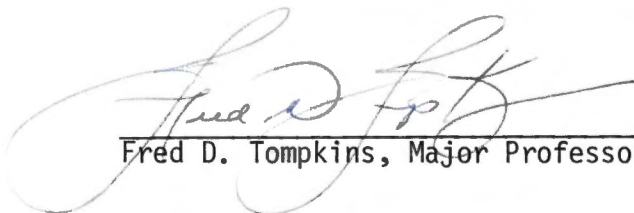


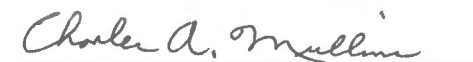
To the Graduate Council:

I am submitting herewith a thesis written by Harold J. Norman entitled "Spray Patterns of a Low-Volume Air-Blast Orchard Applicator." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

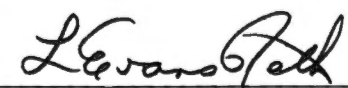

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and recommend its acceptance:


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Accepted for the Council:


Vice Chancellor
Graduate Studies and Research

Thesis

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SPRAY PATTERNS OF A LOW-VOLUME AIR-BLAST
ORCHARD APPLICATOR

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Harold J. Norman

March 1979

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ABSTRACT

A low-volume, high-velocity air-blast applicator was modified and used to apply solutions containing a known volume of micron-sized fluorescent particles at four rates to groups of mature trees within an apple orchard.

Leaves were selected from designated areas on the sprayed trees and evaluated for surface coverage and quantity of material deposited, using a stereo microscope and ultraviolet light.

Application rate, leaf location, and leaf side were considered fixed effects, while trees, leaves within location, and sites within a leaf side were considered random.

Coverage analysis showed that as application rate increased, percentage of leaf surface covered increased, but even at the highest rate (70 gallons per acre), only about 50 percent of the leaf area received spray. Also, at the lowest rate (10 gallons per acre), virtually no material was deposited on leaves in the tree center.

Deposition density of fluorescent particles also increased as application rate increased, but at a lower rate than percentage of coverage. Deposition density and percent leaf coverage were both greater on top leaf surfaces than bottom leaf surfaces except for locations at the tops of trees.

Distance from the fan to the target area proved to be a more prominent factor in percentage spray coverage than foliage obstruction.

Therefore, use of higher rates and shorter distances with the low-volume applicator would seem necessary to attain the particle deposition and percentage of leaf coverage necessary for controlling fungal spores.

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CHAPTER I

INTRODUCTION

I. BACKGROUND AND PROBLEM DEFINITION

The Tennessee apple industry has lost thousands of dollars in the last decade through failure to control spore-bearing fungi. These minute spores, which attack both apple fruit and foliage, have caused crop reduction, fruit grade devaluations, and foliage losses. Moreover, operating expenses for controlling these diseases have soared due to escalating labor and chemical cost.

In 1963, Brann reported that spraying programs accounted for more than 40 percent of the cost of growing apples and 26 percent of the total cost of producing and delivering a bushel of apples to market. Since then, material cost has escalated and expensive spray repetition has continued. Available commercial sprayers have failed to provide adequate coverage in a single application. All of these problems have shown the need for improved management practices and new sprayer technology.

In recent years many apple growers have discontinued using traditional dilute sprayers. Lewis et al. (1969) cited four major reasons for the decline of dilute sprayers and the increase of concentrate sprayers. They are: (1) high labor and water requirements, (2) high cost of chemicals per acre, (3) time required for application

with the resultant reduction in application timeliness, and (4) a tendency of some chemicals to cause injury if large drops form on the fruit. In essence, dilute sprayers apply liquid to the point of run off, whereas, concentrate sprayers apply a reduced quantity of liquid carrier with the same amount of chemical. Thus, a solution is developed which is three or more times as concentrated than the traditional diluted mixture.

As the concentrate sprayer trend has increased, questions have been raised as to efficiency of this application technique. Although concentrate spraying has proven more cost efficient, apple growers have questioned the ability of the sprayer to properly cover the entire area subject to spore exposure. Many of these questions were raised at The University of Tennessee's Plateau Experiment Station near Crossville where a low-volume, high-velocity sprayer was being used to control spore bearing diseases in the station orchard. In response to these questions, a study involving application of concentrate spray material to orchard foliage was initiated.

II. OBJECTIVES

The purpose of this study was to investigate the feasibility of using a low-volume, high-velocity, air-blast sprayer for applying concentrate solutions of pest control material in apple orchards.

The specific objective was to determine uniformity of spray material deposition on leaf surfaces at various low-volume application rates.

CHAPTER II

REVIEW OF LITERATURE

I. EFFICIENCY OF SPRAYERS

Increasing sprayer efficiency has been a motivating factor in pesticide application equipment research. Parameters studied in an attempt to improve chemical applicators include: (1) optimum droplet size, (2) low-volume spraying, (3) deciduous fruit tree conformation, and (4) prevalent fruit tree diseases.

Optimum Droplet Size

Himel (1969a) stated that defining an optimum size for spray droplets is a very controversial matter. He suggested that a 20 μm diameter is the optimum size for insecticide spray droplets. Himel (1969) defined an optimum size droplet as one that is small enough to be produced in maximum numbers for maximum coverage yet large enough to have an optimum critical impingement velocity for optimum impingement on the target insect or surface. The critical impingement velocity is the minimum transport velocity of a spray droplet which will overcome the air barrier which surrounds all objects. He noted that as spray droplet size decreased, critical impingement velocity also decreased. After spraying cotton squares, Himel (1969b) showed that of 600 spray droplets that penetrated the squares, 95 percent were in the 20 μm range. He credited this to the ability of the smaller droplets to pass through

the tree foliage on micrometeorological air currents. While working with spruce budworms which are surrounded by a very strong web, he noted that no spray droplets with a diameter larger than $27\text{ }\mu\text{m}$ were found on the worms.

Himel (1969b) cited one disadvantage of small droplets. This disadvantage was a certain amount of drift, but he also noted that large droplets are probably more dangerous to the ecosystem than small droplets. Large droplets, which contain more chemicals than small droplets, fall to the ground due to gravity. There they are washed off the ground foliage by rain water and into streams where they can affect water quality. Courshee (1957) also agreed that small droplets drift more but are less dangerous. They will spread more thinly over a wider band of ground, whereas, large droplets will fall faster than smaller sizes, creating a higher concentration of chemicals.

Potts (1946) expressed the belief that droplets less than $20\text{ }\mu\text{m}$ would not become deposited on a target surface. He stated that small particles do not have enough force to penetrate the electric fields surrounding these objects. Potts (1946) decided that sprayer droplets should be in a 30 to $80\text{ }\mu\text{m}$ range unless they are distributed from a plane. In that instance the most efficient size would be 70 to $100\text{ }\mu\text{m}$. He concluded that droplet size was an important factor in foliage injury. Howitt (1973) agreed with this supposition, indicating that phytotoxicity appeared to be related to droplet size. Larger drops reflect the sun's rays much like a lens.

Backman et al. (1976) agreed that small particles enhance disease control due to more complete coverage and more chemical availability at

the infection site. But, they also stated that small particles are more easily eroded and more susceptible to photochemical degradation. They suggested that fungicides be applied with a flat particle distribution curve. In terms of the application equipment, this means that the sprayer should produce the same number of small, medium, and large droplets. Photochemical deterioration would thus furnish a constant supply of small particles to the target surface. However, Smith and Burt (1970) concluded that droplets with the same diameters have similar horizontal trajectories when released from a spinning disk.

Burt and Smith (1974) noted that droplets less than 140 μm in diameter should not be used due to drift. They concluded that the optimum droplet size may require a compromise between pest control and spray drift control. To use anything less than 140 μm with ground equipment, they suggested that all drops should be uniform in size and possess a large velocity component in the downward vertical direction.

Wright (1978) reported that the normal wind velocity in the canopy of a growing crop is 2.2 miles per hour and that smaller droplets do drift more than larger droplets. However, lateral movement of spray material in these winds is a contributing factor to better control. He stated that a forest service report based on 30 years of data indicated that in an 11 mile per hour wind, 10 μm droplets, 40 μm droplets, and 100 μm droplets all drift the same. He suggested the best coverage is acquired by using smaller droplets. Wright's (1978) study showed that if the optimum spray droplet is between 20 and 30 μm , present coverage efficiency of most spraying equipment is on the order of 1 percent or less.

Low-Volume Spraying

The concept of low-volume, or concentrate, spraying involves application of pesticides in a reduced quantity of liquid carrier. Thus the active chemical is applied at a greater than 1-X concentration which is the basis for dilute spraying. Lewis et al. (1969) stated that a standard dilute application occurs when trees are sprayed until runoff occurs. This standard dilute method requires 400 gallons of spray per acre or 14.7 gallons per 40 linear feet of row space, when apple trees are 20 to 22 feet high and rows are 40 feet apart. To be considered concentrate spraying, application volumes per unit area must be at least 18 percent less than the dilute spray standard.

Lewis et al. (1969) noted an increase in low-volume or concentrate spraying in large commercial orchards due to four reasons: (1) dilute sprayers require excessive labor and water, (2) increased cost of chemicals per acre in dilute sprays, (3) time required to apply dilute solutions, and (4) a tendency for some chemicals to cause injury if large drops form on the fruit.

★ Webb Wright (1978) stated that low-volume, fine particle application is the most efficient method of applying insecticides and fungicides to growing crops. Without fine particles, low-volume spraying would be ineffective because the small droplets are able to penetrate dense foliage and give good coverage underneath the leaf. Wright reported that more droplets can be obtained from low-volumes with appropriate equipment than with dilute spraying equipment and that the number of droplets rather than the volume of material is responsible for better coverage. Further, Howitt (1973) stated that the number of

droplets in a liquid is an inverse cube function of the droplet diameter. Simply stated, when the droplet size is doubled, an eight-fold decrease in the number of droplets will result from a given volume of liquid. By using a low-volume, fine particle system, Howitt (1973) received what he termed excellent coverage on 900 acres of apples. He used four applications and half the recommended dosage instead of the usual eight or nine applications.

Howitt et al. (1966) stated that exceptional scab control was obtained by an ULV (ultra low-volume) spraying method. This coverage, which was characterized by both uniform-sized and evenly-spaced spray deposits was obtained with an atomizer introduced in 1962. This instrument was called a British Micronair Rotary Atomizer. It duplicated and atomized droplets at low volumes.

The following year, 1963, USDA's Plant Pest Control Division developed an economic miniature rotary atomizer called the Mini-Spin. This atomizer was capable of dispensing very low volumes of liquids uniformly.

Wright (1978) noted that many chemicals were not formulated for low-volume application and neither were they miscible with one another in low-volume formulations. Therefore, Mini-Spin was designed to employ a separate delivery line for transporting each different chemical to the inner cage of the atomizer.

Howitt (1973) used a porous filter called a Beecomist to control droplet size in a low-volume sprayer. This filter was developed in 1968 by Philip Corbett of Beemer Engineering Company. As liquid flowed into a rotating chamber, it was propelled outward through the filter

walls by centrifugal force. The liquid was extruded into threads equal in size to the pores in the filter. These stainless steel sleeves or filters were available in 5-, 10-, 20-, 40-, and 60-micron pore sizes.

McMechan and Halvorson (1977) related that most fruit tree pest and diseases could be controlled with low-volume sprayers. However some pests, such as San Jose and European fruit scales, required high-volume spraying to penetrate behind the bark where the pests were located. Staniland (1960) agreed that spraying should always result in complete coverage of the plant target just short of run-off. Machines which were able to apply material in this manner were suitable for use in all circumstances.

★ Himel (1969a) noted the development of low-volume methodology as one of the most significant events in spray evaluations. He described the droplet size range for low-volume spraying as 5 to 50 μm in diameter with an application rate of 16 fluid ounces of insecticide per acre. A problem discussed by Smith and Burt (1970) was that low-volume applications were more concentrated than conventional sprays, thus creating a greater health hazard with drift. Low-volume spray material is normally 20 to 160 times more toxic than an equivalent amount of conventional spray solution.

Cooke et al. (1976) worked with low-volume spray deposits on apple trees. They concluded that low-volume spraying controlled effectiveness almost equaled that of conventional high-volume spraying on exposed aphids and moderately heavy infections of apple scab (*Venturia inaequalis*). They agreed that further work was needed to establish

optimum deposit concentration requirements for adequate control of diseases by low-volume applications.

Fruit Tree Conformation

Staniland (1960) stated that to adequately control orchard fungal diseases, complete spray coverage was essential. Such coverage was difficult to obtain due to applicator inefficiencies and to the physical nature of individual trees in a given orchard.

For best results, trees should be as uniform as possible. Brann (1963) suggested that tree height and pruning had a definite influence on pest control. Pruning removes excess foliage from the tree. This practice helps prevent masking or packing which hinders uniform leaf coverage with chemical particles.

Brann (1963) also suggested that tops of apple trees sprayed at low humidities received an average of one-third as much deposit as was laid down in tree tops sprayed at high humidities. This difference was attributed to the direct correlation between low humidities and large amounts of evaporation over long distances.

Staniland (1960) concluded from his research that leaves behave differently when being sprayed depending on their conformation and poise. Flat leaves on weak petioles will blow out and be almost completely missed, while flat leaves with short stiff petioles will be largely covered. Leaves that are V-shaped blow to one side, therefore they get good coverage on only half of the leaf.

Another problem Staniland (1960) cited was raised veins on leaves. These veins block other areas of the leaf from the spray

material. This interference prevents a uniform coverage and caused an accumulation of chemicals in one area around the vein.

Staniland (1960) also cited plant hairs as a problem in obtaining complete coverage. The hairs screen out small droplets of fungicide that would otherwise land on the true leaf. For disease prevention, chemical coverage of the true leaf is important.

Fruit Tree Diseases

Although there are many pests that attack deciduous fruit and cause great damage, only the most prevalent spore bearing fungi will be considered here.

Apple Scab. Anderson (1956) stated that the apple scab fungi caused more damage to apples than any other fungal disease. The losses resulted from reduction in crop, devaluation in grade, foliage loss, and an increase in operating expenses.

He noted that the apple scab fungus has two phases in its life cycle. The parasitic, or *Fusicladium*, phase is the imperfect, asexual or summer spore stage. This is the phase of fungus seen on the fruit. The other phase is the saprophytic or *Venturia* phase which develops on the dead leaves during autumn and winter months.

The saprophytic development begins with a dark brown hyphae entering the mesophyll of the dead leaf. On this a perithecia develops. Then asci form inside the perithecia. Enclosed in each asci will be eight ascospores. As the dead leaf becomes saturated with moisture, pressure will build up inside the asci and the ascospores will be discharged into the air. They are so minute in size, 11 to 15 μm in

length and 5 to 7 μm in width, they are swept away by micro-meteorological air currents much like dust particles. Ascospores are discharged over a 4- to 10-week period depending upon weather conditions. In the spring as they contact the developing green foliage, they adhere readily. The disease becomes visible eight days or two weeks after inoculation depending upon temperature.

Through a continuing disease cycle these ascospores give rise to conidia. These conidia are part of the parasitic phase. They are formed in huge numbers and are responsible for the velvety appearance of the scab lesions. These conidia are 12 to 22 μm in length and 6 to 9 μm in width. They are borne on the conidiophore. Upon becoming moist, these conidia detach from the stalks and wash or blow in mist particles to other leaves and fruit where they continue the disease cycle.

Apple Bitter Rot. Anderson (1956) noted that the apple bitter rot fungus usually occurred in the latter portion of the growing season when it was hot and humid and the fruit was ripe. Spores germinated in a few hours after reaching the apple surface. Appressoria were formed by the spores and secured the spores to the fruit. By an enzymatic process the fungus penetrated the cuticle where the mycelium began to grow between the cells. As the fungus spread, another enzymatic action broke down the tissue which caused the rotting appearance.

The fungus that attacks the fruit may overwinter in several ways: (1) as stromatic masses in mummied fruit, giving rise to conidia or ascospores in the spring, (2) in cankers, or (3) in dead bark crevices or other protected places where it can lead a saprophytic existence.

Most primary bitter rot infections come from mummied fruit on the tree. In this fruit, acervuli are formed. These cup-like structures develop just below the cuticle. Conidia may arise from these or from thickened masses of hyphae. These spores are 12 to 16 μm by 4 to 6 μm and may be spread by washing, wind blown mist, or even insects and birds.

Sooty Blotch. Anderson (1956) explained that this fungus grows best in cool rainy weather. It attaches to the apple but usually does not penetrate the skin. Most sooty blotch spores are produced on young twigs of wild hosts. There they are washed or blown to developing fruit.

The fungus itself forms a thallus of branched hyphal threads. The pycnidia are scattered throughout the thallus. They are 20 to 40 μm in height and 70 to 100 μm in diameter. Conidia, which are formed inside the pycnidia, escape when the top of the pycnidium ruptures. These spores, which are 2 to 3 μm by 10 to 12 μm , collect in a gelatinous mass on the surface of the thallus. Another spore of the sooty blotch fungus is the chlamydospore. These spore-like cells are formed by the breaking up of the thick-walled hyphal fragments. This fungus can be controlled by preventing spore production through good orchard management and through spray coverage.

II. TECHNIQUES TO MEASURE SPRAY DEPOSITS

H. W. Riley (1909) developed a machine that would test the performance of sprayer nozzles. This sprayograph was moderately refined and used by Shanks and Paterson (1948) to compare sprayer nozzle

patterns. This apparatus consisted of a 6-foot by 3-foot framework supporting two 6-inch rollers with a canvas belt. A 3-inch consistency slot between the belt ends provided a shutter effect on the paper below. The nozzle and the paper were both stationary while the canvas revolved about the rollers at 200 feet per minute.

Lee (1932) used a technique to test spray nozzles which consisted of catching oil droplets on a film of lamp black and then measuring them by the use of a microscope with a filar micrometer eyepiece.

Davis and Elliott (1953) discussed several methods for estimating aerially applied spray deposits. Indicator cards or recovery plates laid at right angles to the plane's flight path were common. For fast visual assessment, heavy pressed paper cards, known as jump cards, and sensitized paper were used. Tracers were added to the spray material when these devices were used. The results were often questionable.

Isler (1963) noted that the above methods were discontinued about 1952, and a new system was developed. Colorimetric analysis was used for quantitative measurement of aerially applied deposits. Plates of glass or metal were used to catch the falling dye-filled spray. The dye was washed off the plates, and a sample was placed in a spectrophotometer to measure the intensity of the light transmission that passed through. The results were compared to control samples of the known solutions. This method was adversely affected by rain, dew, and sometimes sunshine; therefore, another system was sought. Davis et al. (1953) cited a new development which consisted of treating a medium white paper that has a clay-bearing calendar-roll finish with a oil-soluble red dye. To improve the contrast they later switched to black

dye. They recorded atomization sizes in the neighborhood of 7 μm with this dye. The technique was not affected by rain, and it was easy to administer and evaluate compared to the earlier methods.

Sanders (1953) listed a procedure similar to the one used by Isler. Dusts and sprays were collected on pans representing 1/20,000 of an acre. These pans were aluminum and were 20 inches in diameter. The dye collected from these pans was combined with 500 cc of water. The relative dye concentration was measured by a photometric instrument, and the applied rates were determined by comparing the instrument reading with a previously developed calibration curve for a known concentration.

The titrimetric technique was used by Brittain (1955) to evaluate deposits of pesticides containing copper. This method was quick and inexpensive. By placing a sprayed leaf in distilled water the chemicals would be washed free of the leaf. Potassium iodide added to the solution would react and release free iodine. A starch indicator was added to the solution which turned dark blue. Sodium thiosulfate was added by drops until the water became clear. The quantity of sodium thiosulfate added was equal to the amount of copper on the sprayed leaf. The disadvantage of the titrimetric method was that only copper could be measured, and the method gave no information about the uniformity of leaf coverage.

Brazee (1963) evaluated pesticide deposits by a chemical analysis known as polarography. This system was originated around 1920 by Jaroslav Heyrovsky at Charles University in Prague, Czechoslovakia. The basic theory for polarography is that in the electrolysis of a solution

of electro-oxidizable or electro-reducible substances, with a supporting electrolyte, in a cell in which one electrode consists of mercury falling drop-wise from a capillary tube, a unique current-voltage curve may be plotted. This curve permits qualitative and quantitative determination of all reducible and oxidizable substances present. Ban and Carleton (1955) also suggested the use of the polarography technique instead of the titrimetric technique because it was faster, at least as accurate, and was not restricted to copper detection only.

The activation analysis technique was used for pesticide tracers by Wilkes and Brusse (1963). This process involves the irradiation of a material by nuclear particles and measurement of radioactive isotopes with a gamma ray spectrometer. Nordby and Steenberg (1959) also used this method to obtain illustrated and quantitative evaluation of a fungicide sprayed on orchard trees. They noted the deposit on the inner portions of the tree were 70 percent of the deposit on the outer portions of the tree.

Fluorescent materials became quite popular about 1960 for use in spray and dust deposit studies. Staniland (1959) classified these spray materials into four categories: (1) powders, (2) water soluble dyes, (3) oil soluble dyes, and (4) insoluble dyes. He used a fluorescent tracer technique for his study on spray and dust deposits. He also noted the following applications of fluorescent tracers: (1) use of tracers in spraying investigations, (2) use of tracers to determine spraying hazards, (3) use of tracers in experimental work on insecticides, and (4) use of tracers in the soil.

Liljedahl and Strait (1959) tried a fluorescent system that measured spray deposits rapidly. The fluorescent spray was collected on a paper strip. The strip was then passed under a scanning chamber which illuminated it with a ultraviolet light. The fluorescence was measured with a photocell. The photocell current was amplified and recorded on a strip-chart recorder.

Yates and Akesson (1963) used fluorescent tracers for quantitative microresidue analysis. They noted that this system offered a rapid, highly sensitive and accurate, nontoxic moderate cost procedure that could be utilized to measure spray drift characteristics. A Turner Model 110 fluorometer was used to measure the Brilliant Sulpho Flavine fluorescent dye samples. Stafford et al. (1970) also used the Turner 110 fluorometer to analyze spray coverage. They showed photographs using ultraviolet light. These permitted evaluation of droplet uniformity, type of deposit, and qualitative comparison of amounts deposited.

^{key} Himel (1965) and his co-workers developed a procedure known as fluorescent particle (FP) spray droplet tracer technique. This system was advantageous in that spray droplets could be identified by size and number directly on the foliage or substance sprayed. Himel (1965) noted that this method was based on a uniform suspension of a known number of solid, insoluble, micron-sized, fluorescent (Zn-Cd sulfide) particles in a known volume of nonvolatile pesticide carrier. Use of this system led to the conclusion that optimum spray droplets are in the 20 μ m range.

CHAPTER III

PROCEDURES AND EXPERIMENTAL METHODS

I. FIELD EQUIPMENT

A low-volume, high-velocity, air-blast sprayer (Model 111 Span Sprayer) manufactured by Ring Around Products, Inc., was used to apply a spray containing a suspension of micron-sized fluorescent particles. These fluorescent particles were used to determine the uniformity and quantity of spray material deposition on the apple leaf surfaces.

Power was supplied to the sprayer's hydraulic and solution systems by an International Harvester Model 656 tractor with a 540 revolution per minute power take off. A hydraulic pump (Model RJ-3000) attached to the tractor PTO shaft provided flow to each of the four fan motors of the sprayer and to the hydraulic motor that powered the solution system.

The Span Sprayer, shown in Figure 1, was equipped with a 300 gallon stainless steel tank. Due to the small quantity of liquid to be applied per treatment and the necessity for vigorous agitation of the fluorescent material in the mixture, a 10 gallon stainless steel milk can was installed to replace the larger tank. To insure adequate solution agitation a jet agitator was placed near the bottom on the inside of the 10 gallon tank as shown in Figure 2.

A high-volume centrifugal pump (Model HMIC-9203) used with the 300 gallon tank was replaced by a lower capacity Hypro roller pump

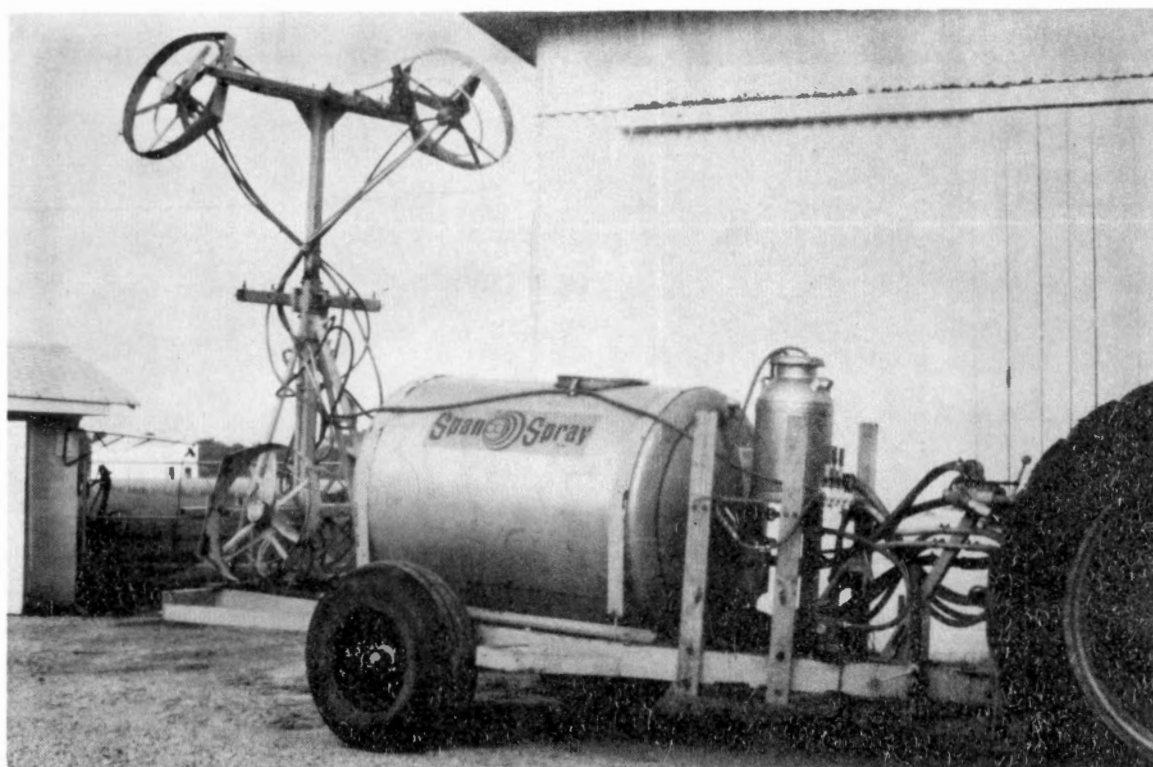


FIGURE 1. Modified low-volume, high-velocity chemical applicator used to distribute fluorescent particles.

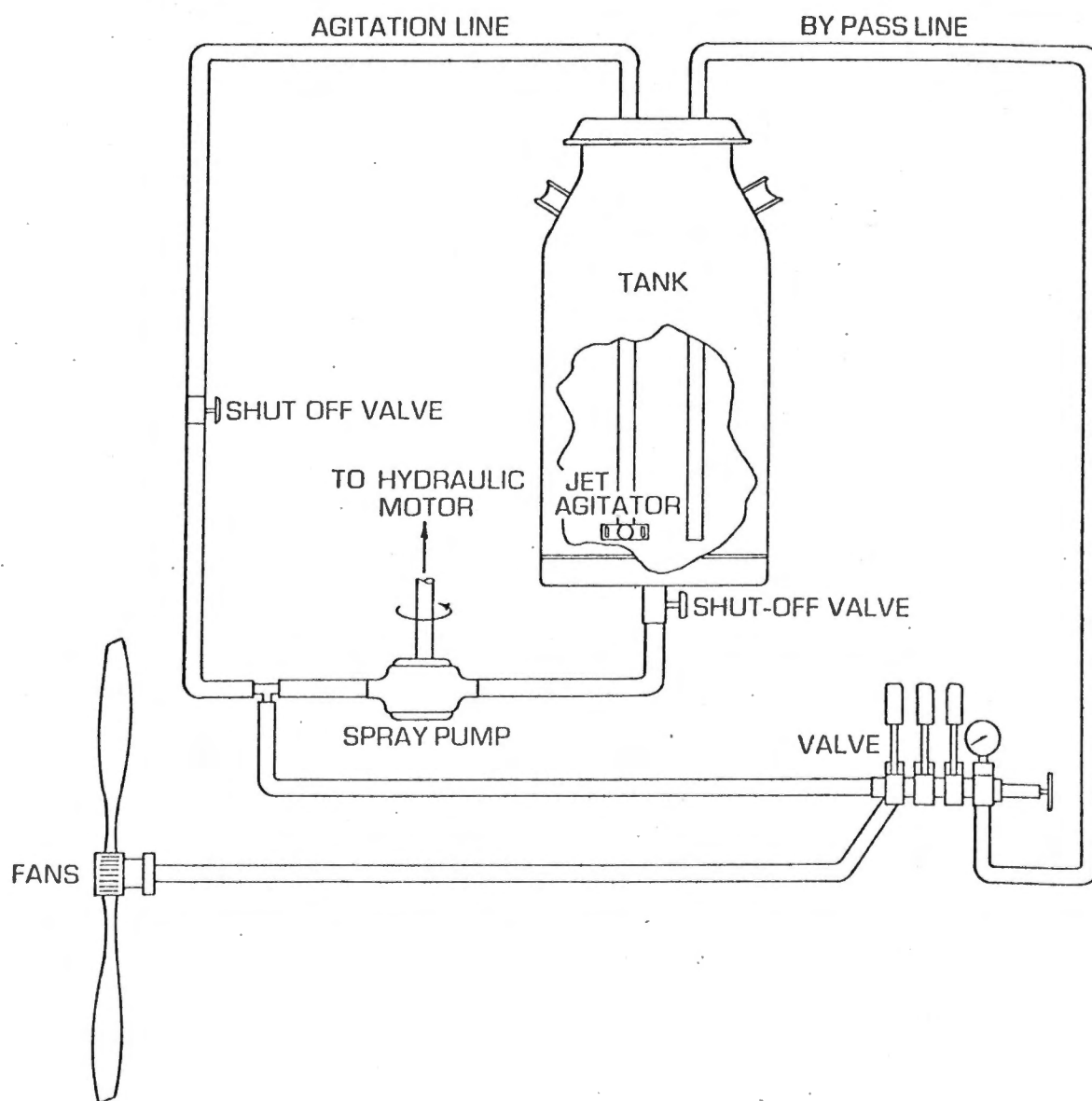


FIGURE 2. A schematic diagram of modifications in the low-volume chemical applicator solution system.

(Model 6600). This solution pump, which was driven by the hydraulic motor (FOR-9203), supplied adequate flow for both agitation and distribution. Flow paths and system controls are shown schematically in Figure 2.

Prior to the individual sprayings, each 24-inch diameter cast iron fan was adjusted in height and delivery angle to accommodate the average tree size in the application area. These adjustments were made to insure uniformity in the spray distribution pattern. Since various solution application rates were employed, orifice plates inside the fan were also changed as needed to establish the required flow rate. Table I lists the orifice plates used to obtain application rates of 10, 30, 50, and 70 gallons per acre.

II. EXPERIMENTAL DESIGN

Treatments were application rates of 10, 30, 50, and 70 gallons per acre. Four groups of five trees each were selected to receive the chemical formulation. A given rate was applied to each of the five trees within a group. The groups were separated sufficiently to insure that spray materials intended for one target area did not drift into another.

Two leaves were randomly selected from each of eight locations shown in Figure 3.

The percentage of surface area receiving spray material was evaluated for both sides of each leaf by examining the leaves under ultraviolet light. The quantity of spray material deposited on either side of the leaf was evaluated by counting the number of fluorescent

TABLE I. Orifice plates used to regulate output in different treatment calibrations.*

Treatment (gallons/acre)	Orifice Plate Number	Output (gallons/minute)
10	4916- 59	.4
30	4916-107	1.25
50	4916-125	2.00
70	4916-151	2.80

*All Orifice Plate Numbers are taken from the Span Spray Operator's Manual.

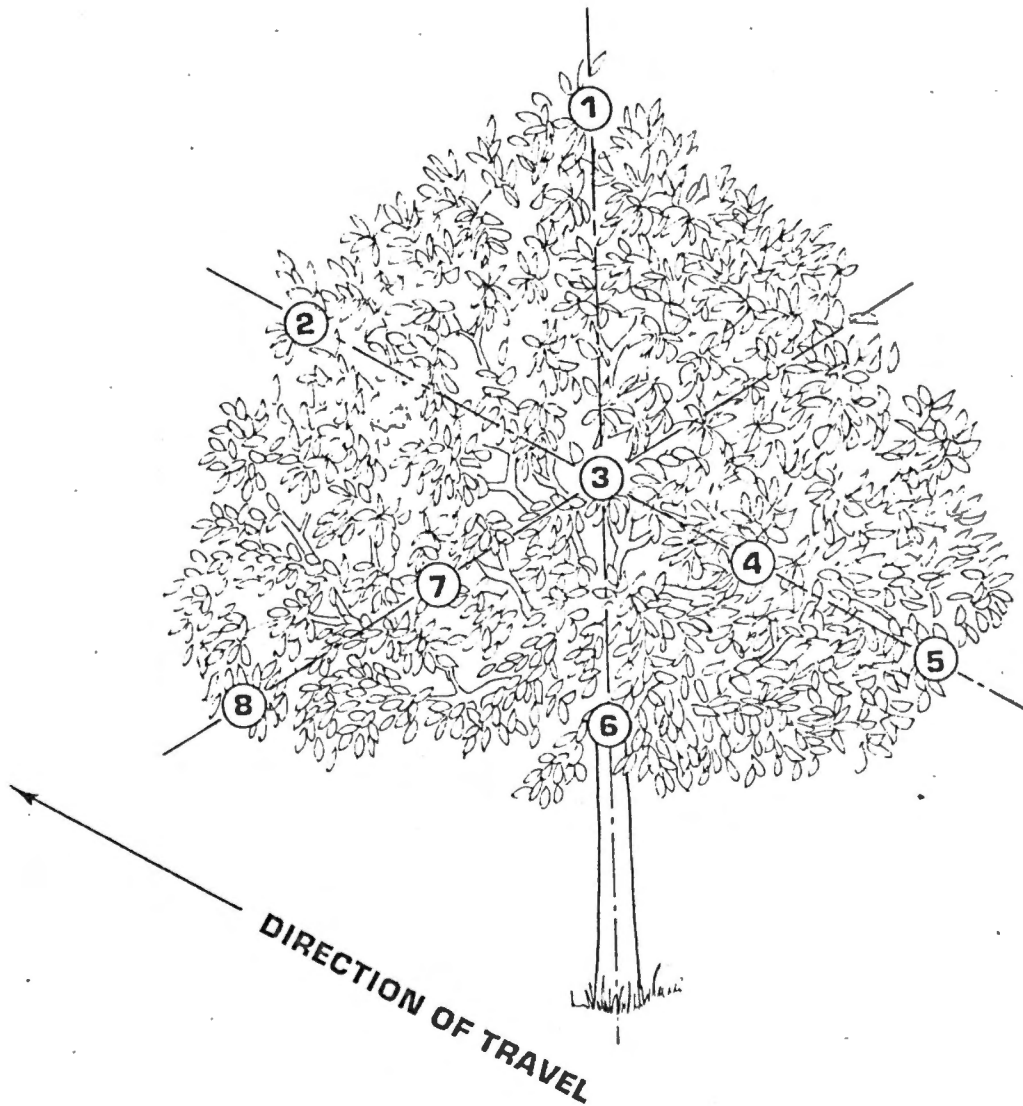


FIGURE 3. Location of eight sampling areas in an apple tree and the direction of travel of the sprayer as it passed the tree.

particles per unit area in two sites randomly selected within the leaf region sprayed.

Particle deposition density and percentage of leaf coverage were the dependent variables. Data were subjected to analysis of variance to determine which of the independent factors (application rate, leaf location, leaf side) significantly affected the coverage percentage and quantity of material deposited. Application rate, leaf location, and leaf side were considered fixed effects while trees, leaves within location, and sites within a leaf side were considered to be random.

The data were analyzed using the Statistical Analysis System (SAS 76) available at The University of Tennessee Computing Center.

III. FIELD DATA ACQUISITION

All data were obtained from field tests. Spraying was done in the middle of October after the fruit was removed. Spraying was done at times when ambient air relative humidity was low and when the foliage was free of moisture. This was necessary since water tends to cause the chemical formulation to coagulate. Wind ranged from one to two miles per hour during the spraying period; therefore, drift due to wind was not considered a pertinent factor. For caution against overlap, treatments were located on extreme sides of the orchard.

Chemical Preparation

A chemical formulation using a fluorescent particle (FP) spray droplet tracer technique was prepared for application at the specified

rates. Using the technique reported by Himel (1969a), spray droplet numbers and sizes were identified directly on the foliage, eliminating the necessity for artificial targets. ^{key} This method was based upon a uniform suspension of a known number (2×10^{10} FP per gram) of solid, insoluble, micron-sized ($2.5 \mu\text{m}$ MMD), fluorescent (Zn-Cd sulfide) particles in a known volume of a non-volatile liquid. As the spray droplets came in contact with the foliage, the carrier evaporated or was absorbed by the leaf, leaving an area of foliage covered with a number of fluorescent particles corresponding to the quantity of liquid applied.

For this experiment 189 grams of fluorescent particles were added to 378 grams of Arlacel 83 and 400 ml of dioctyl phthalate of DOP. Arlacel 83 was used as a suspension and dispersion aid for the FP while DOP was used as a dispersion stabilizer. Once mixed, the liquid was placed into a blender and agitated for two-minute intervals several times throughout the day. Since the particles would settle to the bottom in a short period of time, proper machine agitation became necessary once the mixture was placed into the tank. The machine modifications previously described were designed to accommodate the vigorous agitation requirements of the formulation.

Machine Field Operation

Before the mixture was placed into the spray tank, the equipment was thoroughly cleaned. Three gallons of kerosene, followed by a small amount of DOP, were sprayed through the machine. Excess moisture was drained from the lines, and the system was dried thoroughly.

The sprayer was then transported to the field site. Adjustments were made for both fan height and angle. Due to the physical difference of the trees, these adjustments were altered to accommodate the tree being sprayed. Thus, they were not constant across the entire experiment.

Three gallons of DOP were added to the sprayer tank. As the FP mixture was poured into the tank, the contents were constantly stirred. Additional DOP was added to raise the total amount to the requirements previously selected for each individual rate.

An agitation line and a bypass line were placed through the tank top and inserted into the can. A jet agitator on the end of the agitation line provided a high velocity flow in three directions which eliminated "dead spots" and provided adequate agitation for the FP solution.

The hydraulic pump was engaged to check the system for proper flow and to insure proper agitation in the tank. When the hydraulic system reached the recommended operating temperature, optimum hydraulic pressure was established and maintained between 900 and 1000 pounds per square inch. The solution pressure differed depending upon flow rate and orifice size, but was in a 33 to 42 pounds per square inch range. Although ground speed varied from 2 to 2.5 mph, PTO speed was held constant at 540 revolutions per minute. Orifice size controlled the output. See Table II for operating parameters and Table I (page 21) for orifice sizes used.

Yellow forestry tape was used to label each tree and identify its treatment. Fifty feet prior to the first tree of each treatment

TABLE II. The operating parameters used with low-volume sprayers during the application of four treatment rates.

Rate (gallons/acre)	Speed (miles/hour)	Pressure (pounds/square inch)	Output (gallons/minute)
10	2-2.5	33-42	.4
30	2-2.5	33-42	1.25
50	2-2.5	33-42	2.00
70	2-2.5	33-42	2.80

group and 20 feet after the last tree of each treatment, markers were placed at starting and finishing lines, respectively. Approximately 5 feet from the outer edge of the tree foliage in each treatment, another marker was placed. This marker defined the distance from fan to foliage as the operator traveled from start to finish in each treatment.

When all the parameters were ready the operator started the sprayer. The sprayer operating speed and system pressure was attained before reaching the first tree in a group. One pass was made per treatment. Only right hand side fans were used. Spray delivery by the fan to completely cover the entire tree was assessed visually with fan adjustments made accordingly.

Leaf Collection

After a given spray application was completed, the foliage was allowed to dry. Two leaf samples were selected from each of the eight sampling locations shown previously in Figure 3 (page 22). These leaves were removed by grasping the petiole to prevent disturbing the fluorescent particles on the leaf surfaces. To prevent wrinkling each leaf was placed flat into small paper bags and sealed with tape. Each bag listed the treatment in Roman numerals (I-IV), the tree in Arabic numbers (1-5), and the position on the tree in letters (A-H).

Upon returning from the field, treatments were placed together in a classification order and were pressed. The bags were stored in a dark, dry area until the laboratory analysis began.

IV. LABORATORY ANALYSIS

Laboratory Equipment

Three pieces of equipment were used to acquire the fluorescent particle data. Two Spectroline (Model B-100) ultraviolet lamps provided ideal illumination when placed at 45 degree angles to the surface being observed. An Olympus stereo microscope (Model X-Tr) provided the 40X magnification used to observe and count the individual fluorescent particles and particle clusters. A grid was placed in the eyepiece of the microscope to define a small area where the particles were counted. This area was determined to be 0.44 mm^2 .

Data Acquisition

After the microscope was placed on a table, the two Spectroline ultraviolet lights were placed adjacent to the stage plate on either side of the microscope. The lamps were oriented at 45 degrees to provide equal illumination on the stage plate where the sprayed leaves were to be placed. The paper bags containing the treated leaves were removed from the storage area. For a given leaf, percentage of coverage on the leaf top was estimated and recorded on the data sheet. Percentage of coverage on the leaf bottom was also recorded. The particle count was determined for two locations on both the top and bottom of the leaf. Particle count sites were randomly chosen within a portion of the leaf surface that had received coverage.

CHAPTER IV

RESULTS AND DISCUSSION

Percentage of coverage and fluorescent particle numbers for a designated area of leaf surface were subjected to an analysis of variance procedure as shown in Tables III and IV. F-test were conducted for eight sources of variation. The error terms used in testing hypotheses are depicted in the ANOVA tables. Arrows lead from the appropriate error terms to the tested sources of variation.

Rate, location, and side, which are displayed under the heading of "Source" in the ANOVA tables, were considered to be the fixed variables in these analyses. Particle numbers and percentage of coverage, which are dependent variables, were considered as random variables.

I. PERCENTAGE OF LEAF COVERAGE

As the application rate increased, the low-volume, high-velocity sprayer provided significant increase in the mean percentage of leaf coverage. Although the increases were substantial, they were not proportional to the fixed rate increases. Mean percentage of leaf coverages are shown in Table V for application rates 10, 30, 50, and 70 gallons. These means are compared graphically in Figure 4. At the highest rate (70 gallons per acre), the graph indicates only a 49.5 percent mean leaf coverage. This implies little or no protection is

TABLE III. Analysis of variance for dependent variable, percentage of leaf coverage.

Source	DF	SS	F	PR	F
Rate ←	3	136320.012	34.74	.0001	
Tree (Rate) ←	16	20926.375	3.40	.0001	
Loc ←	7	211034.837	31.80	.0001	
Rate*Loc ←	21	44838.637	2.25	.0035	
Tree*Loc (Rate) ←	112	106170.025			
Leaf (Rate*Tree*Loc) ←	160	61514.000			
Side ←	1	182978.450	83.43	.0001	
Rate*Side ←	3	7380.975	1.12	.3697	
Tree*Side (Rate) ←	16	35092.575			
Loc*Side ←	7	82422.300	9.85	.0001	
Rate*Loc*Side ←	21	42821.875	1.71	.0398	
Tree*Loc*Side (Rate) ←	112	133901.825			

TABLE IV. Analysis of variance for dependent variable, number of particles per unit area.

Source	DF	SS	F	PR	F
Rate ←	3	17586.914	7.30	0.0027	
Tree (Rate) — ←	16	12851.662	2.08	0.0115	
Loc ←	7	47655.342	11.62	0.0001	
Rate*Loc ←	21	22078.328	1.79	0.0273	
Tree*Loc (Rate) —	112	65607.187			
Leaf (Rate*Tree*Loc) —	160	61781.125			
Side ←	1	229702.819	198.95	0.0001	
Rate*Side ←	3	3490.846	1.01	0.4149	
Tree*Side (Rate) —	16	18473.037			
Loc*Side ←	7	36463.186	8.42	0.0001	
Rate*Loc*Side ←	21	30912.422	2.38	0.0019	
Tree*Loc*Side (Rate) —	112	69277.812			

TABLE V. Mean percentage of leaf covered and number of fluorescent particles deposited per unit area at four low-volume spray application rates.

Rate (gallons/acre)	Percentage of Leaf Covered	Number of Fluorescent Particles per 0.44 mm ²
10	20.9 c *	64.9 b
30	34.0 b	68.4 b
50	39.3 b	73.2 a
70	49.5 a	74.0 a

*Means in the same column followed by the same letter are not significantly different at the 95 percent level.

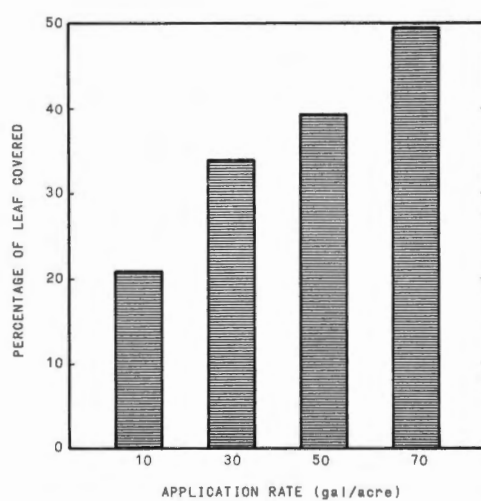


FIGURE 4. Mean percentage leaf coverage for four low-volume spray application rates.

offered against spores over 50 percent of the foliage surface area even at the highest application rate used. This would possibly be sufficient for insect control due to the mobility of the pest. However, when controlling micron-sized spore development, a more complete coverage is necessary.

Another area tested was trees within rates. Although there was a difference in coverage between these individual replications, it varied only 8 percent. The mean percentage coverages of trees one through five in each group to which spray materials were applied are shown in Figure 5. The variation in this test was due partially to the physical difference among the trees and the location of the trees in the orchard.

In testing the foliage coverage for certain regions of individual trees, eight locations were selected per tree and two leaves were chosen from each of these sites. Mean percentages of leaf coverage are shown in Table VI for the eight sampling locations. Figure 6 depicts these mean percentages graphically. Refer to Figure 3, page 22, to identify the various sampling locations.

From these data, results indicated that position three, located in the center of the tree near the trunk, received less coverage than any other area. Also, the obstructed distance from the sprayer was greatest at this point. This result supports the hypothesis that: (1) distance from point of spray material discharge and (2) physical obstruction are the leading determinants in spray coverage. Ranking slightly ahead of location three in mean coverage was location four. This area had the second lowest percentage of coverage and the second

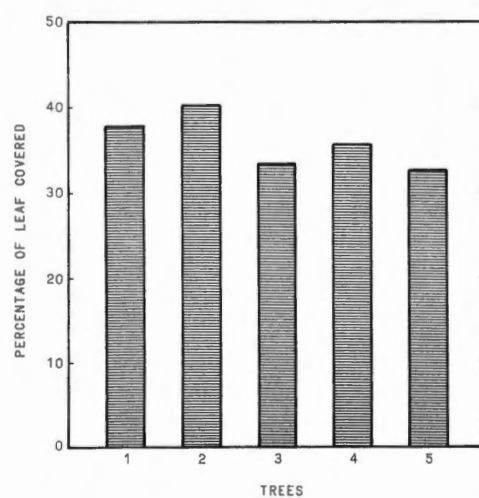


FIGURE 5. Mean percentage coverage for apple trees within groups subjected to four application rates.

TABLE VI. Mean percentage of leaf covered and number of fluorescent particles deposited per unit area at eight designated locations on an apple tree.

Sampling Locations* (gallons/acre)	Percentage of Leaf Covered	Number of Fluorescent ₂ Particles per 0.44 mm ²
1	25.4 d**	66.8 d e
2	25.3 d	66.0 d e
3	23.9 d	64.3 e
4	25.1 d	62.5 e
5	38.1 c	70.5 c d
6	40.6 b c	72.6 b c
7	46.7 b	77.3 a b
8	62.2 a	81.1 a

*See Figure 3, page 22, for location definition.

**Means in the same column followed by the same letter are not significantly different at the 95 percent level.

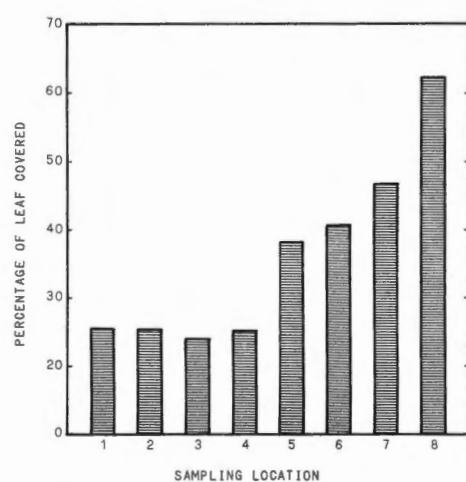


FIGURE 6. Mean percentage coverage for eight sampling locations on apple trees subjected to four low-volume application rates.

greatest obstructed distance from the sprayer. Areas one and two, which were located on the same plane as three and four, received the next lowest coverage. Note that coverage for locations one, two, three, and four varied within two percentage points of one another. Location two, although on the outside of the tree, ranked lower than location one, due to the obstructed spray path created by the direction of travel of the machine.

Mean coverage considering all rates at location one was 25 percent. This low coverage could have resulted partially from gravitational pull on the spray droplets instead of foliage hindrance as was the situation in location two, three, and four. Coverage at location five was 13 percentage points more than coverage at location one. This was perhaps due to the fact that no obstruction existed between the sprayer and sample site five. Yet, location five does not compare favorably with location eight, which is also located on an unobstructed path. The large difference in coverage appeared to depend on distance between the point of droplet discharge and the target surface.

As shown in Figure 6, location eight, which was nearest to the sprayer as it passed the tree, varied most in coverage. This observation suggested that distance was a more prominent factor in obtaining proper spray coverage than obstruction by foliage. This finding is also supported by results for location seven, which lay in a plane between location eight and location three. Although location seven had substantial foliage obstruction, it had a higher coverage percentage than any of the other locations excluding location eight.

Location six, which was on the bottom of the tree in the same plane as locations one through five, had the third highest coverage. Although somewhat obstructed, this location benefited from the gravitational settling of droplets over a given distance. This result prompted the conclusion that gravitational effects and air resistance to droplet motion were greater deterrents to maximum spray coverage than was foliage obstruction.

With respect to leaf side percentage of coverage, results indicated that the leaf tops received only 48 percent mean coverage, while the leaf bottoms received 24 percent coverage. Although these results implied generally poor foliage coverage, several leaves evaluated for rates three and four displayed excellent coverage on both top and bottom. Unfortunately this coverage level did not occur consistently throughout the replications.

Percentage of coverage had a significant three-way interaction between random variables rate, location, and side. Test results at each of eight locations are graphically depicted in Figures 7 through 14. Each graph shows the increase or decrease in mean percentage coverage on either leaf side as the rate of output for the sprayer ranged from 10 to 70 gallons per acre at a given location on the tree.

As shown in Figure 7, location one, in the very top center of the tree, had a higher percentage of coverage on the leaf bottoms than on the leaf tops. This was a unique occurrence because other locations received greater coverage on the leaf tops. Location one is the only area tested that had foliage above the top fan on the sprayer. Therefore, on a direct path from the fan the spray material would

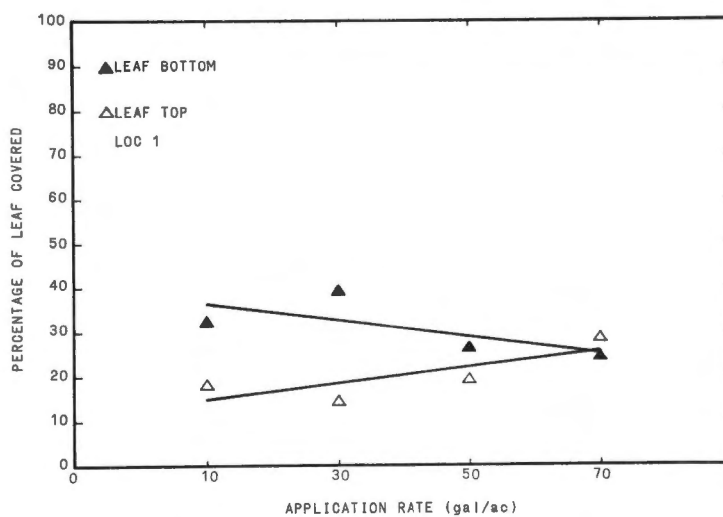


FIGURE 7. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location one.

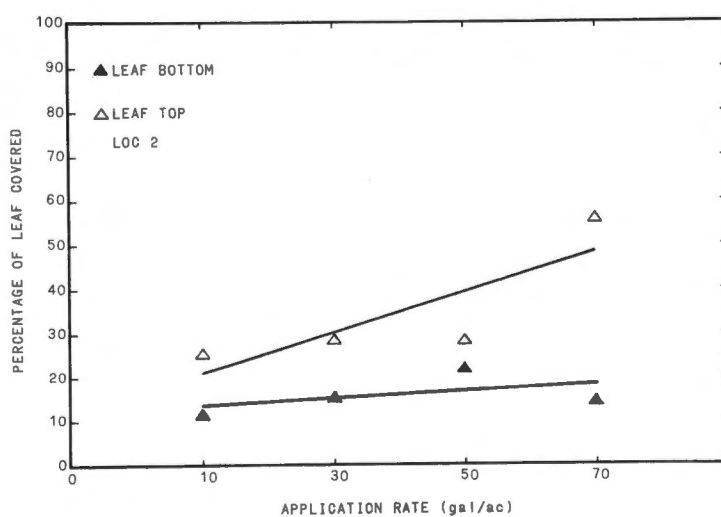


FIGURE 8. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location two.

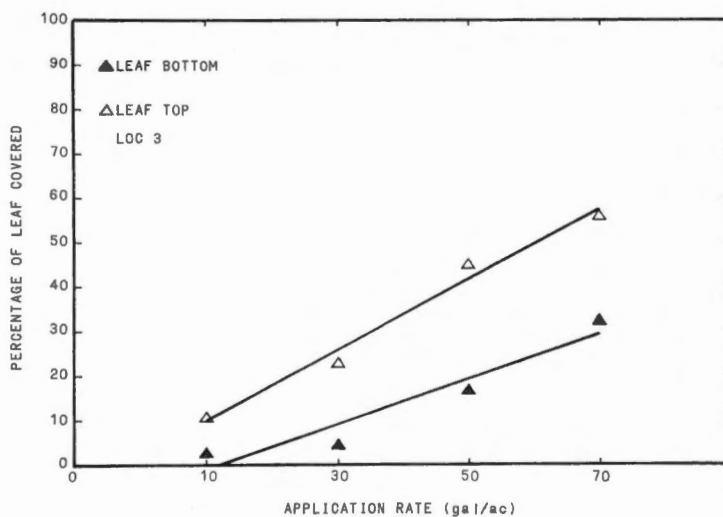


FIGURE 9. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location three.

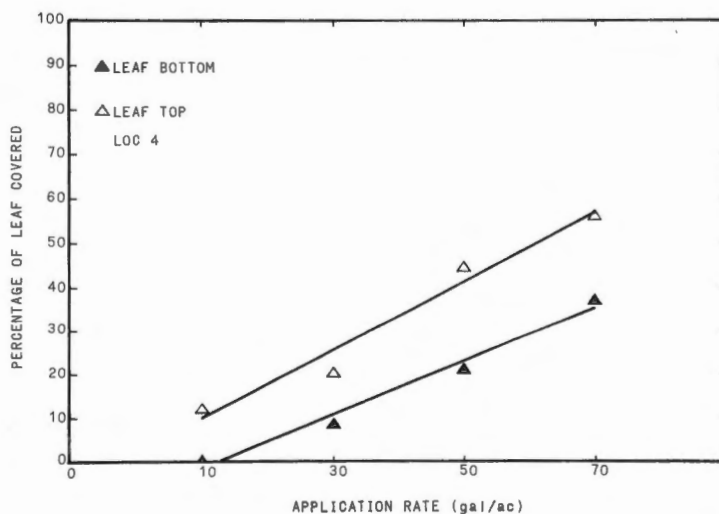


FIGURE 10. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location four.

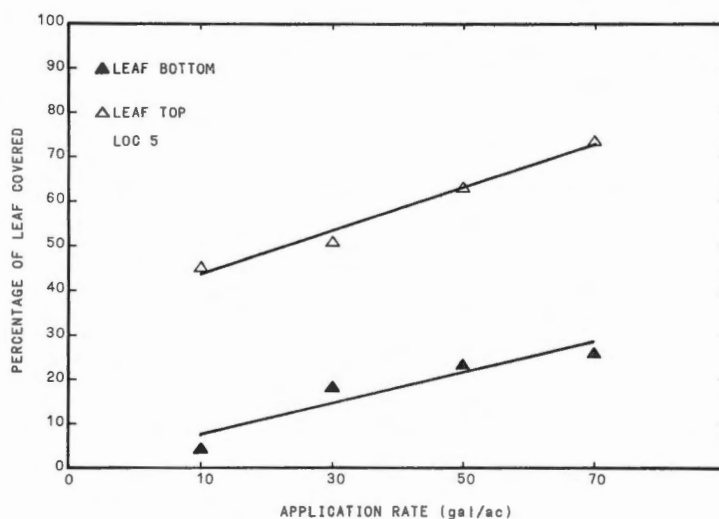


FIGURE 11. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location five.

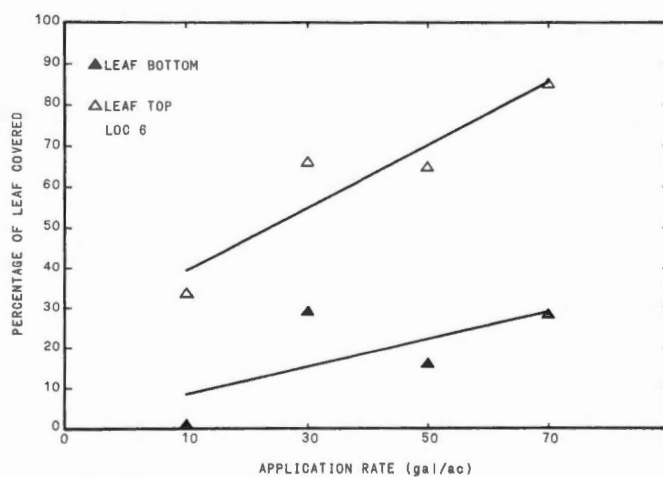


FIGURE 12. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location six.

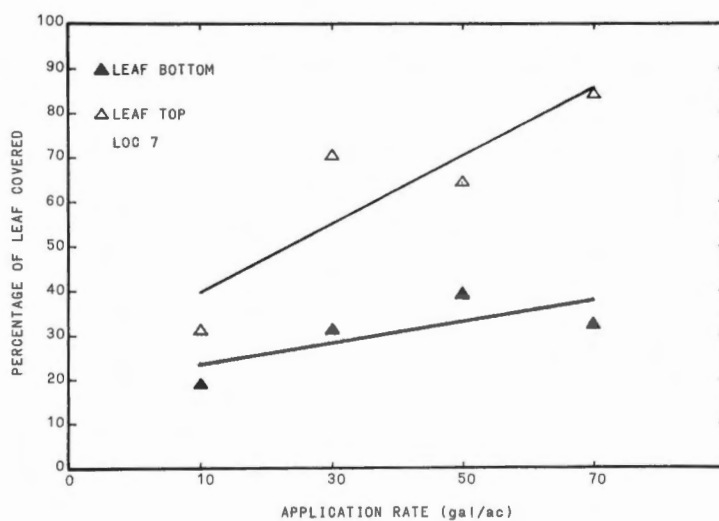


FIGURE 13. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location seven.

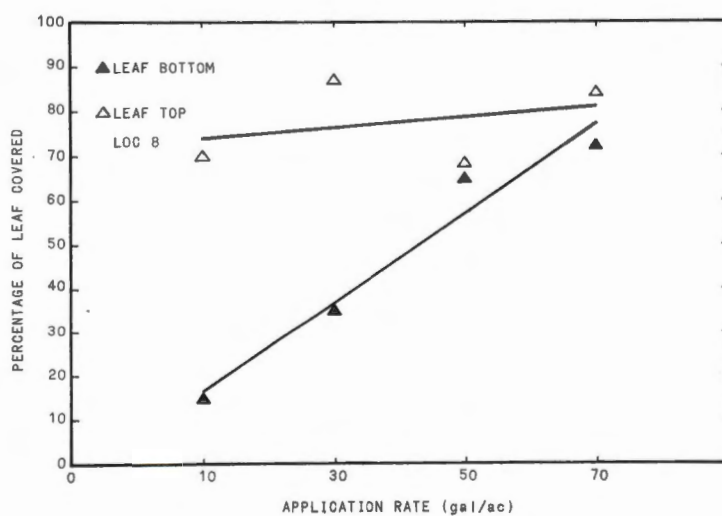


FIGURE 14. Mean percentage of top and bottom leaf surface covered when subjected to four low-volume application rates at sampling location eight.

strike the leaf bottom prior to reaching the leaf top.

As the rate increased in gallons per acre the coverage on the leaf bottoms decreased at location one. Gravity exerting a downward force on the larger spray droplets was partially responsible for this action; whereas wind currents were responsible for transporting the smaller droplets to the underside of the leaf at the lower rates. With the exception of rate one, leaf top coverage at location one increased modestly as rate increased.

At locations two through eight (Figures 8 through 14) coverage of leaf top and bottom surfaces increased at a relatively uniform rate with increases in application rate. Exceptions were the leaf bottoms at location two and leaf tops at location eight. Note that leaf bottoms in locations three and four received virtually no coverage at the 10 gallon per acre application rate.

Observation made during the evaluation of percentage of leaf coverage revealed that veins and ribs displayed a greater accumulation of particles than other leaf surfaces. At the higher rates a runoff effect could have been responsible for more particles being deposited near the veins. Likewise, the raised veins presented a wall-like structure which collected the particles as they were transmitted by wind currents. Other fluorescent particles which were directed to the underside of the leaf were apparently often filtered by the leaf hairs and not allowed to reach the bottom leaf surface to provide protection against the fungal spores.

II. QUANTITY OF SPRAY DEPOSITION

Numbers of deposited fluorescent particles were obtained from the areas on the leaves that displayed visible spray coverage under ultraviolet light. As discussed in the previous section, these areas ranged from zero to almost 100 percent coverage.

The mean number of fluorescent particles are shown in column two of Table V, page 32, for rates 10, 30, 50, and 70 gallons. These means increased slightly as the output rate increased as shown in Figure 15. Never was the increase between rates greater than ten particles per 0.44 mm^2 . Comparing rates three and four, the increase was less than one particle. Intuitively, this means that as the application rate increased, the percentage of coverage improved considerably, but the fluorescent particle density in a given area increased only minutely. Consequently, when a greater volume of the material was sprayed, the material was distributed over a greater leaf area instead of being deposited more densely.

The small variation in particle density among trees within treatments is illustrated in Figure 16. Differences in the physical conformation among trees could be responsible for this variation. Apparently the sprayer did an effective job in providing a consistent particle density over each series of trees.

The mean number of fluorescent particles are shown in column two of Table VI, page 36, for eight designated sampling locations. The mean number of particles counted in these designated locations on the trees are shown in Figure 17. Particle numbers per location followed

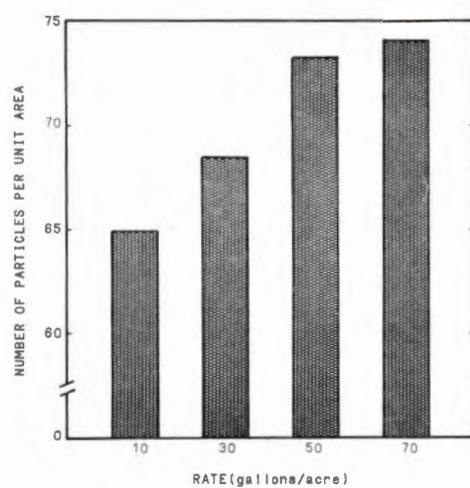


FIGURE 15. Number of particles per unit area for four low-volume spray application rates.

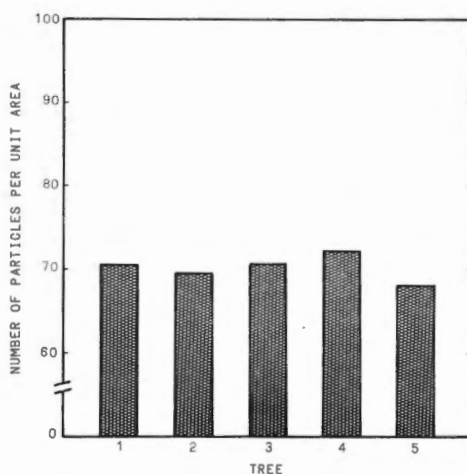


FIGURE 16. Mean number of particles per unit area for groups of trees subjected to four application rates.

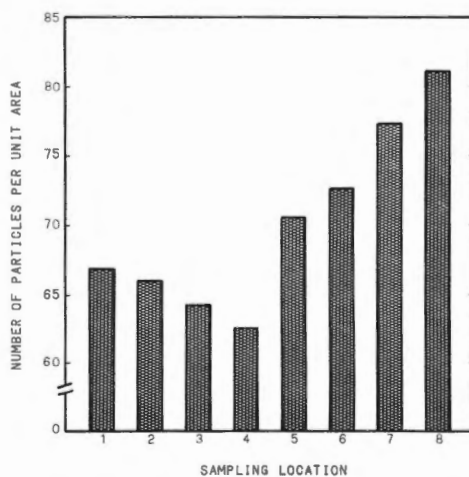


FIGURE 17. Mean number of particles per unit area for eight sampling locations on apple trees subjected to four low-volume application rates.

the same pattern as percentage of coverage for identical locations, with one exception. Location three has the smallest coverage percentage followed by location four, whereas, location four has the smallest number of particles followed by location three. All other locations assumed the same pattern as for particle density. As for the percentage of coverage locations one through six, which lay on the same plane, have fewer particles per site than locations seven and eight. These two locations, which lay on a plane parallel to the fan blast were closer to the sprayer. Particle numbers seemed to be directly influenced by distance more than by foliage obstruction. This observation also held true for coverage percentage. As distance from the sprayer increased, the magnitudes of both dependent variables tended to decrease rather rapidly. Observation of foliage surfaces from all sampling locations indicated that there was a significant difference between particle numbers on leaf tops and bottoms. Due to the natural tendency of droplets to descend when subjected to gravitational forces, more particles were found on the leaf tops. Over the four application rates, leaf bottoms collected nearly one-third fewer fluorescent particles than top leaf surfaces.

The interaction between rates, locations, and sides was tested and the results indicated that as rate increased, fluorescent particle numbers on both leaf tops and bottoms increased. Particle numbers per unit area as a function of application rate for the two leaf sides are shown in Figures 18 through 25. These are plotted for each of the eight locations. Locations one and seven were exceptions to the increased deposition with increased rates. As rates increased, there

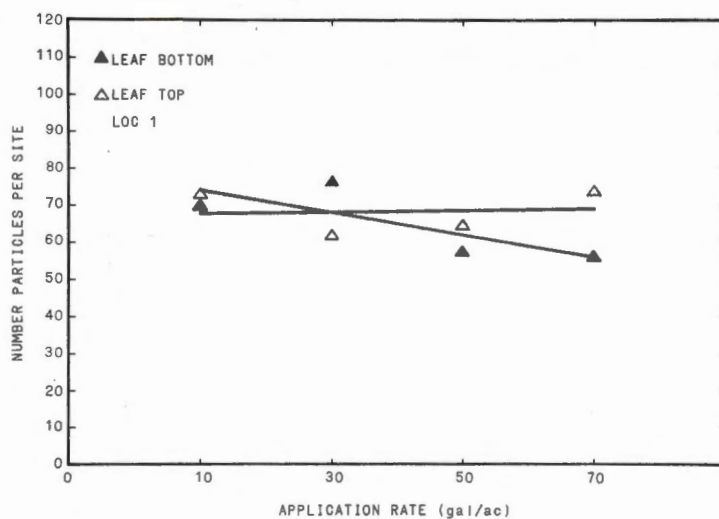


FIGURE 18. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location one.

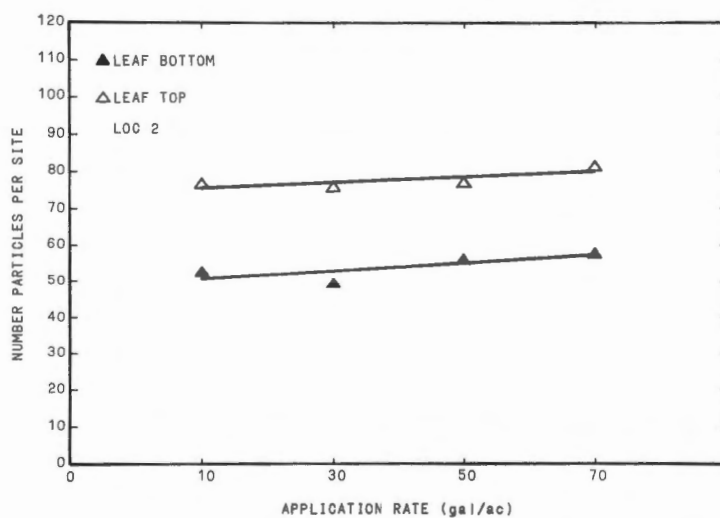


FIGURE 19. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location two.

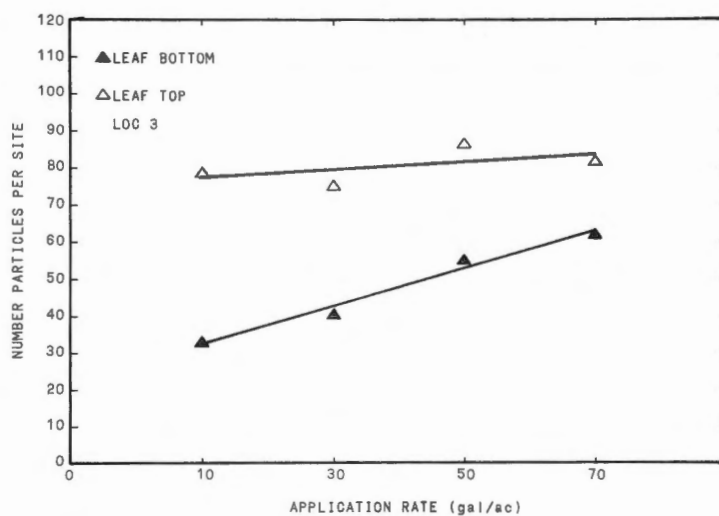


FIGURE 20. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location three.

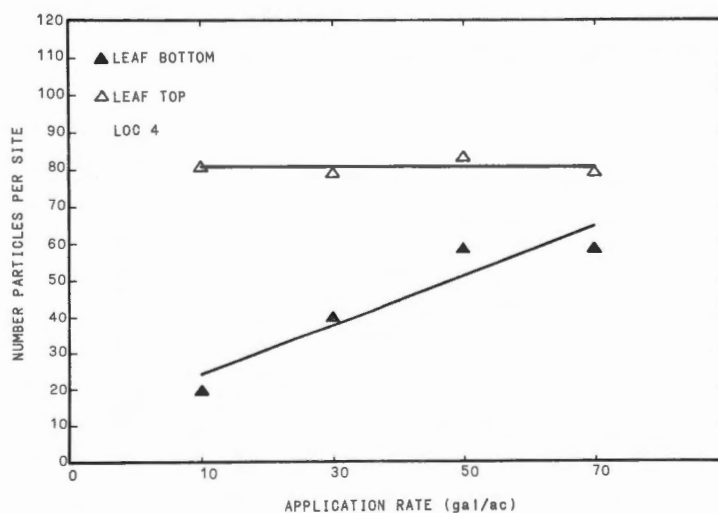


FIGURE 21. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location four.

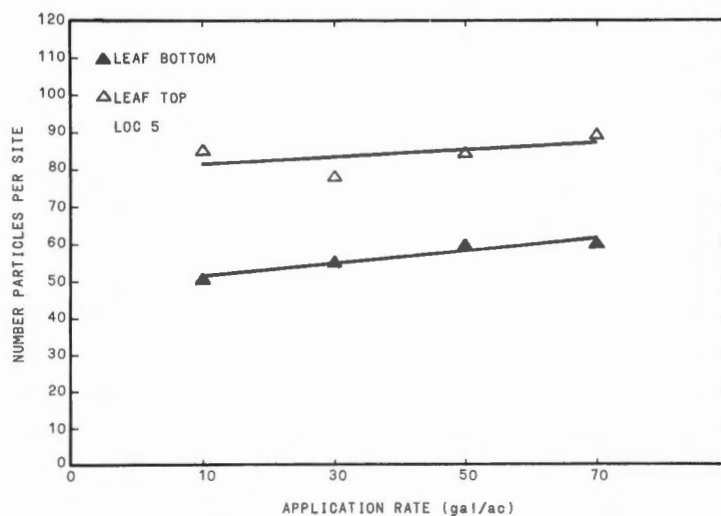


FIGURE 22. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location five.

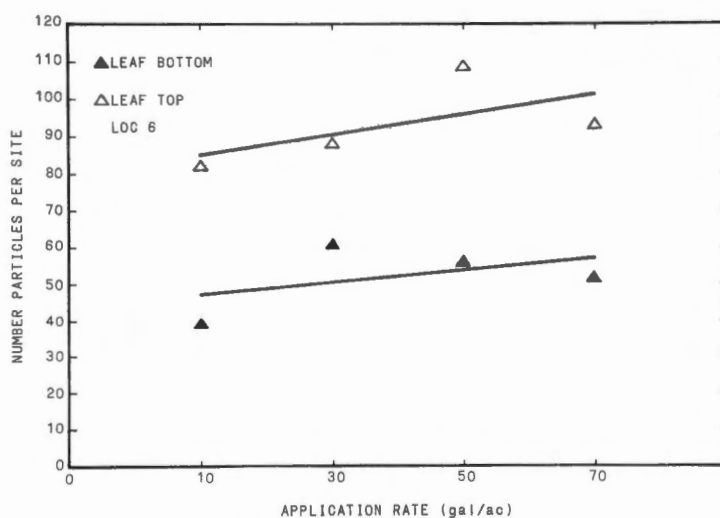


FIGURE 23. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location six.

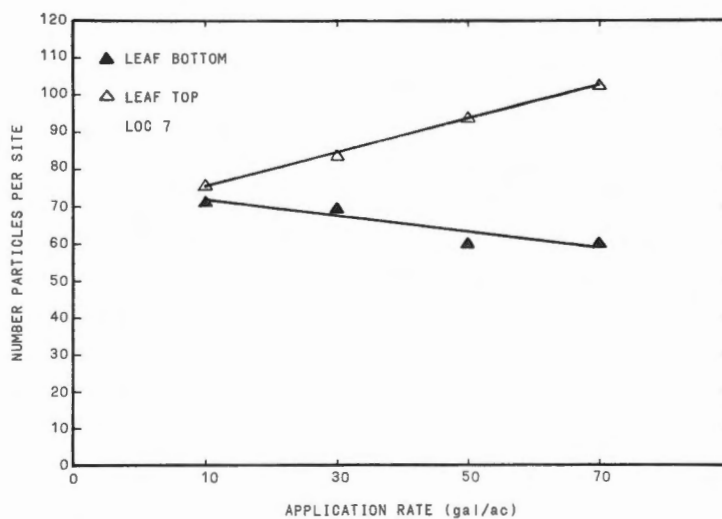


FIGURE 24. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location seven.

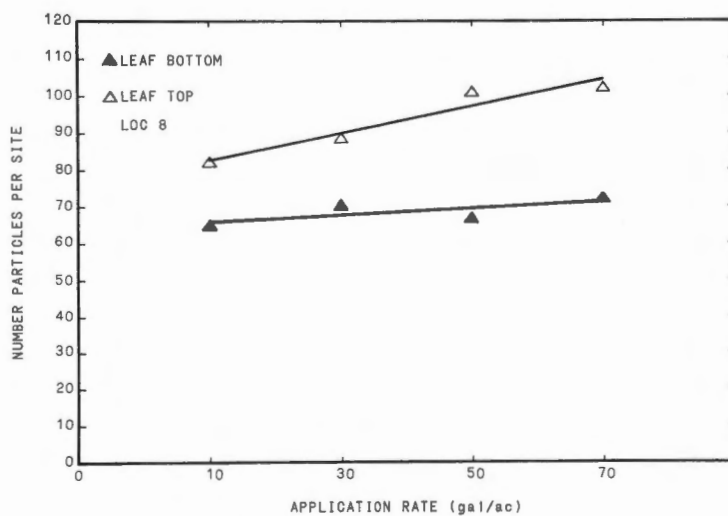


FIGURE 25. Mean number of fluorescent particles per site on top and bottom leaf surfaces at four low-volume application rates at location eight.

was a slight decrease in fluorescent particle numbers on the leaf bottoms at these two sites. At location one, which is in the top center of the tree, the decrease in leaf bottom particles was due to gravity exerting a downward force on the larger droplets as they preceded in their upward path.

Considering the entire tree, more fluorescent particles were located on the leaf tops at the bottom of the tree than leaf tops at the top of the tree.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

A modified low-volume, high-velocity air-blast applicator was used to apply solutions containing a known volume of micron-sized fluorescent particles at four rates to groups of trees within an apple orchard. The material was applied after the fruit was harvested, but before leaf drop. Trees were similar in size, shape, and foliage density, and environmental conditions were similar for all spray applications.

The four groups of five trees each were sprayed at rates of 10, 30, 50, and 70 gallons per acre, respectively. Following spray application, two leaves from each of eight designated locations were selected per tree for evaluation of surface coverage and quantity of material deposited. The leaves were pressed and placed in labeled paper bags for storage prior to laboratory study. Leaves were brought from storage to the laboratory for evaluation. A grid was fabricated for the eyepiece of a Model X-Tr, Olympus stereo microscope. By adjusting the selector drum to a forty-power reading with a ten-power eyepiece, the grid designated a 0.44 mm^2 area of leaf surface which could be examined for fluorescent particle deposition.

The leaves were placed on the microscope stage individually. Two ultraviolet lamps provided the necessary light for the test. Before observing the leaf through the microscope, percentage coverage on leaf top and leaf bottom were estimated and recorded. Two areas on each side of the leaf were randomly selected for observation through the microscope. Both areas were chosen within the portion of the leaf surface which contained deposited particles. The number of fluorescent particles within each 0.44 mm^2 area were counted and recorded. This procedure was repeated for each of the 320 leaves collected.

After all the leaf data were collected, they were analyzed with SAS programming, using The University of Tennessee's Computer facilities.

II. CONCLUSIONS

The following conclusions were drawn from this study:

1. As application rate was increased from 10 to 70 gallons per acre, the leaf surface percentage receiving spray material approximately doubled.
2. Even at the highest application rate, only about 50 percent of the leaf area received spray deposits. This level of coverage is generally considered inadequate for control of fungal spores.
3. Deposition density of fluorescent particles on the leaf surface increased as the application rate increased from 10 to 70 gallons per acre.

4. The distance from the fan to the target surface was a more prominent factor in percentage spray coverage than was foliage obstruction as leaves closest to the fan had more deposited material.
5. Considering all leaf sampling locations and application rates collectively, the top leaf surface received a higher percentage of coverage and more fluorescent particles per unit area than the bottom surface. In only one location, the tree top, did the bottom leaf surface receive a greater percentage coverage than the top surface. Moreover, this only occurred at the lower application rates.
6. Concentrations of particles occurred at veins and ribs. Hairs on the leaf bottom apparently kept the fluorescent particles from reaching the leaf surface in many instances.
7. At the 10 gallon application rate, virtually no material was deposited on leaves in the center of the tree.
8. The percentage of coverage was more sensitive to changes in application rate than was deposition density on target surfaces.

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