This is to certify that the

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ROW CROP PERFORMANCE EVALUATION
OF THE
AIR CURTAIN SPRAYER

presented by

David Langsford Collins

has been accepted towards fulfillment
of the requirements for

M.S. degree in A.E.

Gary R. Van Ee
Major professor

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ROW CROP PERFORMANCE EVALUATION
OF THE
AIR CURTAIN SPRAYER

By

David Langsford Collins

A THESIS

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ABSTRACT

ROW CROP PERFORMANCE EVALUATION
OF THE
AIR CURTAIN SPRAYER

By

David Langsford Collins

A detailed literature review of current row crop spraying technology was conducted to identify and evaluate the key parameters that affect chemical deposition. Controlled droplet atomization, electrostatic charging, and air-blast spraying were reviewed as potential means to optimize deposition uniformity.

Laboratory and field studies were conducted to evaluate the performance characteristics of a sprayer that integrates a rotary atomizer and a crossflow vortex fan. The "Air Curtain Sprayer" is a controlled droplet, low volume, air-carrier sprayer. Results show that the sprayer provides reasonable uniformity and deposition throughout a canopy considering both top and bottom side leaf deposit as well as upper and lower canopy deposits.

Deposit analysis was by colorimetric method.

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LIST OF SYMBOLS AND ABBREVATIONS

centimeter

controlled droplet atomization

.foot

.gallon

.gallons per acre

.inch

.kilovolt

.kilometers per hour

.liters per hectare

.miles per hour

.milliliter

..meter

..number median diameter

..ounce

..revolutions per minute

..volume median diameter

..micrometer (micron)

..percent

CHAPTER I

INTRODUCTION

DESCRIPTION AND BACKGROUND

Since the introduction of the first crop sprayer in late nineteenth century, the basic spray equipment has ged little. The 1896 definition of spraying was "...the wing upon plants of any fluid or semi-fluid in the form ine rain or mist."(Lodman 1896). It cannot honestly be that today's hydraulic nozzle sprayers operate on any r principle. The flat fan and cone-type hydraulic les continue to be the most popular type for row crop yers despite the fact that they have remained essentially inged for many years. The popularity and longevity of nozzles is not due to the the fact that these are the possible nozzle types but rather that nothing has come to take their place. While there have been many novel ing systems developed with improvements in one or more over the conventional (fan or cone) systems, they have roblems of their own. Perhaps the two largest problems been that no other innovation has been as inexpensive or iversally useful as the conventional system.

The spray deposition from conventional sprayers onto

.ving plants in the field has not been studied to a large :tent. The usual method for performance evaluation is an crease in yields or decrease in disease or insect pulation. While this is an indicator of combined chemical d equipment performance, little is known about exactly ere the spray ends up on the plant or how much chemical is ptured. However, enough information is known to regard raying as a very inefficient process. A conventional rayer may be best characterized by the old cliche "a jack all trades but a master of none." It can be used to spray st about anything onto just about everything but with ying degrees of efficiency and effectiveness and each ferent purpose and possibly each different chemical having own ideal application characteristics. In the past, ecticides and energy have been cheap and the cost/benefit io of sprays has been positive even though their iciency is typically less then one percent (Himel 1982).

The goal is to develop a sprayer that would give an roved biological result for a given dose of chemical slop 1983) plus result in an economic benefit to the ner. There is considerable emphasis on reducing the rier volume, the drift, and the amount of active edient applied. To accomplish these things, precision ication equipment must be developed.

Justification

A conventional sprayer has two major deficiencies. The
irst deficiency is the droplet size range that the nozzles
mit. A pressure-feed orfice is unable to form droplets in
n effective size with a narrow size range. The surface-
ension hypothesis puts forth that these nozzles atomize the
quid by forming it into a sheet which is unstable and
srupts into liquid ligaments which further break into
oplets of varying size. Liquid properties such as density,
rface tension and to some extent viscosity as well as
bient air temperature influence the sheet formation and
us the drop sizes (Houghton 1950; Fraser 1958). Droplet
lume median diameter is inversely proportional to fluid
essure and proportional to flow rate with a typical range
100-700 um for regular flat-fan and cone nozzles (Saunders
l Tate 1985). Low-pressure nozzles have improved drop size
ge and reduced drift but have resulted in larger drops
hmann 1983). Drop size from typical nozzles ranges from
s then 20 um to over 500 um (Hedden 1961). Following the
inition that the efficiency of a sprayer is inversely
portional to the size range of droplets it emits (Bals
8), it could be concluded that the hydraulic nozzle is
ut the worst thing to use for spraying.

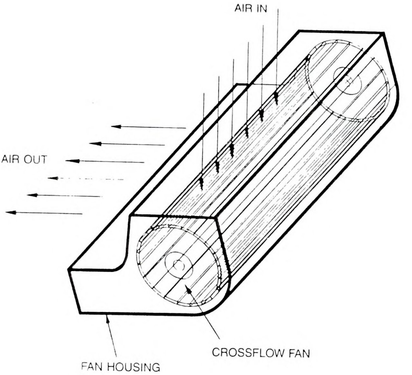
The second major fault is the uniformity of the spray
osit on the canopy. Conventional sprayers cannot
quately penetrate a heavy crop canopy to deposit chemical
he lower parts of the plant, nor do they achieve good

eposits on the undersides of the leaves. In tests on corn
nd soybeans, a conventional sprayer spraying 140 L/ha (15
pa) provided less then 1% coverage on the bottom leaf
rfaces in the upper half of the plant (Watson and Wolff
84).

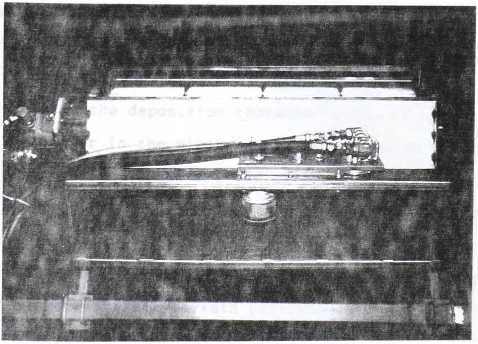
The Air Curtain Concept

The Air Curtain concept (Ledebuhr and Van Ee 1987) grew
t of observation of the air flow from a cross-flow fan
igure 1). At the time, several of these fans were being
ed in a mechanical strawberry harvester to separate leaves
l stems from the fruit. As an experiment, a propeller
ven rotary atomizer on the end of a handle was held in the
stream with its axis of rotation parallel to the direction
the air stream. The water spray was trapped and carried by
air and the concept was born.

The integration of the rotary atomizer and the tangential
crossflow fan (Figure 2) is the key to what makes the Air
tain unique. These fans produce a relatively non-
bulent, straight-stream medium velocity (64-112 kph (40-70
) air pattern. This makes it possible to point the mouth
he fan directly at the crop. The spray solution is
oduced into the air pattern by a hydraulically driven
ry atomizer located at the centerline of the fan outlet.
t spins, the atomizer throws a narrow band of spray across
mouth of the fan. However, the spray distribution is not
orm across the mouth. Whether or not this is a problem is
of the areas addressed in this work.



gure 1. A Tangential or Crossflow fan.



ure 2. A fan from the Air Curtain with the rotary atomizer in place.

The first Air Curtain sprayer assembled to test the
ıcept was a dual-purpose machine with a boom that could be
əd vertically in orchards or horizontally in row crops.
ıs sprayer was used mostly in orchards but enough tests in
v crops were conducted to provide promising results and a
ırting place for further research (Van Ee et al 1984, Van
et al 1985, Ledebuhr et al 1985, Van Ee et al 1987, Van Ee
l Ledebuhr 1988).

OBJECTIVES

The overall objective of this project is to performance
st the new Air Curtain spraying concept as developed at
:higan State University for row crop application. The
əcific objectives are: 1) Review performance reports of
tinent current row crop sprayers and use them as a basis
evaluate the performance of the Air Curtain sprayer.
Quantify swath width uniformity of the Air Curtain
ayer on a flat surface and in the canopy as a function of
velocity, flow rate, and atomizer speed.
Determine the deposition characteristics of the Air
tain sprayer in the plant canopy as air velocity, flow
ə, and atomizer speed are varied.
Suggest operating procedures to optimize Air Curtain
formance.
ecommend what additional research could further explain
or improve the Air Curtain performance.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

This chapter is essentially divided into two parts. first part covers the spray application variables that ect sprayer design. The second section reviews pertinent te-of-the-art spray technologies. This includes spinning k \ Controlled Drop Atomization sprayers, electrostatic ayers, and air carrier sprayers.

APPLICATION VARIABLES

Trying to design the optimum operating characteristics o a new sprayer is very difficult at best. It would be ical to start by defining the requirements of the intended get. However, this is precisely what makes the process so ficult. No one yet knows enough about the complex eractions that take place between the chemical, lication methods, the plant, and the intended target to oughly define the desired performance of an "ideal ayer". What is known only provides very broad and general delines.

Many variables can be influenced during the design and ration of a sprayer. The variables that determine the

effect of the spray deposit, the amount of spray retained on the target and the biological effect of the deposit, are: 1) volume rate, 2) drop size, 3) drop speed, 4) drop trajectory, 5) chemical formulation, (Merritt 1980). Of these, the first four are directly controlled by the machine. However, only volume rate and drop size have been studied to any extent and are thus appropriately discussed in the following paragraphs. Formulation is not controlled by the machine, but rather by the company manufacturing the chemical and is not discussed here.

VOLUME RATE

Reducing the volume of spray solution applied per acre saves the farmer both time and money normally spent hauling large quantities of water to the field and for frequent stops for refilling the spray tank. The effect reduced volumes ave on the biological performance of the chemical varies rom chemical to chemical, as would be expected. As the olume of applied water is reduced, the concentration of the pray solution has to be increased to get the same amount of pplied active ingredient. This increase in concentration an either benefit or hinder the performance of the chemical. n field and greenhouse studies, an increase in concentration aused little difference in the biological effect with anslocated herbicides but reduced the effect of contact rbicides (Cussans and Taylor 1976, Merritt and Taylor 77). In a separate laboratory test, increasing herbicide ncentration reduced the biological performance, apparently because of scorch at the site of each drop. The scorch became more severe as concentration increased and the reduced performance was presumably due to blocking movement of the herbicide out of the scorched area (Merritt 1980).

One positive aspect of increased concentration is in the mortality of insects. As insects mature, the amount of active ingredient needed to cause mortality can increase. Higher concentrations can mean less ingested foliage or less droplet contact required before death occurs.

DROP SIZE

Drop size is probably the most researched, but least understood, variable. It has long been known that reducing the drop size is necessary to use low volumes. After all, one large "drop" in the middle of the field does not give the same control as many small drops on each leaf.

In the 1950's and 1960's, researchers set out to make an atomizer that would generate a uniform drop size. While the idea of more uniform coverage was present, the real emphasis was to reduce drift by elimination of undersized drops. The idea of generating optimum drops for the pest or disease was forgotten, and equipment was developed that produced a droplet size that reduced drift. A number of monosize atomizers were developed and tested. The emphasis on 100% uniformly sized drops and the accompanying lack of consideration of the target continued into the early 1970's and led P.H. Southwell to comment, "...It is necessary to substantiate evidence that absolute uniformity is

necessary:..." (Southwell 1973). He goes on to point out, "The only consensus is that droplets which are too large (biologically inefficient) or too small (hazard of drift) must be eliminated." This remains as about the only definite conclusion that can be drawn today.

This is not to say that more has not been learned. Many studies have since been done to determine the requirements of the target. For insect control, it is necessary to get the spray into the micro-environment of the insect (Himel 1969). In an aerial spray for spruce budworm, of 1113 larvae affected by the spray, 93% had not been contacted by any drops larger than 50 um and no evidence was found that significant numbers of drops larger than 100um reached the insects (Himel and Moore 1967). They went on to report that 23% of the larvae had been hit by drops of less than 21um and that 97% of the drops visible on the larvae were between 21 and 46 um.

A three year test in cotton gave virtually identical results (Himel 1969). The underside of the cotton leaf is the micro-environment of the cabbage looper and for the entire three years, no leaf was found with any drops larger than 40 um on the true underside. Boll weevils and bollworm reside in unopened cotton squares. Of the drops found inside the squares, 98% were less than 30 um. Also, seventeen dead boll weevils and bollworms were found in the tested squares and all showed between one and four 21 um drops on them.

The biggest drawbacks of small drops are that they rift; and, secondly, getting uniform coverage with them is difficult. Even Himel in the cotton study was led to say, "The comfortable concept of `even' distribution of spray droplets was not substantiated. Foliage deposition studies emphasize the ubiquitous `small' droplet." (Himel 1969). The challenge is to develop equipment to effectively apply these small drops.

POWER SPRAYER OVERVIEW

The variations in types of power sprayers are virtually endless. In developing countries knapsack units are used. The units can be dusters, spinning disks or mistblowers. These units are also used in greenhouses worldwide. Aerial application is another application system found worldwide and can be applied by plane or helicopter with standard nozzles or low volume equipment. Ground equipment includes conventional hydraulic nozzle boom types, booms equipped with low volume and/or CDA nozzles, and air-blast sprayers. The CDA nozzles are primarily spinning disk or cone units. The air-blast units are modified orchard units or consist of a central fan feeding four to six round ducts which are directed at the crop. The ducts have standard cone nozzles mounted in their ends to supply the spray solution. These sprayers are used on vegetables, ornamental plants and other speciality crops.

CDA SPRAYERS

Controlled droplet atomizers have received much attention in the last ten years. They gained popularity in

the early 1950's for industrial use. The major advantage these atomizers offer is a narrower drop spectrum than a conventional nozzle. The major disadvantage is the low flow rates needed to hold the precise drop size.

Spinning disks have three distinct modes of atomization (Frost 1981, Hinze and Milborn 1950). The first is direct drop formation. Drops of fairly uniform size are thrown directly from the edge of the disk. This occurs only at very low flow rates--too low for practical use in the field. The second mode occurs as the flow rate is increased. This mode is characterized by ligament formation at the edge of the disk. At first, some drops are still generated directly but eventually all drops result from the breakup of the ligaments. Further increase of the flow leads to the third mode. This mode is much like a standard nozzle in that a liquid sheet extends beyond the edge of the disk then disintegrates into randomly sized drops. Accurate atomization is lost in this mode. Size and type of disk, the liquid properties and disk rotational speed determine the flow rates at which the modes, occur. The ligament mode is the best mode for field spraying because of its higher flow rate than the direct formation mode, but accurate atomization is maintained.

There are two popular modifications or variations of the spinning disk. The first is adding shallow groves extending radially from the center of the disk. This gives the fluid a set path to follow and tends to aid ligament formation. The

second variation is a cone-shaped cup. This provides more surface area and time for the spray to spread into a uniform sheet around the atomizer before reaching the point of atomization. The popular Micromax CDA atomizer is of this design and also has grooves running up the inside edge.

Rotary atomizers have been one new system that has been widely tested both in the laboratory and in the field. In an extensive laboratory test, Bode and colleagues (Bode et al. 1983) analyzed the Micromax rotary atomizer. They used a static test over a spray patternator table to check swath width uniformity and a laser image analyzer for the drop size data. Pointing out that a single unit has an unacceptable co-efficient of variation (> 15%) across the swath, they recommended that 1m boom spacings providing double and triple overlap were necessary to get an acceptable uniformity. However, these results were obtained at an atomizer speed of less then 3000 RPM. The drop size studies indicate that a speed of 5000 RPM is needed to generate a VMD of less then 200 um at flow rates exceeding 0.50 L/min (0.13 gpm). However, they also note that at this speed, the percent of driftable drops (those smaller then 99 um) is at least 10 times as great as at 2000 RPM and that the VMD/NMD ratios are larger indicating that the drop size range at 5000 RPM is greater ie. less uniform than at 2000 RPM.

These studies also included a drift test in a wind tunnel. At a cup speed of 2000 RPM, downwind deposits were roughly the same as with a flat fan nozzle but at 5000 RPM, the do

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the downwind deposit average was 7 times greater than that of the flat fan. Also noted was that the pattern from the cup tended to shift a few meters downwind. This illustrates that while a rotary disk or cup can generate a more precise spray, gravity is not a sufficient force to direct the spray.

Field studies with spinning disks have not resulted in a consensus on the effectiveness or advantages of using the units. One field test conducted in 1970 checked several variables including the size and density of the deposited drops and the drift. A shrouded disk was used such that only drops of the desired size were released. In tests at 140, 200 and 300 um drop sizes, the following conclusions were drawn: 1) The pattern will shift off the row in a cross wind. 2) Mean droplet density decreased from top to bottom of the plant and that with their equipment, 129 drops per square centimeter (20 drops per square inch) was the maximum achieved in the lower portions of the cotton plants. 3) Drift potential can be reduced by reducing the numbers of small drops sprayed. 4) The uniformity of the row-to-row droplet density and mean diameter is increased by controlling droplet sizes and by increasing the droplet size. 5) A droplet size of 140 um appears to be the minimum size for dependable deposit in the immediate vicinity of the target area without other controlling factors (Smith et al 1970).

A test conducted in wheat and barley yielded both good and bad results (Mayes and Blanchard 1978). The equipment used was a stacked triple disk unit applying 20 L/ha (2.14

gpa) at 8 kph (5 mph) with drops in the 250-300 um range. Performance of the disk was evaluated by visual assessment and by measurement of the fresh weight of the weeds not killed. This was compared to a conventional sprayer with flat fan nozzles applying 200 L/ha (21 gpa). The results reported that when a wind arose, the pattern shifted off the row but did not "drift." Also reported was that inferior control at 20 L/ha frequently coincided with areas of thicker crop which shielded the weeds from the spray. Unexplainable patches of poor control were also reported for the CDA sprayer. This reinforces the notion that gravity is an insufficient force for spray penetration and that additional means are needed to drive the spray into the canopy. Another excellent point put forth was that operation of the CDA sprayer required a high level of operator skill. The concentration of the spray solution was ten times greater than that of the conventional application and the penalties for overlapping and operating while standing still were severe. A low volume limit based on human factors rather then equipment limitations may be reached. In general, it was concluded that weed control from the CDA sprayer was generally acceptable, meaning that control was about as good, sometimes worse and never better than the conventional sprayer.

Another test in wheat again yielded similar results. In comparing a triple stacked spinning disk at 30 L/ha (3.2 gpa) to a boom at 225 L/ha (24 gpa) it was concluded that conventional applications were more consistent but not always significantly so. Evidence suggested that control may be marginally inferior at later application dates perhaps due to a failure to penetrate the crop canopy (Ayers 1978). It should be noted that drop size was 225 um and that the test gave every opportunity to the CDA sprayer to penetrate because the unit was hand held and operated at the extremely slow walking speed of 1.8 kph (1.12 mph). The boom was also hand held and paced at 3.6 kph (2.23 mph).

A third test conducted in wheat using a Micromax rotary cup at 42 L/ha (4.5 gpa) and a conventional flat fan boom at 187 L/ha (20 gpa) had similar things to say. Both sprayers achieved similar post emergence weed control. However, pre-emergence weed control in wheat stubble was inferior with the CDA sprayer because it could not penetrate the cover (Gerling et al 1982).

The evidence is conclusive that although the spinning disk is effective at some tasks, it is ineffective at penetrating a canopy and thus quite limited in its use.

ELECTROSTATIC SPRAYERS

Electrostatic charging is another technology that was first used for industrial purposes. It is most useful and successful under controlled conditions where the target is solidly grounded. Paint spraying is probably the most popular industrial use of electrostatic charging.

Research and work on the precipitation of charged agricultural dusts began in the early 1950's, and to charged agricultural sprays in 1961 (Webb and Bowen 1970). Some of the early problems were achieving safety, portability, and reasonable size under field conditions for the 15-20kV electrical equipment (Splinter 1968).

The electrostatic process consists primarily of two main operations: 1) application of an electrical charge to the particles with some form of charging-nozzle; 2) precipitation of these charged particles onto plant parts (Webb and Bowen 1970).

There are two principles of electrostatic charging of sprays. The first is the ionized field method for use with dusts (Bowen et al 1952) and non-conductive sprays (Splinter 1968). A grounded ring is placed close to, but outside the spray path from a hollow cone nozzle such that the spray passes through the inside diameter of the ring. An insulated electrode is extended into the hollow center of the spray pattern with the end of the electrode centered downstream from the nozzle, close to the grounded ring, but not touching the spray. A voltage sufficient to cause corona discharge is applied to the center electrode. Ions are formed in the region between the electrode and the grounded ring and travel from the electrode to the grounded ring at velocities of 80-193 kph (50-120 mph. The ions are traveling at right angles to the spray particles and charging is achieved by collision between the spray and the ions.

The second method is induction charging and works only with conducting sprays. The center electrode is eliminated, the nozzle is grounded and the voltage is placed on the ring. This will induce a charge on the spray as it is emitted from the nozzle (Splinter 1968).

A third method is possible by combining the ionized field and induction methods. A grounded center electrode is used in combination with the grounded nozzle and charged ring. When used with a conducting spray, the two methods combine to charge the spray in an additive manner (Splinter 1968).

Electrostatic spray deposition on a plant works due to two basic laws of physics. First, opposite charges attract and like charges repel. Second, any charged body (like an electrostatically charged spray cloud) will induce an equal and opposite charge on any conducting body (like a plant) placed near it. If the body is earthed (like a plant), the boundary between the charges occurs at the earth's surface, and the body (plant) will contain a one-sign charge opposite to that of the other body (spray cloud) (Bowen et al 1952). As the spray cloud approaches the plant, the plant takes on a charge opposite to that of the cloud. Since opposite charges attract, the spray is made to deposit on the plant.

At this point, electrostatic charging seems almost too good to be true. However, there are significant problems especially in the field -- outside of controlled conditions. The first problem is that in order to utilize the electrical field forces effectively, droplets need to be 50 um or less (Splinter 1968). This problem has been overcome by using a

twin-fluid nozzle specially designed by S. Edward Law, with embedded electrodes for electrostatic charging (Law 1977).

Another problem is that electrostatically charged sprays work better on some crops than on others. Performance depends on the shape as well as the height of the crop. For instance, a test conducted with Law's nozzle on smooth, spherical cabbage plants in full head resulted in up to a seven-fold increase in spray deposition from charged spray versus uncharged spray from the same nozzle (Law 1980). In this case, increasing the spray charge increased the deposit. However, this is not true for all crops. A problem arises in plants with pointed foliar surfaces. A highly-charged incoming spray cloud can experience what can roughly be referred to as a lightning-rod effect, in which a charge of opposite polarity jumps from sharp points of the grounded target and partially discharges the spray (Law 1980). In cotton, deposition from charged spray was limited to 2.5 times the deposition from uncharged spray (Law 1980).

Law has also conducted tests on broccoli in the laboratory. The plants were in 3.79 L (1 gal) metal cans and placed under a motorized boom in a holder-table that provided a continuous ground plane along the can tops. Spray speed was 4.83 kph (3 mph). The electrostatic nozzle was compared to a conventional hollow-cone nozzle at application rates of 9.4 L/ha (1 gpa) and 75 L/ha (8 gpa), respectively. The plants had eight to ten leaves foliated below the bud and were 23-28 cm (9 to 11 in.) tall. The objective was to quantify the active-ingredient (fluorescent dye) deposit density leaf-by-leaf throughout the plants. The results typify the effects of electrostatic charging. First, the charged sprayer deposited an average of 1.85 times more spray than the conventional sprayer. Second, no difference in top-leaf coverage was obtained but the middle leaves received significantly more spray from the electrostatic sprayer. Third, no difference in deposition on the bottom three leaves was apparent (Law 1981). The reasons behind these results are fairly simple. Electrostatic sprayers deposit more overall spray because the spray particles that might normally drift away or miss the plant and deposit on the ground are attracted to the plant. The high middle leaf deposits result from the attraction of the drops destined for the bottom leaves as well as those headed towards the ground. This also explains the low bottom leaf coverage. Top leaf coverage from electrostatic sprayers is typically good but so is the top leaf coverage from a boom sprayer. It is not surprising that no difference was noted. It should be noted that all results are attributable to the charging because all tests were also run using the electrostatic nozzle without charge and the results were slightly better than the conventional sprayer but not significantly so (Law 1981).

Tests conducted in the field on cotton with similar nozzles have been reported (Brasher et al 1971). Custom-made twin-fluid induction charging nozzles, plus 88.5 kph (55 mph) auxiliary air used to blow the atomized spray past the charging ring and into the crop, were tested. Using insect mortality as the basis for evaluation, it was concluded that when using auxiliary air-propelled spray, no significant difference was found between charged and uncharged spray performance but removal of the auxiliary air did reduce performance. This reduction was attributed to the decrease of insecticide penetration into the plant canopy. Also noted was that the addition of the electrostatic charge increased the required equipment and the complexity of operation.

A unique electrostatic system has been developed in England by R.A Coffee (Coffee 1979, Coffee 1980). It is commonly called the "Electrodyn" sprayer, electrodyn being short for electrodynamic. It has no moving parts because only a small gravity-induced pressure head is needed to get the chemical to the nozzle. Atomization is induced by the electric charge. Electrical energy is applied directly to oil-based liquids to achieve atomization and deposition at ultra-low volume and ultra-low energy consumption. This technique applies a coulombic field force directly to the surface of the liquid, thus setting up standing waves from which each crest issues a uniform jet of charged liquid. The wave and jet dimensions are very stable and uniform, thus it is possible to achieve VMD/NMD ratios close to unity (Coffee 1980). This system is capable of producing drops from 40 to 200 um VMD.

Spray trials with this system in mature cotton yielded typical electrostatic results. Overall deposition from charged droplets was 2.4 times the deposition from uncharged droplets. In the top of the plant the ratio of charged to uncharged deposition averaged about 2:1 and in the bottom of the plant it was 1-1.5:1 (Coffee 1979). No statistics were available to indicate whether these differences were significant.

A major problem with the electrodyn is that drop size is adjusted by varying the applied voltage, and the relationship is an inverse one. The small drops are obtained by applying high voltages and thus they carry a large charge. The result is that the drops deposit almost immediately (Bals 1982). Similar results come from a test in winter barley. It was found that most of the charged spray deposits were on the vertical leaves which were the nearest earthed target. Further, the coefficients of variation for the mean deposits were much smaller from a conventional sprayer than from the electrodyn. Finally, evenness of distribution of the electrodyn spray from top to bottom of the cereal plants was inferior to that from the standard hydraulic nozzle (Hislop 1983). In summary, electostatics is solely a force of deposition and thus must be balanced with the forces required for spray dispersion so that the droplets can penetrate the crop canopy and be transported to the target (Bals 1983).

AIR-BLAST SPRAYERS

Air blast sprayers for row crops are one technology that has not been tested to the same extent as the CDA and electrostatic equipment. This is somewhat baffling since there are several manufacturers marketing row-crop air sprayers. It seems that what is tested is mostly one-of-a-kind air-blast equipment that came about while trying to improve on existing ideas by adding air assist. For instance, one such improvement was the addition of auxiliary air to a hydraulic nozzle. No one has really built a row crop unit from the ground up. This observation aside, let us proceed with what information is available.

The usual idea behind an air-blast sprayer is two-fold. First, the air is used as the carrier rather than a large volume of water. Turbulent air is used so that the spray mixes with the air stream and thus everywhere the air goes it carries some spray. The second purpose of the air is to impart sufficient energy to the drops for deposition. Commonly used air velocities range from 161-323 kph (100-200 mph) at the air outlet.

One early machine was developed in Israel in 1961 for use in cotton. It introduced some ideas still used today. A machine was set up on a high-clearance chassis with one fan supplying air to a plenum with outlets over each row. Spray solution was supplied to the air by a 0.48 cm (0.1875 in) inside diameter brass tube terminating in the center of each outlet. Atomization was accomplished by air shear utilizing the 315 kph (196 mph) air emitted at each outlet. Application rate was 56-84 L/ha (6-9 gpa) at 6.44 kph (4 mph) ground speed. A conventional sprayer was used for comparison at 168-196 L/ha (18-21 gpa). Results from the tests indicated no significant differences in insect control, seed-cotton yield, or quality of coverage. However, quantity of deposited spray was higher from the air blast sprayer (Zucker and Zamir 1964).

It is odd that no difference in the quality of coverage was noted with the air blast sprayer. Although no drop size data was included with the report, it is likely that many small drops were generated by the air-shear atomization method. Smaller drops usually result in better coverage. Two probable explanations exist for the lack of better coverage. First is that in a high velocity air blast it is possible for a leaf to stream-line and the spray to bypass it (Mann 1980). However, this should also result in lower spray deposits. Second, and in this case the more probable explanation is that the sample evaluation method is at fault. Since coverage evaluation was by eye, it is likely that many of the small drops that deposited were too small to see. This is especially plausible when also noting that the overall deposit was greater from the air blast sprayer.

Another concept in air-carrier spraying has been developed to specifically target the under leaf surfaces in the top-half of the plant. Hollow cone and flat fan drop nozzles were used at an application rate of 94 L/ha (10 gpa) with specially designed air shrouds. The air served primarily to deflect foliage near the nozzle to allow the spray pattern from the nozzle to develop. Addition of the air aided in deposition and improved uniformity as compared to the same sprayer without the air (Watson and Wolff 1985).

Another common use of the air stream is as an "air boom." Air is employed to carry the spray across the swath. Automatic Equipment Manufacturing Co. has several models of this type. The following information was obtained during a telephone conversation with a company engineer. Their sprayers employ a squirrel-cage fan to blow 180 kph (112 mph) air horizontally across the crop. Using a rotary cage atomizer driven by the air stream, swath widths of 18-24m (60-80 ft) across are possible. Deposition is facilitated by the natural tumbling of the air which carries the spray into the canopy. No solid numbers were offered as to swath deposit uniformity or crop penetration. One report has indicated that the automatic, as well as other sprayers tested, could not penetrate bush beans. However, a proprietary research test conducted by an independent Canadian organization has reported greater overall spray deposit on the underside as compared to the top of potato leaves. No firm answers on drift were available but it was mentioned that drops under 100 um could have that potential (Nemecek 1987).

Another application of the "air-boom" type air blast sprayer was tried in sugarcane. A row crop sprayer similar to the Automatic was modified to be able to spray over 3.4m (11 ft) tall sugarcane. Several conventional nozzles and a rotary atomizer were tested in combination with two fan angles (10 and 20 degrees above horizontal). Water or water

and oil were used as the spray solution. The results were that vertical and lateral uniformity were poor and the sprayer as tested is not recommended for sugarcane (Parish et al 1986). Also noted was that the rotary atomizer threw a great deal of spray outside of the air stream.

There is one study that used a commercial air-blast sprayer and attempted to determine how sprayer variables effect deposit (Carpenter et al 1983). The tests were conducted in an open field without any canopy. The targets were 125 ml (4.23 oz) sampling bottles laid on edge inside tubes secured to stakes at 0.31m (1 ft) and 1.22m (4 ft) above the ground. The conclusions all refer to the spray deposit or deposition, but these figures are misleading and of little value because all that was really measured was the spray still traveling horizontally in the air stream at the given location.

Another form of air-assisted spraying comes from Micronair Ltd.. It employs fan blades attached directly to a CDA atomizer. The system was first designed and used for aerial application. As originally used, the AU series of atomizers were mounted on an airplane wing such that the attached fan blades turned in the slipstream and provided the rotation to the atomizer. The ground units were made by manufacturing a "fan housing" and powering the atomizer with a hydraulic motor.

The atomizer consists of a wire gauze cylinder rotating about a hollow fixed shaft. The spray is pumped through the shaft, and past a deflector at the end of the shaft which spreads the spray onto a perforated metal cylinder. This cylinder spreads the spray for even distribution on the gauze. Drop size depends on the speed of atomizer rotation.

Field data on these ground units is not plentiful. What is available is not complimentary . The difficulty lies with the fan. Personal observation of the units indicates that many of the spray droplets emitted from the cages have enough velocity to carry them outside of the air stream before it has much effect. Deposition is therefore largely limited to gravitational forces. The air emitted by the fan is also very turbulent and its energy is dissipated too rapidly to effectively aid spray penetration.

Field tests tend to confirm this. When tested in barley, Micronair AU5000 units exhibited high coefficients of variation across the swath and poor penetration. Large deposits on upper plant parts resulted in smaller deposits on the lower plant parts (Cooke et al 1986). Contributing to the problem was that the units were run at too slow a speed. They were run at 3000 rpm, which produced a VMD of approximately 150 um. This speed produces very little air velocity and rather large drops which undoubtedly traveled very rapidly outside the influence of the air. The result is that the units acted like little more than glorified spinning disks. Drops of 150 um may be optimum for gravity deposition but not for air-assist.

One last spraying system that has been tried is to employ cross-flow fans fitted with standard hydraulic nozzles in the outlet. This differs from the "air-boom" in that the outlet of the fan is pointed directly at the crop. These fans produce a column of smoothly moving air which gently oscillates crop leaves to facilitate spray deposition (Mann, 1980). Limited work in black currants with these units has shown that good spray cover is possible at low volumes and 180 VMD drops, and that even better coverage is anticipated with smaller drops (Mann 1980). This test is an excellent precursor to the Air Curtain tests because the Air Curtain uses the cross-flow fans and smaller, more uniform drops.

Conclusions

1) Reducing the spray volume can save both time and money, but increasing the spray concentration is not always beneficial.

2) Smaller drops (< 50 um) seem desirable for insect control .

3) Spinning Disk atomizers have limited potential for agricultural use because of limited capacity and the inability to penetrate the canopy.

4) Electrostatic charging can increase overall spray deposit, but hinders crop penetration.

Many unique spraying systems have been developed. Each has its advantages and disadvantages. Many have solved one problem or another, but few have reached an overall level of acceptable performance.

CHAPTER III

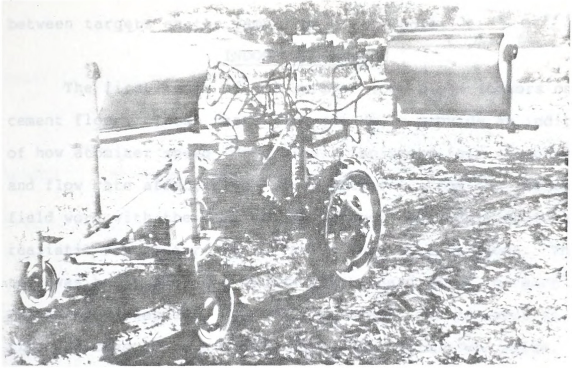
PROCEDURES

EQUIPMENT

A research sprayer was built on an Allis Chalmers Model G tractor (Figure 3). It carried two fans, one cantilevered off each side of the tractor. An auxiliary hydraulic system powered off the tractor was developed to drive one fan and atomizer at a time. The speeds of the fan and atomizer could be controlled independently.

The chemical delivery system consisted of: a 20 L (5 gal) tank; a 12 volt spray pump, and a manifold of valves and orifices to control chemical flow rate and to determine to which atomizer the chemical was delivered.

The spray solution was collected on artificial targets attached to poles placed in the row. The targets were constructed out of drafting mylar cut into rectangles measuring 5.08 cm by 10.16 cm (2 in by 4 in). The poles were made from 1.27 cm (0.5 in) water pipe with a 15.24 cm (6 in) spike in one end and a "T" handle on the other end. Alligator clips were attached to poles starting 2.54 cm (1 in) from the ground and placed every 7.62 cm (3 in) on alternating sides of the pole. This provided 15.24 cm (6 in) of vertical space



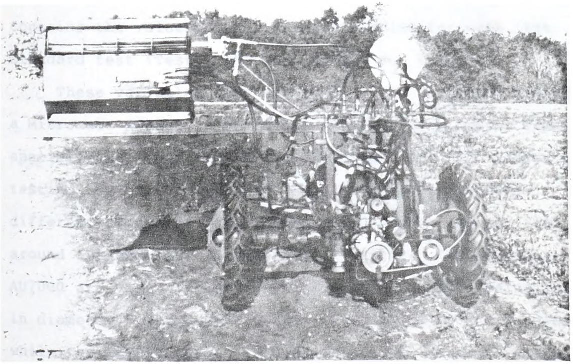


Figure 3. The Air Curtain row crop research sprayer.

between targets on the same side of the pole.

INDOOR PROCEDURES

The first tests of the sprayer took place indoors on a cement floor. These tests were set up to provide an indication of how atomizer speed (drop size), fan speed (air velocity), and flow rate affected the spray pattern. From the initial field work with the combination sprayer, some reasonable and realistic ranges for the variables were already known. The test was built around a median or standard value for each of the three variables. From this standard, one variable at a time was changed to a higher value then to a lower value. For instance, the standard value for the fan was 950 rpm. While the atomizer speed and flow rate remained at their standard values, the fan was run at 1100 rpm, then at 800 rpm. Table 1 contains the values of all three variables for each test. The standard test (Test 1 and Test 2) was run twice.

These variables were tested on three different atomizers: a Micronair AU5000, a Micronair AU7000, and a custom atomizer specially built for the Air Curtain sprayer. The reason for testing the three different atomizers is that each has different dimensions and shapes which affect the air flow around the atomizer (Figures 5, 6, and 7). The AU5000 and AU7000 are very similar in shape with the AU5000 being larger in diameter. The AU5000 basket is 10.16 cm (4 in) in diameter while the AU7000 basket is 8.57 cm (3.375 in) in diameter. The AU5000 is larger overall and presents a larger profile to the air stream. The custom atomizer was developed to present a

Table 1. Atomizer Test Values.

AU5000	Atomizer Speed RPM	Fan Speed RPM	Flow Rate L/MIN	Flow Rate GAL/MIN
Test 1	5500	950	3.4	0.9
Test 2	5500	950	3.4	0.9
Test 3	5500	950	5.7	1.5
Test 4	5500	950	1.1	0.3
Test 5	5500	1100	3.4	0.9
Test 6	5500	800	3.4	0.9
Test 7	6500	950	3.4	0.9
Test 8	4500	950	3.4	0.9
AU7000				
Test 1	9000	1000	3.0	0.8
Test 2	8650	800	3.0	0.8
Test 3	8650	800	1.5	0.4
MSU CUSTOM				
Test 1	5000	1000	3.4	0.9
Test 2	5000	1000	1.5	0.4
Test 3	5000	800	1.5	0.4

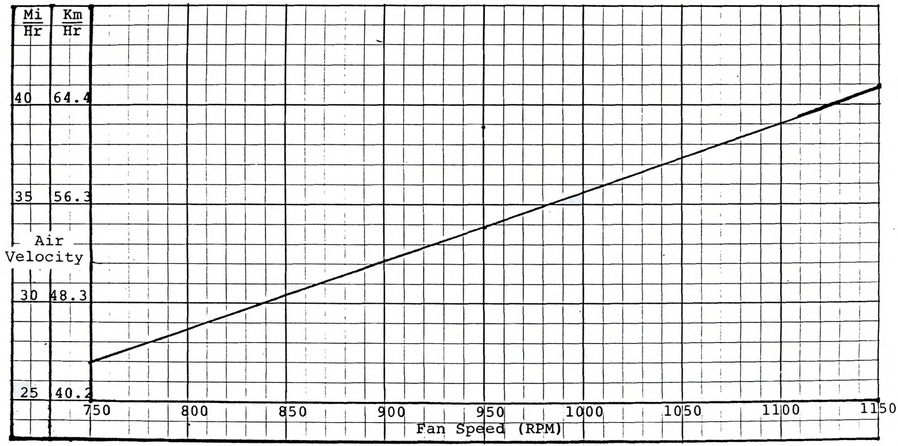


Figure 4. Air velocity vs. fan speed for the Air Curtain fans.

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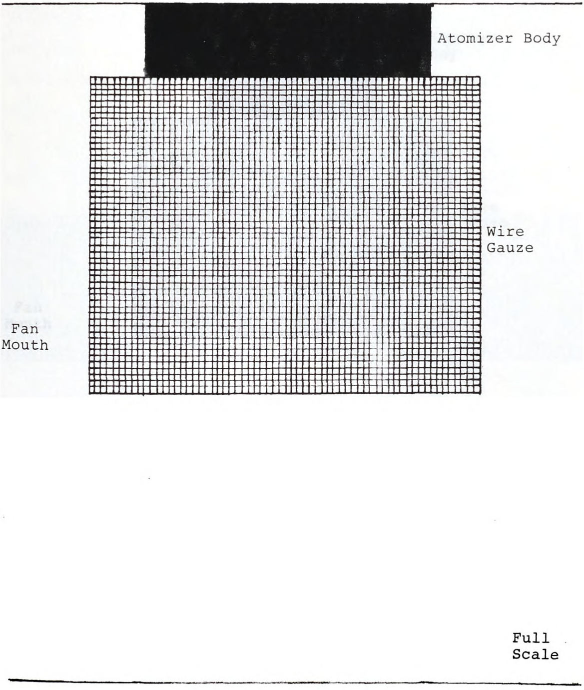
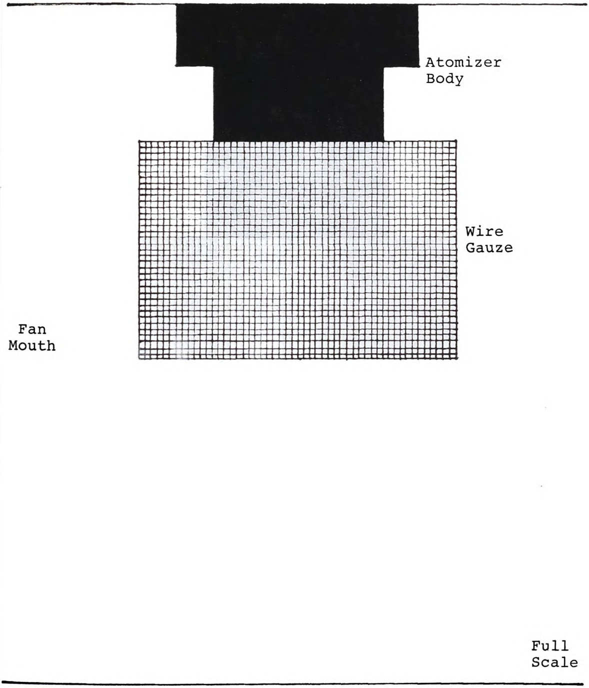


Figure 5. Profile of the Micronair AU5000 atomizer.



igure 6. Profile of the Micronair AU7000 atomizer.

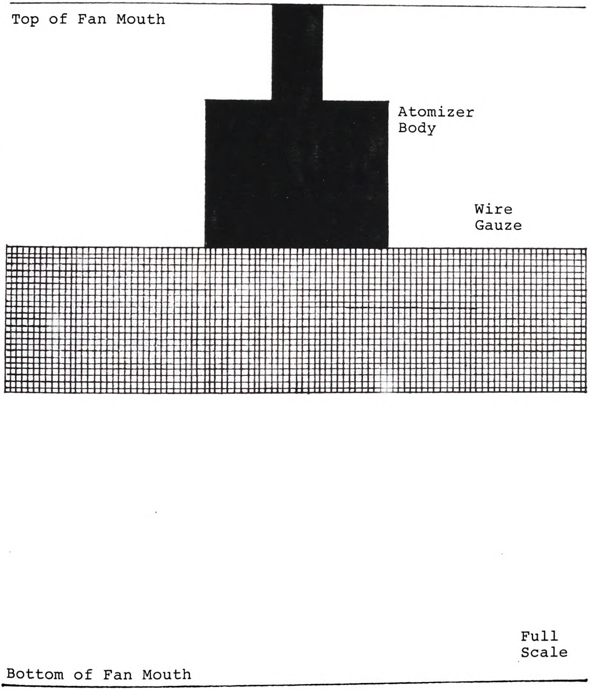


Figure 7. Profile of the MSU Custom atomizer.

maller and more streamlined profile to the air stream and to llow direct mounting of the atomizer on a hydraulic motor haft. The Micronair atomizers are belt-driven and stepped p above motor speed. In these tests, the top speed of the U5000 was about 6500 rpm which corresponds to a basket surface speed of 11 m/s (2166 fpm). The custom atomizer was mounted to a motor with a maximum speed of 5000 RPM. Therefore, to get corresponding basket surface speed, a 15.24 cm (6 in) diameter basket was used. At maximum speed, the basket surface reaches 12.70 m/s (2500 fpm). This basket was only 2.54 cm (1 in) high and had 5.08 cm (2 in) of 3.81 cm (1.5 in) pvc pipe above it to aid in fluid distribution around the circumference of the atomizer.

The spray was collected in 100mm (4 in) diameter petri dishes laid in a wooden fixture on the floor (Figure 8). This fixture held twenty-six dishes in a row and had three rows to provide some replication. The dishes were laid edge-to-edge in a row with 5.08 cm (2 in) strips of wood separating the rows. The over-hanging boom was driven at 5.63 kph (3.5 mph) over the fixture containing the dishes. The dishes were then capped, labeled, and saved for analysis.

FIELD PROCEDURES

The field tests were conducted in soybeans that had eached 76.20 cm (30 in) in height. Due to a problem at lanting time, a field of beans planned on for the spray ests was not planted. The field used for the tests was borrowed" from another department on campus and necessitated

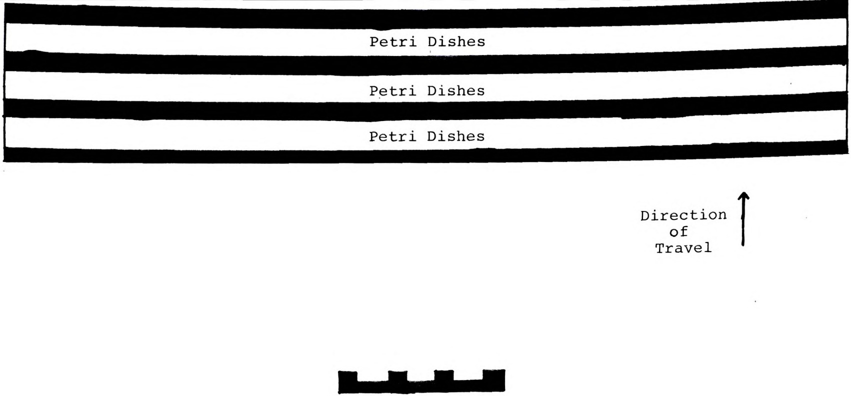


Figure 8. Top and End views of the fixture used to hold the petri dishes. The white areas represent the grooves in which the dishes were located. 1/12 scale.

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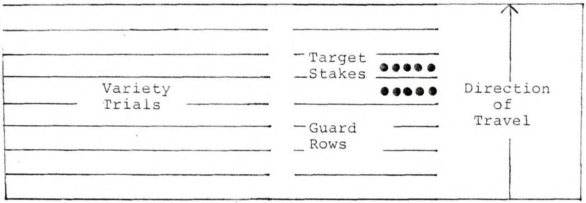
a couple of unconventional practices. Since the field was part of some variety trials, we could only spray the guard rows and could not drive in the rows. The field was planted such that we had to drive perpendicular to the rows along the outside edge. Therefore, our rows of target holders were placed between the rows of plants running parallel to the rows (Figure 9). However, this likely had no effect on the results because the beans were planted with a drill on 50.80 cm (20 in) centers and were tall and full, providing a dense and continuous canopy.

In order to provide some correlation with the petri dish tests, the sprayer variables were set as follows. All three field runs used 93.54 L/ha (10 gpa) which correlates to the low flow rate in the petri dish tests. Similarly, the fan speed in the field was 800 rpm, the same as the low fan speed in the petri dish tests. The flow rate was decided upon to determine the sprayer performance at low application rates. 93.54 L/ha (10 gpa) was as low as we could go and still get sufficient copper deposit for analysis. The fan speed was also determined in part by field conditions as higher fan speeds tended to lodge the bean plants. The remaining variable is, of course, atomizer speed which was run at the high, low and standard speeds (6520 rpm, 4150 rpm and 5620 rpm).

The typical procedure for a test began by clipping the clean mylar targets to the stakes. This takes place before the stakes are placed into the canopy. Two targets were



igure 9. The field where the deposition tests were held.

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clipped at each position to allow for separate analysis of topside and bottom side deposits. The targets were clipped near one end to allow the 10 cm (4 in) length to flutter in the air stream. After all the stakes were prepared they were placed into the canopy. The first stake was placed 30.48 cm (12 in) in from the edge of the canopy with four more stakes, each 30.48 cm (12 in) from the last, completing the row. A second row of stakes was also placed two or three rows of beans up from the other set of stakes to provide some duplication of the test.

After the stakes were in place, the sprayer was started and calibrated. Flow rate was calibrated by using a stopwatch to measure the time it took to fill a 3.79 L (1 gal) container. Fan speed and atomizer speed were checked with a photo-tachometer. When all settings were correct, the sprayer was driven past the targets at approximately 5.63 kph (3.5 mph). The tractor was not equipped with a speedometer so distance versus time measurements were made in the field prior to the trials with the fan and atomizer running. A throttle setting was established to provide the correct ground speed. The throttle was returned there for each run and no attempt was made to measure the exact speed of each run. The fan and atomizer speeds were calibrated with the tractor at a standstill with the throttle at the established ground speed position. The hydraulic system had sufficient capacity and control, through the use of pressure compensated flow controls, so that small changes in engine speed did not change

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After the targets had been sprayed and allowed to dry, the stakes were carefully removed from the canopy to facilitate easier removal of the targets. Each target was carefully unclipped and placed into a 0.30 L (10 oz) wax cold-drink cup. The cup was capped and marked with a code to indicate the exact position the target occupied during the test. The cups were put in plastic garbage bags and stored until needed for deposit analysis. The technique used for deposit analysis is included as appendix 1 at the end of the text.

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CHAPTER IV

RESULTS AND DISCUSSION

Pattern Test Results

One feature common to all the graphs is the general hape of the pattern. It can best be described as having a peak" on each side of the atomizer with a "valley" in etween. The pattern is roughly symmetrical around the enter of the valley, but it is not coincident with the enter of the fan. In all the tests except the high fan est, the minimum of the valley occurred 25.4 cm (10 in) to he right of center. The peak size and shape has slight but erceptible changes in response to changes in the variables. he high atomizer speed tended to reduce the severity of the alley (Figure 12) as compared to the low atomizer speed Figure 13) and the standard speed (Figures 10 and 11). The ow atomizer speed resulted in a deeper valley than to the tandard.

The high flow and low flow tests (Figures 14 and 15) asically show predictable results. The peaks in the high low test have pretty much the same shape as with the tandard flow test peaks, only greater magnitude. The attern in the high flow test is also much wider than in any oth

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other test. The low flow pattern has much shorter peaks compared to the standard test, but does not show much less deposit in the valley. It also has the same overall width.

The high fan test (Figure 16) does have some interesting changes. The peaks are higher and have steeper sides than in the standard tests, but the overall width of the pattern did not change and there seems to be less deposit in the valley. The valley is also located 10 cm (4 in) closer to the fan centerline than in the other tests. The low fan speed pattern (Figure 17) has about the same peak height and shape as the standard patterns, but has more deposit in the valley. It is also about 30.48 cm (12 in) wider on the left side.

Pattern tests were also run on the AU7000 and the new MSU custom design. A very rough idea of the pattern is all that was wanted, so only one row of petri dishes was used. As mentioned before, the AU7000 is a smaller version of the AU5000. The tests of the AU7000 (Figures 18,19 and 20) show that the pattern is nearly symmetrical around the fan centerline. It does not have the offset seen in the AU5000 pattern, but the right side of the AU7000 pattern is about 30.48 cm (12 in) narrower than with the AU5000. The pattern showed little response to the affects of changing variable values.

Tests on the direct-drive MSU custom atomizer yielded nearly the same pattern as with the AU5000. Figures 21, 22, and 23, show the results of these tests. The pattern from the custom atomizer is as wide as the AU5000 pattern but

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seems to have more definite edges. There is not an explanation as to why Figure 22 has the long tails on the outside edges, but the tails only represent 0.1 ppm copper and that amount is usually considered insignificant. As with the AU7000 tests, changing variable values had little effect on the pattern.

DISCUSSION

The explanation for the pattern shape lies in how the fan and atomizer interact. With the atomizer mounted in the mouth of the fan, it is an obstruction and disrupts the even air flow. When the atomizer is spinning and generating drops, the air stream and the drop trajectories combine to create the spray pattern. The pattern shift away from the an centerline is a function of the direction of rotation and he size of the atomizer. In the test of the AU5000 the tomizer was rotating counter-clockwise if observed from bove or by looking into the mouth of the fan. The right side f the atomizer is the side rotating against the air stream into the fan). Any drops emitted from this side of the tomizer are thrown into the mouth of the fan, against the ir. As the drop is released from the edge of the atomizer nd moves against the force of the air, it arcs out toward he side of the fan before being carried out of the fan by he air. Any drops emitted from the backside of the atomizer re carried around the atomizer with the air or are blown ack into the atomizer. As a way of minimizing the latter roblem in these tests, the back of the atomizer mount was

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lowered slightly to tip the atomizer with the hope that the drops emitted from the backside would have a downward velocity component and thus be carried below the atomizer rather then into it.

The overall shape of the pattern is mostly a function of drop size but it is also influenced by air velocity. Higher flows and slow atomizer speeds create larger drops while lower flows and faster atomizer speeds create smaller drops. The larger drops tend to move further away from the atomizer before being trapped by the atomizer than do the smaller drops. This is why there is a difference in the valley between the high and low speed tests. However, the high speed pattern is not wider because the slower atomizer speed results in a lower drop velocity and thus the large drops have insufficient energy to spread the pattern.

Fan speed influences the shape of the pattern by also effecting the distance a drop travels away from the atomizer before being carried by the air. At higher air velocities, the drops are trapped very quickly where as low velocities let the drop travel further.

Atomizer shape also plays a part in the formation of the pattern. The AU7000 pattern is virtually centered on the fan centerline. This is because the AU7000 is smaller then the AU5000 and blocks less air. The pattern from the MSU Custom atomizer has the offset back, in but has narrow, steep-sided peaks. The offset is because the atomizer is wide, but the narrow profile allows the air to create the peak shape.

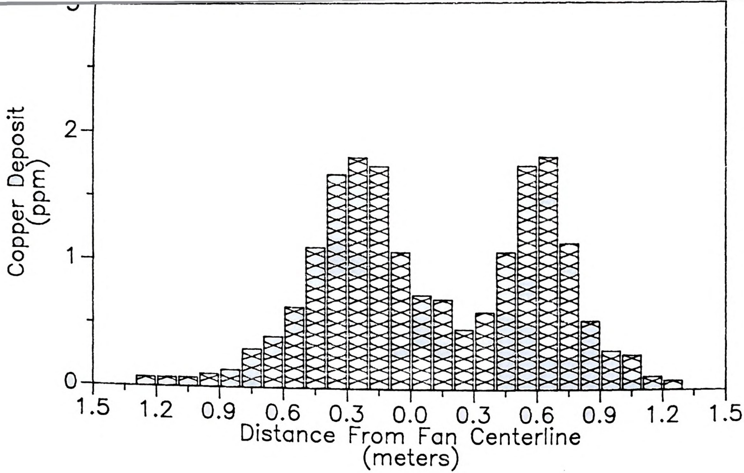

Figure 10. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the Standard test.


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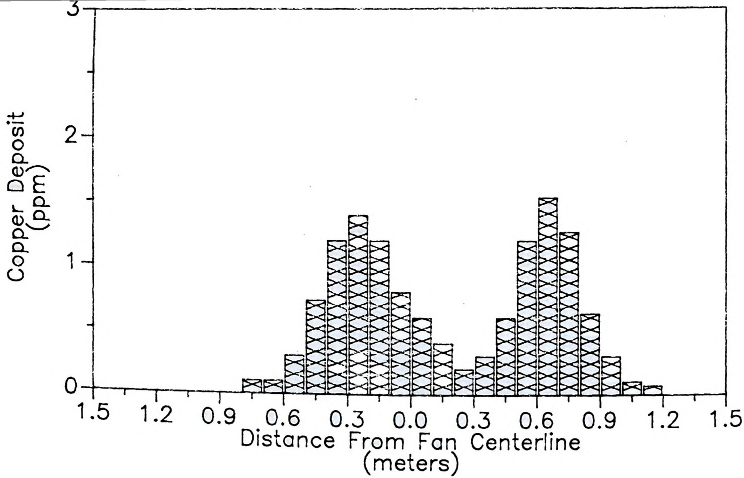

Figure 11. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the second Standard test.

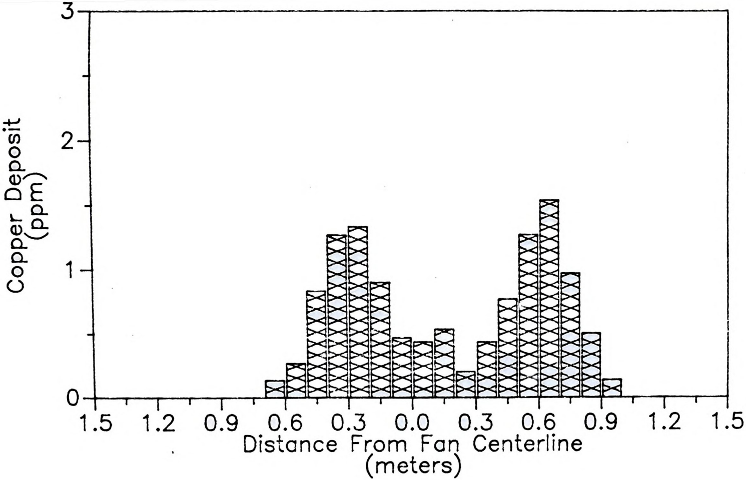

Figure 12. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the High Atomizer speed test.

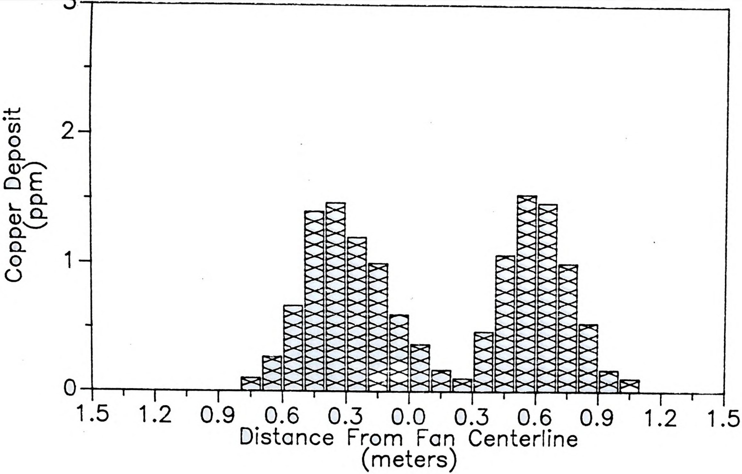

Figure 13. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the Low Atomizer speed test.

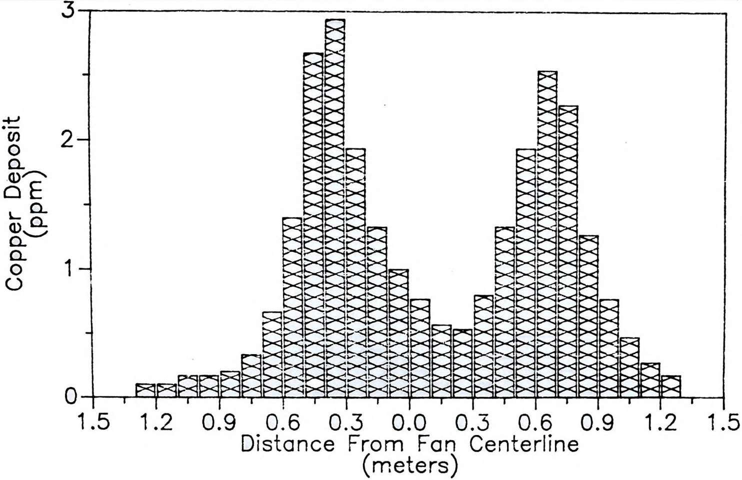

Figure 14. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the High Flow test.

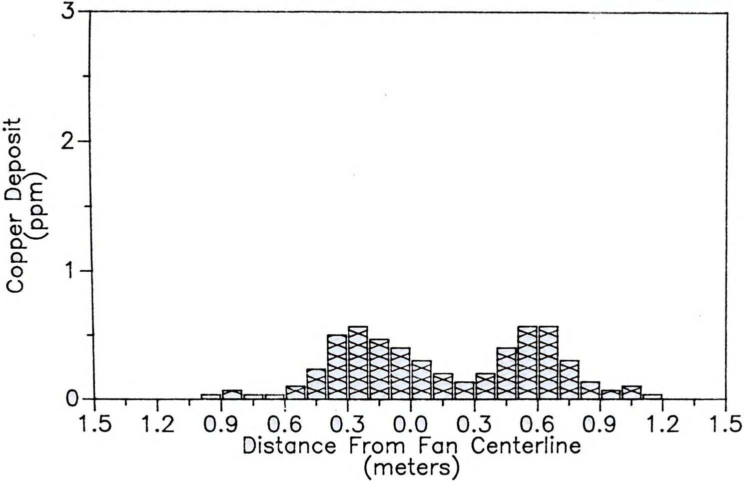

Figure 15. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the Low Flow test.

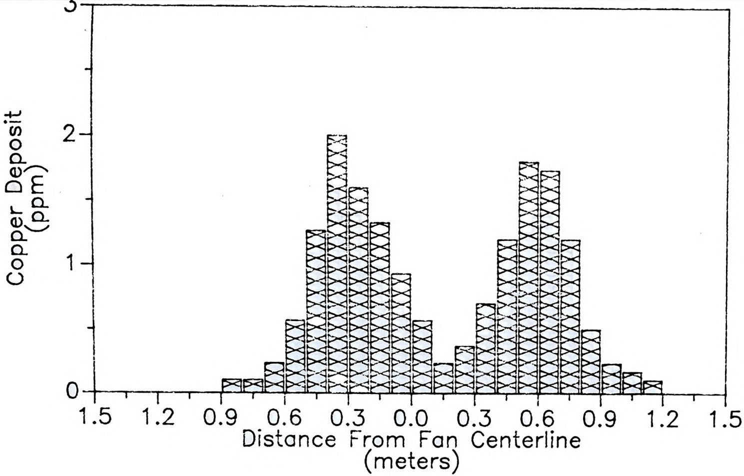

Figure 16. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the High Fan test.

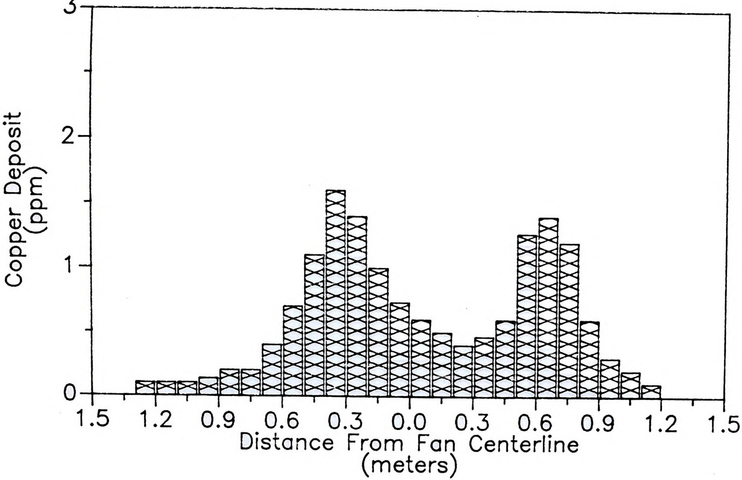

Figure 17. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the Low Fan test.

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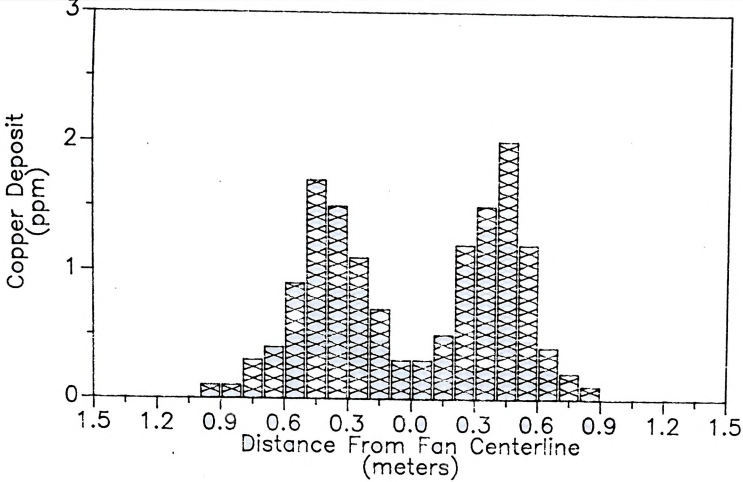

Figure 18. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the first AU7000 test.

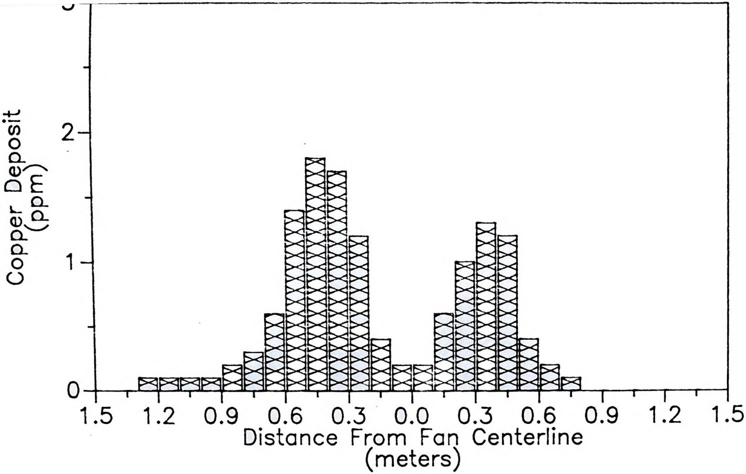

Figure 19. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the second AU7000 test.

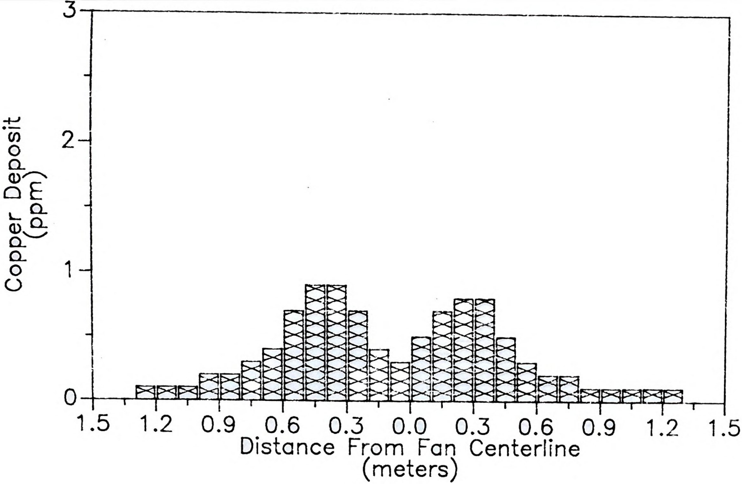

Figure 20. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the third AU7000 test.

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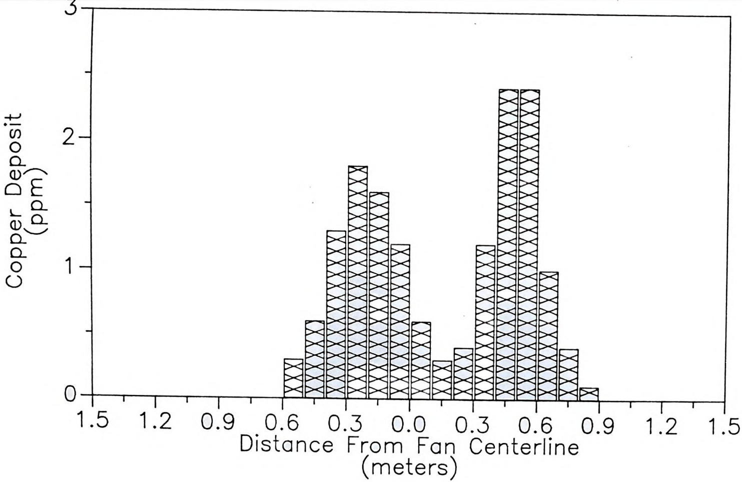

Figure 21. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the first MSU Custom test.

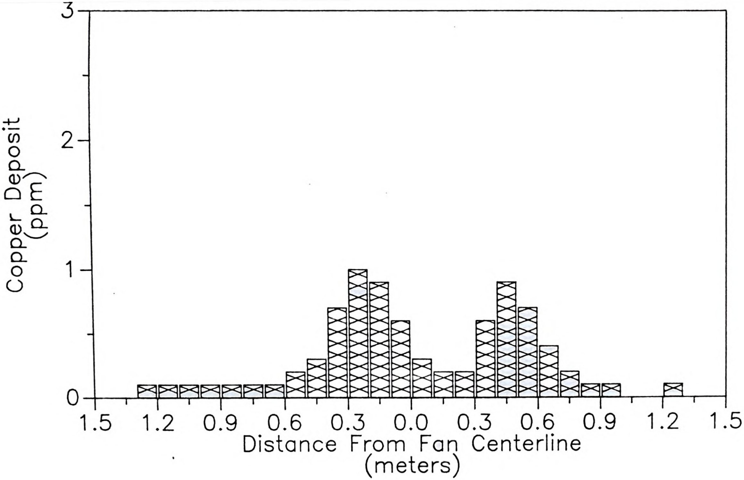

Figure 22. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the second MSU Custom test.

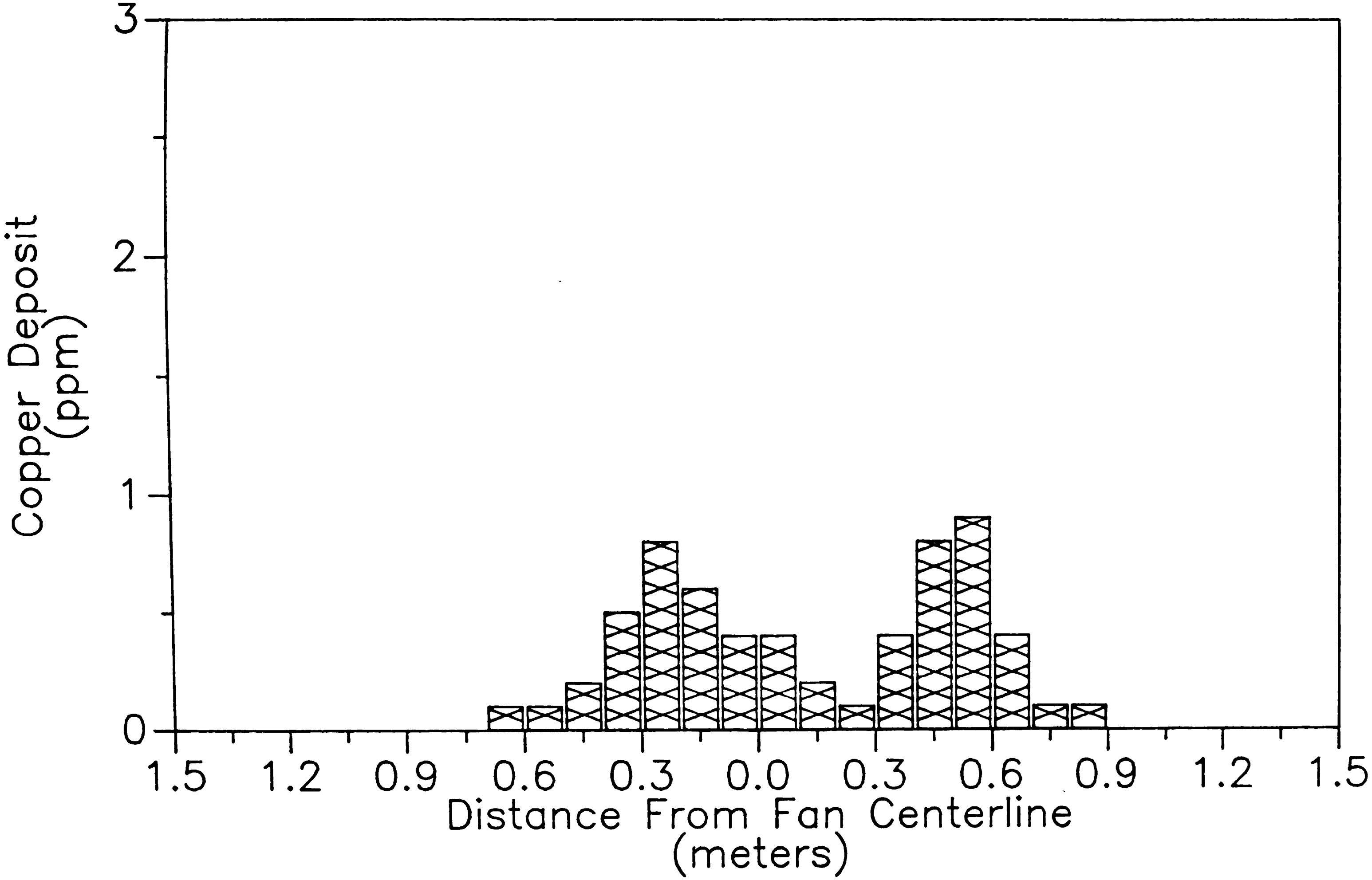

Figure 23. Air Curtain flat surface spray pattern represented by total copper deposit of the three replications for the third MSU Custom test.

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Field Test Results

After the target deposit analysis had been completed, the numbers representing the copper deposit on the target were again plotted in bar graphs. This time, however, both vertical and horizontal graphs were used. These graphs were broken down into three parts: top target only, bottom target only and top and bottom targets combined. Think of each bar in a vertical graph as a plant. Therefore, the height of the bar indicates the total copper deposit in that plant. The whole graph indicates the uniformity of the pattern across the spray swath, much like the petri dishes on the cement floor. A horizontal graph indicates the total copper deposit across a row of plants at the given heights from the ground. This is to illustrate the amount of spray being deposited in the top, middle and bottom of the plants.

A good place to start the discussion of the results is with the vertical graphs representing the uniformity of deposit across the swath. Speaking in general terms, topside coverage retains much of the classical pattern shown in the petri dish tests. The graphs of the bottom leaf surfaces indicate that the spray deposit is much less, but more uniform across the width than with the top surfaces. Remnants of the classical pattern are still present, but insignificant.

Let us move now to a discussion of the specific field tests. The top side coverage of the high atomizer speed test shows the classical pattern of two peaks with the valley

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22.86 cm (9 in) off center (Figure 24). The magnitude of the difference between the peak and valley has been reduced compared to the petri dish tests. The trailing off to the right of the pattern is likely due to a spray mist being carried off to the side with the dissipating air. It is expected that the same tail would be present to the left side if data could have been collected there (to the left side is where the tractor was traveling). The pattern width is effectively 91.44 cm (36 in) wide. The bottom targets (Figure 25) received less spray but quantity was more uniform across the width. The combined graph (Figure 26) really echoes the larger top side deposits but the height of the peaks is somewhat enhanced by the slight peaks in the bottom deposits.

Next is the low atomizer speed test. Again the top surfaces show the peaks and valley although the valley occurs in an odd place (Figure 27). The pattern appears to be wider, likely due to the larger drops from the slower atomizer speed. The bottom surface graph (Figure 28) also shows very even deposits across the swath, with no real trace of the classical pattern. However, the deposits seem to be less than with the high speed test. The combined graph (Figure 29) shows more emphasis to the peaks and really resembles the classical pattern more than the top surfaces graph alone.

The third field test was run at the standard atomizer speed. Another change was also made by tipping the fan from

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45 to 50 degrees from vertical. This did not really do anything to the pattern across the width, but it did change the top-to-bottom deposits (they will be covered later). The top surface graph (Figure 30) is different than those from the other tests in that it lacks a deep valley. The pattern width does seem to fall between the widths from the low and high atomizer speed tests, which follows the logic of drop size affecting pattern width. The top surfaces again captured more spray than the bottom surfaces (Figure 31). However, in this test the bottom surfaces did go back to showing the classical pattern, but they did not capture that much more spray than the low atomizer speed test. The combined graph (Figure 32) really is remarkably uniform across the pattern. The peaks do have more emphasis due to the bottom deposits but this is probably as good a pattern as can be expected.

Top To Bottom Results

In many ways, this analysis is the most significant because it shows the penetration the Air Curtain sprayer provides. Putting spray on the bottom side of the bottom leaves is what makes this sprayer unique.

Looking at the graphs from the high atomizer speed test, the top side deposits (Figure 33) show a rather predictable result. The top of the plant got the most deposit, and the deposit amount decreased in a generally linear fashion moving down the plant. It is significant to note that the top has only three times as much deposit as the bottom because the

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spray reaching the bottom had to travel through an additional 53.34 cm (21 in) of dense canopy. The bottom side deposit (Figure 34) is virtually uniform throughout the plant. It is especially interesting to note how close the top and bottom deposits at the 2.54 cm (1 in) height are to being the same. The graph of the combined deposits (Figure 35) pretty much reflects the top side graph.

The low atomizer speed test shows a markedly different deposit pattern. The top side deposit (Figure 36) at the 56 cm (22 in) and the 48.26 cm (19 in) levels from this test are about equal to the deposits from the high atomizer speed test. The significant difference lies in the shape of the graph from the 40.64 cm (16 in) height downward. In the high speed test, the deposits showed a fairly linear decrease. In this test the deposits show a step decrease between the 48.26 cm (19 in) and 40.64 cm (16 in) levels, with the deposit being roughly uniform from 40.64 cm (16 in) downward.

The bottom side deposits (Figure 37) also show an interesting trend. Rather than the fairly equal deposits at all heights, they show a linear decrease from top to bottom. As in past tests, the combined graph (Figure 38) echoes the shape of the top side graph.

The results of the standard field test also show a very interesting shape. This shape is more attributable to the tilting of the fan than to the change of drop size because the same change occurred to both top and bottom deposits. Laying the fan back from 45 to 50 degrees had a profound affe

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affect on deposits in the top of the plant. Figures 39 and 40 show the topside and bottom side deposits for this test. On both top and bottom surfaces, the highest target retained more spray than in any other test. The next three targets (48.26 cm (19 in), 40.64 cm (16 in), 33 cm (13 in) heights) show a linear decrease in the deposit but the rate of decrease is much more rapid than in any other test. Below the 25.40 cm (10 in) level, the deposit is uniform on the bottom side targets and shows a slight increasing trend on the topside targets.

Discussion

The major finding in the field tests is that drop size influences deposit. For instance, in the vertical plots, the difference in the total deposit between the top surfaces of the high and low speed tests (Figures 24 and 27) is very small. However, the bottom surface deposits are greater for the high speed test than the low speed test (Figures 25 and 28). In comparing the horizontal combined deposit plots for all three tests (Figures 35, 38 and 41), only the high speed test (Figure 35) shows virtually the same deposit on both the top and bottom surfaces of the bottom target. These tests show that it is the smaller drops that both make their way through the canopy and deposit on the bottom surfaces.

The horizontal low speed tests also say something more about drop size. The step change in the deposits on the combined plot (Figure 38) probably indicates a barrier in drop sizes between sizes not influenced and carried into the canc

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The last area to cover in this chapter concerns the tilting of the fan. The combined plot for the standard speed test (Figure 41) shows how tilting the fan generated higher but rapidly decreasing deposits in the top of the plant. The shallower angle of the spray approach means less downward, or penetrating, force being delivered by the air. It also means the spray travels a greater horizontal distance as it enters the plant. These conditions provide more opportunity for the spray to deposit on both top and bottom surfaces in the upper half of the plant. This graph also shows that the increase in top-half deposits did not come at the expense of the bottom-half deposits or that the amount of deposit on either the top or bottom surface of any level of the plant decreased alarmingly.

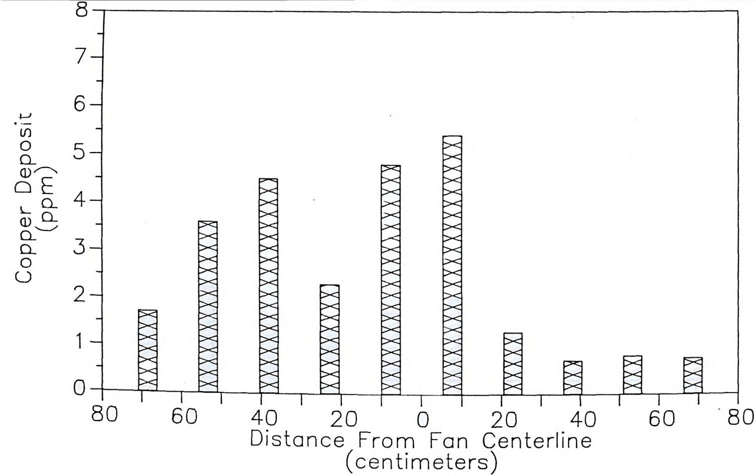

Figure 24. Air Curtain top surface vertical spray pattern represented by total copper deposit of the two replications for the High Atomizer speed test.


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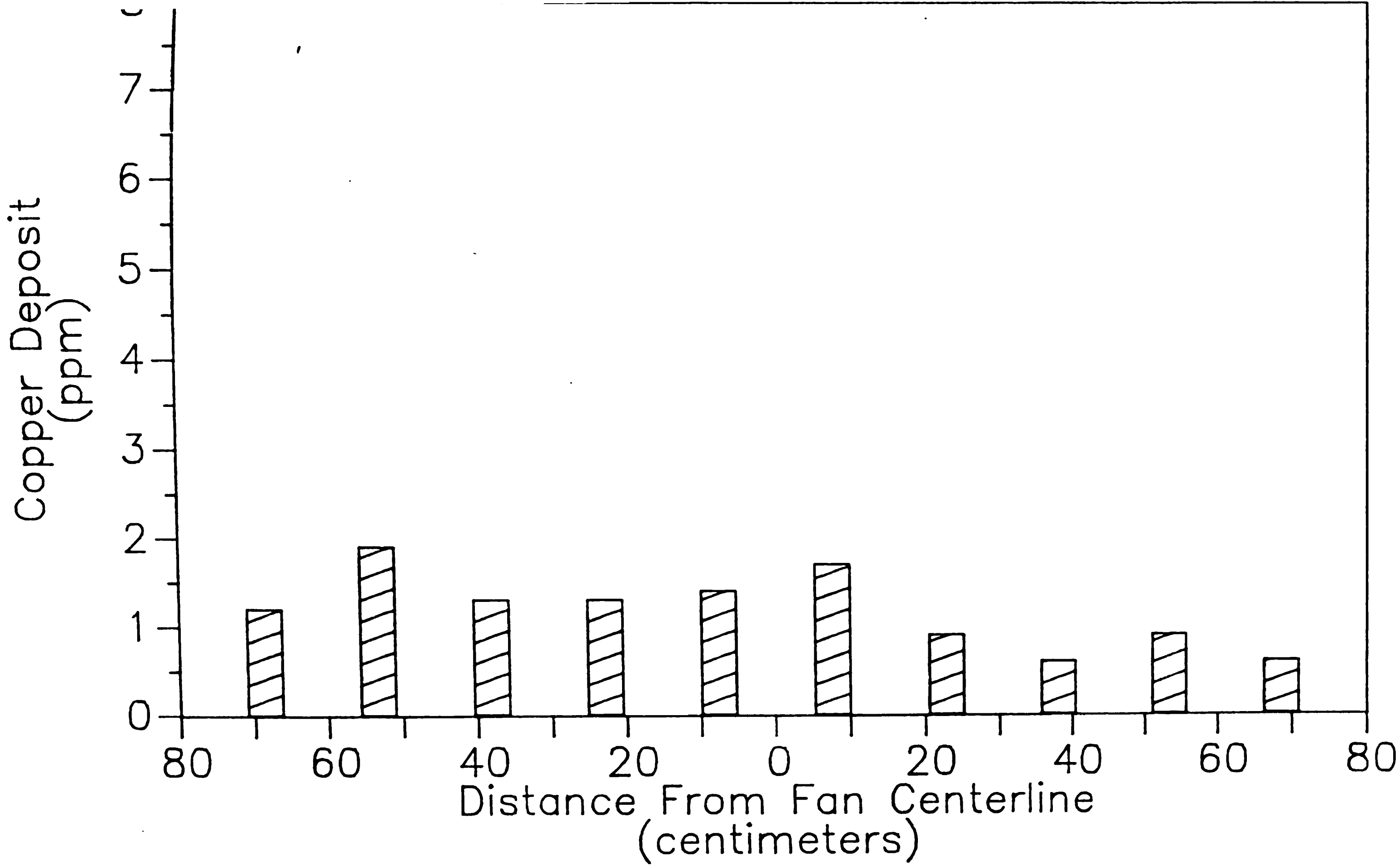

Figure 25. Air Curtain bottom surface vertical spray pattern represented by total copper deposit of the two replications for the High Atomizer speed test.

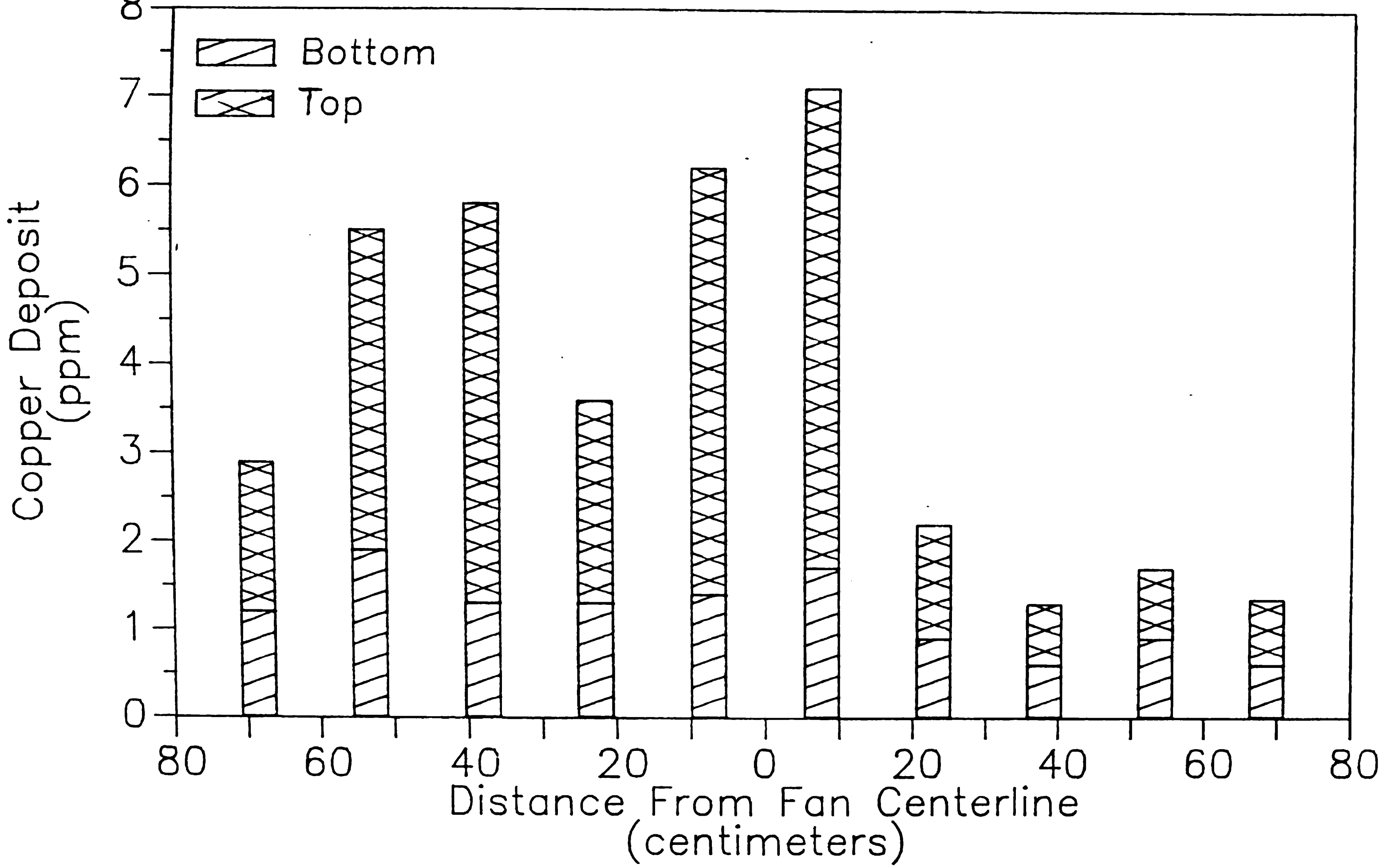

Figure 26. Air Curtain combined top and bottom surface vertical spray pattern represented by total copper deposit of the two replications for the High Atomizer speed tes

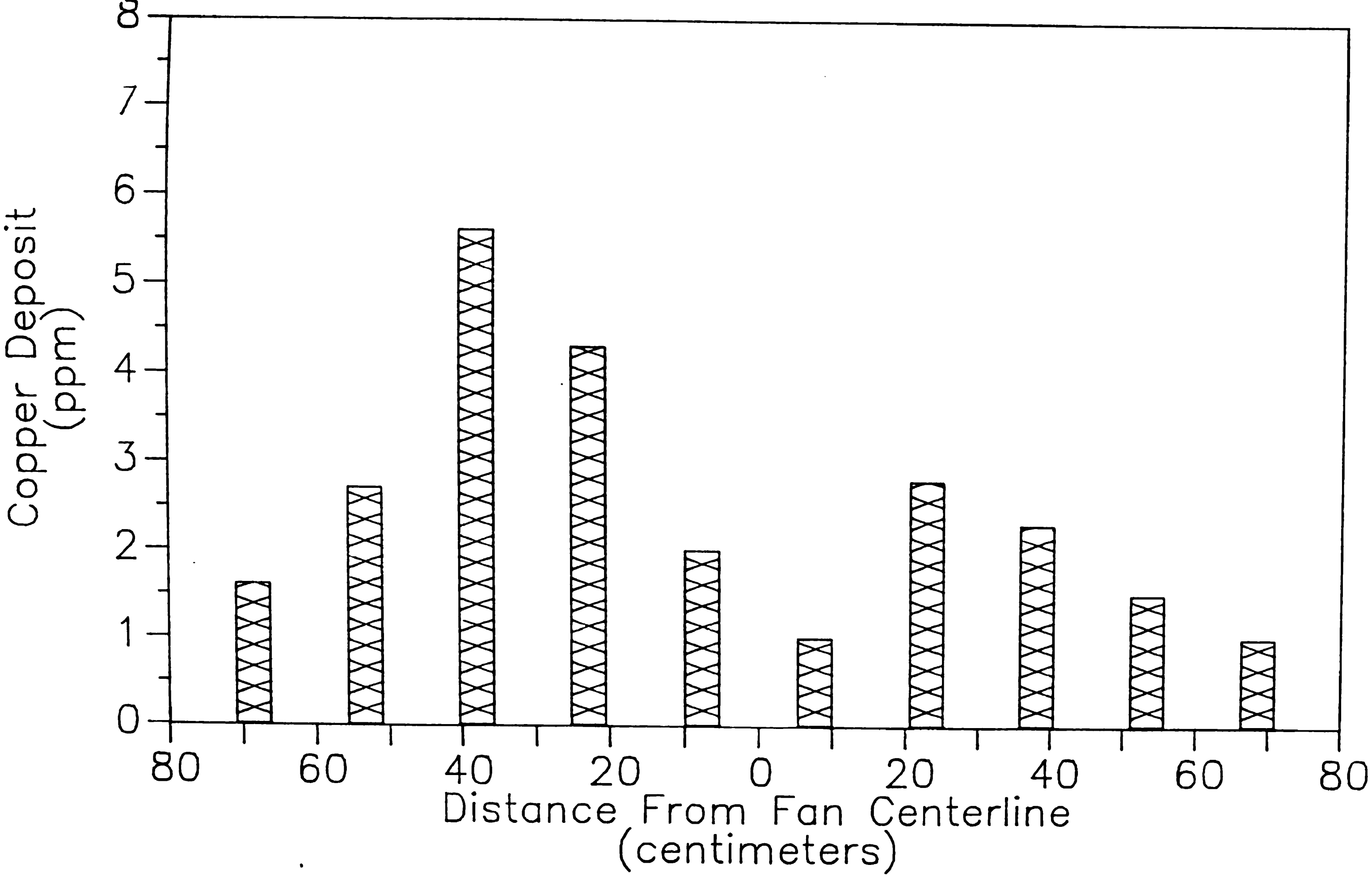

Figure 27. Air Curtain top surface vertical spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test.

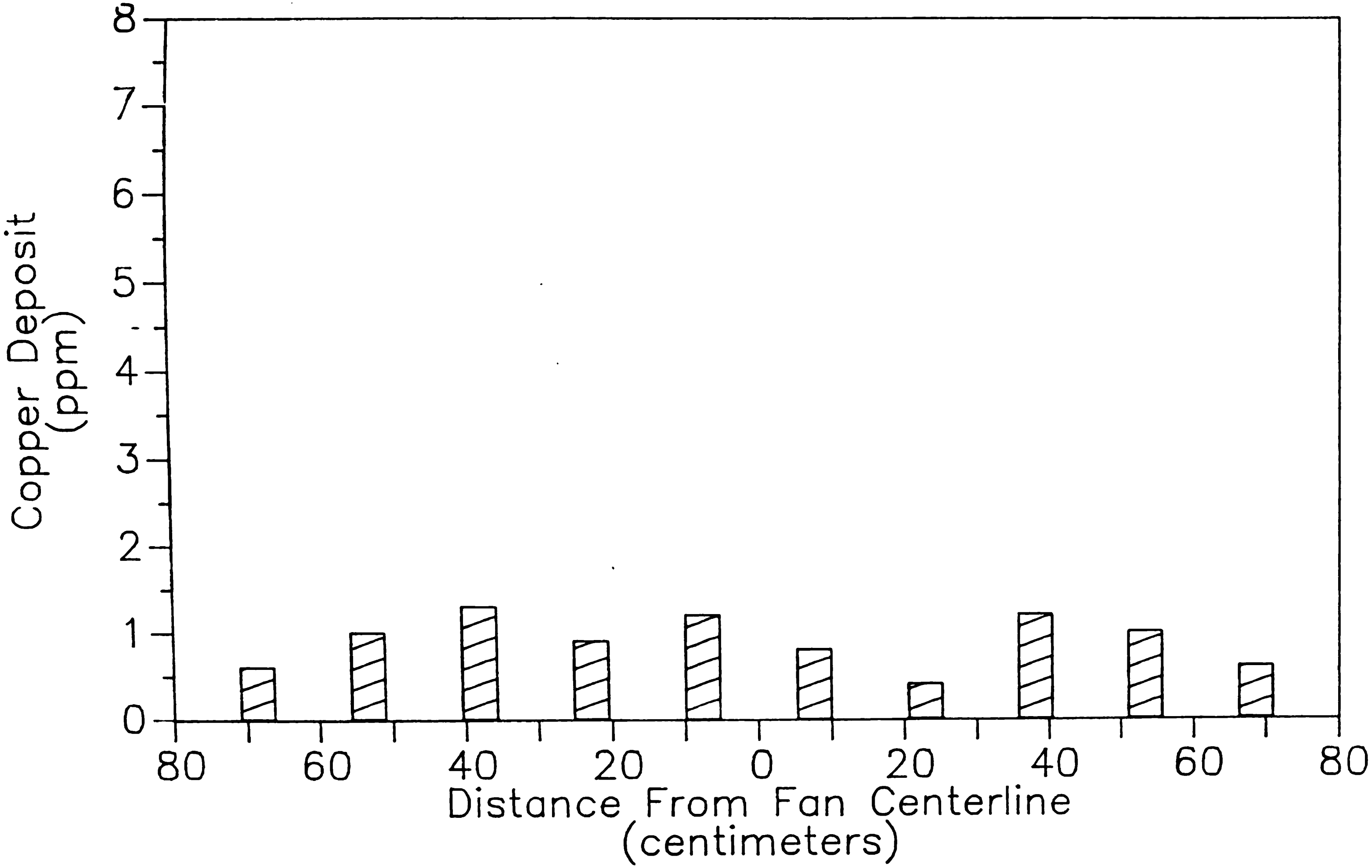

Figure 28. Air Curtain bottom surface vertical spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test.

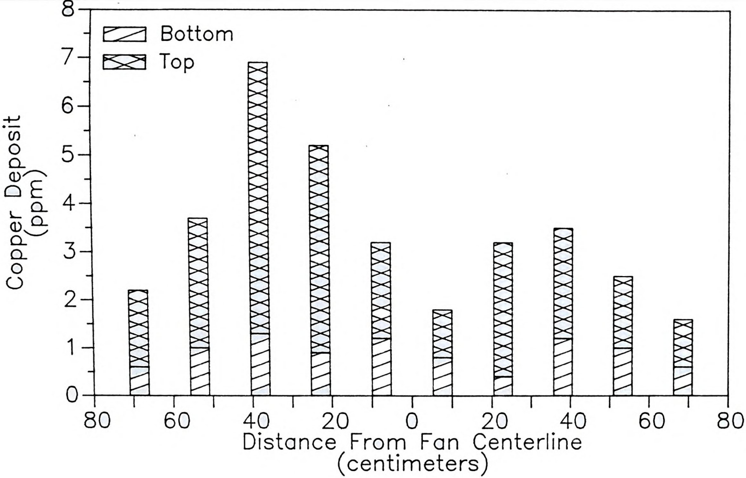

Figure 29. Air Curtain combined top and bottom surface vertical spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test

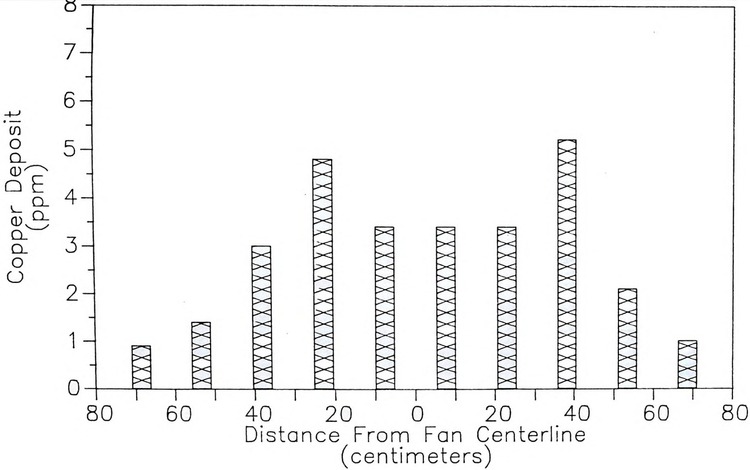

Figure 30. Air Curtain top surface vertical spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

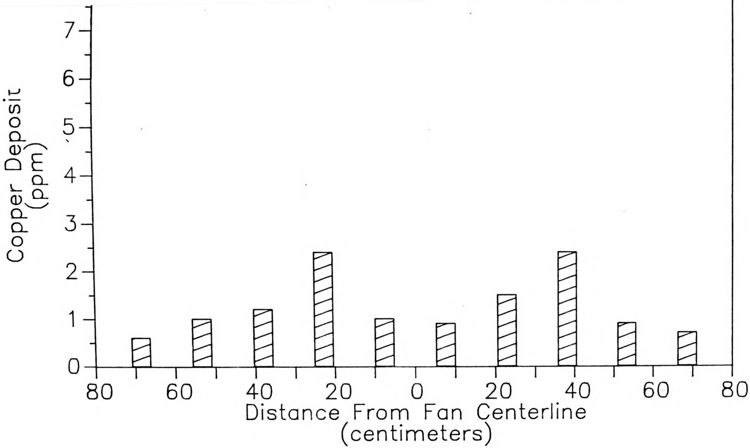

Figure 31. Air Curtain bottom surface vertical spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

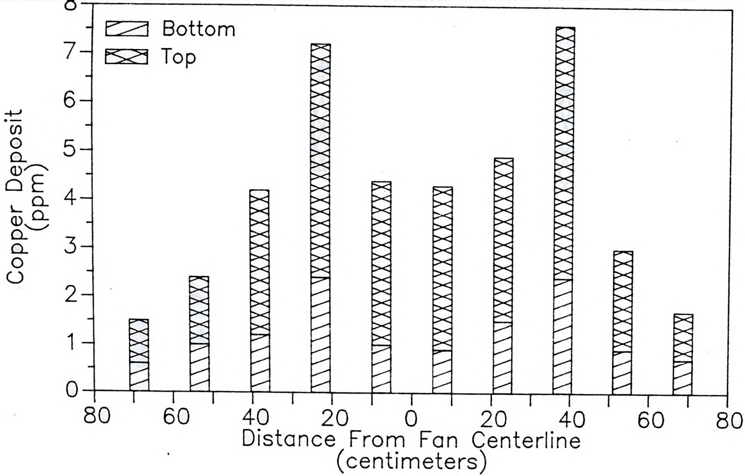

Figure 32. Air Curtain combined top and bottom surface vertical spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

Target Height From Ground
(inches)

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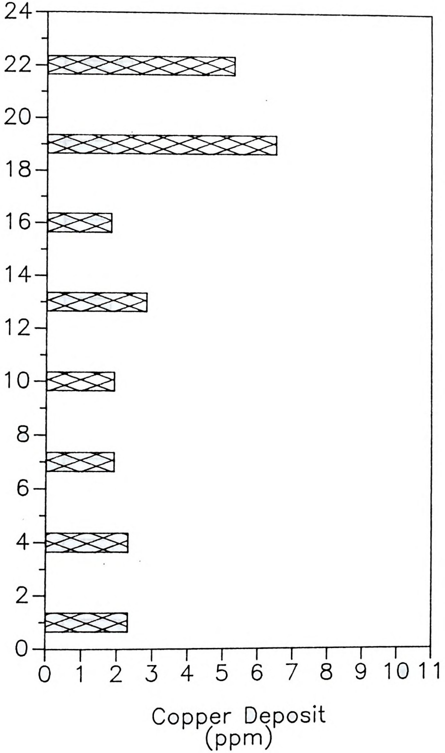

e 33. Air Curtain top surface spray pattern represented by total copper deposit of the two replications for the High Atomizer speed test.

Target Height From Ground

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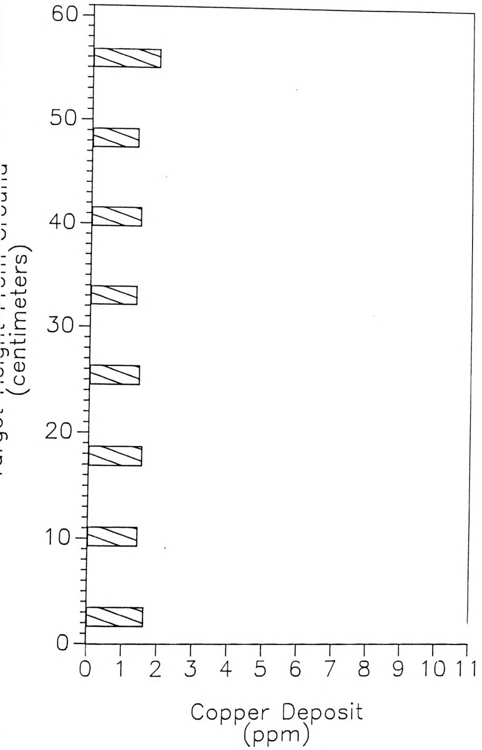
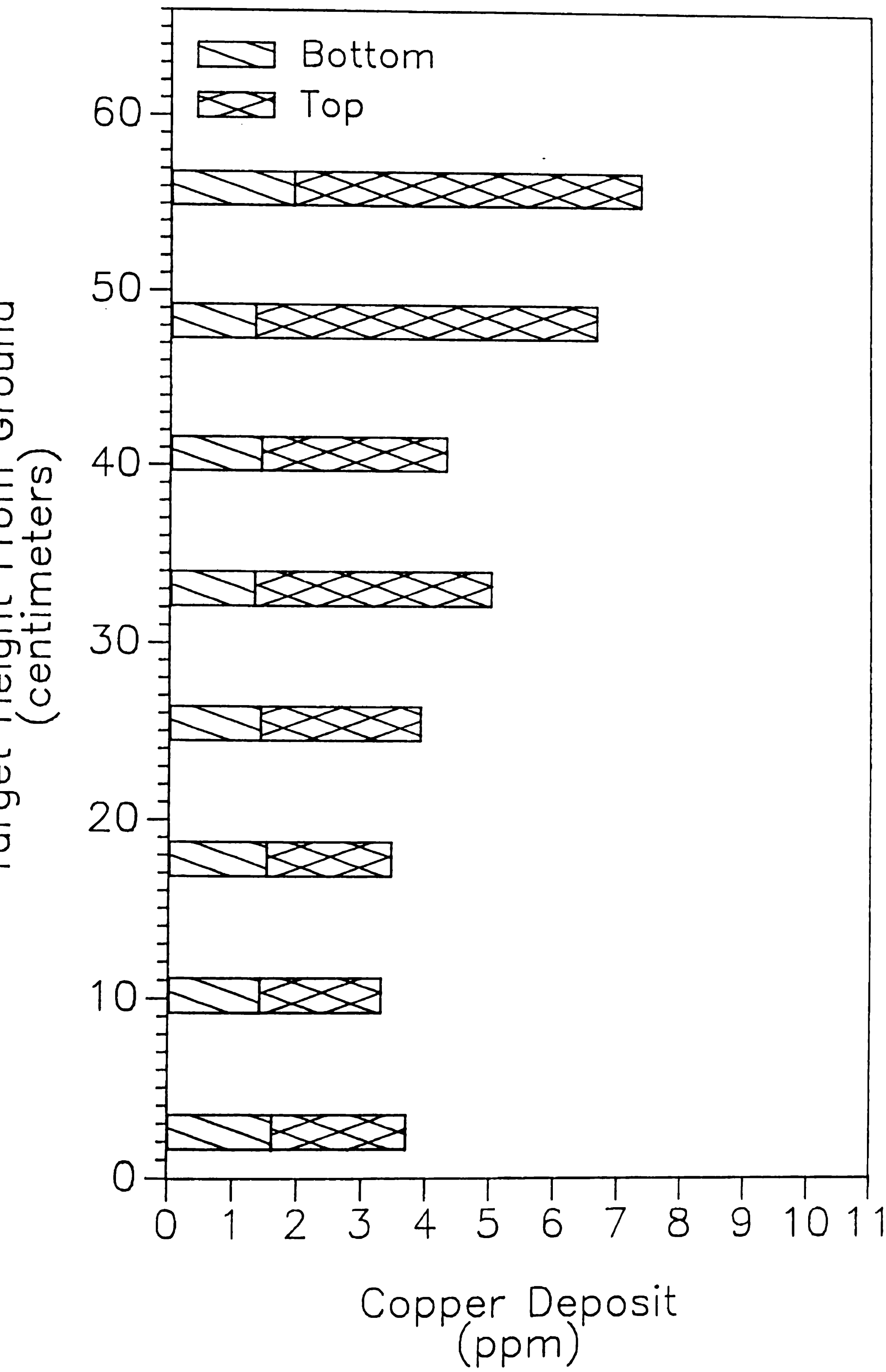


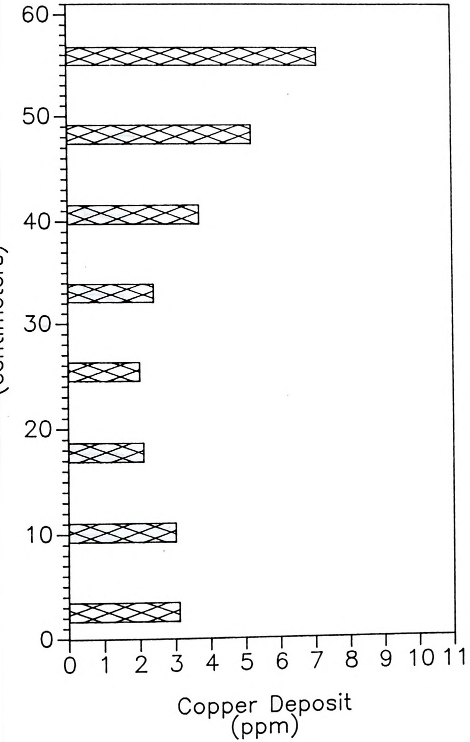
re 34. Air Curtain bottom surface spray pattern represented by total copper deposit of the two replications for the High Atomizer speed test.

Target Height From Ground



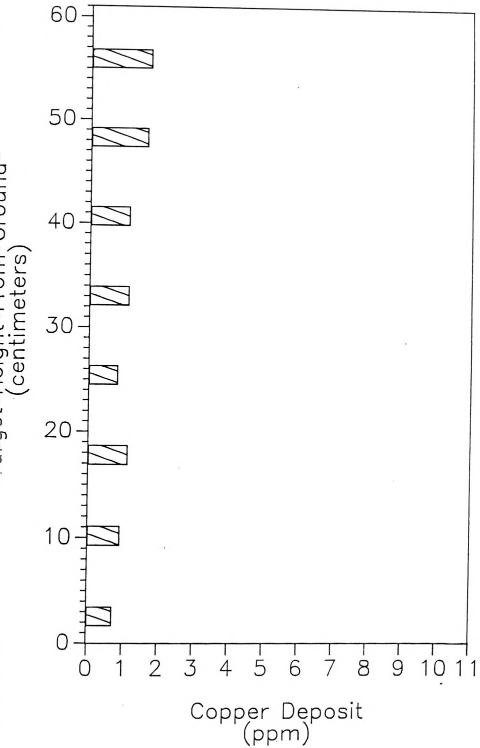
ıre 35. Air Curtain combined top and bottom surface spray pattern represented by total copper deposit of the two replications for the High Atomizer speed test.

Target Height From Ground
(centimeters)



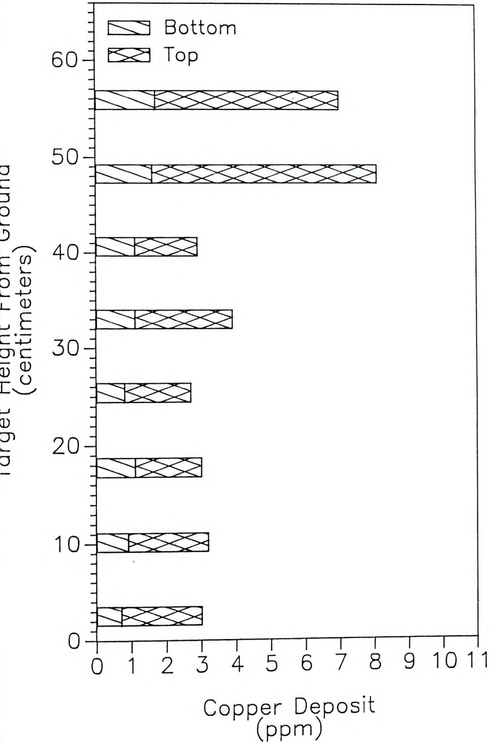
ure 36. Air Curtain top surface spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test.

Target Height From Ground



re 37. Air Curtain bottom surface spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test.

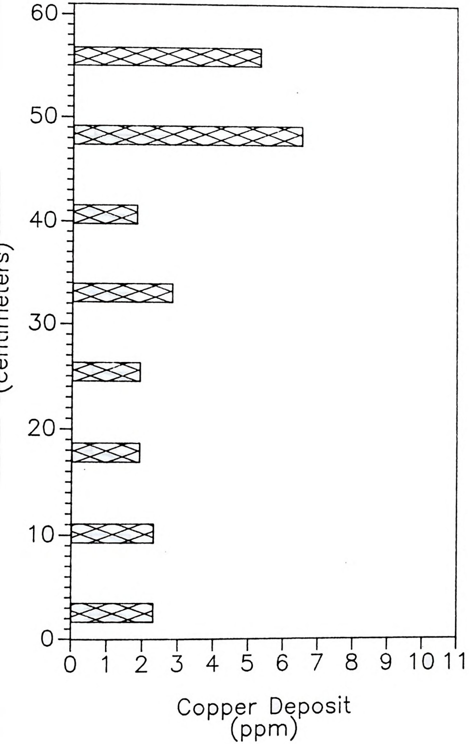
Target Height From Ground



ure 38. Air Curtain combined top and bottom surface spray pattern represented by total copper deposit of the two replications for the Low Atomizer speed test.

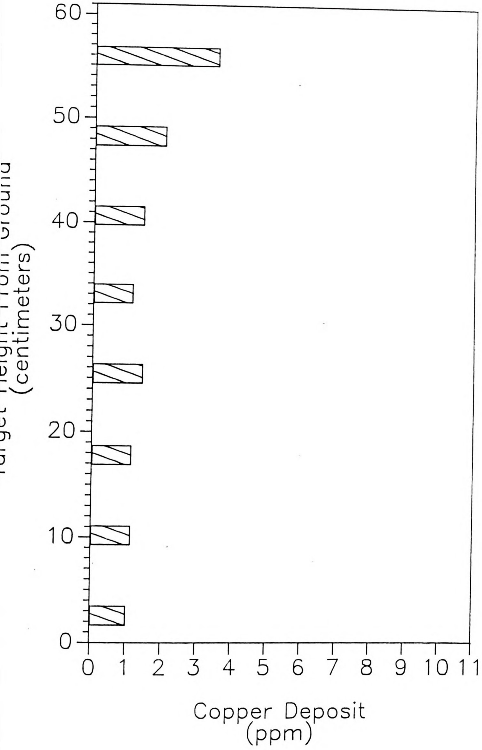
Target Height From Ground
(centimeters)

Fig



re 39. Air Curtain top surface spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

Target Height From Ground



re 40. Air Curtain bottom surface spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

Target Height From Ground

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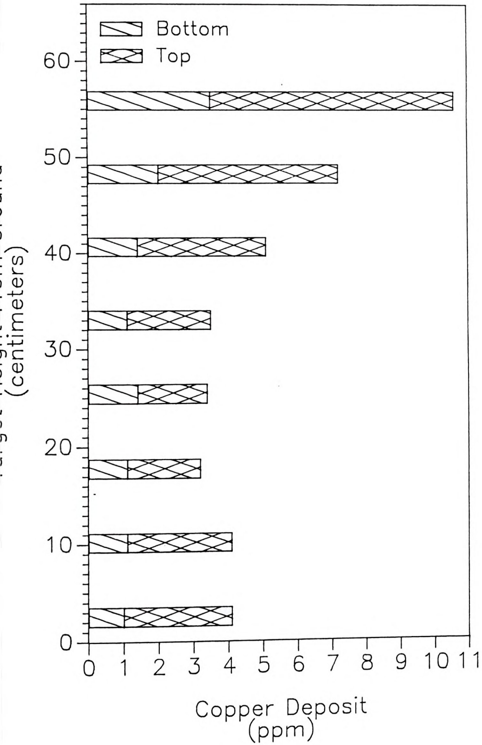

re 41. Air Curtain combined top and bottom surface spray pattern represented by total copper deposit of the two replications for the Standard Atomizer speed test.

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CHAPTER V

CONCLUSIONS

'he Air Curtain flat surface spray pattern is very uneven ›ss its width. Increasing the flow rate or decreasing the or atomizer speed tends to spread the peak spray deposits ırds the edges of the pattern and make the pattern wider. 'easing the flow rate or increasing the fan or atomizer d tends to narrow the peaks and the pattern.

nteraction of the soybean plants and the air stream the spray deposits more uniform across the swath width.

pray deposit is greater in the top of the canopy than in bottom and decreases in a generally linear fashion.

smaller drop size tends to give greater and more uniform sits on the top and bottom surfaces in the bottom of the t.

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CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

Size measurement of the droplets emitted from the atomizer those that deposit on the plant.

Test the droplets for electrostatic charges as they leave atomizer. (Shearing a large droplet with a screen can ate electrostatic charges on the individual smaller plets.)

Conduct a study similar to this on shorter crops to ermine how much canopy is required to even out the tern.

Conduct a detailed study on how atomizer shape and size ects the flat surface spray pattern.

Although seemingly limited in its use, the Electrodyn zle is intriguing. The combination of a linear electrodyn zle and a crossflow fan could be effective and should be sidered.

APPENDIX 1

DEPOSIT ANALYSIS

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Abstract

A copper and water solution is sprayed into the canopy where mylar targets have been placed. The targets are allowed to dry, then removed from the canopy and placed in cold drink cups and capped for storage. In the laboratory, dilute nitric acid is added to the cups to dissolve the copper from the targets. The deposition data is obtained by analyzing the acid from the cups in a colorimeter for copper concentration.

Procedure

The targets are made out of drafting mylar or heavy cellophane. Typically, two inch by four inch rectangles are used to roughly simulate the size and shape of a leaf.

The spray solution is prepared by mixing a copper fungicide with water to provide a known concentration of copper. Normally, 160 ppm copper is sufficient to get enough copper on the targets for good readings from the colorimeter. Spray volume rate has a big effect on the copper deposits so the concentration of the spray solution can be adjusted up or down to make sure the copper in the acid samples falls in the range of the colorimeter.

Once the solution is prepared and the targets have been placed in the canopy, the sprayer can be run. After the canopy and the targets have dried, the targets can be removed and placed into cold drink cups. With the cup lid in place, he target can be both stored and analyzed in the same ontainer.

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The remainder of the analysis procedure involves the use of a commercial copper analysis system. The system used for these trials was purchased from the Hack Co. of Ames Iowa. The system consists of the DR-100 Colorimeter, 10 ml glass sample vials for use in the meter, and capsules (referred to as "pillows") of Hack Co. proprietary colorimetric reagents. The meter has a range of 0-3 ppm copper.

The analysis of the targets begins by preparing the 0.05N Nitric acid solution used to dissolve the copper. Adding 15ml of 70% Nitric acid to 20L of distilled and deionized water will give the proper concentration. It is necessary for the acid solution to have a pH of at least 2.5. The solution is usually too acidic and is adjusted by adding Sodium Hydroxide as necessary.

The actual analysis begins by adding 25ml of the acid solution to each target in a cup. Usually, thirty or so cups can be done at a time. A pipetetter is particularly handy for adding the acid, but a small cup or beaker will also work. No matter how the acid is introduced into the cup, a little should be run down each side of the target. The cups are then capped and gently shaken for thirty seconds. When all the cups have been shaken, they are uncapped and the targets removed. The targets can be saved and used again if they are washed in some more acid solution and rinsed in distilled water. Keeping two dish pans available, one with two or three inches of acid solution in it, and the other

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containing the water, works well for washing. The targets can be left to soak in the acid until all the analysis is done, then rinsed and laid to dry.

The next step is to pour 10ml of the acid from each cup into a glass sample vial. The vials are marked, so no measurement is needed. A reagent pillow is then opened with small scissors and emptied into a vial. The vial is then capped and shaken two or three times.

A purple color indicates copper. The sample must be allowed to develop at least two minutes, but must be read in the colorimeter within thirty minutes.

Before using the Hack DR-100 colorimeter, it must be calibrated. The calibration procedure is as follows. First, place the black plastic "cell" in the meter so that it blocks the light. Close the lid and press and hold the "on" button. Adjust the "left set" knob to align the meter needle at the arrow. Remove the plastic cell. Fill a clean glass vial with 10ml of the 0.05N acid. Add a reagent pillow, cap and shake. When the reagent has dissolved, wipe the vial with a clean cloth to remove any dirt or fingerprints that could affect the meter reading. Place the vial in the meter, close the lid, press the "on" button. Adjust the "right set" knob, aligning the meter needle at 0.0. The meter is now ready to use for the test. The calibration should be repeated every fifteen to twenty samples for greatest accuracy.

The procedure for the sample vials is the same as for the clear calibration vial. Wipe the vial with a clean cloth, p

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cloth, place in the meter, close the lid, press and hold the "on" button. The meter reads directly in ppm.

When all the samples have been read, uncap the vial and discard the contents. Put all the caps and empty vials in the acid bath with the targets to be washed as needed.

APPENDIX 2

DATA

Table

Dish Number
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Table 2: Copper deposit for the standard test.
Fan 950 rpm, Atomizer 5530 rpm, Flow .9 gpm.

Dish Number	Row A	Row B	Row C
01	0.1	0.1	0.1
02	0.0	0.1	0.2
03	0.1	0.5	0.2
04	0.3	0.4	0.2
05	0.5	0.6	0.5
06	1.0	1.2	1.2
07	1.6	*	2.0
08	1.4	1.8	2.0
09	0.8	1.0	1.4
10	0.4	0.6	0.8
11	0.4	0.5	0.5
12	0.5	0.8	0.8
13	0.4	0.8	1.0
14	0.8	1.2	1.2
15	1.2	2.0	2.0
16	1.4	2.4	1.6
17	1.4	2.4	1.2
18	1.0	1.6	0.7
19	0.6	0.8	0.5
20	0.4	0.5	0.3
21	0.4	0.3	0.2
22	0.1	0.1	0.2
23	0.1	0.1	0.1
24	0.1	0.0	0.1
25	0.1	0.0	0.1
26	0.1	0.0	0.1

* N.A.

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Table 3: Copper deposit for the High Flow test.
Fan 950 rpm, Atomizer 5530 rpm, Flow 1.5 gpm.

Dish Number	Row A	Row B	Row C
01	0.2	0.2	0.1
02	0.3	0.3	0.2
03	0.5	0.6	0.3
04	0.8	1.2	0.3
05	1.0	1.4	1.4
06	1.8	2.4	2.6
07	2.4	2.6	2.6
08	2.4	1.8	1.6
09	1.4	1.2	1.4
10	0.8	0.8	0.8
11	0.7	0.5	0.4
12	0.5	0.5	0.7
13	0.7	0.8	0.8
14	1.0	1.0	1.0
15	1.2	1.6	1.2
16	1.6	2.4	1.8
17	2.8	3.0	3.0
18	3.0	2.8	2.2
19	1.8	1.4	1.0
20	0.8	0.6	0.6
21	0.4	0.3	0.3
22	0.2	0.2	0.2
23	0.2	0.2	0.1
24	0.2	0.2	0.1
25	0.1	0.1	0.1
26	0.1	0.1	0.1

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Table 4: Copper deposit for the Low Flow test.
Fan 950 rpm, Atomizer 5530 rpm, Flow .3 gpm.

Dish	Row		
Number	A	B	C
01	0.0	0.0	0.0
02	0.0	0.1	0.0
03	0.0	0.3	0.0
04	0.0	0.2	0.0
05	0.1	0.2	0.1
06	0.2	0.4	0.3
07	0.4	0.8	0.5
08	0.5	0.8	0.4
09	0.4	0.5	0.3
10	0.2	0.3	0.1
11	0.1	0.2	0.1
12	0.2	0.2	0.2
13	0.2	0.3	0.4
14	0.3	0.5	0.4
15	0.3	0.6	0.5
16	0.4	0.6	0.7
17	0.4	0.6	0.5
18	0.2	0.3	0.2
19	0.1	0.1	0.1
20	0.0	0.1	0.0
21	0.0	0.1	0.0
22	0.1	0.1	0.0
23	0.0	0.0	0.1
24	0.0	0.0	0.0
25	0.0	0.0	0.0
26	0.0	0.0	0.0

Tabl

Dish Numb
01
02
03
04
05
06
07
08
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10
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12
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14
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16
17
18
19
20
21
22
23
24
25
26

* N.

Table 5: Copper deposit for the High Fan speed test.
Fan 1100 rpm, Atomizer 5530 rpm, Flow .9 gpm.

Dish Number	Row A	Row B	Row C
01	0.0	0.0	0.0
02	0.1	0.1	0.1
03	0.1	0.1	0.1
04	0.2	0.3	0.3
05	0.5	0.5	0.5
06	1.2	1.2	1.2
07	1.4	1.8	2.0
08	1.8	1.6	2.0
09	1.2	1.2	1.2
10	0.6	0.9	0.6
11	0.3	0.5	0.3
12	0.2	0.3	0.2
13	0.5	0.7	0.5
14	0.9	1.0	0.9
15	1.4	1.2	1.4
16	1.8	1.4	*
17	1.8	2.0	2.2
18	1.2	1.6	1.0
19	0.6	0.6	0.5
20	0.2	0.3	0.2
21	0.1	0.1	0.1
22	0.1	0.1	0.1
23	0.0	0.0	0.0
24	0.0	0.0	0.0
25	0.0	0.0	0.0
26	0.0	0.0	0.0

* N.A.

Tabl

Dish Numb
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
1
1
1
1
2
2
2
2
2
2
2

Table 6: Copper deposit for the Low Fan speed test. Fan 800 rpm, Atomizer 5530 rpm, Flow .9 gpm.

Dish Number	Row A	B	C
01	0.1	0.1	0.1
02	0.1	0.1	0.1
03	0.2	0.2	0.2
04	0.3	0.3	0.3
05	0.6	0.7	0.5
06	1.2	1.2	1.2
07	1.2	1.8	1.8
08	1.2	1.2	1.4
09	0.6	0.6	0.6
10	0.5	0.4	0.5
11	0.4	0.4	0.4
12	0.5	0.5	0.5
13	0.6	0.5	0.7
14	0.6	0.6	1.0
15	0.8	0.8	1.4
16	1.2	1.4	1.6
17	1.6	1.6	1.6
18	0.9	1.2	1.2
19	0.7	0.7	0.7
20	0.4	0.5	0.3
21	0.2	0.2	0.2
22	0.2	0.2	0.2
23	0.2	0.1	0.1
24	0.1	0.1	0.1
25	0.1	0.1	0.1
26	0.1	0.1	0.1

Tabl

Dish
Numb
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02
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04
05
06
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1
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1
1
1
1
1
1
1
2
2
2
2
2
2
2

Table 7: Copper deposit for the High Atomizer speed test.
Fan 950 rpm, Atomizer 6400 rpm, Flow .9 gpm.

Dish	Row		
Number	A	B	C
01	0.0	0.0	0.0
02	0.0	0.0	0.0
03	0.0	0.0	0.0
04	0.1	0.2	0.1
05	0.5	0.5	0.5
06	0.9	1.0	1.0
07	1.4	1.6	1.6
08	1.6	1.0	1.2
09	0.8	0.7	0.8
10	0.5	0.4	0.4
11	0.2	0.2	0.2
12	0.6	0.5	0.5
13	0.5	0.4	0.4
14	0.4	0.5	0.5
15	0.9	0.9	0.9
16	1.2	1.6	1.2
17	1.0	1.6	1.2
18	0.9	0.9	0.7
19	0.4	0.4	0.2
20	0.2	0.2	0.0
21	0.0	0.0	0.0
22	0.0	0.0	0.0
23	0.0	0.0	0.0
24	0.0	0.0	0.0
25	0.0	0.0	0.0
26	0.0	0.0	0.0

Tabl

Dish
Numb
01
02
03
04
05
06
07
08
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1
1
1
1
1
1
1
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2
2
2
2
2
2
2
2

Table 8: Copper deposit for the Low Atomizer speed test. Fan 950 rpm, Atomizer 4440 rpm, Flow .9 gpm.

Dish Number	Row A	Row B	Row C
01	0.0	0.0	0.0
02	0.0	0.0	0.0
03	0.1	0.1	0.1
04	0.2	0.1	0.2
05	0.5	0.5	0.6
06	1.0	1.0	1.0
07	1.4	1.4	1.6
08	1.6	1.6	1.4
09	1.2	1.0	1.0
10	0.5	0.4	0.5
11	0.1	0.1	0.1
12	0.1	0.2	0.2
13	0.3	0.4	0.4
14	0.5	0.6	0.7
15	0.8	1.2	1.0
16	1.2	1.2	1.2
17	1.2	1.4	1.8
18	1.2	1.6	1.4
19	0.7	0.6	0.7
20	0.2	0.3	0.3
21	0.1	0.1	0.1
22	0.0	0.0	0.0
23	0.0	0.0	0.0
24	0.0	0.0	0.0
25	0.0	0.0	0.0
26	0.0	0.0	0.0

Table 9: Copper deposit for the second standard test. Fan 950 rpm, Atomizer 5530 rpm, Flow .9 gpm.

Dish Number	Row A	Row B	Row C
01	0.0	0.0	0.0
02	0.1	0.1	0.0
03	0.1	0.1	0.1
04	0.3	0.3	0.3
05	0.8	0.6	0.5
06	1.6	1.2	1.0
07	1.4	1.4	1.8
08	1.2	1.2	1.2
09	0.7	0.6	0.5
10	0.3	0.3	0.3
11	0.2	0.2	0.2
12	0.4	0.4	0.4
13	0.6	0.6	0.6
14	0.8	0.8	0.8
15	1.2	1.2	1.2
16	1.4	1.4	1.4
17	1.2	1.2	1.2
18	0.7	0.7	0.8
19	0.3	0.3	0.3
20	0.1	0.1	0.1
21	0.1	0.1	0.1
22	0.0	0.0	0.0
23	0.0	0.0	0.0
24	0.0	0.0	0.0
25	0.0	0.0	0.0
26	0.0	0.0	0.0

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Table 10: Copper deposit for the first AU7000 test.
Fan 1010 rpm, Atomizer 8650 rpm, Flow .8 gpm.

Dish Number	Row A
01	0.1
02	0.0
03	0.0
04	0.0
05	0.0
06	0.1
07	0.2
08	0.4
09	1.2
10	1.5
11	1.2
12	0.5
13	0.5
14	0.3
15	0.3
16	0.7
17	1.1
18	1.5
19	1.7
20	0.9
21	0.4
22	0.3
23	0.1
24	0.1
25	0.0
26	0.0
27	0.0

Table 11: Copper deposit for the second AU7000 test.
Fan 800 rpm, Atomizer 8650 rpm, Flow .8 gpm.

Dish Number	Row A
01	0.0
02	0.0
03	0.0
04	0.0
05	0.0
06	0.0
07	0.1
08	0.2
09	0.4
10	1.2
11	1.3
12	1.0
13	0.6
14	0.2
15	0.2
16	0.4
17	1.2
18	1.7
19	1.8
20	1.4
21	0.6
22	0.3
23	0.2
24	0.1
25	0.1
26	0.1
27	0.1

Table 12: Copper deposit for the third AU7000 test.
Fan 800 rpm, Atomizer 8650 rpm, Flow .41 gpm.

Dish Number	Row A
01	0.1
02	0.1
03	0.1
04	0.1
05	0.1
06	0.1
07	0.2
08	0.2
09	0.3
10	0.5
11	0.8
12	0.8
13	0.7
14	0.5
15	0.3
16	0.4
17	0.7
18	0.9
19	0.9
20	0.7
21	0.4
22	0.3
23	0.2
24	0.2
25	0.1
26	0.1
27	0.1

Table 13: Copper deposit for the first MSU Custom test.
Fan 1010 rpm, Atomizer 4880 rpm, Flow .87 gpm.

Dish Number	Row A
01	0.0
02	0.0
03	0.0
04	0.0
05	0.0
06	0.1
07	0.4
08	1.0
09	2.4
10	2.4
11	1.2
12	0.4
13	0.3
14	0.6
15	1.2
16	1.6
17	1.8
18	1.3
19	0.6
20	0.3
21	0.0
22	0.0
23	0.0
24	0.0
25	0.0
26	0.0
27	0.0

Table 14: Copper deposit for the second MSU Custom test. Fan 1100 rpm, Atomizer 5050 rpm, Flow .43 gpm.

Dish Number	Row A
01	0.1
02	0.1
03	0.0
04	0.0
05	0.1
06	0.1
07	0.2
08	0.4
09	0.7
10	0.9
11	0.6
12	0.2
13	0.2
14	0.3
15	0.6
16	0.9
17	1.0
18	0.7
19	0.3
20	0.2
21	0.1
22	0.1
23	0.1
24	0.1
25	0.1
26	0.1
27	0.1

Tabl

Dish Numb
01
02
03
04
05
06
07
08
09
10
11
11
11
14
1
1
1
1
1
2
2
2
2
2
2
2
2

Table 15: Copper deposit for the third MSU Custom test. Fan 820 rpm, Atomizer 5140 rpm, Flow .43 gpm.

Dish Number	Row A
01	0.0
02	0.0
03	0.0
04	0.0
05	0.0
06	0.1
07	0.1
08	0.4
09	0.9
10	0.8
11	0.4
12	0.1
13	0.2
14	0.4
15	0.4
16	0.6
17	0.8
18	0.5
19	0.2
20	0.1
21	0.1
22	0.0
23	0.0
24	0.0
25	0.0
26	0.0
27	0.0

TABLE 16: *Copper deposit for the high atomizer speed test.*

COPPER DEPOSIT (PPM)

TABLE 16: Copper deposit for the high atomizer speed test.

COPPER DEPOSIT (PPM)

TOP TARGETS

TARGET HEIGHT FROM GROUND (CM)	(IN)	76.20	60.96	45.72	30.48	15.24	15.24	30.48	45.72	60.96	76.20
(CM) / (IN)		30	24	18	12	6	6	12	18	24	30
55.88	22		1.80		1.00		2.30		0.20		0.15
48.26	19	0.60		2.60		1.80		0.20		0.15	
40.64	16		0.90		0.30		1.40		0.10		0.20
33.02	13	0.40		0.90		0.90		0.30		0.20	
25.40	10		0.50		0.50		1.10		0.20		0.20
17.78	7	0.30		0.50		0.60		0.40		0.15	
10.16	4		0.40		0.50		0.60		0.20		0.20
2.54	1	0.40		0.50		0.50		0.40		0.30	

DISTANCE FROM FAN CENTERLINE

BOTTOM TARGETS

(CM)	(IN)	76.20	60.96	45.72	30.48	15.24	15.24	30.48	45.72	60.96	76.20
		30	24	18	12	6	6	12	18	24	30
55.88	22		0.70		0.30		0.60		0.10		0.20
48.26	19	0.40		0.10		0.50		0.10		0.20	
40.26	16		0.50		0.30		0.40		0.10		0.10
33.02	13	0.30		0.50		0.20		0.10		0.20	
25.40	10		0.50		0.30		0.30		0.20		0.10
17.78	7	0.30		0.40		0.40		0.20		0.20	
10.16	4		0.20		0.40		0.40		0.20		0.20
2.54	1	0.20		0.30		0.30		0.50		0.30	

TABLE 17: Copper deposit for the low atomizer speed test.

COPPER DEPOSIT (PPM)

for the low atomizer speed test.

COPPER DEPOSIT (PPM)

TARGET HEIGHT FROM GROUND (CM)	(IN)										
		TOP TARGETS									
55.88	22		1.80		2.80		0.20		0.40		0.10
48.26	19	0.70		3.20		0.90		1.50		0.20	
40.64	16		0.20		0.50		0.30		0.60		0.20
33.02	13	0.30		1.10		0.50		0.50		0.40	
25.40	10		0.30		0.70		0.30		0.40		0.20
17.78	7	0.20		0.60		0.30		0.30		0.50	
10.16	4		0.40		0.30		0.20		0.90		0.50
2.54	10	0.40		0.70		0.30		0.50		0.40	
		DISTANCE FROM FAN CENTERLINE									
(CM)		76.20	60.96	45.72	30.48	15.24	15.24	30.48	45.72	60.96	76.20
(IN)		30	24	18	12	6	6	12	18	24	30
		BOTTOM TARGETS									
55.88	22		0.60		0.40		0.30		0.30		0.10
48.26	19	0.30		0.50		0.40		0.30		0.10	
40.26	16		0.10		0.10		0.10		0.70		0.10
33.02	13	0.10		0.30		0.30		0.00		0.40	
25.40	10		0.20		0.20		0.20		0.10		0.10
17.78	7	0.10		0.40		0.30		0.00		0.30	
10.16	4		0.10		0.20		0.20		0.10		0.30
2.54	1	0.10		0.10		0.20		0.10		0.20	

TABLE 18: Copper deposit for the low fan speed test.

COPPER DEPOSIT (PPM)

COPPER DEPOSIT (PPM)

TOP TARGETS

TARGET HEIGHT FROM GROUND (CM)	(IN)	76.20 (30)	60.96 (24)	45.72 (18)	30.48 (12)	15.24 (6)	15.24 (6)	30.48 (12)	45.72 (18)	60.96 (24)	76.20 (30)
55.88	22		0.70		2.90		0.80		2.40		0.30
48.26	19	0.30		1.40		1.60		1.20		0.70	
40.64	16		0.20		0.60		1.50		1.20		0.20
33.02	13	0.10		0.50		0.60		0.80		0.40	
25.40	10		0.20		0.30		0.60		0.80		0.10
17.78	7	0.20		0.30		0.50		0.70		0.40	
10.16	4		0.30		1.00		0.50		0.80		0.40
2.54	1	0.30		0.80		0.70		0.70		0.60	

DISTANCE FROM FAN CENTERLINE

BOTTOM TARGETS

TARGET HEIGHT FROM GROUND (CM)	(IN)	76.20 (30)	60.96 (24)	45.72 (18)	30.48 (12)	15.24 (6)	15.24 (6)	30.48 (12)	45.72 (18)	60.96 (24)	76.20 (30)
55.88	22		0.30		1.60		0.40		1.00		0.20
48.26	19	0.20		0.60		0.40		0.60		0.20	
40.26	16		0.20		0.40		0.20		0.50		0.10
33.02	13	0.20		0.20		0.20		0.30		0.20	
25.40	10		0.40		0.20		0.10		0.50		0.20
17.78	7	0.10		0.20		0.20		0.40		0.20	
10.16	4		0.10		0.20		0.20		0.40		0.20
2.54	1	0.10		0.20		0.20		0.20		0.30	

APPENDIX 3

PRELIMINARY INDEPENDENT AIR CURTAIN RESEARCH REPORT

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APPENDIX

APPLICATION TECHNOLOGY FOR CONTROL OF EUROPEAN CORN BORER IN VEGETABLES FOR PROCESSING

E. Grafius and G. Van Ee
Michigan State University

PRELIMINARY RESEARCH REPORT
October 1986

Funding for this project was received May 28, 1986. Laboratory and greenhouse studies continue and results will be included in the final report. Experiments were designed to investigate the interactions between: 1) Improved application efficiency of an experimental sprayer designed by Van Ee et al. (1985) and adapted to vegetable crops; 2) Mode of activity of insecticide (systemic or local in action); and 3) Behavior and movement of newly-hatched ECB larvae on the plant prior to penetration into the fruit.

Materials and Methods

Crops chosen for study were snap beans, green bell peppers, and sweet banana peppers. These crops were chosen on the basis of zero or near zero tolerance for damage or contamination and, therefore, extremely high rates of pesticide usage and potential for misuse. (Pesticide usage on these crops was estimated to be as much as 82 times the amount needed to prevent yield loss - see Proposal.) Bell peppers and sweet banana peppers were transplanted on 6/11 and 6/23, respectively. Beans were planted on 6/26. Plots were four rows wide (30" between rows) by 30' long (20 pepper plants per row, 4 bean plants per ft.) set up in a randomized complete block design with four replicates. Hot cherry peppers were originally proposed, instead of the banana peppers, but the initial planting was delayed by 6+ inches of rain, after which replacement cherry pepper plants were not available.

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Treatment. Pesticide application was made with a conventional boom sprayer or with an experimental model of the M.S.U. air curtain sprayer (Van Ee et al. 1985), modified for application to vegetable crops. Application with the conventional boom sprayer was made at 50 gpa and 40 psi with two standard D-2 hollow cone nozzles over each row (one angled in from each side of the row). Air curtain application was made at 5.8 gpa and 60 psi using a laminar, non-turbulent air flow to enclose the active material, dispensed by a Micronair® applicator.

Controlled droplet application was originally proposed as a third technique. Data from other crops indicate that CDA droplets would be even more restricted to the upper leaf surfaces than material applied by conventional boom and, therefore, CDA application would not add to the analysis of effects of high-precision application. CDA application was therefore dropped from the experimental design, allowing more intensive sampling and data collection to compare conventional boom and air curtain application.

The insecticides used in the study were fenvalerate (Pydrin 2.4 EC, 0.1 lb ai/A) and acephate (Orthene 75S, 0.5 lb ai/A). Rates were selected to be minimum effective doses, to emphasize the effects of differences in spray coverage. Additional treatments were an untreated and a water-sprayed control, to assess the physical effects of air curtain application. Treatments were applied to peppers on 8/4, 8/12, 8/19, 8/29, and 9/5. Application dates for beans were 8/19, 8/29, and 9/5. A maintenance spray of Cygon 400 (0.5 lb ai/A) was applied to the snap beans on 8/3 for leafhopper control.

Spray deposition. Spray deposition was measured on 9/5 and 9/17, by spraying plots with both boom and air curtain sprayers. On 9/17, fruit were slightly larger and wind was higher (ca. 8-10 mph), which may have affected distribution. Blue food dye (Floline® FD&C Blue No. 1) was used in the boom sprayer and yellow dye (Floline® FD&C Yellow No. 5) in the air curtain. Both dyes were applied at a rate of 368 g/Ha (2 lb/A). Leaves were randomly selected from upper and lower parts of the 10 plants per plot (1 upper and one lower leaf per plant) and marked prior to treatment. Deposition by both sprayers on top and bottom surfaces of the same leaf were sampled. To measure deposition on the top leaf surface, the bottom of 1/2 of the leaf was rinsed with water from a laboratory wash bottle and five 0.64 cm diam. disks per leaf were punched out with a standard hole punch and placed in a vial with 10 ml of water. The top of the remaining half of the leaf was rinsed and holes punched and retained to measure deposition on the bottom surface of the same leaf. Dye

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concentrations were read on a Shimadzu UV-160 scanning spectrophotometer at the wavelength corresponding to peak absorbance for the respective dyes and compared with standards to determine quantity of dye present. Deposition from both sprayers could thus be measured simultaneously from the same leaf, standardizing variation due to leaf position in the row and within the plant, orientation of the leaf, etc.

Spray deposition on the pepper fruit was measured by taking samples from both cap and pericarp (sides) of randomly-selected fruit, rinsing the samples in 20 ml of distilled water and reading, as before. For the bell peppers, the area around the cap and 6.45 cm^2 samples of pericarp were taken from each of 5 peppers. For the banana peppers, each replication consisted of cap areas (or 1.61 cm^2 pericarp samples) from 4 peppers. Spray deposition on the beans was estimated by harvesting 5 replications of 50 beans each, rinsing in 500 ml of water and estimating the quantity of dye, as before. The dimensions of 25 randomly-selected beans were measured to estimate surface area.

Sampling. Two randomly-selected plants per plot were examined for ECB egg masses, weekly. No egg masses were found on the beans and they were therefore artificially infested with egg masses (obtained from the U.S.D.A. Corn Insect Research Laboratory, Ankeny, Iowa) on 9/2. Two egg masses (in blackhead stage) were placed on each of four randomly-selected plants per plot.

The level of ECB infestation of fruit was determined at harvest (9/12 and 9/15 for bell and banana peppers, respectively). For both types of peppers, all mature fruit were harvested from the center 24 feet of the middle two rows of each plot. Forty fruit were randomly selected and examined for evidence of ECB. In plots where less than 40 fruit were harvested, all fruit were examined. For the beans, four plants in the immediate area of the introduced egg masses (16 plants/plot) were stripped of their fruit, which were then examined for ECB damage.

To determine ovicidal activity of the insecticides, ECB egg masses were introduced onto pepper plants immediately prior to treatment and collected after the spray had dried. Egg hatch in all of the treatments was very low and no useable data was obtained. This study will be repeated in the laboratory.

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Green peach aphid numbers on peppers were counted on two upper and two lower leaves from two plants per plot on 8/27, 9/3, and 9/15.

ECB larval behavior. Preliminary field studies and laboratory observations were conducted on movement and behavior of first instars placed on lower leaf surfaces within 2 hours of hatching. Larvae were observed individually and their position on the plant and movement were recorded for 1 hour after placement on the plant. Studies are not complete at this time. More extensive and intensive studies are planned for the laboratory and the greenhouse, this winter.

Results and Discussion

Spray deposition. The air curtain sprayer provided much more uniform coverage than conventional boom application. For all three crops, conventional boom application resulted in heavy deposition on the top surfaces of upper leaves, less deposition on top surfaces of lower leaves and very little material on bottom surfaces of leaves (Fig. 1). With air curtain application, bottom surfaces of leaves exhibited almost the same spray deposition as top surfaces. Lower leaves (including the bottom surfaces of lower leaves) were well covered. In addition to increased quantities of material on lower leaf surfaces, the air curtain application reduced varibility of deposition from leaf to leaf (Fig. 2).

Spray deposition on the bell and banana pepper fruit was significantly higher with air curtain application (Fig. 3). Deposition on the beans was not different between application methods. Variability in deposition on the fruit was less with air curtain application, compared to conventional boom treatment, for all three crops. S.E. to mean ratios for the boom application were: 0.26, 0.20, and 0.24, for bell peppers, banana peppers, and beans, respectively. Ratios for the air curtain application were: 0.18, 0.17, and 0.20, for bell peppers, banana peppers, and beans.

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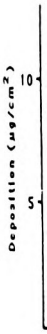
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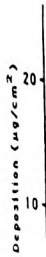
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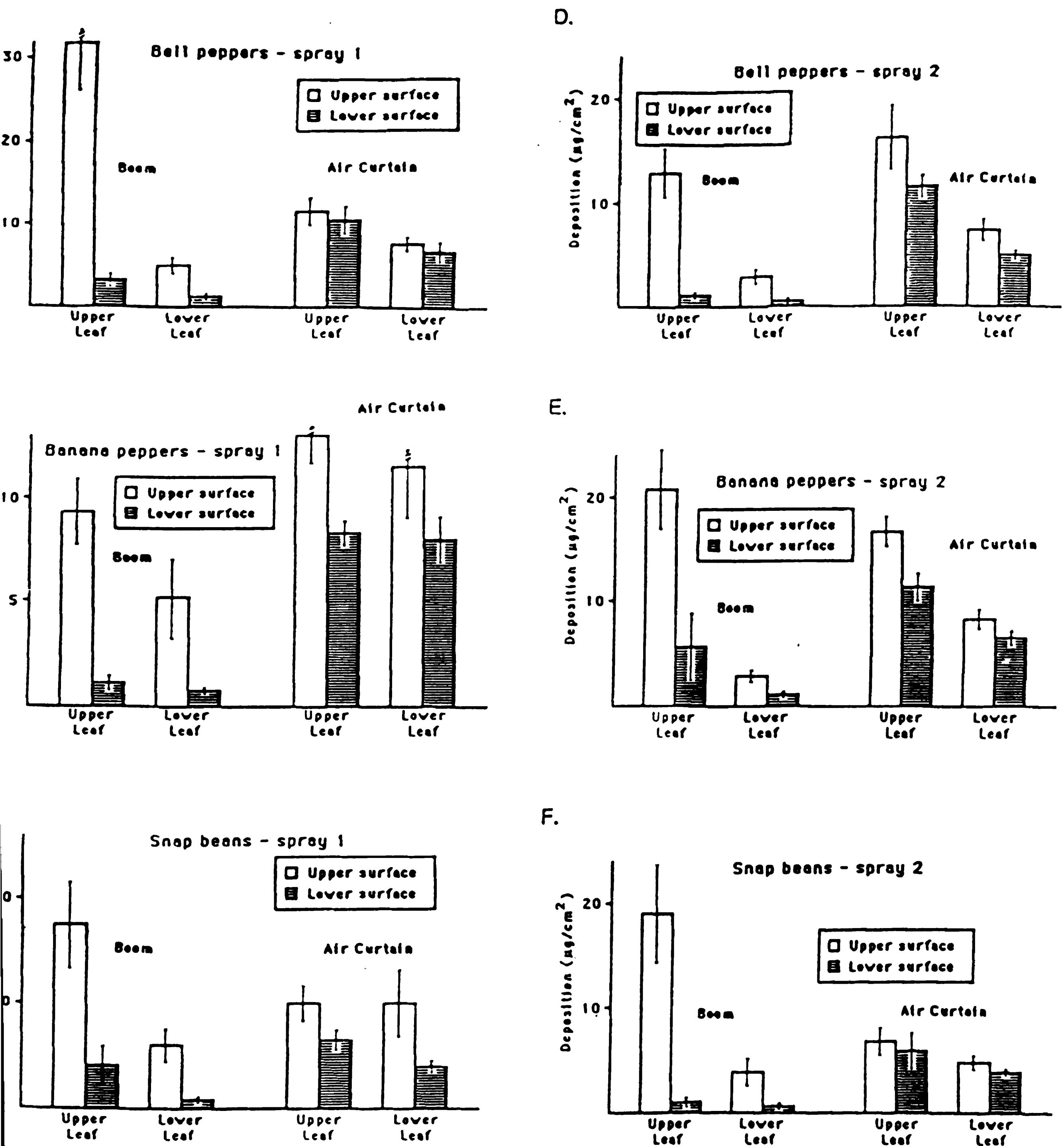

Figure 1. Spray deposition on top and bottom surfaces of upper and lower leaves of bell peppers, banana peppers, and snap beans on two treatment dates (means ± S.E.).

a. Bell peppers, first treatment date. b. Banana peppers, first treatment date. c. Snap beans, first treatment date. d. Bell peppers, second treatment date. e. Banana peppers, second treatment date. f. Snap beans, second treatment date.

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S.E./Mean Deposition

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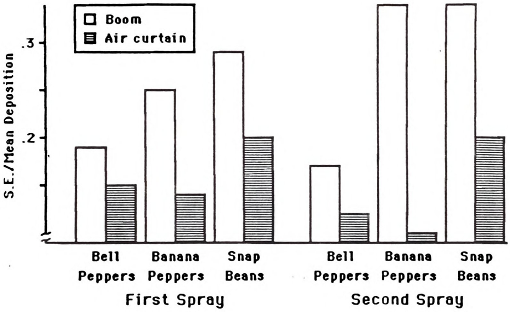

Figure 2. S.E. to mean ratios for spray deposition on foliage of bell peppers, banana peppers, and snap beans on two treatment dates.

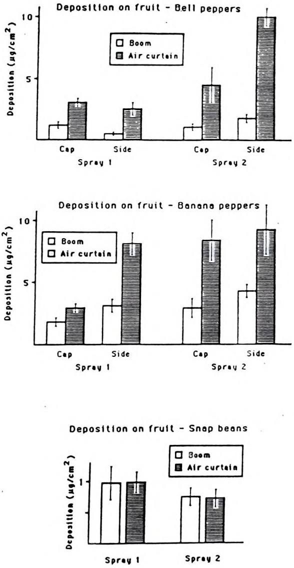

Figure 3. Deposition of spray on fruit of bell peppers, banana peppers, and snap beans (means ± S.E.).

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ECB populations. No egg masses were observed on the snap beans. Soon after artificial infestation with egg masses, numerous dead larvae were observed stuck on the leaf trichomes. Preliminary laboratory observations indicates virtually 100% of the first instars diedwithin 1 - 2 hours, trapped on the trichomes. Only 1 of 586 beans harvested from unsprayed plots was infested. Further studies will be conducted in the laboratory to estimate survival rate and factors affecting survival.

Mean number of egg masses observed on the bell and banana peppers on the three sample dates did not differ significantly with respect to treatment, although differences between sample dates and crop were apparent. Thus, no repellency of ECB females was occurring and the physical effects of treatment did not dislodge the egg masses.

ECB larval behavior. Preliminary behavioral observations indicate that mortality on snap beans is nearly 100%. Environmental conditions affecting trichome effectiveness, such as temperature, moisture availability (affecting turgidity), or dust on the leaves need to be evaluated.

Field observations on bell and banana peppers indicate that newly-hatched larvae are very active and spend considerable time moving about on top as well as bottom surfaces of the leaves. Some feeding on leaves and tunneling into leaf veins was also observed. This behavior has not been reported in the literature. Further observations on movement and feeding behavior will be required to predict the impact or interprete the results of improved spray deposition and the relative merits of different insecticides. For example, contact toxicity of some materials to larvae as they move across the leaf surface may be critical. Other materials with low contact toxicity or tight adsorption to the leaf surface, may act primarily through ingestion, as larvae feed on leaves, leaf midribs and bore into the fruit.

Green peach aphids. Aphid counts indicated higher populations in the fenvalerate plots, as reported in other studies (Table 1). Coccinellids were common in the plots. Some parasitism was also observed. Air curtain treatment had no apparent advantage over conventional boom treatment for green peach aphid control under the test conditions. Acephate probably has enough systemic activity to compensate for poor spray distribution. Fenvalerate has little or no activity against aphids. There did not appear to be any physical effect of the air curtain treatment (spray with water alone) on aphid numbers.

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Table 1.

Aphid densities in bell and banana peppers on 3 sample dates.

Treatment	Rate	Mean number of green peach aphids/leaf [a]					
		Bell Peppers			Sweet Banana Peppers		
		8/27	9/3	9/15	8/27	9/3	9/15
Acephate 75S (boom)	0.5 lb/A	0.0a	0.0a	0.0a	0.0	0.0a	0.0a
Acephate 75S (air curtain)	0.5 lb/A	0.0a	0.1a	0.0a	0.0	0.0a	0.0a
Fenvalerate 2.4EC (boom)	0.1 lb/A	11.7b	17.3c	11.5bc	4.0	8.5c	7.0b
Fenvalerate 2.4EC (air curtain)	0.1 lb/A	7.7b	8.2bc	24.9c	2.9	5.3c	4.0b
Water (air curtain)	-	7.2b	6.1b	5.6b	3.1	2.6b	3.6b
Untreated	-	7.9b	2.6b	12.7bc	1.3ns	0.7a	2.4b

[a]Means followed by the same letter are not significantly different from each other (SNK test of log transformed data, P<.05).

Harvest data. Significantly better control was obtained with the air curtain sprayer on bell peppers, compared with untreated or conventional boom treatment (Fig. 4). Differences were largest with fenvalerate, a local insecticide, and were smaller and not statistically significant with acephate, a systemic material. For banana peppers, levels of injury were low in all treatments and there were no differences between application methods. Levels of ECB infestation and injury in the snap beans (1/586 in the untreated plots) were much too low to determine any differences between treatments.

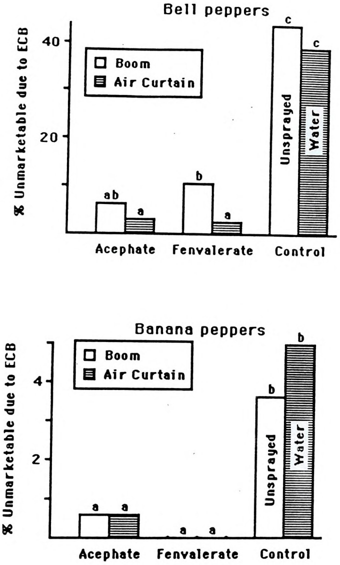

Figure 4. Loss of marketable fruit at harvest due to European corn borer.

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Conclusions

Results clearly demonstrate that air curtain application technology can be beneficial for controlling ECB in peppers. Although, acephate is thought to be systemic in action, it appeared that improved spray distribution still resulted in improved control. The effect of improved spray distribution was even more dramatic with fenvalerate, where systemic activity is not known to occur. Data clearly show interactions between application technology, type of insecticide used. The possible interactions between application technology, insect behavior and insecticide mode of action need further investigation. These interactions are undoubtedly not unique to the pepper/ECB system. Results have implications for a variety of pest/crop situations. Improved spray deposition and reduced variability may result in increased levels of control, increased reliability of control, and reduced pesticide use (and misuse) on a variety of crops, depending on insect behavior and type of insecticide.

APPENDIX 4

AIR CURTAIN UNITED STATES PATENT

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United States Patent [19]

Ledebuhr et al.

[11] **Patent Number: 4,659,013**

[45] **Date of Patent: Apr. 21, 1987**

[54] **SPRAY UNIT FOR CONTROLLED DROPLET ATOMIZATION**

[75] Inventors: **Richard L. Ledebuhr**, Haslett; **Gary R. Van Ee**, Williamston, both of Mich.

[73] Assignee: **Board of Trustees of Michigan State Univ.**, East Lansing, Mich.

[21] Appl. No.: **671,521**

[22] Filed: **Nov. 14, 1984**

[51] **Int. Cl.⁴** **A62C 1/12;** B05B 9/06; B05B 1/20; F04D 5/00

[52] **U.S. Cl.** **239/8;** 239/77; 239/166; 415/54

[58] **Field of Search** 239/77, 166, 167, 168, 239/223, 224, 8; 415/54

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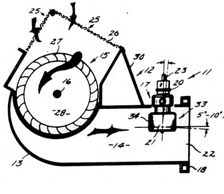
Primary Examiner—Andres Kashnikow
Assistant Examiner—Patrick N. Burkhart
Attorney, Agent, or Firm—Miller, Morriss & Pappas

[57] **ABSTRACT**

A spray unit and process for controlled droplet atomization in which a tangential vortex type fan with wide mouth passes operation from low-to-medium pressures at high volume, passes air through a throat in which controlled droplet atomization of spray material is being achieved prior to emission from the fan in a plane generally parallel to the flow of air. The flow of air sweeps the droplets into a parallel orientation in substantial avoidance of contact of the spray material on the fan parts, throat or mouth thereof and the airflow confines the continuous core of controlled droplets and projects the protected spray toward a target. The spray units are arranged to permit plural end-to-end adjacent articulated mounting with directional adjustment and flexible conduits for power at the individual units, including spray material delivery and power to lineal actuators and are carriage mounted on wheels for easy movement in the target area.

6 Claims, 11 Drawing Figures



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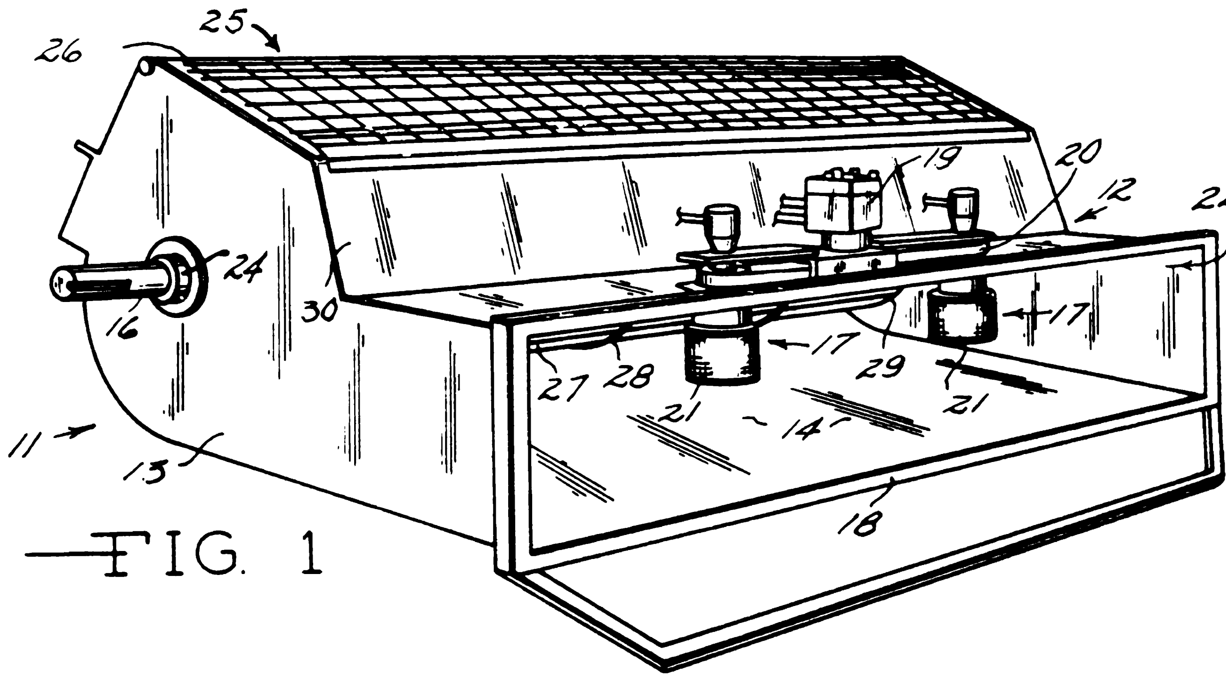

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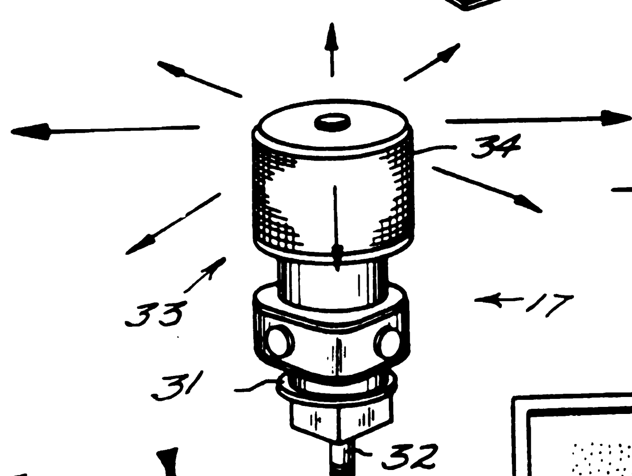

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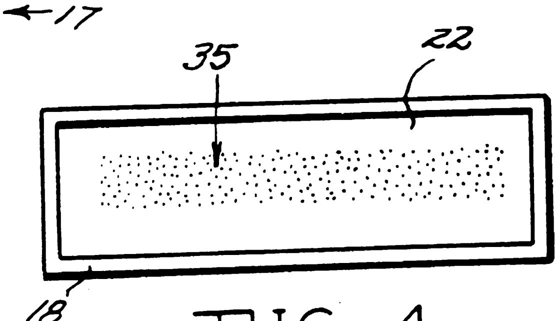

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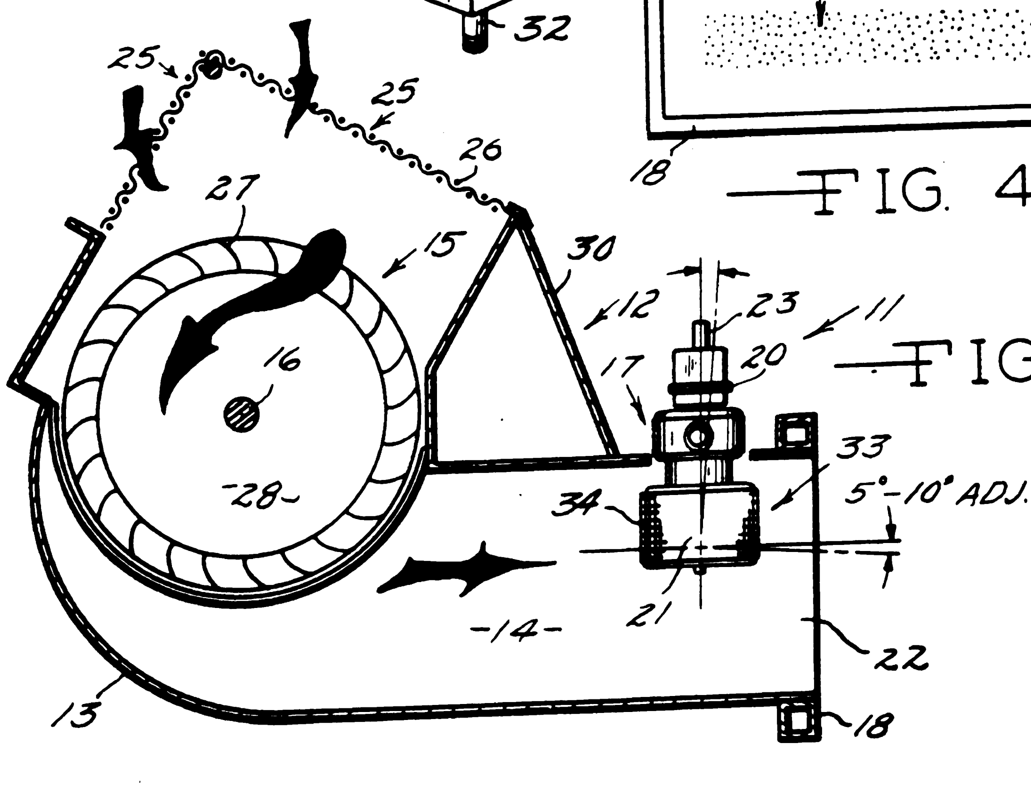

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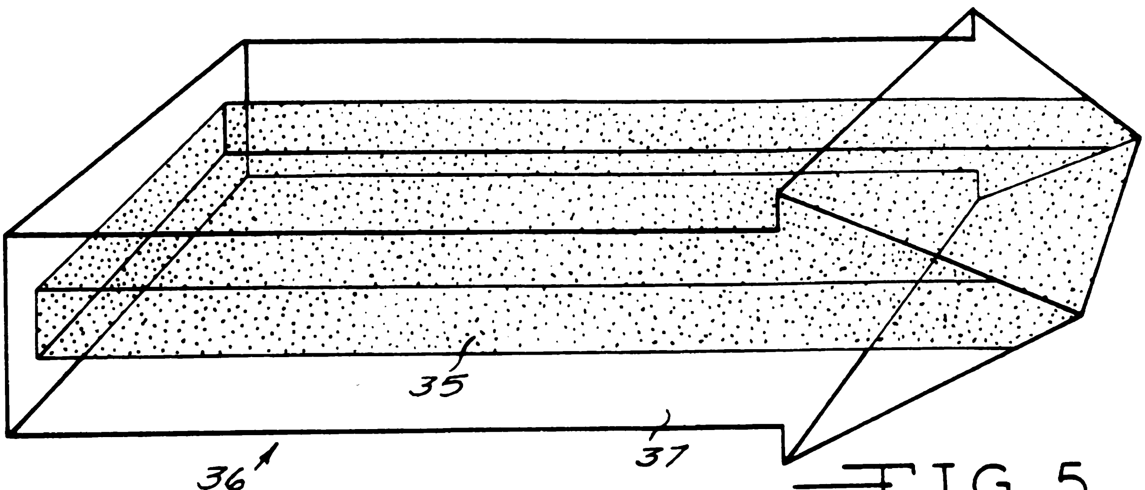

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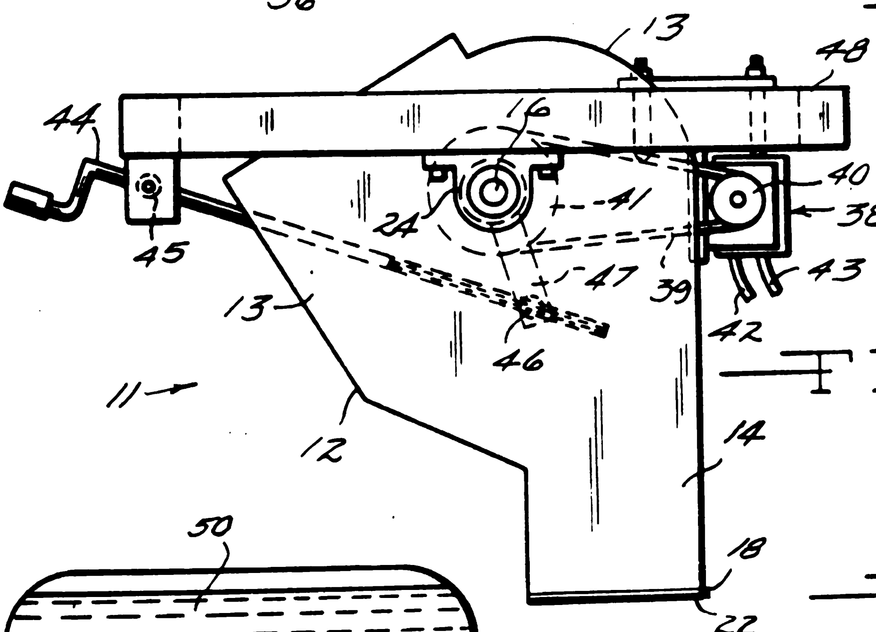

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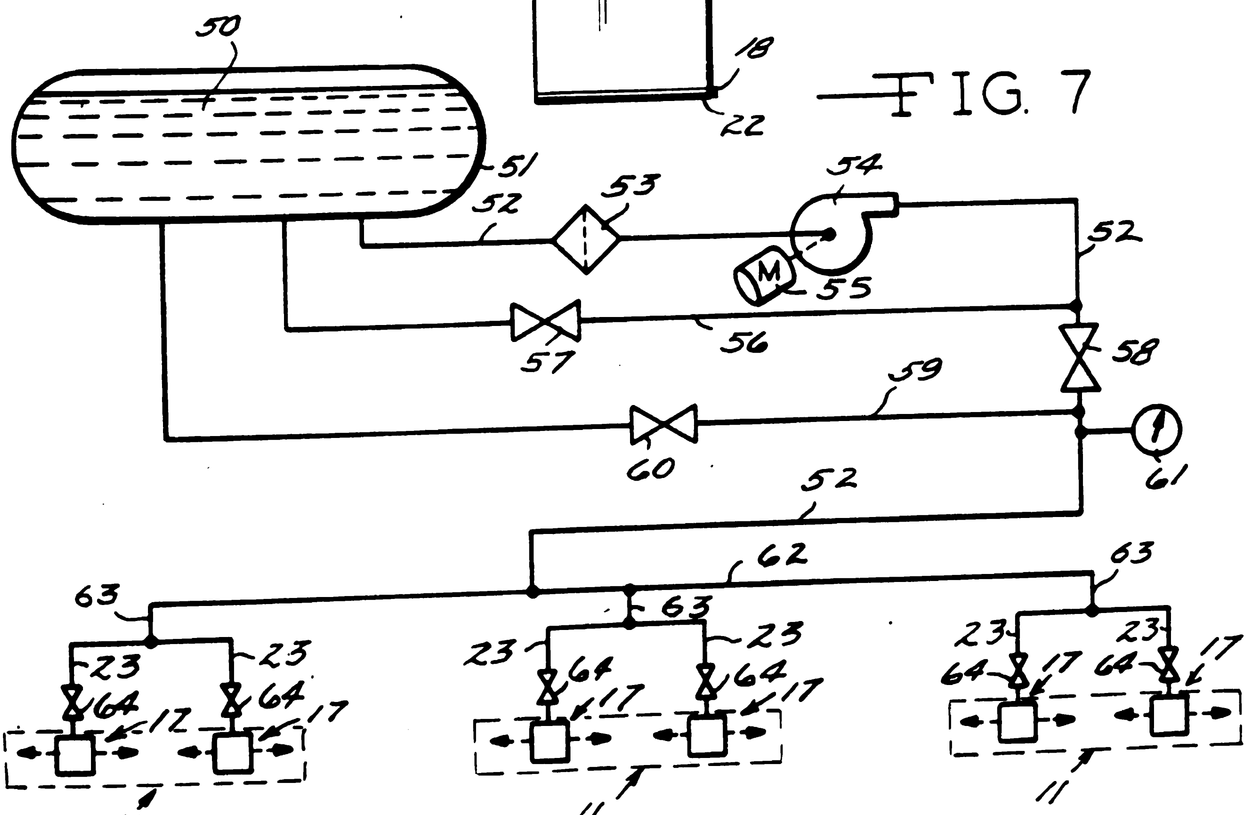

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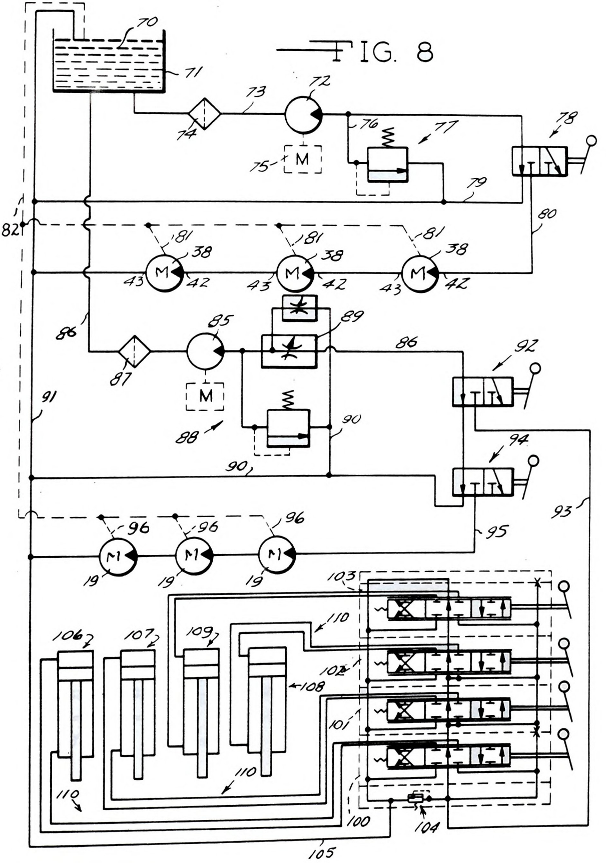
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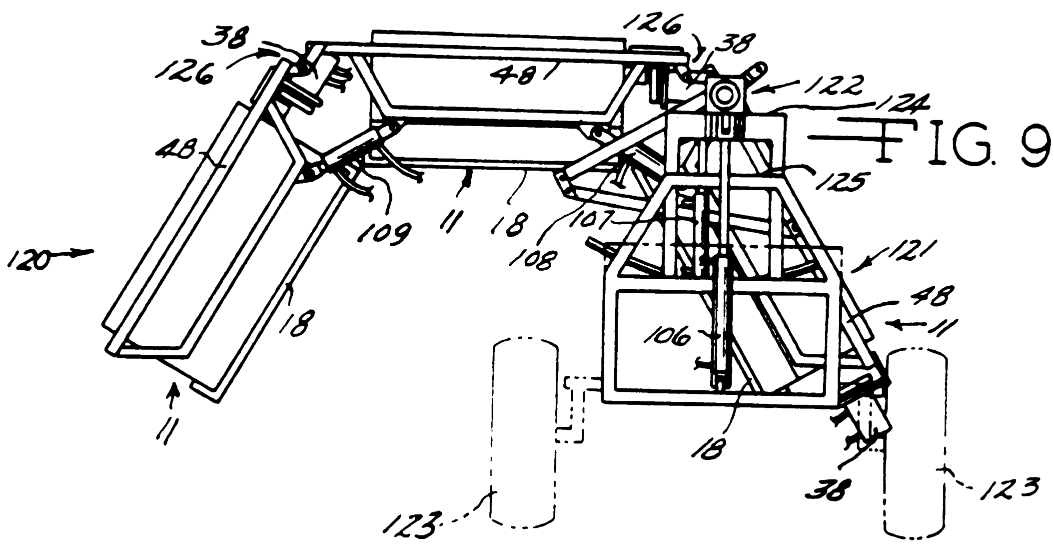
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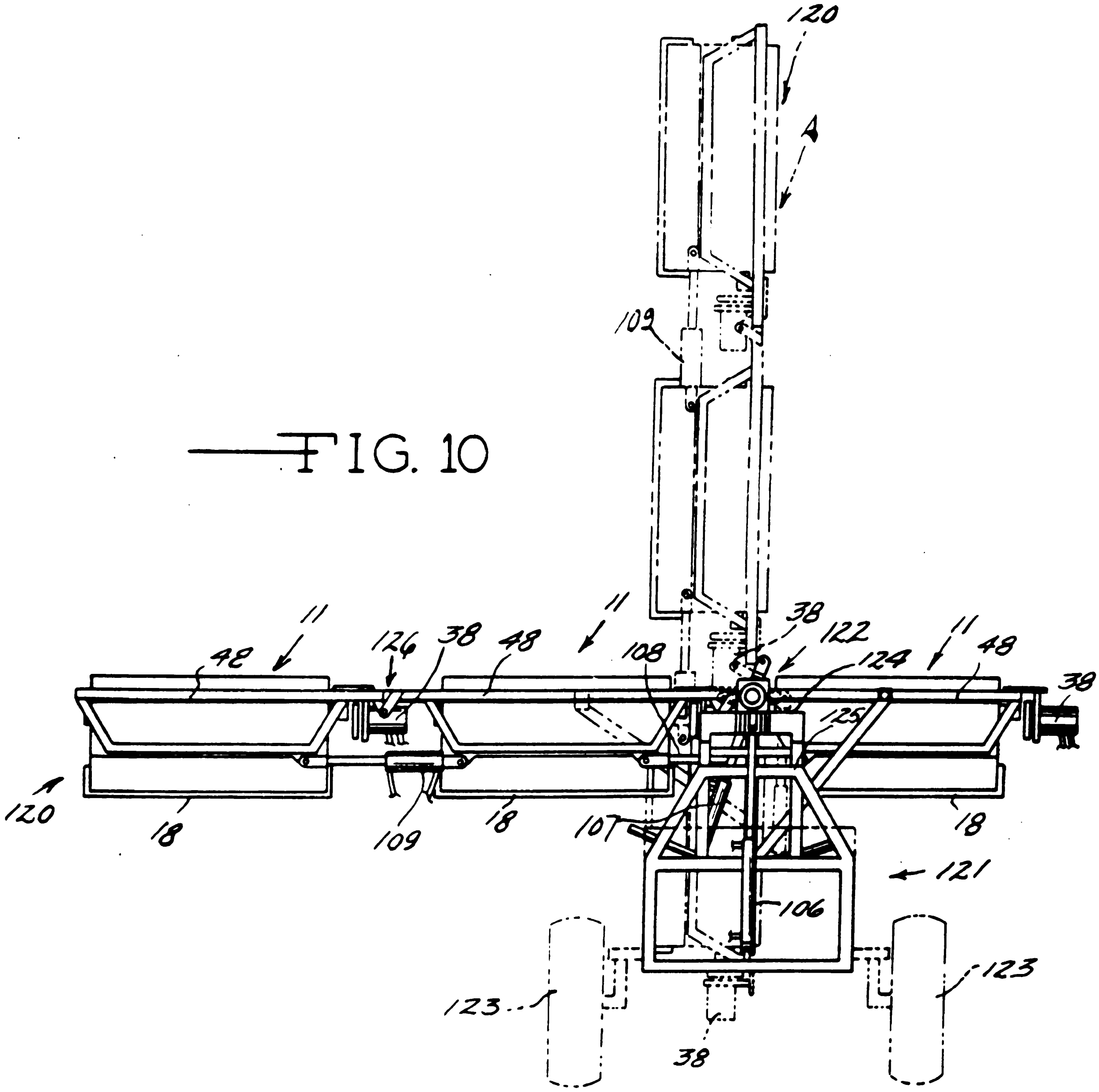
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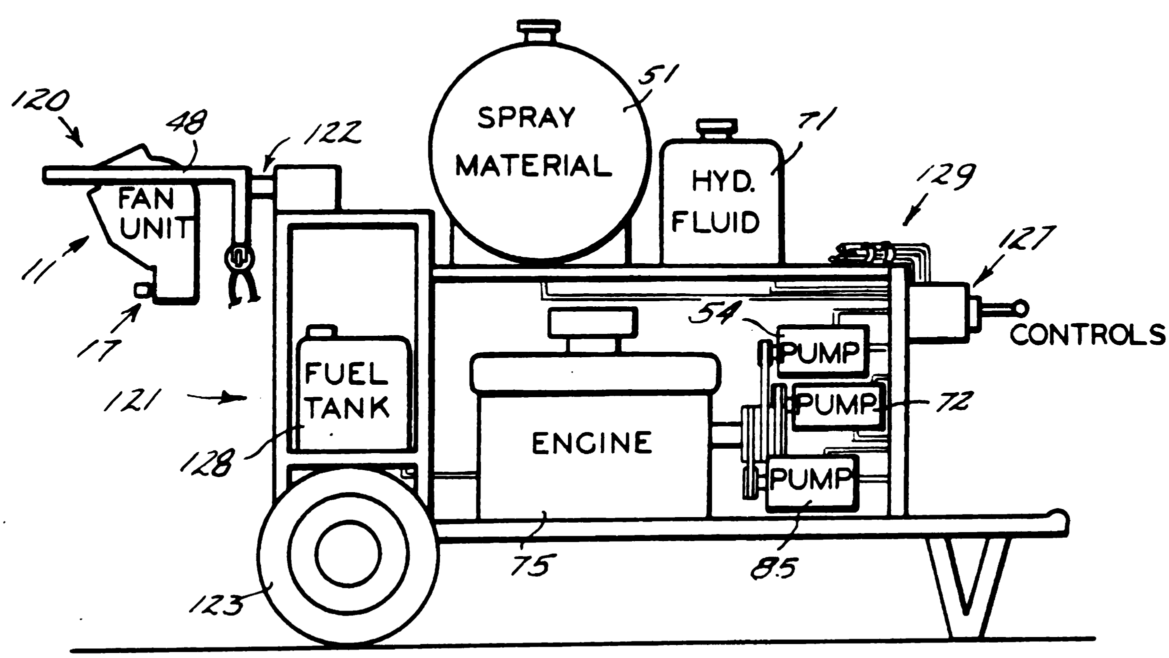
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FIG. 11

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SPRAY UNIT FOR CONTROLLED DROPLET ATOMIZATION

The present invention is an apparatus and procedure for driving or projecting controlled droplet atomization in agricultural applications. More particularly, the present invention is an apparatus facilitating improved low-to-medium velocity projection of spray generated by controlled droplet atomization of a chemically active ingredient as, for example, in fungicides, herbicides, bacteriostats, pesticides, plant nutrients and other materials applied to crops, ground and foliage for agricultural and horticultural beneficiation.

Controlled droplet atomization, as exemplified in the work of Bals in U.S. Pat. Nos. 3,063,644, 4,221,332, 4,222,523 and 4,225,084 and others, has been available to the agricultural industry for a number of years and allows spraying equipment to project selectively sized droplets ranging from micron size to heavy raindrop size in crop applications. While this step forward was heralded as a means to reduce the volume of active ingredient required for a given area, and it suggested ideal particle or droplet size matched to the particular use or crop and the active ingredient, its full potential has not been completely realized because the application to the fields and crops required a means to drive or project the generated and uniform sized droplet spray to the subject crops without wide dispersion and "float" (dispersion migration from the spray target) which was the consequence of the existing spray and delivery means employed in the projection of the controlled droplet generated product.

Relatively high velocity devices were used and the consequent quick diffusion of the controlled droplet spray caused spray to be extensively wasted on nonagricultural targets. Efficient spraying did not result and expensive sprays were lost despite the advantage of droplet size selections.

Aircraft frequently have used controlled droplet atomization or generating equipment in dispersing agricultural sprays. Improved results were obtained with controlled droplet atomization since the droplet size could be selected to match the optimum application as contrasted with the prior known random size droplet systems. However, the introduction of the sized droplets into the highly turbulent air minimized the effective application to the specific target.

A wide variety of high velocity fans, turbines and air nozzles have been used for blowing mainly transversely across or through the plane of droplet generation from the generating heads of the controlled droplet atomizers with a consequent random dispersion of the droplets or particles to the point of causing a substantial missing of the target plants. The random trajectories of the limited spray particles adversely diffused the spray at emission from the fans, blowers or turbines. The air employed was high velocity air seeking maximum entrainment of spray and extended projection of the active ingredient. While for specific usage (for example in orchards), some of these projection techniques of high velocity usefully extended the controlled droplet application, these high velocity processes and apparatus were regarded as falling short of maximizing contact of active ingredient to the crop target without substantial loss of active ingredient to the environment and damage to the crops. The high velocity application of active ingredient resulted in masking by the facing foliage and prevented application of spray to both leafy surfaces, for example. This was especially apparent in orchards but was equally apparent when projected vertically downward against row and ground crops, shrubs and bushes. Loss of active ingredient to the ground and nontargeted environment was ever present.

In the belief that better and more efficient projection could be achieved by earlier entrainment of the generated and sized droplets, others designed fans of extremely high velocity and bled the controlled droplets into the eye of the impeller or blower units so that the droplets were agitated and whirled by the fast-moving rotors and blades under fast turbulent air conditions in which a somewhat homogenous mix of turbulent air and particles were emitted from the sprayer. Whether from differences in specific gravity, or from centrifugal forces inherent in the system, an emission resembling an expanding fog occurred at the blower nozzles. In such systems, some of the spray material and active ingredient remained, after frictional projection in contact with the fans, turbines, blowers and ducts, and were found coating and caking the interior surfaces of the apparatus. No satisfactory solution was forthcoming and the high velocity projection of controlled droplet sprays was never the success originally anticipated in achieving the coverage and efficiency advantages projected for controlled droplet atomization.

The relatively low velocity, high volume, crossflow vortex fans, sometimes called tangential fans, have been known to us at least since the designs of Motier in 1892 for mine ventilation in France. Later, Eck and Laing, German inventors, extended the usage to fan heaters and small appliances. Typical was the work of Nikolaus Laing in U.S. Pat. No. 3,232,522. Yamamoto in U.S. Pat. No. 4,014,625 further extends the knowledge of the transverse flow fan. While finding application in agriculture as in harvesting, separation and processing applications, these high volume, low-to-medium velocity fans had never been considered for spraying. Conventional spraying had moved in the direction of high velocity entrainment and dispersion. The higher the particle speed, the better the "throw" at all particle size levels. This high velocity fascination ignored the consequent highly turbulent mixes of air and particles within the fast-moving mass. Freed from confinement, diffusion of the spray particles was inevitable at emission.

The present invention extends the controlled droplet atomization or generation to its fuller potential by a wholly nonobvious route using an apparatus in which the controlled droplet atomizers are combined with the crossflow vortex fan to entrain and columnize the drops by an achievement of encapsulation of the droplet product or mist in a moving wrapper of nonturbulent air assuring an orientation of parallel and nonrandom movement of the particles or droplets and with substantially no impingement of spray materials with the surfaces of the blower apparatus and ducting. The apparatus and the procedure of the present invention generates the uniformly sized droplets in a plane parallel to the ducted delivery of high volume, low-to-medium velocity air in a wide mouthed orifice or throat. The atomizers or generators are located upstream of the lips of the emission mouth or orifice of the crossflow vortex fan and the droplets are dispersed in complete avoidance of impingement with the ducting. The moving column of air, then, envelops the core of droplets, reorients all of the droplets in a columnar manner, and projects the column of air and protected uniformly and selectively

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sized spray droplets in a powerful high volume movement at selected low-to-medium velocity from the mouth of the sprayer unit. The combination of fan and controlled droplet atomization proximate to emission from the blower results in a simple, wide mouth spray unit useful in single and multiple unit forms to allow optimum control over droplet size, parallelism of droplet particles with columnar envelopment and amazingly sustained projection. Excellent control over fan performance within the low and medium velocities is obtained and this results in maximum field flexibility in adaptation, directionalizing and even while focusing the structure of the spray rig to accommodate particular crops, foliage, terrain, and speeds. A bonus effect is observed particularly in orchards where the sustained powerful columnar projection permits sudden dispersion of the parallel moving particles upon impingement with foliage, limbs and fruit to the point of achieving a fixing impact of droplets on all surfaces of the target and with minimal masking effect.

An improved extension of controlled droplet spraying is the consequence. The potential of attendant economies in use of minimum power, achievement of maximum coverage and improved deposition upon the targets using minimum active ingredients per unit of area is substantially advanced.

Hence, the objects of the present invention are in the achievements of improved effectiveness and demonstrable economy in spray practice; a better and simpler spray unit for projection of controlled droplet application; and extreme simplification of drive and controls with flexible usage of the units in the field for a variety of applications in orchards, vineyards, row crops, and close-to-the surface crops. Other objects and advantages will be increasingly obvious to those skilled in the art as the description proceeds.

GENERAL DESCRIPTION

In general, a spray unit is provided which can be directionalized and adjusted for substantially all agricultural spray utilization. The spray unit comprises a powered, high volume, low-to-medium velocity crossflow vortex fan, the fan having a delivery throat through which a high volume of low-to-medium velocity air moves in a parallel columnar manner. A controlled droplet atomizer is located in the delivery throat and is adjustably positioned to generate selective sized droplets of spray in a generating plane parallel to the airflow in the delivery throat and the column of air envelopes the droplets and protectively projects the droplets from the fan to a target or target area.

The combination of elongate rotor or impeller in a relatively simple scroll configured elongate case, as in the U.S. Pat. No. 3,232,522 to Laing, achieves at selected speeds of rotation a high volume delivery of air at low-to-medium velocities in which the air is moved through the fan structure in a parallel direction and orientation and without the intense turbulence produced by the other fans, particularly if the other fans or blowers are functioning at extremely high speeds and velocities. In the latter type fans, the air is in a turbulent condition as it is moved by such fans. In the crossflow vortex fan, the airflow is smooth, nonturbulent and with relatively even velocity through the entire column. Operation of such crossflow vortex fans requires substantially less power to drive than centrifugal and high velocity airflow generators and the quality of the columnar product of moving air is desirable in obtaining a projection of spray droplets.

The fan used in the present invention is a wide mouthed fan with rectilinear confinement of the parallel moving air from the impeller to create a distinct columnar movement of air at emission from the fan. The controlled droplet atomizers found in the throats of each fan are powered, can be individually controlled and are of a type generally seen in the work of Bals and others exemplified in U.S. Pat. No. 4,225,084. These controlled droplet atomizer devices rotate to provide a climbing movement of liquid material to be sprayed which moves up the rotating and usually grooved surfaces so that at emission from the controlled droplet atomizers, the particles or droplets are relatively and uniform at a selected size dependent upon selected rotational speed, characteristics of the atomizer and the material sprayed (such as viscosity, specific gravity and dilution) and the pumping rate of the actual spray materials or ingredients. The atomizers generate the droplets, sized as selected, in a planar pattern radially emanating from each atomizer and transverse of the principal axis of the atomizer. The emission from the atomizers may be tangential to the rotation of the atomizer but the plane of droplets, as generated, extends radially from the atomizer. The extent of projection of the droplets from the atomizer depends upon the volume and velocities of the air moving in the throat of the fan since the atomizers or generators project into the throat of the fan and depend thereinto. The location and number of atomizers in each fan throat is selected so that at the spraying speed of the fan the spray droplets do not impinge upon the fan surfaces and the fraction of projected droplets moving toward the impeller or rotor are reversed in flow direction and the rearwardly projected fractions join the airflow in a core-like manner within the moving air column. The airflow interfacing with the wide throat and mouth confine the spray particles or droplets from contact with the fan surfaces so as to project the spray with unusual power and definition from the wide mouth of fan toward the selected targets.

Plural of the spray units are attached to an articulating frame and boom structure in which each spray unit can be oriented for particular spray applications as, for example, horizontal disposition for ground and row crops, vertical and canted orientation for trees, orchards and bushes. Each unit is powered, each unit is movable in respect to the next. The boom structure of unit frames, articulating joints, and actuators, is operably mounted on a wheeled carriage. The carriage provides the element of portability for the spray units and carries the entire power pack, pumps, motors, spray reservoirs, tanks (fuel and hydraulic), and control elements needed to drive and adjust one or all of the spray units and to select the orientation of the units on the boom. Each spray unit is provided with adjustment means for directional rotation of the unit around the axis of the fan.

The preferred power means is hydraulic to provide good remote control and flexibility. A drive motor, for example gasoline or diesel, drives all of the necessary pumps for the spray material, for driving the motors for the atomizers, for the motors driving the fans, for the orienting cylinders used in articulation of the frame-boom structure and for auxiliary power as may be needed where the carriage is, itself, powered and steerable. The structure described is a towed structure. The hydraulic controls simplify and centralize the control

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location so that an operator can adjust substantially all units from a single station. Flexible lines and conduit connect the pumps to the motors and drive cylinders allowing selective control through attenuation of speeds, feeds and settings.

IN THE DRAWINGS

FIG. 1 is a perspective view of a spray unit for controlled droplet atomizers in accord with the present invention and indicating a tangential vortex crossflow fan with a pair of controlled droplet atomizers in the throat of the fan located in spaced-apart relation from each other and upstream of the mouth or wide emission opening of the fan.

FIG. 2 is a perspective view of a controlled droplet atomizer of the type seen in the fan of FIG. 1 and the radial lines with arrows indicate the generating plane for the radially generated and tangentially diffused controlled droplets substantially adjacent the diffusion end of the generator.

FIG. 3 is a full cross section elevation view taken through the fan and spray unit of FIG. 1 intermediate the controlled droplet atomizers and indicating the drive motor. This FIG. 3 also shows the tilt adjustment of the axis of the controlled droplet atomizers and their preferred position in the throat of the fan.

FIG. 4 is a full front view of the wide mouth or emission port of the fan under spray emitting conditions and indicating, somewhat schematically, the encapsulated planar core of the atomized droplets and the droplets substantially isolated from contact with the fan surfaces as the cushion of air projects and confines the sized spray particles.

FIG. 5 is a somewhat schematic perspective view shaded to indicate the projected core of droplets shielded from dispersion by the surrounding and projecting columnar air blast of the tangential fan after emission.

FIG. 6 is an end elevation view of the tangential vortex or crossflow fan element of the present invention secured to a boom frame and limitedly rotatable around the fan blade axis for adjustment of the direction of emitted air and controlled size droplets.

FIG. 7 is an hydraulic, partially schematic, diagram and indicating the delivery of spray material (active ingredients and carrier with diluent or additives) to the controlled droplet atomizers or generators.

FIG. 8 is an hydraulic circuit diagram indicating the powering of the vortex fan, the controlled droplet atomizer or generators and the selective control of the boom manipulating power cylinders for articulated orientation of the spray units.

FIG. 9 is a front elevation view of the carriage supporting the spray units of the present invention and with the units articulated by actuating cylinders as desired and all three units in individual frames articulated to form a desired targeting pattern for spray projection.

FIG. 10 is a front elevation view of the carriage supporting the spray units as in FIG. 9 but indicating the articulation or orientation of the machine boom to the vertical and horizontal extremes. From these positions the boom may be oriented parallel to the line of travel of the wheeled carriage and is then in travelling position.

FIG. 11 is a side elevational view of the carriage and spray rig of FIG. 10 and somewhat schematized to indicate the location of the principal elements in the power package and supported by the wheeled carriage.

SPECIFIC DESCRIPTION

Referring to the drawings and with first specificity to the FIG. 1, a spray unit 11 in accord with the present invention is first appreciated. The spray unit 11 includes a low-to-medium velocity crossflow or vortex fan or blower 12 with an outer scroll casing 13, a throat portion 14, a rotor or impeller 15 on drive shaft 16, one or more powered atomizers 17 of the controlled droplet type and the entire unit is supported on the frame 18. The frame 18 provides structural support and rigidity for the individual spray units 11 and permits plural units 11 to be hingedly articulated in end-to-end relationship and to be rotated on the axis of the shaft 16 and impeller 15 for further individual directionalization, as will be seen. Each unit 11 is separately driven by the motors (not shown) connected to the shaft 16 in FIG. 1. The atomizer drive motor 19 is secured to the casing 13 of fan 12 and drives the atomizer or spray generators 17 as by the drive belts 20 to rotate the drive shafts of the atomizers 17. As can be seen, the generator head portions 21 of the atomizers 17 project and depend (as shown) into the throat 14 of the fan or blower 12 and upstream of the wide mouth or emission opening 22 of the fan or blower 12. The axis of the atomizers or droplet generators 17 is adjustable, as will be seen, so that each atomizer 17 generates a radially disposed planar region of droplets in the throat 14 without droplet impingement on the walls of casing 13 or throat 14 of the fan 12 while exposed to the columnar movement of air from the impeller 15 and through the throat 14. As will be understood, the coluimn of air sweeps the droplets which are generated into a core or zone of droplets delivered out of the throat 14 and the wide mouth 22 in parallel entrainment and buffered from contact with the parts of fan 12.

The width of the mouth 22 is generally determined by the length of the impeller 15. The height of the mouth 22 is established to suit the capacity ranges of the fan 12 in respect to the high volume and selected low-to-medium velocities. The throat 14 is designed to receive the relatively nonturbulent air, as delivered from the impeller 15, and to level or equalize the velocities across the throat and through the planar zone of generated droplets to achieve the sweep of the droplets into a core and the core is given direction by the columnar movement of nonturbulent air proceeding parallel to the throat direction and the droplet generating plane and to and through the mouth 22.

The spray material reaches the atomizers 17 via the supply lines 23 connected to a spray reservoir remote from the unit 11. The impeller 15 is very simply positioned in the casing 13 turning and supported on bearings 24 located at both ends of the casing 13. Ingress of air to the impeller 15 is via the elongate air intake opening 25 and covered by the screen 26 which prevents entrainment of objectionable debris to the impeller 15. The opening 25 is sized generally equal to or exceeding the wide mouth 22. As will be seen, the rotor or impeller 15 runs the length of the case 13 and has the appearance of an open cylinder with the blades 27 being generally radially disposed and longitudinally cupped defining the outer perimeter and running the length of the rotor 15 with spaced-apart intermediate ring supports 28 intermediate the end disc plates 29. As the rotor or impeller 15 is turned, a vortex of air is generated substantially within the cylinder loosely defined by the blades 27 and is delivered by the blades 27 (in horizontal

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spaced-apart relation as indicated) into the throat **14** at low-to-medium velocities and at relatively high volumes. The screened opening **25** provides ample replenishment of air to the impeller **15**. The reinforcing plate **30** connected to the scroll case portion **13** and the top of the throat **14** (as shown) provides reinforcement and structural integrity to the housing or case **13** and throat **14** of the fan **12**. With the frame **18**, the plate **30** rigidifies and allows extension of the length of the units **11**. The stark simplicity of the fan **12** and unit **11** is readily appreciated and it is economical to build.

By reference to the FIG. **2**, a controlled droplet atomizer **17** is shown detached from the insertion into the fan **12** of FIG. **1**. The device is an atomizer in general accord with the teachings of Bals in U.S. Pat. No. 4,225,084 and others and the description thereof is incorporated here by reference. The atomizer drive shaft is drivably connected to the pulley or drive sheave **31** and this spins the internal mechanism with spray material feeding through the supply line **23** and through a conduit into shaft **32**. The spray material climbs a whirling spray generating structure internally to emission with the spray head **33** enclosed by an open mesh screen **34**. The droplets of spray sized by the speed and adjustment of the atomizer **17** are radially flung from the head **33** as indicated by the force arrows in a planar pattern surrounding the head **33**. The emanation of the droplets in the plane are primarily diffused adjacent the ends of the screen **34** most remote from the driven and feed end of the atomizers **17**. It will be appreciated that in FIG. **2** the atomizer **17** is inverted from the working position shown in the FIG. **1** where the driven and feed end of the atomizer **17** is outside the throat **14** while the generating head projects (as shown) into the throat **14** of the fan **11** so that generation of the planar radial mass of droplets is proximate to the midpoint between the upper and lower throat surfaces in the throat **14**. They are also located intermediate the ends of the casing **13** adjusted so that substantially no spray or droplets impact the walls of the casing **13**. As shown in FIG. **1**, the head **33** depends into the throat **14**.

The cross section of FIG. **3** assists in visualizing the interior of the fan **12** and the simplicity of the rotor or impeller **15** on its driven shaft **16** supporting the plural blades **27** by the end discs **29** and the intermediate ring supports **28** into which the blades **27** are fitted. As indicated by the flow arrows, air enters the case **13** through the opening **25**, penetrates the cylindrical array of blades **27** and is emitted into the throat portion **14** in a defined column moving parallel to the throat **14** in a relatively nonturbulent manner and at fairly uniform velocities across the throat **14** in relatively high volume where it entrains and envelops the droplets generated from the atomizers **17**, placing all droplets in a parallel orientation with flow and emitting the whole unit **11** as a moving column from the mouth **22**. The reinforcement aspect of the plate **30** to the fan **12** is better appreciated in the FIG. **3**.

In the FIG. **4**, the mouth **22** of the fan **12** is defined by the frame **18** in a rectangular lip-like manner. At emission, the droplet core **35** is seen buffered on all sides by the parallel moving air and the core **35** is swept along in the force column **36** leaving the mouth **21** of the unit **11**.

The FIG. **5**, somewhat schematized to illustrate the force column **36**, includes the continuously produced core **35** of selectively sized spray droplets. Surrounding the core **35** is an enveloping and protecting blanket of moving air **37**. The stylized arrow point indicates the direction of movement of the force column **36** and indicates the directionalizing integrity of the column **36** and especially the core of agricultural spray **35** as it approaches a target remote from the spray unit **11**. On impact with the target, the resistance breaks the column **36** and the core **35** is deflected in a manner to coat all surfaces of the target since the active spray droplets are accurate, placid and sized.

The force column **36** establishes a trajectory for the core **35** that is protective during projection of the core of droplets **35** and against premature dispersion and loss of active ingredients to the environment. The column **36** is powerful and well-defined by visual observation and the definition between ambient air and the moving column **36** is well-defined at distances of 45 to 50 feet from the mouth **22**. The particles of spray as uniform droplets are oriented in parallel paths carrying the inertial force and orientation upon leaving the mouth **22** of the spray unit **11** without serious dissipation. By contrast, prior art spray units cause random movement of particles without the protection of the blanket or cushion of air **37**. Their dissipation and diffusion starts at the mouth of the spray unit **11**.

The FIG. **6** is an end or profile view of one of the spray units **11** connected to its drive motor **38** which is drivably connected to the fan **12** as by the drive belt **39** which connects to the shaft **16** via the drive and driven pulleys **40** and **41**.

The motor **38** illustrated is an hydraulic motor and the powering hydraulic fluid is fed to and from the motor **38** through the hydraulic lines **42** and **43**. It will be observed that the location of the drive axis of the motor **38** is on a radius extending from the shaft **16** supported in the bearing **24** so that the fan **12** can be directionally rotated on the bearing **24** in selected directional orientation of the mouth **22** and throat **14**. This is achieved by the threaded crank arm **44** rotational in the pivotal socket **45** and operatively threaded into the pivotal nut **46** on rocker arm **47** which is an extension of the case **13** at the shaft **16** whereby the entire fan **12** is selectively rotatable on the frame or base **48**. The frame or base **48**, as will be seen, admits of hinged articulation as between adjacent spray units **11**.

It will be appreciated that, while hydraulic motors **38** are preferred, they may be directly coupled to the shaft **16** for driving the fan **12** or they may be electric, pneumatic, or internal combustion type motors so long as they are speed controllable and accommodate flexibility in the power transmission, as will be seen. Similarly, hydraulic motors are preferred for driving the atomizers **17** (not shown in FIG. **6**). One hydraulic motor **19** can drive plural atomizers **17** for controlled droplet generation in each unit **11**. It will be understood that electric, pneumatic, combustion engine or other power means can also be used without departure from the spirit of the present invention.

By reference to the FIG. **7**, the delivery of the agricultural spray material **50** to the atomizers **17** can be appreciated as paired in three separate spray units **11**. A spray reservoir **51** is provided. The spray material **50** is in the form of a liquid containing dispersed chemical or biological ingredients in a suitable solvent or vehicle such as water, oils, or other liquid mixes of materials in accord with desired application as fungicides, insecticides, pesticides, fertilizers, systemic addatives, growth modifiers, or the like, as found requiring spray application in agricultural and horticultural environments.

From the reservoir **51**, the main delivery line **52** runs to and through a filter **53** and to the intake side of a pump **54** driven by a motor **55**. The pump **54** delivers the spray material **50** from its high pressure side continuing in the main line **52** to a return bypass line **56** which includes the valve **57** and back to the reservoir **51**. The main line **52** continues through the shutoff valve **58**. When the valve **58** is closed, the spray material **50** can circulate back to the tank or reservoir **51** provided the bypass line **56** is open at the valve **57**. After valve **58**, the main line **52** connects with a second valved bypass return line **59** which is also operably connected in flow relation to the reservoir **51**. The valve **60** can be regarded as a throttle valve adjusting the working pressure in the continuing main line **52**. A read-out gauge **61** allows monitoring of the pressure in the main line **52** when delivery of the spray material **50** extends to supplying the atomizers **17**. The main line **52** distributes the spray material to the header line **62**. The header line **62** and connecting tubing **63**, to the supply lines **23** of the atomizers **17**, are flexible to permit directing adjustment of the units **11** and articulation of the spray units **11** as between each other, as will be seen. Thus, volume and pressure control of supplied spray material **50** is very simply achieved to optimize selection of droplet size when combined with driving speed of the atomizers **17**. The header **62**, tubing **63** with the supply lines **23** are arranged to provide uniform flow of spray material **50** to all atomizers **17**. Valves **64** at each atomizer provide for fine tuning or shutoff of each atomizer **17**. While the valves and monitoring gauges constitute the control means, the valves, as described, may be automated and remotely controlled and the remote control may include a selectively programmable system as is well known in the control art and the manual valves, as shown, are schematic located and operative.

Referring to the FIG. **8**, the preferred hydraulics of the plural spray units **11** are easily appreciated to drive the fans **12**, to drive the motors **19** for atomizers **17**, and to control the articulating of the spray units **11**, as will be seen. This achieves extended flexibility by using flexible supply lines which can accommodate the directionalization of the units **11** and the articulation as between them. Hydraulic fluid **70** is provided in tank **71** which is open to the atmosphere. The tank **71** is in flow communication with the high pressure pump **72** through the hydraulic main line **73**. The pump **72** and circuit is protected by the filter **74**. The motor **75** is operably and drivably connected to the pump **72**. The hydraulic fluid **70** moves from the pump **72** past the valved bypass line **76** which returns to the tank **70** in accord with the selectively set pressure relief valve **77**. Otherwise, the main line **73** delivers the fluid to the two-way valve **78** shown dumping to tank in the bypass line **79**. Upon shifting the valve **78**, the hydraulic fluid **70** enters the drive line **80** and thence to and operably through the hydraulic fan motors **38** through their hydraulic supply and return lines **42** and **43** shown as serving three of the spray units **11**. Then the hydraulic fluid **70** returns to the tank **71**. Case drain vents **81** on each motor also dump to tank at atmospheric pressure through vent return line **82**.

Motor driven pump **85** utilizes the same tank or reservoir **71** and receives hydraulic fluid **70** from the tank connected actuator main line **86** passed through the filter **87**. The pumped hydraulic fluid **70** runs in the main **86** to and through a pressure controlled bypass **88** and a variable pressure flow control valve **89** with pressure controlled bypass **90** to tank **70** through return line **91**. The pressure controlled fluid **70** in the main **86** goes, then, to the two-way control valve **92** for optional selected routing to the lineal actuator line **93** or the valve **94** in control of the atomizer drive motors **19**. With the valve **94** positioned as shown, the fluid **70** is bypassed through return lines **90** and **91** to the tank **71** and the atomizer motors **19** do not operate. However, by shifting the two-way valve **94**, the motors **19** are actuated through motor line **95** and fluid **70** is returned to the tank **71** through the return line **91**. The case drain vent lines **96** dump to the atmospheric pressure line **82** to tank **71**.

The linear actuator supply line **93** feeds to the four banked, three-position, four-way valves **100**, **101**, **102**, and **103** and the pressure relief valve **104** serves as a dump to tank **71** from the actuator supply **93** and the return line **105** extending to the tank return line **91** is also a collector for dumping fluid **70** from each of the valves **100**, **101**, **102**, and **103**. As will be seen, each of the actuators **106**, **107**, **108**, and **109** are double-acting cylinders. The actuator **106** is for transport positioning and vertical tilt and is served by the control valve **100**. This unit erects the entire boom of plural units **11**, as will be seen, or lowers it into horizontal and carrying position. The actuator **107** is for articulating rotation of the first one of the three spray units **11** in a boom and the actuator **107** is controlled by the manipulation of the valve **101**. The actuator **108** is for the third spray unit **11** articulation and its operation is controlled by the valve **102**. The actuator **109** is for articulating movement of the second spray unit **11** relative to boom rotation by movement of the first spray unit **11** and its function is controlled by the valve **103**. The fluid delivery lines **110** reaching from the respective valves **100**, **101**, **102**, and **103** to actuators **106**, **107**, **108**, and **109** are flexible hydraulic lines for easy bundling and routing to the specific use locations. All valving shown in the FIG. **8** may be directly or remotely controlled and the controls may be computer programmed for selected settings, as desired. As shown, the valves are manually and selectively controllable.

In FIGS. **9** and **10** the boom **120** (comprising plural connected spray units **11**) is appreciated and mounted on a wheeled carriage **121**. It will be readily appreciated that units **11** are adjustable in their relationship to each other and around each fan axis. Each fan **12** in each spray unit **11** is individually driven by the motors **38** and the atomizers **17** are powered by the motors **20** (previously described). In the FIG. **9** the spray units **11** are directed downwardly in a converging array, as shown, and the actuators **106**, **107**, **108**, and **109** are shown as used in manipulating the entire boom **120** together and each of the units **11** in the boom **120** being movable relative to each other. The main boom pivot **122** is centered between and over the wheels **123** and on the carriage **121**. The actuator **106** extends and lowers the entire boom **120** from and onto its carrying position resting on the rest bars **124** and **125** of the carriage **121**. This actuator **106** levels the boom **120** to horizontal position (full line in FIG. **10**); to vertical position A (phantom line in FIG. **10**); and to any selected intermediate position. In carrying position, the boom **120** is turned 90° from the horizontal position (FIG. **10**) to a substantially horizontal carrying position with the boom **120** extending (not shown) longitudinally of the carriage **121**. The articulating actuators **107**, **108**, and

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109, previously described in the circuit diagram of FIG. 8, act to move the units 11 in the boom 120 on the respective hinges 126 in respect to each other so as to achieve any selected directional deviation within the boom 120 as between full horizontal and full vertical (A) orientation. This is especially useful in working with various agricultrual subjects as surface crops (horizontal), bushes and shrubs (arcuate) and orchards (vertical and focused (as converging) deviations from vertical). The conduits of hydraulic fluid and spray material supply lines are flexible and move to accommodate selected position adjustment as can be appreciated. In the FIGS. 9 and 10, the carriage 121 is intended for towing. It is within the contemplation of the invention that the units 11 may be on a self-powered and steered carriage and where the single operator would select the desired adjustments and directionalization would occur from an operator console within a cab, for example.

The FIG. 11 indicates the character of the carriage 121 in side elevation to indicate that in the FIGS. 9 and 10 the carriage 121 carries a power plant 75 which powers the pump 54 (for spray delivery), the pump 72 (for driving the vortex fans 12 in the units 11), and the pump 85 driving the atomizers 17 and the actuators 106, 107, 108, and 109, as required. A control console 127 serves the power plant 75 and substantially all of the adjustment means for the spray units 11 as set out in the hydraulic diagrams in FIGS. 7 and 8. The fuel tank 128 feeds the internal combustion engine 75. Bundled flexible conduit 129 runs from the console manifolds to the remotely driven components, as described.

In operation, the spray units 11 perform well in the generation and projection of spray material in a manner not previously available at low-to-medium pressures and at high volumes. They minimize losses to the ambient surroundings and thus extend the coverage of the spray material to agricultural subjects or targets. The spray units 11 are light in weight and thus admit of ganging or plural boom groupings, each unit 11 being individually adjustable. Since the low pressure vortex type fans of the units are simple in construction, the vortex or crossflow fans 12 are economical to manufacture and economical to operate and repair. Because the parallel orientation protects the enveloped sized droplets and avoids impingement on the fans 12, throats 14, and mouths 22, the projection without waste to the target is extended efficiently. Finally, the impact of the spray at the target area is such as to surmount masking and the targets are coated on all sides, for example, allowing a row of trees in an orchard to be sprayed from one side and with coverage as if the trees had been sprayed on both sides. Droplet sizing and delivery conditions are easily adjusted to accommodate the field encountered conditions and optimum performance.

Having thus described our invention and the preferred embodiment thereof, others may perceive improvements, changes and modifications therein and such improvements, changes and modifications within the skill of the art are intended to be included herein, subject to the limitations of our hereinafter appended claims.

We claim:

1. A spray unit for controlled droplet projection comprising:
- a powered, high volume, low-to-medium velocity crossflow vortex fan;
- a delivery throat in said fan through which high volume, low-to-medium velocity air moves in a parallel columnar manner; and
- a controlled droplet atomizer located in said delivery throat and generating a core of droplets in a plane substantially parallel to said airflow in said delivery throat, the air enveloping said core of droplets and projecting said core of droplets from said fan.

2. A spray unit for controlled droplet projection comprising:
- a powered, high volume, low-to-medium velocity fan;
- means included in said fan for diminution of turbulence prior to columnar movement and emission whereby air moves in a substantially parallel uniform direction at emission; and
- at least one powered, controlled droplet atomization structure in said fan generating controlled droplets of spray material in a plane generally parallel to the columnar movement of air whereby said droplets are entrained, propelled and projected from said fan at selected low-to-medium velocities carried as a core of droplets in substantially parallel nonturbulent manner by said air.

3. A spray unit for controlled droplet projection comprising:
- a low-to-medium velocity, high volume powered, wide mouth fan providing a columnar, high volume, medium velocity nonturbulent flow of air; and
- at least one powered, controlled droplet atomizer oriented in said fan and adjacent said mouth thereof and generating droplets of spray in a plane substantially parallel to the column of substantially nonturbulent moving air whereby said generated droplets in said air in avoidance of impinging against the interior surfaces of said fan and said droplets are oriented, entrained, surrounded, propelled and projected from said fan at selected low-to-medium velocities with said air.

4. In the structure of claim 3 wherein plural of said fans and included atomizers are supported on an hydraulically manipulated articulated boom and said boom is operably and directionally connected to a movable carriage which includes a power source, a spray reservoir and flexible conduit means connected to and driving said fans and said atomizers, and means adjusting the drive speed of said fans and said atomizers in control of droplet size and the flow of spray material to said atomizers.

5. A multiple unit spray rig for directionalized, controlled droplet projection at low-to-medium velocities comprising:
- plural spray units each comprising a powered, wide mouth, high volume, low-to-medium velocity crossflow vortex fan and each of said spray units having at least one powered, controlled droplet atomizer in the throats of each of said fans, and between the impeller thereof and the mouth of said fan, said atomizers adjustably mounted to generate droplets of spray material at controlled sizes in a plane substantially parallel to and within the column of air moving through said throat of said fan;
- a frame connected to each of said units, each frame having hinge means therebetween and adjusting means on each frame connected to said fans selectively positioning said fans directionally around the axis of the impeller of each of said fans;

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power means on each of said frames and operably connected to respective of said fans;

power means between said units and acting at each said hinge adjusting the alignment of said units from parallel end-to-end relation to an angular articulated displacement permitted by said hinges and said power means;

extendable and retractable piston means connected operably to said frames and acting on all of said power means, frames, and units as a boom manipulable within the limits of said piston;

a wheeled carriage supporting said units for transport and use and including equipment such as motors, pumps, hydraulic fluid source, spray material reservoir, fuel supply and control means for said units, said booms and said spray materials and conduit lines from said equipment to operative connection at said fans, said atomizers and said power and piston means; and

flexible conduit lines from said equipment to said units, atomizers, piston and power means between said units in full control of droplet size, spray volumes, and fan velocities.

6. A spray procedure for projecting controlled droplets comprising:

removing turbulence from a column of high volume, medium-to-low velocity air; and

passing said column of air over, under and around a plane of selectively controlled droplets of active spraying ingredients, the plane being controlled parallel and central to the column of air whereby said droplets are prevented from contact with air moving apparatus and are moved in said column of air parallel to said flow and said air enveloping said droplets, said droplets carried as a core in said low velocity, high volume column of air.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,659,013

DATED : April 21, 1987

INVENTOR(S) : Richard L. Ledebuhr, Gary R. Van Ee

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

FOREIGN PATENT DOCUMENTS:

411599, 4/1966, Fed. Rep. of Germany should read ---
411599, 4/1966, Switzerland ---

Column 6, line 32 "coluimn" should read --- column ---

Signed and Sealed this

Eighteenth Day of August, 1987

Attest:

Attesting Officer

DONALD J. QUIGG

Commissioner of Patents and Trademarks

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