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AN ANALYSIS OF SOME SPRAY FACTORS IN
CONTROLLED POROSITY LOW VOLUME AND CONVENTIONAL
GROUND ORCHARD SPRAY SYSTEMS

presented by

Henry William Hogmire, Jr.

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Entomology

Angus J. Howitt
Major professor

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AN ANALYSIS OF SOME SPRAY FACTORS IN CONTROLLED POROSITY LOW VOLUME AND CONVENTIONAL GROUND ORCHARD SPRAY SYSTEMS

By

Henry William Hogmire, Jr.

A DISSERTATION

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ABSTRACT

AN ANALYSIS OF SOME SPRAY FACTORS IN
CONTROLLED POROSITY LOW VOLUME AND CONVENTIONAL
GROUND ORCHARD SPRAY SYSTEMS

By

Henry William Hogmire, Jr.

A controlled porosity low volume spray system generally transported more pesticide to semi-dwarf apple trees than a conventional spray system, however, the low volume spray distribution was usually less uniform. The use of a water soluble dye to study spray transport revealed that the uniformity of low volume spray distribution could be improved by increasing air velocity and, to a lesser extent, droplet size. The low volume spray system was generally as effective, if not superior to the conventional system in the level of pest control achieved.

An analysis of the spray pattern from each of 2 Beecomist sleeves on the low volume spray system revealed that the position of the spinning sleeves should be altered when spraying different size trees in order to optimize spray distribution and maximize spray deposition.

The mean tree deposit in standard size trees was 44 and 47% less than that delivered to semi-dwarf trees by the conventional and low volume spray systems, respectively. The differences in mean deposit between tree sizes is largely due to low deposits in the center region of standard size trees which had a denser foliage canopy and were wider in diameter than semi-dwarf trees.

Beecomist spinning sleeve nozzles produced much narrower, smaller droplet spray spectra than those produced by conventional nozzle types.

Conventional spray droplet distributions which passed through foliage contained a greater proportion of droplets in smaller size classes than distributions obtained in an open environment. The fact that this difference was practically non-existent, with the low volume spray system supports the use of small droplet sprays for efficient pesticide transport into foliage habitats.

The porosity and construction material has virtually no effect on the spray droplet spectra produced by porous Beecomist sleeves. The spray droplet spectrum produced by a perforated stainless steel sleeve is quite similar to that of the porous sleeve types.

Spray droplet spectra are greatly influenced by the rotational velocity of spinning sleeves and spray formulation, and to a lesser extent by flow rate and air velocity.

The efficiency of a droplet impingement harp for sampling spray spectra depends on the wire size used, the droplet size being delivered and velocity of droplet travel.

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A very special thanks is extended to all the staff at the Trevor Nichols Experimental Farm during the past 3 years, without whose help this work would not have been possible.

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INTRODUCTION

The production of marketable fruit is heavily dependent upon the airborne transport of pesticides for suppressing pest populations. The needless application of pesticides ("insurance" sprays) plus the fact that only a small proportion of the applied dose reaches the target makes pesticide use both an economically and ecologically inefficient tool for pest management (Von Rumker et al. 1975, Steiner 1969). Despite the fact that spray application accounts for a sizeable percentage of fruit production costs (41% for apples in 1962) past concern was focused on the pest suppression effectiveness of a pesticide rather than on the efficiency of the application process (Brann 1964). As a result of the continually increasing costs of pesticides and energy required for their application, as well as stricter regulations imposed by governmental agencies, increased emphasis has been placed on the efficiency of pesticide application.

Research has resulted in a reduction of pesticide usage through better timing of spray applications (Brann 1964), and the development of integrated pest management (IPM) programs (Croft 1975, USDA 1974). A more efficient use of pesticides, however, through improvements in spray application methodology has been rather limited. Throughout the developmental history of air assisted spraying (outlined by Fleming 1962) the only major improvement has been the gradual conversion from dilute to concentrate spray application. This reduction in spray volume has reduced the expenditure of time and labor in spraying operations, and conserved precious pesticide by minimizing loss due to run-off (Brann and Gunkel 1951, Williams and McMechan 1961, Brann et al. 1967). Although the development of concentrate spraying improved the efficiency of pesticide application, other facets of spray methodology including equipment design remained virtually unchanged.

Improvements in spray application methodology rely on a thorough understanding of the factors inherent in application equipment responsible for pesticide transport to the target. The efficiency with which a lethal pesticide dosage is delivered to the target organism is primarily dependent upon the sprayer's air stream and the size of the transport agent, the spray droplet, as well as interrelationships between these 2 factors (Fleming 1962). The air velocity and volume requirements for efficient pesticide transport and deposition depend upon the spray system, the size of droplet being transported, the nature of the spray target, and the environmental conditions encountered during spraying.

A pneumatic nozzle requires a higher air velocity than a hydraulic type because the liquid is atomized by the air stream rather than by pressure (French 1942). It is believed that the pesticide transport efficiency for a given spray system depends upon a proper balance between the volume and velocity of air delivered (Ingerson and Irons 1952, Potts et al. 1950, Garman 1953). Fleming (1962) concluded that the amount of spray transported over a given distance is proportional to the horsepower of the air stream, and that the proper ratio of air volume to velocity is dependent upon droplet size. For a given air energy, the larger the droplet the greater the initial air velocity which will be required to keep it airborne for a given distance. In studying the distribution of sprays in apple trees as delivered by 3 sprayers (with different air velocities and volumes but equivalent energy) Randall (1971) discovered that the uniformity of distribution throughout the trees increased with increasing air volume. Hall et al. (1975) discovered that sprayers delivering lower volumes of air tend to lose their air velocity more rapidly as the distance from the outlet is increased. This reduction in air velocity also influences the uniformity of spray distribution since a certain minimum air velocity is needed to deflect canopy foliage to allow for droplet penetration and impingement. In a survey of grower practices in Ontario apple orchards, Fisher et al. (1976) discovered that the air stream's effect on spray coverage density and uniformity depended upon tree height, spacing, foliage density, and wind conditions.

Out of the concern for increased insecticide efficiency has arisen the concept of the biological optimum spray droplet size. According to Himel (1969a), "optimum-size droplets are those sizes small enough to be produced in maximum numbers for maximum coverage and large enough to have an optimum critical impingement velocity for optimum impingement on the target insect." In the use of space aerosols, Mount (1970) found that only droplets from 5-25 um diameter impinged efficiently on adult mosquitoes. Hadaway and Barlow

(1965) discovered that only 10-30 um droplets penetrated foliar vegetation and impinged on the wings of tsetse flies. Himel and Moore (1967, 1969) indicated that insecticide spray droplets less than 50 um in diameter impinged with greatest efficiency on target insects in forest and cotton ecosystems. More recently, Spillman (1976) has shown that the catch probability for most flying insects reaches a maximum for droplets of 10-30 um in diameter. Statements up to this point concerning optimum droplet size have pertained to the impingement of droplets on insects at the time of application. Chemical control is also achieved secondarily through pest contact with pesticide residues. The atomization of a given volume of liquid as a fine spray provides for a greater droplet density on a treated surface as compared to an equivalent volume of liquid delivered as a coarse spray. The greater droplet density provided by small droplets increases the frequency of pest contact with pesticide residues resulting in higher mortality levels and/or shorter exposure times to achieve mortality as compared to an equivalent pesticide rate delivered as large droplets (Fisher et al. 1974, Fisher and Menzies 1973, 1976). If droplets are too small however, as a result of atomization and/or evaporation, they may not have sufficient momentum to impinge on plant surfaces (Yeomans and Rogers 1953, Potts 1946, Cunningham et al. 1962).

Although an abundance of experimental evidence supports the efficiency of small droplet sprays (less than 50 um) for pest control, the literature also contains data supporting the use of coarse sprays. Yeomans (1952) and Davis et al. (1956) reported that sprays having an MMD (mass median diameter) of 200-300 um provided the best control of forest defoliators. Wilson et al. (1963) indicated that there was little difference in the effect on pest control when spray was delivered as droplets ranging from 100 to 400 um in diameter.

The existing controversy concerning an optimum spray droplet size for pesticide delivery systems is largely due to a lack of standardization in methodology for spray spectra analysis. The accuracy achieved in analyzing a spray droplet spectrum is dependent upon obtaining a droplet sample that is representative of the total spray spectrum produced. The droplet sample obtained is influenced by the sampling device employed as well as the manner in which the sample is taken.

Numerous techniques and devices are available for the collection and/or sizing of landed as well as airborne spray droplets. A variety of flat impingement devices including kromekote cards (Rathburn 1970), slides coated with magnesium oxide (May 1949) or teflon (Anderson and Schulte 1971), or containing a well filled with viscous polybutene (Fisher and Dougan 1970) have been used for the collection and sizing of spray droplets. These devices suffer from problems associated with variable spread factors and critical impingement velocity, and frequently do not provide a representative sample of the total spray spectrum. Slides and cards may provide a biased sample in favor of large droplets because smaller droplets cannot resist the deflected air flow around the sampling device as easily, and as a result do not impinge with the same degree of efficiency (Pieper 1972). Conventional spray cards can provide an unrealistic analysis of a spray spectrum in which a close correlation between spray deposit and insect mortality may be lacking (Buffam et al. 1967).

Yeomans et al. (1949) and Rathburn (1970) demonstrated that small diameter wires are a much more efficient collecting device for small diameter droplets than glass slides, filter-paper, or leaf discs. In comparing the impingement efficiency of small diameter wire with magnesium oxide, and teflon coated slides, McDaniel (1976) discovered that a droplet impingement harp strung with 5 um diameter tungsten wire was the only collection device that provided a representative sample of the total spectrum of small droplet sprays.

Although the sampling devices outlined above perform a useful function in particular spray situations they are artificial targets which do not necessarily mimic the droplet catch capabilities of natural surfaces. Himel (1969b) reported on the use of a fluorescent particle (FP) spray droplet tracer method whereby the size of spray droplets impinging on insects and their natural foliage environments could be determined. More recently, photography with scanning electron microscopy has also provided a means for sizing spray droplets impinged on pest organisms (Lofgren et al. 1973, Owens and Bennett 1978). In addition to spray spectrum analysis by the measurement of landed droplets, various photographic techniques for the study of suspended aerosols have been reported (Cadle and Wiggins 1953, Ràthburn and Miserocchi 1967). The application of laser technology to spray spectrum analysis provides the methodology for the measurement of spray droplets while in flight (Knollenberg 1970, Reichard et al. 1977, 1978) and after impingement on target organisms (Zinky 1969, Roberts et al. 1971).

While the importance of small droplet sprays for pest control has clearly been demonstrated by fluorescent particle tracer studies, scanning electron microscopy, and laser holography, it would appear that the significance of experimental data has not been realized by manufacturers of air blast spray equipment. Most agricultural spray nozzles deliver a wide range of droplet sizes, however, droplets smaller than 50 um in diameter typically constitute less than 1-2% of the total spray volume delivered (Brown 1951, Bode et al. 1968, Reichard et al. 1977, 1978). According to Himel (1969a) spray droplets larger than 100 um in diameter are primarily deposited on the ground, ground forage, and peripheral foliage within the ecosystem. These data indicate that conventional agricultural spray equipment is a highly inefficient means of delivering pesticides to the target organism, frequently resulting in unnecessary environmental contamination.

The production of narrow-spectrum, small droplet spray was realized with the development of an ultra low volume ground sprayer for fruit pest control (Howitt and Pshea 1965). Employing a Mini-Spin rotary nozzle delivering spray droplets estimated at 70-80 um in diameter resulted in excellent fruit pest control with less than 6.3 liters of spray volume per hectare. The narrow-spectrum, small droplet spray was produced by utilizing a sprayer air velocity of 54 m/s for rotating the Mini-Spin nozzles at 150 r/s. It was discovered that variation in the rotational speed of the Mini-Spin caused by changes in sprayer air velocity effected the size of spray droplets produced. By employing a variable speed electric motor to power a rotary orifice cage it was possible to accurately control droplet size in a range varying from coarse to aerosol sized spray droplets (Howitt et al. 1966). In 1969 (Howitt et al. unpublished) the concept of controlled porosity low volume spraying was introduced by the replacement of orifice cages with porous Beecomist (Beeco Products Company) rotary sleeve nozzles. This spray system combines the advantages of reduced spray volumes (described above) and narrow-spectrum, small droplet sprays which is currently lacking in conventional air blast spray equipment.

Due to the present inefficiency of spray application, this research was conducted to study the spray mass transport properties and spray spectra characteristics of a controlled porosity low volume and conventional air blast spray system with the hope of providing methodology for the improvement of spray application efficiency.

METHODS AND MATERIALS

Insecticide Mass Transport Study.

Two John Bean air blast sprayers, a model TM 1229 modified for low volume application and a C-336 CP conventional model were used to study insecticide transport to Jonathan apple trees during 1976. Guthion 2S was applied on a seasonal schedule (8 applications) beginning at petal fall at rates of 0.88, 1.75 and 3.51 l/ha with both spray systems. Benlate 50 WP was also applied in combination with the insecticide, at a rate of 1.7 kg/ha, for disease control. The low volume spray system was equipped with a Barnant model 7017 Masterflex peristaltic pump driven by a Graham model BD4R4 variable speed transmission. Liquid was pumped through tygon tubing to each of 4 (2 per side) electrically powered Beecomist perforated stainless steel sleeves (Beeco Products Company) operated between 150 and 183 revolutions/second (r/s). The low volume spray system (PTO driven) was mounted by a 3-point hitch to a model 544 International tractor, and delivered 9.4 l of spray/ha at an average air velocity of 35.8 m/s. The engine driven conventional spray system was pulled by a model 504 International tractor, and delivered a spray volume of 1402.3 l/ha at an average air velocity of 40.2 m/s. Both sprayers, traveling at 1.34 m/s, applied spray to both sides of semi-dwarf Jonathan apple trees averaging 3.4 m high and 4.0 m in diameter.

A sample, consisting of twenty-five (2.54 cm diameter) leaf discs (5 from each of the 4 peripheral quadrants (1.5 m above ground) + the top center (3.0 m above ground)), was taken from each of 3 replications/treatment. Samples were taken the day before and 2 hrs after a given application to quantify the actual deposit delivered on 4 separate dates of application. Samples were stored in a cooler with coolant and transferred, within 2-4 hrs after sampling, to a freezer (-25°C) until residue analyses were made.

For residue analyses leaf discs were transferred from sample vial to a 500 ml flask to which several hexane washings of the sample vial were added. Sixty ml of 25% acetone in hexane extractant were added to the flask which was stoppered and shaken for 10 minutes on a Burrell wrist-action shaker. The liquid was poured into a 250 ml separatory funnel and the process was repeated with 2 more 10 min extractions of equivalent volume. Acetone was removed with three 15 ml washings of 1% NaCl in distilled water. The hexane layer was dried with anhydrous sodium sulfate and concentrated to 10 ml under vacuum on a roto-evaporator at 55°C.

Analyses were made with a Tracor 560 gas chromatograph equipped with a flame photometric detector set at optimum sensitivity for phosphorus. The chromatographic column was glass, 1.83 m x 4 mm i.d., packed with 3% SE-30 on 60/80 mesh Gas Chrom Q. Carrier gas was helium at 50 cc/min. Operating temperatures were: column, 220°C; inlet, 240°C; detector, 320°C. Under these conditions, the retention time was 5 minutes. Quantitation was by peak area. The mean (duplicate determinations) recovery of guthion from spiked apple leaves was 90% at the 0.50 ug/cm^2 level, and 95% at the 5.0 ug/cm^2 level. The detection limit was 0.01 ug/cm^2.

One hundred apples (20 from each of the 5 sampling regions) from each of the 3 replications/treatment were picked and evaluated for insect injury 2 weeks after the last application.

Miticide and Mite Distribution Study.

Both John Bean sprayers described above were employed in this study, and operated under the previously described air stream conditions. The electric motor power source for the Beecomist sleeves on the low volume spray system was replaced with a model 361 hydraulic gear motor (Beeco Products Company) since it was discovered that high liquid flow rates and/or viscous pesticide formulations may reduce the spinning speed of electrically driven sleeves. The use of a hydraulic power source reduced the variation encountered in sleeve spin speed and consequently droplet size produced under various flow conditions. Beecomist 60 um porous polyethylene sleeves were substituted for the perforated stainless steel type (used above because of wettable powder fungicide formulation which would not pass through porous sleeves).

Acaraben 4E was applied by both spray systems at a rate of 9.4 l/ha with the low volume and conventional spray systems calibrated to deliver a total spray volume of 18.7 and 1869.8 l/ha respectively. The miticide was delivered (June 22, 1977) at a sprayer travel speed of 1.34 m/s to both sides of semi-dwarf Red Delicious apple trees averaging 4.1 m high and 4.6 m in diameter. Each of

5 replications/treatment was sampled in 4 tree regions consisting of the periphery, middle (halfway between periphery and center) and center at 1.8 m above ground, and top center at 3.7 m above ground. A sample consisting of twenty (2.54 cm diameter) leaf discs (5 from each of the 4 tree quadrants) was taken from each sampling region at 2 hrs, and 3,7,14 and 21 days after application. Samples were stored in a cooler with coolant and transferred, within 2-4 hrs after sampling, to a freezer (-25°C) until residue analyses were made.

For residue analyses, the same extraction procedure as outlined in the previous study was followed. The 10 ml hexane extract was transferred to a micro-column packed with 2.0 g of deactivated 60/100 mesh Florisil used for sample clean-up. Acaraben 4E (chlorobenzilate) was eluted with 70 ml of 47% hexane/3% acetonitrile/50% methylene chloride eluant. The eluted liquid was concentrated under vacuum to 10 ml using a roto-evaporator at 55°C.

Analyses were made with a Beckman GC 72-5 gas chromatograph equipped with a non-radioactive Beckman electron-capture detector set at optimum sensitivity. The chromatographic column was glass, 1.83 m x 4 mm i.d., packed with 5% SE-30 on 60/80 mesh Gas Chrom Q. Carrier gas was helium at 50 cc/min. Operating temperatures were: column, 210°C; inlet, 250°C; detector, 320°C. Under these conditions, the retention time was 3.8 min. The identity of chlorobenzilate was confirmed using an identical sized column packed with 1.5% OV-17/1.95% QF-1 on 80/100 mesh Gas Chrom Q, and operated at a temperature of 200°C and helium flow rate of 60 cc/min. Retention time under these conditions was 4.6 min. Sample quantitation was by peak area. The mean (duplicate determinations) recovery of chlorobenzilate from spiked apple leaves was 95% at the 0.63 ug/cm^2 level, and 99% at the 6.3 ug/cm^2 level. The detection limit was 0.01 ug/cm^2.

The population distribution of European red mite (*Panonychus ulmi* Koch) active stages was determined, for miticide treated trees and a control, 1 day before, and at 3,7,14 and 21 days after spray application. Twenty leaves were sampled, as described above, from each of the 4 tree regions. Leaves were placed in covered pint containers (Lily-Tulip Cup Corp.) and stored in a cooler with coolant until transfer to a refrigerator for storage until mites could be counted. All samples were counted, within 48 hrs, by brushing leaves with a mite brushing machine (Leedom Engineering) onto a revolving plate and making count determinations with a stereozoom microscope.

The Effect of Air Velocity, Sleeve Spin Speed and Ratio of Liquid Proportioning to 2 Beecomist Sleeves on The Spray Distribution Delivered by a Low Volume Spray System.

Due to the discovered inferior air characteristics of the modified John Bean model TM 1229, a new experimental model low volume spray system was developed. This trailer type model utilized a Bessler 8-bladed, 0.914 m fan powered by a 55 horsepower air-cooled, gasoline engine. The sprayer was pulled with a model 544 International tractor.

Because of the expense of pesticide residue analysis, which limited experimentation, and the delay in obtaining experimental results, it was felt necessary to investigate other methodology for studying spray distribution.

Fluorescein (Matheson Coleman & Bell Manufacturing Chemists), a highly water soluble dye, was used in combination with Orthene 75S (Chevron Chemical Co.), a water soluble insecticide used to provide wettability, for studying spray distribution. The fluorescein and orthene were applied at 3.7 and 0.74 kg/ha respectively in a total spray volume of 28 l/ha. Since apple trees were sprayed from only 1 side however, the amounts of solution and spray ingredients delivered were one half the above amounts. Fluid was delivered through tygon tubing to 2 Beecomist perforated stainless steel sleeves by a Barnant model 7017 Masterflex peristaltic pump powered by a 7 Hp gasoline engine, and driven through a Graham model BD4R4 variable speed transmission. The fluid was dispensed to each of 2 sleeves in equal proportions or with 2/3 of the spray volume being delivered to the top sleeve by connecting the flow from 2 pumping units in the Masterflex pump to the top spray head with a y-connector. Both sleeves were hydraulically driven at a rotational velocity of 100 or 183 r/s as determined with a model 36 Pioneer photo-tach (Pioneer Electric and Research Corp.). The low volume spray system was operated at an air velocity of 22.4, 33.5 or 44.7 m/s. A model 3002 velometer (Salford Electrical Instruments LTD) was used to measure air velocity which was then related to fan speed with the photo-tach. The desired air velocity was then achieved in the field by producing the required fan speed as determined with the photo-tach.

Dye spray applications to semi-dwarf Red Delicious apple trees (averaging 4.1 m high and 4.6 m in diameter) were made during the early evening (after 7:00 p.m. E.D.T.) to minimize photo-degradation and unfavorable wind conditions. Treatments were replicated on 4 different evenings. The trees were sampled 15 minutes after spray application in each of 4 regions at 1.83 and 3.66 m above ground (Fig. 1). Ten leaves were picked from each region and placed in a covered pint container (Lily-Tulip Cup Corp.) which was transported to a station set up in the field for leaf punching. Ten leaf discs (2.54 cm diameter) were punched into 20 ml of 0.094 M anhydrous K_2HPO_4 (Mallinckrodt Inc.) and 0.047 M L-ascorbic acid (Sigma Chemical Co.) solution contained in 20 dram plastic screw cap vials (Owens-Illinois Prescription Containers). The K_2HPO_4 was used to buffer the extracting solution at a pH of 7.2-7.4 preventing changes in solution color intensity as a result of changes in pH. The ascorbic acid was used to inhibit the oxidation of the cut leaf disc which contributed to background interference. Vials containing punched leaf discs were rotated on a conveyor for 15 minutes, and the % transmittance of the sample was then determined using a Bausch & Lomb Spectronic-20 colorimeter set at a wavelength of 485 nm (maximum absorbance, see Fig. 2B). The dye deposit was quantitated using a standard curve (Fig. 3B) prepared by series dilution of a

Figure 1. - Sampling regions in semi-dwarf Red Delicious apple trees.

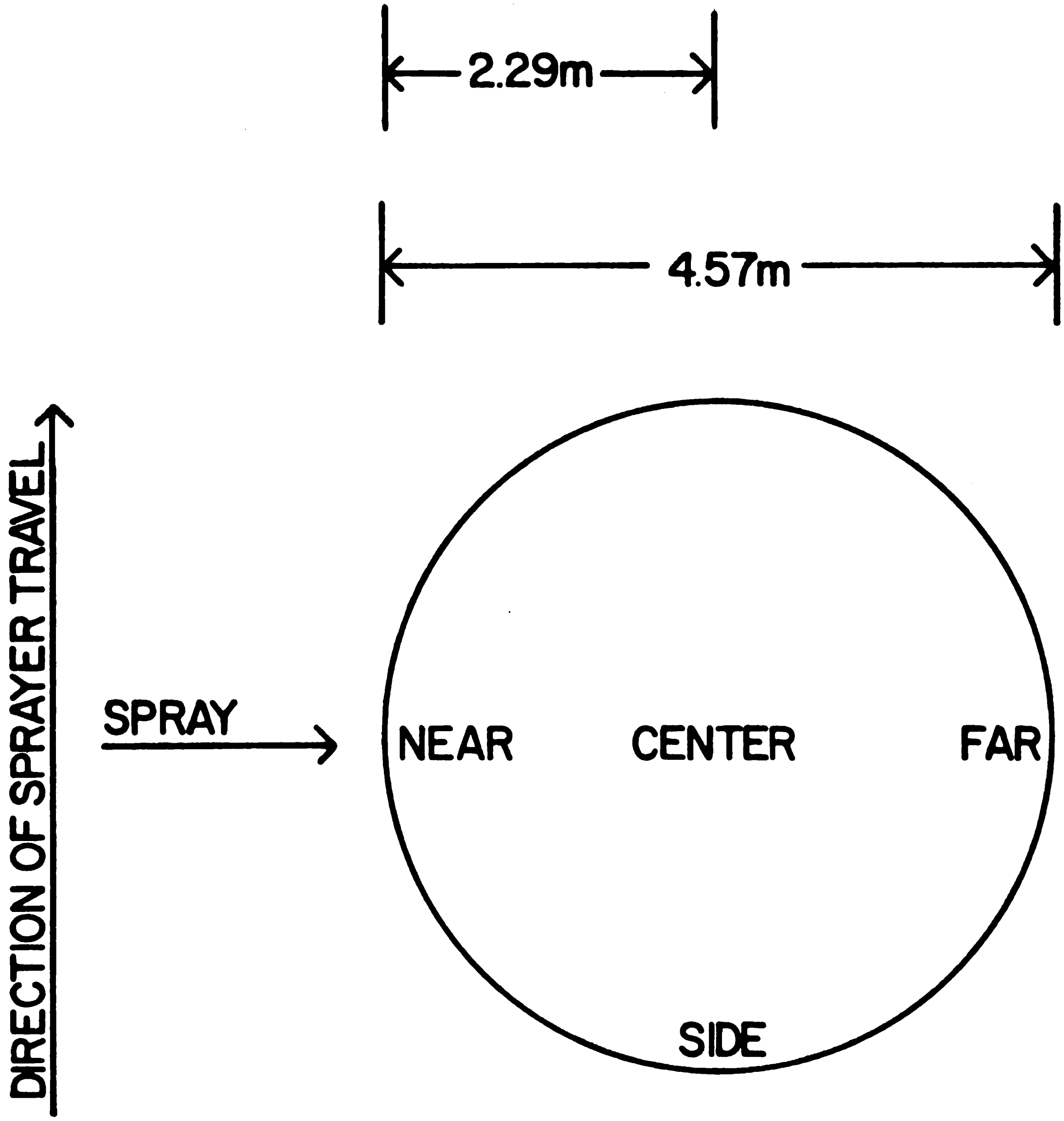

2.29m
4.57m
DIRECTION OF SPRAYER TRAVEL
SPRAY
NEAR
CENTER
FAR
SIDE

Figure 2. - Absorbance spectrum of water soluble dyes at a concentration of 4 ug/ml + 0.8 ug/ml of Orthene 75S in buffered ascorbic acid solution.

A = Nigrosine (Eastman Kodak Company).

B = Fluorescein (Matheson Coleman & Bell Manufacturing Chemists).

C = Uranine (Sodium Fluorescein) (Fisher Scientific Company).

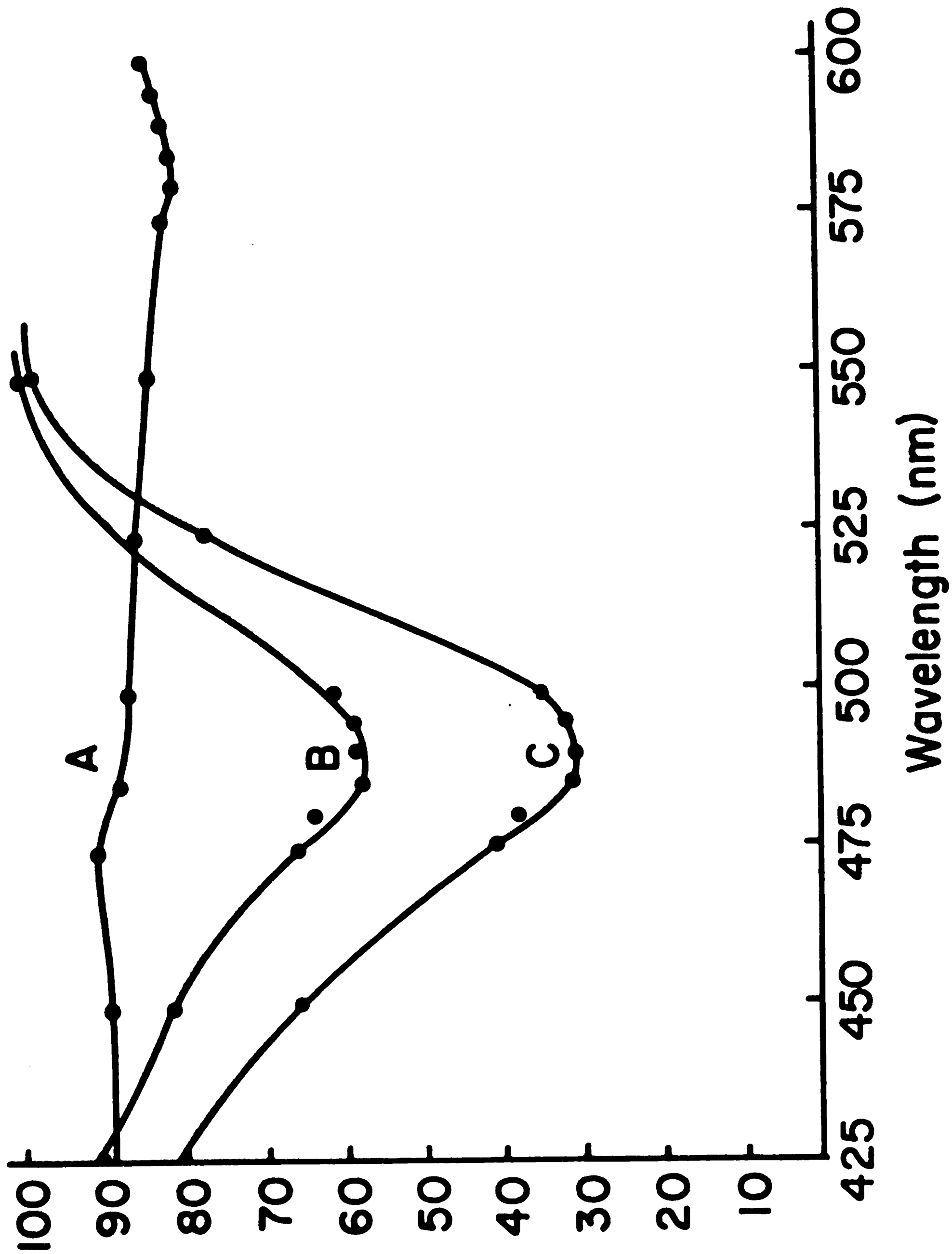
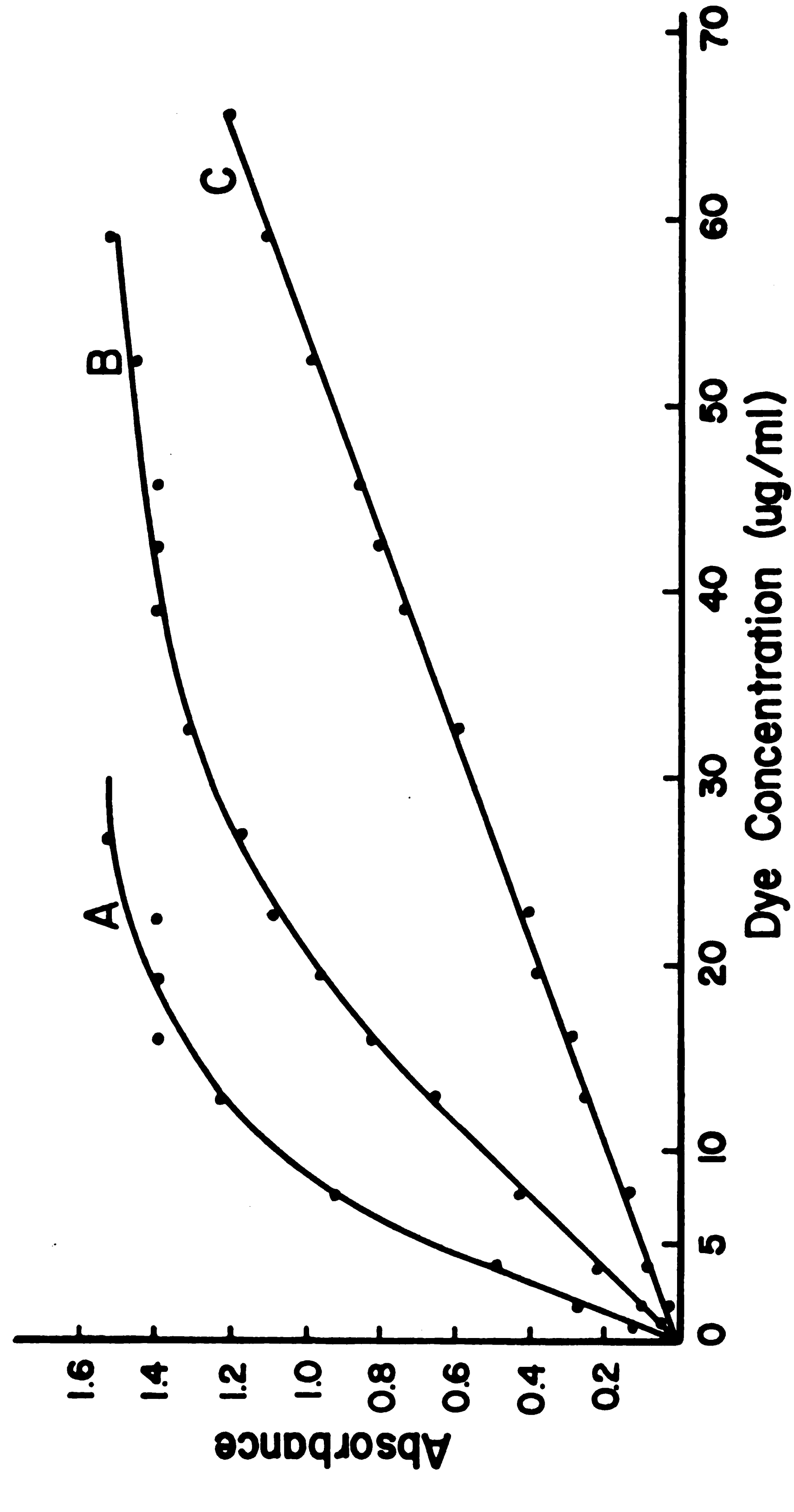

% Transmittance
100
90
80
70
60
50
40
30
20
10
425
450
475
500
525
550
575
600
Wavelength (nm)
A
B
C

Figure 3. - Absorbance of water soluble dyes as a function of concentration (+ Orthene 75S at 1/5 of dye concentration) in buffered ascorbic acid solution.

A = Uranine (Sodium Fluorescein) (Fisher Scientific Company).

B = Fluorescein (Matheson Coleman & Bell Manufacturing Chemists).

C = Nigrosine (Eastman Kodak Company).


Absorbance
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
20
30
40
50
60
70
Dye Concentration (ug/ml)
A
B
C

known concentration. The colorimeter was calibrated (100% transmittance) using a sample obtained from a solution containing 10 blank leaf discs processed in the same manner as treated discs. In order to determine percent dye recovery, 5 ul of the spray solution was deposited onto an apple tree leaf (3 replications in field nearby) with a syringe at the time of spray application. This sample was harvested (leaf disc) at the end of experimentation, combined with 9 blank leaf discs and processed as outlined above. The colorimeter reading obtained was compared to that from a sample in which 5 ul of the same spray solution was injected into a vial containing 10 blank leaf discs in solution which were then processed in the same manner. A percent dye recovery of 95-97% was obtained.

The methodology for determining the spray droplet spectra produced under the above operating conditions is reported under "studies on the parameters which affect spray spectra characteristics from rotary sleeve nozzles."

Analysis of Spray Distribution Delivered From Each (2) Beecomist Sleeve on a Low Volume Spray System.

Two water soluble dyes, uranine (sodium fluorescein) (Fisher Scientific Co.) and nigrosine (Eastman Kodak Co.), were used to study the distribution of spray in an apple tree delivered from each (2) Beecomist perforated stainless steel sleeve on the Bessler low volume spray system described previously. The sprayer was operated at a traveling speed of 1.34 m/s, with an air velocity of 40.2 m/s, and a sleeve spin speed on 183 r/s. Uranine + orthene were applied (in combination) to 1 side of the trees at a rate (equivalent to 2-sided spraying) of 3.7 and 0.74 kg/ha respectively in a total spray volume of 56 l/ha delivered through the top (1.83 m above ground) sleeve. Each of 4 semi-dwarf Red Delicious apple trees (averaging 4.1 m high and 4.6 m in diameter) was sampled in the near, center and far regions (Fig. 1) of the tree at elevations of 1.22, 1.83, 2.74 and 3.66 m above ground. The sampling and sample processing procedure outlined above was begun 15 minutes after spray application. The uranine deposit was quantitated at a wavelength of 485 nm (maximum absorbance, see Fig. 2C) using a standard curve (Fig. 3A) prepared by series dilution of a known concentration. The percent recovery of uranine was 97%.

Immediately after sampling all 4 uranine-treated replications, these same trees were sprayed at the same rate with nigrosine + orthene delivered in combination through the bottom (1.22 m above ground) sleeve. After sample processing, the nigrosine deposit was quantitated at a wavelength of 580 nm (maximum absorbance, see Fig. 2A) using a standard curve (Fig. 3C) prepared by series dilution of a known concentration. The percent recovery of nigrosine was 92%.

Experimentation revealed that the presence of uranine (100% transmittance at 580 nm) did not interfere with the quantitation of nigrosine at 580 nm. The trees were not sprayed with uranine and nigrosine delivered simultaneously through their respective sleeves because the absorbance of nigrosine at 485 nm interfered with uranine quantitation at this wavelength.

The spray pattern from each (2) Beecomist perforated stainless steel sleeve was also studied utilizing a wooden spray stand (5.49 m high and 4.58 m wide) placed in an apple orchard. Two 2.2 cm^2 cover slips were fastened (with double-sided tape) to each of 3 (1x3") glass slides which were clipped with clothespins to the wooden stand at heights of 1.22, 1.83, 2.74, 3.66 and 5.49 m above ground at distances of 0.91, 3.20 and 5.49 m from the traveling sprayer. Nigrosine + orthene were applied in combination to 1 side of the stand at a rate (equivalent to 2-sided spraying) of 3.7 and 0.74 kg/ha respectively in a total spray volume of 56 l/ha. The sprayer was operated under the same conditions described in the previous experiment in this study. The wooden stand was first sprayed with spray being delivered only through the bottom sleeve. Five minutes after spraying, the slides were removed and placed in slide boxes, and new slides were positioned. The procedure was repeated to provide a total of 3 replications. The experiment was then repeated with spray being delivered for 3 replications through the top sleeve. Cover slips were removed from the slides (in the lab) and deposited in 10 ml of buffered ascorbic acid solution. After brief agitation the nigrosine was quantitated as described above.

<u>Comparison of Dye Distribution Delivered by Low Volume and Conventional Spray Systems to Semi-Dwarf and Standard Size Red Delicious Apple Trees.</u>

A Bessler experimental low volume (described above) and John

Bean model C-336 CP conventional sprayer were used to study dye mass transport to semi-dwarf (4.1 m high and 4.6 m in diameter) and standard size (6.1 m high and 7.3 m in diameter) Red Delicious apple trees. Both sprayers were operated at a travel speed of 1.34 m/s and average air velocity of 40.2 m/s.

On August 10, 1978 at 2:40 p.m. E.D.T., semi-dwarf trees (4 replications) were sprayed with the conventional spray system. Uranine + orthene were applied (in combination) to 1 side of the trees at a rate (equivalent to 2-sided spraying) of 3.7 and 0.74 kg/ha respectively in a total spray volume of 1869.8 l/ha. The top 2 nozzles of the sprayer were closed to avoid excessive spray loss over the tops of the trees. Samples were picked, processed and quantitated (as described previously) from 4 sampling regions (Fig. 1) at heights of 1.83 and 3.66 m above ground, beginning 1/2 hr after spray application.

After sampling completion, the same trees were sprayed with the Bessler low volume spray system delivering nigrosine + orthene (in combination) at an equivalent rate in a total spray volume (equivalent to 2-sided spraying) of 56 l/ha. Spray was delivered in equal proportions through 2 perforated stainless steel sleeves operated at a spinning speed of 183 r/s. Samples were picked, processed and quantitated beginning 15 minutes after spray application. The percent recovery of uranine and nigrosine was 98 and 91% respectively.

On August 15, 1978 at 3:00 p.m. E.D.T., standard size trees

(4 replications) were sprayed with the conventional spray system delivering uranine + orthene (in combination) at the same rate and volume per hectare as delivered to semi-dwarf trees. The spray system was operated as previously described, however, all nozzles (12) were employed. Samples were picked, processed and quantitated from 7 sampling regions (Fig. 4) at heights of 1.83, 3.66 and 5.49 m above ground. After sampling completion, the same trees were sprayed with the Bessler low volume spray system. Nigrosine + orthene were delivered (in combination) under the same conditions as described for semi-dwarf trees except that 2/3 of the spray volume was delivered through the top sleeve. Samples were picked, processed and quantitated to determine the nigrosine deposit. The percent recovery of uranine and nigrosine was 97 and 92% respectively.

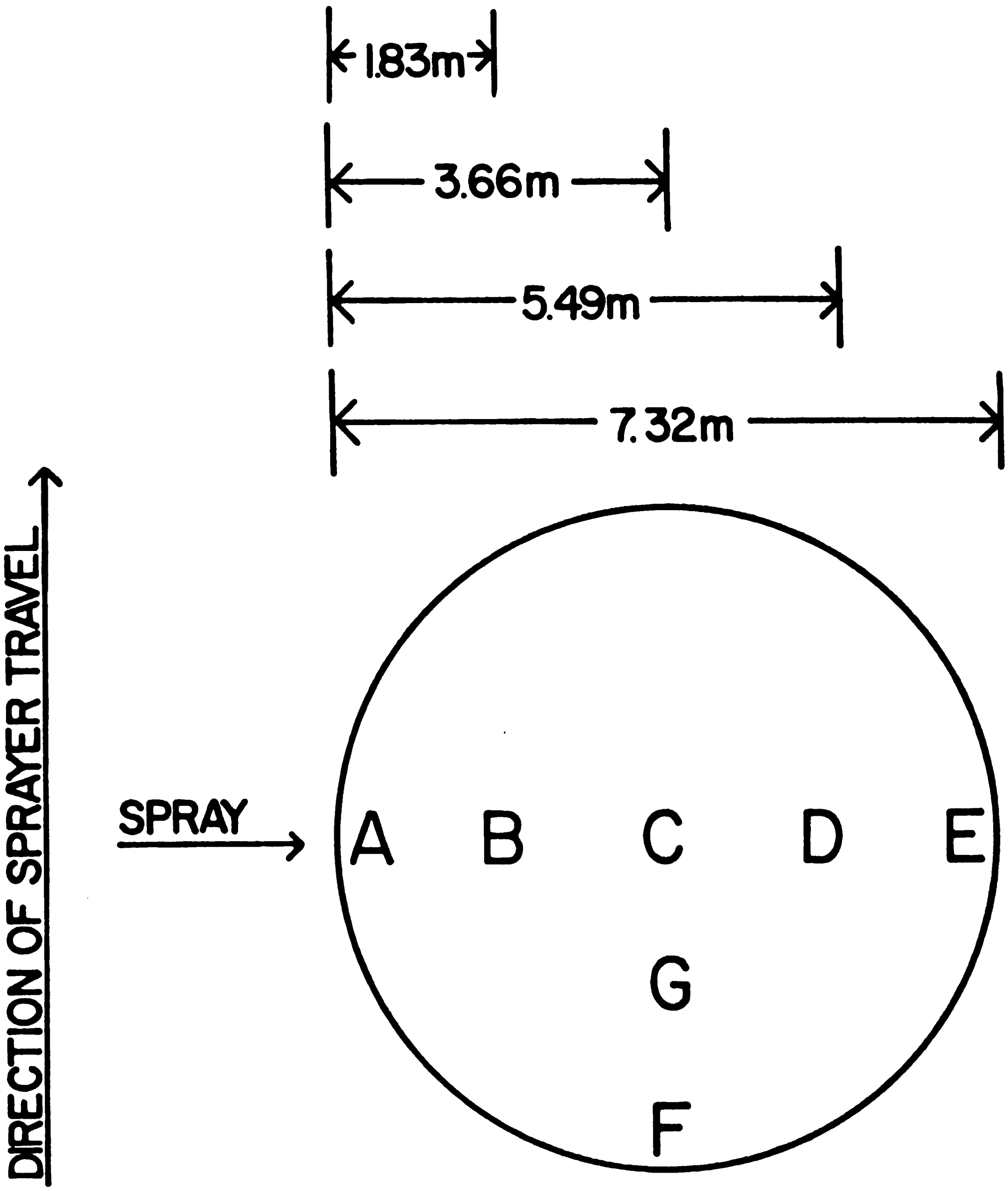
Spray Droplet Spectra Analysis of a Conventional and Low Volume Spray System as Determined in Open and Foliage Environments With a Droplet Impingement Harp.

Two John Bean sprayers, a modified model TM 1229 (described under "insecticide mass transport study") and a conventional model 477 CP were employed in this study.

The conventional spray system was fitted with 10 No. 5 Whirlmist nozzle caps (each delivering 90 ml/s at 7 kg/cm^2) and operated at an average air velocity of 44.7 m/s.

The low volume spray system was equipped with 2 hydraulically driven (183 r/s) Beecomist 60 um porous polyethylene sleeves (delivering 4.5 ml/s of liquid/sleeve) and operated at an average air

Figure 4. - Sampling regions in standard size Red Delicious apple trees.


1.83m
3.66m
5.49m
7.32m
DIRECTION OF SPRAYER TRAVEL
SPRAY
A
B
C
D
E
G
F

velocity of 35.8 m/s.

A droplet impingement harp (described by McDaniel 1976), strung with fine diameter wire, was used for collecting spray droplets of dioctyl phthalate (Wolverine Solvents Company). Dioctyl phthalate was used as a spray liquid in order to provide relatively non-volatile droplets for size determination. Strands of 5 um tungsten and 15 um stainless steel wire were used to collect droplets delivered from the low volume spray system, and these 2 sizes plus 25 um and 50 um stainless steel (Sigmund Cohn Corp.) were used for the conventional spray system. Harps were fastened with clothespins to a horizontal pole at a height of 1.83 and distance of 3.05 m from the sprayers' air outlet. The average air velocity at this distance for the low volume and conventional spray systems was 5.4 and 11.6 m/s, respectively. Each sprayer was driven at 1.34 m/s and made 1 pass by their respective harps. Immediately after spraying, the harps (5 replications) were placed in covered boxes and transported to a photographic darkroom.

The above procedure was repeated with harps positioned at the same height in the center of semi-dwarf Red Delicious apple trees (4.1 m high and 4.6 m in diameter) approximately 3.2 m from the sprayers' air outlet. The harps (5 replications) were sprayed as above, removed and placed in covered plastic boxes, and transported to the photographic darkroom.

An Omega 10 x 13 cm photoenlarger was equipped with a Graflex Optar (Graflex, Inc.) 101 mm lens and a metal negative holder with a 3.8 cm^2 opening. The harp was positioned over the opening, and the enlarger was adjusted to project an image 25.4 cm long onto 20.3 x 25.4 cm Agfa BEH 1 No. 6 contrast photographic paper. The wire-droplet image was focused and then photographed (f. stop of f 22) onto the photographic paper thus providing a 6.67 fold enlargement. All harps were photographed within 6 hrs after sampling. Upon development of the photographic paper, the wire and spray droplets appeared white on a black background. The prints were cut into 0.64 cm wide strips and spliced end to end. The strips were threaded onto a photoreel viewing device (described by McDaniel 1976) and the droplets were sized by turning the threaded spool and moving the strips through the microscope field of view. The long and short axis of the droplet (impinged as an ellipse on the wire) was measured. The ocular micrometer measurements were fed into a computer program written to convert these data to spherical droplet size and volume statistics. A total of 200 droplets/replication for each wire size were measured for the low volume spray system. For the conventional spray system all the droplets on each wire size were measured. The total count ranged from 200-400 droplets/ replication, with the lower values characteristic of harps which had been placed in trees.

Studies on The Parameters Which Affect Spray Spectra Characteristics From Rotary Sleeve Nozzles.

General Methods, Materials and Experimental Conditions.

The size of spray droplets delivered by the Bessler low volume spray system under various operating conditions was determined with an optical array cloud droplet spectrometer probe [Particle Measuring System (PMS) model OAP-200X]. Data from this probe was collected and stored in the particle data system (PMS model PDS-100) which in turn was interfaced to a programmable desk calculator (Hewlett-Packard model 9815 A) that was programmed to print out droplet distribution statistics.

The probe illuminates particles passing through the sampling area with laser light. Shadows of these particles are projected onto a linear array of photodiodes. An electrical signal proportional to the number of photodiodes shadowed is sent to the particle data system. Built-in electronics reject out-of-focus, simultaneous, and partial drop images. In flight size measurements of droplet diameters can be made in the range of 18 to 563 um (22 size classes in 25 um increments) at particle velocities up to 125 m/s. When a sampling run is completed the size and number data is fed by manual switching into the calculator. This calculator has been programmed to divide the counts in each size class by the sampling area for that class, and then compute droplet distribution statistics. A sampling time of 2-4 minutes was used so that the total number of corrected counts was above 1000.

Calibration of the systems was checked prior to experimentation by pouring glass beads of a known size range through the sampling area of the probe. A 1.3 cm thick sponge rubber boot covered by an absorbent cloth was fitted over the tips of the sampling tubes to absorb the spray hitting the ends of the tubes and dribbling through the sampling area as random large drops. While this procedure reduced random large drops it is not clear that all such drops were eliminated.

Fluid was delivered to the Beecomist sprayheads by either an electronically controlled solid state peristaltic pump (Manostat Corp.) or by a gasoline engine (7 Hp) driven peristaltic pump (Barnant Corp. model 7017) driven through a Graham model BD4R4 variable speed transmission. Flow rates were adjusted to within ±0.3 ml/s of the reported values. Reported air velocities represent the average speed at the volute which was achieved by producing the required fan speed as determined with the Pioneer phototach. Sleeve rotational velocities were measured with an electronic strobe (General Radio Co. model 1531) and represent ±2 r/s of reported values. Exept where otherwise noted the experimental sprayer delivered spray (water) at the rate of 6.7 ml/s through the bottom sleeve of 1 side. The sprayer was operated at an air velocity (at the volute opening) of 33.5 m/s, and a sleeve rotational velocity of 183 r/s. The optic probe was positioned at a horizontal distance of 0.91 m and a vertical distance of 0.15 m from the functioning sprayhead.

Surface tension of spray solutions was determined with a DuNouy tensionmeter (Central Scientific Co.) at 23-25°C.

All points in spray spectra plots are based on droplet size means of the individual counting ranges (droplet size classes).

A. The Effect of Sleeve Construction, Rotational Velocity and Sprayer Air Velocity on Droplet Spectra.

To test the effect of sleeve construction (both constructional material and differences in porosity) the following sleeves were used: 20 and 60 um porous stainless steel, 70 um porous polyethylene and perforated stainless steel. All combinations of air velocities of 22.4 and 44.7 m/s and sleeve rotational velocities of 50, 100 and 183 r/s were studied.

Data were compared with spray spectra delivered by a model 3P50 Kinkelder and a model 3000 CP FMC spray system.

B. The Effect of Flow Rate on Droplet Spectra.

The effect of spray liquid delivery rate on droplet spectra was studied at rates of 1.7, 6.7, 13.3 and 26.7 ml/s with both the 70 um porous polyethylene and perforated stainless steel sleeves.

C. The Effect of Two Sprayheads on Droplet Spectra.

The possibility of in-flight coalescence affecting droplet spectra in zones of overlap from 2 or more sprayheads was studied with 2 sprayheads equipped with perforated stainless steel sleeves at flow rates of 6.7 and 17.8 ml/sleeve. The probe was positioned at horizontal distances of 0.91 and 3.05 m and vertical distances of 1.37, 2.13 and 3.05 m (0.15, 0.91 and 1.83 m above lower sprayhead) above ground.

D. The Effect of Formulation on Droplet Spectra.

Diazinon 4EC (Ciba Geigy Corp.), Sevin 80WP (Union Carbide Corp.)

and Captan 4F (Stauffer Chemical Co.) were selected as representative of emulsifiable concentrate, wettable powder and flowable pesticide formulations, respectively. Pesticide concentrations used were: Diazinon, 42, 84 and 167 ml/l; Sevin, 200 g/l; Captan, 333 ml/l. The effects of Bivert (Stull Chemical Company) and Nalco-Trol (Nalco Chemical Company) were studied alone and in combination with each of the formulations. The concentrations of Bivert and Nalco-Trol in all cases were 83 and 0.8 ml/l, respectively. Formulation concentrations used in combination with Bivert or Nalco-Trol were: Diazinon, 167 ml/l; Sevin, 200 g/l; Captan, 333 ml/l. The effect of formulation on droplet spectra was studied using 70 um porous polyethylene (for Bivert, Nalco-Trol and Diazinon formulations) and perforated stainless steel (all formulations) sleeves.

The droplet spectrum of a dye formulation (uranine + orthene 75S) was also studied. Uranine + orthene were delivered (in combination) at a concentration of 132.1 and 26.4 g/l respectively, at a flow rate of 6.7 ml/s. All combinations of sprayer air velocities of 22.4, 33.5 and 44.7 m/s, and sleeve rotational velocities of 100 and 183 r/s were studied using the dye formulation.

The effect of a non-aqueous formulation (technical Malathion) (American Cyanamid Company) on the droplet spectrum delivered by 20 um, 60 um and perforated stainless steel, and 70 um polyethylene sleeves was studied. The technical Malathion was delivered at a rate of 15.8 ml/s.

E. The Droplet Spectrum of a Non-Aqueous Spray Medium as Determined With Both an Optic Probe and Droplet Impingement Harp.

The spray droplet spectrum of dioctyl phthalate as delivered by 70 um polyethylene and perforated stainless steel sleeves (at 6.7 ml/s) was determined with an optic probe positioned at a height of 1.37 m (0.15 m above sprayhead) at distances of 0.91 and 3.05 m from the sprayer air outlet. Following a probe sampling time of 120 or 240 seconds (depending on distance), a droplet impingement harp (described above) was used to also determine the droplet spectrum from each sleeve type at both distances. Harps (3 replications/sleeve type/distance), strung with 5 um tungsten and 15 um stainless steel wire, were attached to a lath with a clothespin and positioned 1 at a time in the sprayer's airstream (13.4 m/s at 0.91 m; 6.3 m/s at 3.05 m) for 1-2 sec at a height of 1.37 m. Immediately after obtaining a sample a harp was placed in a covered plastic box. At the end of all sampling, harps were packed in a cardboard box layered with cotton for transport from Beltsville, Maryland (location of experiment) to a photographic darkroom in Fennville, Michigan. All harps were photographed (as described above) within 48 hrs after sampling.

Droplets were measured through a microscope employing the photoreel viewing device. A total of 400 droplets/replication, or the total number present (if less) were measured for each wire size. Smaller sample sizes (200-300 droplets) were encountered at the greater sampling distance.

A computer program was used to convert droplet (ellipse) measurements to spherical droplet size and volume statistics. Volume percentages for the total number of droplets of a given size were cumulated and converted to probit values. Droplet sizes and probit values were fed into a linear regression program to determine the predicted droplet size (this size and smaller) representing 10, 50 and 90% of the spray volume.

RESULTS AND DISCUSSION

Insecticide Mass Transport Study.

The quantitation of Guthion 2S transport to semi-dwarf Jonathan apple trees by low volume and conventional spray systems is reported in table 1. This table also reports the insect injury to fruit encountered as a function of both spray systems as well as a control. Although the average (season) insecticide deposit delivered by the low volume spray system was higher (for all rates) than for the conventional system, the difference was not significant ($P=0.05$) except for the 1.75 l/ha rate. In a separate analysis, no significant difference in deposit between dates of application was found except for the low volume spray system at a rate of 1.75 l/ha and the conventional spray system at a rate of 3.51 l/ha, where in both cases 1 date with a low deposit was encountered.

No significant difference between spray systems on the percent of insect injured fruit encountered was noted. In comparing the percent of insect injured fruit encountered at insecticide rates of 0.88 and 1.75 l/ha, no significant difference was noted in the conventional treatments, however, in the low volume treatments injury encountered at the low rate was significantly greater. At first this difference appears puzzling since the low volume system delivered more insecticide (although not significant) at the low rate than the conventional system. It is believed that the reason for this occurrence lies in the fact that the insecticide deposit represents an average deposit on leaves taken from

Table 1. - Guthion 2S residue (ug/cm^2) and insect injury encountered as a function of low volume and conventional spray treatments to semi-dwarf Jonathan apple trees during 1976.[a]

Treatment	Guthion 2S (l/ha)	Date of Application 6/4	7/2	7/29	8/26	Season Mean	% of fruit damaged by: Codling Moth	Plum Curculio	Leafrollers[b]
Low Volume	0.88	-	.16 b	.13 ab	.12 ab	.14 ab	4.7 c	6.0 b	1.0 a
"	1.75	.31 bc	.39 cd	.10 ab	.24 cd	.26 c	0.3 a	0.3 a	0.0 a
"	3.51	.55 e	.45 de	.57 cd	.42 e	.50 de	1.0 ab	0.0 a	0.7 a
Conventional	0.88	.08 a	.08 a	.07 a	.07 a	.08 a	2.3 bc	3.0 ab	0.3 a
"	1.75	.21 b	.16 b	.11 ab	.15 bc	.16 b	1.0 ab	0.3 a	0.3 a
"	3.51	.41 cd	.34 c	.53 c	.45 e	.43 d	0.3 a	0.0 a	0.3 a
Control	-	-	-	-	-	-	71.3 d	15.7 c	4.3 b

[a] Means in a given column followed by a common letter are not significantly different (P=0.05 level).

[b] Includes red-banded leafroller, oblique-banded leafroller, fruit-tree leafroller and green fruitworm.

5 areas (4 bottom, 1 top) of the tree. The sample, representing the average tree deposit, could in fact have masked large differences in deposit between the top and bottom regions of the tree. For example, inferior transport to the top of the tree by the low volume spray system could have resulted in the significant increase in injured fruit encountered at 0.88 l/ha, whereas the deposit achieved at twice this rate may have been sufficient to provide control. A low deposit in the top could have been offset by high deposit in the bottom thus yielding an average tree deposit greater than that provided by the conventional spray system.

Even though it appears that large differences in tree region deposit (which need to be investigated) occur with the low volume spray system, an acceptable level of pest control is possible at reduced insecticide rates with both spray systems.

Miticide and Mite Distribution Study.

The residue level of Acaraben 4E in 4 tree regions as a function of spray system and time after application is presented in table 2. Miticide delivery by the low volume spray system resulted in a significant (P=0.05) difference in deposit between tree regions which was not observed in the conventional treatment. Even though the distribution was less uniform, the deposit delivered by the low volume spray system was significantly greater than that in the conventional treatment in 3 of the 4 tree regions. The reduced low volume deposit in the top of the tree supports the suspected occurrence in the previous experiment. It is believed

Table 2. - Acaraben 4E residue (ug/cm^2) distribution as a function of low volume and conventional spray treatments to semi-dwarf Red Delicious apple trees on June 23, 1977.[a]

Treatment	Tree Region	Days After Application				
		0	3	7	14	21
Low Volume	Periphery[b]	8.20 d	5.00 f	1.38 d	0.63 c	0.38 b
"	Middle[b]	4.31 c	2.58 e	1.16 cd	0.32 b	0.35 b
"	Center[b]	4.75 c	2.11 de	0.98 c	0.35 b	0.33 b
"	Center[c]	1.47 a	0.53 a	0.23 a	0.06 a	0.07 a
"	Tree Mean	4.68 c	2.56 e	0.94 c	0.34 b	0.28 b
Conventional	Periphery[b]	2.95 b	1.85 d	0.58 b	0.16 a	0.09 a
"	Middle[b]	2.64 b	1.32 c	0.31 a	0.13 a	0.07 a
"	Center[b]	2.58 b	1.11 bc	0.26 a	0.10 a	0.05 a
"	Center[c]	2.24 ab	0.71 ab	0.20 a	0.05 a	0.03 a
"	Tree Mean	2.60 b	1.25 c	0.34 ab	0.11 a	0.06 a

[a] Means in a given column followed by a common letter are not significantly different (P=0.05 level).
[b] At 1.83 m above ground.
[c] At 3.66 m above ground.

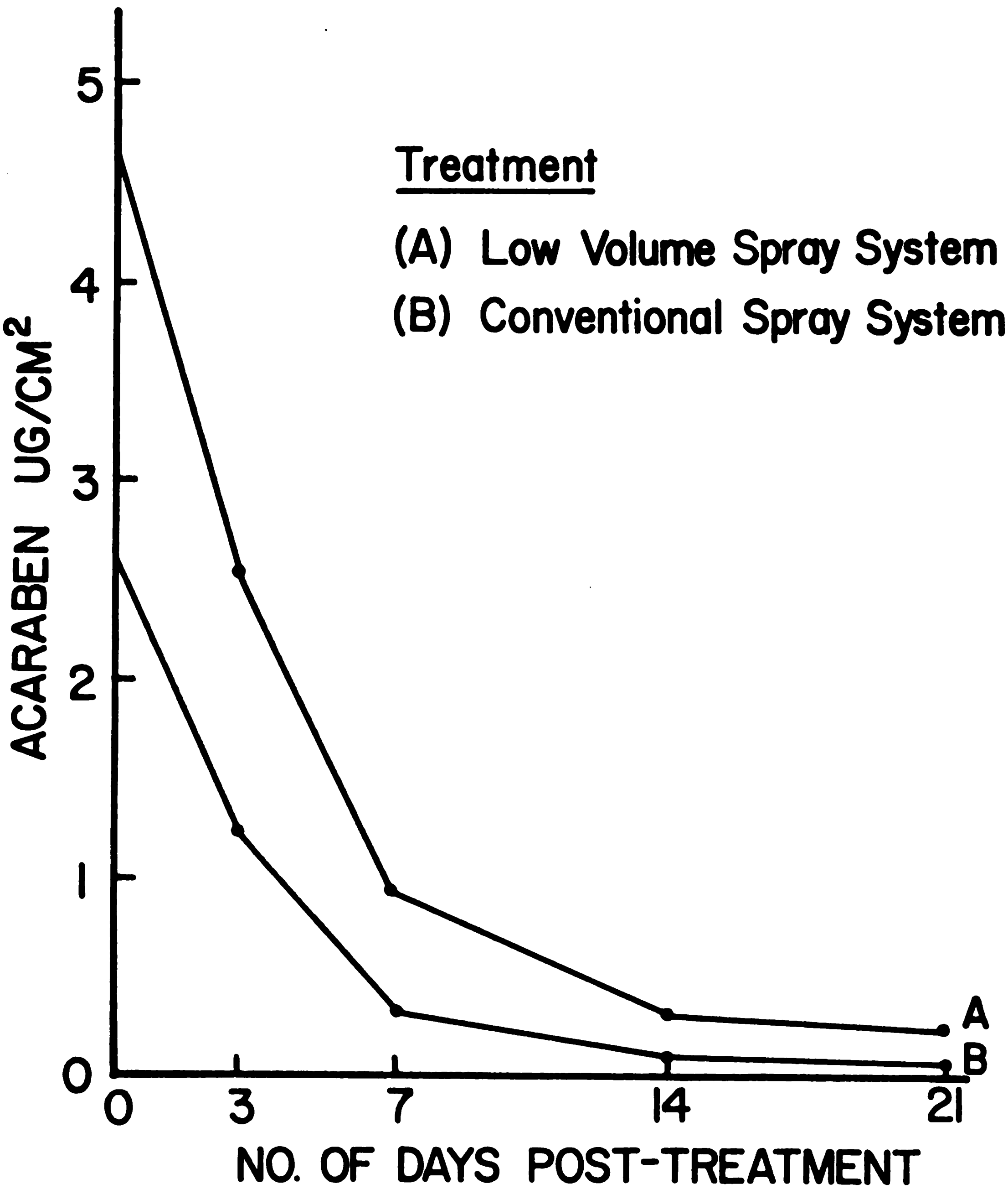
that miticide loss due to run-off (from high volumes of water) is part of the reason for the lower deposit in the conventional treatment. This was probably enhanced by the fact that the application was made in the early morning when the trees were laden with a heavy dew deposit.

The residue level in the low volume treatment was significantly greater than the conventional treatment in all 3 regions in the bottom of the tree, as well as the tree average, through 21 days after application. The average tree residue through 21 days after application is graphically presented in figure 5.

A comparison of both spray systems with respect to the percent decrease in residue from the initial deposit (table 3) revealed a similar rate of loss (no significant difference at $P=0.05$) except for the middle region at 7 days after the application. Although not significantly different (except for 3 days after application) the rate of loss was highest in the top center region of the tree. This is probably a result of increased rates of photodegradation and volatilization in this region.

The effect of residue levels on the population distribution of European red mite active stages is presented in table 4. No significant difference ($P=0.05$) in the population distribution between tree regions was noted with either spray system, however, in the control the population level was significantly less in the top center of the tree after application was made to treatment trees. This may be due to the fact that this region would be less

Figure 5. - Mean tree residue (ug/cm^2) of acaraben 4E as a function of time after spraying semi-dwarf Red Delicious apple trees with low volume and conventional spray systems.



5
4
3
2
1
0
ACARABEN UG/CM2
Treatment
(A) Low Volume Spray System
(B) Conventional Spray System
A
B
0
3
7
14
21
NO. OF DAYS POST-TREATMENT

Table 3. - Percent decrease from initial acaraben 4E deposit delivered by low volume and conventional spray systems to semi-dwarf Red Delicious apple trees on June 23, 1977.[a]

Treatment	Tree Region	Days After Application 3	7	14	21
Low Volume	Periphery[b]	39 a	83 ab	92 a	95 a
"	Middle[b]	40 a	73 a	93 a	92 a
"	Center[b]	56 bc	79 ab	93 a	93 a
"	Center[c]	64 c	84 ab	96 a	95 a
"	Tree Mean	45 ab	80 ab	93 a	94 a
Conventional	Periphery[b]	37 a	80 ab	95 a	97 a
"	Middle[b]	50 ab	88 b	95 a	97 a
"	Center[b]	57 bc	90 b	96 a	98 a
"	Center[c]	68 c	91 b	98 a	99 a
"	Tree Mean	52 bc	87 b	96 a	98 a

[a] Means in a given column followed by a common letter are not significantly different (P=0.05 level).
[b] At 1.83 m above ground.
[c] At 3.66 m above ground.

Table 4. - Distribution of European red mites, Panonychus ulmi (Koch), in semi-dwarf Red Delicious apple trees as effected by low volume and conventional spray applications of acaraben 4E on June 23, 1977.[a]

Treatment	Tree Region	Number of European red mites (active stages)/leaf				
		Pre-Treatment	Days After Application 3	7	14	21
Low Volume	Periphery[b]	140 de	99 ab	49 a	25 a	21 a
"	Middle[b]	156 e	77 a	48 a	29 a	23 a
"	Center[b]	144 de	73 a	50 a	29 a	24 a
"	Center[c]	124 cde	68 a	59 ab	26 a	27 a
"	Tree Mean	141 de	79 a	52 ab	27 a	24 a
Conventional	Periphery[b]	144 de	92 a	68 ab	34 a	37 a
"	Middle[b]	138 de	78 a	67 ab	39 a	44 a
"	Center[b]	139 de	80 a	57 ab	41 a	46 a
"	Center[c]	101 bcd	71 a	62 ab	25 a	35 a
"	Tree Mean	131 de	80 a	64 ab	35 a	41 a
Control	Periphery[b]	76 ab	149 c	184 c	138 c	184 c
"	Middle[b]	110 bcde	192 c	211 c	142 c	164 bc
"	Center[b]	98 bcd	159 c	188 c	139 c	182 c
"	Center[c]	51 a	68 a	112 b	81 b	144 b
"	Tree Mean	84 abc	142 bc	174 c	125 c	169 bc

[a] Means in a given column followed by a common letter are not significantly different (P=0.05 level).
[b] At 1.83 m above ground.
[c] At 3.66 m above ground.

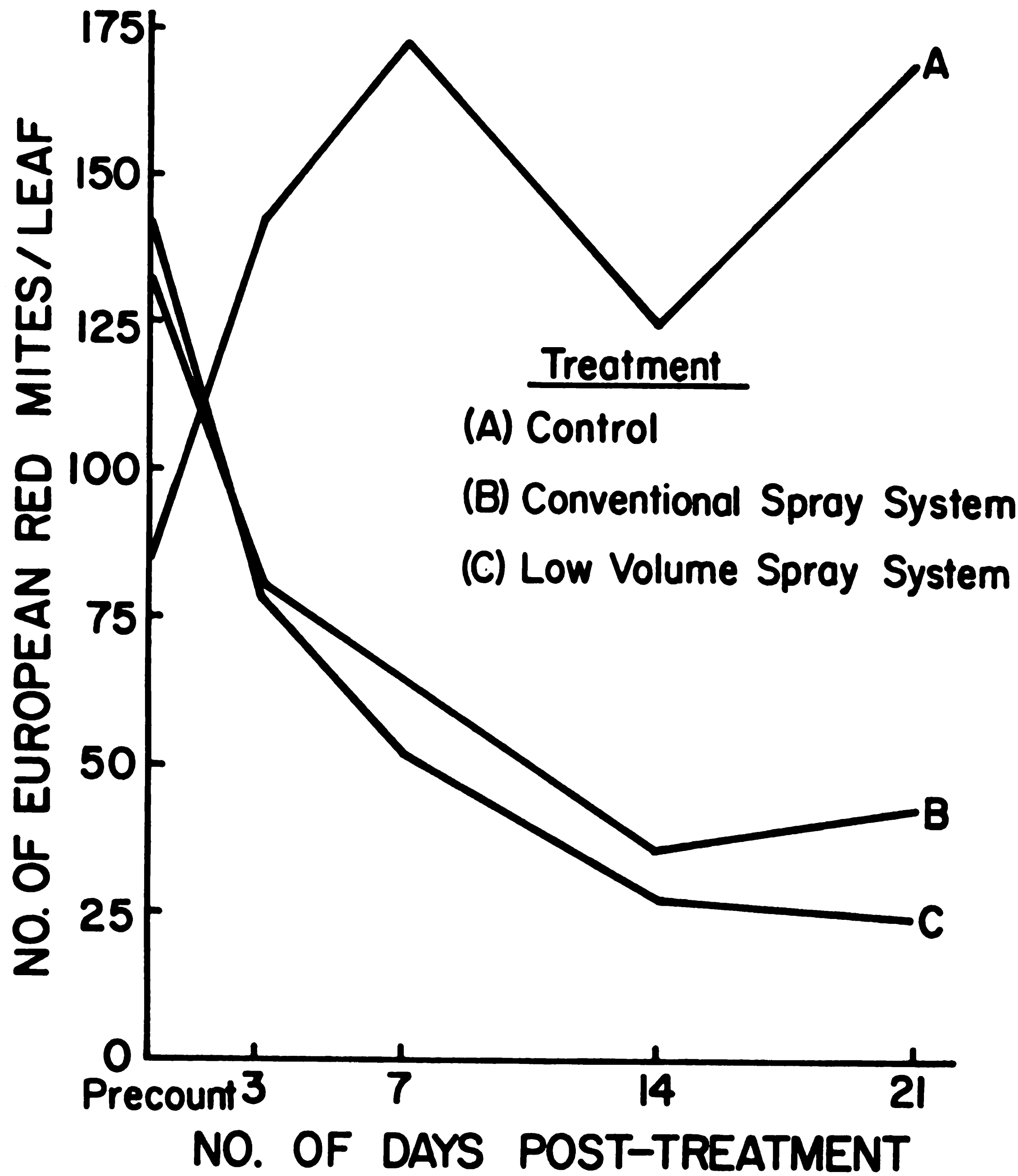
environmentally protective.

Both spray systems reduced the mite population in all regions through 14 days after application, however, the population then started to increase in the conventional treatment but continued declining in the low volume treatment. This is presented for the mean tree population in figure 6. Although the number of European red mites present 21 days after application is not significantly less in the low volume treatment when compared to the conventional treatment in table 4, it becomes significant, for all tree regions, when the control is removed from statistical analysis.

A more realistic comparison of spray treatments, based on percent reduction in population rather than absolute numbers of mites present, can be seen in table 5. These data reveal that 21 days after application the low volume spray system effected a significantly greater reduction in mite population than that achieved with the conventional system.

Although the low volume spray system generally provided the advantage of increased deposit, this was realized as a severely non-uniform distribution characterized by minimal transport to the top center of the trees. The relatively uniform distribution achieved with the conventional spray system would be more desireable, however, this was probably achieved as a result of "washing" the tree with a large volume of water in which a lower average deposit is realized because pesticide is lost by water run-off from the trees.

Figure 6. - Mean tree population of European red mites in semi-dwarf Red Delicious apple trees as a function of time after spraying acaraben 4E with low volume and conventional spray systems.



175
150
125
100
75
50
25
0
NO. OF EUROPEAN RED MITES/LEAF
Precount
3
7
14
21
NO. OF DAYS POST-TREATMENT
A
B
C
Treatment
(A) Control
(B) Conventional Spray System
(C) Low Volume Spray System

Table 5. - Percent reduction (from pre-treatment count) of European red mite population in semi-dwarf Red Delicious apple trees as effected by low volume and conventional spray applications of acaraben 4E on June 23, 1977.[a]

Treatment	Tree Region	Days After Application 3	7	14	21
Low Volume	Periphery[b]	29 a	65 bc	82 b	85 c
"	Middle[b]	51 b	69 c	81 b	85 c
"	Center[b]	49 b	65 bc	80 b	83 c
"	Center[c]	45 ab	52 bc	79 b	78 c
"	Tree Mean	44 ab	63 b	81 b	83 c
Conventional	Periphery[b]	36 ab	53 b	76 ab	74 bc
"	Middle[b]	43 ab	51 b	72 a	68 ab
"	Center[b]	42 ab	59 bc	71 a	67 ab
"	Center[c]	30 a	39 a	75 ab	65 a
"	Tree Mean	39 ab	51 b	73 ab	69 ab

[a] Means in a given column followed by a common letter are not significantly different (P=0.05 level).
[b] At 1.83 m above ground.
[c] At 3.66 m above ground.

<u>The Effect of Air Velocity, Sleeve Spin Speed and Ratio of Liquid Proportioning to 2 Beecomist Sleeves on The Spray Distribution Delivered by a Low Volume Spray System.</u>

The effect of air velocity, sleeve spin speed and ratio of liquid proportioning to 2 sleeves on dye distribution is presented in table 6 and figures 7-10.

In general as the air velocity is increased, the deposit decreases in the near region of the tree while increasing in the side, center and far regions. The difference in regional deposit as a function of air velocity, however, was usually only significant (P=0.10) for the 2 extreme air velocities. It is believed that as air velocity is increased, the peripheral (near) foliage is deflected to a greater extent which allows more spray into the tree canopy. This belief is also held by Hall <u>et al</u>. (1975) and Randall (1971). It is believed that an increase in air velocity also provides for more efficient impingement of available spray droplets within a region. A greater reduction in dye deposit occurred as the spray moved from the near to the center region of the tree (77% average) as compared to the equivalent distance from the center to the far region (53% average).

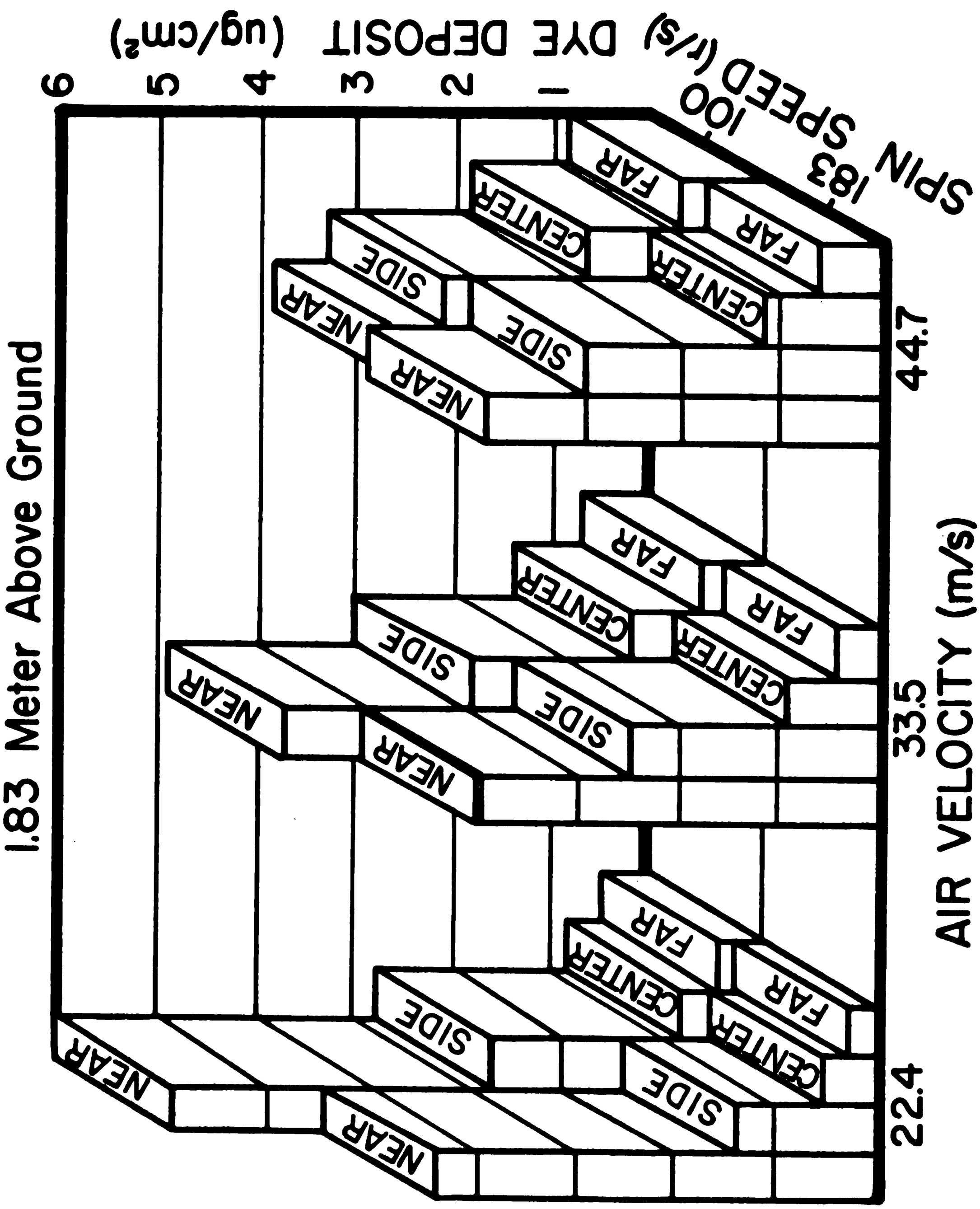
A greater deposit was achieved at the slower sleeve spin speed although the difference was significant (P=0.10) in only 9 of 48 comparisons. Table 17 reveals that a larger droplet size is produced at the slower spin speed which could result in the increased deposit through more efficient impingement. Whether or not the increased deposit provided by larger droplets is advantageous would depend entirely upon the situation encountered. For example, in

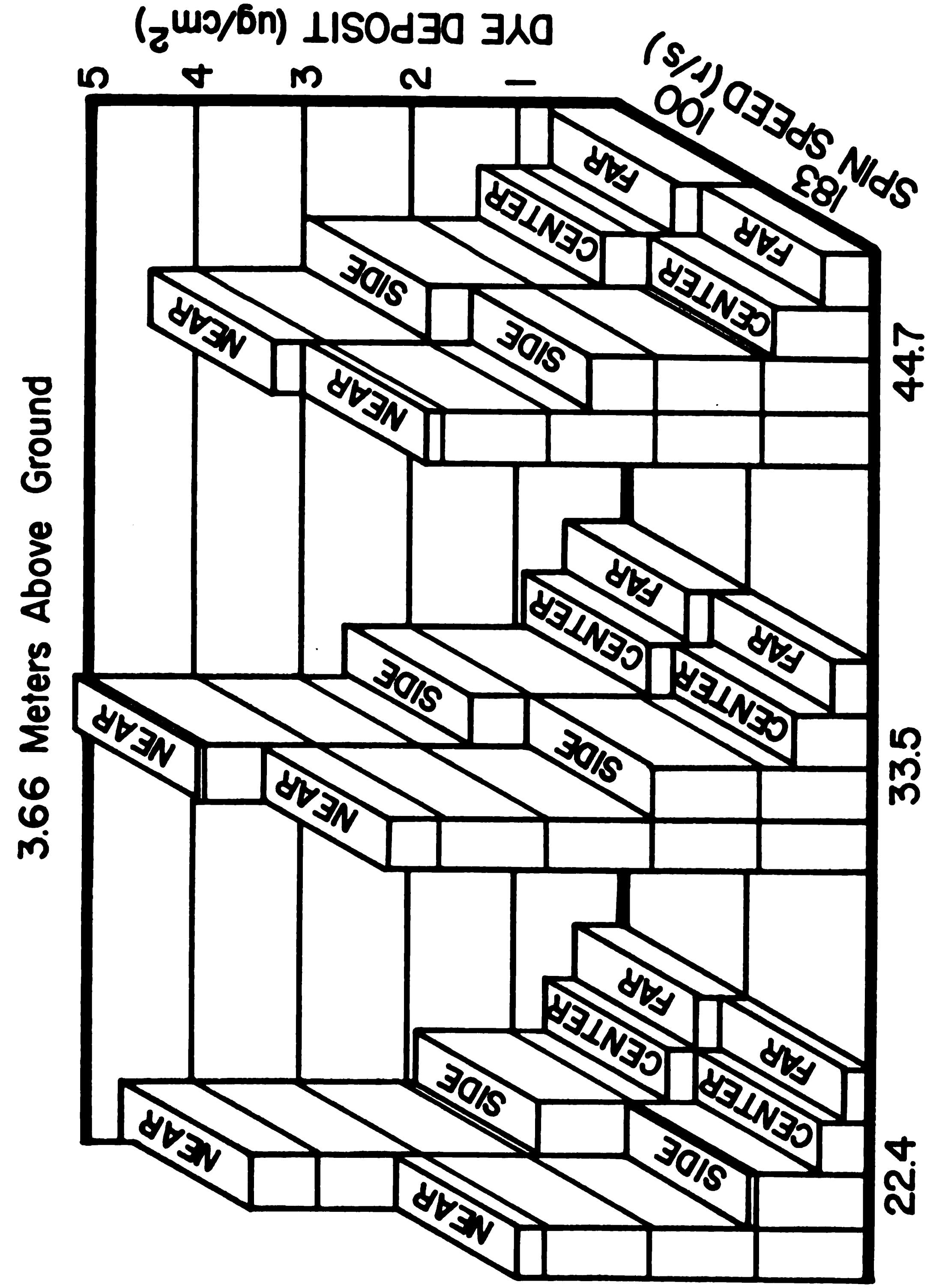
Table 6. - The distribution of dye, delivered by a low volume spray system, in semi-dwarf Red Delicious apple trees as effected by air velocity, sleeve spin speed and ratio of liquid proportioning to 2 sleeves.[a]

	Air Velocity (m/s)	Sleeve Spin Speed (r/s)	Fluorescein Deposit (ug/cm^2) Tree Region (1.83 m above ground)				Tree Region (3.66 m above ground)			
			Near	Side	Center	Far	Near	Side	Center	Far
EQUAL SLEEVE DELIVERY	22.4	100	6.07 e	2.78 de	0.82 abc	0.52 bcde	4.63 abc	1.89 abc	0.73 ab	0.44 bcd
	"	183	4.51 bcd	1.50 ab	0.58 ab	0.32 ab	3.30 a	1.13 a	0.45 a	0.26 ab
	33.5	100	4.86 cde	3.04 e	1.41 de	0.70 def	5.13 bc	2.63 cde	0.98 abcd	0.57 de
	"	183	4.14 abc	2.56 cde	0.98 bcd	0.46 abcd	4.55 abc	2.15 bcd	0.74 ab	0.37 abc
	44.7	100	3.79 abc	3.28 e	1.82 e	0.84 f	4.44 abc	2.96 def	1.41 cd	0.70 e
	"	183	4.07 abc	3.02 de	1.21 cd	0.59 cde	4.19 abc	2.66 cde	0.92 abc	0.48 cd
UNEQUAL SLEEVE DELIVERY	22.4	100	5.70 de	1.99 abcd	0.51 ab	0.31 ab	5.32 bc	2.57 cde	0.95 abcd	0.36 abc
	"	183	4.01 abc	1.16 a	0.37 a	0.21 a	4.09 ab	1.62 ab	0.72 ab	0.18 a
	33.5	100	4.11 abc	2.41 bcde	0.97 bcd	0.52 bcde	6.86 d	3.35 ef	1.50 de	0.41 bcd
	"	183	3.31 ab	1.72 abc	0.60 ab	0.30 ab	5.63 cd	2.71 cde	1.05 bcd	0.28 ab
	44.7	100	3.27 ab	2.74 de	1.36 cde	0.72 ef	5.71 cd	3.83 f	1.98 e	0.53 cde
	"	183	3.05 a	2.33 bcde	0.85 abc	0.40 abc	5.02 bc	3.46 ef	1.43 cd	0.36 abc

[a] Means in a given column followed by a common letter are not significantly different (P=0.10 level).

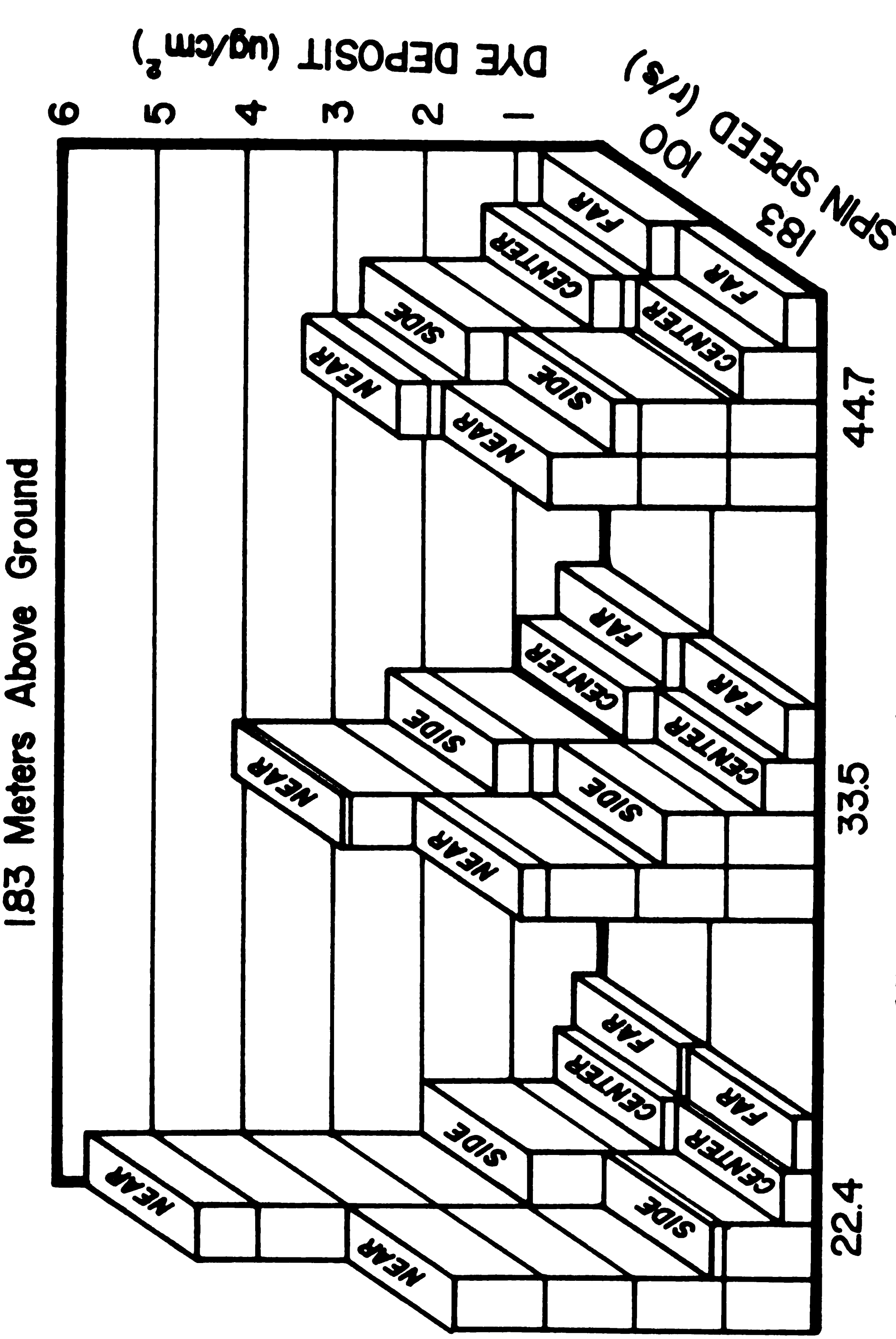
Figures 7 and 8. - The effect of air velocity and sleeve spin speed on the distribution of dye, delivered (equal sleeve delivery) by a low volume spray system, in semi-dwarf Red Delicious apple trees.


1.83 Meter Above Ground
DYE DEPOSIT (ug/cm²)
6
5
4
3
2
1
SPIN SPEED (r/s)
100
183
NEAR
SIDE
CENTER
FAR
AIR VELOCITY (m/s)
22.4
33.5
44.7

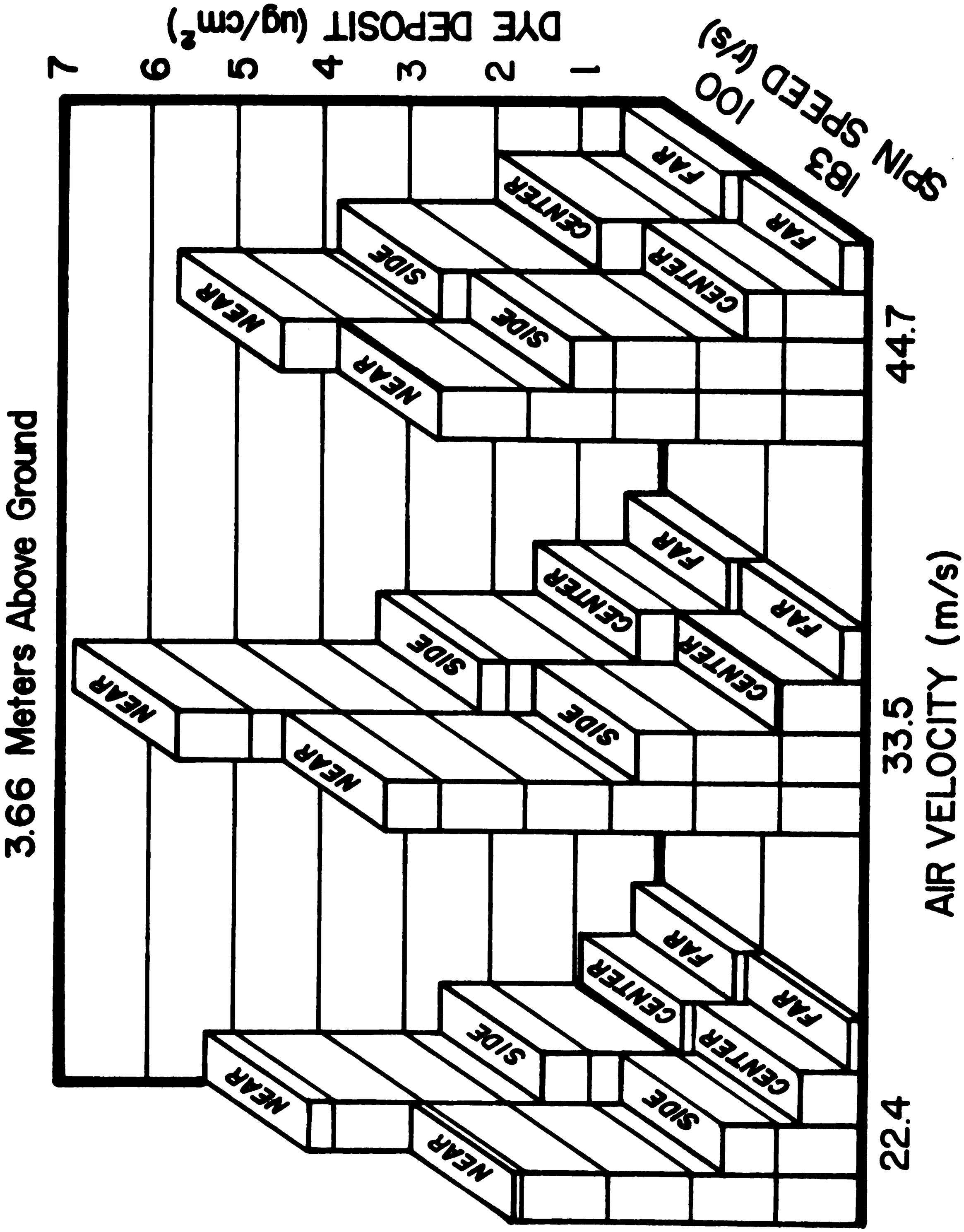


3.66 Meters Above Ground
DYE DEPOSIT (ug/cm²)
5
4
3
2
1
SPIN SPEED (r/s)
100
183
AIR VELOCITY (m/s)
22.4
33.5
44.7
NEAR
SIDE
CENTER
FAR

Figures 9 and 10. - The effect of air velocity and sleeve spin speed on the distribution of dye, delivered (unequal sleeve delivery) by a low volume spray system, in semi-dwarf Red Delicious apple trees.



183 Meters Above Ground
DYE DEPOSIT (ug/cm²)
1
2
3
4
5
6
SPIN SPEED (r/s)
100
183
NEAR
SIDE
CENTER
FAR
AIR VELOCITY (m/s)
22.4
33.5
44.7


3.66 Meters Above Ground
DYE DEPOSIT (ug/cm²)
1
2
3
4
5
6
7
SPIN SPEED (r/s)
100
183
AIR VELOCITY (m/s)
22.4
33.5
44.7
NEAR
SIDE
CENTER
FAR

the control of diseases or relatively sessile arthropod pests, it may very well be more advantageous to produce a greater droplet density, provided by smaller droplets, at a small sacrifice in spray deposit. On the other hand, if a highly mobile pest is the target the higher droplet density may not be required and deposit could be maximized with larger spray droplets. Deciding on the proper droplet size for a given situation is not as simple as presented above however, and must involve consideration of the method of application, the target crop, environmental conditions, as well as the pest organism.

The delivery of 2/3 of the spray volume through the top sleeve resulted in a reduction of dye deposit in the bottom half and an increase in the top half of the tree except for the far region. Except for 2 instances, however, the differences were not significant ($P=0.10$).

Table 7 represents a simulation of dye distribution as would be expected to occur from 2-sided spraying using the data acquired (table 6) in which trees were sprayed from one side. These data reveal that the most uniform distribution of deposit (least difference between tree regions) occurs at the highest air velocity, especially at the lower sleeve spin speed. In comparing tree mean deposit for different air velocities at the same spin speed, no significant difference is seen except between 22.4 and 44.7 m/s at 183 r/s for equal sleeve delivery. No significant difference in tree mean dye deposit occurred as a function of delivery proportioning

Table 7. - Simulated dye distribution as effected by 2-sided spraying using data from low volume spray applications to 1-side of semi-dwarf Red Delicious apple trees (table 6).[a]

	Air Velocity (m/s)	Sleeve Spin Speed (r/s)	Fluorescein Deposit (ug/cm^2) 1.83 m above ground Periphery	1.83 m above ground Center	3.66 m above ground Periphery	3.66 m above ground Center	Tree Mean
EQUAL SLEEVE DELIVERY	22.4	100	6.59 d	1.64 abc	5.07 bc	1.45 ab	3.69 cdef
	"	183	4.83 abc	1.16 ab	3.55 a	0.90 a	2.61 a
	33.5	100	5.56 bcd	2.82 de	5.70 bc	1.96 abc	4.01 def
	"	183	4.60 ab	1.96 bcd	4.93 abc	1.47 ab	3.24 abcd
	44.7	100	4.63 abc	3.63 e	5.14 bc	2.83 cd	4.06 ef
	"	183	4.66 abc	2.42 cd	4.67 abc	1.83 abc	3.40 bcde
UNEQUAL SLEEVE DELIVERY	22.4	100	6.01 cd	1.03 ab	5.67 bc	1.90 abcd	3.65 cdef
	"	183	4.22 ab	0.74 a	4.27 ab	1.43 ab	2.67 ab
	33.5	100	4.63 abc	1.95 bcd	7.27 d	3.01 de	4.22 f
	"	183	3.61 a	1.21 ab	5.91 cd	2.10 bcd	3.21 abc
	44.7	100	3.99 a	2.72 cde	6.24 cd	3.96 e	4.23 f
	"	183	3.45 a	1.70 abc	5.38 bc	2.86 cd	3.35 abcde

[a] Means in a given column followed by a common letter are not significantly different (P=0.10 level).

when comparing the same air velocity and sleeve spin speed.

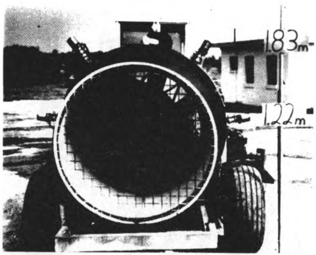
It appears that the variables of air velocity and ratio of delivery proportioning do not have much influence on the average dye deposit but rather influence how the dye is distributed throughout the tree. Which variable condition would be most desireable would depend on the nature of the tree being sprayed as well as the pest distribution within this tree.

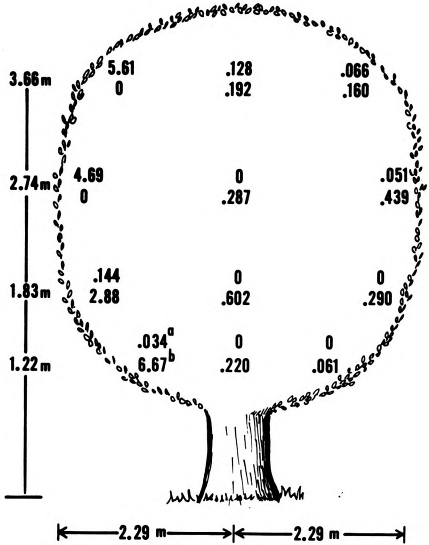
Analysis of Spray Distribution Delivered From Each (2) Beecomist Sleeve on a Low Volume Spray System.

The distribution of dye in a semi-dwarf Red Delicious apple tree as delivered by each Beecomist sleeve is presented in figure 11. The bottom sleeve was responsible for most of the dye delivered to heights of 1.22 and 1.83 m in the tree, whereas most of the deposit encountered at the 2 highest elevations was delivered by the top sleeve. If one compares tree regions at a given height, however, a more representative picture of spray pattern can be seen. Dye delivered by the bottom sleeve was found in 10 of the 12 sampling regions, whereas only 7 of the regions contained dye delivered by the top sleeve.

For some unexplained reason a very low level of transport into the center of the tree was achieved. It would appear that a substantial portion of spray from the top sleeve, which passed through the near region, was transported over the top of the tree above the center sampling region. These data indicate that more efficient spray transport to semi-dwarf trees might be achieved by lowering

Figure 11. - The distribution of dye in a semi-dwarf Red Delicious apple tree as delivered by each (2) Beecomist sleeve on a low volume spray system.





[a] TOP NOZZLE [b] BOTTOM NOZZLE

the top sleeve and channeling the air stream to make the spray pattern more compatible to the smaller size tree.

The distribution of dye in a wooden spray stand (Fig. 12) verifies that a substantial amount of dye from the top sleeve was transported above the center tree region at 3.66 m. In fact, the dye deposit (from the top sleeve) in the center region is slightly greater at 5.49 m than at 3.66 m.

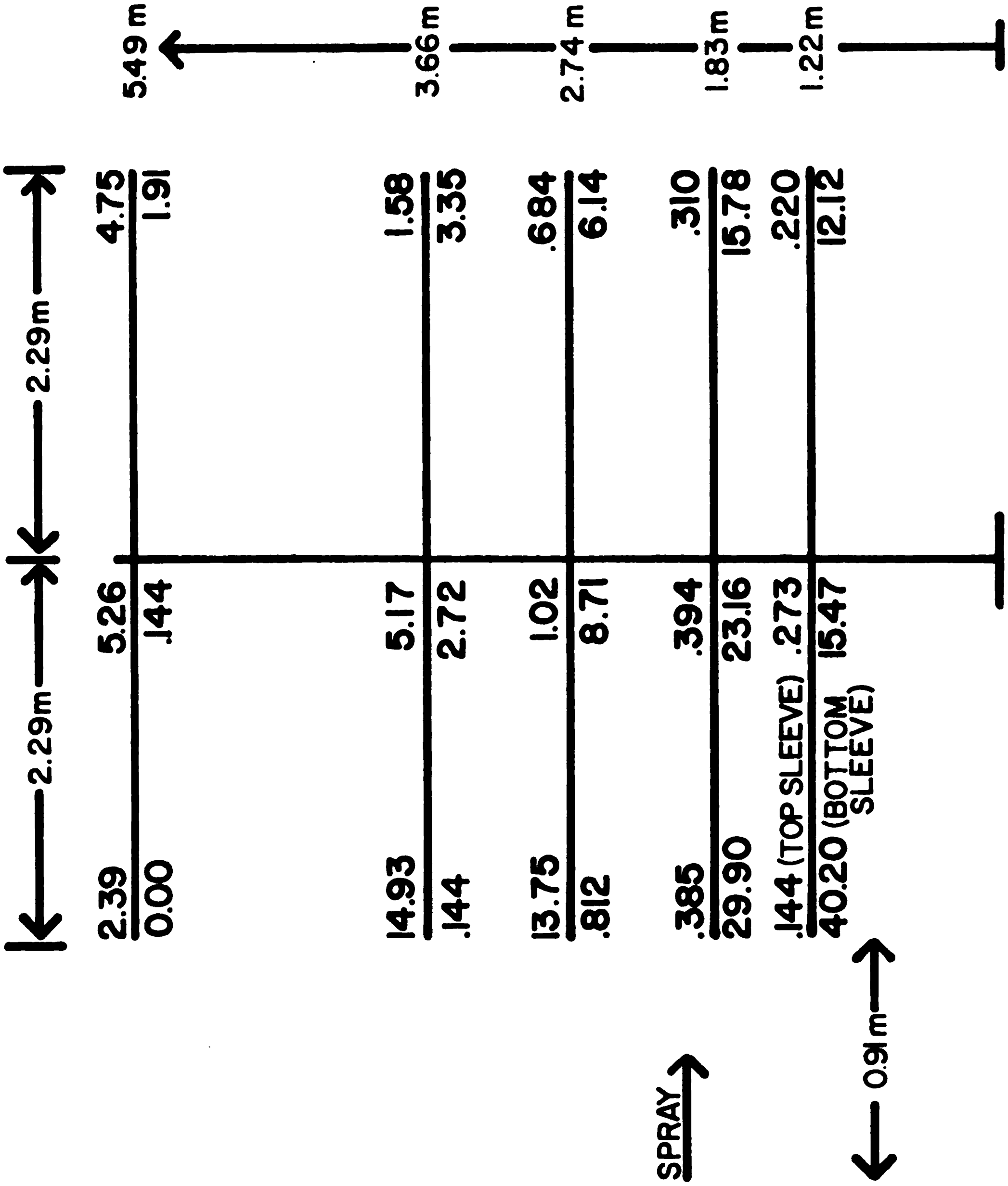
One can also clearly see the expanding spray pattern as delivered by the bottom sleeve. This sleeve delivered over twice as much dye as the top sleeve to the far side of the stand (5.49 m from sprayer) at a height of 3.66 m. This occurrence is also seen in the semi-dwarf tree mentioned above. This helps to explain why a slight reduction in dye deposit occurred in the top far side of the tree when 2/3 of the spray was delivered through the top sleeve in the previous study. By proportioning more liquid to the top sleeve, less is available to the bottom sleeve which is responsible for most of the spray transport to the far region at 3.66 m.

The use of a wooden spray stand in spray distribution studies can yield valuable information concerning spray patterns from particular nozzle arrangements in order to maximize pesticide transport to a given size (height and diameter) tree.

Comparison of Dye Distribution Delivered by Low Volume and Conventional Spray Systems to Semi-Dwarf and Standard Size Red Delicious Apple Trees.

The distribution of dye in semi-dwarf Red Delicious apple trees as delivered by both spray systems is presented in table 8

Figure 12. - The distribution of dye in a wooden spray stand as delivered by each (2) Beecomist sleeve on a low volume spray system.


5.49 m
3.66 m
2.74 m
1.83 m
1.22 m
2.29m
2.29m
4.75
1.91
1.58
3.35
.684
6.14
.310
15.78
.220
12.12
5.26
.144
5.17
2.72
1.02
8.71
.394
23.16
.273
15.47
(TOP SLEEVE)
(BOTTOM SLEEVE)
2.39
0.00
14.93
.144
13.75
.812
.385
29.90
.144
40.20
SPRAY
0.91 m

and figure 13. Although no significant difference ($P=0.05$) in deposit between the spray systems was noted, except for the side region (1.83 m above ground) and the near region (3.66 m above ground), a greater reduction in deposit as the spray moved through the tree is observed with the low volume spray system.

The distribution of dye in standard size trees (table 9, figure 14) delivered by both spray systems reveals that the low volume spray system delivered significantly ($P=0.05$) less dye to region A (near) at 1.83 m and 5.49 m above ground, yet slightly more (not significant) than the conventional system to this region at a height of 3.66 m. The lower deposit at 1.83 m is probably due to the fact that 2/3 of the spray volume was delivered through the top sleeve which is transported in greatest quantity to a height of 3.66 m. The lower low volume deposit at 5.49 m (region A) is believed to be due to the short horizontal spray travel distance (from sprayer to tree) which is not sufficient to allow the expanding spray pattern from the top sleeve to reach this height. This is not a severe problem with the conventional spray system because the spray droplets are dispensed in this direction under hydraulic pressure, whereas the spray droplets from the Beecomist sleeve are dispensed perpendicular to the air stream and must be turned by the air stream to be transported to the tree.

By the time the spray pattern has traveled the horizontal distance required to reach region C (center) at 5.49 m above ground, sufficient expansion of spray pattern from the top sleeve has

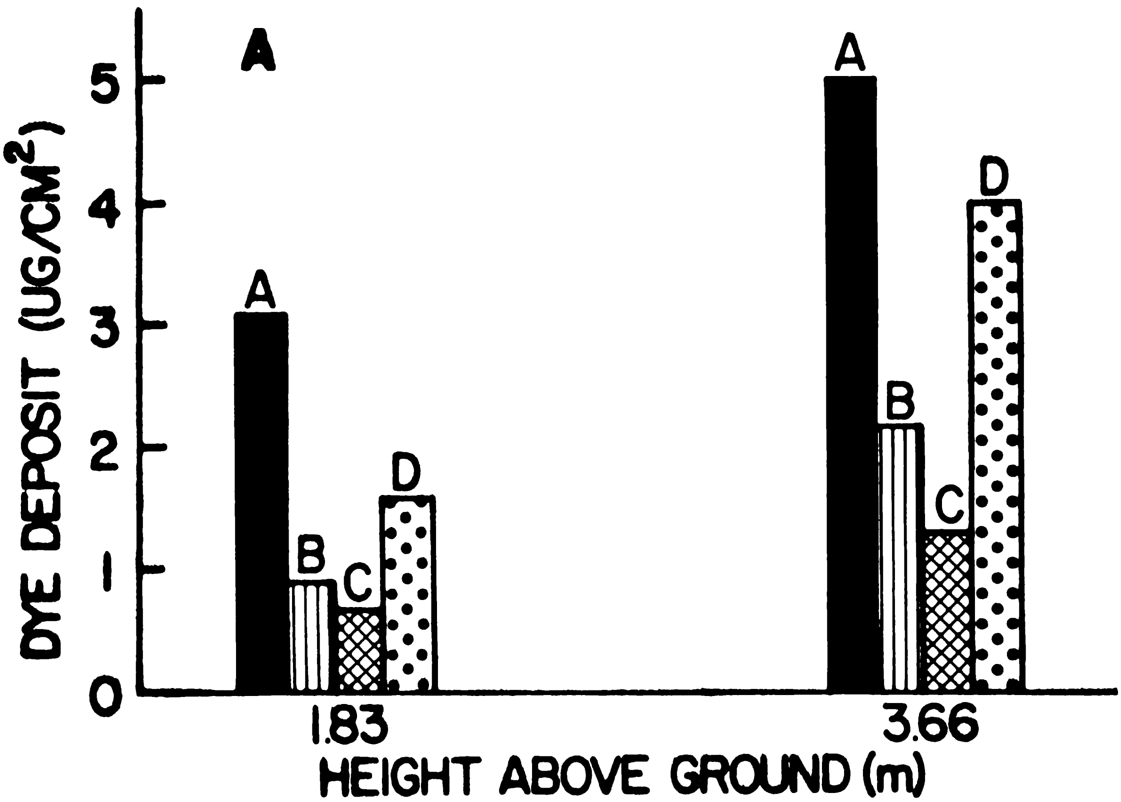
Table 8. - The distribution of dye delivered by low volume and conventional spray systems to semi-dwarf Red Delicious apple trees on August 10, 1978.[a]

	Dye Deposit (ug/cm^2)							
	Tree Region (1.83 m above ground)				Tree Region (3.66 m above ground)			
Treatment	Near (A)	Center (B)	Far (C)	Side (D)	Near (A)	Center (B)	Far (C)	Side (D)
Low Volume	3.04 ef	0.89 ab	0.65 a	1.54 bc	4.95 h	2.13 cd	1.28 abc	3.91 g
Conventional	3.80 fg	1.45 abc	0.95 ab	2.77 de	3.63 fg	2.64 de	1.45 abc	3.45 efg

[a] Any means followed by a common letter are not significantly different (P=0.05 level).

Figure 13. - The distribution of dye in a semi-dwarf Red Delicious apple tree as delivered by low volume (A) and conventional (B) spray systems.

A = Near
B = Center
C = Far
D = Side


A
DYE DEPOSIT (UG/CM²)
0
1
2
3
4
5
A
B
C
D
1.83
3.66
HEIGHT ABOVE GROUND (m)

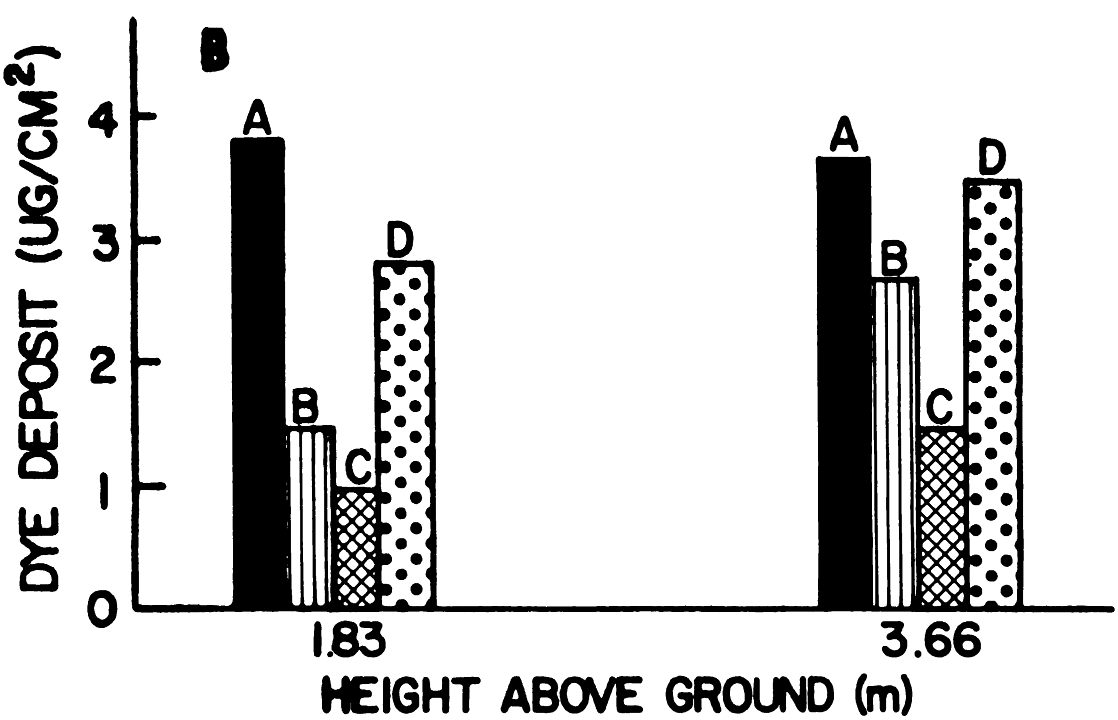

B
DYE DEPOSIT (UG/CM²)
0
1
2
3
4
A
B
C
D
1.83
3.66
HEIGHT ABOVE GROUND (m)

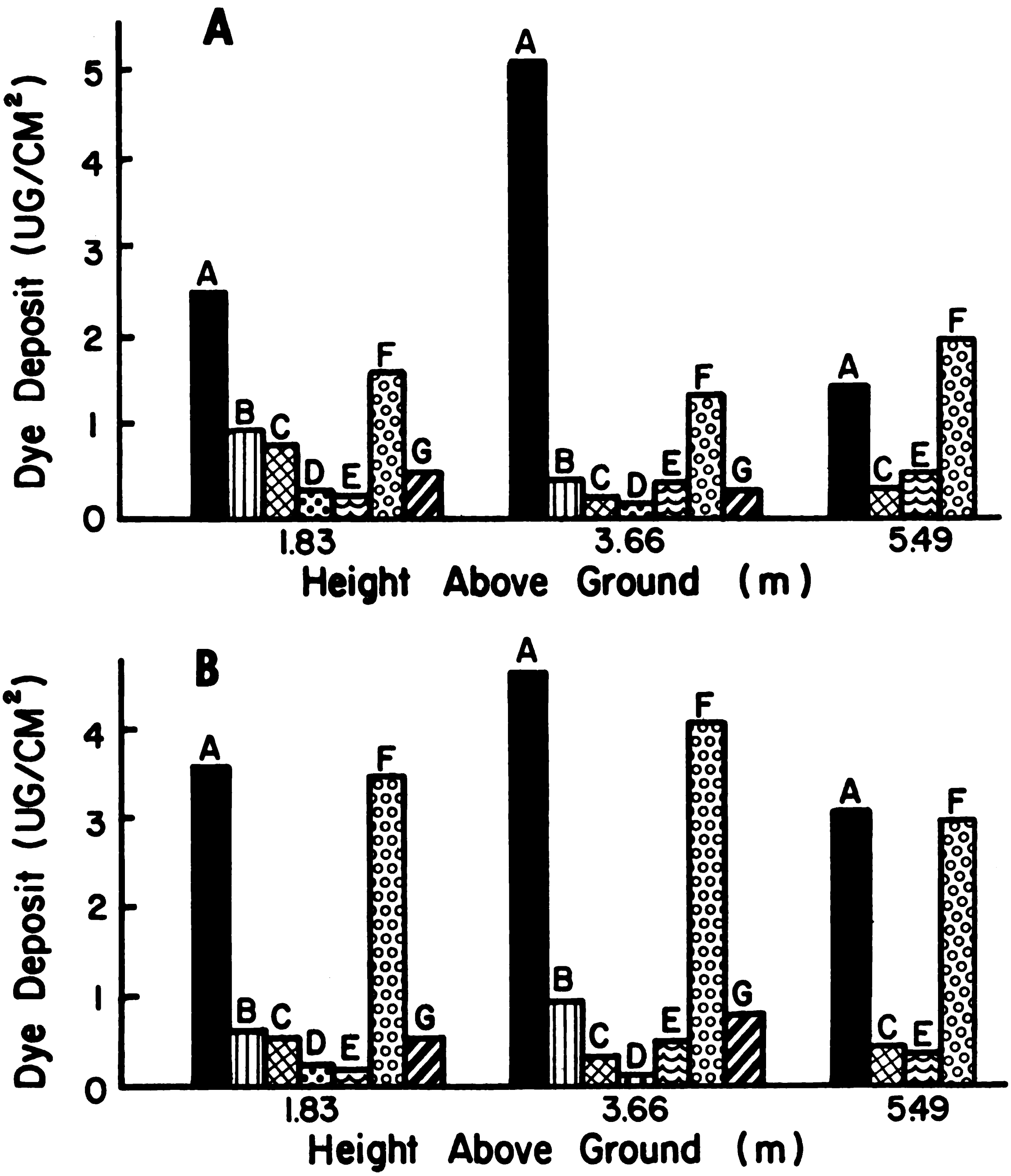
Table 9. - The distribution of dye delivered by low volume and conventional spray systems to standard size Red Delicious apple trees on August 15, 1978.[a]

Height Above Ground (m)	Dye Deposit (ug/cm^2) Tree Region						
	A (Near)	B (Near-Middle)	C (Center)	D (Far-Middle)	E (Far)	F (Side)	G (Side-Middle)
1.83	2.51[b] gh	0.94 cde	0.77 abc	0.27 ab	0.24 ab	1.62 ef	0.48 ab
	3.58[c] ij	0.65 abc	0.57 ab	0.24 ab	0.20 ab	3.48 ij	0.55 ab
3.66	5.12 l	0.40 ab	0.17 ab	0.15 a	0.40 ab	1.37 def	0.26 ab
	4.63 kl	0.95 cde	0.35 ab	0.15 a	0.54 ab	4.11 jk	0.82 bcd
5.49	1.51 def	--------	0.32 ab	--------	0.49 ab	2.07 fg	--------
	3.13 hi	--------	0.43 ab	--------	0.39 ab	2.97 hi	--------

a Any Means followed by a common letter are not significantly different (P=0.05 level).
b Low volume spray system.
c Conventional spray system.

Figure 14. - The distribution of dye in a standard size Red Delicious apple tree as delivered by low volume (A) and conventional (B) spray systems.

A = Near
B = Near-Middle
C = Center
D = Far-Middle
E = Far
F = Side
G = Side-Middle


A
Dye Deposit (UG/CM^2)
0
1
2
3
4
5
A
B
C
D
E
F
G
A
B
C
D
E
F
G
A
C
E
F
1.83
3.66
5.49
Height Above Ground (m)
B
Dye Deposit (UG/CM^2)
0
1
2
3
4
A
B
C
D
E
F
G
A
B
C
D
E
F
G
A
C
E
F
1.83
3.66
5.49
Height Above Ground (m)

occurred resulting in no significant difference in deposit between spray systems. The effect of spray pattern expansion from Beeco-mist sleeves on deposit can clearly be seen by comparing the deposit at 3.66 m and 5.49 m for regions C and F, both of which are equivalent horizontal distances from the sprayer. The greater deposit (although not significant) at 5.49 m for regions C and F is believed to be due to the fact that the bulk of the spray from the top sleeve has passed above these regions by the time the same horizontal distance has been traveled at 3.66 m.

A simulated, 2-sided spraying, deposit (table 10) reveals that no significant difference (except for standard trees, periphery region at 5.49 m) occurred between spray systems in the deposit obtained in a given region for a given tree size. A drastic difference in deposit (with both spray systems) was noted in the center region at 3.66 m when comparing both tree sizes. The significantly lower deposit in the standard size tree is believed to be due largely to a denser foliage canopy and the greater travel distance required to reach this region in the standard size tree. The reduced deposit in the center regions of the standard size tree is the major factor contributing to a mean tree deposit that is significantly less than that achieved in semi-dwarf trees with both spray systems. Although the mean tree deposit was 44-47% less for standard size trees as compared to semi-dwarf, no significant difference between spray systems for a given size tree was discovered.

The above data reveals that efficient spray transport to apple

Table 10. - Simulated dye distribution as effected by 2-sided spraying using data from low volume and conventional spray applications to 1 side of semi-dwarf (table 8) and standard size (table 9) Red Delicious apple trees.[a]

		Dye Deposit (ug/cm^2)						
		1.83 m above ground		3.66 m above ground		5.49 m above ground		
Treatment	Tree Size	Periphery	Center	Periphery	Center	Periphery	Center	Tree Mean
Low Volume	Semi-Dwarf	3.69 efg	1.78 bcd	6.23 j	4.25 fgh	---------	------	3.99 fgh
Conventional	"	4.76 ghi	2.91 de	5.07 hij	5.29 hij	---------	------	4.50 ghi
Low Volume	Standard	2.74 de	1.54 abc	5.52 ij	0.34 a	2.00 cd	0.63 ab	2.13 cd
Conventional	"	3.78 efg	1.14 abc	5.18 hij	0.70 ab	3.52 ef	0.86 abc	2.53 de

[a] Any means followed by a common letter are not significantly different (P=0.05 level).

trees must involve a consideration of tree height, diameter and foliage density so that spray nozzles can be positioned, and pesticide rates adjusted to achieve sufficient coverage for effective pest control.

Spray Droplet Spectra Analysis of a Conventional and Low Volume Spray System as Determined in Open and Foliage Environments With a Droplet Impingement Harp.

The percent number of droplets and volume of spray in various droplet size classes for a conventional and low volume spray system as determined in open and foliage environments is presented in tables 11 and 12, respectively. The low volume spray system produced a much narrower, small-droplet, spectrum as compared to the conventional spray system.

For the conventional spray system, droplet distributions which passed through foliage contained a greater proportion (by number and volume) of droplets in smaller size classes than those obtained in an open environment. The largest droplet caught in an open environment was 584 um, whereas in a foliage environment no droplets larger than 437 um were encountered. This same filtering effect of a foliage environment on spray spectra was reported by Reichard et al. (1978), using an optic probe for droplet sizing. The increase in percent volume in smaller droplet size classes, of spray passing through foliage, is not due so much to greater numbers of small droplets but rather to a lack of large droplets which contribute greater volume percentages. Because the large droplets are not as prevalent in the foliage environment a greater percentage of the

Table 11. - Spray[a] droplet statistics for a conventional spray system as determined in open and foliage environments with a droplet impingement harp.

Droplet Size Class (um)	Wire Size (Diameter): 5 um Tungsten % Number	5 um Tungsten % Volume	15 um Stainless Steel % Number	15 um Stainless Steel % Volume	25 um Stainless Steel % Number	25 um Stainless Steel % Volume	50 um Stainless Steel % Number	50 um Stainless Steel % Volume
0 - 100	83.4[b]	9.1	60.9	2.8	54.9	1.4	24.8	0.5
	93.5[c]	16.6	82.6	13.5	74.4	9.6	43.9	3.4
101 - 200	13.1	32.0	26.4	19.0	26.3	11.0	37.1	9.3
	5.1	29.4	13.4	23.1	21.3	24.5	41.8	23.6
201 - 300	2.7	33.9	9.7	35.0	11.4	25.7	23.4	23.5
	1.2	36.3	3.3	32.6	3.4	32.9	12.6	36.5
301 - 400	0.7	25.0	2.2	22.0	5.4	28.7	9.7	27.4
	0.2	17.7	0.7	30.8	0.9	33.0	1.5	26.8
401 - 500	0.0	0.0	0.7	15.6	1.2	14.6	3.3	19.2
	0.0	0.0	0.0	0.0	0.0	0.0	0.2	9.7
501 - 600	0.0	0.0	0.2	5.6	0.8	18.6	1.6	20.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[a] Dioctyl Phthalate (Wolverine Solvents Company).
[b] In open (height of 1.83 m; distance of 3.05 m).
[c] In foliage (height of 1.83 m; distance of 3.20 m).

Table 12. - Spray[a] droplet statistics for a controlled porosity low volume spray system as determined in open and foliage environments with a droplet impingement harp.

Droplet Size Class (um)	Wire Size (Diameter) 5 um Tungsten % Number	5 um Tungsten % Volume	15 um Stainless Steel % Number	15 um Stainless Steel % Volume
0 - 25	51.1[b]	8.5	30.1	3.2
	51.9[c]	9.1	29.9	3.4
26 - 50	41.2	50.3	54.8	46.6
	41.3	55.3	57.1	55.9
51 - 75	7.5	38.7	13.7	40.5
	6.8	35.6	12.6	38.0
76 - 100	0.2	2.5	1.4	9.7
	0.0	0.0	0.4	2.7

[a] Dioctyl Phthalate (Wolverine Solvents Company).
[b] In open (height of 1.83 m; distance of 3.05 m).
[c] In foliage (height of 1.83 m; distance of 3.20 m).

spray volume is occupied by small droplet size classes.

At an air velocity of 11.6 m/s (at 3.05 m), no droplets larger than 375 um were obtained on 5 um tungsten wire. Of a total of 1966 droplets measured (in the open) on this size wire only 14 were discovered between 301-400 um. Under the conditions tested it is believed that the 50 um wire was of sufficient size to capture the largest droplet delivered by the conventional spray system. This belief is based on the fact that only 3 droplets were obtained with the 50 um wire that were larger (by 5-32 um) than the largest droplet obtained with the 25 um wire.

With the low volume spray system very little difference in the droplet distribution encountered in open and foliage environments was observed. The largest droplet obtained in the open and foliage environments was 91 and 78 um, respectively. Under the conditions tested it is believed that the 15 um wire did catch the largest droplet produced by the low volume spray system because only 2 droplets were caught which were larger (by 3 um) than the largest size obtained with the 5 um wire.

The data suggests that smaller droplets would be more efficient pesticide transport agents into inner foliage habitats. The results obtained are believed to be due to the tendency of small droplets to follow the air flow pattern around obstructions rather than impinging on the first obstacle in their path, as is frequently the case with large droplets. Although small droplets may be more efficient transport agents into foliage microhabitats, the efficiency of deposition would depend upon droplet velocity, target configuration and environmental conditions.

Studies on The Parameters Which Affect Spray Spectra Characteristics From Rotary Sleeve Nozzles.

A. The Effect of Sleeve Construction, Rotational Velocity and Sprayer Air Velocity on Droplet Spectra.

Table 13 presents droplet size statistics for spray distributions delivered by various Beecomist sleeve types under different operating conditions. The individual spectra are presented in their entirety in figure 15, whereas the spray spectrum from 2 Beecomist sleeve types is illustrated in a 3-dimensional form in figure 16. The terms D_{10}, D_{50} and D_{90} in table 13 represent cut-off points (in droplet sizes) on the abscissa at which 10, 50 and 90 percent of the volume has been accumulated. The difference between D_{10} and D_{90} is used as an index of the spectrum's width.

From the data presented it can be seen that porosity and construction has very little effect on the droplet spectrum produced by porous sleeve types. These findings are in agreement with information presented by Schmidt (1967). Even the perforated stainless steel sleeve produced spray spectra quite similar to the 3 porous types, except that the spectra are a little wider, and the D_{50} values are higher for the 2 high sleeve velocities but not for the low one.

Of the porous sleeve types, the stainless steel produces a droplet spectrum that is slightly narrower than the polyethylene,

Table 13. - The effect of sleeve construction, rotational velocity and carrier air velocity on the aqueous droplet spectrum delivered by Beecomist sleeves.[a,b,c,d]

Sleeve Type	Air Velocity (m/s)	Sleeve Velocity (r/s)	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume D_{10}	D_{50}(VMD)	D_{90}	D_{90}-D_{10}
20 um stainless steel	22.4	50	299	349	422	123
" " "	"	100	142	191	264	122
" " "	"	183	56	98	157	101
" " "	44.7	50	253	406	485	232
" " "	"	100	167	209	282	115
" " "	"	183	57	93	135	78
60 um stainless steel	22.4	50	276	333	390	114
" " "	"	100	136	196	263	127
" " "	"	183	58	101	159	101
" " "	44.7	50	243	363	457	214
" " "	"	100	152	200	283	131
" " "	"	183	57	91	136	79
70 um polyethylene	22.4	50	190	319	420	230
" "	"	100	110	173	250	140
" "	"	183	52	98	160	108
" "	44.7	50	243	345	443	200
" "	"	100	134	193	285	151
" "	"	183	49	85	137	88
perforated stainless steel	22.4	50	182	299	416	234
" "	"	100	123	198	283	160
" "	"	183	57	112	204	147
" "	44.7	50	198	309	410	212
" "	"	100	141	205	281	140
" "	"	183	68	115	214	146

[a] Beeco Products Company.
[b] Operating parameters: delivery rate (1 sleeve) = 6.7 ml/s; optic probe distance = 0.91 m; optic probe height = 1.37 m.
[c] Environmental conditions: temperature range = 21-25°C; RH range = 37-42%.
[d] Surface tension = 72.8 dynes/cm at 24°C.
[e] ±15 um of reported values.

Figure 15. - The effect of sleeve construction, rotational velocity, and carrier air velocity on the aqueous spray droplet spectrum delivered by Beecomist sleeves.

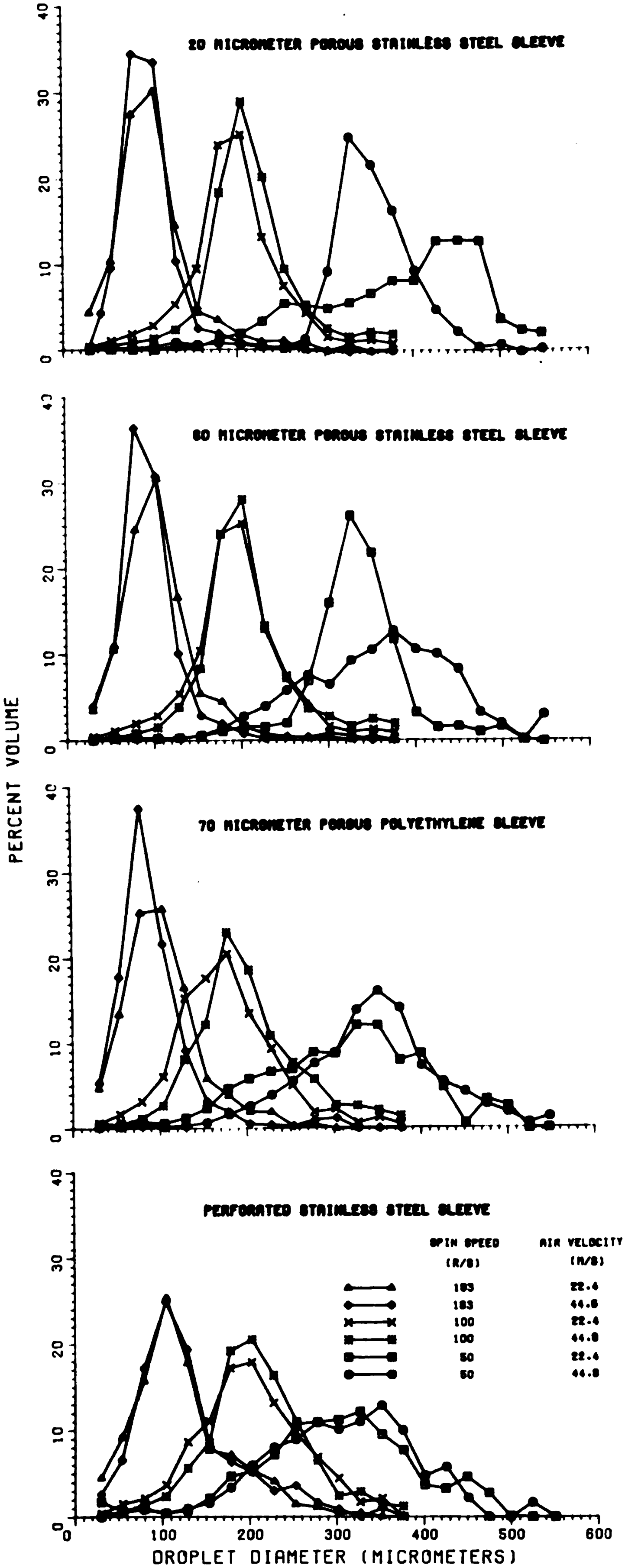
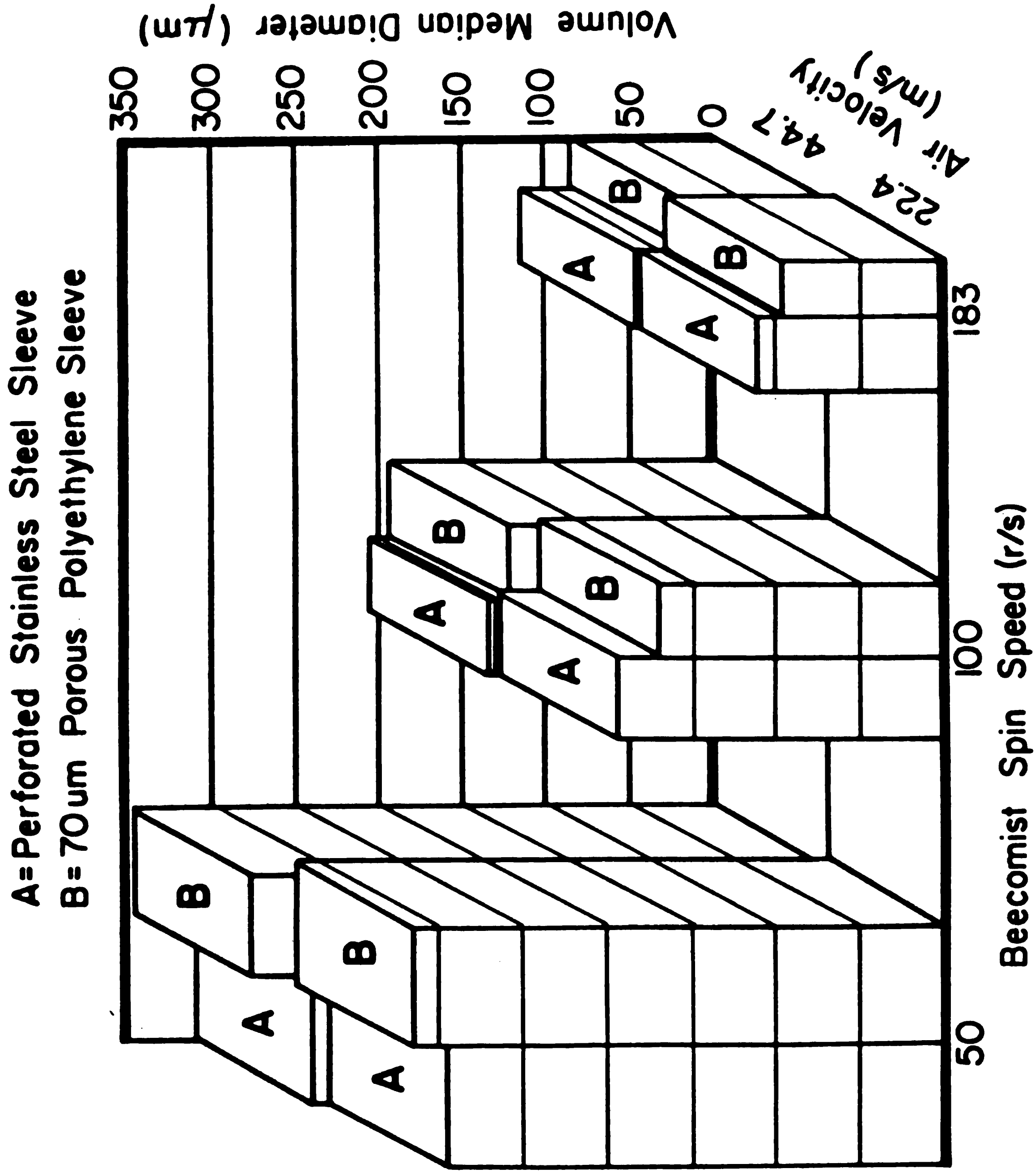

PERCENT VOLUME
20 MICROMETER POROUS STAINLESS STEEL SLEEVE
60 MICROMETER POROUS STAINLESS STEEL SLEEVE
70 MICROMETER POROUS POLYETHYLENE SLEEVE
PERFORATED STAINLESS STEEL SLEEVE
SPIN SPEED (R/S)
AIR VELOCITY (M/S)
183 22.4
183 44.8
100 22.4
100 44.8
50 22.4
50 44.8
0 10 20 30 40
0 100 200 300 400 500 600
DROPLET DIAMETER (MICROMETERS)

Figure 16. - The effect of sprayer air velocity and sleeve rotational velocity on the aqueous spray droplet spectrum delivered by 2 Beecomist sleeve types.
Droplet size (volume median diameter) is indicated on the vertical axis, and the width of the droplet spectrum (D_{90}-D_{10}) is indicated by the relative width of the blocks.


A=Perforated Stainless Steel Sleeve
B=70um Porous Polyethylene Sleeve
Volume Median Diameter (μm)
350
300
250
200
150
100
50
0
Air Velocity (m/s)
44.7
22.4
Beecomist Spin Speed (r/s)
50
100
183
A
B

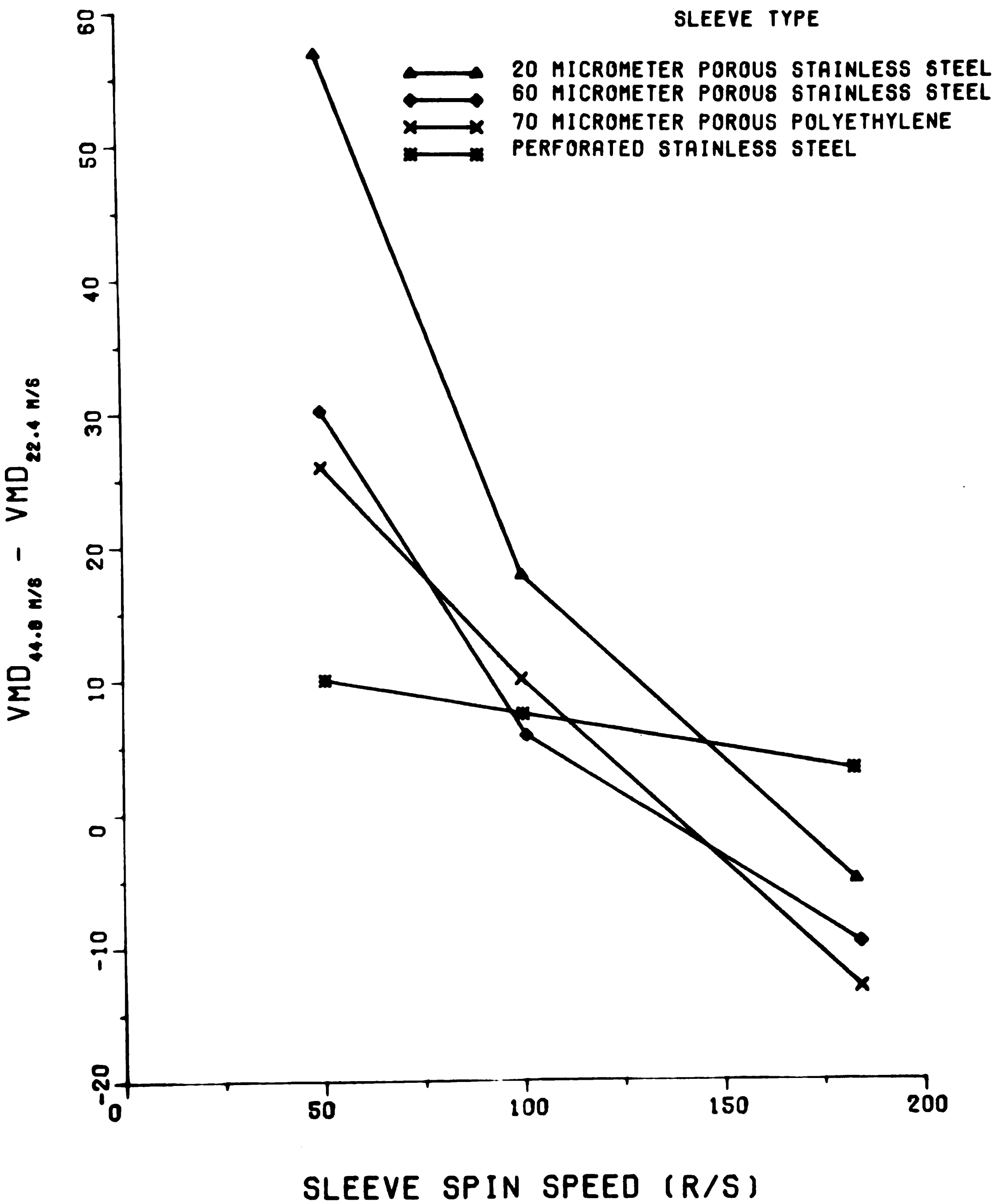
except for an air velocity of 44.7 m/s and rotational velocity of 50 r/s. This exception may have resulted from poor sampling in which the larger droplets delivered at 50 r/s may have caused a more rapid liquid build-up on the sampling tubes which was blown by the sampling window as random large drops by this higher air speed. The differences between stainless steel and polyethylene decreased as the rotational velocity increased. This relationship occurred with all rotational velocities at an air speed of 22.4 m/s and for rotational velocities of 100 and 183 r/s at an air speed of 44.7 m/s.

The rotational velocity of the spinning sleeve has a significant effect on the droplet spectrum produced. In all cases, as the rotational velocity of the sleeve is increased, the D_{50} of the spectrum decreases. The width of the spectrum (D_{90}-D_{10}) also decreases, except for the 60 um stainless steel when going from 50 to 100 r/s at the low air velocity.

In figure 17, the change in VMD occurring as a result of increasing the air velocity from 22.4 to 44.7 m/s is plotted against 3 rotational velocities for each sleeve type. These data indicate that there is clearly an interaction between sleeve rotational velocity and the difference that occurs in VMD between the 2 air velocities. The difference in VMD that occurs with increasing air velocity decreases from a positive value to a negative value as the rotational velocity increases from 50 to 183 r/s.

In figure 18, the droplet spectrum of a 20 um stainless steel

Figure 17. - The effect of sprayer air velocity on volume median diameter (VMD) at 3 rotational velocities for 4 Beecomist sleeve types.


SLEEVE TYPE
20 MICROMETER POROUS STAINLESS STEEL
60 MICROMETER POROUS STAINLESS STEEL
70 MICROMETER POROUS POLYETHYLENE
PERFORATED STAINLESS STEEL
$VMD_{44.8\ M/S}$ - $VMD_{22.4\ M/S}$
60
50
40
30
20
10
0
-10
-20
0
50
100
150
200
SLEEVE SPIN SPEED (R/S)

sleeve is plotted as percent number of droplets as a function of droplet size. When droplet number is considered rather than spray volume, the spectra take on a bimodal characteristic which is particularly pronounced for the 2 slowest rotational velocities. Analagous spectra for each of the other sleeve types show this characteristic, though this phenomenon is less pronounced for the perforated sleeve. Comparison of figures 15 and 18 shows that the left hand peak of a droplet number spectrum contributes very little to the volume of the total spray, and that the right hand peak is the one that is shifted by changing sleeve rotational velocity.

In figure 19, the aqueous droplet spectrum delivered by a 70 um polyethylene sleeve is compared with that produced by several typical hydraulic and one pneumatic type nozzle. Of all the nozzles tested, the spinning sleeve nozzle produced the narrowest, smallest droplet spectrum.

The operational characteristics of variable VMD and narrowness of droplet spectra relative to other commercial nozzles would seem to make the spinning sleeve sprayhead an attractive candidate for both droplet size/efficacy studies and future prescription spray application programs.

B. The Effect of Flow Rate on Droplet Spectra.

As the delivery rate is increased with both sleeve types tested (table 14) the spray droplet size is increased as well as the width of the spectrum (D_{90}-D_{10}). This could be a result of the intrinsic effects of delivery rate on the droplet formation mechanism, a

Figure 18. - The effect of sleeve rotational velocity and sprayer air velocity on the percent number aqueous spray droplet spectrum delivered by a Beecomist 20 um porous stainless steel sleeve.

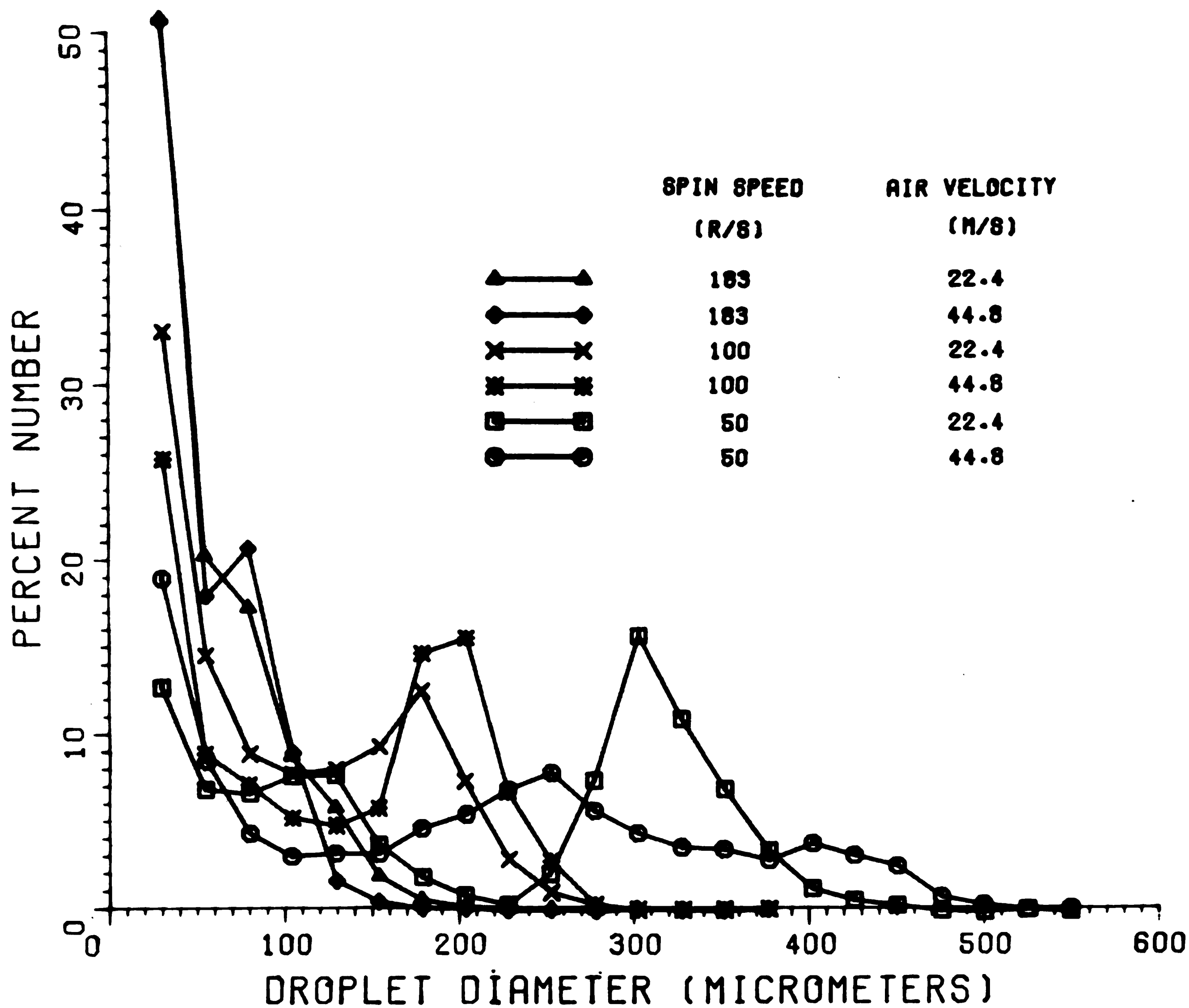

SPIN SPEED
(R/S)
AIR VELOCITY
(M/S)
183 22.4
183 44.8
100 22.4
100 44.8
50 22.4
50 44.8
PERCENT NUMBER
0
10
20
30
40
50
0
100
200
300
400
500
600
DROPLET DIAMETER (MICROMETERS)

Figure 19. - Aqueous spray droplet spectra delivered by various nozzle types.

Operating Conditions:

Beecomist: carrier air velocity = 33.5 m/s.
sleeve rotational velocity = 183 r/s.
delivery rate = 6.7 ml/s.
distance = 0.91 m.

Spraying Systems: pressure = 14.1 kg/cm^2.
distance = 0.61 m.

Kinkelder: dial setting = 80.
PTO = 9 r/s.
distance = 1.1 m.

FMC No. 3 Disc, No. 2 Core: pressure = 14.1 kg/cm^2.
distance = 0.61 m.

FMC No. 5 Disc, No. 3 Core: pressure = 14.1 kg/cm^2.
distance = 0.61 m.

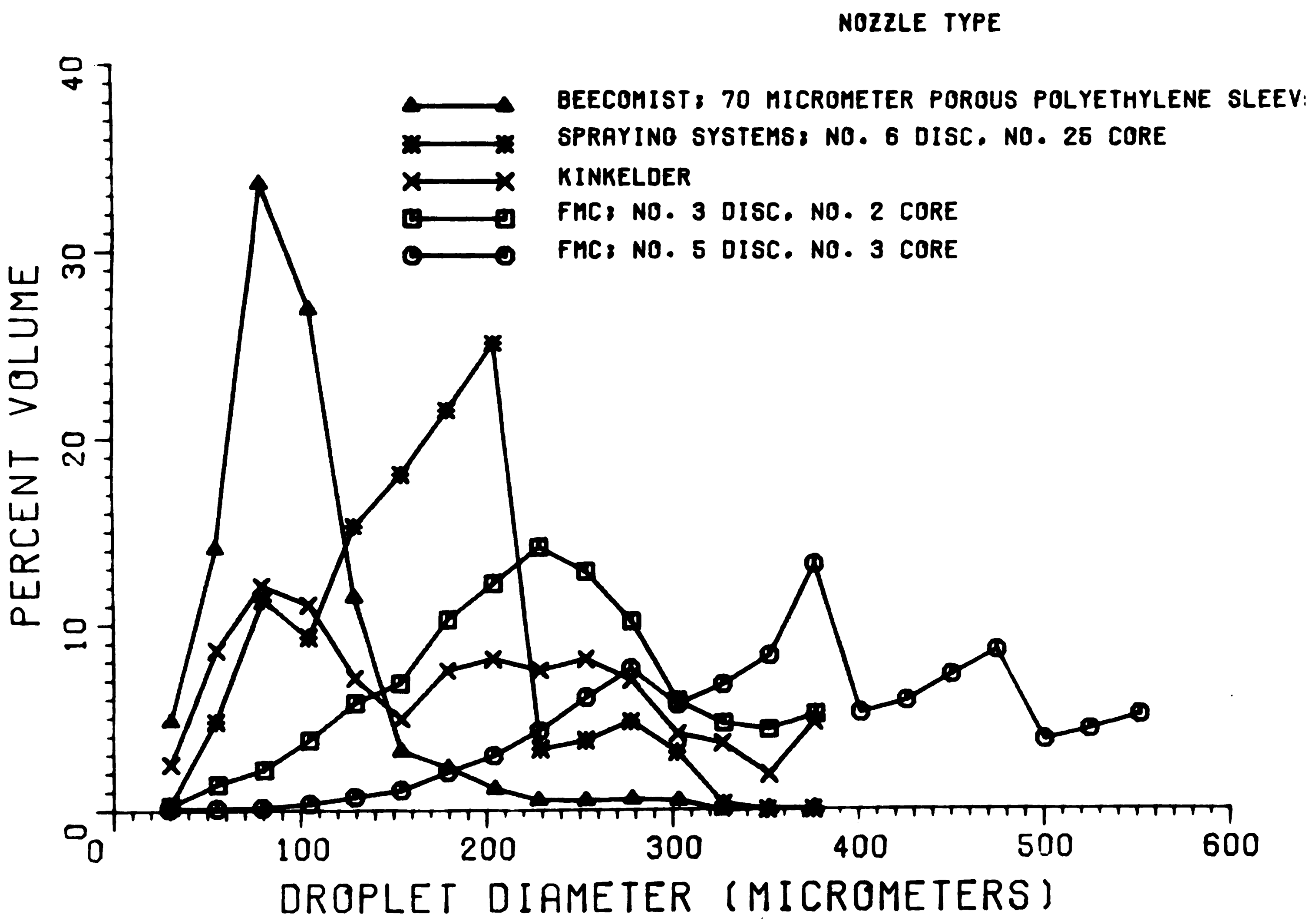

NOZZLE TYPE
BEECOMIST; 70 MICROMETER POROUS POLYETHYLENE SLEEV
SPRAYING SYSTEMS; NO. 6 DISC, NO. 25 CORE
KINKELDER
FMC; NO. 3 DISC, NO. 2 CORE
FMC; NO. 5 DISC, NO. 3 CORE
PERCENT VOLUME
0
10
20
30
40
0
100
200
300
400
500
600
DROPLET DIAMETER (MICROMETERS)

Table 14. - The effect of delivery rate on the aqueous spray droplet spectrum produced by 70 um polyethylene and perforated stainless steel Beecomist sleeves.[a,b,c,d]

Sleeve Type	Delivery Rate (ml/s)	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume			
		D_{10}	D_{50}(VMD)	D_{90}	$D_{90}-D_{10}$
70 um polyethylene	1.7	44	80	113	69
" "	6.7	51	90	138	87
" "	13.3	57	100	173	116
" "	26.7	70	127	241	171
perforated stainless steel	1.7	52	99	180	128
" "	6.7	57	109	204	147
" "	13.3	69	120	214	145
" "	26.7	87	167	285	198

[a] Beeco Products Company.

[b] Operating parameters: carrier air velocity = 33.5 m/s.
sleeve (1) rotational velocity = 183 r/s.
optic probe distance = 0.91 m.
optic probe height = 1.37 m.

[c] Environmental conditions: temperature range = 23-24°C.
relative humidity range = 39-44%.

[d] Surface tension = 72.8 dynes/cm at 24°C.

[e] ±15 um of reported values.

result of increased in-flight coalescence caused by increased particle density (number of droplets/volume) in the air, or a combination of both factors.

C. The Effect of Two Sprayheads on Droplet Spectra.

The occurrence of in-flight coalescence in a zone of spray pattern overlap from 2 sleeves is shown in table 15.

The path of a droplet from the time it leaves the sprayhead to the time it lands follows an arched trajectory that is influenced by several factors. Because spray droplets are dispensed from the Beecomist sleeve in a direction perpendicular to the air stream flow, the initial arch of the flight curve is determined by the centrifugal momentum of the expelled droplet and the entraining force of the air stream. Once entrained, the droplet is carried in a direction parallel with the air flow until the force of gravity exerts an influence greater than the diminishing horizontal droplet velocity.

If two sprayheads are placed close enough together in the air stream their patterns would overlap at some distance resulting in a greater density of droplets in the overlap area. If in-flight coalescence occurs, droplet sizes in a zone of spray pattern overlap should be larger than in non-overlap areas.

At a distance of 0.91 m, for both delivery rates, droplet size at the intermediate height (2.13 m) is larger than the other 2 heights (1.37 and 3.05 m). By looking at figure 12 one would expect significant spray pattern overlap to occur at this distance and

Table 15. - The effect of delivery rate, and sampling height and distance on the aqueous spray droplet spectrum produced by two Beecomist perforated stainless steel sleeves.[a,b,c,d]

Delivery Rate (ml/s/sleeve)	Distance From Lower Sleeve (m)	Height (m)	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume			
			D_{10}	D_{50} (VMD)	D_{90}	$D_{90}-D_{10}$
6.7	0.91	1.37	72	125	236	164
"	"	2.13	91	144	235	144
"	"	3.05	74	127	241	167
"	3.05	1.37	72	122	219	147
"	"	2.13	70	123	259	189
"	"	3.05	72	126	216	144
17.8	0.91	1.37	75	137	253	178
"	"	2.13	99	160	262	163
"	"	3.05	81	144	259	178
"	3.05	1.37	80	135	243	163
"	"	2.13	79	137	229	150
"	"	3.05	84	138	236	152

[a] Beeco Products Company.

[b] Operating parameters: carrier air velocity = 33.5 m/s.
sleeve (2) rotational velocity = 183 r/s.

[c] Environmental conditions: temperature range = 17-23°C.
relative humidity range = 46-63%.

[d] Surface tension = 72.8 dynes/cm at 24°C.

[e] ±15 um of reported values.

height. At a distance of 3.05 m it doesn't appear that a significant region of in-flight coalescence was detected. This may be due to the fact that the zone of spray pattern overlap at this distance passed slightly above the highest sampling height (3.05 m). By again referring to figure 12, however, some overlap should have occurred at this position. As would be expected, the percent increase in droplet size in the intermediate height is greater for the higher delivery rate. This is because the droplet density would be greater at a higher delivery rate thus offering more possibility for in-flight coalescence.

D. The Effect of Formulation on Droplet Spectra.

Because low volume applications utilize high concentrations of pesticide formulations in water, it might be expected that these formulations would greatly influence the spray droplet spectrum produced. Table 16 reports droplet size statistics for a water spray compared to several formulations delivered by perforated stainless steel and 70 um porous polyethylene sleeves. Wettable powder and flowable pesticide formulations are not represented for the polyethylene sleeve because the formulation components are not sufficiently fine to travel through the sleeve.

Formulation clearly has an important influence on droplet spectra. All formulations tested decreased the D_{50} of the spray spectrum as compared to that of water. This is probably due to a reduction in surface tension resulting from the formulation surfactants. A 4-fold change in Diazinon 4EC concentration had little

Table 16. - The effect of various chemical formulations on the spray droplet spectrum delivered by 70 um polyethylene and perforated stainless steel Beecomist sleeves.[a,b,c]

Chemical	Concentration/1.	Surface Tension (dynes/cm)[d]	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume							
			Perforated Stainless Steel Sleeve				70 um Polyethylene Sleeve			
			D_{10}	D_{50}(VMD)	D_{90}	$D_{90}-D_{10}$	D_{10}	D_{50}(VMD)	D_{90}	$D_{90}-D_{10}$
Water	-----	72.8	57	109	204	147	51	90	138	87
Bivert	83 ml	30.9	44	64	135	91	34	62	113	79
Nalco-Trol	0.8 ml	44.7	51	97	244	193	53	99	178	125
Diazinon 4EC	42 ml	34.2	45	70	132	87	28	56	90	62
"	84 ml	33.9	46	78	137	91	32	59	90	58
"	167 ml	33.7	45	61	93	48	34	61	95	61
" + Bivert	" + 83 ml	32.7	38	58	89	51	34	61	92	58
" + Nalco-Trol	" ÷ 0.8 ml	33.3	43	74	229	186	43	67	107	64
Sevin 80 WP	200 g	36.3	44	64	103	59	--	--	---	--
" + Nalco-Trol	" + 0.8 ml	36.1	44	75	220	176	--	--	---	--
Captan 4F	333 ml	44.3	46	71	169	123	--	--	---	--
" + Nalco-Trol	" + 0.8 ml	42.4	45	81	237	192	--	--	---	--

[a] Beeco Products Company.

[b] Operating parameters: carrier air velocity = 33.5 m/s.
sleeve (1) rotational velocity = 183 r/s.
delivery rate = 6.7 ml/s.
optic probe distance = 0.91 m; height = 1.37 m.

[c] Environmental conditions: temperature range = 23-25°C; relative humidity range = 60-62%.

[d] Surface tensions determined between 23-25°C.

[e] ±15 um of reported values.

effect on the droplet spectrum delivered by the 70 um porous polyethylene sleeve. Droplet size production from the perforated stainless steel sleeve using Diazinon 4EC, however, appeared to be more sensitive to formulation concentration (as judged by decreases in D_{50}).

The effect of the two drift control agents was quite different. Nalco-trol had only a minor effect on the D_{50} values, but increased the D_{90} values substantially. This means that there is little effect on the small droplet portion of the spectrum, but that a few more large droplets are produced that shift the D_{90} values. This contradicts information supplied by the manufacturer claiming that Nalco-trol eliminates small droplets (less than 200 um), however, no data is presented for spinning sleeve type nozzles.

Bivert had little effect on the droplet spectrum of the Diazinon 4EC formulation for either sleeve. Spectra of all sprays containing Bivert, however, were made up of droplets considerably smaller than the corresponding spectra of water. This is believed to be due to a reduction in surface tension accompanied with the addition of Bivert. According to information supplied by the manufacturer, Bivert provides an oil coat surrounding the pesticide-water droplet thus inhibiting evaporation and consequently reduction in droplet size. Had Bivert been evaluated under increased sampling distances and environmental conditions more favorable for evaporation, the results with Bivert containing sprays may have been different.

The spray droplet spectrum of a water soluble dye formulation as effected by air velocity and sleeve rotational velocity is presented in table 17. These data are discussed under "the effect of air velocity, sleeve spin speed and ratio of liquid proportioning to 2 Beecomist sleeves on the spray distribution delivered by a low volume spray system."

The droplet size statistics for a non-aqueous spray medium (technical Malathion) delivered by several Beecomist sleeve types is presented in table 18. Again, it is clear that for the porous sleeve types, porosity and construction material has virtually no effect on the droplet spectrum produced. As with water, the perforated stainless steel sleeve produced a droplet spectrum that is shifted more toward larger droplet sizes as compared to that produced by the porous sleeve types. The shift is more pronounced with the non-aqueous spray medium than with water. The greater variation in the D_{90} value is probably attributable to droplet fly-off problems from the tip of the probe, which appeared to be more severe with non-aqueous systems than with aqueous formulations.

E. <u>The Droplet Spectrum of a Non-Aqueous Spray Medium as Determined With Both an Optic Probe and Droplet Impingement Harp.</u>

Table 19 presents droplet size statistics for dioctyl phthalate delivered by 70 um porous polyethylene and perforated stainless steel sleeves.

For the perforated stainless steel sleeve, the droplet impingement harp did not capture as large of droplets (at either distance) as detected by the optic probe.

Table 17. - The effect of carrier air velocity and sleeve rotational velocity on the spray droplet spectrum of a water soluble dye formulation delivered by a Beecomist perforated stainless steel sleeve.[a,b,c,d]

Air Velocity (m/s)	Sleeve Velocity (r/s)	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume			
		D_{10}	D_{50}(VMD)	D_{90}	$D_{90}-D_{10}$
22.4	100	98	192	265	167
"	183	46	104	184	138
33.5	100	94	193	259	165
"	183	51	102	193	142
44.7	100	110	201	271	161
"	183	56	111	191	135

[a] Beeco Products Company.

[b] Dye formulation = Uranine (Sodium Fluorescein) 132 g/l
+ Orthene 75S 26 g/l.

[c] Operating parameters: delivery rate (1 sleeve) = 6.7 ml/s.
optic probe distance = 0.91 m; height = 1.37 m.

[d] Environmental conditions: temperature = 24°C; relative humidity = 61%.

[e] ±15 um of reported values.

Table 18. - The spray droplet spectrum of technical malathion delivered by several Beecomist sleeve types.[a,b,c,d]

Sleeve Type	Droplet Diameter[e] (um) at Cumulative Percentages of Spray Volume D_{10}	D_{50}(VMD)	D_{90}	D_{90}-D_{10}
20 um stainless steel	35	69	112	77
60 um stainless steel	35	72	126	91
70 um polyethylene	34	73	131	97
perforated stainless steel	74	151	248	174

[a] Beeco Products Company.

[b] Operating parameters: carrier air velocity = 33.5 m/s.
sleeve (1) rotational velocity = 183 r/s.
delivery rate = 15.8 ml/s.
optic probe distance = 0.91 m; height = 1.37 m.

[c] Environmental conditions: temperature range = 22-25°C.
relative humidity range = 58-63%.

[d] Surface tension of technical malathion = 33.6 dynes/cm at 24°C.

[e] ±15 um of reported values.

Table 19. - The spray droplet spectrum of dioctyl phthalate delivered by 70 um polyethylene and perforated stainless steel Beecomist sleeves as determined with an optic probe and a droplet impingement harp.[a,b,c,d]

Sleeve Type	Sampling Distance From Lower Sleeve (m)	Droplet Diameter (um) at Cumulative Percentages of Spray Volume											
		Wire Size on Droplet Impingement Harp								Optic Probe[e]			
		5 um Tungsten				15 um Stainless Steel							
		D_{10}	D_{50}	D_{90}	$D_{90}-D_{10}$	D_{10}	D_{50}	D_{90}	$D_{90}-D_{10}$	D_{10}	D_{50}	D_{90}	$D_{90}-D_{10}$
70 um polyethylene	0.91	33	56	78	45	54	73	92	38	39	71	123	84
" "	3.05	49	88	126	77	63	99	135	72	39	71	114	75
perforated stainless steel	0.91	35	56	82	47	59	79	99	40	64	144	256	192
" "	3.05	56	91	132	76	84	120	163	79	63	145	259	196

a Beeco Products Company.

b Operating parameters: carrier air velocity = 33.5 m/s.
sleeve (1) rotational velocity = 183 r/s.
delivery rate = 6.7 ml/s.
optic probe and harp sampling height = 1.37 m.

c Environmental conditions: temperature range = 22-25°C; relative humidity range = 58-63%.

d Surface tension of dioctyl phthalate = 46.5 dynes/cm at 24°C.

e ±15 um of reported values.

In comparing the harp with the probe for the 70 um polyethylene sleeve, the D_{10} and D_{50} values were more comparable at 0.91 m that at 3.05 m, whereas the D_{90} values were more equivalent at 3.05 m. The fact that the harp does not catch the same size droplets at each distance is indicated by a shift in the whole spectrum (D_{10}, D_{50}, D_{90} values). The droplet impingement harp was more efficient in collecting larger droplets as sampling distance and/or wire size was increased. The shift in the spectrum as a function of wire size is partly due to an increase in catch efficiency but also due to the inability in measuring as many small droplet size classes with the 15 um wire as compared to the 5 um (6 versus 9 under 50 um).

Virtually identical droplet spectra were obtained at both distances with the optic probe. One cannot eliminate the possibility that droplet fly-off problems from the probe, however, may have contributed to the droplet spectrum obtained.

The selection of a wire size for use on a droplet impingement harp must involve consideration of the droplet size being delivered and its traveling velocity at the point of collection.

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