

Research to Reduce Potential Damage From Spray Drift Loss By The USDA-ARS Application Technology Research Unit

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Abstract

For over two decades, several research programs related to spray drift reduction have been conducted at the USDA-ARS Application Technology Research Unit (ATRU) in Wooster, Ohio. In capture efficiency studies, nylon filter screens, cotton floss, plastic tapes, and cellulose filters in high volume air samplers were investigated for effectiveness in collecting spray drifts in the field and wind tunnel. The ATRU staff studied droplet sizes, spray patterns, and drift reduction using various drift retardant additives in a wind tunnel, and developed a test stand system to evaluate shear effects on spray drift retardant performance. A simple viscometry system was developed to measure viscosity at high shear rates for spray mixes containing different drift retardants composed of either polyethylene oxides, polyacrylamides, or a polysaccharide. The ATRU conducted nursery field experiments to determine off-target drift loss in a commercial nursery using electron beam and conductivity analysis. FLUENT software and a wind tunnel were used to design shields with various shapes to reduce spray drift potential from sprayers fitted with conventional hydraulic nozzles. Wind tunnel and atomization studies demonstrated the potential for air induction nozzles to reduce drift. Drift reduction nozzles have been incorporated into efficacy evaluations in disease and insect management trial and in some cases demonstrate little loss in efficacy for the larger droplet applications. Studies of the drift potential of conventional, axial fan sprayers as well as tower sprayers in semi-dwarf apple canopies as well as shade trees and other nursery crops reveal the effect of sprayer configuration and spray direction.

Introduction

The USDA Agricultural Research Service Application Technology Research Unit (ATRU) and its predecessors at Toledo have a history of application related research dating back into the 1920's and were consolidated at Wooster beginning in 1959. The ATRU is a multi-disciplinary research unit consisting of engineers, pathologists, horticulturalists, and entomologists. The current mission of the ATRU is, "To conduct fundamental and developmental research on new and improved application technologies to protect floricultural, nursery, landscape, turf and horticultural crops against damage from diseases, pests, and adverse environmental conditions, while safe-guarding environmental quality, food and worker safety." Over the years, the ATRU has engaged in a wide variety of multi-disciplinary projects. The fate of spray within and outside of a target area, the impact of spray delivery on biological control agents like nematodes, spray retention, physical properties of spray mixes, collection efficiencies of different surfaces, spray dispersion in turbulent flow, methods of measuring spray retention and deposition, injection of pesticides into spray lines as well as into the soil are among a few of the projects areas studied over the passed several years. Recent research has emphasized the needs of nurseries as well as fruit and vegetable production systems.

Research Programs

Deposition Efficiency of Air-Assisted Sprays.

Wind tunnel studies conducted at the ATRU have demonstrated the importance of air assistance for helping spray on target as well as minimizing off-target movement. In one study using artificial corn and cotton canopies, and an air jet directly just behind the atomizer, losses to the ground and air were highly dependent on droplet size (130 vs. 300 μm) (Bayat et al. 1999). Even the slowest air jet speed (20 m/s) significantly reduced airborne losses. Air-assisted delivery also improved penetration of the artificial plant canopy erected in the wind tunnel as well as underside leaf deposition.

Small spray droplets which rely primarily on electrostatic and gravitational forces for transportation and deposition are highly susceptible to drift. Also, spray penetration into dense plant canopies is often inadequate. A laboratory study was conducted to evaluate the effectiveness an air jet might have on reducing drift from an electrostatic nozzle and increasing canopy deposits (Almekinders et al. 1993). Spray deposits of air-assisted, charged sprays, with volume median diameter of 92 μm , were collected in a wind tunnel with wind velocities up to 5 m/s. The results indicated that an air jet with 11 m/s downward air velocity at the point spray was entrained, greatly increased the amount of spray deposited in the target area and also improved penetration of the spray downward into the canopy while reducing drift.

Computer Simulation of Spray Drift from Field Sprayers

Computational fluid dynamic software (Fluent[®]) was used to determine the effects of several variables on drift distances of individual spray droplets (Reichard et al. 1992; Zhu et al. 1995). Variables were initial droplet size, velocity and height of discharge, wind velocity and turbulence intensity, relative humidity, and volatility of the liquid. Drift distances of water droplets as large as 200 μm diameter were influenced by initial droplet velocity and height of discharge. Experimental data from tests in a wind tunnel verified the accuracy of the computer program in predicting drift distances of water droplets. A computer program was developed to calculate mean drift distances for individual spray droplets. This program accepts input parameters, then interpolates among a data base of results from flow simulation trials to obtain drift distances for the input conditions.

Use of Shields to Reduce Drift

The effects of partially covering spray booms with six different mechanical shields on deposition distances of spray droplets were simulated by using computational fluid dynamic software, Fluent[®] (Tsay et al. 2002). The same shields were mounted in a wind tunnel and drift distances of uniform-sized droplets in a 30 m/s air stream were measured. Use of solid bluff-plate shields inevitably resulted in a low velocity zone immediately behind the shield or within the shielded area. As compared with conventional straight-down spraying, all shields simulated, except one, reduced drift potential. The double foil shield was confirmed to be the best design for mechanical shields in this study. The optimal operating parameters of pneumatic shielded spraying, obtained by a multi factor analysis of variance, were jet velocity of 145 km/h, jet flow rate of 102 m^3/min , and jet angle of 15 degrees. Mean deposition distances from simulation and experimental distances to centers of masses agreed well for only 2 of 6 mechanical shield designs tested. Effect of shield-induced vibration and improper size ratio of shields to the wind tunnel may be reasons for this inconsistency.

Jet-Velocity Profiles and Models for Orchard Sprayers

The mathematical model for ideal, plane jets was modified to include the effect of radial expansion as the air jet moved away from a circular jet (or polar) outlet. This model was found to have an improved fit to the maximum velocity across a jet as distance from the jet increased, as compared to the plane jet model previously used (Brazee et al. 1981). Jet profiles were measured for two axial fan sprayers and agreed well with model predictions using the radial jet model. Centerline velocities in an air jet produced by a cross-flow fan sprayer were measured and agreed well with predicted values computed using a plane jet

model. For jets that have equal air power at the jet outlet, models for ideal jets predict that axial jet velocities from jets with greater air volume and lower maximum air velocities will decrease much less as distance from the outlet increases, compared to jets with high velocity and lower air volume. Measured air velocities for sprayers passing an array of hot-film anemometers on towers in the open and in apple trees found that maximum jet velocities produced by moving sprayers was much less than velocities measured for the same jets when stationary (Fox et al. 1992). A model of the deflection of an air jet by travel speed or cross wind was developed. Jet deflection and velocity profiles predicted for the deflected jet were similar to velocities measured for a model jet operated in a wind tunnel (Fox et al 1985).

Nursery Crops

Spray penetration and off-target spray drift from a conventional, air-assist, axial-fan sprayer and a high-clearance, boom-type sprayer have been investigated in Honey Locust and Canadian Hemlock plantings in two production nurseries (Krause et al. 2004). Aqueous tracer solutions of $\text{Ca}(\text{NO}_3)_2$ foliar fertilizer, were used in the experiments to assess spray retention. Spray distribution and drift were assessed via residues collected on foliage, electron microscope stubs, vertical and ground-level profile tapes, clamp-mounted, fresh leaves, and high-volume air samplers. Electron beam analysis (EBA) was used to assay residues on stubs, leaves and needles placed and/or collected at several locations and elevations in the canopy. Profile-tape samples were evaluated with the ATRU's spray deposit analyzer (Fox et al. 1998). Spray coverage for hemlock and locust treatments were incomplete throughout either canopy as assessed by either method. Experimental results indicated that ground-level spray deposits and airborne drift varied with the spray method used. In the Honey Locust planting treated with an axial fan sprayer, downwind spray losses on the ground decreased from 213 to $0.9 \mu\text{L}/\text{cm}^2$ as target distance from the treatment area increased from 2.1 m to 19.8 m. Over-the-row air-assisted treatment of Canadian Hemlock plantings resulted in far less downwind ground deposits with an average of 40.92 to $0.82 \mu\text{L}/\text{cm}^2$ as target distance increased from 0.6 to 11.4 m from the centerline of the first row.

Another production-nursery study compared coverage on red maple by an axial-fan sprayer with that by a cross-flow fan, air-curtain sprayer (Derksen et al. 2004). Spray deposits on red maple trees, *Acer rubrum* L (about 3.5 m tall) were measured using blue food coloring and $\text{Cu}(\text{OH})_2$ fungicide. Colorimetry and EBA were used to measure deposits on leaves clamped at 12 locations in each of three trees. The air-curtain sprayer produced more uniform distributions throughout the trees, but the axial-fan sprayer produced greater deposits than the air-curtain sprayer at almost all locations. This continuing study will be aimed at more effective implementation of air-curtain concepts, nozzle types and placements, and other technological advancements to improve coverage uniformity and reduce drift losses.

An experimental cross-flow (CF) fan sprayer and a conventional, orchard, air blast type sprayer (DW) were used to treat multiple rows consisting of four year old, multi-stem, red maple trees, *Acer rubrum* L. and Turkish Filbert trees, *Corylus colurna* L (Derksen et al. 1999). The trees were located in a commercial Ohio nursery. These sprayers were used to evaluate the effects of sprayer type, fan orientation, application volume, and ground speed on foliar and ground spray deposits and spray coverage across multiple target rows. Six different single pass treatments and two second pass treatments were applied within the target area. Blue food coloring (FD&C No. 1) was used to estimate spray deposits and water sensitive cards were used to evaluate spray coverage. Spray deposit and coverage measurements were made across three rows in the nursery. Significant differences in deposits and coverage were observed from one side of the canopy to the other. Variations in deposits and coverage across the canopies were generally smaller for the CF sprayer than the DW sprayer. The air blast sprayer (Durand Wayland 1500) produced the highest overall deposits in the first row nearest the sprayer. Reducing the DW sprayer ground speed (6.4 to 4.0 km/h) while maintaining the application rate (532 L/ha) did not significantly change any of the performance measures. The CF sprayer produced significantly higher deposits two and three rows downwind from the sprayer than the DW sprayer. Reducing fan speed on the CF sprayer increased deposits in the row closest to the sprayer and decreased downwind losses to the

ground. Reducing the CF application rate (266 L/ha) did not significantly affect deposits compared to the standard CF treatment in either Rows 1 or 2 downwind from the sprayer. A second spray pass by the standard CF and DW treatments around a two-row treatment block significantly reduced the variation in canopy deposits between treatments. The CF sprayer treatments produced higher coverage ratings in the second and third rows downwind from the sprayer compared to the DW treatments. These deposit and coverage results indicate that the conventional, air blast treatment is limited to making applications on each side of every treatment block if uniform spray deposits are required. The CF sprayer may not need to be operated down every drive row depending on the overall deposits and coverage needed to provide the desired biological impact. The performance of the reduced application rate CF sprayer also indicates that this sprayer design may provide equivalent or superior biological control compared to the conventional type of air blast sprayer while reducing the time and water requirements necessary to make the application.

Effectiveness of Low-Drift Nozzles

Small-to-medium size droplets are desirable when applying insecticides and fungicides because they provide better canopy penetration and coverage, yet more drift-prone small droplets can travel long distances beyond the targeted area. Almost all major agricultural nozzle manufacturers have recently introduced low-drift nozzles which are claimed to be effective in reducing spray drift. An initial objective of this study was to determine effectiveness of two commercial “low-drift” nozzles by measuring droplet sizes and deposition distances in a wind tunnel, comparing data for the low-drift nozzles with those for a standard flat-fan nozzle (Derksen et al. 1999). Low-drift nozzles produced fewer drift-prone droplets and less downwind deposits than the standard flat-fan nozzle. Low drift nozzles may provide improved pest management in some cases by producing a larger percentage of spray material that stays in the target areas rather than drifting off-target.

Among spray applicators, it is popular to use high-pressure atomization to provide the best canopy penetration and coverage. However, small droplets produced by these nozzles often lack sufficient energy to deposit deep in a canopy and are susceptible to wind movement. The objective of this research was to monitor the affect of different application techniques on management of Sclerotinia stem rot (SSR) of soybean and foliar and fruit disease of tomatoes and to assess spray deposit characteristics within the canopy. Protectant fungicides were applied on a calendar schedule. Soybean trials showed little difference in SSR control between low-drift and conventional disc-core and flat fan nozzles (Mueller et al. 2002). Spray deposit characteristics on tomato leaves were evaluated using imaging technology and colorimetry techniques (Derksen et al. 2001). Differences in spray deposit characteristics between drift reduction, flat fan, and hollow cone nozzles all using the same carrier volume were relatively small. Higher application rates produced higher leaf surface spray coverage. Air-assisted spray delivery produced significantly higher spray coverage on underside leaf surfaces and on leaves deeper in the canopy. Air-assisted delivery also deposited more chemical tracer within the canopies. There were no significant differences in foliar infection observed in treatments made with either full or half-rate applications of chlorothalonil. No significant differences in the yield of marketable fruit between treatments were measured. These experiments demonstrate how growers can improve placement of and use of pesticides, particularly how to better target areas of plant canopies that are more susceptible to infection. They also illustrate that low-drift nozzles could potentially have a wider role in pest management programs. Further evaluations are necessary to determine how to optimize use of low-drift nozzles for disease and insect management programs using materials with different modes of action and activity.

Orchard canopy experiments were conducted on the outside row of a semi-dwarf apple block to measure differences in foliar coverage, canopy deposits, and downwind sedimentation and airborne deposits produced by different nozzle sets (Derksen et al. 2000). A conventional, axial flow, orchard sprayer was

used to make the applications using either Spraying Systems Co. D3-25 or D4-25, hydraulic, disc-core nozzles or TurboDrop[®] 02 (TD02), air induction nozzles. Coverage for a tracer mixture containing a non-ionic, spreader was highest for the D3-25 treatment. There were few differences in foliar coverage between the D4-25 and TD02 nozzle sets. Canopy spray deposits were similar for the D4-25 and TD02 treatments. The TD02 treatment produced the lowest sedimentation deposits from 4 to 128 m downwind. The D4-25 produced three times higher deposits on passive nylon screens, 8 m downwind than the TD02 treatment. The D4-25 treatment produced higher airborne deposits on Staplex air sampler filters out to 64 m. At 128 and 256 m, sedimentation and airborne deposits were similar for the D4-25 and TD02 treatments.

Target Collection Efficiency

Studies conducted using computational fluid dynamics program (FLUENT) determined the effects of several variables on collection efficiencies of spray droplets directed horizontally toward vertical targets in turbulent air (Zhu 1996). These simulations revealed that collection efficiency increased with increasing droplet size, wind velocity, and target width but decreased with increasing turbulence intensity. The simulations also revealed that models used to predict collection efficiencies of aerosols were not satisfactory for larger droplet agricultural applications. Zhu et al. (1996) found that collection efficiencies measured in a wind tunnel were similar to those determined by the computer simulations.

Field and laboratory studies have used a wide range of targets to assess airborne particulate movement. Most allow some sort of air movement through them. Fox et al. 2004, studied the effectiveness of several nylon filter screens for collecting spray droplets. The collection efficiency of the best screen was compared to cotton string and plastic tape collectors. Using an air atomizing nozzle to emit spray in a wind tunnel, a screen with 56% opening had the highest collection efficiency for sprays with VMDs of 30 to 45 μm . The screen collected more droplets per unit of frontal area than did plastic tapes but less than cotton or polyester string. These experiments could be used to better estimate the actual amount of airborne spray material moving past a particular point downwind assuming droplets were approximately 40 μm in diameter.

Drift Assessment and Mitigation in Orchard Tree Canopies

The ATRU has a long history of studying the release of spray for treating fruit canopies, especially semi-dwarf, apple canopies. Ground and airborne spray samples are collected in these experiments using active and passive targets or samplers (Derksen et al. 2000; Fox et al. 1990; Fox et al. 1993a; Fox et al. 1993b). The sprayer used in this work has primarily been a conventional, axial fan sprayer using high pressure, disc-core nozzles. In general, studies making a single pass treatment to the outside row of an apple orchard (3.5 m height) from the inside of the orchard found that downwind ground deposits decreased rapidly with increasing distance from the treatment area. Ground deposits at 60 m downwind were about 1/250 deposits near the tree row. Ground deposits found beyond 30 m were not influenced by the presence of a tree canopy. As a whole, all the ATRU orchard tests show that beyond 60 m downwind, deposits per unit area of collector showed that airborne spray samples were about 10 times greater than ground deposits.

Effect of Drift Retardant Additives on Spray Drift, Droplet Size and Spray Pattern; Shear Effects on Drift Retardants

Laboratory studies were designed to determine effects of various drift retardant additives on droplet size, spray pattern, and spray-drift reduction. Effectiveness of drift retardants for minimizing off-target spray deposit distances has been shown closely related to their ability to increase droplet size. All drift retardants studied have been found to create patterns with greater spray volume in the center of the swath than does water alone. Several researchers have reported that some retardants degrade owing to shearing actions of recirculation through agricultural sprayer pumps. A laboratory test stand was developed to simulate shear on spray mixtures of water and drift retardants by means of a controlled, recirculating

pump and sprayer-tank system (Reichard et al. 1996). A simple system based on a Cannon-manning vacuum viscometer was developed to measure viscosities of Newtonian and non-Newtonian liquids, such as drift retardants, at high shear rates, up to $200,000 \text{ s}^{-1}$ (Reichard and Zhu 1996). Three test drift retardants were evaluated in both an orchard air blast sprayer and the laboratory setup. Droplet size distributions of sprayed samples from the sprayer and the laboratory system were measured with a Phase/Doppler Particle Analyzer (PDPA). Droplet size distributions of sprayed samples with drift retardants sheared with the laboratory system had similar trends to those of samples sheared with the air blast sprayer as the number of recirculations increased. In a further study (Zhu et al. 1997), twelve polymers which are primary active ingredients in commercial drift retardants were compared. Samples of the solutions were taken after increasing numbers of passes through the laboratory test system, and apparent extensional viscosity was measured for all samples. After being sheared by more than 4 passes through the pump, both non-ionic and anionic polymer-solutions at 100 ppm did not increase droplet sizes much over values for water alone. Apparent extensional viscosity was directly correlated with spray droplet size ($r^2=0.72$).

Dynamic Surface Tension

Several physical properties of the droplet liquid, such as surface tension and extensional viscosity, may affect reflective potential of spray droplet from plant leaves. Equilibrium surface tension, a commonly measured liquid property, is not a reliable indicator of reflection tendency. However, dynamic surface tension has been found to be strongly related to droplet reflection. An oscillating jet method was developed enabling measurement of dynamic surface tension at a range of short surface ages, even as short as 1 ms (Brazee et al. 1994). Bohr's equation and Bechtel's inverse method were used to calculate surface tension from measurements of the jet waveforms. Some surfactants are unable to reduce surface tension rapidly at short air-liquid interface ages typical of droplet impaction processes. Hence, they may be unable to effectively limit reflection and improve retention. A thin-film diffusion model was developed which can be used to calculate dynamic surface tension at a range of surface ages, given liquid properties, surfactant diffusivity, apparent interfacial film thickness, and surfactant concentration. Correlating measured dynamic surface tension data with the diffusion model provides estimates of apparent film thickness and diffusion of surfactant/water mixtures. These activity properties are useful in understanding surfactant effects on high shear rate physical processes such as droplet atomization and leaf-surface impact, where short surface ages are critical. Most agricultural sprays are mixtures of materials, not true solutions, and as such their surface tensions change with surface age. Measuring surface tensions at short surface times may also be valuable in predicting droplet size spectra from atomization processes, because these processes are usually completed in less than 3 ms.

Conclusions and Impact

The ATRU has made significant contributions to the understanding of the contributions to spray drift as well as means for assessing and mitigating spray drift. Research from these programs has led to the development of standards used in application system and formulation performance that are widely used today. Collaborations with nursery, greenhouse, and other industry professionals help ensure that the research is relevant and will make an impact on production practices. These associations also help identify experimental field sites for future studies. ATRU collaborations with Ohio State University and the Ohio Agricultural Research and Development Center, including long-term use of field space that permits orchard drift experiments, enables research resources be to directed toward application issues, including drift issues, that will benefit producers and consumers alike.

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