	Manufacturing companies too small to pay for independent testing
	More complicated, need training, need to be rinsed a couple times a day (a switch to hit). Canes can be draped over tubes and cause problems.
	People want to see the water on the crop and there is no visual here.
	Bad reputation from first generation of ES sprayers.
	Nozzles have to be a specific distance from the canopy

## 6. Barriers to Technology Adoption and Progress

Solutions for many of the problems discussed are commercially available or easily manufactured. Yet few of the more sophisticated technologies or even simple solutions are being utilized. The industry identified barriers to adoption within 4 major categories: machine related issues, lack of trust, lack of knowledge, and horticulture related issues.

Changes to and reliability of machinery are large problems for producers. Often a new sprayer or technology is thought to be cost prohibitive. Many growers are willing to pay more for a value-added sprayer (i.e. things that do more than spray), but a price point could not be identified. The required return on investment from a technology varied from 2-5 years. Incentives through cost sharing are highly desired because it potential decreases the ROI and risk to the producer. For example, many producers have been able to cost share directed spray towers through EQIP programs run by the Natural Resource Conservation Service.

The reliability and service of new machines is continuously questioned. Growers identified warranties, support, and readily available parts as top reasons for selecting technologies. Increasing warranties and support could increase confidence in newer sprayers. Working directly with the manufacturer is preferable over a dealer. However, growers are more likely to purchase from a local dealer who has familiarity with the customers and equipment. Regardless of where the technology is purchased, growers desired the ability for tools to rapidly assess the problem. Rapid diagnosis could sway their decision to purchase a technology.

Lack of trust in the machine, manufacturers and performance claims is probably not very different from other markets. There are basic points that growers wanted before purchase, but the points could apply to anything being sold. They want to be informed consumers with unbiased reviews on the reliability, performance and value. There needs to be proof that the technology works and the best selling point is the “neighbor effect”. Large changes and purchases take time. Specifically to sprayers, growers indicated that having a machine that allows them to test coverage could sway their decisions and have more confidence in their purchasing decisions.

There are many unknown issues that prevent growers from investing in technologies. In some of the cases, the research may not have been disseminated to the growers, but there is also the need for more work. There is a basic lack of knowledge on how the environment affects chemicals. Different practices—such as spray volume, materials used, and machines used—vary across geographic regions. These diversities of methods are often attributed to different environments (i.e. temperature, humidity, disease/pest pressure). Compounding this issue is that there is uncertainty on how the interaction of chemical, adjuvants, plant and application method affects the efficacy of the material and coverage. Lastly, as new technologies are purchased, there is a perceived risk in how long the machine will work with new materials being developed. For example, how will new delivery mechanisms like capsules change machines and nozzles? All of the uncertainty can lead to immobility, where no purchases or advances are made because they know that what they have now is working.

Changing the horticultural system on a perennial crop is not easily done. Good coverage with minimal drift is more easily attained on a smaller, trellised canopy. However, in some

commodities it is not yet possible to change the horticulture. More work must be done in pear rootstocks and training before there can be a significant decrease in size. In almonds, there is no financial incentive, other than spraying, to grow tree smaller than 15-20 feet. No ladders are used for harvest and all other maintenance operations can occur with a machine. Since it is unlikely that some of these systems will change in the near future, it is important to understand that there are at least two horticultural systems (i.e. small and trellised, large and free standing). Each perennial system needs solutions adapted to its architecture and unique problems.

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