To the Graduate Council:

I am submitting herewith a thesis written by Luis Enrique Olivo entitled "Evaluation of Low-Volume Herbicide Application Technology for No-Till Soybeans." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

Fred D. Tompkins, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

The Graduate School

EVALUATION OF LOW-VOLUME HERBICIDE APPLICATION TECHNOLOGY FOR NO-TILL SOYBEANS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Luis Enrique Olivo

June 1984

ACKNOWLEDGMENTS

I wish to express my gratitude and appreciation to Dr. Fred D. Tompkins, my major professor, for his advice, guidance, and expertise in the organization of this project and excellent leadership throughout this program.

Appreciation is also extended to:

Dr. Luther Wilhelm and Dr. B. L. Bledsoe, committee members, for their counsel and excellent classroom instruction provided to me during this program;

My fellow graduate students, Dr. Robert Hayes and Mr. William Hart, and to the staff at the Milan Experiment Station for their assistance in the collection of the data;

Wanda Seagle for her assistance in documenting this paper;

Roberto and Maria Cristina Olivo and Hall and Geneva Sayles, my parents and parents-in-law, who provided financial and moral support for the past years;

My wife, Kathy Ann, who provided moral support and understanding throughout the entire program;

Everyone associated with this project.

ABSTRACT

A study performed at The University of Tennessee Milan Experiment Station during 1983 evaluated and compared preemergence and postemergence herbicide application techniques in no-tillage and conventionally-cultivated soybean plots. The equipment utilized for herbicide application included conventional medium-volume hydraulic flat fan nozzles, low-volume flat fan nozzles, controlled droplet applicators (CDA), and an ultra low-volume electrostatic sprayer.

Various application parameters and techniques were compared: low-volume versus medium-volume spray rates, ultra-low versus medium-volume application rates, flat fan nozzles versus controlled droplet applicators (CDA) for low-volume spraying, and water-only carrier versus oil-in-water diluents for low-volume application.

Sprayed plots were evaluated for percentage control of selected weed species and for soybean yields. Results showed that spray application volume (5 gal/acre versus 20 gal/acre) applied either preemergence or postemergence did not affect the level of weed control in no-till soybeans. Moreover, low-volume hydraulic nozzles and controlled droplet applicators (CDA) at 5 gal/acre were equally effective in controlling weeds.

Roundup plus Lorox plus Lasso applied preemergence in wheat stubble gave significantly better control of Pennsylvania smartweed than a tank mix of paraquat plus Lorox plus Lasso. Both full and half-label rates of Basagran plus Blazer applied postemergence in

wheat stubble were significantly more effective in controlling cocklebur than Pennsylvania smartweed. Addition of a crop oil concentrate did not increase weed control in the low-volume treatments.

Application of Fusilade in conventionally-cultivated soybeans using an electrostatic spray system at 0.8 pt/acre total spray volume gave similar levels of weed control to applications of the same herbicide rates at 20 gal/acre using conventional hydraulic nozzles.

Soybean yields overall in 1983 were much below normal due to drought conditions during the growing season. Crop yields within a given production practice were not significantly affected by spray application techniques.

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CHAPTER I

INTRODUCTION

I. BACKGROUND AND PROBLEM DEFINITION

The earliest use of chemicals for weed control in the farming industry involved saturation sprays of high gallonage and agent rates per acre. Since the introduction of highly active growth-regulatory herbicides, research has made possible much lower active ingredient application rates. These lower application rates have decreased the machinery operating expenses associated with controlling weeds and other pests. Wiese (1982) found that the amount of Roundup (Monsanto) and paraquat (Chevron) required to control wheat using conventional broadcast TeeJet 730308 flat fan nozzles (Spraying Systems Co.) at 26 gallons per acre (gal/acre) was three times greater than when controlled droplet applicators (CDA) at 3 gal/acre were used.

Farmers are interested in knowing if new equipment and techniques will provide an advantage over their present equipment in providing increased weed control and/or reducing the quantity of their chemical formulations needed. The development of synthetic and biological pesticides has prompted design of improved spraying equipment for rapid, uniform, and precise application of these pesticide sprays. Other motivations for emphasizing the need for better equipment are rapidly increasing pesticide costs, lower

margins of profit in crop production, and environmental quality requirements.

Yeomans (1966) applied undiluted technical malathion at doses as low as 2 fl. oz/acre, using a spinning-air nozzle. He noted that more effective disposition of the spray was produced by this technique as compared with a straight-through atomizing nozzle because the former technique reduced the loss from run-off of the pesticide carrier.

In recent years researchers have investigated the efficiency of pesticide application techniques. Great emphasis has been given to specific parameters such as maximum plant coverage, low application cost, and control of spray drift. For example, Himel (1969) determined in his research on spray efficiency that less than 1 percent of the applied insecticide was actually performing the task of controlling the intended pest.

As new sprayer technology is made available to the farmer, improved management practices became necessary to insure effective and efficient pesticide application. Some of this new technology was available to The University of Tennessee Agricultural Engineering Department. A study involving application of spray material using improved low-volume and ultra low-volume equipment in no-till and conventional soybean plots was initiated at the Milan Experiment Station.

The spraying techniques used for preemergence and postemergence (over-the-top) herbicide application in no-till soybeans were

low- and medium-volume flat fan hydraulic nozzles and low-volume rotary atomizers (CDA). An electrostatic chemical sprayer system also was used for over-the-top postemergence herbicide application in conventionally-prepared soybean plots.

II. OBJECTIVES

The purpose of this study was to evaluate and compare the performance of preemergence and over-the-top postemergence herbicide application techniques and equipment for effective weed control in no-till soybeans. Specific objectives were:

1. To compare low-volume and medium-volume spray applications on the basis of effective weed control and soybean yield enhancement.
2. To compare low-volume flat fan hydraulic nozzles and controlled droplet applicators (CDA) for low-volume spray application effectiveness in weed control and soybean yield enhancement.
3. To establish a chemical application rate at which consistent grass control is achieved with an electrostatic spray system on conventional soybean plots.

The methodology involved determining percentage control of various weed species, observation of spray penetration into foliage canopy and spray droplet drift, and evaluation of spray coverage and crop yield.

CHAPTER II

REVIEW OF LITERATURE

I. LOW-VOLUME SPRAYING SYSTEMS

The idea of applying pesticides in concentrated spray form arose from the need for a rapid and effective method to replace the slow, difficult, and expensive application method which used large volumes of spray solution per unit area from high pressure-hydraulic sprayers (Potts, 1958). Improving the efficiency of sprayers has been an important objective for several research studies on pesticide application equipment.

Attique and Shakeel (1983) compared a hand-held, battery-operated spinning-disc sprayer (Turbair X) at 0.27 gal/acre with a hand-operated knapsack sprayer (CP3) at 42.7 gal/acre. They found that both techniques effectively controlled cotton pests but that the Turbair X sprayer was less expensive to use and covered a significantly greater area per unit time than the conventional knapsack sprayer.

A number of application techniques are available to evenly distribute currently available pesticides over the target area. These spraying techniques are often classified according to the spray volume used at the time of application (Maas, 1971). Taft and Hopkins (1967) defined the term "ultra low-volume" (ULV) as rates of 1 to 16 fl. oz/acre, "low-volume" (LV) as rates of

16 fl. oz/acre to 1 gal/acre, and "conventional volume" as rates greater than 1 gal/acre. Applications at rates defined as ULV and LV are now accepted by many growers in the United States because of the high cost of chemicals in the solution, labor, and because of large time requirements to apply conventional volumes of pesticide solutions.

Four different techniques of spray applications were to be considered in this study: (1) medium-volume flat fan hydraulic nozzles, (2) low-volume flat fan hydraulic nozzles, (3) low-volume controlled droplet applicators (CDA) rotary atomizers, and (4) ultra low-volume electrostatic particle charging nozzles.

Flat Fan Hydraulic Nozzle

The flat fan nozzle is used to apply pesticides on soil and plant surfaces that require an even distribution across the swath. Although chemical application rates have been increased to accommodate the inaccuracies of hydraulic nozzles (Potts, 1958), these nozzles are generally capable of delivering any kind of mixture at appropriate rates. But with the current concern for environmental protection, increased chemical usage is highly undesirable.

Concentrated low-volume formulations are inherently more hazardous than diluted mixtures of the same chemical. Consequently, equipment must be designed to maximize contact between pesticide and the target so spray formulations would not jeopardize the environment (Ahmad et al., 1979). The mechanism of drop formation and droplet size are two of the most important factors affecting the

deposition of pesticides on the intended target using flat fan hydraulic nozzles. Pimentel (1981) stated that the flat fan nozzles distribute pesticide solutions through creation of a moving thin liquid sheet. This sheet of liquid breaks into droplets that are moved toward the target by internal and external forces and by the physical properties of the liquid. These forces may be caused by the induced air currents that result from the flow of the liquid sheet into the air, by gravity, and by the momentum developed during the atomization process.

Courshee (1957) noted that low-volume hydraulic nozzles must deliver small quantities of spray solution while operating at low pressure. The liquid thus leaves the nozzle at a low discharge velocity. Break-up of the spray must be accomplished by using a high-speed air stream, or the liquid itself must be forced rapidly through the atmosphere by pressure generated by a pump.

Ennis and Williamson (1963) stated that droplet size is very important in the case of low-volume spray applications to achieve proper pest control. Howitt (1973) demonstrated that only very small droplets (diameter of less than 50 microns) have the ability to allow penetration of dense foliage canopies and deposition on the intended target.

The ordinary hydraulic sprayer nozzle produces an array of spray droplet sizes ranging from very small to quite large. The number of small droplets constitutes a very small percentage of the total spray volume so that the majority of droplets are not fully utilized due to either evaporation or run-off (Howitt, 1973).

Adler et al. (1965) developed a low-volume sprayer that was mounted behind a farm tractor. Essentially, the application consisted of a paint spray gun that emitted insecticides beneath a plastic canopy. Harrell et al. (1966) designed the first prototype of a low-volume sprayer. This sprayer was designed to emit spray through a flat-fan-type nozzle mounted on a high-clearance tractor.

White (1980) noted that sprayer booms to which hydraulic nozzles are attached bounce and whip, causing distortion of the nozzle spray pattern. In addition, the nozzle height varies because of ground contour changes, making precise and uniform application difficult to accomplish.

Spraying Systems Company (1978) classified flat fan nozzles according to a four number code that begins with the angle of the fan, such as 65--, 73--, or 80-- nozzles. The additional digits of the nozzle identification referred to the flow capacity of the nozzle at a spray pressure of 40 psi expressed as US gal/min. Thus a 8003 nozzle produces a spray fan with a discharge angle of 80 degrees and a 0.3 US gal/min capacity at 40 psi.

Arnold (1983) used a laser diffraction system to measure the droplet-size spectra from 11003, 8003, and 6503 flat fan nozzles (Spraying Systems Co.) with equal output. He noted that the droplet volume median diameter (VMD) at various distances (2 to 18 in.) from the nozzles decreased with increasing nozzle angle.

Mullins (1968) worked with a low-volume row-crop ground sprayer. He noted that at a discharge angle of 45 degrees into the

air stream, the flat fan nozzle 730039 (Spraying Systems Co.) gave acceptable droplet break-up for good coverage of the target surface.

Hydraulic fan nozzles have been evaluated and compared by numerous researchers. Hopkins et al. (1979) reported results of comparative tests in cotton with insecticides applied by conventional hollow cone Conejet TX6 nozzles (Spraying Systems Co.), by the 8001 (Spraying Systems Co.) low-pressure flat fan nozzles, and by the Raindrop 33974 (3-23) nozzles (Delavan Manufacturing Co.). Their data indicated equal pest control for the Raindrop and low-pressure fan nozzle in comparison with the conventional nozzle.

Harrell et al. (1967) evaluated low-volume ground equipment for effectiveness in the control of corn earworm. They used a 650017 flat fan nozzle (Spraying Systems Co.) and an electrical charge pneumatic F-1 nozzle (Spraying Systems Co.). This pneumatic nozzle consisted of a 2850 fluid nozzle and 73420 air nozzle which mixed liquid and air internally and produced a flat spray pattern. They reported that equal control of corn earworm was achieved with both nozzles using various rates of malathion. They also found that the F-1 nozzle was as efficient as the 650017 nozzle for placing low-volume formulation on corn ear tips.

Harrell and Leuck (1967) found that the coverage at the top of soybean plants was not significantly different when using pneumatic nozzles and 650017 flat fan nozzles (Spraying Systems Co.) at solution application rates of 32 fl. oz/acre. However, the flat fan nozzles gave better coverage in the middle of the soybean canopy.

Thomas and Goddard (1966) evaluated low-volume concentrate sprays (up to 2 lb/acre of malathion) for control of the boll weevil, Anthonomus grandis Boheman, using TeeJet 730023 flat fan nozzles (Spraying Systems Co.). They noted that satisfactory control of the weevil was obtained by this method of application and indicated that the method showed great promise in reducing the cost of pest control.

Controlled Droplet Applicator (CDA)

Controlled droplet application has been commonly used to refer to the application of chemicals using rotary spray nozzles or atomizers which produce a spray containing droplets relatively uniform in size. Most commercially available agricultural nozzles produce sprays with a wide range of droplet sizes. Many spray devices, including air and rotary atomizers, have been developed to produce a narrower range of droplet sizes than that produced by hydraulic nozzles.

Rotary atomizers were designed with the goal of producing a narrow spectrum of droplet sizes about a chosen median droplet size. Early rotary device designs did little more than equal the performance of hydraulic nozzles and were far more complicated. Their main failing was the small liquid issuing surface which consisted of spinning discs and wire brushes (Maas, 1971).

Reichenberger (1981) stated that application of pesticides in the form of spray solutions may be on the verge of the biggest change since the use of the first spray nozzle 70 years ago.

Heading this change was the relatively new concept called controlled droplet application or CDA. Controlled droplet applicators have only recently been used on tractor-mounted booms, although this technique has been utilized on hand-held devices and aircraft-mounted applicators for the past 24 years (Bals, 1975).

Controlled droplet applicators typically involve use of the centrifugal force generated by a spinning disc to produce spray droplets. This method allows greater control over spray droplet size than afforded by conventional nozzles. In theory, the spinning disc atomizer produces uniform micron-sized droplets. These spray droplets are too large for much evaporation and drift, yet are small enough to minimize run-off and overkill, allowing good coverage with low-volume application rates (Bode et al., 1982).

Adler and Marshall (1951) evaluated the performance characteristics of a spinning disc atomizer. They studied the effect of disc speed indicating that increased liquid velocity should result in finer atomization and higher initial velocity of droplets from the disc. Also, an increase in disc velocity appeared to result in shorter distances of travel, indicating a greater deceleration rate of the drops due to their smaller masses.

Bode et al. (1972) reported the effect of flow rate of the distribution pattern and drop-size spectrum of a spinning atomizer. Their results showed that both flow rate and vehicle speed significantly affected band width and spray distribution. The distribution pattern deteriorated at low atomizer speeds (2000 rpm) but only improved

slightly for speeds above 3000 rpm. Drop-size distribution was also markedly affected by the flow rate with the mean droplet diameter decreasing as the flow rate decreased. Goering et al. (1972) also reported the effect of the flow rate on the band width at various disc speeds. They noted that the atomizer performance was best at two rotational speeds (1800 and 3600 rpm) and poor at 900 rpm.

The theory behind the formation of droplets using controlled droplet applicators has been studied by many researchers. Hinze and Milborne (1950) studied the liquid supplied through a stationary tube to the inner part of a rotating cup widening toward the brim. Friction between the liquid and the wall of the cup caused the liquid to attain the same linear speed as the cup surface. Centrifugal forces acting on the liquid caused a flow of liquid toward the brim of the cup, and a state of ligament formation occurred. Ligaments were then broken up into droplets by disturbances of rotational symmetry.

Boize and Dombrowski (1976) studied the atomization characteristics of the Micron ULVA (Micron Corp.) rotary atomizer using only oil at different flow rates. They found that drop formation at low flow rates occurred directly on the peripheries of the double-disc assembly, creating an effective monodisperse spray. For higher flow rates, the fluid was discharged in the form of ligaments which broke down into a wide spectrum of drop sizes.

Rayner and Haliburton (1955) developed a rotary device to produce uniform drops of liquid in the diameter range of

50 to 700 microns. A blade rotating in a horizontal plane detached drops in a steady stream of regular trajectory from a stabilized liquid mass fed under constant head through a stationary capillary tube.

Roth and Reins (1957) described a rotating disc device built primarily as a uniform droplet source for determination of spread factor with various spray fluids. They noted that spray droplets having small diameters could be separated from the primary cloud since they projected a smaller horizontal distance from the disc.

Burt et al. (1966) developed a rotary disc device for ground application of ultra low-volume undiluted pesticides. The applicator consisted of two rotating discs powered by a small electric motor and a metering nozzle. They compared this device with a mist blower ULV applicator and concluded that although both devices gave about the same particle deposition on the plant, the rotary disc applicator gave a more uniform coverage of the intended target across the swath.

Taylor and Merritt (1975) described the development of an experimental type of field equipment for controlled droplet application (CDA) at low-volumes of spray solution. They noted that with volume rates down to 2 gal/acre, distribution of pesticide solutions was comparable to that obtained with a conventional medium-volume sprayer.

Hugo (1979) described a ULV sprayer with a rotating disc stack atomizer in a spray tube to control the droplet size spectrum. He noted that by placing a rotary-type atomizer within a spray tube, the droplet spectrum could be controlled to any range of droplet sizes.

Roehl (1982) evaluated several applicators which employed rotary action to produce a spray containing uniform sized droplets and the relationship of droplet size to herbicide effectiveness. His results were poor and inconclusive because windy conditions existed at the time of the application.

Richard Mohan, Iowa State University research assistant, found that controlled droplet application of Lasso (Monsanto) plus Roundup (Monsanto) showed greater weed control than conventional application. However, he noted that one conventional postemergence application of Basagran (BASF) showed better weed control than a similar application with the CDA, probably due to better foliage canopy penetration (Anonymous, 1983a).

Gerling et al. (1982) evaluated the overall effectiveness of CDA units for applying herbicide solutions to growing wheat or wheat stubble. They noted that the CDA units provided adequate control with low water rates in most field situations. However, in the preemergent herbicide trial, the CDA units exhibited control problems due to an apparent inability to adequately penetrate the stubble and get the chemical down to the soil. On the other hand, in the postemergent treatment with paraquat, the CDA units exhibited a higher level of weed control than the conventional nozzle.

Wiese (1982) reported that applying paraquat and Roundup (Monsanto) to a wheat-cotton cropping sequence using CDA rotary atomizers markedly increased control (up to 95 percent) of volunteer wheat, barley, and pigweed compared to control obtained with application using conventional sprayers. Three times the amount of

Roundup and paraquat were required to provide control of wheat when applied with conventional sprayers as when applied with CDA sprayers.

Kempen (1982) reported that the Micromax (Micron Corp.) atomizer would not penetrate the canopy of larger weeds laterally. Therefore, it was necessary to place the Micromax at an angle with the horizontal and above the larger weeds to obtain good coverage and penetration in the plant canopy.

Ultra Low-Volume Electrostatic Spraying Technology

The principles of electrostatics have been successfully exploited by industry for improvement of such seemingly diverse processes as fly ash and fume removal from industrial smoke stacks, paint spraying, and the development of electric force fields for enhancement of the basic droplet-deposition process in agricultural pest management (Law and Lane, 1979). For example, Bowen and Splinter (1968) demonstrated that electrostatic application of sprays or dusts can increase particle deposition by a factor of three over conventional techniques. Thus, for a given level of pest control, application rate and associated drift could conceivably be reduced to one-third of the conventional level.

Casselman et al. (1966) studied electrostatic dusting of vegetables. They found that in most experiments deposition of charged dusts was significantly greater than uncharged dusts on both upper and lower leaf surfaces.

Electrostatic deposition of agricultural sprays involves two sources of electrostatic charge: electrical charges carried by

the spray droplets in the unsigned cloud and the charge produced when droplets impinge upon the target surface (Hoskins and Wampler, 1939).

Droplet charging and electrostatic deposition technology has been proposed and investigated by numerous researchers for the past 30 years as a potential means for improving the basic droplet impingement process. The electrification of these droplets and their consequential electrostatic precipitation improved overall plant coverage and spray droplet distribution emerging from the spray atomizer (True, 1980).

McCartney and Woodhead (1983) developed a simulation model to assess the importance of induced image charge forces in increasing the deposition of charged pesticide drops on plant stems and upper and lower leaf surfaces as compared to uncharged droplets. Using this model, they predicted that within the crop canopy, considerable increases in the rate of both contact and sedimentation could be achieved if drops, particularly small drops, could be given electrostatic charges nearly as large as their maximum drop charge.

Hendricks (1962) obtained sprays of charged oil droplets using small hollow needles raised to a high potential (12 to 13 kV). These droplets had radii in the range of 0.2 to few microns.

Law and Bowen (1966) developed the induction method of charging sprays, and Splinter (1968) developed the ionized field method and combination method for spray charging using the air curtain principle to protect the charging electrode from spray

contamination. These researchers also reported that the charging of spray droplets did not appreciably alter the size distribution of the particles. However, charging did have a considerable effect on the distribution pattern of the spray.

Lane and Law (1979) stated that in the course of the electrostatic deposition process, free charges flow to the plant leaves in response to the presence of an electrical field which is created by the charged cloud. This surface charge is of opposite polarity of the charged cloud and has a magnitude and distribution that will maintain the plant at ground potential (zero volts) in the presence of the charged spray. Previous research defining electric field strengths and potential distribution (resulting from the electrostatically charged cloud) had assumed that plants behave as if they were a ground, conductive surface.

Law and Lane (1979) divided the electrical activity of the plant into two categories. The first category involved the charge generation (current) source. Charge was generated in the plant by the presence of a charged droplet cloud. The current could be the result of relative motion, deposition, or corona. The second category involved the mode of conduction of the charge through the plant. They also noted that as the charged spray cloud approached and enveloped the plant, a level of induced charge, appropriate to maintain the plant at ground electrical potential, was naturally established.

Electric field theory, verified by experiments, indicated that whenever a recipient body experienced an electric potential gradient, greater quantities of inductively charged sprays accumulated in those regions of the conducting body having smaller radii of curvature. This undesirable condition is known as "corona" discharge or ionization (Bowen and Splinter, 1968). Bowen et al. (1964) detected visible corona discharges present on the tips of celery leaves when doing experimental studies with smaller-scale electrostatic crop dusting techniques.

Law and Bowen (1966) treated mature cotton plants with both charged and uncharged sprays of an aqueous suspension of fluorescent tracer. With plants chosen at random, they evaluated coverage on both sides of leaves taken from lower, middle, and top sections of the plants. They noted that inductive spray charging significantly increased the spray coverage on the bottom sides of the leaves.

Brasher et al. (1971) studied the effectiveness of an electrostatic ULV sprayer in controlling the cotton boll weevil using malathion. They concluded that treatments administered with the electrostatic unit exhibited an average of 8 percent greater control than the uncharged treatments.

Harrell and Leuck (1967) compared an electrically charged pneumatic nozzle with flat fan nozzles (650017, Spraying Systems Co.). They treated soybean plants about 20 inches high with malathion at a rate of either 16 or 32 fl. oz/acre. Their results showed that the pneumatic nozzle plus electrical charging gave

equivalent or better results than those obtained with flat fan or conventional nozzles.

Law and Lane (1981) measured the spray deposition density on broccoli, corn, and cabbage foliage to compare the mass transfer characteristics of electrostatic spray application with conventional spraying systems. They noted that the deposition of charged droplets in the foliage was significantly greater than conventional deposition achieved on broccoli, cabbage, and corn.

Manley (1982) compared an FMC electrostatic sprayer with a conventional John Deere high-clearance sprayer equipped with hydraulic nozzles for insect control in cotton. He noted that the electrostatic sprayer provided adequate insect control with no significant crop yield loss at about one-half the insecticide cost incurred with the conventional sprayer.

Morton (1982) reported the performance of the "Electrodyn" sprayer (ICI Americas) in a 1977 experiment in Spain for the control of insects on cotton. He found that 2.5 times more spray was recovered in the crop when the spray was charged than when uncharged and that the only underleaf spray coverage obtained at the top of the plants was with charged spray.

Hislop et al. (1983) studied the deposition of a fungicide in barley and wheat using boom-mounted conventional hydraulic nozzles, experimental hydraulic electrostatic nozzles, electrically-driven spinning discs, and the Electrodyn spray system using both oil and aqueous sprays. They reported that the Electrodyn spray system

often produced large total deposits relative to the other spray systems.

Researchers have not shown explicitly those factors that limit the level to which sprays may be charged. However, there are several factors which appear to influence this process. One is the weather condition at the time of application. For example, Bowen and Splinter (1968) discussed the effect of certain environmental factors (relative humidity, temperature, solar radiation, cloud cover, wind, and atmospheric ion content) on electrostatic charging and on the deposition of pesticide materials on the target. They reported the results of field operation under a variety of weather conditions including day and night operations, fog, dew, and drizzle rain. The results indicated that electrostatic charging and deposition were effective and that the equipment was reliable in any weather condition where pesticide application might reasonably be considered.

Law and Bowen (1966) studied the fate of the charge on aqueous spray droplets in an evaporative environment. Studies showed that no measurable charge loss was experienced by an evaporative droplet as a result of the water vapor loss. But Lane and Law (1979) noted that electrostatic charging of the chemical was of little value if the plant electrical resistances became very high as was the case when the plant was drought stressed.

II. SPRAY DRIFT AND EVAPORATION

One of the major concerns when applying agricultural chemicals by spraying is to minimize or control the drift and evaporation

losses from spray droplets. Introduction of ultra low-volume (ULV) techniques and use of agents (adjuvants), oils, and foam applicators have improved deposition of spray solution on the target (Kaupke and Yates, 1966).

Spray dispersion is probably the most important determinant of drift. Akesson and Yates (1964) noted that controlling spray drop size for precision spray application appeared to be the most logical approach to reduce, if not eliminate, transport or drift of small spray particles.

The liquid volume used in low-volume spraying is much smaller than in conventional applications. To obtain a similar coverage of the intended target, it is therefore necessary to divide the spray liquid into much smaller droplets. Johnstone and Huntington (1977) studied the deposition and drift of small spray droplets (70-130 microns) of an insecticide (carbaryl) plus an indicating dye. They used low- and conventional-volume rates (0.64-1.29 gal/acre) of water-based formulations and low-volume rates (0.32 gal/acre) of waterless formulations. They found that deposition and drift of both LV insecticide sprays were closely related to spray droplet size, formulation, and a combination of meteorological factors, principally wind speed and temperature.

The use of LV spray requires fine droplets for adequate coverage; but droplets should not be so small that losses due to drift and evaporation become excessive. Consequently, a compromise is necessary in determining an acceptable droplet size that will

provide good coverage without increasing drift or evaporation. Smith et al. (1975) noted that for LV applications of azinphosmethyl with ground equipment, a droplet size between 140 and 200 microns provided adequate solution for good control of the boll weevil while avoiding excessive drift.

Mullins (1968) defined spray drift as the movement of airborne spray particles away from the target area. The amount of spray drift depends upon: (1) size of the droplets, (2) wind velocity, and (3) height above the ground from which the spray is released.

There is some disagreement on the particle size necessary to eliminate drift and to control pests. Researchers have been hampered by the lack of a quick, uniform method for determining particle size and drift.

Courshee (1959a) studied the fraction of the spray formed into small drops and the size of the spray drops which became drift at different wind speeds and nozzle heights. He noted that drift was best reduced by keeping the nozzle low, using flat fan rather than cone nozzles, and combining low pressure with spray liquid additives.

The size of the droplets depends primarily on pressure, design of the nozzle, and fluid properties such as density, surface tension, and viscosity. Kaupke and Yates (1966) noted that, in general, low pressure has a tendency to produce large droplets, and high pressure small droplets.

Different nozzle designs produce different ranges of droplet sizes. Researchers in England compared the droplet size spectrum

from a standard 8002 (Spraying Systems Co.) fan tip nozzle with that from a Micromax (Micron West, Inc.) rotary applicator. The 8002 nozzle developed drops ranging in diameter from 3 to 560 microns. In contrast, the rotary nozzle created fewer smaller droplets (9 percent were below 100 microns) resulting in less drift. They concluded that the drift from the 8002 nozzle was 5 to 10 times greater than from the Micromax (Reichenberger, 1981).

Burt and Smith (1974) reported that droplets 140 microns in diameter or larger are necessary for reasonably good control of spray drift. But the truly acceptable droplet size will have to be determined by its effectiveness in controlling the target pest.

Meterorological conditions become increasingly important in relation to deposition and drift as the spray droplet size decreases. But because of the variability in climatic conditions, not enough data are available to show the actual amount of drift reduction obtained from different droplet sizes (Yates et al., 1966).

Yates et al. (1966) were among the first to make field studies of spray drift from aerial applications. Barnes (1968) showed that a change from air to ground equipment offers a drift reduction factor of 5 to 10.

Threadgill and Smith (1971) reported the effect of certain physical and meteorological parameters on drift of selected non-pesticidal liquids when applied from surface vehicles. They concluded that when the impact of such environmental factors as temperature, relative humidity, wind velocity/direction, among others, is

minimized, the potential of sprays to drift decreases. Moreover, the drift potential of droplets larger than 140 microns in diameter is negligible for a wide range of atmospheric conditions.

Goering and Butler (1973) used a dual sprayer that allowed them to simultaneously test two formulations or the same formulation at different nozzle pressures. They found that lowering the nozzle height decreased the drift deposits and lowering the nozzle pressure decreased the spray loss.

Bode et al. (1976) made up to 30 direct comparisons of drift deposits using different spray solutions, nozzle pressures, nozzle orientations, and nozzle designs. They concluded that drift deposits could be reduced by reducing nozzle pressure.

Courshee (1959b) investigated several factors that minimize the occurrence of drift. He found that by increasing the nozzle capacity from 5 gal/acre at 35 psi to 10 gal/acre at 15 psi, by lowering nozzle height to 12 in. above the ground, and using an 80-degree spray nozzle to replace the conventional 60-degree spray nozzle, drift can be reduced by about 90 percent.

Hopkins et al. (1979) reported results of a comparative test using cotton insecticides applied with Raindrop nozzles 33974 (3-23) (Delavan Manufacturing Co.), hollow cone Conejet TX6 nozzles (Spraying Systems Co.), and 8001 (Spraying Systems Co.) low-pressure fan nozzles. Their data indicated that the Raindrop nozzles gave equal pest control with less spray drift than the conventional nozzles.

Another factor is often overlooked when pesticide solutions have been sprayed: evaporation. Evaporation losses from the moving spray droplets have come under consideration when, inexplicably, pesticide spray applications fail to produce expected control. Avant et al. (1979) were quoted as saying "it is often hard for a farmer or a commercial pesticide applicator to realize the impact of seemingly innocuous, small droplets of pesticide. After all, these droplets usually evaporate and disappear out of sight, out of mind." Evaporation of pesticide spray droplets can prove costly in dollars and peace of mind when neighbors complain of pesticide damage.

Ranz and Marshall (1952) defined evaporation as an operation in which heat is transferred by conduction and convection from hot gases (air stream) to the drop surface from which vapor is transferred by diffusion and convection back into the gas stream. The rate at which a droplet evaporates depends on a number of factors: (1) diameter, temperature and relative velocity of the drop, (2) temperature, humidity, and transport properties of the surrounding gas (air), (3) the length of time the droplet is airborne, and (4) the proportion of relatively non-evaporative liquids and solids in the solution (Potts, 1958). Spray droplet evaporation losses can be expected to be greater in conditions where a finely divided spray is carried a relatively great distance in a rapidly moving, turbulent air stream. Picot et al. (1981) recognized that a knowledge of atomizer droplet spectra is essential

for proper application of pesticide sprays. Since evaporation of the spray occurs in flight, the rate of evaporation must be known in advance to allow an assessment of the droplet diameter at the target.

Smith (1970) studied in-flight evaporation of spray drops in a disturbed medium and developed an analog simulation of the spray evaporation phenomenon. He found that moderate-sized droplets of herbicidal sprays in water carrier rapidly become very small droplets because of the high rate of evaporation. This evaporation resulted in inability to adequately control the spray coverage.

The extent of evaporation is closely related to the size of the droplet by its surface to volume ratio (S/V=3/r) (Maas, 1971). It can be seen from this equation that as the diameter of droplets become smaller, the surface to volume ratio becomes larger. This implies that the relative rate of evaporation of spray droplets, which is directly proportional to the surface area, is higher with smaller droplets.

Amsden (1962) stated that the life of a drop of pure water falling in air is proportional to the square of its diameter. Droplets may contain dissolved materials which lower the normal vapor pressure of the liquid such that the evaporation rate becomes lower than that for pure water drops of the same size.

Cunningham et al. (1962) measured the evaporation losses from spray droplets carried in an air stream by determining the increase in concentration of a previously dissolved chemical. They concluded that evaporation losses using airblast spraying

equipment with water as a carrier can be quite large. They found that droplets may evaporate more than 40 percent of their original volume as they travel to the target. Although evaporation losses may not seriously lower the amount of active ingredient that is deposited on the target, the losses probably affect the area covered. Potts (1958) noted that in order to prevent rapid evaporation, it is desirable that at least one-fourth of the pesticide solution be a non-volatile liquid.

Effect of Spray Adjuvants

Much has been accomplished to control evaporation and minimize drift hazard of pesticide solutions by improving the design and operation of application equipment and altering pesticide formulations. However, modifying the spray mixture itself by adding solvents, emulsifiers, wetting agents, and thickening agents appears to be the most promising way of eliminating these unwanted hazards (Van Valkenburg, 1963).

Publications concerning the use of adjuvants in formulating agricultural sprays have appeared for the past 75 years. Only recently, however, have researchers become concerned with the use of surfactants to increase the efficiency of herbicides (Bode et al., 1976).

Hassall (1969) stated that although water remains the most satisfactory and readily available liquid diluent, it is from the physical-chemical viewpoint one of the worst materials used as a carrier to deposit pesticide spray on foliage targets. In addition,

some organic pesticides available in the market are almost insoluble in water and, if dispersed in water, can cause serious difficulties when applied at a low volume. As a result, the addition of spray supplements is necessary to minimize some of the disadvantages already mentioned and to allow the active ingredients in the solution to act as effectively as possible.

Haq and Yates (1979) established that pesticide solutions in general are normally quite similar to water (Newtonian fluid) in viscosity when used as a diluent. They tested various formulations using paraquat in conjunction with Nalco-Trol, a polyvinyl viscoelastic additive manufactured by Nalco Chemical Co., and X-77, an adjuvant-spreader manufactured by Chevron Chemical Co., which reduce interfacial tension of liquid drops. They noted that some additives have a tendency to make the formulation non-Newtonian in behavior. This means that the viscosity decreases as the shear rate is increased and that viscosity and surface tension are strongly related to drop formation.

Akesson and Yates (1964) noted that some oil-base sprays appear to affect the surface tension in that: (1) the drop spectrum produced by the atomizer does not have as many larger drop sizes, (2) drops are deposited with less run-off from the target surface, and (3) drops are retained better by foliage surfaces compared to water only sprays.

Maas (1971) studied the influence of spray liquid viscosity on droplet penetration into cotton plants. He found that the

penetration into the foliage was better for a non-viscous spray liquid than when a viscous spray was used.

Yates et al. (1976) found that adjuvants which alter the physical properties (viscosity, surface tension, and viscoelastic properties) of the spray fluid may affect the basic atomization process and thereby reduce the number of small droplets (less than 100 microns in diameter) produced. Butler et al. (1969) stated that changing the viscosity of the spray mixtures is the most logical approach to modifying the droplet spectrum. They found that Decagin (Diamond Shamrock Co.), Norbak (Dow Chemical Co.), and Vistik (Hercules Powder Co.) increased the spray droplet size, reducing the danger of drift.

Ware et al. (1970) used Decagin (Diamond Shamrock Co.), blackstrap molasses at 24 to 25 percent, and Cab-O-Sil (Cabot Corp.) at 3.5 percent as spray thickeners for aerial application of insecticides. They noted that all three additives reduced that downwind drift of the solutions compared to an unthickened control solution.

Gakenheimer (1966) tested the effect of two herbicidal adjuvants (ATLOX 209 and ATLOX 210), manufactured by Atlas Chemical Industries Inc., in linuron, atrazine, and 2,4-D ester. His results indicated that the addition of less than 2 percent concentration of these two adjuvants increased the activity of all three herbicides giving excellent broadleaf weed and young grass control.

Herbicidal Emulsions

Drift and evaporation of drops during fall can be reduced or at least controlled by varying the properties of the liquid to be sprayed. This can be done by mixing certain additives with the chemical solution. In LV spray, the pesticide is generally presented as a true solution in an oil carrier. In some cases the active material is sprayed without dilution (Maas, 1971).

Inman and Kapusta (1982) reported the use of soybean oil as a preemergence and postemergence soybean herbicide carrier. They concluded that excellent control was obtained using Lasso 4EC (Monsanto) and Sencor 4F (Bayer) with soybean oil at spray volumes as low as 1 quart/acre and with Basagran 4EC (BASF) with oil at a volume of 2.5 pints/acre (Anonymous, 1983b). The advantage of oil carrier over water carrier is that oil reduces evaporation and volatility of the spray droplets, thereby increasing herbicide efficiency.

Stoller Enterprises marketed a new pesticide surfactant and carrier made of natural soybean oil (93 percent) and emulsifiers and preservatives (7 percent). The product, called Natur'l Oil, is designed to be used as a surfactant to replace petroleum-based crop oils and non-ionic spreader-stickers. This product mixes well with water and reduces evaporation and drift by decreasing the vapor pressure of the spray liquid. Woodward (1983) reported that the extremely low vapor pressure of the Natur'l Oil reduces evaporative losses and extends pesticide residuals although it is

essentially non-phytotoxic even at the high concentration required for a carrier.

Van Valkenburg (1963) stated that the most important benefits of using oil as spray additive are:

1. Slower evaporation of sprays.
2. Better adhesion of spray droplets to both dry and wet foliage surfaces.
3. Increased resistance of spray droplets to wash off in light rain.
4. Drift reduction.

Given that the oil droplets being generated are of the proper size, the problem of evaporation is eliminated because vegetable oil is a nonevaporative fluid. Powell (1943) noted that the rate of evaporation of water becomes appreciably lower due to the presence of a multi-molecular film of oil, and that this reduction becomes greater as air velocity is increased.

Apart from reducing evaporation, oil emulsions are resistant to washoff, providing they have had an opportunity to make a film over the area before exposure to rainfall. Colthurst et al. (1966) noted that sprays of water-in-oil (w/o) emulsions were better retained in leaf deposits than when water only diluent was used. Van Valkenburg (1963) noted that when conventional formulations are added to water, the oil in the formulation becomes finely divided in droplets that are surrounded by water.

Courshee (1959a) noted that the proportion of the drops under 50 microns was reduced by 75 percent when an oil-like solution

(Celacol M20) was added to water at a rate of 0.6 percent by weight. The reduction in small droplets decreased spray drift.

Banks and Oliver (1983) compared the use of conventional hydraulic nozzles at 20.1 gal/acre of water with 3.01 gal/acre of water, oil, and oil/water mixture applied with conventional hydraulic nozzles and CDA rotary atomizers. They concluded that the 3.01 gal/acre spray volume was as effective as 20.1 gal/acre of water, and the use of soybean oil was found to have adjuvant effects upon the spraying fluid.

III. DESCRIPTION OF HERBICIDES USED IN FIELD TESTING

The chemical solutions (herbicides) used in this study are briefly described to provide basic information concerning properties, commercial forms, field use, and toxicity levels (LD) of the compounds. The commercial formulation followed by the chemical name of these herbicides are given. Subsequent references use only the commercial formulation.

Paraquat

Paraquat, (1,1'-dimetyl-4,4'-bipyridinium ion), produced by Chevron and ICI Americas, is usually used as a general contact weed control agent and has a very rapid contact action. Paraquat translocation following a foliar application appears to be almost exclusively via the apoplastic system, but its translocation from root application to the shoot of the plant is poor (Ashton and Crafts, 1981).

Paraquat causes wilting and rapid desiccation of the foliage to which it is applied by interfering with cell division and increasing the size of the stomatal aperture resulting in significantly higher levels of transpiration. At the cellular level, paraquat causes loss of integrity of the membranes in the chloroplasts, inhibiting photosynthesis (Herbicide Handbook, 1967).

Paraquat is used in treatments where direct contact with the crop is avoided, that is, preplant, preemergence, or directed-postemergence. It is highly soluble in water and tenaciously binds to soil components. This compound is more effective when applied in the late afternoon or evening rather than in the morning or midday. Paraquat is a white crystalline solid with a faint ammoniacal odor with water as a carrier with a lethal oral dose (LD) of 150 mg/kg (Anderson, 1977).

Lorox

Lorox, [3-3(3,4-Dichlorophenyl)-1-methoxy-1-methylurea], manufactured by DuPont, is one of several urea herbicides widely used. Lorox is relatively nonselective and is usually applied to the soil as a preemergence or postemergence treatment. When used with a suitable surfactant, Lorox controls weeds up to 5 inches high as a direct spray in certain crops (Ashton and Crafts, 1981).

The absorption and translocation of Lorox appears to vary with different weed species, although the pattern of distribution suggests that Lorox is absorbed through the root system and rapidly translocated to the upper plant parts via the apoplastic system.

Lorox selectively controls germinating and newly established broadleaf weeds and grasses in crops such as soybean. It is also used for short term control of annual weeds in noncropland areas (Herbicide Handbook, 1967).

Lorox is an odorless, white and crystalline solid material with a lethal oral dose (LD) of 1500 mg/kg. Water is used as a carrier with this herbicide, and continuous agitation in the spray tank is required.

Lasso

Lasso, [2-Chloro-2',6'-diethyl-N-(methoxymetyl)-acetamilide], is manufactured by Monsanto. Lasso is recommended for use as a preemergence spray for control of most annual grasses and certain broadleaf weeds. Evans et al. (1968) found that soybeans are highly tolerant to preemergence treatments using this herbicide.

Lasso inhibits growth and reduces cell division and enlargement. This herbicide is readily absorbed by the plant root system or seeds of plants, inhibiting root elongation. Translocation appears to be primarily through the apoplastic system (Evans et al., 1968).

Crops tolerant to this herbicide include corn, soybeans, potatoes, and cotton. Lasso is an odorless, cream-colored solid material with a toxicity level of 1200 mg/kg (Ashton and Crafts, 1981). Water or fluid fertilizer are generally used as carriers.

Roundup

Roundup, [N-(Phosphonomethyl) glysine], manufactured by Monsanto, is relatively nonselective and particularly valuable for

the control of most perennial weeds. This chemical also controls most annual species. Roundup must be applied to the foliage of the target vegetation for postemergence control because it is non-phytotoxic when applied to the soil. Spray drift must be minimized to avoid contact with the crop (Ashton and Crafts, 1981).

Roundup is readily absorbed by leaves and translocated through the symplastic system. Symptoms of its presence on the plant are foliar chlorosis followed by necrosis showing a growth inhibiting effect.

Because Roundup works through the treated plant and not through the soil, there is no residual soil activity, allowing double-cropping of the land without any side effects. This compound has a lethal oral dose (LD) of 4320 mg/kg (Ashton and Crafts, 1981).

Basagran

Basagran, [3-Isopropyl-1H-2,1,3-benzothiadiazin-4 (3H)-one 2,2-dioxide], manufactured by BASF, is an unclassified herbicide because of its compounds. Basagran is a selective herbicide that controls a number of broadleaf and sedge weeds, primarily by contact action.

Ground or aerial postemergence contact sprays of Basagran are very effective application methods, but best results are obtained when this compound is applied to the soil. Basagran is not absorbed by soil particles, making weed absorption through the root system

a very effective mode of action. This herbicide has a toxicity level of 1100 mg/kg (Ashton and Crafts, 1981).

Blazer

Blazer, {5-[2-Chloro-4-(trifluorometyl) phenoxy]-2-nitrobenzoic acid}, manufactured by Rohm and Haas, is a diphenyl ether type herbicide. This chemical is used to control many annual weeds with preemergence of early postemergence application in several crops (Herbicide Handbook, 1967).

Blazer is considered to be a contact herbicide absorbed by both leaves and roots of the plant. Very little translocation occurs once it is absorbed. This compound induces chlorosis and necrosis when applied to leaves, and the presence of light intensifies its mechanism of action (Ashton and Crafts, 1981).

Fusilade

Fusilade, {butyl(R-S)-2-[4-[[5-(trifluorometyl)-2-pyridinyl] oxy]phenoxy]propanoate}, manufactured by ICI Americas, is a selective postemergence herbicide which has been tested under the code number PP009 for control of annual and perennial grasses in cotton and soybeans. This herbicide does not control broadleaf or sedge weeds.

Ed Ready, ICI Americas technical services coordinator, pointed out that Fusilade controls giant foxtail, bermudagrass and other problem species. He warns that Fusilade should be applied only to actively growing grasses (Ready, 1982). Application rate varies from 0.25 to 1 pint per acre, depending on the grass species.

The chemical is readily absorbed by the foliage of treated grasses. Symptoms, visible within 3 weeks, are loss of vigor, yellowing and/or reddening followed by necrosis showing growth inhibiting effect (ICI Americas, 1982).

A unique property of Fusilade is that, in addition to foliar and systematic activity, the product offers some soil residual control. New growth of grasses may be controlled up to several weeks after application (O'Brien, 1983).

IV. RATES OF APPLICATION OF ACTIVE INGREDIENTS

The use of new spray application technology has allowed the user to apply lower spray volumes and to reduce rates of active ingredients (concentrations) in the spray solution. Therefore, producers and researchers must determine in some way the proper rates of chemical application or dosage at which a chemical pesticide should be applied in the field (Ahmad et al., 1979).

Fryer and Makepeace (1972) stated that the dosage of an expensive herbicide can be reduced by replacing it partly by a cheaper compound. This may increase the performance of the compound due to the combination of different modes of action.

Lloyd et al. (1967) applied azinphosmethyl at three different rates (0.2, 0.25, and 0.125 lb/acre of active ingredients) as ultra low-volume sprays to control boll weevil. They found that 0.2 and 0.25 lb/acre of azinphosmethyl were as effective as water emulsion sprays of methyl parathion at 0.5 lb/acre in reducing the boll weevil population up to 98 percent.

Ludwig (1973) noted that the lowest dose of atrazine used in a 1967 experiment was 0.5 lb/acre which was very effective, giving complete control of a heavy weed infestation in maize. These encouraging results indicated that a further reduction in dosage might be practical. Thus, he reduced the rate to 0.25 lb/acre and compared it with Lorox, 2,4-D amine, propachlor, pyriclor, and fluorimidine at recommended rates. He reported that preemergence application of atrazine at a rate of 0.25 lb/acre was reasonably effective under wet conditions.

Paul Sprankle, weed control specialist for Monsanto, conducted a series of tests using Roundup treatments at 1- and 2-quart rates in johnsongrass-infested fields. He found that with 2 quarts/acre, the average control was 93 percent. At 1 quart/acre, 87 percent control was obtained. This new 1 quart label rate allows the farmer to cut the cost of this treatment in half while still achieving excellent johnsongrass control (Anonymous, 1983c).

Ralph Weems, a farmer in West Point, Mississippi, applied Fusilade (ICI Americas) to about 500 acres of soybeans at two different rates. In one location, he used 0.25 pint of the herbicide, which was half the minimum company recommendation, plus crop oil in 20 gal/acre of solution. At the other location, he used the recommended label rate. He reported no difference in the effectiveness of the two rates (Anonymous, 1983d).

Mullins et al. (1974) conducted various experiments to study soybean tolerance and johnsongrass control from topical and

directed applications of 0.5, 1 and 2 lb/acre of Roundup (Monsanto). They noted that as the rate of Roundup was increased, soybean injury increased and yields were reduced regardless of application method used. At 0.5 lb/acre, soybeans showed some tolerance. The 2 lb/acre rate was too high, causing severe injury in most cases. Better control of johnsongrass was obtained with topical applications at 0.5 and 1 lb/acre rates than with 2 lb/acre.

V. COVERAGE AND DEPOSITION EVALUATION

The effectiveness of deposited spray depends not merely on the amount of active chemical material deposited on the intended target but also on the distribution of the chemical over the plant. Moreover, the inability to evaluate spray coverage and drop size is thought to be among the most important impediments to the development of equipment and operating procedures for improved effectiveness of spray materials (Carlton et al., 1981).

Brittain et al. (1955) used the titrimetric technique to evaluate deposits of a pesticide containing copper. The copper-containing pesticide applied to the plant was removed by washing the leaf samples. Potassium iodide was added to the solution to release free iodine. Then a starch indicator was added, turning the solution dark blue, indicating the presence of free iodine. A quantity of sodium thiosulfate was added drop by drop until the solution became clear. The amount of sodium thiosulfate was proportional to the quantity of copper present, which in turn

was proportional to the total weight of the pesticide present on the leaf surface. This technique was useful in determining the total quantity of material deposited, but gave no information about the uniformity of the spray coverage on the target.

Brazee (1963) reported the use of the polarography technique to analyze numerous types of pesticide deposits on foliar targets. This method was designed by Jaroslav Heyrovsky in the 1920's. It is based on the electrolysis of electro-reducible or electro-oxidizable substances in a cell with a dropping-mercury electrode from which a current-voltage curve is obtained. This curve gives the amount of electro-reducible material present in the applied spray solution. This is a fast and accurate procedure to evaluate deposition efficiency of any type of spray material providing the solution to be measured is electro-reducible or electro-oxidizable.

Ban and Carleton (1955) reported the use of polarographic chemical analysis to evaluate the application of dust and spray material. They noted that copper concentrations as low as one part per million (ppm) could be detected in the applied pesticide using this procedure.

Wilkes and Brazee (1963) reported the use of the activation analysis technique for evaluating spray distribution patterns. This method is based on making chemical analyses using atomic energy. Radioactive isotopes are formed as a result of neutron bombardment of the applied spray solution. Quantitative measurements of these radioactive isotopes are made using a gamma ray spectrometer for

monitoring the amount of radioactivity present on the sprayed sample. This is a fast and highly sensitive technique for evaluating spray coverage.

Norby and Steemberg (1959) also used the activation analysis technique to evaluate the spray distribution of Orthocide, a fungicide manufactured by Chevron Chemical Co., on leaf samples taken from apple trees. They noted that the action of the spray material used would not be satisfactory for chemical or biological studies because of changes in its chemical composition due to the neutron irradiation.

Stafford et al. (1970) noted that biological considerations should be included in analyses of spray coverage effectiveness. Factors to be considered include the mobility of the pest to be controlled, the ability of the plant surface to absorb the pesticide, and the nature of the pesticide.

VI. FLUORESCENT PARTICLE TRACER TECHNIQUES

The main purpose of adding fluorescent dyes and pigments to agricultural spray fluids is to have a quantitative and qualitative idea, by visual examination of sprayed plants, of the spray deposit on the intended target (Maas, 1971). The techniques considered here are generally aimed at measuring the amount, distribution, and droplet size characteristics of spray deposited on the foliage target by a spraying apparatus by using fluorescent additives in the spray solution.

Fluorescent materials are those which absorb light of one wavelength and emit it as light of a greater wavelength. This emitted radiation cannot be seen by the human eye, but it is visible under ultraviolet radiation applied in a dark room (Staniland, 1960).

Carlton et al. (1981) stated that the addition of a soluble fluorescent tracer to a spray solution provides a means for obtaining a spray deposit profile. This can result in increasing the knowledge about the general level of efficiency of the spraying machine so that growers themselves can see the extent to which their operations are successful.

Staniland (1959) worked with various fluorescent tracer materials using different spraying techniques. He classified these materials into four categories:

1. Luminescent powder--This material was found to be difficult to mix with inert dusts and suspension sprays and was not economically feasible for large-scale work.
2. Fluorescent powder--This material is finely ground with very good trace efficiency when used in suspensions.
3. Water-soluble fluorescent dyes--These materials perform well for high- and low-volume spraying. They are readily absorbed by the chemical present in the spray and can be seen after the target surface is wetted by rain.
4. Fluorescent spray simulating emulsion--In this case the chemical is dissolved in oil and emulsified. The fluorescent particles will show the site of the droplets on the target.

Staniland noted that fluorescent tracer techniques could have other applications in such areas as: (1) evaluating soil-pesticide relationships, (2) evaluating the performance of spraying machines, (3) tracing contamination from spray application, and (4) evaluating results obtained from different pesticide formulations.

Davis and Elliott (1953) described a method to determine the aerial dispersion and deposition of spray material in the field. This procedure consisted of placing indicator cards or recovery plates at right angles to the trajectory line of the aircraft in order to receive spray samples. They used a white, glossy, even-textured paper treated with an oil-soluble red dye. When a spray droplet fell on these dye-coated cards, the dye was dissolved and lighter colored circular spots with dark colored perimeters were formed.

Liljedahl and Strait (1959) described a new and very accurate technique to study spray distribution from any type of sprayer. They reported that a spray solution containing fluorescent material could be collected on paper strips. The paper was then passed under a scanning chamber with an ultraviolet light measuring the fluorescence with a photocell. The current generated in the photocell was amplified and recorded on a strip-chart recorder, graphically indicating the distribution of the spray on the target.

Yates and Akesson (1963) worked with a tracer technique that could be utilized to accurately measure spray drift and evaluate pesticide deposits on the foliage target. They noted that the tracer

material used must be soluble in spray mixtures with minimal effect on the atomization and droplet evaporation. Additionally, this material must be highly sensitive, accurate, and nontoxic.

Sharp (1976) described a technique for the measurement of paraquat spray deposits on various broadleaf weeds and bean leaves by using a soluble fluorochrome dye (UL39, Industrial Colours Ltd.). He found that microgram quantities from dried deposits of the dye/herbicide mixture were obtained by extracting the fluorochrome from deposits on the foliage surface. He then measured the fluorescent residues in a fluorometer.

Himel (1969) developed a unique method for tracing fluorescent particles. His fluorescent particle (FP) spray droplet tracer method makes it possible to identify pesticide spray droplets by number and size directly on the sprayed target. This method is based on using a uniform suspension of a known number of fluorescent (Zn-Cd sulfide) micron size particles in a known volume of non-volatile pesticide solution. He noted that predictable numbers of these fluorescent particles, based on the diameter of the droplets, are contained in the droplets formed from the spray solution.

Byass (1969) described a technique for presenting leaf samples to the fluorometer for making sensitive comparisons of the deposition uniformity of the spray material on the foliage surface. He stated that water-soluble fluorescent dyes gave satisfactory indications of the location of the pesticide but that caution was necessary when employing fluorescent tracer in oil solutions.

Dean et al. (1961) determined the relative deposits of dilute oil spray mixtures on various parts of grapefruit trees using soluble fluorescent dye (Fluorescent Yellow C-4) manufactured by the Ethyl Corp. visible upon exposure to ultraviolet light. Using this procedure, they were able to compare oil deposits with different concentrations of oil in the spray mixture, plus various surfactants and concentrations of surfactant.

Stafford et al. (1970) evaluated spray coverage for insect control on plum trees and grapevines. A Turner fluorometer was used to measure the amount of ultraviolet light emitted from the zinc sulfide fluorescent pigment deposited on the foliage target. They noted that this procedure was very promising for use in studies of spray coverage on crops since it gave a good correlation between deposits of pigments and insecticide.

Carlton et al. (1981) developed a method for using a fluorescent tracer called "blazed orange" (AX-15-N), manufactured by Day-Glo Color Corp., to measure spray coverage on soybean leaves. They added the tracer to a common soybean fungicide (Benomyl), manufactured by DuPont, and measured the coverage by using a III Turner Fluorometer. This procedure enabled the researchers to measure spray deposit coverage directly from the leaf surface, a technique that was previously impractical.

Staniland (1960) reported the use of various fluorescent tracer techniques using a wide range of spraying apparatus on a number of crops under field conditions. He noted that distribution

of deposits on the sprayed crops was sometimes poor although good control was obtained. This may suggest that fluorescent tracer may not necessarily give a true picture of the presence or absence of the spray chemical on the target.

Isler (1963) enumerated some of the disadvantages of using fluorescent tracer. These disadvantages included considerable time and manpower required to handle the sampling procedures, and the fact that the tracer is subject to fading due to exposure of samples to sunlight. These disadvantages make these techniques impractical for use in large operations.

Freedlander and Anderson (1983) developed a simple photographic technique to evaluate droplet deposition of the spray material. Their method allowed the researcher to evaluate spraying techniques by photographing fluorescent particles on the target in the field.

CHAPTER III

PROCEDURES AND EXPERIMENTAL METHODS

I. INTRODUCTION

A field research study was conducted at The University of Tennessee Experiment Station at Milan during the summer of 1983 to compare preemergence and postemergence herbicide applications using low-volume and conventional spraying techniques. This research compared various spray application techniques including controlled droplet applicator (CDA) rotary atomizers (Micromax/DR4, Micron Corp.), conventional hydraulic flat fan nozzles (8003, Spraying Systems Co.), and low-volume hydraulic flat fan nozzles (800067, Spraying Systems Co.) using either water or oil-in-water as a diluent in the spray mixture.

The preemergence applications consisted of two different spray formulations at label rates, while the postemergence application consisted of one spray formulation at two different rates. The experimental plots for these application treatments consisted of soybean (Glycine max (L.) Merr) of the variety ASGRO-5474 planted no-tillage in wheat stubble in a double-cropping system. In an additional postemergence over-the-top test, an electrostatic sprayer unit (Electrodyn, ICI Americas), was compared with conventional flat fan nozzles (8003, Spraying Systems Co.) using various rates of active ingredients applied on conventionally-cultivated soybean plots.

II. PLOT SELECTION AND PREPARATION

Due to wet field conditions and cool weather which delayed wheat maturity, wheat was harvested on June 22, 1983 from the two preemergence and postemergence herbicide application test plots. These areas, measuring 219 by 133 feet each, were situated on a Calloway silt loam soil. Soybeans were then no-till planted on June 24, 1983 in wheat stubble measuring 12 to 15 inches in height.

Each area received 10 different spray application treatments, each replicated three times. An experimental unit consisted of eight rows of soybeans (20-inch spacing), 60 feet in length. A 20-foot alley for turning machinery was maintained between replicate blocks. A portion of the plot area is shown in Figure 1.

A conventional soybean plot was used to compare an Electrodyn electrostatic spray system with a conventional hydraulic sprayer. This area received six different chemical application treatments and a control (no treatment), each applied to four rows of soybeans (40-inch spacing). Row length was 30 feet. Three replications of each treatment were used. These plots had been previously treated with preemergence herbicides to control broadleaf weeds. Thus, annual grasses were the predominant weeds present in the test area.

All application treatments were assigned to the experimental units at random within blocks and properly tagged in the field for later identification. Markers were placed along the centerlines of the experimental units at the beginning and end of each sprayer

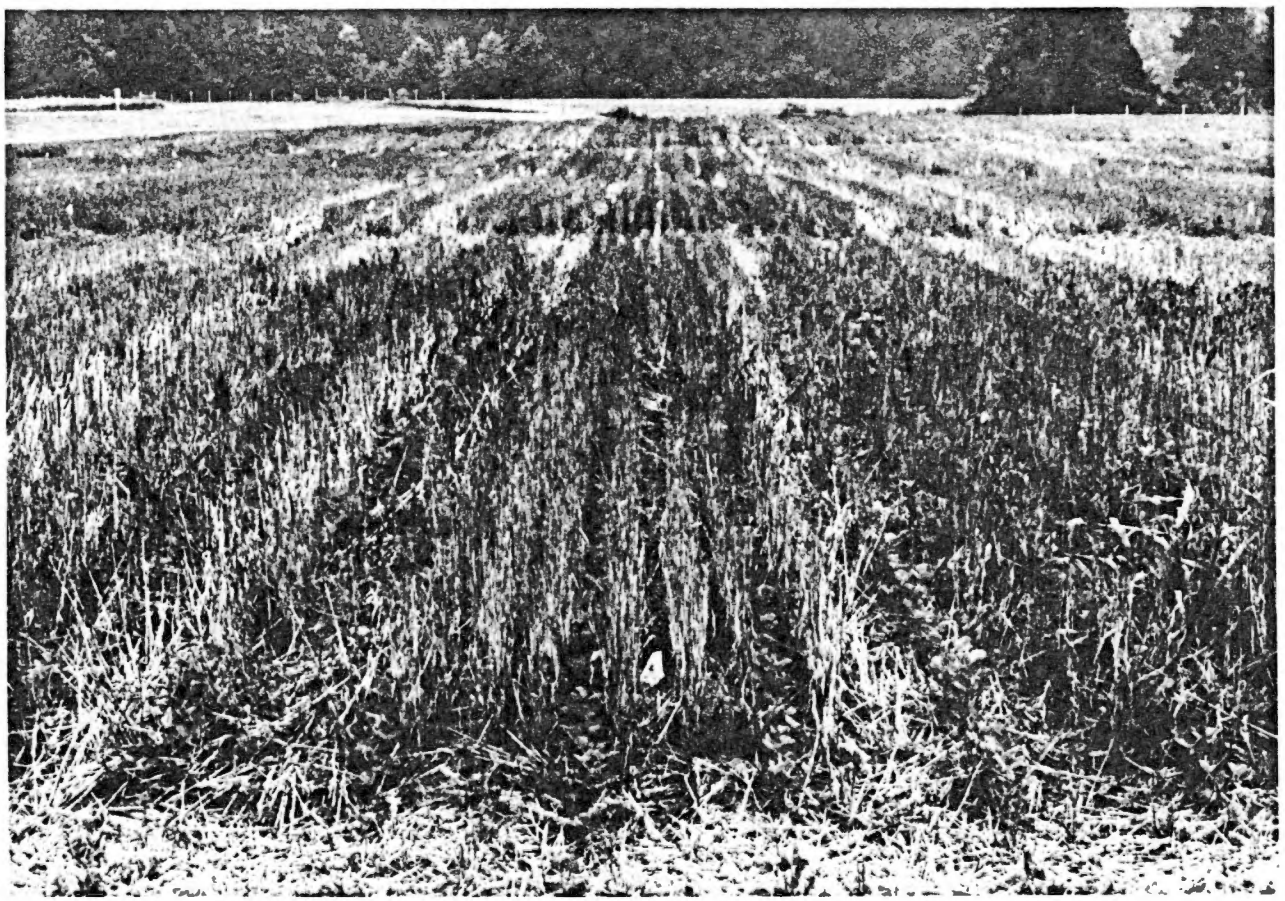


Figure 1. No-tillage soybean plots at the Milan Experiment Station treated with preemergence or postemergence herbicide applications.

pass so the equipment operator could deliver the spray material over the middle rows with a minimum of driving adjustment.

III. EXPERIMENTAL DESIGN

Treatments using the CDA units and conventional nozzles in the no-till soybeans were arranged in a split-split plot experimental design with a factorial arrangement of treatment combinations. For the preemergence test, the whole plot treatment consisted of two spray formulations: paraquat plus Lorox plus Lasso, and Roundup plus Lorox plus Lasso, all at label rates. Basagran plus Blazer at both full and half label rates comprised the whole plot treatments for the postemergence applications. Five different herbicide application techniques used were:

Water only as a carrier:

1. 800067 flat fan nozzles (4 gallons per acre).
2. CDA atomizers (4 gallons per acre).
3. 8003 flat fan nozzles (20 gallons per acre).

Crop oil-in-water as a carrier:

1. 800067 flat fan nozzles (4 gallons per acre).
2. CDA atomizers (4 gallons per acre).

A total of 10 treatments including two spray formulations and five spray application techniques were used for each of the preemergence and postemergence herbicide applications to no-till soybean plots.

Treatments for the Electrodyn electrostatic spray system were arranged in a randomized complete block design. These treatments

consisted of conventional applications of Fusilade at rates of 0.25, 0.125, and 0.06 pounds of active ingredients per acre (lbs ai/acre) using 8003 flat fan nozzles, electrostatic application of the same levels of active ingredients, and an untreated plot as a control. A total of seven treatments were randomly assigned to each of three replicate blocks.

IV. FIELD EQUIPMENT

Flat fan 8003 and low-volume 800067 flat fan hydraulic nozzles manufactured by Spraying Systems Co. and the Micromax/DR4 controlled droplet applicator (CDA) rotary atomizers, manufactured by the Micron Corporation, were used to apply the preemergence and postemergence herbicide treatments in the no-till soybean plots. The spray nozzles were arranged along booms mounted on a Spirit T-260G self-propelled sprayer, manufactured by Spirit Manufacturing Inc./Division of Storall Manufacturing. This equipment was used to apply all treatments in the no-till soybeans.

The self-propelled sprayer was equipped with a 24-horsepower two-cylinder, four-cycle, air-cooled engine and an Ace model FMCH centirfugal-type pump driven directly by the engine. The self-propelled sprayer carried four 25-gallon fiberglass tanks (Figure 2) with a flow control valve system that allowed independent use of each individual tank for agitation, tank balancing, and spray selection.

Two liquid strainers were installed in the lines between the pump and the tank flow control valves to prevent clogging of

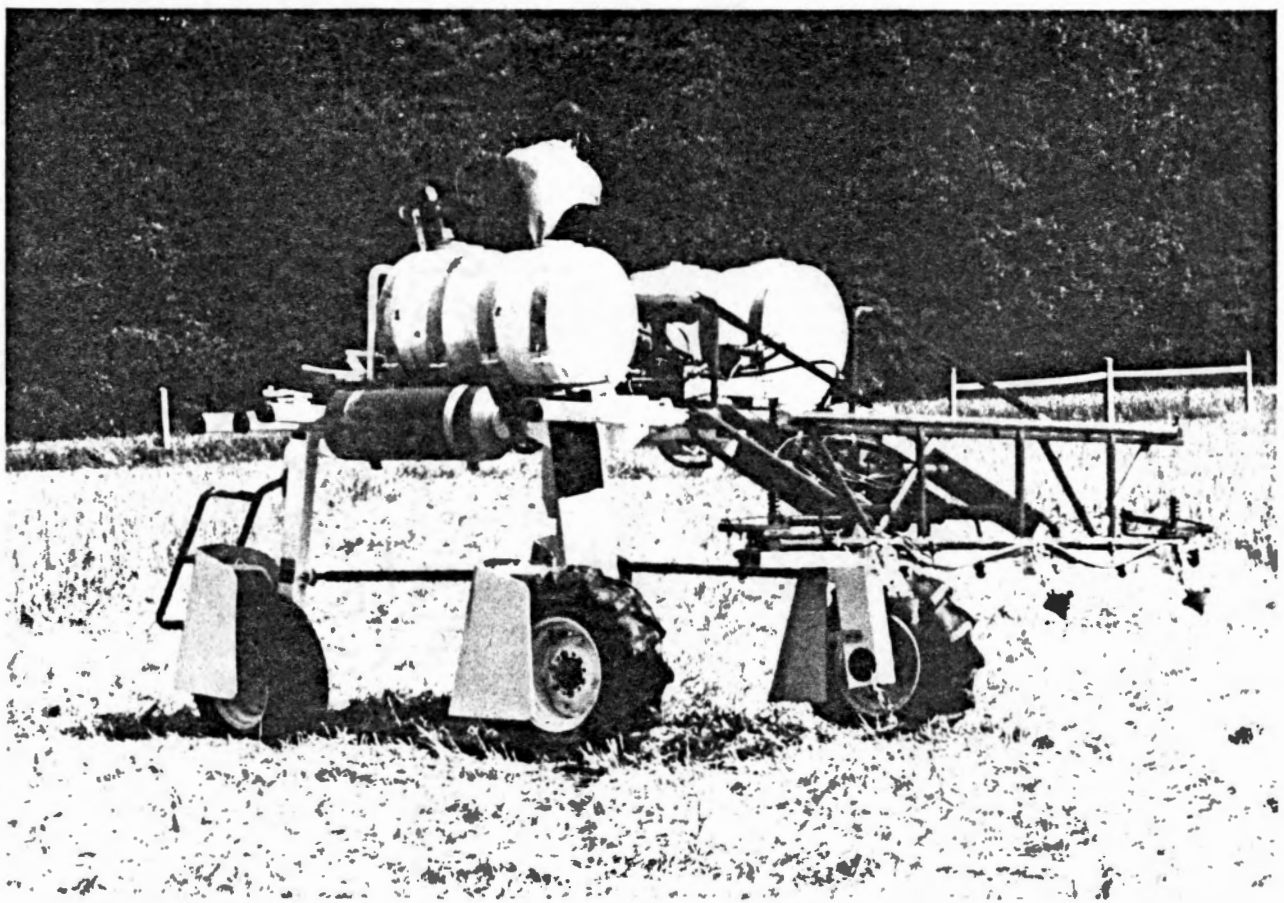


Figure 2. Self-propelled plot sprayer used to apply medium- and low-volume preemergence and postemergence herbicide treatments.

the hydraulic nozzle tips and orifice plates in the CDAs. The CDA rotary atomizers were installed along an 11-foot piece of 2-inch square aluminum tubing which was attached to the rear of the existing boom on the self-propelled unit. Mounting the CDA units on a separate member allowed either the CDAs or the hydraulic nozzles to be operated independently without interference from the other spraying system. The height of these booms was controlled hydraulically by a lever located at the right side of the driver seat. Thus boom height for individual spray treatments was easily accommodated. The sprayer was equipped with a control valve that allowed the operator to route flow to various boom sections. This valve allowed installation of eight flan fan spray nozzles spaced 20 inches apart along one boom section and three CDA rotary atomizers placed 40 inches apart on another boom section (Figure 3).

Since both application rate and type of diluent varied during the test, use of orifice plates inside the CDA atomizers and adjustments in the spraying pressure were necessary to obtain the desired flow rates. Nozzles were calibrated prior to treatment applications.

A plastic shield, shown in Figure 4, was utilized during application in the no-till plots to insure that spray material intended for one experimental unit did not drift and contaminate adjacent plots. The shield was fabricated by attaching a plastic sheet to a wooden framework.

The Electrodyn electrostatic sprayer unit, manufactured by ICI Americas, was used to apply postemergence herbicide on

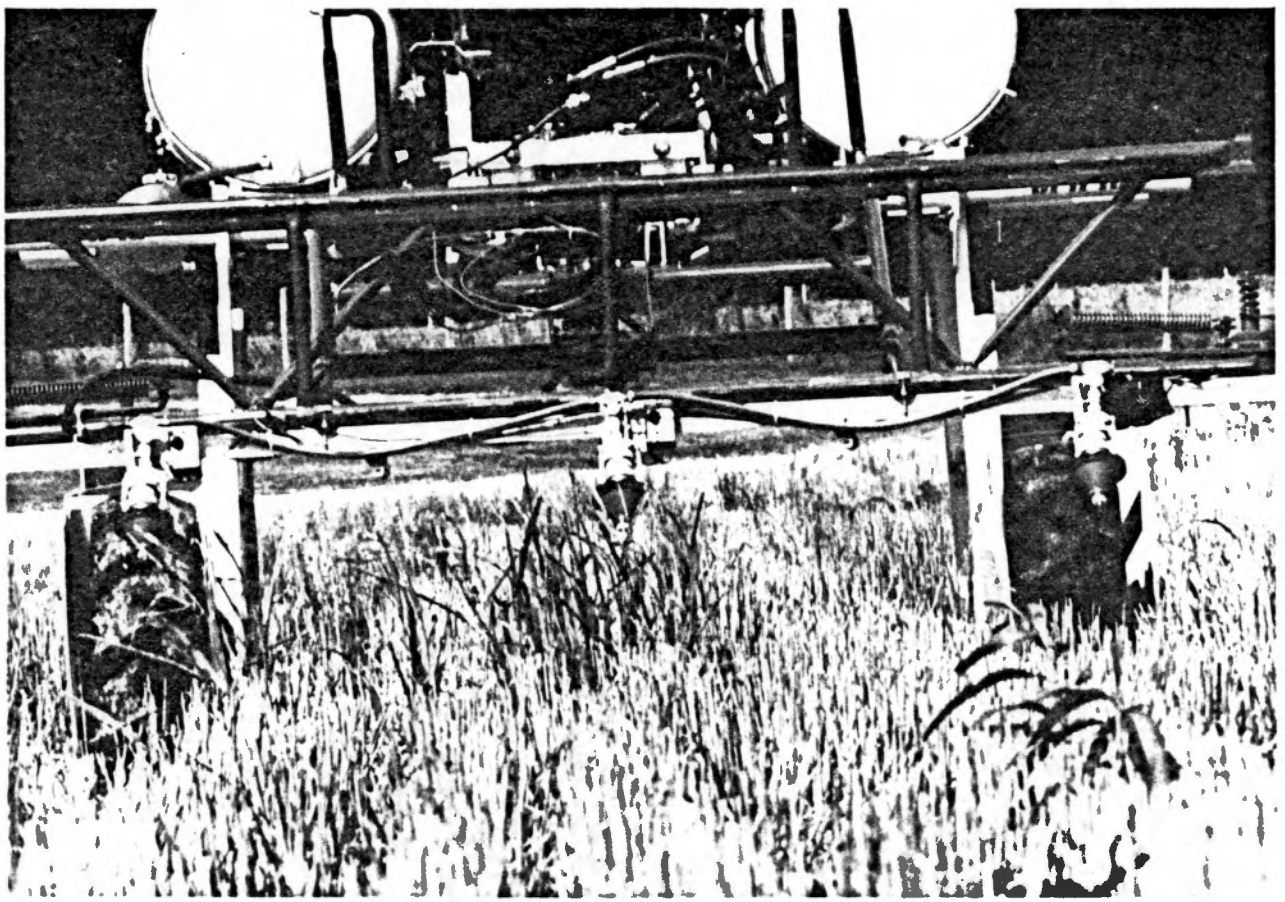


Figure 3. Controlled droplet applicators (CDA) spaced 40 inches apart and hydraulic flat fan nozzles spaced 20 inches apart along separate boom sections on the self-propelled plot sprayer.



Figure 4. The plastic shield held at the plot perimeter during equipment operation minimized spray droplet drift onto adjacent plots.

conventional soybean plots. The spray dispersing units were mounted on a specially designed boom provided by the manufacturer. This boom was then mounted on an International Harvester Model 454 tractor as shown in Figure 5. The generator/nozzle assemblies were installed 40 inches apart across the boom and centered over the crop interrow space. Generators were operated at about 16 inches above the grass target. Soybean plants in the plot ranged from 16 to 20 inches tall at the time of application.

Flat Fan Hydraulic Nozzles

The flat fan nozzle tips used in this research were the 8003 medium-volume and 800067 low-volume flat fan hydraulic nozzles manufactured by the Spraying Systems Company. Both spray tips produced a spray angle of 80 degrees. The 800067 flat fan tip had a pressure range of 20 to 60 psi with a capacity ranging from 0.05 to 0.08 gal/min. The 8003 flat fan tip had the same pressure range but with a discharge capacity ranging from 0.21 to 0.37 gal/min.

Controlled Droplet Applicator

The controlled droplet applicator (CDA) used in this study was the Micromax/DR4, an electric-powered rotary atomizer, manufactured by the Micron Corporation of Houston, Texas. These CDA rotary atomizers were mounted on the self-propelled sprayer previously described. Unit spacing was 40 inches, and boom height was approximately 17 inches above the weed target.

The CDA rotary atomizers used centrifugal force rather than hydraulic pressure to form the spray droplets. The spray solution

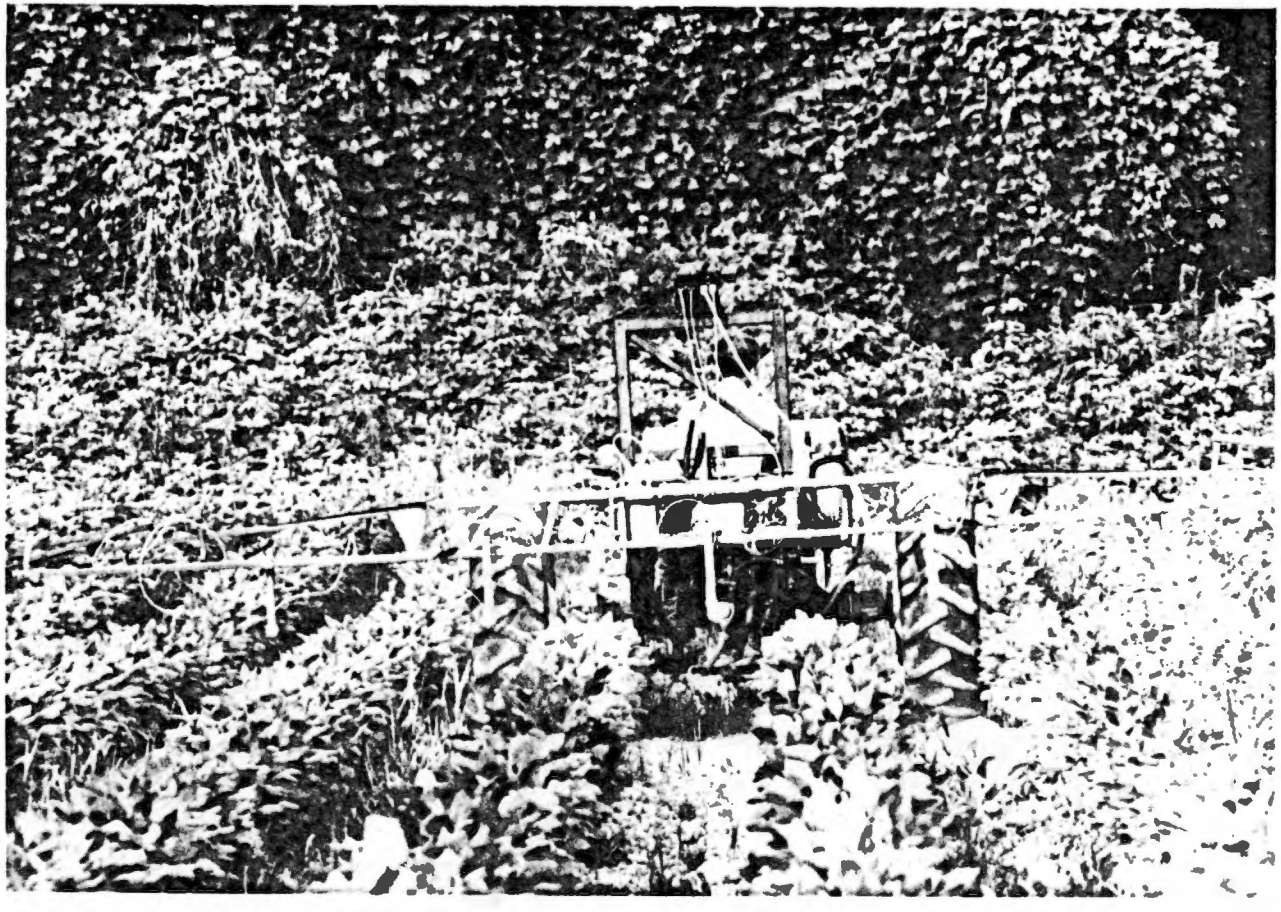


Figure 5. The vehicle-mounted prototype electrostatic spray applicator used to apply postemergent herbicide treatments in soybeans.

was introduced at the bottom center of a spinning cup through two flexible hoses (1/4 inch), leading from a tee hose connector (Figure 6) where the strainer and orifice plate were located. The fluid was then forced upward, by action of centrifugal forces, along a series of groove cuts in the inner wall of the cup. At the periphery of the cup, a state of ligament formation, leading to droplet development, occurred. Droplets, shown in Figure 7, were formed at or near the periphery, depending on the operating conditions.

This CDA atomizer model used a direct-drive, 12-volt electric motor that required 3 amps per unit when operated at maximum cup speed (5000 rpm). The unit featured an electronic, solid-state speed control that allowed adjustment of the rotational speed of the cup to either 1600, 2000, 3500, or 5000 rpm for applying spray solutions under different conditions. An on/off switch was installed near the driver seat to control the electric motors on the CDA units.

Micron Corporation recently introduced a four-position mounting bracket for the Micromax/DR4 controlled droplet applicator, allowing the disc to be oriented at either 0, 15, 30, or 45 degree angles to the horizontal. The manufacturer claims that increasing the angle helps to provide better coverage and increase the penetration of the spray solution into the crop canopy for postemergence and no-till spray application treatments. This new bracket also had a spring-loaded break away feature that prevented damage to the CDA atomizer in case the unit accidentally made contact with the ground

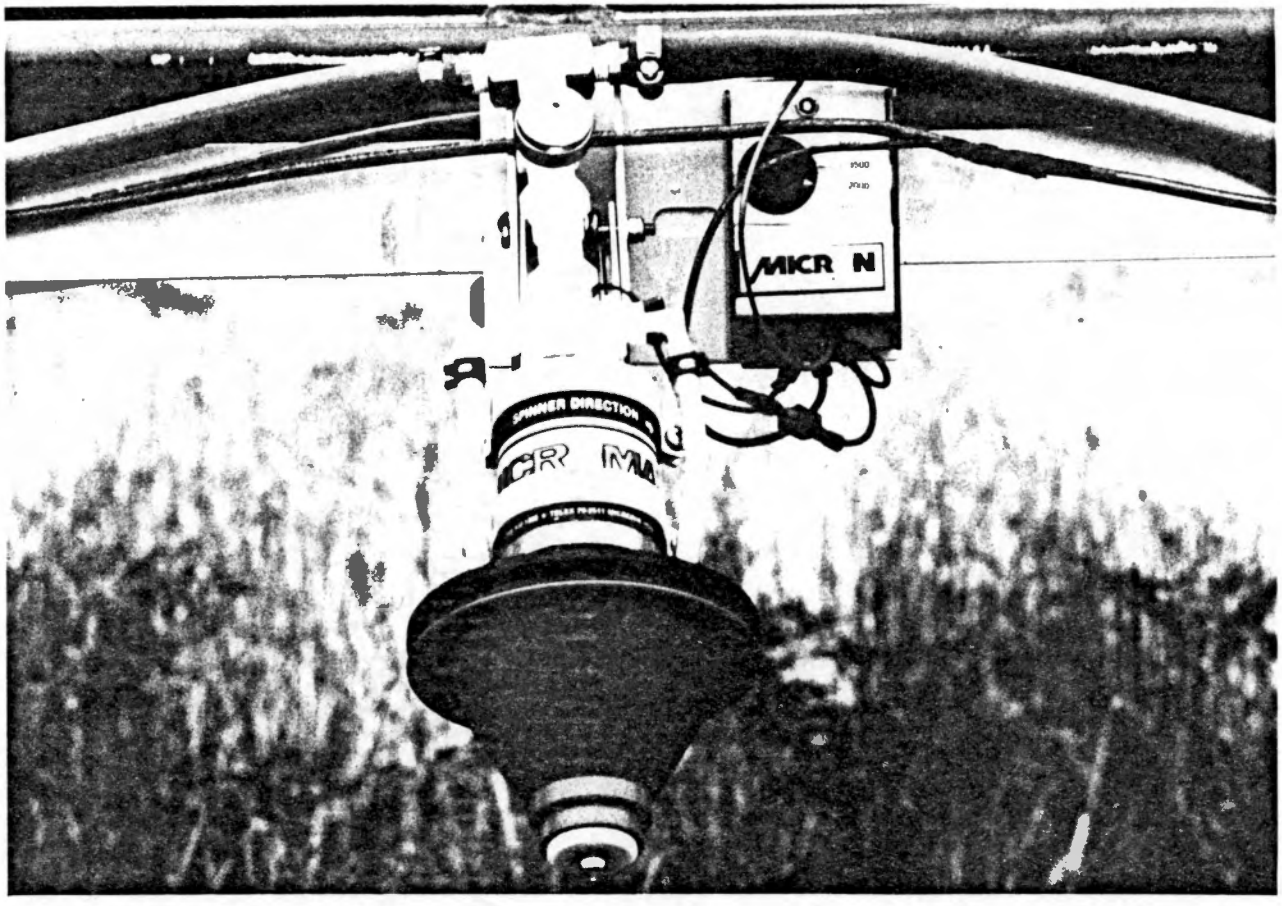


Figure 6. Controlled droplet applicator (CDA) with solid-state electronic speed control mounted on sprayer boom.

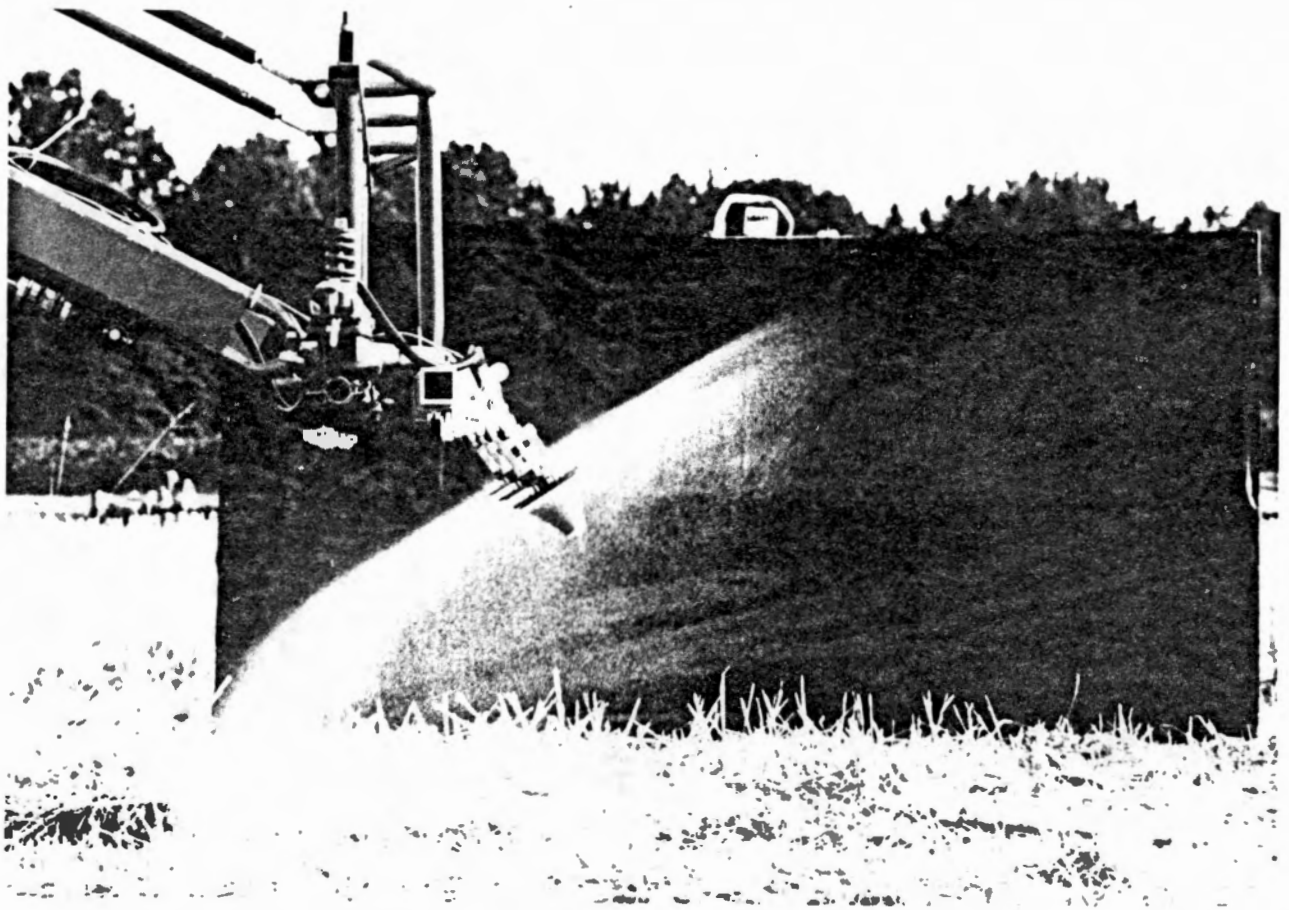


Figure 7. Spray droplets of an oil-in-water solution discharged from a controlled droplet applicator (CDA).

or a stationary object. All CDA treatments were made with the atomizer oriented at 30 degrees to the horizontal, as shown in Figure 7.

Electrostatic Applicator

The Electrodyn electrostatic sprayer unit used electricity from the 12-volt tractor battery to charge the pesticide spray droplets. These droplets were formed when accumulation of surface electric charge produced a loss of the fluid surface tension (Law and Bowen, 1966). This unit was divided into two major systems: the plumbing and the electrical systems (Hodgekiss et al., 1982).

The plumbing system consisted of a pump box, product tank, and liquid conduits. The pump box consisted of two parts: the micropump and the motor. The 24-volt DC motor used the 12-volt tractor battery as its power source through the control box. This motor was connected to the pump by a magnetic coupling so there was not physical contact between the motor shaft and the moving parts of the pump, although a single housing was shared by the two components. The micropump was a gear pump (positive displacement) providing a maximum flow rate of 0.25 ml per sec per nozzle. This pump operated at high pressure because of the tight fit between gear and housing, minimizing back leakage. Two sets of micropump and motor combinations were available in the pump box for use in case of a breakdown of one system unit.

The product tank consisted of a sealed 5-liter aluminum can, as shown in Figure 8. This tank had two male quick fit connectors on the top for 6-mm and 4-mm diameter tubes for the pump inlet and the breather conduit, respectively.

The electrical system consisted of a control box (Figure 9), powered by the 12-volt tractor battery, and the generator/nozzle assemblies. The control box was used to provide electrical power to the motor, to adjust the nozzle voltage, and to regulate the flow rate of the spraying system. This box was installed on the top of the sprayer boom frame for easy access by the tractor operator.

The control box indicated the quantity of fluid flowing to the nozzles from the micropump and displayed the cumulative amount on a counter. The pump application rate could be set by adjusting the speed of the pump through the flow dial. The nozzle voltage was also adjusted from the box by turning the voltage screw until the desired voltage was reached at the nozzles.

The generator/nozzle assemblies were mounted on the boom on 40-inch centers. A 4-mm feed tube was fitted into the Schrader elbow at the base of each generator/nozzle assembly (Figure 10) where the solution would flow into the nozzle. Once the nozzle voltage and the flow rate were set, the high potential nozzle was expected to produce a conical-shaped spray pattern with at least 10 ligaments of fine spray, as shown in Figure 11.

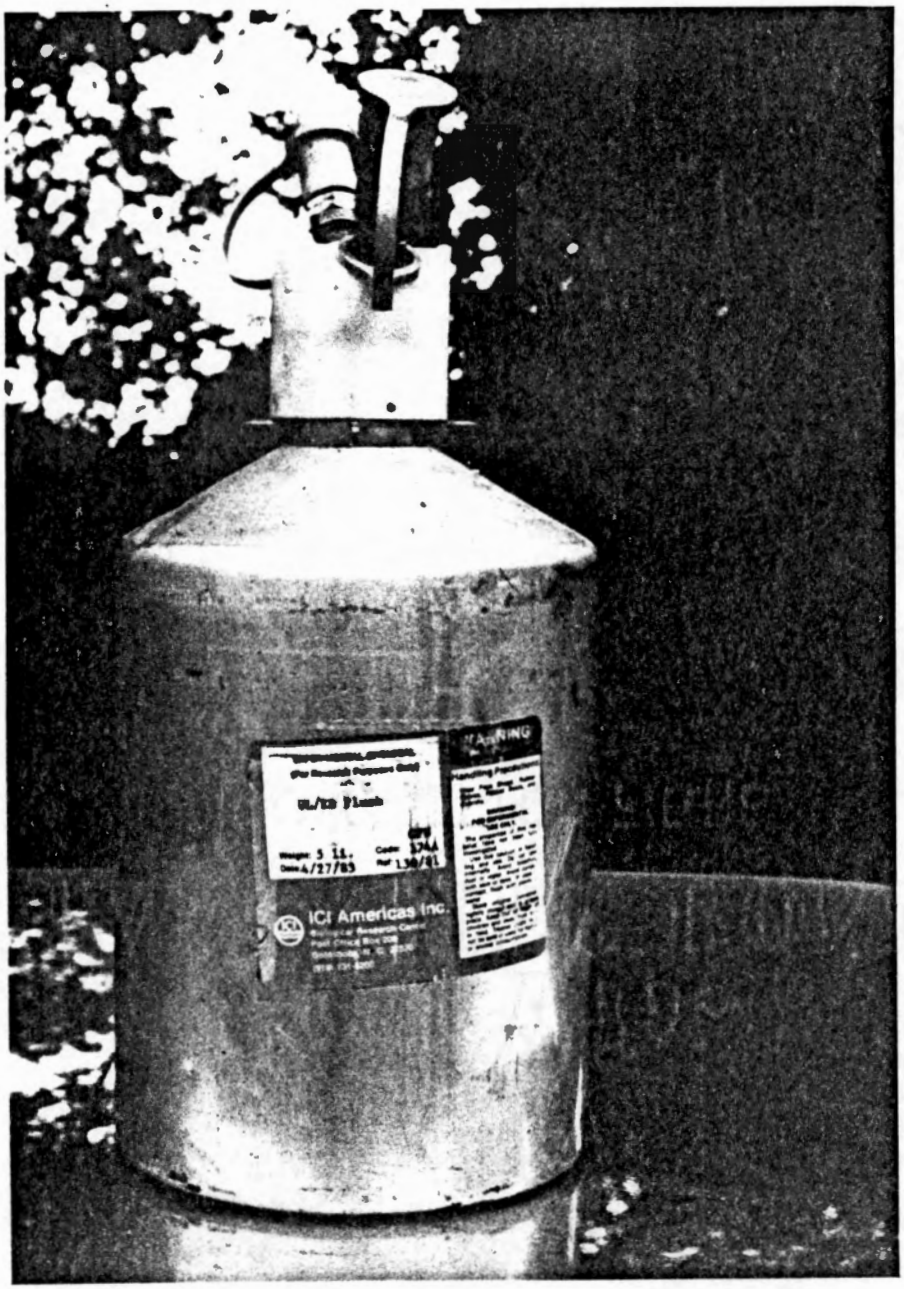


Figure 8. Five-liter aluminum product tank equipped with quick-connect couplers for use on the ultra low-volume electrostatic applicator.

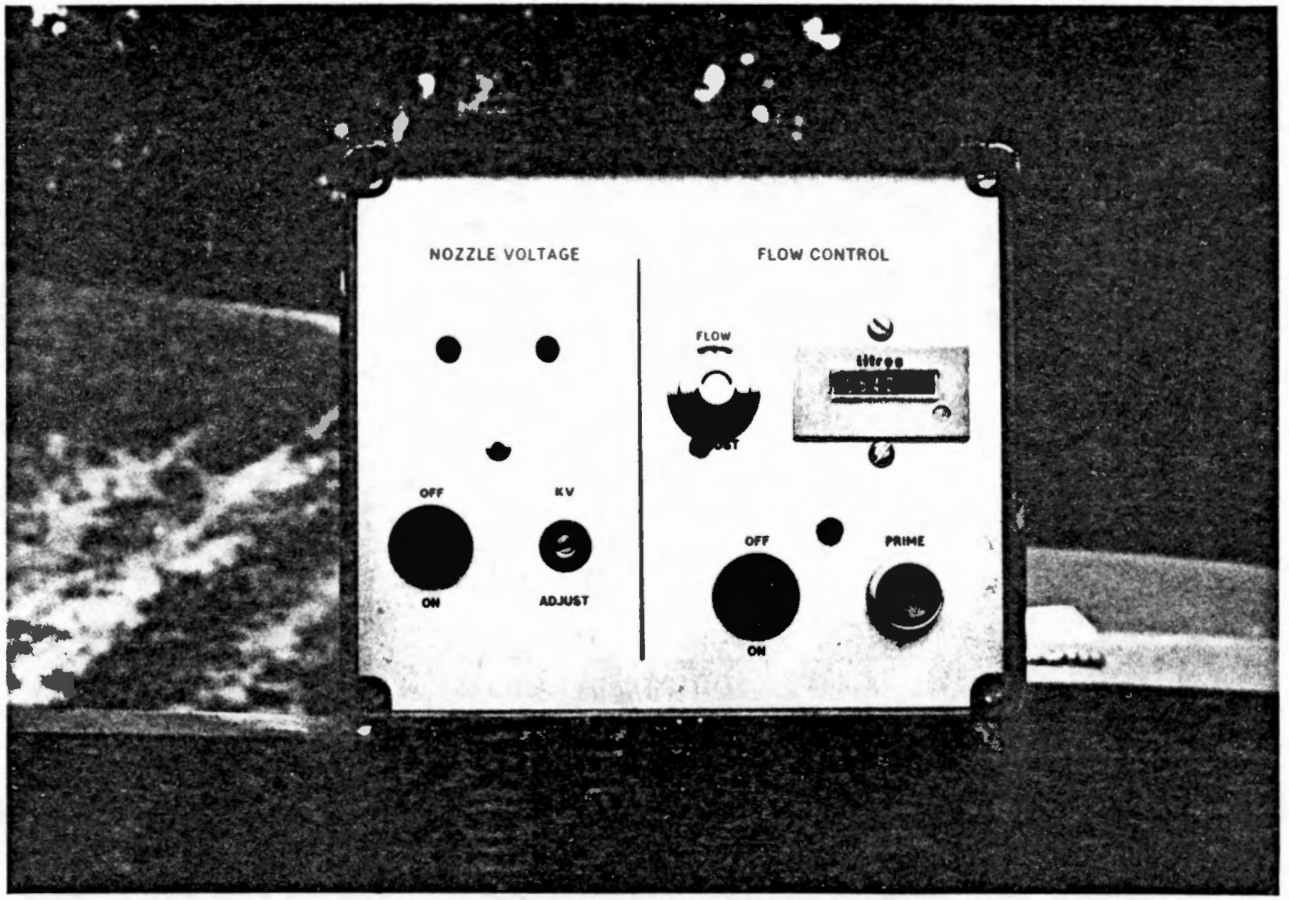


Figure 9. Flow control and voltage regulator control unit used on the prototype electrostatic sprayer unit.

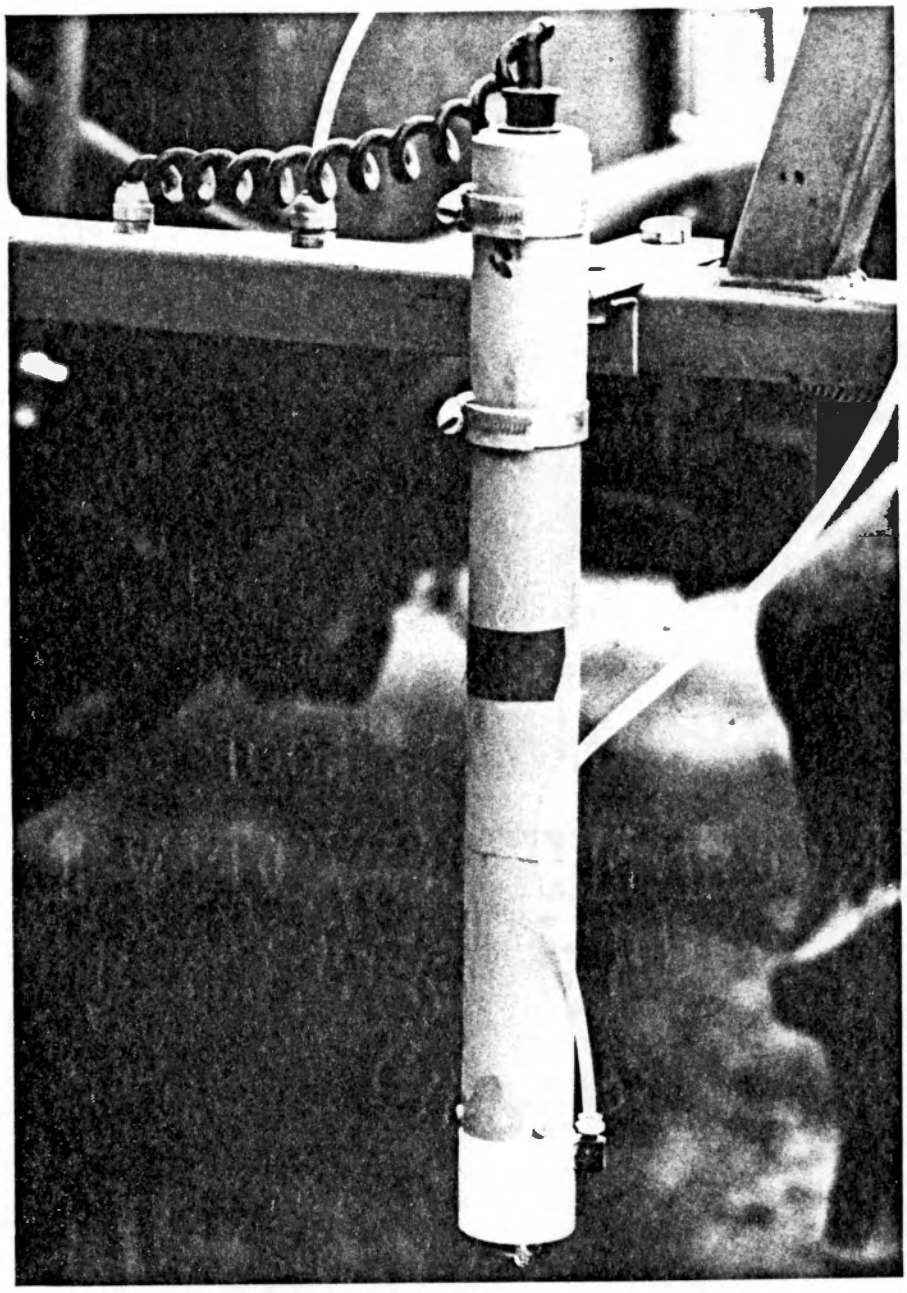


Figure 10. Electrostatic chemical applicator generator/ nozzle assembly mounted on the boom and supplied with spray solution through the 4-mm tube.

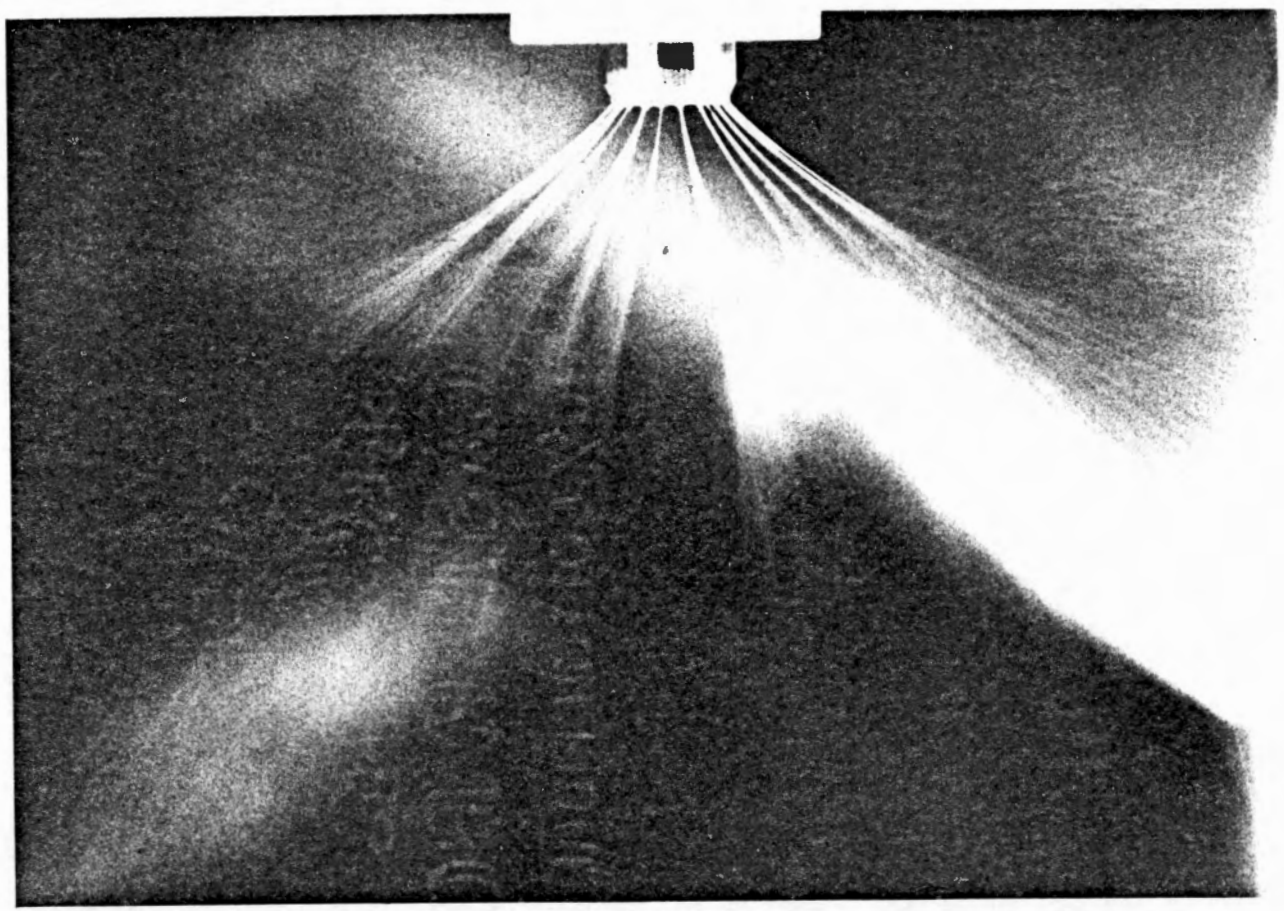


Figure 11. Electrostatic chemical applicator generator/nozzle assembly producing a steady stream of solution in the form of fluid ligaments.

V. HERBICIDE APPLICATION

Table 1 lists the herbicide solutions used in this research as well as their common name, commercial formulation, and chemical name. In this text, the commercial formulation is used to refer to these herbicide solutions.

Chemical Preparation

The flow rate calibration of the sprayer units was completed prior to the calculation of the tank mixes. For the preemergence and postemergence herbicide applications the control sprayer (8003 flat fan nozzles) was calibrated at 20.35 gal/acre with a spraying pressure of 22 psi. The low-volume sprayers (800067 flat fan nozzles and CDA rotary atomizers) were calibrated at 4.7 gal/acre for water and water-in-oil carriers.

The chemical formulations for these herbicide applications were prepared at the specified rate recommended by The University of Tennessee Agricultural Extension Service (Ashburn, 1983). Table 2 lists the formulation rates used in this research for both applications. Natur'l Oil included in the spray mixture as an additive to the formulation was used at a rate of 2 quarts per acre and a non-ionic surfactant, Triton AG-98 manufactured by Rohm and Haas, was included with each herbicide formulation at a rate of 0.5 percent on a volume basis.

For the Electrodyn electrostatic sprayer each application was calibrated for flow rate and voltage according to the treatment on each plot, as shown on Table 3. The manufacturer (ICI Americas)

Table 1. Common name, commercial formulation, and chemical name of herbicides used in chemical application equipment and technique study.

Common Name	Commercial Formulation	Chemical Name
Acifluorfen	Blazer	{5-[2-chloro-4-(trifluorometyl) phenoxy]-2-nitrobenzoic acid}
Alachlor	Lasso	[2-chloro-2',6'-diethyl-N-(methoxymetyl) acetamilide]
Bentazon	Basagran	[3-Isopropyl-1H-2,1,3-benzo-thiadiazin-4(3H)-one 2,2-dioxide]
Fluazifop	Fusilade	{butyl(R-S)-2-[4-[[5-(trifluoro metyl)-2-pyridinyl] oxy] phenoxy] propanoate]
Glyphosate	Roundup	[N-(phosphonomethyl) glycine]
Linuron	Lorox	[3-3(3,4-Dichlorophenyl)-1-methoxy -1-methylurea]
Paraquat	Paraquat	(1,1'-dimetyl-4,4'-bipyridinium ion)

Table 2. Formulation rates used for preemergence and postemergence herbicide application treatments in no-till soybeans.

Application Treatment	Formulation	Application Rate
Preemergence	Paraquat + Lorox + Lasso	2 pt/ac + 1.5 pt/ac + 2.5 qt/ac
	Roundup + Lorox + Lasso	2 qt/ac + 1.5 pt/ac + 2.5 qt/ac
Postemergence	Basagran + Blazer (full label rate)	1 pt/ac + 1 pt/ac
	Basagran + Blazer (half label rate)	0.5 pt/ac + 0.5 pt/ac

Table 3. Electrostatic and medium-volume hydraulic sprayer treatments for postemergence over-the-top selective herbicide application in conventionally-cultivated soybeans.

Treatment Number	Chemical	Form g/l	Rate lb ai/acre	Application Volume	Flow Rate ml/sec	Nozzle Voltage kV
1	PP009	280	0.25	0.8 pt/acre	0.2124	22.5
2	PP009	140	0.125	0.8 pt/acre	0.2124	22.5
3	PP009	70	0.06	0.8 pt/acre	0.2124	22.5
4	Fusilade + OC	4E	0.25	20 gal/acre	-	-
5	Fusilade + OC	4E	0.125	20 gal/acre	-	-
6	Fusilade + OC	4E	0.06	20 gal/acre	-	-
7	Control (no application)					

supplied the PP009 herbicide formulations in sealed 5-liter aluminum cans for each treatment to be considered. A flushing agent used to clean the equipment before using a given solution was also provided.

Machine Field Operation

Once the calibration of the nozzles was accomplished and the chemical formulations to be used on the preemergence and postemergence no-till plots were mixed, the solutions were placed into the two front tanks of the self-propelled sprayer. Only the two front tanks were used to carry the solutions. The two on the back were filled with water for cleaning purposes. This water was used to flush the lines and clean the front tanks after spraying designated plots.

The sprayer was then transported to the field site while continuous agitation of the mixture was occurring in the tanks. Before plot spraying was initiated, necessary machine adjustments were made including boom height, spray angle and rotary speed of the CDA applicators, and spraying pressure.

The hydraulic boom system on the self-propelled sprayer facilitated the adjustments of boom height, which was always set between 16 and 18 inches above the intended target. The spraying angle and rotational speed of the CDA cups were set at 30 degrees and 3500 rpm, respectively, for all application treatments. This rotary speed was recommended by the Micromax Operating Manual (1983) for the specific flow rate used (approximately 0.09 gal/min). At this flow rate, the spray pressure used differed depending on the

orifice plate size and the spray solution carrier. A 4916-32 (Spraying Systems Co.) orifice plate with a slotted nozzle strainer was installed in each of the CDA atomizers for both water and water-in-oil carrier. For the low-volume flat fan nozzle (800067), two different pressures were used: 15 psi for water and 21 psi for the oil-in-water carrier. TeeJet stainless steel 100-mesh strainers were used to prevent clogging in the spray tips. The self-propelled sprayer speed was calibrated for operation at 3 mph.

The Electrodyn electrostatic spray system was calibrated for a total flow rate of 1.062 ml/sec. At this flow rate, the flow control dial was set at the 4.8 mark. The nozzle voltages were adjusted to 22.5 kV, and the tractor speed was 5 mph. The total liquid volume sprayed was calculated to be 0.8 pts/acre. After each spraying application was concluded, a flushing agent was then pumped through the spraying lines at the highest pump setting for about 60 seconds to remove any residual chemicals in the lines.

VI. FIELD DATA COLLECTION TECHNIQUE

The preemergence herbicide treatments in wheat stubble were applied on June 28, 1983 while the postemergence treatments were applied on July 12 and 13, 1983. All spray applications were made either early in the morning or late in the afternoon when weather conditions were calm (low wind velocity). Postemergence, over-the-top applications in conventionally-cultivated soybeans were made on July 27, 1983. Wind velocity during spray application was close to zero.

During the growing season, rainfall was far below normal with a total of only 5.8 inches of rain. The rainfall record showed that 0.2 inches of rain fell on June 26, 0.78 inches on June 27, 3 inches on June 29, and 2 inches on July 2. Relative humidity was particularly high during the spraying applications (81 to 92 percent) while the temperature was in the high 80's F. Winds were calm during the spraying periods. Therefore, drift due to wind was not considered a pertinent factor. However, as an added precaution against contamination among the plots, a protective shield was used to avoid drifting of the spray.

Percentage of Weed Control

Although the no-till plots consisted of eight rows of soybeans in wheat stubble, only the middle four rows of each experimental unit were evaluated for weed control. Evaluations were made by an experienced weed specialist from the West Tennessee Experiment Station at Jackson. The weed control data were based upon counts of weed skeletons and visual assessment of weed regrowth in each plot. Specific numerical values were then assigned to these experimental units using a 0 to 100 scale, with zero being no stand reduction (weed control) and 100 being complete kill of the target weed.

The weed species considered were large crabgrass (Digitaria sanguinalis L.) and Pennsylvania smartweed (Poligonum pennsylvanicum L.) in the preemergence application plots and cocklebur (Xanthium pennsylvanicum L.) and Pennsylvania smartweed in the postemergence

no-till plots. Fall panicum (Panicum dichotomiflorum L.), large crabgrass, and goosegrass (Eleusine indica L.) were the grass weed species evaluated for weed control in the postemergence over-the-top treatments in the conventionally-cultivated soybean plots. The weed specialist selected these weed species because of their general prevalence throughout the field.

Leaf Collection

A fluorescent dye formulation was prepared for application with the Electrodyn electrostatic sprayer in the experimental plots. The fluorescent dye facilitated visual observation of the extent of foliage coverage on the target weeds.

Leaf collection from the preemergence and postemergence plots was not accomplished because the fluorescent dye was not available in time for the CDA application treatments. Following the electrostatic spray application of the fluorescent dye, the foliage was allowed to dry. Samples of grass leaves were then randomly collected from the plots treated with the solution containing the fluorescent dye. These leaves were removed carefully from the plant to prevent disturbing the fluorescent particles on the leaf surface. To prevent wrinkling, each leaf was placed flat in small plastic bags. These samples were then observed under two Spectroline (Model B-100) ultraviolet lamps. An assessment of the coverage obtained from the Electrodyn electrostatic spray system was made from these leaf samples.

CHAPTER IV

RESULTS AND DISCUSSION

Percentage control of various weed species and soybean yields for the preemergence and postemergence application treatments were subjected to analyses of variance using the Statistical Analysis System (SAS). Results are shown in Tables 4 through 7. A split-split plot experimental model was used for evaluation of the percentage control because two different weed species were considered within each application treatment. F-tests were conducted for 11 and 6 sources of variation for the percentage of weed control and soybean yield, respectively. Arrows lead from the appropriate error terms used in testing the hypotheses in the analysis of variance tables.

In this research spray application techniques (SPAPLI), chemical formulations (CHEM), and weed species (WEED) were considered to be the independent variables while percentage weed control and soybean yield were the dependent variables.

I. PERCENTAGE CONTROL OF VARIOUS WEED SPECIES

Mean percentages of weed control for the preemergence and postemergence applications in no-tillage soybean plots are summarized in Tables 8 and 9, respectively. For the preemergence application, the spray techniques used provided acceptable weed control ranging from 50 percent control of large crabgrass using the paraquat

Table 4. Analysis of variance table for the dependent variable percentage weed control for preemergence herbicide application in no-tillage soybean plots.

Sources of Variation*	df	SS	F-Value	PR>F
BLK	2	6981.43	.	.
CHEM	1	4860.00	1.23	0.3829
CHEM*BLK	2	7903.90	.	.
SPAPLI	4	2156.10	1.87	0.1653
CHEM*SPAPLI	4	1949.50	1.69	0.2013
SPAPLI*BLK(CHEM)	16	4617.00	.	.
WEED	1	777.60	3.72	0.0682
CHEM*WEED	1	1092.26	5.22	0.0334
SPAPLI*WEED	4	252.90	0.30	0.8731
CHEM*SPAPLI*WEED	4	499.23	0.60	0.6693
ERROR TERM	20	4185.00	.	.

*BLK = Replications.
CHEM = Herbicide formulation.
SPAPLI = Spray application technique.
WEED = Weed species.

Table 5. Analysis of variance table for the dependent variable soybean yields for preemergence herbicide application test plots.

Sources of Variation*	df	SS	F-Value	PR>F
BLK	2	11.42	•	•
CHEM	1	200.31	7.34	0.1136
CHEM*BLK	2	54.60	•	•
SPAPLI	4	6.95	0.63	0.6465
CHEM*SPAPLI	4	4.65	0.42	0.7890
SPAPLI*BLK(CHEM)	16	43.99	•	•

*BLK = Replications.
CHEM = Herbicide formulation.
SPAPLI = Spray application technique.

Table 6. Analysis of variance table for the dependent variable percentage weed control for postemergence herbicide application in no-tillage soybean plots.

Sources of Variation*	df	SS	F-Value	PR>F
BLK	2	571.60	.	.
CHEM	1	147.26	1.13	0.3985
CHEM*BLK	2	259.73	.	.
SPAPLI	4	2240.76	0.62	0.6548
CHEM*SPAPLI	4	6456.90	1.79	0.1810
SPAPLI*BLK(CHEM)	16	14460.33	.	.
WEED	1	18797.40	47.40	0.0001
CHEM*WEED	1	32.26	0.08	0.7784
SPAPLI*WEED	4	821.76	0.52	0.7234
CHEM*SPAPLI*WEED	4	541.90	0.34	0.8466
ERROR TERM	20	7931.66	.	.

*BLK = Replications.
CHEM = Herbicide formulation.
SPAPLI = Spray application technique.
WEED = Weed species.

Table 7. Analysis of variance table for the dependent variable soybean yields for postemergence herbicide application test plots.

Sources of Variation*	df	SS	F-Value	PR>F
BLK	2	72.00	.	.
CHEM	1	21.96	0.31	0.6319
CHEM*BLK	2	140.11	.	.
SPAPLI	4	13.11	0.31	0.8702
CHEM*SPAPLI	4	20.81	0.48	0.7470
SPAPLI*BLK(CHEM)	16	171.88	.	.

*BLK = Replication.
CHEM = Herbicide formulation.
SPAPLI = Spray application technique.

Table 8. Mean percentages of weed control for preemergence herbicide application treatments in no-tillage soybeans comparing herbicide formulations and spraying techniques. Subjective evaluations were made June 11, 1983 by visual inspection.

Preemergence Herbicide Application Treatments	Percentage Control*	
	Large Crabgrass	Pennsylvania Smartweed
Paraquat + Lorox + Lasso		
1. CONTROL (20 gal/acre)	92	97
2. HYDRAULIC NOZZLE with OIL	50	73
3. CDA	70	85
4. HYDRAULIC NOZZLE	67	87
5. CDA with OIL	70	75
Roundup + Lorox + Lasso		
6. CONTROL (20 gal/acre)	98	100
7. HYDRAULIC NOZZLE with OIL	98	100
8. CDA	98	100
9. HYDRAULIC NOZZLE	93	76
10. CDA with OIL	94	98

*Percentage control mean: 0 = no weed control, 100 = total weed control.

Table 9. Mean percentages of weed control for postemergence herbicide application treatments in no-tillage soybeans using full and half label chemical rates. Subjective evaluations were made July 11, 1983 by visual inspection.

Postemergence Herbicide Application Treatments	Percentage Control*	
	Pennsylvania Smartweed	Cocklebur
Basagran + Blazer (full rate)		
1. CONTROL (20 gal/acre)	57	90
2. HYDRAULIC NOZZLE with OIL	40	73
3. CDA	58	95
4. HYDRAULIC NOZZLE	47	93
5. CDA with OIL	60	94
Basagran + Blazer (half rate)		
6. CONTROL (20 gal/acre)	48	90
7. HYDRAULIC NOZZLE with OIL	70	95
8. CDA	13	63
9. HYDRAULIC NOZZLE	57	95
10. CDA with OIL	65	80

*Percentage control mean: 0 = no weed control, 100 = total weed control.

formulation to 100 percent control of Pennsylvania smartweed using the Roundup formulation. Postemergence application failed to provide good control of Pennsylvania smartweed with percentages as low as 13 percent. Low-volume flat fan nozzles (800067) were as effective as other application techniques used in both preemergence and post-emergence application plots. A tank mix of Basagran plus Blazer at full or half label rates was more effective in controlling cocklebur than Pennsylvania smartweed in the postemergence plots.

The F-test results from the analyses of variance did not reveal significant differences within the premeergence or post-emergence spray application treatments tested at the 0.05 level. This lack of significance among treatments may have been affected by the drought conditions characterizing the area during the growing season.

The overall percentage weed control obtained from the electro-static spray plots was quite low, as shown in Table 10. No clear trends in results were obtained from these treatments other than that there was a significant difference between the control plot (untreated) and the sprayed plots. Again, results were probably affected by the dry soil and stressed plant conditions present during the spray application period. Also, grasses in the plots were larger than desirable for optimum control. These results lend support to Lane and Law's (1979) finding regarding the electro-static charging of the chemical when the plant is drought stressed, making the Fusilade less effective in controlling these weed species.

Table 10. Mean percentages of weed control for postemergence over-the-top herbicide application in conventionally-tilled soybeans comparing herbicide formulations and application techniques. Subjective weed control evaluations were made August 12, 1983 by visual inspection.

Spray Treatment Techniques	Fusilade Rate lb ai/acre	Percentage Control*		
		Fall Panicum	Large Crabgrass	Goosegrass
CONV. 20 gal/acre	0.06	10	10	10
CONV. 20 gal/acre	0.125	30	30	30
CONV. 20 gal/acre	0.25	30	30	30
ELECTRODYN	0.06	30	30	30
ELECTRODYN	0.125	30	30	30
ELECTRODYN	0.25	60	30	40
CONTROL (no application)				

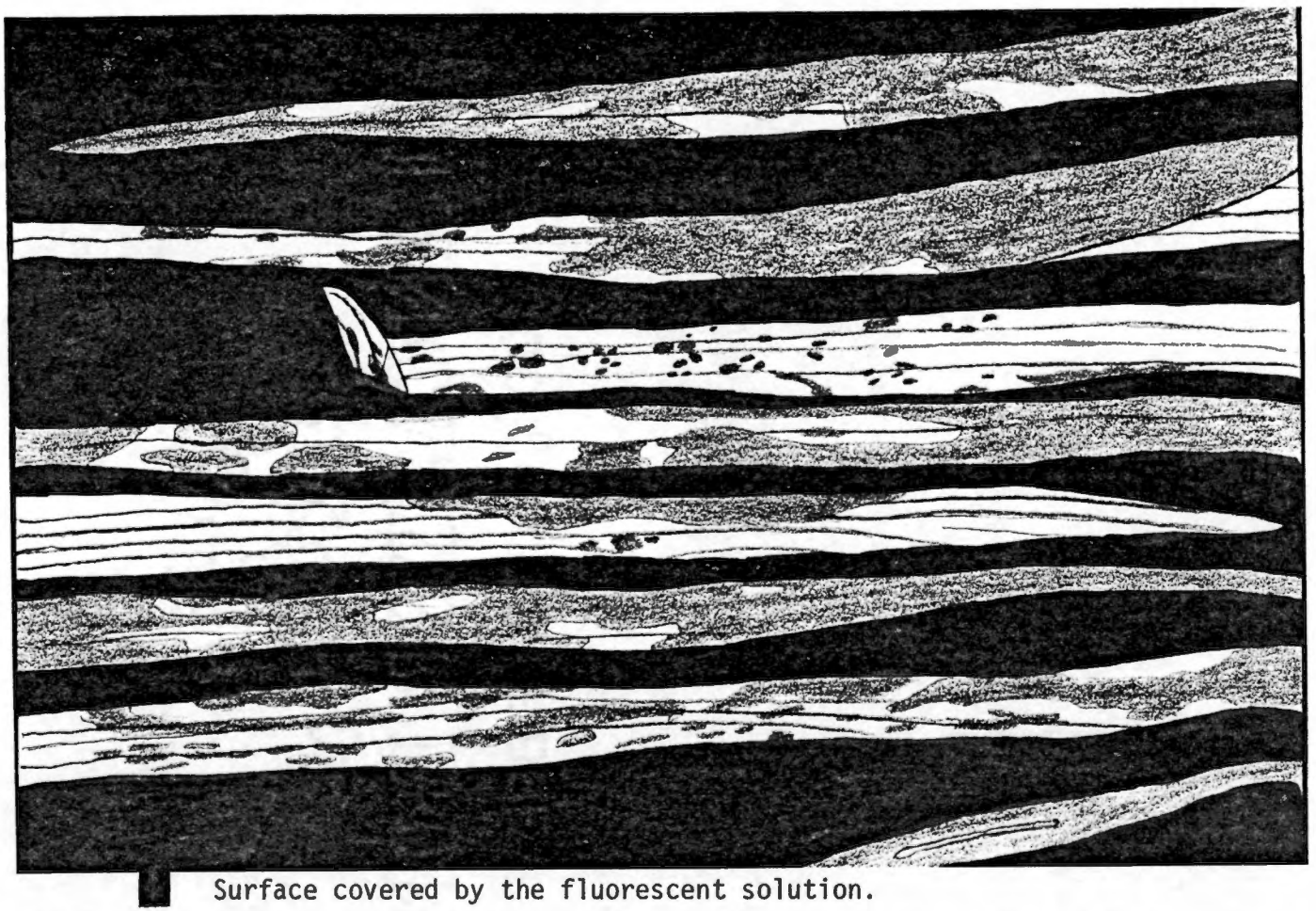
*Percentage control mean: 0 = no weed control, 100 = total weed control.

The effect of soybean oil (Natur'l Oil) as an additive to the chemical formulations was observed. Visual observations of the spray solutions suggested that the drift and evaporation of the oil-containing spray were reduced. However, F-test results indicated that weed control was not significantly affected by the presence of this additive in the spray formulation.

II. PERCENTAGE OF FOLIAGE COVERAGE

Percentages of leaf coverage were not measured in the no-till preemergence and postemergence plots because the fluorescent dye was not obtained before the time that treatments had to be applied. However, several samples of grass leaves were collected from the electrostatic postemergence plots. A fluorescent material had been mixed with the spray solution to facilitate evaluation of the foliage coverage obtained from the Electrodyn electrostatic sprayer.

These randomly collected leaf samples showed coverage by fluorescent particle deposition ranging from 85 to 100 percent of the total leaf surface, as shown in Figure 12. The amount of particle deposition and surface coverage of these samples was probably due to the strong electric field present around pointed objects, supporting observations of Bowen et al. (1968) that greater quantities of electrically charged sprays accumulated in those regions on the plant leaves with small radii of curvature. This phenomenon is known as the "corona" discharge or ionization.



Surface covered by the fluorescent solution.

Figure 12. Fluorescent particle deposition and spray coverage of weed leaf samples taken from the electrostatic spray application treatment (artist's representation).

III. SOYBEAN YIELD

Soybean yield was recorded for each experimental unit, and data were subjected to analyses of variance. The F-test results, obtained from plots of the same type (no-till or conventionally-tilled) indicated no significant yield differences among the various spray application techniques.

Yields were determined by harvesting the four middle rows of each plot. Samples were taken from each plot to determine the soybean moisture content at harvest. Yield was then expressed in bushels per acre at 13 percent moisture content, wet basis.

Tables 11 and 12 indicate mean soybean yields for the preemergence and postemergence no-tillage applications, respectively. Yields ranged from 4.7 to 10.9 bushels per acre (bu/acre) for the preemergence application treatments, and from 9.7 to 14.5 bu/acre for the postemergence treatments. These yields were very low due to the inadequate quantity of rainfall that occurred in the area. Less than 6 inches of rain fell during the 1983 growing season. Soybean yields obtained from the preemergence no-till plots tended to be somewhat different when paraquat plus Lorox plus Lasso was used as compared to when Roundup plus Lorox plus Lasso was used. No satisfactory reason could be found to explain this fact.

Yields of the conventionally-tilled soybeans receiving the postemergence, over-the-top herbicide treatments were low, ranging from 15.0 to 18.7 bu/acre, as shown in Table 13. The F-test results from the analysis of variance indicated no significant differences

Table 11. Mean soybean yields for preemergence herbicide application treatments in no-tillage soybeans comparing herbicide formulations and application techniques.

Preemergence Herbicide Application Treatments	Soybean Yield* (bu/acre) (13% Moisture Content)
Paraquat + Lorox + Lasso	
1. CONTROL (20 gal/acre)	9.9
2. HYDRAULIC NOZZLE with OIL	9.2
3. CDA	10.7
4. HYDRAULIC NOZZLE	10.9
5. CDA with OIL	10.7
Roundup + Lorox + Lasso	
6. CONTROL (20 gal/acre)	4.7
7. HYDRAULIC NOZZLE with OIL	5.1
8. CDA	4.8
9. HYDRAULIC NOZZLE	4.7
10. CDA with OIL	6.3

*Yields collected October 28, 1983.

Table 12. Mean soybean yields for postemergence herbicide application treatments in no-tillage soybeans using full and half label chemical rates.

Postemergence Herbicide Application Treatments	Soybean Yield* (bu/acre) (13% Moisture Content)
Basagran + Blazer (full rate)	
1. CONTROL (20 gal/acre)	12.6
2. HYDRAULIC NOZZLE with OIL	10.6
3. CDA	9.7
4. HYDRAULIC NOZZLE	10.7
5. CDA with OIL	11.9
Basagran + Blazer (half rate)	
6. CONTROL (20 gal/acre)	13.4
7. HYDRAULIC NOZZLE with OIL	12.6
8. CDA	14.5
9. HYDRAULIC NOZZLE	11.3
10. CDA with OIL	12.1

*Yields collected October 26, 1983.

Table 13. Mean soybean yields for postemergence over-the-top herbicide application in conventionally-tilled soybeans comparing herbicide application rates and application techniques.

Spray Treatment Techniques	Fusilade Rate lb ai/acre	Soybean Yield* (bu/acre) (13% Moisture Content)
CONV. 20 gal/acre	0.06	15.0
CONV. 20 gal/acre	0.125	18.7
CONV. 20 gal/acre	0.25	17.0
ELECTRODYN	0.06	16.5
ELECTRODYN	0.125	17.1
ELECTRODYN	0.25	18.6
CONTROL (no application)	-	16.2

*Yields collected November 18, 1983.

among soybean yields associated with the various application techniques and chemical rates.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

A research study was performed at The University of Tennessee Milan Experiment Station during 1983 to evaluate and compare preemergence and postemergence herbicide application techniques in no-tillage and conventionally-cultivated soybean plots. The equipment used for chemical application included conventional medium-volume hydraulic flat fan nozzles, low-volume flat fan nozzles, controlled droplet applicators (CDA), and an ultra low-volume electrostatic sprayer.

The study compared low- and medium-volume spray application rates, ultra-low and medium-volume application rates, low-volume flat fan nozzles and controlled droplet applicator (CDA) for low-volume spray application, and water-only carrier and oil-in-water diluents for low-volume application.

The preemergence and postemergence application treatments in no-tilled soybean plots consisted of five spray application techniques, including low-volume hydraulic flat fan nozzles (5 gal/acre) using oil-in-water and water only as a carrier, conventional hydraulic flat fan nozzles (20 gal/acre), and controlled droplet applicators (5 gal/acre) using oil-in-water and water only as a carrier. Two different spray formulations were used in the

preemergence test including paraquat plus Lorox plus Lasso and Roundup plus Lorox plus Lasso. The postemergence treatments used Basagran plus Blazer at full and half label rates. Oil-in-water tank mixes included 1 quart/acre of Natur'l Oil, an additive containing soybean oil. An additional postemergence test in conventionally-cultivated soybeans compared an electrostatic sprayer unit applying 0.8 pt/acre with a conventional hydraulic sprayer applying 20 gallons of liquid per acre at various formulation rates of active ingredient (Fusilade).

Treatments were evaluated for percentage control of selected weed species and soybean yield obtained from each experimental plot. Percentage weed control was based upon counts of killed weeds and visual assessment of weed regrowth in each plot. The ratings were made by an experienced weed specialist at the experiment station. The weed species considered were large crabgrass and Pennsylvania smartweed for the preemergence treatments and Pennsylvania smartweed and cocklebur for the postemergence no-tilled plots. Fall panicum, large crabgrass, and goosegrass were evaluated in the conventionally-cultivated postemergence over-the-top treatments.

A fluorescent dye formulation was applied using the electrostatic sprayer unit to estimate by visual inspection the extent of foliage coverage on the target weeds.

Results showed no significant differences among the spray application techniques used for controlling the intended weed species with the preemergence and postemergence application treatments in

no-tillage soybeans. The additive Natur'l Oil in the spray formulations did not affect weed control but visual observation of the spray droplet suggested that evaporation and drift were markedly improved.

Various application rates of Fusilade using the electrostatic spray system gave comparable weed control to similar applications using the conventional sprayer nozzles. Crop yields obtained from the experimental plots were not significantly different among the various spraying techniques for a given production system. Yields were quite low due to the dry weather conditions which existed during this study.

II. CONCLUSIONS

The following conclusions were drawn from this evaluation, although extremely dry weather conditions during this test undoubtedly affected research results. Further research should be conducted to obtain data during seasons favoring crop production.

1. The volume of spray liquid (20 gal/acre versus 5 gal/acre) did not significantly affect the level of weed control obtained with either preemergence or postemergence applications of recommended herbicides in soybeans planted no-tillage in wheat stubble.

2. Percentage of weed control obtained in no-tillage soybeans was not significantly affected by the method of applying the low-volume (5 gal/acre) rate. In particular, preemergence and post-emergence applications with the low-volume hydraulic nozzles were

as effective as similar applications with the controlled droplet applicators (CDA).

3. Use of crop oil concentrate (Natur'l Oil) as an additive in the spray solution did not increase weed control effectiveness of either low-volume application technique. However, visual assessment suggested that the presence of the crop oil in the spray solution reduced both the rate of droplet evaporation and the amount of droplet drift.

4. Roundup plus Lorox plus Lasso gave significantly better control of Pennsylvania smartweed than the paraquat plus Lorox plus Lasso tank mix in preemergence applications in wheat stubble.

5. Tank mix containing both full and half label rates of Basagran plus Blazer were significantly more effective in controlling cocklebur than Pennsylvania smartweed when applied postemergence in wheat stubble.

6. Applications of Fusilade using the electrostatic spray system at a total spray volume of 0.8 pt/acre gave similar levels of weed control to applications of the same herbicide at 20 gallons of spray solution per acre using conventional hydraulic nozzles. However, all treatments gave relatively poor weed control, although control in the treated plots was significantly better than in plots receiving no herbicide.

7. Soybean yields within a given production system were not significantly affected by spray application technique. Crop yields were much below normal due to drought conditions during the growing season.

8. Further research is needed to determine if results were substantially affected by the unusually dry growing season.

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