RECENT TRENDS IN AGROCHEMICAL APPLICATION IN THE U.S.A.

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ABSTRACT

New pesticides are more potent and require more precise application. Research is continuing in universities, government, and industry to develop new methods and equipment to achieve maximum efficiency in the use of pesticides while minimizing the potential risk to the applicator and the environment. This paper summarizes major developments in spray application technology research and recent developments to reduce spray drift and to improve application efficiency. These developments include low drift nozzles that produce larger drops, air-induction, electrostatic, and air-atomizing nozzles. Other drift reduction technology discussed includes air-assisted sprayers, boom shields, and tunnel sprayers. Technology to support precision farming includes variable rate sprayers, GPS and GIS techniques, closed chemical transfer systems, and flow control systems. New orchard spray technology include tower sprayers and canopy sensing techniques. Biological pest control agents often require special delivery systems to prevent damage to the living organisms being distributed on the plant canopy.

INTRODUCTION

About 1/3 of all pesticides produced worldwide are sold in the USA (NACA, 1993). Pesticide usage in the U. S. has been relatively stable at about 500 Million kg of active ingredient during recent years. Due to increasing concerns about crop production costs and environmental pollution, it is essential to apply pesticides with precision and care. New pesticides are more potent and require more precise application.

Current chemical application methods and equipment have improved application accuracy considerably; however, efficiency is still low and many unanswered questions remain. Research is continuing at universities, government, and industry to develop new methods and equipment to achieve maximum efficiency in the use of pesticides while minimizing the potential risk to the applicator and the environment.

Pesticide application is a complex operation and it requires more skills, management and precision than many other operations in crop production. It involves many critical steps such as uniform mixing of pesticides in the tank, efficient transportation of pesticides from the spray equipment to the target, retention of pesticides on the target and finally

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uptake of the pesticide active ingredients by plants, insects, or diseases.

The least efficient aspect of liquid pesticide application is transporting spray droplets from the nozzle to the target. Research indicates that often only a small portion of the intended chemical dose actually reaches the target and contributes to the desired biological effect (Pimentel and Levitan, 1986). A portion of the spray never reaches the target. This problem of spray drift remains a serious health and safety problem. Recently, reduction of spray drift has been a focus of many research projects in universities and research stations around the world, because reduced spray drift not only improves application efficiency, but it also reduces environmental pollution.

OBJECTIVES

The objectives of this paper are to provide a summary of major developments in spray application technology research and development in the U.S.A. This includes advances directed toward reduced spray drift and improved application efficiency. Although important developments in spray technology has taken place all over the world, the summary provided below includes mostly the developments taking place in the U.S.A.

I. Research and Equipment Development to Reduce Spray Drift

Although complete elimination of spray drift is very difficult, its magnitude can be reduced significantly if factors that increase the risk of drift can be altered or eliminated. Smith et al. (1982) discussed variables affecting drift in detail. Weather conditions, especially the wind, which the applicator cannot control, play an important role in the generation and movement of drift. Factors under operator control include chemical formulation and application parameters, including selection and proper operation of the spray equipment. The most important application factor influencing drift is the size of droplet sprayed. Small droplets, if deposited on the target, provide better coverage and this usually results in increased control of some pests. However, small droplets are susceptible to drift. Zhu et al. (1994) have shown that for typical applications with boom type sprayers, droplets of 100 μm or less often drift out of the intended swath, and 50 μm or less diameter droplets, completely evaporate before reaching the target.

When using conventional spray equipment, the total volume of spray made up of droplets less than 100 μm in diameter is relatively small, but even such small amounts may sometimes cause serious heath problems and/or damage crops in nearby fields. Several possible solutions have been suggested to combat spray drift. Most of these solutions are centered around three major concepts: 1) not spraying at all when the weather conditions are not favorable, 2) reducing the volume of spray contained in small droplets, 3) altering the flight paths of small spray droplets by mechanical means to increase efficiency of deposition on the target.

Although most operators are aware of spray drift and the problems associated with it, treatment of a field during unfavorable weather conditions may be unavoidable when the pest population is at a level such that further delay in spraying may result in total crop

loss. Realizing this fact, most researchers and equipment manufacturers have been focusing their attention to developing equipment to reduce drift.

Some manufacturers have introduced nozzles that reduce the volume of spray contained in small droplets. Other companies have developed chemical additives called "drift retardants" to achieve the same goal: reducing the volume of spray contained in small droplets. Research has proven that adding these products to the spray mixture creates a change in some of the basic physical characteristics such as surface tension, viscosity and density of the mixture causing an increase in volume median droplet size for a given atomizer (Richardson, 1974, Bouse et al., 1990). Ozkan et al. (1993) investigated the effects of various drift retardant chemicals (Direct, Driftgard, Formula 358, Nalco-trol, and Target) on droplet size, spray pattern, and spray drift reduction. The results of this study indicated that, the mixture of water and Nalco-trol (at recommended rates) provided the largest increase (63%) in volume median diameters (VMD) in comparison to that of water. Percent increase in VMD with Direct, Target, Driftgard, and Formula 358 were much smaller, 59.8, 38.9, 28.6, and 3.5%, respectively. All drift retardants caused spray patterns with greater volume in the center than for sprays with water only. Although their chemical make-ups are similar, there are over 30 "drift retardants" used by the applicators in the USA.

Several recent developments have been aimed at modifying existing equipment to increase deposition efficiency of the more effective small droplet while reducing the potential for drift. In general, this has been accomplished by using either air-assist technology or some kind of shield or shroud to overcome the drift-producing air currents and turbulence that occur near the nozzle during spraying.

Nozzle classification system

The American Society of Agricultural Engineers (ASAE) has recently accepted a new standard that defines several classes of droplet sizes produced by nozzles. This system is patterned after the British Crop Protection Council (BCPC) guidelines that have been used in Europe for several years. Defined droplet size classes include very fine, fine, medium, coarse, very coarse, and extremely coarse. In this system, the boundaries between classes are defined by a group of "standard" nozzles using the drop size versus cumulative volume plot. This makes nozzle class definitions independent of the droplet size instrument used for measuring droplet size. A set of standard nozzles is available for laboratories that need to establish size classifications for their specific droplet-sizing instrument.

In about the year 2000, agricultural pesticide manufacturers will begin to specify, on the pesticide label, the smallest nozzle class to be used with each pesticide. This system is intended to reduce drift by assuring that nozzles applying spray produce a specified, minimum droplet size. In some cases, the label may specify different nozzles for specific wind speed conditions, that is, a coarse nozzle must be used if wind speed is above 20 km/hr, but a medium nozzle may be used if wind speed is below 10 km/hr. Nozzle manufacturers catalogs will contain information about the droplet size

classification for each nozzle, at each operating pressure.

A) New Atomizers/Nozzles

"Low-Drift" Nozzles

Most major agricultural nozzle manufacturers have recently come up with "Low-Drift" nozzles which are designed to create larger droplets at the same flow rate and operating pressure than comparable, standard flat fan (SFF) nozzles. This has been accomplished by adding a pre-orifice to the nozzle tip assembly just ahead of the conventional discharge orifice. SFF tips have a straight bore that carries liquid from the boom to the tip. With these new "low-drift" nozzles (Figure 1), liquid enters through a small orifice

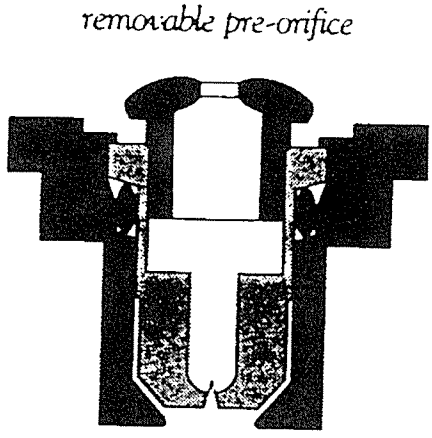


Figure 1. DriftGuard nozzle

and flows into a chamber machined into the nozzle body. The liquid then flows from this chamber into a short passage and out of the discharge orifice. The pre-orifice reduces liquid velocity, creating larger droplets which should significantly reduce drift. According to one of the manufacturers of these nozzles, their "low-drift" nozzle tips reduce the number of droplets smaller than 200 μm by 50 to 80 percent. In addition to "low-drift" nozzles, Spraying Systems Co. has introduced a new flat-fan nozzle ("Turbo TeeJet®") that can be used for the same applications as a SFF nozzle. The advantage of the new "Turbo TeeJet" nozzles are twofold: they can be operated at a wider range of pressure (207 to 414 kPa with SFF vs. 103 to 621 kPa with Turbo TeeJet), and they produce fewer drift-prone droplets compared to the same size SFF.

"TurboDrop®" Nozzles

These nozzles are originally manufactured in Germany by Agrotop Company, and distributed to the US by Greenleaf Technologies (Covington, Louisiana). The TurboDrop nozzles (Figure 2) are designed to produce larger droplets while reducing the

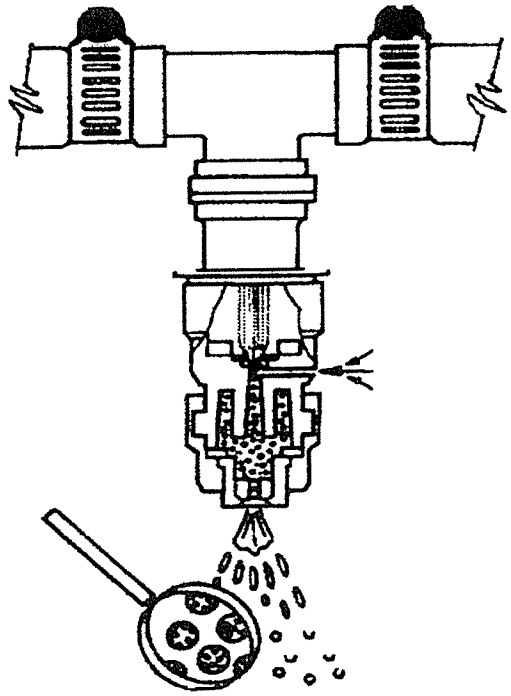


Figure 2. TurboDrop nozzle

percentage of fine droplets. As with other "low-drift" nozzles, TurboDrop nozzles also have a pre-orifice ahead of the exit orifice to reduce the pressure exerted on the liquid at the point of discharge. The liquid flow rate is controlled by a ceramic orifice plate located at the bottom of top section. As the liquid passes through the orifice plate, a region of low pressure is created by this venturi, which results in air being drawn into the nozzle body. Air and spray solution are blended in the mixing chamber. As the liquid is discharged from the nozzle tip, spray droplets with trapped air bubbles are produced. The bottom (exit) nozzle does not control the output rate. It is there to form the desired pattern. Therefore, a standard flat fan tip with a larger orifice can be used to produce larger droplets. Upon leaving the nozzle orifice, the air included in the droplets expands which makes droplet size somewhat larger, causing an increase in droplet velocity. In addition to producing larger droplets, producing higher velocity droplets further improves the chances of droplets reaching the target before becoming subject to drift. Another benefit mentioned by the manufacturer of this nozzle is that large droplets shatter and splatter on contact, causing the small air-filled drops to spread out on the target for better coverage. According to its manufacturer, TurboDrop nozzles reduce the drift of small droplets considerably.

Our studies have shown little or no air bubbles in droplets of pure water. However when a surfactant was added to the sprayed mixture, spray droplets did contain entrained air bubbles.

Air-Induction (AI) nozzles

Most agricultural nozzle manufacturers have developed and are now marketing air-induction nozzles. These nozzles all use the same principle as the TurboDrop nozzles. They have a pre-orifice, then a venturi section which draws are from an air-inlet port, and a final mixing chamber before the air-spray mixture leaves the nozzle through a nozzle tip. The nozzle tip atomizes the spray and develops the spray pattern. These nozzles reduce the percentage of driftable droplets (less than 150 μm) and should reduce drift problems. They have become very popular with farmers in Europe and the USA. We have found that blocking the air-inlet port does not change the droplet size spectra. Our studies show that using larger orifice nozzles such as Turbo-TeeJet under lower system pressure will produce similar droplet size spectra and drift patterns.

Electrostatic atomizers

Electrostatic charging of small droplets has been considered as a way to increase deposition efficiency and reduce drift of small droplets. Although research on electrostatic spraying in industrial applications has been conducted for more than 50 years, the use of charged sprays was not extended to agriculture until early 1970's. Several electrostatic atomizers have been designed and marketed, especially in Europe. However, these atomizers have not gained wide acceptance by farmers. Currently there are two companies (ESP, Melroe, Bismark, North Dakota, and Electrostatic Spraying Systems (ESS) Inc., Watkinswille, Georgia) manufacturing and marketing sprayers that are capable of discharging electrostatically charged droplets.

Until recently all electrostatic sprayers have used an inductive charging technique which involves passing spray liquid through an electrostatically charged ring or plate. During this process, the electric charge is transferred to the droplets as they pass through this electrical field. Some companies such as ESS also used air assist in addition to charging of droplets to improve penetration of droplets and better coverage on both upper and under-side of the target leaves. The airflow rate at the atomizer is 17 to 20 m^3 /min. Approximately 7.5 to 40 kW of power is required to run the compressor which produce the air supplied to the atomizer. The latest version of this commercial sprayer uses lower air pressure for the atomizing nozzle. This permits the use of a lower-energy blower to replace the air-compressor.

The ESP System uses the principle of contact charging for electrostatically charging of droplets. With this system, the spray liquid is charged before it reaches the nozzles. The ESP System delivers a 40000-volt charge to the spray liquid while it is in the charging tank. This allows the producer to use any standard hydraulic nozzle recommended for an application. It has no electrical wires going to individual nozzles and since it does not use air-assistance, there is no need for an air compressor.

Although it has been demonstrated in research trials that electrostatic sprayers work well under certain conditions, this technology has not consistently produced good results. Electrostatic sprayers have not yet been widely accepted by the producers in the USA,

mostly because of higher initial costs of electrostatic atomizers. However, increased public concern about the environment and the push towards reduced pesticide consumption are likely to provide the impetus to stimulate further adoption of electrostatic spray systems.

Air Atomizers

When using standard hydraulic nozzles, as the applicator changes travel speed, an automatic rate controller adjusts spray pressure to maintain the desired flow and application rates. Changes in pressure also influence droplet size. As speed increases, to keep the application rate per hectare constant, an automatic controller increases system pressure which produces a larger flow rate with smaller droplets. When the operator slows down, pressure decreases and droplet size increases.

Increasing droplet size is a common strategy to reduce drift when working with conventional hydraulic nozzles. Usually, this is accomplished by increasing spray volume and/or decreasing pressure. Unfortunately, higher spray volumes require larger sprayer tanks and/or more frequent refills. Also, larger droplets may not be suitable for the type of coverage required by certain chemicals. Recently introduced air atomizer nozzles may provide a solution to this dilemma.

Air atomizers may use just air pressure, or both air and liquid pressure to atomize and carry the spray solution to the target. The sprayer operator can vary droplet size independently of nozzle flow rate. In windy conditions, larger droplets can be used to reduce drift. Where a thorough coverage is required, (both upper-side and under-side of the leaves covered) smaller droplets can be generated.

Currently two true air atomizers are available in the U.S.A. The air atomizer "AirJet®" (Figure 3), manufactured by Spraying Systems Co. (Wheaton, Illinois), works by mixing

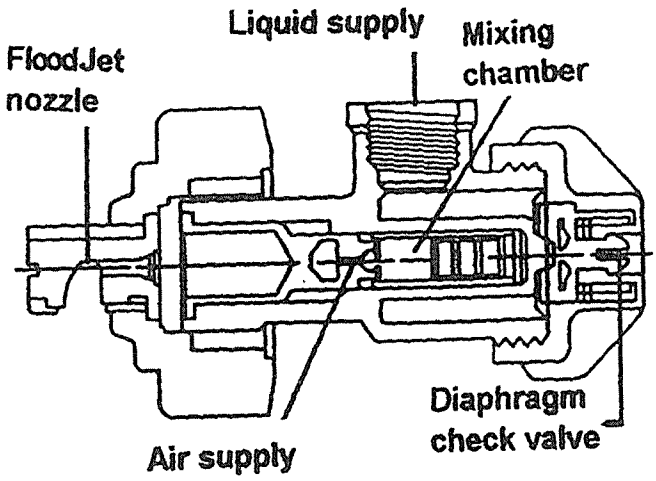


Figure 3. AirJet nozzle

air with the spray solution inside the nozzle to atomize the spray. A metering insert

determines the liquid capacity, as pressure increases, the liquid volume decreases. An on-board compressor provides about 4 m^3/s air supply to the atomizer. The air enters the nozzle body through a 3 mm port from one side of the atomizer body. By adjusting both air and liquid pressures, the operator can control droplet size over a wide spectrum without changing nozzles. The AirJet nozzle uses conventional FloodJet® spray tips to create the spray pattern. The recommended distance between atomizers on a spray boom is 50 cm.

The other air atomizer, "Shear Guard™ PLUS" (Figure 4) manufactured by Spray-air

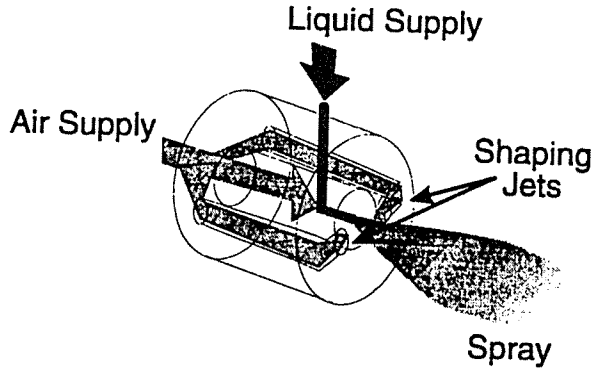


Figure 4. Shear Guard PLUS nozzle

USA Inc. (Grangeville, Idaho), is inserted at 20 cm intervals in a boom assembly that spans from 24 to 28 m. The boom, a hollow fiberglass tube 24 mm in diameter, delivers air from a fan, powered by the tractor PTO, to the atomizer at low pressure (25 to 90 cm of water gage). The air is used to atomize liquid into droplets, as well as to develop a high momentum jet to agitate the crop canopy thereby increasing droplet penetration and coverage. Air travels through the hole at the center of the atomizer as well as two narrow ports on both sides of the center port. The air exiting the side ports is directed toward the center of the main vertical air port where liquid is discharged. The main function of the air coming from the side ports is to give the discharging liquid a spray pattern that is similar to the pattern obtained from a standard flat fan nozzle. Liquid is pumped to each atomizer on the boom via a separate manifold attached to the boom. It is introduced to the air stream in the center of the main air jet port of the atomizer, between the two cross-flow pattern-shaping jets. When the air and liquid meet, the liquid is atomized. An orifice disc is used to control the amount of liquid flow to each atomizer. With Shear Guard™ PLUS, it is possible to choose the droplet size that will give the best performance and still minimize drift. The operator can adjust the velocity of air and thus change the droplet size from the cab regardless of the ground speed. The range of droplet size produced by this atomizer is from 100 to 500 μm.

B) Air-Assisted Spraying

The use of air-assisted boom sprayers for application of pesticides has increased over the last few years. The major factors behind this increased use are concerns related to drift

of small droplets outside the application area, and inefficiency of existing hydraulic nozzles to provide adequate spray coverage on the under-side of leaves.

Several sprayer companies (Hardi Inc., Denmark; Durand Wayland, Inc., USA; Rau Agrotechnic, Germany) have versions of air-assist sprayers. The principle of air-assistance is nearly the same in all three sprayers. An inflatable air tube is positioned just behind the conventional hydraulic boom. Air is forced into the tube using a centrifugal fan. The air exits the inflatable tube through approximately 5 cm diameter holes along the bottom of the air tube, at a slight angle to the vertical (this angle is adjustable on some machines). Droplets are produced by nozzles just ahead of the air tube and entrained in the high velocity air exiting the tube and carried to the target. The air flow rate can be varied or stopped altogether if not needed.

Airtec Sprayer, Inc., USA, uses a 30 cm diameter horizontal aluminum tube to deliver air to individual outlets (short, 7 cm diameter pipes) fitted vertically to the aluminum tube. Standard "ConeJet" type hollow cone nozzles are inserted inside the small air outlet pipes. Air velocity at the nozzle is 80-100 m/s. Nozzles are operated at a pressure of 250-300 kPa.

Howard et al. (1994, 1995) evaluated all currently marketed air-assisted sprayers, including the ones described above, for penetration, drift and deposition of pesticides. Droplet size, leaf coverage, and deposition on the upper- and under-sides of leaves at the top and middle canopy locations were measured and compared to a conventional boom sprayer. Results showed that air-assisted sprayers provided much better coverage on the under-side of the leaves compared to the conventional sprayer. However, they also pointed out that, with air-assisted sprayers, there could be a greater potential for off-target drift of droplets when lower rates of carrier volume and the higher air speeds were used in a bare ground situation. Some small spray droplets can be forced back up into the air and become susceptible to drift, if the crop canopy below is not sufficient to stabilize the energy in high speed air penetrating the canopy.
Although air-assist technology has been proven to be effective in increasing deposition while reducing drift, commercially available equipment using this technology currently has not been adopted by the applicators yet, mostly because of relatively high cost of the equipment.

C) Sprayer Boom Shields

Shields have been considered as economically viable alternatives to expensive air-assist sprayers. Furness (1991) compared a simple shield, mounted vertically in front of a boom with conventional nozzles, with an air-assist system that consisted of a set of rotary sleeve atomizers in the center of a shrouded axial fan. He concluded that shields are "simple, cheap and reliable, with no moving parts, whereas axial fans are complex, expensive and high in power requirement by comparison."
Smith et al. (1982) conducted both laboratory and field experiments to quantify the effects of a mechanical and a pneumatic shield on drift deposits. Results from laboratory tests indicated that a mechanical shield could reduce spray drift deposits by

up to 70%. However, field tests produced mixed results. While one mechanical shield reduced downwind drift deposits by 65%, the same shield under a different sprayer speed/wind speed configuration caused 81% more downwind drift deposits than the conventional boom.

Studies conducted by other researchers (Fehringer and Cavaletto, 1990, Cenkowski et al., 1994, and Wolf et al., 1993) to evaluate effectiveness of shields indicate that most of these devices reduce off-target spray drift. However, the results vary considerably among studies. In addition, experiments conducted in the field are subject to errors due to varying atmospheric conditions. Therefore, a more precise way to compare shield designs such as those discussed in the literature, would be to test them under controlled environmental conditions.

Ozkan et. al. (1996) studied the effect of several types of spray boom shields on spray drift by conducting experiments in a wind tunnel that is 10 m long, 1.5 m wide, and 1.0 m in height. A 3 by 3 m spray patternator table, half of which lies in the wind tunnel, was used to evaluate effectiveness of nine shield designs (Figure 5) by analyzing the spray deposition patterns with and without shields. Flat fan nozzles with 110° of spray angle and 0.6 L/min nominal flow rate (at a pressure of 0.3 MPa) were used for experiments. More information about the wind tunnel and the shields tested is given by Ozkan et al. (1996).

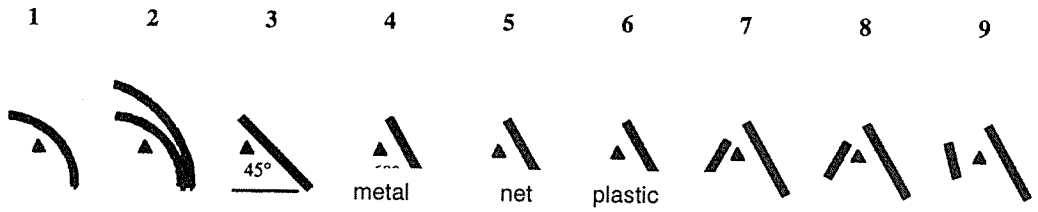


Figure 5. Nine shield designs used by Ozkan et al. (1996)

The performance of all experimental shields were evaluated under two spray pressures (0.15 and 0.3 MPa), and two air flow rates (2.75 and 4.80 m/s) in the wind tunnel. In addition to tests with shields, one set of tests at both pressures and airflow rates was conducted without shields. The volume of liquid collected in all 59 cylinders of the patternator was recorded and analyzed. Following conclusions were reached:

1. All nine shields effectively reduced spray drift from 0.61 L/min capacity nozzles by directing more of the small, drift-prone spray droplets toward the ground. Even the least effective of the shield designs (shields made of a porous material) produced a 13% improvement in deposition of spray on the ground. The double-

foil shield (Shield 2) produced the best performance; it improved spray deposition by 59% in comparison to same nozzles spraying without the shield.

2. The shields were effective even when used with nozzles with higher flow rates (producing fewer small droplets).

3. If applicable, choosing a nozzle with a larger nominal flow rate may be as effective at reducing drift as constructing a costly shield around the spray boom.

D. Tunnel Sprayers

Commercial tunnel sprayers are now available in Europe and USA. These sprayers have a frame covered with sheet metal or plastic that encloses a section of tree or vineyard canopy being sprayed. They are typically 4 or 5 m long and wide enough and tall enough to straddle a row of dwarf trees or a row of grapes. Some sprayers have fans that provide air-assisted spraying, while others have only spray nozzles. Some models collect spray that deposits on the tunnel walls and recycle it through filters, back into the spray tank. Tunnel sprayers enclose the section of the orchard being sprayed, therefore they reduce spray movement out of the sprayed area. Some studies show that more spray is deposited on the ground under the row than with conventional sprayers. Tunnel sprayers are not widely used in the USA because only about 10 percent of the apple trees are small enough for these machines. Most other fruit or nut trees grown in the USA are also too large for practical tunnel sprayers. Vineyards are one crop where this technology could be applied. Some farmers do not like tunnel sprayers due to their size. They are difficult to turn and maneuver in orchards where open space is limited.

II. Other Major Developments in Chemical Application Technology

A. Technology for Variable-Rate Application of Chemicals

On-the-go change of application rate of agricultural chemicals and change of plant population using information provided by satellites orbiting the earth is no longer a theory. Technologies to accomplish these tasks are now available to farmers in the USA and some other countries around the world. Variable-rate application of chemicals has been given many names, including: site-specific farming, prescription farming and precision farming. Major tasks involved in precision farming include: 1) identification of a given location in the field (longitude, latitude, altitude); 2) collecting site-specific information regarding soil physical characteristics, soil nutrient content, areas infested with pests, crop yield, etc.; 3) using computer hardware and software to store this information; 4) processing and analyzing this data; and 5) using proper equipment to do the actual application of chemicals on-the-go in accordance with the information stored in the on-board computer. Many computer software companies have recently introduced a new generation of mapping software.

The location of the field at any given time is determined by using the Global Positioning

System (GPS) of earth-orbiting satellites. Other information related to soil and other management practices is gathered using specific equipment and monitors. And finally, computer software called Geographic Information Systems (GIS) provides a means of graphically presenting, analyzing and interpreting the data, linking management information and records to specific points within a field.

So far, the most popular application of precision farming technology has been in the area of fertilizer application. This technology allows farmers to apply variable fertilizer rates based on the existing fertility of the soil and the crop needs, to each small division of a field. Although not documented yet, the variable rate application of fertilizers is expected to result in a reduction in cost of fertilizer inputs, and a reduction in the potential for water contamination as a result of runoff and/or leaching of fertilizers.

Using soil maps, farmers can alter tillage practices in sections of the field that are prone to erosion or compaction. Again the soil maps and yield data obtained from yield monitors can be used to determine the yield potential of areas in the field. This information can lead to changing fertilizer rates and planting populations to maximize profit and reduce waste.

With new technology using GPS and GIS, it is now possible to identify and isolate weedy areas of the field. By overlying weed maps along with soil maps, farmers can determine proper herbicide rates based on weed pressure, soil type and organic matter content. Using this information and the variable-rate technology, farmers can achieve weed control that uses the right amount of herbicides for each area of the field. Unfortunately, variable rate-application of herbicides for weed control using GPS/GIS technology has not yet been fully implemented.

Profitability of the precision farming technology is still under scrutiny. But savings in cost of inputs when using variable-rate technology is well documented.

B. Marking Systems Using GPS

When working with sprayers with a wide boom, it is difficult to determine the next sprayer path after a turn around. Improper positioning of the sprayer, resulting from inadequate marking of swath, may lead to excessive overlaps and skips that may cause chemical waste or insufficient pest control. Currently, foam or mechanical marking systems are used to identify the area covered during one pass of a sprayer. Now this task can be accomplished by using the GPS or perhaps FM radio signal systems. To use these systems, first a pass is made running the perimeter of the field. Then, using GPS, the location of the sprayer is recorded in one corner of the field. After entering the swath width of the sprayer in the controller, a pass is made across the field. This first pass of the length of the field establishes the "master swath". As the sprayer turns around for the second pass, a light bar indicates (by a series of lights right and left of center) where the sprayer is in relation to the centerline of the master swath.

C. Closed Chemical Transfer Systems

Since current pesticides are more potent than pesticides manufactured only 10 or 15 years ago, they require more care during mixing and handling. The major source of water contamination by pesticides is spills that occur during mixing and transport of pesticides. Although closed chemical transfer systems are not required in the USA, these systems are becoming standard equipment on most currently manufactured sprayers because they reduce the risk of operator exposure to pesticides, and reduce the risk of contaminating the environment. Using closed transfer systems, an operator can automatically meter only the desired portion of liquid product, transfer it to the spray tank and automatically rinse empty containers and the interior of the sprayer tank.

D. "SYNCHRO" - A System for Digital Control of Flow Rate and Droplet size from Agricultural Nozzles

The conventional technique for controlling the flow rate of liquid from an agricultural nozzle has been to vary the pressure of the liquid supply. This may not be the most ideal way of altering the flow rate for three major reasons: 1) the system response can be slow (less than 1Hz), 2) excessive pressure may be required to satisfy the flow rate required (flow is proportional to square root of pressure), and 3) changes in pressure is likely to affect nozzle performance: specifically the droplet size spectrum and the spray pattern. Recent, improved nozzle designs have reduced the influence of nozzle operating pressure on droplet size and spray pattern, but changing flow rate without effecting pressure and pattern when working with ordinary hydraulic nozzles still remains to be a problem.

A flow control system developed by Giles and Camino (1990) allows independent control of the liquid flow rate and droplet size spectrum emitted from hydraulic nozzles. They employed principles of Pulse-Width Modulation (PWM) to accomplish their objectives. PWM has been typically used in industrial control systems using electrical, hydraulic or pneumatic actuators. Recently, a commercial company (Capstan Ag System, Topeka, Kansas, USA) has successfully applied this technology to control flow rate from agricultural nozzles. With this system (called SYNCHRO), nozzle flow is modulated by intermittent operation of an electrically-actuated solenoid valve coupled to the inlet of the conventional spray nozzle. Controlling the relative proportion of time during which the valve is open or closed controls the volumetric flow rate from the nozzle. Wires along the boom connected to the SYNCHRO controller activate individual valves pulsing in the range of 1-25 cycles per second. Fluid flow is determined by the length of time valves remain open- their "duty cycle". System response time is relatively fast, providing a flow rate change of 5 to 1 in 0.3 second. Droplet size remains the same as the flow rate is reduced from 5 to 1. Changes in flow rate are made from an electronic controller that sends a signal to control the valve. Flow is adjusted at the nozzle by the solenoid valve. The valves attach to the standard nozzle diaphragm check valve port, replacing the diaphragm and cap. SYNCHRO is designed as a retrofit kit to work with conventional boom-type spraying systems equipment with an ordinary (commonly used)

electronic controller.

In addition to changing flow rate and droplet size, SYNCHRO also allows the operator of a sprayer to rotate the nozzles up to 90 degrees around its vertical axis when concentration of spray material in a narrow band is desired.

Giles and Ben-Salem (1992) and Giles (1996) confirmed experimentally the independence between PWM-controlled nozzle flow rate and resulting spray droplet size. As shown in Figure 6, the volume median diameter (VMD) from an 8004 spray nozzle (80° spray angle with 1.51 L/min nominal flow rate at 280 kPa) at various operating pressures remained relatively constant within each operating pressure. PWM at 10 Hz and duty cycles from 10% to 100% were used to modulate flow while liquid was supplied to the valve at 70, 140, 280, 420, and 700 kPa. Using the data in Figure 6, one

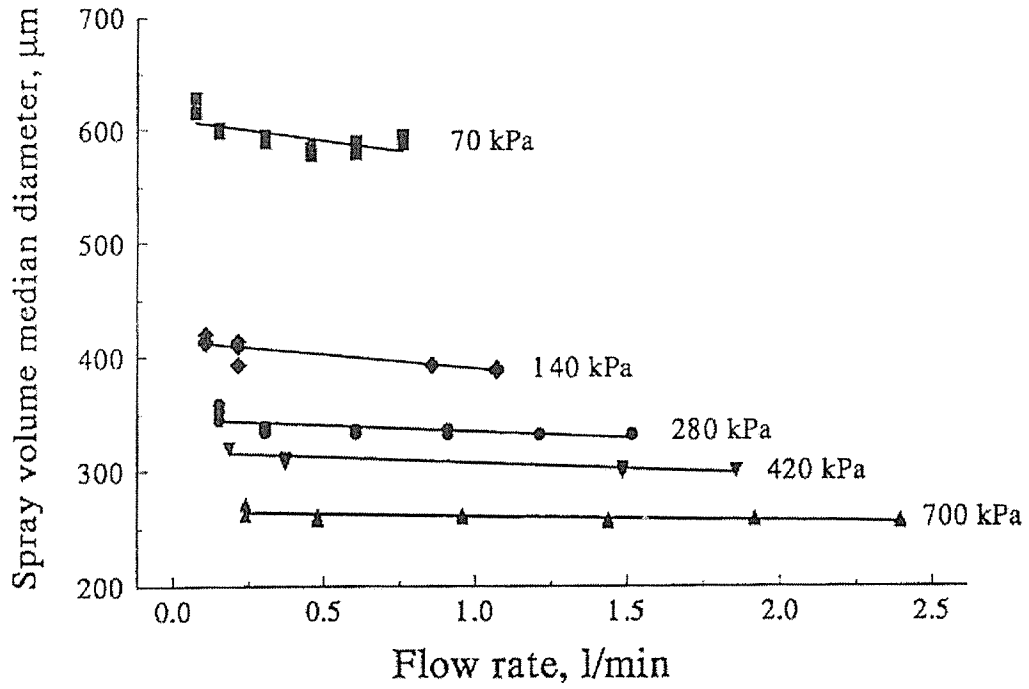


Figure 6. SYNCHRO system performance at various pressures (8004 nozzle)

can develop a flow rate and droplet size control envelope using the boundary points of the response lines. It is suggested by the manufacturers of SYNCHRO that one can choose any combination of flow rate and droplet size which falls within this envelope by exciting the valve/nozzle device with a corresponding PWM duty cycle and liquid supply pressure. Similar flow rate/droplet size envelopes has been established for other nozzles with different nominal flow rates.

Uniformity of deposition with SYNCHRO was a concern since PWM technique results in intermittent flow from nozzles. To avoid this concern, the control system was

designed such that adjacent valves received PWM signals approximately 180° out of phase. Giles (1996) compared uniformity of deposition from SYNCHRO system to that from a commercial, pressure-based, rate controller. Both control systems were mounted on the same sprayer and calibrated to maintain an application rate of 150 L/ha. Deposition was measured by placing 4 m strips of water sensitive paper perpendicular and parallel to the direction of vehicle travel. Results from nozzles with 80° fan pattern showed variation to be significantly greater from the PWM technique in some cases. However, when tests were conducted with 110° fan pattern nozzles, the resulting deposition from the SYNCHRO system was significantly more uniform.

This technology has just been introduced, and has not been tested in the field adequately. The cost of the system may be a deterrent to its adoption by the farmers. However, as the variable rate application of agricultural chemicals gains more acceptance; as more pesticide labels start displaying recommended droplet sizes; and as spray drift continues to be a major health and safety problem, systems like SYNCHRO are likely to gain more popularity among applicators of pesticides in the future

E. The "CP" Nozzles

CP nozzles (manufactured by CP Products, Mesa, AZ) are designed to bring convenience to the commercial applicators who change nozzle size as they move from one field to another. The atomizer (Figure 7) consists of an orifice plate with a range of

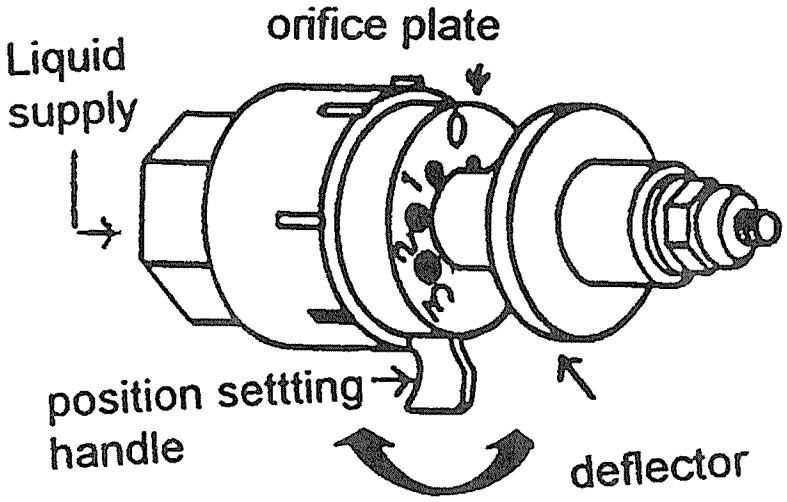


Figure 7. CP nozzle

hole sizes (orifices), and a curved, circular deflection plate which provides a spray pattern similar to the pattern produced by flood-fan nozzles. By simply dialing in the desired orifice, the applicator can choose the flow rate desired without changing the tips. Depending on the orifice selected, this nozzle can provide application rates ranging from 10 to 40 L/min. For best results, it is recommended that this nozzle body should be mounted on the boom at an angle of 0 to 30 degrees above the horizontal, pointed opposite to the travel direction.

F. Tower Orchard Sprayers

Several sprayer manufacturers now supply modification kits, or new airblast orchard sprayers with vertical duct (tower) air-distribution systems. Most of these sprayers redirect air produced by the axial fan to a vertical duct (metal or plastic) where it may exit from a continuous vertical slot or an air jet outlet at the top of the tower. Tower attachments to sprayers redirect the vertical component of the sprayer air jet to the horizontal direction. Thus spray is released much closer to the top of the tree canopy than with a conventional axial-fan sprayer. Also by directing the air jet horizontally through the tree canopy, less spray should be lost to drift through the top of the orchard. Commercial versions of cross-flow fan sprayers are available in both Europe and USA. Fans on these sprayers are usually about 1.5 m long and 0.4 m in diameter. The air jet from this type of fan is similar to an ideal plane jet; it is about 0.15 m wide and 1.5 m vertically. Several fans are stacked one above the other and produce a continuous jet directed horizontally toward the tree. Because these jets do not spread radially as distance for the jet outlet increases, the jet tends to maintain its centerline velocity better than axial-fan jets. Thus cross-flow fan sprayer jets will transport spray greater distances horizontally than axial-fan jets. They also should achieve more uniform spray coverage, because the spray droplets are released closer to all parts of the tree canopy. The air jets are directed horizontally (sometimes the top jet is even directed a few degrees downward), therefore, less spray is blown out of the top of the orchard canopy as drift, compared to a conventional axial-fan sprayer.

G. Spray control using canopy sensing

The canopy of tree fruit crops often is not uniform. There are often gaps in the canopy near the tops of trees. Sometimes trees die and are replaced with much smaller trees, which increases the irregularity of the canopy. As a result, we lose pesticide that is sprayed through these gaps in the tree canopy. During the last decade, several companies have developed canopy sensors that are aligned with a nozzle or group of nozzles. If these sensors detect canopy, the sensor(s) are turned on, if no canopy is detected, the nozzle(s) are turned off. Several types of sensors have been used, including infrared, ultrasonic, and imaging systems that detect the color of chlorophyll in leaves. In 1992, a company in Florida decided to use a technology developed for the Department of Defense called "Range Image Sensors with Automatic Target Recognition" (RISATR). This system detects three dimensional images of targets on the ground using laser lights. The Florida company used RISATR to detect tree canopies in an orchard. The sensor system takes tree measurements every 2.5 cm when traveling at a speed of 4 km/hr, and provides a map of the shape of the tree just before the sprayer is in line with the tree. This sensor, called TREESENSE, provides more precision than other sensors because more samples are taken. It can detect targets at a greater distance (30 m compared to 10 m or ultrasonic sensors), and there is no travel speed limit (8 km/hr for ultrasonic system). TREESENSE requires only 1 sensor, whereas an ultrasonic system may require 10 to 20 per sprayer.

H. Use of biological controls

Several types of biological pest control agents are currently being used. These control agents include nematodes, insect pathogens, predator insects, pheromones, etc. New application techniques are required to apply these materials that are often living creatures.

Many fruit and vegetable growers in western states such as California, Washington, and Oregon are greatly interested in biological pest control. The idea of applying beneficial insects to destroy pest insects is not new. But there are not many effective, economical ways to distribute these beneficial insects to the target plant. In some cases, they were applied as part of a dry product which was difficult to keep on the plant surface long enough to be effective. Even beneficial insects applied with a liquid carrier would often not stay where they were deposited. In many cases, beneficial insect eggs would fall to the ground because they did not adhere to the target foliage. Also, these beneficial insect eggs or larvae, or even bacteria such as Bt, would not survive the high pressures in the sprayer system. A carrier substance for delicate biological agents has been developed using 100 percent food grade materials. This carrier suspends the beneficial insect eggs for even distribution on the plants, and adheres them to the target leaves where they hatch. These materials are applied with a low-pressure applicator that does not damage the eggs in the storage tank or in the atomizer. Tractor mounted units for orchards and a back-pack sprayer for ornamentals are available.

Other research on specialty applicators for other biological materials is cited in the article by Fox et al. (1998) included in these proceedings.

CONCLUSIONS

Yield and crop quality depend on effective application of herbicides, insecticides, fungicides, fertilizers, growth regulators, etc. Applying an insufficient amount of chemical wastes time, money, and materials; an overdose adds to the cost, may damage the crop, and cause environmental pollution. Traditional methods and equipment used for application of pesticides are highly inefficient. Significant developments have been made in the last 5 years in design of application equipment. Unfortunately some of these innovations have not yet been widely accepted by the pesticide applicators mainly because of high initial costs of the equipment, and lack of knowledge about these technologies on the part of applicators. Although there are still many unanswered questions, pesticide application can become a more efficient operation as we continue to educate the applicators and as the new, more efficient application equipment becomes available to applicators at an affordable price.

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