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Pesticide Spraying in Indian River Grapefruit: II. Overview of Factors Influencing Spray Efficacy and Off-target Deposition

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Summary. **Foliar application of spray materials is an integral component of commercial citrus production. An intensive assessment of spray application practices has been stimulated by low fruit value and increased concern about potential surface water contamination in the Indian River citrus region of Florida. Many publications report research results regarding distribution of spray materials within orchards and off-target deposition, but interpretation is challenging because so many factors influence spray results, and integrating this information into practical recommendations is difficult. Canopy geometry and density are prominent factors contributing to variable deposition and spray drift. Environmental factors such as temperature, relative humidity, wind speed, and wind direction also greatly influence spray deposition and drift, and substantial changes can occur within seconds. In addition the physical and/or mechanical set up of the sprayer interact significantly with the other factors. A better understanding of these interactions should help growers optimize spray effectiveness and efficiency while reducing potential off-target effects.**

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Several important citrus (*Citrus* spp.) pests are controlled using foliar application of spray materials. Fresh market citrus typically demands more intensive pest control than fruit grown for juice, since common citrus pests often induce fruit blemishes that reduce market value (Knapp, 2001). The Indian River (IR) area is the primary fresh fruit producing region of Florida, representing 60% of the Florida fresh market citrus (Citrus Administrative Committee, 2001), but only 22% of Florida citrus acreage (Florida Agricultural Statistics Service, 2001). Since grapefruit (*Citrus paradisi*) represents 59% of fresh citrus shipped from the IR region of Florida (Florida Agricultural Statistics Service, 2001), and is also highly susceptible to common rind blemishing fungi (primarily melanose, caused by *Diaporthe citri*; greasy spot, caused by *Mycosphaerella citri*; and citrus scab, caused by *Elsinoë fawcettii*) (Timmer, 2001; Whiteside, 1988), it receives a high proportion of all sprays made to IR citrus. For this reason, pesticide application to grapefruit is the primary focus of this paper.

An intensive assessment of spray application practices has been stimulated by recent developments as indicated in Stover et al. (2002b), where information was presented from a 2001 survey of IR citrus spraying practices. In this document, relevant literature is explored and summarized (tabular summary in Appendix 1) to provide an understanding of factors influencing spray efficacy and off-target deposition. A future publication will outline opportunities for improving efficiency and reducing potential environmental impacts.

Developments in foliar spray application methods, 1940–2002

Early stages. Before the 1940s, trees were sprayed using hand-sprayers. Workers sprayed from 20 to 25 gal (75.7 to 94.6 L) per tree and attempted to completely cover all tree surfaces (Morgan, 1983). This method provided excellent uniformity of coverage, and likely provided maximum potential pest control given the timings and materials used. However, hand-spraying was a slow, labor-intensive process that routinely exposed applicators to spray materials. By the mid 1940s growers began to experiment with single side boom sprayers that saved time and reduced personnel exposure, but only applied materials to the tree exterior. Boom sprayers of that period used high pressure nozzles, but lacked fans to aid spray dispersion into the tree canopy. Boom sprayers further evolved into double-sided machines that covered two adjacent rows with each pass down the row middle. Similar sprayers using oscillating booms are still used in some citrus growing areas but only at very high spray volumes (Cunningham and Harden, 1998).

Airblast sprayers. With the invention of the airblast sprayer in 1937 (Fleming, 1962), it became possible to cover acreage more quickly, with fewer people and with even less applicator exposure. Use of these sprayers became routine for Florida citrus in the 1950s (P.J. Driscoll, personal communication). Airblast sprayers are now the most common sprayers used for commercial citrus production in the IR area (Stover et al., 2002b). Most airblast sprayers consist of a tank, a pump, two banks of nozzles which emit materials at a selected volume and pressure, and a fan which forces the spray material outward. Some units have an independent engine that drives the pump and fan while others are powered by the tractor power take-off (PTO).

Spray volume rate. The volume rate recommendations for Florida citrus were initially intended to duplicate handgun delivery rates: complete coverage was calculated as 5 gal + 1 gal per 1 ft of tree height (18.8 L + 12.4 L per 1 m of tree height) (Cromwell, 1975). Thus, a mature 20 ft (6.1 m) tree needed 25 gal of material, resulting in more than 2000 gal of spray per acre (18,707 $L \cdot ha^{-1}$) for a typical planting of 85 trees/acre (203 trees/ha). Since an individual sprayer had a capacity of 200 to 500 gal (760 to 1890 L) (Cromwell, 1975), it was necessary to refill with water and chemicals several times for each acre sprayed. Partly for this reason, growers and the scientific community began investigating the use of more concentrated sprays (Griffiths et al., 1950; King and Griffiths, 1948). Very low volume spraying was quickly recognized as problematic, requiring great attention to detail to be effective (Fleming, 1962). As a result, commercial interest waned. However, many growers recognized that spray volume could be reduced by half or more from full dilute rates without seriously compromising pest control (Cromwell, 1975; Griffiths et al., 1950). It was also recognized that reduction in leaf runoff could permit use of less spray material for the same degree of control (Cromwell, 1975; Steiner, 1977). The trend continues to be toward ever further spray volume reductions.

Dilute spraying still referred to application rates of 2000 gal/acre as late as 1975, and 500 gal/acre (4700 $L \cdot ha^{-1}$) was considered a 4× concentrated application (Cromwell, 1975). However, most IR growers now consider 500 gal/acre a dilute spray. Current application volumes of 250 gal/acre (2338 $L \cdot ha^{-1}$) or less are common for growers using airblast sprayers for fresh grapefruit sprays (Stover et al., 2002b). Very low application volumes [25 to 35 gal/acre (234 to 327 $L \cdot ha^{-1}$)] are used for some sprays on 14% of IR grapefruit acreage (Stover et al., 2002b) using sprayers such as the Curtec (BEI, Inc., South Haven, Mich.). These sprayers are equipped with stacked cross-flow fans and rotary atomizers, and are designed for low volume applications.

Diversity in current practices. Various innovations in sprayer design have been attempted to increase uniformity of coverage at low to moderate spray volumes. However, current spray application technology seldom realizes the same control potential of the hand-sprayer's more uniform coverage. They do, however, provide an opportunity for achieving the optimal balance between efficacy and efficiency based on existing economic conditions. The wide array of equipment available, combined with the variability and complexity inherent in spray coverage, has contributed to widespread uncertainty about actual differences between spray options, and their benefits and limitations. Growers largely approach spraying as an art, adopting new practices according to their tolerance of risking reduced disease control and experience to find an acceptable efficiency/efficacy balance. As a result of this *ad hoc* experimentation, spray practices are now extremely diverse within the IR citrus industry (Stover et al., 2002b). While the following analysis focuses on details of IR grapefruit spraying, we hope that it will provide useful guidance for anyone trying to select among diverse spray options through understanding the compromises and limitations inherent in each of them.

Factors influencing spray application efficiency and efficacy

Nonuniform spray coverage of trees and fruit is a significant concern for most commercial fruit growers. Variability in spray deposition is evident in almost all field trials reported in the tree fruit spray technology literature. As described in more detail below, spray deposition is strongly influenced by a wide array of factors, making this area extremely difficult for research. Canopy geometry and density are prominent factors contributing to variable deposition and spray drift (Derksen and Breth, 1994; Hall, 1991; Juste et al., 1990; Knoche et al., 2000; Whitney and Salyani, 1991). Environmental factors such as temperature, relative humidity, wind speed, and wind direction also greatly influence spray deposition and drift (Steiner, 1977; Zhu et al., 1994), and substantial changes can occur within seconds. In addition, the physical and/or mechanical set up of the sprayer (air volume and velocity; nozzle size, characteristics and arrangement; and physical profile) interact significantly with the other factors (Carman, 1977; Derksen and Breth, 1994; Derksen and Gray, 1995). The interrelationships between canopy geometry, environmental conditions, sprayer design, and operating parameters are so confounding that attributing results to any one element by itself is extremely difficult.

The practical significance of coverage varies according to the pesticide used and the pest requiring control. In most cases, control of mites [primarily citrus rust mite (*Phyllocoptruta oleivora*)], scale insects [over 40 species infest Florida citrus, the most important include florida red scale (*Chrysomphalus aonidum*), soft brown scale (*Coccus hesperidum*), purple scale (*Cornuaspis beckii*), cottonycushion scale (*Icerya purchasi*), glover scale (*Lepidosaphes gloveri*), chaff scale (*Parlatoria pergandii*), caribbean black scale (*Saissetia neglecta*), and citrus snow scale (*Unaspis citri*)], and most fungal diseases of foliage and fruit (primarily melanose, greasy spot, citrus scab, and alternaria caused by *Alternaria citri*) will not occur without achieving a minimum threshold concentration of the pesticide on treated surfaces (Bullock et al., 1968). Uniform deposition is not as important with pests such as mobile arthropods, since they may contact the pesticide as they move through treated trees. However, it is very important for controlling most fungal diseases of foliage and fruit, since infection develops where spores are passively deposited. Variability is also a factor when using pesticides that may cause phytotoxicity to the target trees, since higher levels of spray deposition may cause localized injury to foliage or fruit. For example, copper fungicide levels needed for disease control can produce minor fruit phytotoxicity, but risk is increased as copper levels increase (Albrigo et al., 1997; Schutte et al., 1997).

Interpretation of spray studies is often hampered by wide variability in procedures used for measuring parameters such as droplet size, spray deposition/coverage, and drift. Also, most researchers have focused on measuring spray deposition (total amount of material per leaf or fruit, often comparing different regions within the tree) since this is more objective and less difficult than measuring spray coverage (uniformity of material distribution on individual leaves or fruits throughout the tree) (Bateman, 1993; Salyani, 2000; Salyani and Whitney, 1988), even though coverage may be more important for commercial production. In addition, few experiments assess actual pest control or include deposition data for the upper canopy of tall trees. These factors hinder translation of experimental data into a real-world context.

Combined, these factors result in widespread grower perception that spray research information often does not help them make useful decisions. The following sections focus on the factors and interactions that affect spray deposition efficiency and efficacy. These factors are grouped into four categories: 1) canopy geometry and density, 2) weather (environmental conditions), 3) spray machine set-up and design, and 4) interactions between these factors. This information should provide a useful background for anyone interested in optimizing orchard spraying.

CANOPY GEOMETRY AND DENSITY. A tree crop is a complex target in which thickness, shape, and foliage density varies (Knoche et al., 2000). Variability in deposition within the tree canopy appears to increase as tree canopy density increases (Hall, 1991). Since current sprayers only apply materials from the trees' exterior, there is usually greater deposition on the exterior foliage, with total deposition declining toward the interior and top of the tree canopy regardless of spray volume (e.g., Salyani and Hoffmann, 1996). Citrus trees generally have greater canopy density than most other tree crops, making uniform coverage especially difficult. Shielding by neighboring leaves and fruits results in some fruit surfaces with poor deposition (Albrigo et al., 1997) and can result in wide variability in deposition between neighboring leaves. The higher exterior canopy density, common to grapefruit, typically results in the interception of a large proportion of the spray before it reaches the tree interior (Salyani and McCoy, 1989). In addition, high outer canopy density may also result in greater spray reflection/deflection over trees and consequent drift compared with similar sized trees of other crops (Spray Drift Task Force, 1997). Several studies have documented rapid decline in air velocity and material distribution as spray enters the tree canopy, especially in the upper interior of the tree (Bukovac, 1984; Carman and Jeppson, 1974; Fox et al., 1983).

WEATHER. Weather conditions such as wind speed and direction, relative humidity and temperature can markedly affect both tree and off-target deposition during a spray application. Previous research indicates a strong interaction between these weather parameters and droplet size (Hoffmann and Salyani, 1996; Reichard et al., 1992; Steiner 1977).

Wind. Wind speed is probably the single most important environmental factor affecting spraying. Therefore, studies focusing on spray technology are usually conducted under low-wind conditions (Salyani, 2000; University of California, 1996). Zhu et al. (1994) reported that wind speed as low as 3 to 5 miles/h (mph) (1.3 to 2.2 $m{\cdot}s^{-1}$) substantially altered movement of droplets less than 200 μm in diameter. Distance that droplets were deflected was inversely related to droplet size (i.e., smaller droplets deflected more than larger droplets) (Fig. 1; Zhu et al. 1994)

Channeling and blocking of wind within the confines of the grove and surrounding structures make wind speed and direction highly irregular in the field. In a recent survey, IR citrus producers reported no direct monitoring of wind conditions when spraying (Stover et al., 2002b). Those growers most commonly relied on visual evidence that the sprays were not reaching the trees to decide whether or not to spray. This practice may be misleading, since the more visible, larger droplets are less affected by wind, and may readily reach target surfaces. However, the smaller, less visible droplets may be carried away with the wind, and some droplets may never reach their intended targets. Wind speed during spray application can also play an important role in pollution resulting from off-site drift.

Temperature and humidity. Along with wind speed and direction, temperature and relative humidity affect the likelihood of smaller droplets impinging on the target. At a relatively high temperature and low humidity, significant evaporation can occur before some spray droplets reach the adjoining tree (Reichard et al., 1992; Zhu et al., 1994).

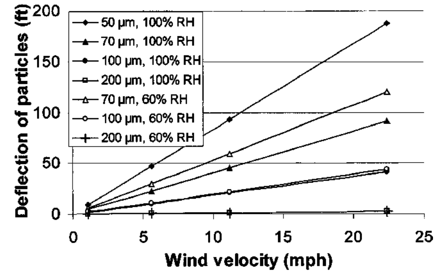

Fig. 1. Effect of windspeed on spray droplet deflection. Droplets discharged at 44 miles/h (mph) (20 $m{\cdot}s^{-1}$) at a target 1.6 ft (0.5 m) below at 68 °F (20 °C). RH = relative humidity, 1 ft = 0.3 m, 1 mph = 0.45 $m{\cdot}s^{-1}$. Adapted from Zhu et al. (1994).

This is especially important with droplets smaller than 70 μm (Fleming, 1962; Zhu et al., 1994). At 80% humidity, 86 °F (30 °C) and wind speeds of 11.2 mph (5 $m{\cdot}s^{-1}$), any 50 μm or smaller droplet will evaporate before it travels 1.6 ft (0.5 m) (Zhu et al., 1994). Even larger droplets evaporate to some extent as the temperature increases or the humidity decreases.

SPRAY MACHINE DESIGN AND SET-UP. A central goal of sprayer design is development of machines which efficiently and effectively deliver spray materials with reasonable uniformity over tree surfaces. Most orchard sprays in the U.S. are applied using some type of air-assisted tractor-drawn sprayer. Various modifications to these sprayers have been made with the goal of increasing application efficiency and/or effectiveness of pest control. The following sections describe each sprayer type and equipment modifications commonly employed for improving spray coverage.

Airblast sprayers. Airblast sprayers are by far the most common sprayer type used by IR citrus growers (Stover et al., 2002b) and for most other tree fruit industries (Derksen and Breth, 1994). The majority of sprayers currently in use are fundamentally unchanged since the first airblast machines were released. Most have a single axial fan that is used for blowing spray materials at target trees. The spray materials are delivered to the air currents through a radial configuration of spray nozzles. Airblast sprayers may be engine-driven or tractor PTO-powered.

The sprayers are designed to accommodate 7 to 40 nozzles per side. Nozzles with different output can be selected for different positions along the manifold, providing opportunities for tailoring the spray pattern to individual needs. Sprayer output can be adjusted by selecting nozzle disc and core combinations, changing the pressure, or by selectively shutting off nozzles. While most IR citrus growers use airblast machines for spray volume rates of 125 gal/acre (1170 L·ha^{-1}) or higher, they can be nozzled to deliver much lower volumes, while providing reasonable spray coverage (Whitney and Salyani, 1991). However, small orifice nozzles clog frequently when using particulate spray materials and unfiltered water supplies. These factors establish a practical lower limit for sprayer output in each individual operation.

Application rate per unit area is determined by the output per minute and sprayer ground speed. Since fan rpm is controlled by a separate engine for the engine-driven sprayer, application rate can easily be adjusted through a continuous range of tractor speeds. However, a PTO-driven machine must use the rpm designated for sprayer operation, and tractor speed is a function of gear selection at that rpm.

Airblast sprayers vary widely in the air velocity and volume displaced per minute. While these factors are determined by sprayer design and set-up, they are best understood by considering their interaction with tree characteristics, and are discussed below.

Low-volume sprayers. The second type of sprayer in common usage for IR citrus is specifically engineered for applications at low volumes (i.e., 20 to 50 gal/acre; 185 to 470 L·ha^{-1}). Often called concentrate sprayers, machines such as the Curtec and AgTec (AgTec Crop Sprayer, Minnetonka, Minn.), are also air-assist sprayers. Unlike airblast sprayers, AgTec and similar machines use squirrel cage fans to generate high-velocity air for air-shear nozzles, while Curtec uses 6 to 8 individual cross-flow fans with rotary atomizers stacked in a tower. The fans can be angled to fit the tree geometry. Manufacturers recommend spray application at ground speeds as high as 3 mph (4.8 km·h^{-1}) versus the standard 1 to 2 mph (1.6 to 3.2 km·h^{-1}) for most airblast applications. The higher ground speeds during spraying and reduced fill-time (compared to airblast sprayers operating at higher volumes), greatly increases the potential acreage sprayed per hour, and may reduce the number of sprayers needed to effectively manage the same amount of acreage. However, there is concern that these low volume machines may not provide adequate coverage in larger, dense trees (Albrigo et al., 1997; Whitney and Salyani, 1991), or provide the complete coverage recommended when using oil sprays for pests like snow scale (Brooks and Whitney, 1973) or red scale (*Aonidiella aurantii*) (Carman, 1983).

Interactions between sprayer parameters, tree characteristics, and weather conditions. These factors may significantly interact, influencing spray efficacy and efficiency. Important sprayer parameters involved in these interactions include sprayer air velocity and displacement, droplet size, and height and distribution of spray nozzles.

Sprayer air velocity and tree characteristics. An understanding of spray stream and canopy interactions is essential for understanding the spray deposition process. Air volume and speed affect the ability of droplets to impinge on leaves or fruit, and the ability of large droplets to reach the target before falling to the ground (Fleming, 1962). Even when unobstructed, air velocity of the spray stream declines rapidly over short distances (Fig. 2; Fox et al., 1983). Disruption of air movement by the canopy further reduces air velocity (Fox et al., 1984). Pressure builds up in front of leaves, branches and fruit as air flows through and around the tree, resulting in a pressure boundary layer. As a result, smaller droplets with less kinetic energy cannot impinge on the target and are deflected (Cromwell, 1975; Fleming, 1962) when they encounter this boundary layer. In contrast, larger droplets possess more kinetic energy, have higher terminal velocity, and are less easily deflected from their original trajectory. However, the higher percentage of the larger droplets impacting the outside foliage often results in greater amounts of spray material runoff from the foliage. Slower application speeds using the same spray volume may result in more even interior spray deposition (Salyani, 1995).

Sprayer air displacement. Sprayer air volumetric flow rate, often described in cubic feet per minute (ft^3/min) or cubic meters per second (m^3·s^{-1}), affects the sprayer's ability to replace the air in the tree canopy with spray-laden air. It has been widely accepted for the past 50 years that successful tree coverage requires a sprayer capable of completely replacing the volume of air in the tree with the same volume of air issuing from the sprayer (Cromwell, 1975). This idea was expressed in the recommendation that travel speed should not exceed the value which allows complete air displacement within the tree row, as determined by the sprayer fan air capacity and the number of seconds in which an individual tree is sprayed. Agricultural engineers now consider this recommendation to be conservative, since additional air is entrained with the spray stream to push aside the volume in the tree canopy. However, there clearly is some level where adequate interior coverage will not be possible because of excessive ground speed. This may contribute to the observation by Salyani and Whitney (1991) that uniformity of deposition is highest at lower ground speeds, and decreases as speed increases (especially towards the interior of the tree), when they compared ground speeds ranging from 1 to 4 mph (1.6 to 6.4 km·h^{-1}) with the same spray delivery volume. Also, melanose control on interior grapefruit was reduced at partial versus complete air displacement (Stover et al., 2002a). It is worth noting that most published airblast trials are conducted using conditions that approximate complete air displacement (calculations on published data, e.g., Derksen and Gray, 1995; Whitney and Salyani, 1991).

Sprayer modifications to enhance coverage. Sprayer design can substantially influence coverage and potentially influence pest control. Good spray coverage in the upper interior of a tall tree is the greatest challenge in citrus pest control (Bullock and Brooks, 1983; Carmen and Jeppson, 1974). A typical airblast sprayer has its highest nozzles at 5 to 8 ft (1.5 to 2.5 m) above the ground, while height of a mature grapefruit tree may exceed 20 ft (6 m). Spray from the upper nozzles must travel some distance to reach the upper interior of such a tree, in addition to having to pass through several layers of leaves in the upper tree exterior. The density of spray droplets per cubic foot of airstream

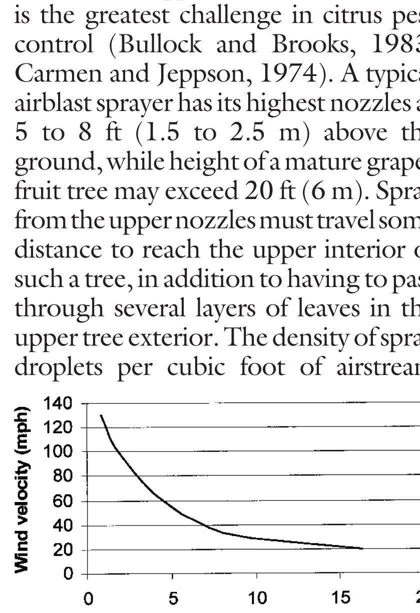

Fig. 2. Effect of distance from outlet on air velocity from a fan jet; 1 ft = 0.3 m, 1 mph = 0.45 m·s^{-1}. Adapted from Fox et al. (1983).

decreases greatly with the distance from the nozzle to the target. This is the basis for the recommendation that 2/3 of the total spray material be directed to the upper half of the tree when using an airblast sprayer with conventional radial delivery. In the past this was achieved by placing larger nozzles in the top half of the sprayer, but in most modern sprayers, the same effect is achieved by designs that position nozzles closer together in the upper half of the sprayer manifold.

Adjusting the sprayer configuration to better match the canopy shape can provide more even spray distribution (Carman, 1977; Derksen and Gray, 1995). One low volume study which utilized nine different sprayer models demonstrated how difficult it is for a low profile machine to place material at the top of a tree due to canopy geometry (Carman and Jeppson, 1974). Some sprayer manufacturers have either placed the nozzles on towers or directed the spray through a tower volute to bring the air-blast closer to the top of the tree for more even deposition (Carman, 1977; Derksen and Gray, 1995). Comparison of sprayers with and without towers has shown that towers increased deposition in the upper portion of the tree, although the towers must be properly aimed (Carman, 1977). Recommendations for California growers have included the suggestion that no tree over 11 ft (3.4 m) be sprayed without a tower (University of California, 1984). The low volume Curtec sprayer uses towers to enhance spray delivery.

Another common modification of sprayers has been the inclusion of oscillating nozzle banks or airstreams. Use of oscillators is based on the idea that fluctuations in air stream direction will more effectively move aside leaves and increase spray penetration into the tree interior and coverage on both sides of leaves. Data on the value of oscillation are conflicting. Salyani and Whitney (1991) reported no increase in coverage or deposition using oscillators; while Brooks (1969) suggested a benefit for dilute sprays but minimal value for concentrate sprays. Some growers have a strong preference for use of oscillation in trees with dense foliage.

Droplet size and interactions. Spray droplet size distribution is a crucial factor influencing many aspects of both deposition on-tree and off-target spray losses. Sprayer design and nozzle configuration influence the distribution of droplet sizes, which is further influenced by environmental conditions during the application.

Disc-core nozzles currently used for airblast spray machines generate a wide range of droplet sizes while rotary atomizers used with low-volume Curtec machines produce a much narrower range and generally smaller droplet sizes. On conventional airblast sprayers, fine droplets are generally generated by smaller nozzles. Droplet sizes are conventionally indicated by their diameter in micrometers. A useful statistical parameter used to describe sprayer output is the volume median diameter (VMD), which is the droplet diameter at which half of the total spray volume is comprised of smaller droplets. The advantages and disadvantages of small versus large droplet sizes amply illustrate the complexity associated with optimization of spray applications.

In general, larger droplets have more kinetic energy and therefore have a more sustained trajectory toward the target, with less risk of being diverted by wind, evaporating to prevent deposition, or being unable to impinge on tree surfaces by penetrating the boundary layer. However, Hislop (1987) reported that droplet sizes of 300 μm or less have greatest retention, since larger droplets are more likely to roll off of the foliage and fruit, contributing to runoff. Total spray retention is greater with smaller versus larger droplets. This is true even when spraying to drip (i.e., 100-μm drops providing 33% greater spray retention than 200-μm drops) (Cunningham and Harden, 1998). Proper selection of a spray adjuvant can increase retention of larger droplets and reduce runoff, but may increase runoff if excessive surfactant is present (Hock, 1994) or spray volume exceeds foliar retention capacity.

For practical considerations with currently available sprayers, it is not possible to completely separate the issues of droplet size and spray volume per acre. Nozzles producing small droplets also produce less volume per unit time. With the limited spaces for nozzle placement on most sprayers and a fairly narrow range of reasonable tractor speeds, smaller droplet sizes translate into lower spray volumes per acre. Use of larger droplets also requires more spray volume to achieve the same coverage of the target surface area (Dibble, 1983) because of the greater volume per surface area in large droplets. In contrast, good coverage can be achieved with lower volumes when smaller droplets are used.

When different spray volumes were applied to mature citrus, Salyani and McCoy (1989) concluded that the larger droplets associated with higher volumes were more likely to coalesce and runoff of outer foliage, while a higher proportion of smaller droplets were retained on exterior surfaces and were distributed less consistently throughout the canopy. These two properties contribute to greater variability of deposition between exterior and interior surfaces with low volume, fine droplet applications (Bukovac, 1984; Salyani and McCoy, 1989). Smaller droplet sizes also increase drift potential (Bukovac, 1984; Salyani, 1995) regardless of spray volume (Knoche et al., 1998). In practice, both environmentally and economically, one must weigh the relative importance of runoff from larger droplets versus greater deflection of smaller droplets (Fleming, 1962).

Selection of an appropriate array of nozzles may provide the best compromise for use in airblast sprayers. Salyani (1988) demonstrated that greatest deposition on leaves close to the sprayer occurred with spray comprised primarily of moderately small droplets (length mean diameter of 270 to 340 μm), while spray including much larger droplets (610 to 720 μm) provided maximal deposition on the most distant targets. The benefit of large droplets on distant targets may be even greater in the field, since droplet size may decrease by 25% to 50% before reaching the tops of trees (Brann, 1965). This suggests that optimal field configuration may involve use of smaller nozzle diameters in mid to low manifold positions, with larger nozzles in the upper positions.

Factors influencing drift and off-target environmental contamination

Off-target deposition of spray material is both an economic loss to the grower and a potential environmental problem. Environmental issues related to spraying in the IR area include off-target deposition due to drift and to foliar runoff. These are considered below.

DRIFT. Drift refers to spray material that is carried away aerially by sprayer generated air movement or natural wind, and is not deposited on the intended target. Evaluating these losses is very difficult since accurate studies are expensive and variability of factors influencing drift is high. Actual measurement of total on-target deposition is prohibitively difficult, so researchers typically measure ground deposition and drift to develop estimates. Problems associated with drift measurement are exemplified by a study in mature grapefruit where substantial spray material was recovered even at the maximum sampled height [39 ft (12 m)] (Spray Drift Task Force, 1997) making total drift assessment virtually impossible. Ideally samples would be collected to heights and distances from the spray source where the tracer becomes nondetectable.

When considering past research regarding spray drift measurement, it is important to realize the limitations of those studies. Differences in methodology, canopy characteristics, wind and other weather factors, and planting density may all significantly affect the results of drift studies.

Results from studies measuring off-target deposition share several common conclusions. Smaller droplets are more prone to drift, and the percentage of material drifting off-site increases with both wind speed and decreased droplet size, and ground deposits typically are greatest within 50 ft (15.2 m) of the sprayer (Fox et al., 1993; Hobson et al., 1993; Salyani and Cromwell, 1992; Walklate, 1992). This occurs because the larger droplets fall out within a short distance, due to gravity and air resistance, whereas smaller droplets tend to travel for extended distances. When samples are collected during spraying, ground deposition per unit air volume declines rapidly with the distance from the sprayer; however, airborne material typically exceeds ground deposits at about 200 ft (61 m) from the spray course (Fox et al., 1993; Salyani and Cromwell, 1992). This airborne material can travel great distances before deposition.

Identification of a drift-prone droplet size threshold or critical wind speed is attractive but somewhat arbitrary. Some authors have suggested 100 μm as the threshold for droplets with high drift potential (Demitrievits, 1994; Hislop, 1987; Hobson et al., 1993), others have suggested 141 μm (Spray Drift Task Force, 1997), while still others indicate that droplets under 200 μm are very prone to drift when wind speed exceeds 5 mph (Reichard et al., 1992; Zhu et al., 1994). Sprayers built specifically for low volume applications, such as Curtec and AgTec, generally produce droplet spectra well within the range specified for high drift potential. However, even conventional nozzles used for higher volume applications produce a significant volume of droplets smaller than 200 μm in diameter (Steiner, 1977). Therefore, some potential for drift is evident with most spray applications. Spray directed above the trees is considered much more likely to be carried considerable distances. Proper adjustment of sprayer nozzles so that they hit the target trees is recommended for minimizing drift. Use of technology that directs spray more closely to the target trees may also aid in reducing off-target losses due to drift. Such technology may include the use of towers that direct spray laterally or downward onto the tree (Carman, 1977).

Salyani and Cromwell (1992) considered losses due to drift from airblast applications to citrus. Within the first 50 ft, they reported 50% greater ground deposition of the applied material in the high volume applications [544 gal/acre (5088 $L \cdot ha^{-1}$)] versus low volume [72 gal/acre (673 $L \cdot ha^{-1}$)]. However the same study revealed a 22% loss due to drift past the target tree for low volume and 8% for high volume applications (based on nominal application rate). Estimates of off-target deposition in apples ranged from a low of 30% using an application rate of 60 gal/acre (560 $L \cdot ha^{-1}$) to a high of 45% at 400 gal/acre (3740 $L \cdot ha^{-1}$) (Steiner, 1977).

A number of strategies have been proposed for decreasing drift from orchard pesticide applications. Heijne (2000) reviewed proposed strategies and concluded an easily implemented approach with high probability of success is use of air-injection nozzles to increase droplet size, combined with routine use of surfactants to reduce reflection and enhance coverage from these larger droplets. However, Heijne indicated that tests of pest control and drift from use of this system are needed.

Runoff of spray from the canopy. The potential for surface water contamination in the IR area is not restricted to long-range drift of spray materials as is common in many agricultural areas. Most of these groves are situated on poorly drained soils with shallow hardpans. These groves are almost always bedded to facilitate drainage and contain networks of water furrows and relatively closely spaced ditches. Off-target spray deposition to water in these ditches may present significant ecological risks. Likewise, materials deposited on the grove floor may be quickly carried into surface water through grove drainage.

Estimation of the environmental significance of spray material running off of tree surfaces is difficult. Efficient spray retention may reduce the total amount of pesticide needed to control a given pest, since materials not remaining on the target are not contributing to pest control. However, few studies have examined the fate of pesticides that runoff onto soil during the spray process versus more gradual runoff from the canopy during weathering. Materials that are decomposed by ultraviolet radiation are likely to decline more rapidly on foliage than in the soil. It is also possible that heavy deposition at the canopy drip line from a high-volume spray may increase the probability of substantial spray entry into surface waters by exceeding the soil binding capacity, whereas more gradual and widely distributed weathering from leaves may prolong the soil's ability to retain agrochemicals.

Cunningham and Harden (1998)

Table 1. Estimates of spray deposition and loss following application with a commercial orchard sprayer at several spray volumes to mature 'Ellendale' trees in Australia (from Cunningham and Harden, 1998). All applications compared at 1 mile/h, volume median diameter (VMD) of 136 to 138 μm and identical tracer concentration

Application rate (gal/acre)[z]	Leaf spray recovery (%)	Runoff from canopy (%)	Unaccounted spray material (%)[y]
107	39.8 a	4.7 c	56
214	34.5 ab	5.4 c	60
428	21.8 cd	9.0 b	69
856	16.9 d	16.2 a	67

[z]Spray volume: 107, 214, 428, and 856 gal/acre = 1000, 2000, 4000, and 8000 $L \cdot ha^{-1}$, respectively.

[y]Calculated from Cunningham and Harden (1998) data. This category would include material on trunk and branches, fallout onto orchard middles, and drift.

investigated efficiency of application to mature citrus trees at 107, 214, 428, and 856 gal/acre (1000, 2000, 4000, and 8000 $L \cdot ha^{-1}$). With the tracer material applied at a uniform concentration, total deposition was increased with greater spray volume, but efficiency of deposition declined. Compared at 1 mph sprayer speed, they estimated that 40% of the material was deposited on the canopy at 107 gal/acre, 34% at 214 gal/acre, 22% at 428 gal/acre, and 17% at 856 gal/acre (Table 1). The percentage of spray material falling from the canopy as runoff increased substantially when application rate exceeded 214 gal/acre; 5% of material was lost as runoff at 107 to 214 gal/acre, 9% at 428 gal/acre, and 16% at 856 gal/acre.

Conclusions

Many factors influence spray deposition and distribution both on- and off-target. Further confounding the issue, surprisingly few experiments find significant differences when comparing aspects of spray technology such as ground velocity, nozzle arrangement, deposition, etc. The largest problem confronting such research is high variability for deposition, making it necessary to use large numbers of replicates to identify real differences.

Interactions between the factors influencing spray deposition, efficiency, and efficacy prevent conclusions of single cause-and-effect relationships for achieving good pesticide activity while minimizing environmental contamination and inefficiency. However, attention to interactions between a few factors appear likely to give growers a large measure of control over spraying while still permitting improved economic efficiencies and reduced potential for environmental contamination. This approach will be explored and summarized in part III of this series.

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Appendix 1. Summary of critical points from references on spray practices. Readers are encouraged to refer to the original papers to understand the experimental context.

Reference	Points of interest
Albrigo et al., 1997	1. Copper (Cu) fungicide levels (in combination with spray oil) used for disease control can blemish fruit. Risks increase as copper levels increase. 2. Shielding by neighboring leaves and fruits results in some fruit surfaces with poor deposition. 3. Concern exists that low volume spray machines may not provide adequate coverage in larger, dense trees. 4. Total spray deposits were inversely related to spray volume.
Bateman, 1993	1. Coverage may be more important than total amount deposited if most deposited droplets contain a lethal dose. 2. Control of immobile insects requires excellent coverage.
Brann, 1965	1. The velocity of the sprayer airstream decreases rapidly with distance from the outlet. 2. Under field conditions, sprayer air velocity in the tops of apple trees is generally 20 miles/h (mph) (8.9 $m \cdot s^{-1}$) or less. 3. As sprayer air velocity decreases, larger sized droplets tend to fall out of the airstream. 4. Deposition of small droplets is not likely in tops of trees due to low air velocity. 5. Low relative humidity (RH) increases evaporation of spray droplets. 6. As RH decreases, the rate of droplet deposition in tree tops decreases.
Brooks, 1969	1.Oscillation improved coverage with speed-sprayer dilute sprays, but interfered with the effective ness of concentrate applications.
Brooks and Whitney, 1973	1. Dilute high-volume sprays resulted in better citrus snow scale control than low-volume concentrate sprays.
Bukovac, 1984	1. Optimum pesticide performance requires complete and uniform coverage of target by the appropriate dose. 2. Nonuniform distribution of sprays over trees appears to be a common deficiency of low-volume application (i.e., lower portions of tree oversprayed, while upper portions are undersprayed). 3. Low-volume sprays contain a high percentage of small droplets (80 µm and less). Efficient transfer and impaction of these droplets poses a special challenge.

Appendix 1 (continued). Summary of critical points from references on spray practices. Readers are encouraged to refer to the original papers to understand the experimental context.

Reference	Points of interest
Bullock and Brooks, 1983	1. Delivery of spray materials to the top, interior of trees is a measure of success for sprayers.
Carman, 1977	1. The physical and/or mechanical set up of the sprayer influences spray deposition. 2. Adjusting the sprayer configuration to better match the canopy shape can provide more even spray distribution. 3. Comparison of sprayers with and without towers has shown that use of towers increased deposition in the upper portion of the tree, although the towers must be properly aimed. 4. Substantially higher droplet deposition in all areas of the tree (including top center area) was achieved using units equipped with air tower modifications.
Carman, 1983	1. Inadequate droplet deposition in the upper tree top canopy limits usefulness of low volume spray units.
Carman and Jeppson, 1974	1. Citrus trees are difficult spray targets because of dense canopy structures. 2. The basic growth pattern of citrus poses a particular difficulty for low silhouette machines since the spray can not be carried to the top center of the tree with sufficient force or efficiency. 3. Ground sprayers may differ greatly in spray droplet deposition patterns.
Cromwell, 1975	1. Spray volume recommendations for Florida citrus were initially intended to duplicate handgun delivery rates: complete coverage per tree was calculated as 5 gal + 1 gal per 1 ft of tree height (18.9 L + 12.4 L per 1 m of tree height) 2. Larger-sized droplets are more likely to have sufficient momentum to impinge on the tree. 3. Described air displacement theory (ADPT): air within a tree must be completely displaced by the pesticide-laden air from the sprayer. States that ADPT may be too conservative. Some sprayers are effective at speeds in excess of that dictated by the theory. 4. Reduced filling time is probably the biggest advantage of a concentrate spray program. 5. Concentrate spray program disadvantages: affected more by relative humidity and sprays must be applied more carefully.
Cunningham and Harden, 1998	1. The amount of spray deposited on the canopy decreased as the spray volume increased, when compared at constant sprayer ground speed. 2. With a tracer material applied at a uniform concentration, total deposition was increased with greater spray volume, but efficiency of deposition declined. 3. The percentage of spray material falling from the canopy as runoff increased substantially when application rate exceeded 214 gal/acre (2000 $L \cdot ha^{-1}$). 4. Total spray retention is greater with smaller versus larger droplets. This is true even when spraying to drip (i.e., 100-µm drops providing 33% greater spray retention than 200-µm drops). 5. The use of air-tower sprayers, operating at 214 gal/acre or less, could significantly reduce the amount of pesticide used on mature citrus compared to spraying with high-volume equipment. 6. Use of lower water volumes increases on-target retention of spray material, which will increase effectiveness of pesticides registered on a dose per acre basis, and reduce pesticide contamination risk for the soil and air.
Demitrievits, 1994	1. Droplets below 100µm in diameter can drift several hundred meters with 9 to 13 mph (4 to 6 $m \cdot s^{-1}$) wind velocities. 2. 11.8 to 16.6 percent of total spray applied in fruit orchards was deposited on soil within the sprayed orchard
Dibble, 1983	1. Properly applied concentrate sprays are as effective as properly applied dilute treatments. 2. Droplet size must decrease as spray volume rates decrease, potentially increasing drift hazards.
Derksen and Breth, 1994	1. Tree management and application rate appear to be the most significant factors affecting spray coverage. 2. Spray coverage was not a function of sprayer type, but was more closely related to the rate of application. Applications using more than 50 gal/acre (470 $L \cdot ha^{-1}$) had best coverage. 3. The top inside of all tree sizes generally had the poorest spray coverage.
Derksen and Gray, 1995	1. Fan speed did not significantly influence levels of deposit. 2. Air deliver ratings from manufacturers are not good indicators of spray deposition. 3. More uniform deposit patterns were produced by uniform emission of spray along the vertical plane of the canopy. 4. No direct relationship existed between air speed within a tree canopy and spray deposition for sprayer configurations evaluated.
Fleming, 1962	1. The first precursor to the air-blast sprayer was invented in 1937. 2. Very low volume spraying requires greater skill and attention by operators to avoid phytotoxicity. 3. As much as 60% of the volume of a spray may be lost to evaporation. 4. The likelihood of impingement on the spray target decreases as droplet size and velocity decreases. 5. Three factors control droplet impingement on an object: droplet size, air velocity at the object, and the size/shape of the object. 6. Greater initial air velocity is needed to keep larger droplets airborne for a reasonable distance. 7. For spray stream transport, the greatest inefficiency results from larger droplets settling out before they reach the target. These droplets represent a much greater volume than small droplets that fail to impinge.

Appendix 1 (continued). Summary of critical points from references on spray practices. Readers are encouraged to refer to the original papers to understand the experimental context.

Reference	Points of interest
Fox et al., 1983	1. Air velocity and uniformity of spray distribution decrease rapidly as spray penetrates the tree canopy, especially in the upper interior of the tree. 2. Air velocities are much more variable in the center and far side of the tree.
Fox et al. 1993	1. Off-target deposition due to drift varies considerably. 2. At locations beyond 200 ft (61 m) downwind, most droplets are small or have evaporated to small residue particles that are easily carried by air currents and have very low settling velocities. 3. Airborne spray deposits decreased less with increased downwind distance than did ground deposits. 4. At 100 ft (30 m) downwind, ground deposits from spraying through trees were not significantly different from deposits resulting from similar sprays with no trees present.
Griffiths et al., 1950	1. A savings of 75% in the amount of water handled can be realized if spray mixture is concentrated four times the ordinary strength. Similar savings are also associated with the amount of time saved in filling tanks.
Hall, 1991	1. Vital factors influencing the efficiency of the spray application process include tree height, planting distances, tree shape, growth (and seasonal) patterns, and the expertise of the operator to match the application with the target geometry. 2. Efficient applications require accurate control of travel speed and adjustment of liquid flow to the foliar target. 3. Delivery to arrays of canopies or tree geometries can be improved by a) matching sprayer delivery/canopy geometry for each block, b) developing a block-by-block crop protection strategy, and c) improving grower appreciation for information management and knowledge of productiv ity/price relationships and crop losses on their farms to optimize pesticide management in their orchard.
Hislop, 1987	1. In general, droplet sizes of 300 µm or less are retained on foliage and fruit better than larger ones. 2. Some authors have suggested 100 µm as the threshold for droplets with high drift potential 3. Frequently, spray deposition and biological results are poorly correlated. 4. Deposit variability in the field is often greater for small compared with larger spray volumes.
Hobson et al., 1993	1. Spray drift increased approximately linearly with wind speed. 2. Drift was shown to increase significantly in atmospheric conditions that enhanced droplet evaporation. 3. Predicted spray drift increased with increasing crop height for the same wind speed measured at 6.6 ft (2 m) above the ground.
Hoffmann and Salyani, 1996	1. Mean deposition and variability of deposition increased as spray volume decreased. 2. Diurnal timing of spray application had a significant effect on deposition. In general, depositions were higher for night-time [lower temperature (T) and higher RH] as compared to daytime (higher T and lower RH) applications. 3. Spray volume had a significant effect on deposition. The lowest and the highest spray volumes gave the highest and lowest depositions, respectively. Variability of deposition within the tree increased as spray volume decreased. 4. Deposition generally decreased and coefficient of variation increased as the sampling height within sprayed trees increased and became more distant from the sprayer.
Juste et al., 1990	1. Lower deposition was obtained with air-assisted equipment than with hydraulic equipment, especially in the interior and central zones of the tree. 2. Tree height was a significant factor contributing to lower depositions in upper parts of the tree because the trees were taller than the effective reach of the air-assisted equipment.
King and Griffiths, 1948	1. Lack of complete coverage would appear to eliminate the use of concentrated sprays for routine grove spraying (as conducted in 1948). 2. There are certain inherent problems which prevent practical or general use of concentrate spray programs in groves.
Knoche et al., 1998	1. Decreasing droplet size and increasing carrier volume improved performance of plant growth regulators. This effect was related to a corresponding change in coverage. 2. Decreasing droplet size at constant volume may also increase spray drift and hence off-target deposition. In contrast, increasing coverage by increasing volume will improve performance without compromising the efficacy of droplet transfer to the target, provided that the volume applied does not exceed the retention capacity of the leaves.
Knoche et al., 2000	1. Increasing travel speed decreased the volume of spray solution retained per unit leaf area. 2. Retention efficiency was independent of the spray volume applied at the speeds and volumes used. 3. A positive relationship was obtained between leaf coverage and volume applied, until volumes were reached were droplets began to coalesce, indicating overlap of deposits.
Reichard et al., 1992	1. Drift distances of droplets increased with increasing wind velocity and height of discharge, but decreased with increasing initial droplet size and velocity. 2. Changes in RH had much greater influence on drift distances of water droplets less than 100 µm in diameter than on larger droplets.

Appendix 1 (continued). Summary of critical points from references on spray practices. Readers are encouraged to refer to the original papers to understand the experimental context.

Reference	Points of interest
Reichard et al., 1992 (continued)	3. The range of drift distances increased with atmospheric turbulence intensity and was much greater for 100 than 200 µm diameter water droplets.
Salyani, 1988	1. Greatest deposition on leaves close to the sprayer occurred with spray comprised primarily of moderately small droplets (length mean diameter of 270 to 340 µm), while spray including much larger droplets (610 to 720 µm) provided maximal deposition on the most distant targets.
Salyani, 1995	1. Spray volume had a significant effect on deposition, but the effect varied at different canopy locations. 2. Sprayer travel speed did not affect mean deposition; but variability of deposition increased at higher speeds. 3. Both high and low volume applications produced measurable ground and airborne drift deposits up to 640 ft (195 m) downwind of the applications. 4. Overall the high volume application resulted in more ground deposition than did low volume application
Salyani, 2000	1. Spray technology research suffers from lack of an accurate, easy, and inexpensive method for evaluation of pesticide deposition that works for diverse situations.
Salyani and Cromwell, 1992	1. When samples are collected during spraying, ground deposition per unit area declined rapidly with the distance from the sprayer; however, airborne material typically exceeded ground deposits about 200 ft (60 m) from the spray course. 2. More than 70% of the airborne deposits resulted from applications to the last two rows closest to the downwind edge of the grove. 3. Within the first 50 ft (15 m) from the airblast sprayer, 50% greater ground deposition of the applied material occurred in the high volume applications [544 gal/acre (5088 $L \cdot ha^{-1}$)] versus low volume [72 gal/acre (673 $L \cdot ha^{-1}$)]. However, a 22% loss due to drift past the target tree for low volume and 8% for high volume applications was also reported.
Salyani and Hoffmann, 1996	1. Night time applications made to dry leaves showed greater spray material deposition than similar applications during the day. However, applications made to wet leaves showed increased runoff and reduced deposition. 2. At the same material application rate per acre, low spray volume [50 gal/acre (468 $L \cdot ha^{-1}$)] resulted in greater total material retention than higher volumes [200 to 500 gal/acre (1870 to 4680 $L \cdot ha^{-1}$)] but almost all of the increase occurred on the exterior foliage. 3. Regardless of spray volume, total deposition declines toward the interior and top of the tree canopy. 4. In all canopy regions except the exterior, variability in deposition was greater with low spray volume.
Salyani and McCoy, 1989	1. Mean copper deposition and variability of deposition increased as spray volume decreased. 2. Variability of deposition, in general, is due to natural differences in location and orientation of the leaf samples in the tree canopy. 3. Small drift-prone droplets, predominately produced at low spray volumes, are mostly transported by the entrained air and deposited inconsistently throughout the canopy. 4. Large size droplets, produced at higher volumes, are deposited by direct inertial impaction and thereby result in more uniform and predictable deposition.
Salyani and Whitney, 1988	1. Variation for spray deposition within the tree decreased as spray volume increased.
Salyani and Whitney, 1991	1. Based on their experimental conditions, spray oscillation did not have a significant effect on deposition, and sprayer ground speed did not have a significant interaction with oscillation.
Schutte et al., 1997	1. Copper fungicide levels needed for disease control can induce fruit-blemishing phytotoxicity. Risks increase as copper levels increase.
Spray Drift Task Force, 1997	1. Droplet size, tree height, canopy density, and orchard geometry are prominent factors contributing to spray drift. 2. High outer canopy density in citrus often results in greater spray reflection/deflection over trees and consequent drift compared with similar sized trees of other tree crops. 3. Demonstrated great reduction in wind within most orchards, with much less reduction in apples (*Malus ×domestica*) before budbreak. 4. Stated that less than 0.5% of applied material drifts from orchard in a typical airblast application to orange (*Citrus sinensis*) groves of 1200 ft (366 m) width, but substantial spray material was recovered even at the maximum sampled height [39 ft (12 m)] making total drift assessment virtually impossible. 5. The amount of material passing through the rows of grapefruit (*Citrus paradisi*) from air-blast applications was about double that of oranges, particularly over the top of the trees. However, grapefruit were bedded and sprayers weren't adjusted between bed tops and furrows so sprayers substantially overshot grapefruit canopies on bed tops. 6. Downwind deposition in the first 100 ft (30 m) was greater for air-blast than mist blowers, but the relationship reversed at greater distances. 7. Suggested 141 µm as the threshold for droplets with high drift potential.

Appendix 1 (continued). Summary of critical points from references on spray practices. Readers are encouraged to refer to the original papers to understand the experimental context.

Reference	Points of interest
Steiner, 1977	1. Estimated that up to 40% of the pesticide deposited on the outer foliage of trees in full leaf is acquired indirectly as a result of spraying other trees in the orchard. 2. The most serious shortcoming of all sprayer airstreams is that they lose velocity rapidly after leaving the sprayer, regardless of air volume or starting velocity. 3. Airblast sprayers produce a variety of droplets ranging in size from 5 to 600 μm in diameter 4. Adequate coverage of trees was difficult at distances of 25 to 30 ft (7.6 to 9.1 m) from the sprayer due to dropping out of large droplets and failing of smaller droplets to impinge (due to decreasing airstream velocity). 5. With the standard swirl-type nozzles, small changes in the operating pressure do not seriously affect the droplet size produced because the pressure must be increased nearly 4× to reduce the average droplet size by one-half. 6. The effect of humidity on particle size and spray distribution is frequently overlooked in many spraying operations, with low humidity more likely to adversely affect fine sprays employed in low volume applications. 7. Reduction in spray volume can result in significant savings because of more efficient material use. 8. No one set of guidelines can be written which would be equally suited for all sprayer types, orchard conditions, and grower experience.
Stover et al. (2002b)	1. Airblast sprayers are the most common commercial sprayers in use within the Indian River (IR) area of Florida. 2. Current application volumes of 250 gal/acre (2340 $L\cdot ha^{-1}$) or less are common for growers using airblast sprayers for fresh grapefruit sprays 3. Very low application volumes [25 to 35 gal/acre (234 to 327 $L\cdot ha^{-1}$)] are used for some sprays on 14% of IR grapefruit acreage 4. Growers largely approach spraying as an art, adopting new practices according to their risk tolerance and experience to find an acceptable efficiency/efficacy balance, resulting in extreme diversity within the IR citrus industry. 5. IR citrus producers reported no direct monitoring of wind conditions when spraying.
University of California, 1996	1. To achieve proper coverage, apply low-volume treatments only when it is relatively calm. 2. When treating scale insects, do not treat if wind exceeds 2 mph (0.89 $m\cdot s^{-1}$) since coverage is especially important. 3. For pests other than scale, if wind exceeds 2 mph, shut off nozzles on one side of the machine and spray only with the wind. 4. Never apply low volume applications if wind speeds exceed 5 mph (2.2 $m\cdot s^{-1}$).
University of California, 1984	1. Air blast sprayers without an air tower cannot achieve thorough coverage of trees taller than about 11 ft (3.4 m). 2. Low volume spraying requires great precaution because the chemical concentration is much higher than in dilute spraying. 3. Longer residual activity of certain pesticides has been observed when concentrate sprays are used.
Walklate, 1992	1. The combination of measurements of spray volume flux with height and droplet size close to the sprayer, coupled with a spray drift model, can provide an alternative strategy for assessing the far-field spray contamination hazard from air-assisted orchard sprayers. 2. The present simulation model can be extremely time consuming to estimate drift contamination at large distances from the sprayer.
Whitney and Salyani, 1991	1. Based on their experimental conditions, the mean spray deposit of the air curtain sprayer was significantly less than that of the conventional sprayer in orange trees, but not significantly less in grapefruit trees. 2. The coefficients of variability for spray deposits were similar for both sprayer types in both types of citrus.
Zhu et al., 1994	1. Changes in wind velocity, discharge height, ambient temperature, and RH had much greater influence on the drift distances of droplets 100 μm or less in diameter, than on 200 μm diameter and larger droplets. 2. For droplets that did not evaporate before deposition, there was a nearly linear relationship between wind velocity and drift distance. 3. With 100% RH, 10 μm diameter droplets drifted beyond 656 ft (200 m) when wind velocity exceeded 5.6 mph (2.5 $m\cdot s^{-1}$). 4. Droplets 50μm diameter and smaller completely evaporated before reaching 1.6 ft (0.5 m) below the discharge point, regardless of initial velocity for RH 60% and lower and temperatures between 50 °F (10 °C) and 86 °F (30 °C). 5. Mean drift distance for 100 μm diameter and larger droplets increased with increased wind velocity and discharge height, but decreased with increased droplet size and discharge velocity. 6. The drift potential of 200 μm diameter droplets is considerably less than for 100 μm droplets.