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A TECHNIQUE
TO EVALUATE SPRAY DEPOSITION
IN ORCHARD TREES USING WRK STRING TECHNOLOGY

By

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ABSTRACT

A TECHNIQUE TO EVALUATE SPRAY DEPOSITION

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STRING TECHNOLOGY

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A qualitative technique has been developed to evaluate spray pattern and spray penetration in the canopy of fruit trees. This technique is based on the WRK string technology developed to analyze aerial spraying. The technique produced basically the same deposition pattern as the copper tracing technique but reduced the time and labor required to perform the analysis, thus enabling several passes and tests to be done within a short time and providing almost immediate results.

In operation, the modified WRK technique uses a cotton string placed vertically in the tree. Three 15-foot support poles hold the string, one at the front tree edge, one at the center and one at the

back tree edge. The string comes from the supply string dispenser, goes up and down each support pole, and goes to the motorized take-up spool. A fluorescent dye, Rhodamine WT, was mixed with the spray water in the sprayer tank and sprayed toward the tree canopy under study. The sprayed string was then retrieved by winding it onto the take-up spool. The string was delivered to the computer and fluorometer operator, who analyzed the amount of dye deposited on the string. The relative fluorescence values read by the fluorometer were immediately displayed on the monitor and plotted on the plotter paper, and results were saved on the floppy diskette for later use. The graphical simulation of the spray pattern made it possible to identify faulty spray nozzles, improper nozzle arrangement and other factors so they could be changed to improve the spray deposition.

This technique provides fast evaluation of spray deposition in the field site and so greatly assists Extension and educational work. The printout of the spray deposition pattern in the plant canopy provides an excellent guide to assist growers, sprayer operators and sprayer manufacturers in achieving better sprayer performance.

To my Mother, Asma, ...

the Memory of my Father, Othman, ...

"...may ALLAH forgive and bestow upon them mercy

as they pampered me since childhood."

and to all my Family members, including:

my wife, Jawaher,

and my children: Jasman, Johan, Jihad, and Muhammad Jaafar......

"...may ALLAH continue to show us the Right Path."

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Agricultural pesticides, insecticides, fungicides and herbicides are used in great quantity to protect agricultural and horticultural crops from damage by insects and fungi and to reduce competition from weeds. The pesticide industry has grown tremendously in the past 50 years. In 1989, there were 14 major pesticide producers marketed more than 35,000 products in the United States. Pesticide application in the agricultural sector has increased from negligible amounts in the pre-World War II era to over 1 billion pounds per year. Despite the use of these pesticides, crop losses in the United States were estimated at about 30 percent. This translates to an economic loss of $16 billion per year (Wolff et al., 1989).

Most of these agricultural chemicals were applied as sprays using agricultural sprayers. Many studies have confirmed the misapplication of these agricultural sprays in the field. Couch reported individual spray application errors of 25 percent to 35 percent in the United States (Couch, 1988). Ozkan found that thousands of gallons of pesticides were wasted annually because of improperly calibrated sprayers (Ozkan, 1987). Overapplication of pesticides increases production costs, potential crop damage, pollution and excessive residue carryover (Grisso et al., 1988). Underapplication of pesticides can be costly because the chemical may not effectively control the target pest. Underapplication may lead to the need for an additional application that may not be timely and may lead to a reduction in crop yield (Hoehne and Brumet, 1982).

1.2 Concerns

It is always the objective of the sprayer operator to have 100 percent of the spray hit the target. This is never completely achieved. There are always spray losses due to misapplication, evaporation and drift. These losses, besides costing a lot of money, can cause environmental problems, endanger human health and wildlife, and damage plants.

In an effort to reduce misapplication and to improve the efficiency of these sprays, various types of agricultural sprayers and nozzles have been used and are constantly being improved. Training programs for sprayer operators focus on proper calibration, nozzle selection, spray height or distance from target, and operating pressure, which can drastically reduce misapplication.

The fruit production industry, as well as other agricultural industries that require the use of sprayers to protect crops, has the problem of not knowing exactly how the sprays that are being used are being deposited. The deposition pattern of the spray droplets in the plant canopy with various sprayers and nozzles is not well understood. All who are involved -- fruit growers, sprayer owners and sprayer manufacturers -- are concerned about the deposition patterns of these sprayers.

Fruit growers are concerned that the sprayers can uniformly deliver and efficiently deposit the spray droplets throughout the canopies of their fruit trees. The marketable yield of fruit trees depends on how well the trees are protected against insects and diseases. Fruit trees that are not fully protected are susceptible to attack and many suffer damage that results in low fruit production and poor fruit quality. The grower's income is further reduced if the spraying costs -- which include chemicals, labor and machinery -- are high.

Poor sprayer performance can be the result of many factors, including blocked spray nozzles, extremely high or extremely low spray pressure (which may cause excessive drift or dripping), incorrect setting of the air blast and incorrect nozzling of the sprayer. Once the spray deposition pattern for a particular sprayer and a particular type of trees has been determined, sprayer adjustments and replacements can be made to improve the deposition pattern.

Sprayer owners and custom operators need to know how their sprayers perform. Sprayer performance includes droplet distribution patterns, droplet penetration and deposition throughout the plant canopy. Custom operators who fail to provide effective spray coverage to the tree crop may experience reduced demand for their spraying services in the coming season.

Sprayer manufacturers are concerned about the designs and operational concepts of their sprayers. Their objective is to produce sprayers that can propel spray droplets, penetrate various types of plant canopies and uniformly deposit the spray droplets. The development of a tool or technique to quickly measure the deposition pattern of spray droplets throughout the plant canopy would help greatly in evaluating sprayer performance.

Various attempts have been made to develop a method or procedure to measure the amount of spray solution being deposited on the target plant and correlate this with the amount of spray solution leaving the spray nozzles. Another concern of researchers is the evaluation of the spray pattern delivered by the sprayer and the size of spray droplets. The current methods of measuring chemical deposition using a copper tracer are slow, laborious, complex and expensive. A more recent method for measuring deposition is the WRK fluorescent string technology. This method, developed to pattern aircraft sprayers, has potential to conveniently and rapidly determine chemical deposition in orchard trees. Because this new measuring technique is fast and easy to use, adjustments and changes in the sprayers and nozzles can be rapidly evaluated. The result will be a saving of costly agricultural chemicals, a reduction in energy use and reduced environmental contamination.

1.3 Objectives of the Study

Recognizing the need for a simple, reliable, easy to use, affordable and less laborious technique or procedure to quickly measure and evaluate the amount of chemical deposition throughout the canopies of orchard trees, this research had the following primary objectives :

1. To develop a modified WRK string method for evaluating spray deposition in the canopies of fruit trees (based on the WRK string method for aerial spraying).

2. To develop equipment or modify existing hardware to facilitate the use of the modified WRK string method .

3. To make field tests on several typical sprayers with the modified WRK string method.

4. To compare results of sprayer deposition using the modified WRK string method and the copper colorimetry method.

CHAPTER 2
LITERATURE REVIEW

2.1 Methods of Measuring Chemical Deposition

A number of techniques or methods have been developed to measure spray deposition . In general, the methods used have been based on visual judgment, optical measurement or chemical analysis. The methods usually involve the use of a tracer material such as a luminescent dye that can be seen under ultraviolet light or an element that can be isolated and measured by chemical analysis. Each method has some merit. Its suitability is determined by the nature of the crop, the chemical application technique and the degree of reliability required.

Efforts to study chemical deposition were documented as early as 1909. Riley (1909) designed and developed an instrument to study spray droplets that was later improved by Barger et al. in 1948. In Riley's equipment, the spray nozzle sprayed a dye solution on a sheet of paper through a slot in a moving curtain. Barger improved the method by using a corrugated surface to divide the spray into narrow bands and measured the amount of material intercepted in each band.

In 1952, Corl used the direct titration technique for testing and comparing the spray deposition produced by broadjet sprayers operating in a field (Corl, 1952). In 1953, Sanders reported using a photoelectric colorimeter to measure the amount of dye deposited by an aerial application (Sanders, 1953). In the same year, Weick reported using direct weighing of the deposition collected from aerial spraying (Weick, 1953). Davis and Elliot made visual estimates from deposits collected on cards as a rapid method to determine the pattern of aerial deposition (Davis and Elliot, 1953) . In 1955, Liljedahl and Strait used a bioessay technique in both laboratory and field tests to determine the deposition performance of broadcast sprayers (Liljedahl and Strait, 1955). Generally, these methods are tedious or not particularly accurate.

Before 1959, most workers were using equipment similar to that described by Riley (1909) or by Barger et al. (1948) for the laboratory testing of spray droplets. Unfortunately, laboratory testing was not a particularly good indicator of the distribution of spray material in the field because of the influence of factors such as ground roughness, wind and the characteristics of the sprayers (Liljedahl and Strait, 1959).

Currently, several methods of measuring spray deposition are still in use. These methods are usually based on visual judgment, optical measurement, chemical analysis or some combination of the above. These methods are briefly explained and described in the next sections.

2.1.1 Visual Judgment Method

This is one of the earliest methods ever used to monitor spray deposition. In this method, the spray solution -- which can be plain water, water with dye or water with fluorescent elements -- is sprayed onto the target or collecting material. The target can be tree foliage itself or an artificial target to replace the foliage such as a mylar card, white card, black card, glass plate or aluminum plate. Staniland (1959) described a technique for using a number of fluorescent tracers to study the spray and dust deposits on plants, insects and soil in the field. He found out that some of the tracers were suitable for use as suspensions, while others can be mixed with sprays containing chemicals in solution.

Chemicals such as malathion were sprayed onto a malathion-sensitive card, while insecticides consisting of finely ground powder in the suspension form were sprayed onto the black cards. In some cases, vegetable oil was used to replace water when it was found that oil was more suitable for mixing with the dye or fluorescent elements (Blinn and Lovell, 1965). Individual targets with water droplets, dye deposits or fluorescent deposits can be directly examined or inspected with the naked eye or with the help of a magnifying glass or microscope, or be illuminated by an ultraviolet light, whichever is appropriate (Bullock et al., 1968).

Other information -- such as the number of spray droplets per sprayed area, the amount of chemical deposited per sprayed area, the volume sprayed or even the spray pattern produced by the sprayer -- can be calculated or estimated using this visual method of analysis. Because individuals may evaluate or judge the amount of deposition differently, the results produced by this method are not reliable and uniform. Also it is an eye-straining, time-consuming job to check and count droplets on this type of individual target (Markin, 1978).

The visual judgment method can be considered simple, easy to understand and easy to implement (Salyani et al., 1987). This method consumes much time however, especially in preparing and evaluating deposition targets. Each deposition target -- either the actual leaf or other artificial targets such as paper cards, mylar sheets, glass plates or aluminum plates -- has to be individually inspected and the deposition amount measured or at least estimated. Because this method requires a minimum of equipment, the material and equipment cost is the lowest of all the methods. The greatest disadvantage in using this method is the variation in deposition readings from one evaluator to another. Human error due to eyestrain while counting and evaluating individual deposition targets is hard to avoid. The same person may give different values to the same deposition cards as fatigue and stress levels vary. Thus, this method is too variable to give reliable data for deciding which sprayers give superior performance.

Staniland (1959), Edwards et al. (1961), Bullock et al. (1968) and Salyani et al. (1987) agreed that the visual judgment method of evaluating deposition patterns is simple, fast and adequate for determining large differences in spray coverage, but they also felt that this method was too subjective for more detailed studies. Other methods for quantitive measurement of spray deposition and for more reliable deposition assessment must be sought.

2.1.2 Image Analyzer Method

To make the visual judgment method more reliable and to speed up the reading of the number of droplets on the deposition targets, the image analyzer method was developed. This method is an improvement over the earlier visual judgment method. It uses several sophisticated pieces of equipment, including a video camera, a video digitizer board, a high speed mathematical board, a fluorescent ring light, a black and white monitors, a printer keyboard, and a microcomputer development system with at least 64K RAM and two dual-density 8-inch diskette drives. This method requires well trained operators to get reliable data and results (Sistler et al., 1982).

The image analyzer method described by Sistler is faster than the visual judgment method in measuring chemical deposition. The readings given by this method are reliable and consistent. The major objections to this method are its high cost and the extensive training and experience required of the equipment operator. The accuracy of this method depends on prior calibration of the equipment, which must be done only by specially trained personnel (Sistler et al., 1982). Because of these disadvantages, this method is not widely used in the determination of chemical deposition.

2.1.3 Spray Table or Patternator Method

The spray table or patternator method is widely used in Extension and other educational efforts. It is a fast way to show the spray pattern delivered by the sprayers or spray nozzles under study. A typical spray table consists of a corrugated collection tray, an electrically driven pump, a pressure gauge, a spray boom with several nozzle bodies and necessary plumbing. With present designs, the spray table method can detect only the amount of spray solution coming out of the nozzles, which are placed over the corrugated spray table. This method indicates how much material is leaving the nozzles but is not a reliable method to measure the amount of chemical deposition on a field target, and it is certainly not suitable to measure chemical deposition in the tree canopy (Azimi et al., 1985).

This method, although easy and simple, does not give a true picture of the spray deposition on the tree foliage. The volume of the spray collected by each test tube shows the overall spray pattern of the sprayer. The spray pattern is affected by nozzle wear, plugging, spray pressure, nozzle type, spray viscosity, etc. An overcollection of spray volume may indicate worn-out nozzles. This method is not a reliable and accurate method of measuring chemical deposition (Wolak and Horton, 1989).

2.1.4 Optical Method

An optical method for analyzing spray deposition was reported by Edwards et al. (1961). This is a very time-consuming method and results vary with the skill of the operators. This method can be of two types: indirect and direct. In the indirect optical method, sprays containing copper tracings are sprayed on the leaves. The leaves are removed from the plant. Individual leaves are then brought together and pressed against a specially treated paper. The paper, which is the second target, picks up the copper tracing deposited on the leaf, which is the first target. The copper deposits on the paper are then viewed under ultraviolet light.

The direct optical method, used by the same researcher, differs from the indirect method in that fluorescent chemicals such as Anthracene and Saturn Yellow pigments are used instead of copper deposits. The fluorescent chemicals deposited on the leaves are then viewed directly under ultraviolet light. This method is an improvement on the indirect optical method because it speeds up the overall process (Edwards et al., 1961).

2.1.5 Fluorometry Method

This is one of the most widely used methods for measuring chemical deposition and has received a lot of attention from many reseachers. This method uses fluorescent chemicals or dyes mixed with water as the spray solution. This solution is then sprayed onto the targets under varying conditions. Deposition analysis is done after the targets have dried.

The work of Liljedahl and Strait (1959) is the first known attempt to measure spray deposits continuously across the entire spray swath. Their continuous paper sampling surface collected a transection of the spray deposit across the entire swath. A fluorescent tracer incorporated into the spray was the component detected and quantified. The fluorescent emission was continuously monitored and recorded as the paper strip containing the fluorescent deposit was moved at a fixed speed past the detector. The fluorescent detector used was a photocell. Their research concluded that the measurement of the fluorescence of spray deposited across the swath of a sprayer was a good indication of the actual distribution of the spray. Their research also showed that the fluorescence of the deposit of a spray containing a suspension of a fluorescent material was linearly proportional to the amount of spray material deposited, with maximum inaccuracies under adverse test conditions probably on the order of 10 percent. Their laboratory test showed that deposits of large droplets were somewhat less fluorescent than deposits of smaller droplets. However, the effect of droplet size in a field test of a sprayer could not be detected.

In a separate experiment, Byass (1969) added fluorescent dyes to the pesticide to compare the deposition of the dye and the active ingredient of the pesticide when it was sprayed on leaves. Individual leaves were measured for deposition with the fluorometer. Byass found that the amount of fluorochrome deposited on the leaf was equivalent to the amount of active material deposited on the leaf when it was sprayed by the same machine at the same time. He also found that fluorescence measurements could be made at least 10 times faster than chemical measurements of simple active materials. Chemical measurements gave information that related only to groups of leaves because of the relative insensitivity of this technique. He also showed that measurements from several thousand leaf samples were required to compare the uniformity of deposition of materials in different treatments of an apple tree, or similar targets, with reasonable sensitivity. A rapid method of making such measurements was yet to be developed. Thus, this method did not help to save time nor make the work less laborious.

Sharp (1973) designed and used another method to assess spray deposition by spraying machines in apple orchards. The trees were sprayed with a 0.4 percent suspension of MT grade Saturn Yellow fluorescent in water. When the spray deposit was dry, whole leaf trusses were picked and leaf disks were punched into a circular polypropylene support using a pneumatic leaf punch. Filled supports were accumulated in a tubular magazine. When the tubular magazine was full, it was sealed and brought back to the laboratory. This magazine was attached to the fluorometer and each leaf disk sample was allowed to drop into the fluorometer in turn. This fluorometer was automated by an electrical drive to the dial and the null-point sensed electronically. At the instant of balance, the fluorometer dial reading was recorded by data-logging equipment. Byass concluded that this technique produced reliable mean deposit values and frequency distribution curves and provided a clear indication of the efficiency of the spraying machine.

In 1979, a team of researchers headed by L. O. Roth pursued the experiment done by Liljedahl and Strait 10 years earlier, to measure the chemical deposition using fluorescent tracers deposited on paper tape. The fluorometer was again used to measure the chemical deposition. In 1985, Whitney and Roth improved and speeded up the analysis. Instead of the paper tape used by Roth in 1979, they used a cotton string to collect the spray. The fluorescent dye used was Rhodamine-B, and the equipment used to measure the flourescence was the fluorometer. This method was a major breakthrough in the improvement of chemical deposition measuring technique using fluorescent material and a fluorometer. A problem was the photosensitivity of common water-soluble fluorescent dyes, which required very careful calibration of the fluorometer (Salyani et al., 1987).

The fluorometry method is recognized as a simple and fast method to measure the relative amount of chemical deposition (Whitney and Roth, 1985; Salyani et al., 1987). The use of cotton string or paper tape in place of individual leaves, paper strips or mylar sheets has made the reading process faster and provides a more continuous set of data points. Fewer people are required to operate this system. The calibration of the fluorometer is easily done by following short, simple, easy to understand instructions.

The use of paper tape or cotton string instead of individual paper strips, leaves or other kinds of deposition strips greatly decreases the time required to take data. The use of cotton string is also more efficient at collecting deposition than the paper tape (Whitney et al., 1985). The reported cost of the equipment using the WRK string and fluorometer method for aerial spraying deposition was $ 23,000 (Whitney, personal communication, 1987). The equipment consisted of a flightline string sample collection system, string analysis and graphic system, and flightline data acquisition system.

2.1.6 Colorimetry Method

Another popular method of measuring chemical deposition is known as the colorimetry method, which assesses the chemical deposition by using a colorimeter. In 1982, J. B. Carlton measured chemical deposition by using FDC 3 in a water spray and collected the spray droplets on 135 mm film and then measured the deposition by passing the film through the colorimeter. Van Ee et al. (1985) used emulsified copper as a tracer material in the spray solution to compare penetration and deposition characteristics of the airflow through dense citrus foliage. The penetration and the deposition performance of the conventional air-blast sprayer and the air curtain sprayer were compared. Mylar targets, 2 inches by 4 inches, were placed within the tree canopy and oriented in four directions with opposing targets turned 90 degrees from each other. Once dried, the mylar targets were removed from the tree and copper was washed from the targets with dilute nitric acid and the deposition level measured by using a colorimeter.

In 1986, R.W. Whitney headed a team of researchers measuring chemical deposition in citrus trees. They used trace copper as the depositing material and mylar cards as deposition targets. The copper deposits were washed off the targets and measured with the colorimeter. In 1987, J. B. Carlton tried another method of collecting chemical deposits. This time he placed a long, continuous PVC microtubing across the field to collect deposits of FDC 3 sprayed aerially (Carlton, J. B., 1987). The collected deposits were then read by the colorimeter.

Petri dishes placed across the field were also used as collectors for chemical deposition measurement. Copper was added to the spray solution for the aerial spraying. After spraying, the petri dishes were taken to the laboratory for deposition analysis. The colorimeter was used to measure the amount of copper deposited in each of the petri dishes. The use of the colorimeter required washing the collected deposition material from the deposition targets and carefully calibrating the equipment.

The colorimetry method of measuring chemical deposition may be the most precise method to measure chemical deposition. It gives a quantitative amount of deposition collected by the deposition targets. The equipment cost is much lower than the equipment cost of the fluorometer method but, at present, more time is required to set up and pick up deposition targets, make the spray solution and add reagents prior to reading the colorimeter. All this time and work translate into costs and labor that may make this method less popular than the WRK fluorometry method. However, the reading given by the colorimetry method may be desirable when quantitative and reliable readings are required for research results.

2.1.7 Spectrophotometry Method

The use of an atomic absorption spectrophotometer for measuring the amount of chemical deposited on a tree canopy has also been reported. In 1984, R.E. Byers and his research team sprayed chelated copper on apple leaves. The apple leaves were then plucked from the tree and washed with an appropriate chemical. The wash solution was then analyzed to determine the amount of copper it contained by using a special spectrophotometer (Byers et al., 1984). This method has not been widely used to measure chemical deposition by sprayers because it is laborious, slow and expensive.

The deposition efficiency of a sprayer, given as the percentage of the amount deposited on the leaves over the maximum deposition expected, could be calculated as follows (Byers et al.,1984):

$$\text{Deposition efficiency, \%} = C2V / yf'nL \times AVc$$

where: f' = liquid flow rate in liters/second.

$C2$ = color factor= 0.000588.

y = initial concentration of the fluorescent tracer in spray liquid in gm/liter.

L = distance covered in one spray pass.

n = number of passes the sprayer has travelled for a test run.

V = forward velocity of the sprayer in meters/second.

The amount of tracer deposits deposited on the leaves can be calculated as follows (Byers et al.,1984):

Tracer deposit in ng/cm2 = C1 A Vc

where:

A = the absorbence reading given by the spectrophotometer when read at 640 nm wavelength.

Vc = the volume of the deposit solution collected in milliliters.

C1 = the deposition coefficient = 30.637.

2.2 Limitations of Existing Methods

The previous sections briefly described the various methods to measure chemical deposition. The two most widely used and popular methods are the colorimetry method and the fluorometry method.

These methods are popular and commonly used, and each has its advantages and disadvantages. Measuring chemical depositions in the tree canopy adds another degree of difficulty.

Salyani, Whitney and Hedden (1987) did a study evaluating the fluorometry method and the colorimetry method for spray deposition on a citrus canopy. Four common methods of deposition assessment -- i. e., fluorometry on a leaf target, fluorometry on a mylar target, colorimetry on a leaf target and colorimetry on a mylar target -- were studied to find the merits and limitations of each. Rhodamine-B fluorescent dye and copper (in the form of 50 percent cupric hydroxide) were used as tracing materials. They found that photosensitivity of common water-soluble fluorescent dyes was a serious problem and required very careful calibration of the fluorometer. On the other hand, the colorimetry method was time consuming, especially adding the reagent.

The chemical deposition readings given by the fluorometer indicate the relative amount of dye deposits collected by the collection targets, i. e., paper cards, paper tape, microtubing or cotton string. The simulated spray pattern produced by all the collected data reveals which of the many nozzles are not functioning as they should be and which part of the field area is not being sprayed properly.

The use of individual deposition spray targets is very time consuming, whether it is for analysis with the fluorometer or for analysis with the colorimeter. When artificial deposition targets are used, each of these targets has to be attached by staple, pin or clip to the leaves or other kinds of supports as appropriate. After spraying has been done, these targets must be individually removed with great care from their supports or from the leaves to avoid contaminating them. Careful handling is still required when taking the sprayed targets from the field to the fluorometer or colorimeter station to avoid contaminating or disturbing the amount of deposition collected on the targets. The targets must be properly labeled before and after the spraying so that their identification can be maintained and readings assigned correctly. If the colorimeter is used to read the amount of deposition, the chemical deposits must be washed off the targets with the proper wash solution.

When a Hach Model DR100 Colorimeter was used for copper colorimetry, the procedure involved:

a) Taking 10 ml of the solution in a sample glass vial.

b) Clipping a reagent powder pillow and pouring its contents into the vial.

c) Shaking the sample a few times for uniform mixing.

d) Adding a drop or two of 6N sodium hydroxide to adjust the pH.

e) Waiting for at least 2 minutes for full color development.

f) Placing the vial inside the colorimeter.

g) Reading the copper concentration.

Samples with higher concentrations had to be diluted two or four times to be read by this model colorimeter because its intended reading range was from 0 to 3 mg/l (ppm). If Rhodamine-B was also present in this spray, it's purple color directly affected the copper reading. The colorimetric readouts were then corrected as follows

(Salyani et al., 1987):

$$C2 = C1 - (F2 \times Sc)$$

where:

C2 = corrected copper concentration (mg /l),

C1 = colorimeter reading (mg /l),

Sc = slope of the colorimeter reading vs. Rhodamine-B concentration line (Sc = 2.206).

The quantity of the copper or Rhodamine-B per unit area of the sample was calculated as follows (Salyani et al,1987):

$$QFC = FC2 \times Vn / As$$

where:

QFC = quantity of fluorescing Rhodamine-B or copper per unit area (ug /cm2),

FC2 = concentration of Rhodamine-B or copper in sample solution (mg /l),

Vn = volume of nitric acid solution (ml),

As = sample surface area of both surfaces (cm2).

If the fluorometer is used, each target with fluorescent deposits has to be inserted into the fluorometer to measure its fluorescence. All the readings are manually recorded and plotted to show the overall spray or deposition pattern. All these activities are time consuming and laborious. The high number of human operations increases the chance of human error.

The use of a fluorescent chemical as spray deposit requires timely collection and analysis. Testing of several water-soluble fluorescent dyes, including Fluorescein, Uranine and Rhodamine-B, revealed that they do not fluoresce when dried; therefore, visual judgment of deposition patterns could not be accomplished. The dyes were photosensitive and their fluorescence diminished with time.

The following is the equation for finding the rate of decay for Rhodamine-B fluorescence as established by experiment done by Salyani et al. in 1987:

$$FL = 107.513 \times EXP(-0.00525 \times Te)$$

where:

FL = fluorescing Rhodamine-B concentration (ug /l),

Te = exposure time (minutes).

Collecting deposition targets before the fluorescent deposits on them are dried causes smearing of the targets. Delaying the collection of the deposition targets causes the deposits to lose their fluorescence or diminish in intensity. Thus, picking up treated deposition targets too soon or delaying the pickup causes inaccurate fluorometer readings.

Using continuous PVC microtubing as a collecting target is a way to automate the collection and analysis process (Carlton et al., 1985). For field deposition, a special tripod is required to hold the microtubing at a uniform height. This method of collecting spray droplets is suitable only for spraying from the top, i.e., aerial or boom spraying, but not for collecting deposits coming sideways as for orchard sprayings. The use of microtubing to monitor the amount of spray deposition in the tree canopy is not yet possible.

The current methods of measuring deposition require many people, especially to place and pickup the deposition targets. The process is also slow during the fluorometer or colorimeter analysis stage. Some modifications to the existing methods are necessary to make them acceptable for measuring deposition in the tree canopy and to speedup the total process of set-up, collection and analysis of the deposition data.

2.3 Advantages of the WRK String Method over Current Methods

The use of leaves, mylar sheets, sensitive paper cards or any other deposition targets to collect spray deposits for chemical deposition measurement is very time consuming and laborious. Petri dishes and microtubing are not appropriate for measuring chemical deposition in tree canopies.

The WRK system for aerial spraying, which uses a 1 mm cotton string as the deposition target, is a convenient, flexible and inexpensive way of measuring deposition on the testing sites and can expedite deposition testing. The whole length of the string acts as the deposition target. Numerous data points can be obtained without much additional effort. This string can be laid out in various ways, in different lengths and locations, easily and quickly. After the spray passes have been done, the string is wound onto a take-up reel and another length of new, clean string drawn into place ready for the next spray pass. The treated string can be immediately analyzed by passing it through the fluorometer or kept for a few days inside a closed reel container for later analysis. It is very important that the sprayed string be kept away from light because the fluorescence will diminish when exposed to light. The fluorescent values read by the fluorometer are digitized, fed into the computer for analysis and then stored on a diskette. The data are usually graphed with the X-Y plotter immediately after analysis. These graphics, along with other information, are then reviewed and action is taken to improve the performance of the nozzles and sprayers.

2.4 Effects of Meteorological Conditions on Spray Deposition

Weather conditions influence the effectiveness of pesticide spraying. Wind, temperature and humidity influence pesticide deposition on the plant surface, as well as the amount of chemical spray that drifts away from the targeted plant surface. Smaller droplets may provide more complete deposition within the crop but have a greater tendency to drift. Bigger droplets have less tendency to drift away from the targeted plant surface but coverage of plant surfaces is poorer. Bigger droplets also tend to run off and drip from plant surfaces. Droplets produced by orchard sprayers are generally in the size range of 25 to 500 microns (0.025 to 0.5 millimeter). The best spray droplet size for good deposition was reported to be between 200 and 300 microns (Hag et al., 1983).

Wind plays a major role in carrying and directing spray droplets. An atmosphere without much wind blowing is a stable atmosphere. It features minimal turbulence. Spray concentrations are greater under these conditions but less uniform. Pesticide drift is lower but air droplet mixing is very poor. This condition does not permit good penetration of spray droplets through the plant canopy and so gives poor deposition of spray droplets (Carlson, 1988).

The blower of the sprayer produces turbulence and causes the atmosphere to be unstable. Wind turbulence is known to be a major factor in mixing and distributing spray droplets in the plant canopy. With the blower-produced turbulence, the excellent mixing of air and spray droplets results in more uniform mixing and reduced droplet concentration. Pesticide drift is also greater, and canopy penetration of the droplets is much improved (Carlson, 1988). In a 3 mph wind, a 400 micron spray droplet would be carried a horizontal distance of 8.5 feet for every 10-foot fall, but the same droplet would be carried a horizontal distance of 126 feet if the wind speed was 15 mph. A smaller droplet such as a 20 micron droplet, would be carried 0.21 mile and 1.05 miles, respectively (Carlson, 1988).

The temperature at the time of spraying is also important in influencing the number of spray droplets deposited and the amount of spray that drifts off. Higher temperatures combined with lower humidities generally will cause greater evaporation of water from the droplet. This evaporation process takes place from the time the droplet leaves the nozzle of the sprayer until it reaches the target. Smaller droplets experience much faster evaporation, which results in greater drift. Higher humidity, on the other hand, means less evaporation so the droplets maintain their size and weight longer.

2.5 Current Technology in Orchard Spraying

In the early years of mechanized orchard spraying, high-pressure orchard sprayers were the principal means of applying liquid pesticides to orchards, using either hand guns or various types of booms or masts for automatic spraying (Kepner et al., 1978). Then a new concept, using an air stream as the carrier for spray droplets was developed in the 1940s for applying sprays to trees. Ever since, this type of sprayer, also known as the airblast sprayer, has largely replaced high-pressure sprayers in orchards.

For decades, these air-carrier sprayers have been the primary type of sprayer used to spray orchard trees in North America. Some examples of this kind of sprayer used in Michigan orchards are the FMC air blast sprayer, the FMC tower sprayer, the AgTec standard sprayer, the AgTec tower sprayer, the Myers air blast sprayer and the Turbo Mist sprayer .

A typical conventional air-carrier sprayer consists of a fan and nozzle system located at the rear of the sprayer unit. The fan is either an axial, turbine or centrifugal type that produces high speed, turbulent air. The nozzles of the conventional sprayer are usually hollow-cone types that produce a wide droplet spectrum. A high-pressure pump that produces pressures of 100 to 300 psi discharges the spray mix through a manifold of nozzles into the turbulent, high-speed air stream. This air stream acts as a medium for uniform mixing and a carrier for the spray droplets throughout the tree canopy. Dilute sprays are usually applied until run off from the leaves begins. This requires large amounts of water and some chemical loss, so more concentrated applications have become more common.

Van Ee et al. (1988) reported that the air turbulence associated with the 96 to 192 mph (160 to 320 kph) speed produced by the conventional sprayer, combined with the radial distribution pattern of spray droplets, resulted in a rapid loss of air velocity. The air blast from the fan outlet drops to half its original velocity at a distance of only 2.3 to 3.3 feet (0.7 to 1 meter) from the outlet, and to one quarter of that velocity at between 4.3 and 6.6 feet (1.3 to 2 meters). This rapid decrease in air velocity prevents uniform air penetration and chemical deposition in the tree canopy.

As the height and size of the tree increase, more spray has to be applied to the tree. This is achieved when using the traditional method of dilute spraying by increasing the spray volume and decreasing the forward speed of the sprayer. The air velocity also has to be increased to achieve better spray drop penetration.

Uniform deposition of chemical in the canopy is aided by applying spray solution to the point of runoff, but, as noted, this leads to a considerable waste of chemicals.

Concentrate spraying uses less water in the spray solution and so saves water handling costs and time. The main problem with concentrate spraying is that it must be done with greater accuracy and under favorable weather conditions. Mistakes in calibrating and spraying, or even a change in the wind, can result in chemically burned foliage, injured fruit or inadequate protection to the tree. With the conventional orchard sprayer, two-sided spray application are necessary for satisfactory protection of orchard trees.

In 1985, a new type of sprayer, the air curtain sprayer was developed at Michigan State University. This sprayer has been field-tested in both Michigan, on apple and cherry trees, and in Florida, on citrus trees. This sprayer uses smaller, simpler and more efficient cross-flow or tangential fans, which produce a relatively non-turbulent, straight-stream air flow. Four units of cross-flow fans are attached to the boom of the air curtain sprayer and aligned end to end. Within the outlet of each fan unit, a hydraulically powered CDA atomizer is mounted to incorporate the spray droplets into the air stream. Studies in Europe and Germany have shown that the air flow produced by cross-flow fans is better in both its droplet-carrying ability and foliage-penetrating characteristics.

The first prototype of the MSU air curtain sprayers was built and tested in spring and summer 1986. Researchers found that the average deposition rate of the air curtain sprayer was higher than that of the conventional sprayer. This may be the result of the adjustable CDA atomizers, which produced smaller droplets (in the 75 to 100 micron range) and the ability of this fan to apply less carrier volume per unit area .

The combination of non-turbulent air flow, controlled droplet size and reduced spray volume eliminated runoff, thus resulting in higher total deposition. It was also observed that using the air curtain sprayer reduced spray drift (Van Ee, and Ledebuhr, 1988).

Commercial prototype air curtain sprayers, known as CURTEC sprayers, were built and tested in 1986. This sprayer was an improvement over the earlier version of the MSU air curtain sprayer. It incorporated an improved atomizer design and delivered approximately 50 percent more air power than the original sprayer. The CURTEC sprayer was also reported to deliver more uniform deposition -- it reduced excess deposition on the side of the tree closest to the sprayer and increased the deposition on the far side of the tree (Van Ee and Ledebuhr, 1988). One application from either side of the tree was reported to give deposition equivalent to that of conventional two-sided spraying. It was claimed that the non-turbulent, straight-flow air improved spray droplet penetration through the tree canopy and at the same time uniformly distributed spray droplets on both surfaces of the leaves.

CHAPTER 3
METHODS AND PROCEDURES

3.1 Introduction

In keeping with the primary objective of developing a new, improved method or modifying an existing method to measure and evaluate spray deposition in fruit trees, and considering the advantages and limitations of various systems, the WRK string method was considered to have the best potential for success.

The equipment used by the WRK to analyze aerial spraying was modified so the string could be run vertically in a tree rather than horizontally.

3.2 Theory of Cotton String as Spray Deposition Collector

The string line that was set up vertically from the ground to the top of the tree acted as an artificial plant canopy to collect a sample of sprayed droplets passing by it. The droplets collected at each location along the string line reflected the number of droplets also available to the tree foliage around that location. The more vertical strings placed within the width of the tree canopy, the more information could be known about the deposition performance within the tree canopy. A fluorescent dye, Rhodamine WT, was used as a tracer material for the deposition. The amount of spray deposited could be estimated by the intensity of the fluorescence emitted by the dye deposited on the string as read by the fluorometer. Generally, the more fluorescent dye on the string, the more intense the fluorescence. Vertical strings placed in several locations within the tree canopy enabled us to study the deposition patterns at those locations.

Comparing spray deposition on a string placed within the tree with the spray deposition on a string placed in an open area next to the tree showed the effect of the foliage and tree branches on deposition. Comparing the spray deposition on a string closer to the sprayer to that on a string placed farther away when both strings were in the open or both in the canopy indicated how evenly or uniformly the droplets were being distributed.

With the typical air blast orchard sprayer, the string from the middle string support was expected to have less spray deposited on it than the outer string, the closest to the sprayer. The string from the farthest string support usually had the lowest deposition of the three string supports, unless the tree was sprayed from both sides. This result was expected because of the inability of spray droplets to penetrate a heavily foliated canopy. If deposition on the middle and the farthest strings were acceptable even with a one-side spray application, then it would follow that the sprayer was doing a good job in propelling and carrying the droplets through the leaves and branches of the tree.

The placement of three vertical strings on string supports A, B and C in a tree canopy as developed and used in the spray analysis is shown in Figure 3.1.

3.3 Design Requirements

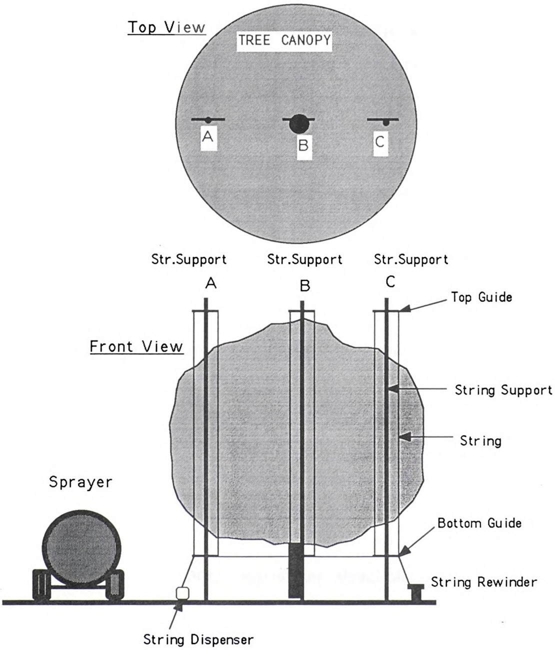
The following design criteria were used as guidelines in developing and modifying components to evaluate spray deposition in the tree canopy.

1. The overall evaluating method should be FAST. The whole procedure, including setting up the spray collector, spraying, retrieving the sprayed collectors and analyzing the deposition on the collectors, should be faster than the current methods. With the equipment set up, the time to spray and analyze the pattern should be less than an hour.

2. The overall evaluating method should be SIMPLE. Setting up the equipment and operating it should not require special skills and training for the users.

3. The additional costs due to the addition of new equipment to the existing WRK equipment for aerial spraying should not be too high.

Figure 3.1: The set-up diagram of field equipment



4. The overall evaluating method should require LESS LABOR than other methods. One or two people should easily be able to run the test, collect data and analyze them.

5. The method should produce results that are reliable enough to allow Extension workers, orchard owners, sprayer operators or manufacturers to use the results to make critical decisions.

Based upon these design criteria, other components from the WRK system used for evaluating aerial spraying that were relevant for use in evaluating orchard spraying were selected and modified, if necessary. Some other components were constructed in the laboratory.

3.4 Components to Collect Spray Deposition in the Trees

The components to collect the spray deposition in the trees consisted of the fluorescent spray material, the spray deposition collector, collector supports, a string dispenser, a string take-up spool and a power winder.

3.4.1 The Spray Deposition Material: Rhodamine WT

A fluorescent dye, Rhodamine WT, which was used in determining spray depositions for aerial spraying, was found to be suitable for use in determining spray depositions in tree canopies. Rhodamine WT mixes easily with water, and its fluorescent intensity is proportional to the amount of spray droplets collected. The fluorescence values are read by a fluorometer. Another characteristic of this fluorescent dye that recommends it is that it is non-toxic and safe to handle. When properly mixed with water in the spray tank, it becomes an excellent tracer for the spray material. Rhodamine WT was also found to be a good substitute for the chemical active ingredient in the amounts used in actual crop spraying.

3.4.2 Spray Deposition Collector: Cotton String

White cotton string 1 mm in diameter was used as a spray deposition collector. This six-strand string was purchased from a hardware store or ordered from the WRK Incorporated. It came in a 1-pound truncated cone with a typical length of 6,100 feet per pound. The string cone was placed in a string supply dispenser, then enclosed in a transparent plastic casing to prevent possible contamination from drifted spray material. The lead end of the string was threaded out from the string dispenser and positioned around the string supports in the tree. The exposed string collected spray droplets that came into contact with it.

The length of string that made up one data file was twice the vertical length of the string between the bottom guide and the top guide plus 12 inches (the horizontal length of the top string guide).

The bottom guide could be slid up or down along the vertical standing poles to give the final string position for the string support. All the bottom guides were set at the same height. The same procedure was followed for the top guides. In this manner, we maintained the same string lengths for all the string supports in the tree under study. With three string supports for one tree, three data files of the same series were collected for that tree.

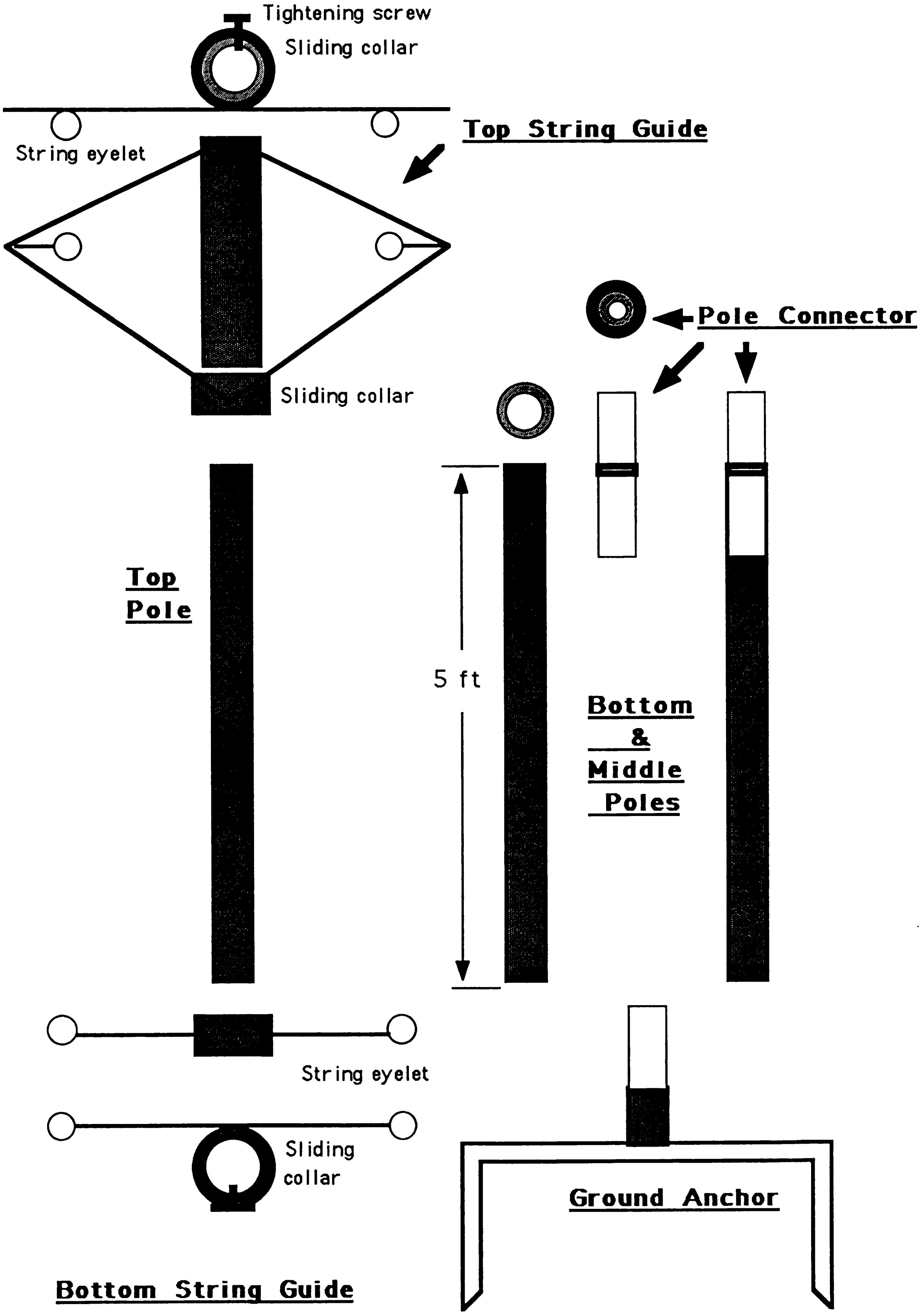
3.4.3 String Supports

A complete string support comprised a bottom ground anchor, a central column of three or four pieces of electrical metallic tubing (EMT) connected together, pipe connectors, a sliding bottom string guide and a top string guide. Figure 3.2 shows sketch diagrams of the parts of a string support pole.

The height of the string support could be increased by adding more EMT pieces to the central pole. Usually the height of this support was set about the height of the tree that we were working on. Each piece of tubing used with this research was about 5 feet long.

For one tree canopy, three string supports were positioned at the desired locations to hold the string in the vertical position to collect spray depositions. The first string support was placed three-quarters to halfway of the radius, out from the center of the tree. If the selected tree was heavily foliated, the first string support was placed three-quarters of the distance from the center

Figure 3.2: Sketch diagram of a string support



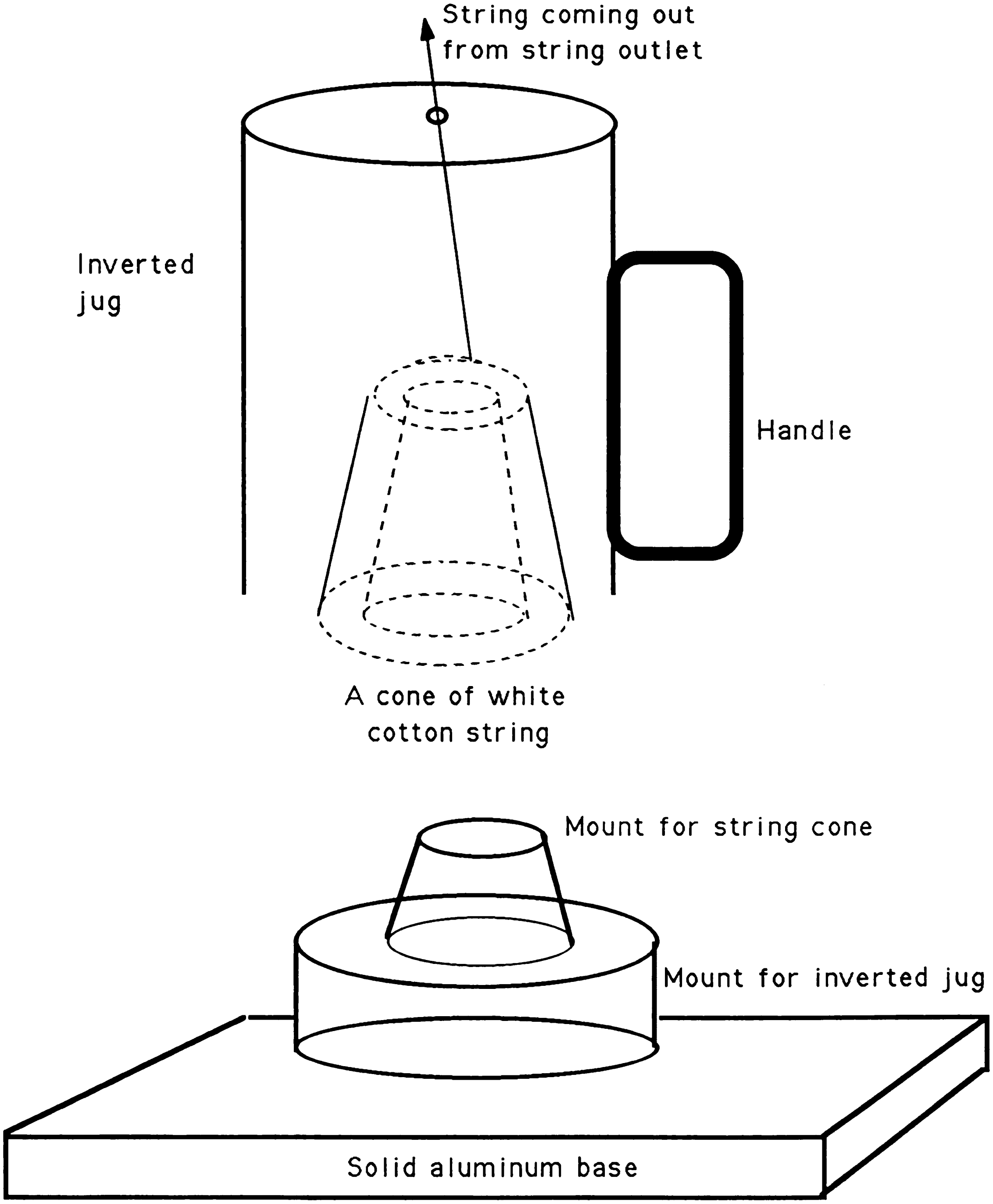
of the tree. If the foliage was not heavy, the string support was placed a bit deeper inside the canopy, halfway of the radius and closer to the tree trunk. The first string support, usually the closest to the sprayer, was identified or labeled as the A pole. In the data code or data file, the string collecting the deposition from this area was designated "A" to differentiate it from other string support locations. Compass directions -- north, east, south or west -- were sometimes used to identify the positions of the string supports relative to one another.

The second string support was placed in the center area of the tree, close to the trunk, or halfway between the first string support and the third string support . This location was identified as the B or middle (M) pole, and string occupying this string support was usually identified by the code "B" or "M" in the data file.

The third string support was placed at the other side of the tree's basal area. It was located about the same distance from the tree trunk as the first pole. The pole at this location was called the C pole and the string on this support had a similar identification code. When the first pole was identified as the north or the N pole, then the C pole was identified as the south or S pole.

These three string positions were considered sufficient to give a reasonable number of readings on the amount of chemical deposited throughout the tree canopy.

Figure 3.3: Sketch diagram of a string dispenser



3.4.4 String Dispenser

The string cone was placed in a special see-through string dispenser made from a locally purchased half-gallon water jug. The string dispenser is shown in Figure 3.3.

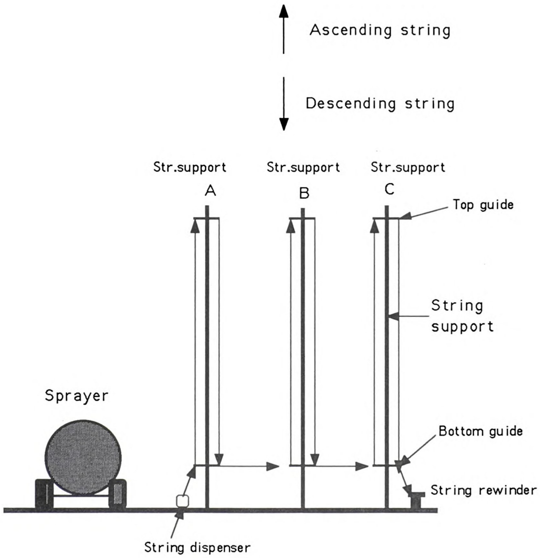
The loose end of the string from the string cone was threaded out of the string dispenser through a piece of plastic tubing and run through the first loop of the string guide at the bottom of the first string support, pole A. The string was then pulled up and threaded through the second loop, located on the upper string guide on the same side of the string support, pulled across to the third loop of the upper string guide and then brought downward to the fourth loop, located at the bottom string guide.

After that, the same lead end of the string was pulled across to the second string support (pole B or M). The same string placement procedure was repeated on the second string support and then on the third string support (pole C). The sequence of this threading process is illustrated in Figure 3.4.

3.4.5 String Take-up Spool and Power Winder

Once the lead end of the string reached the last loop of the third string support, it was taped to the string take-up spool. This spool was 4 inches in diameter and powered by a battery-driven power

Figure 3.4: Sequence of threading the string on the string supports A,B & C



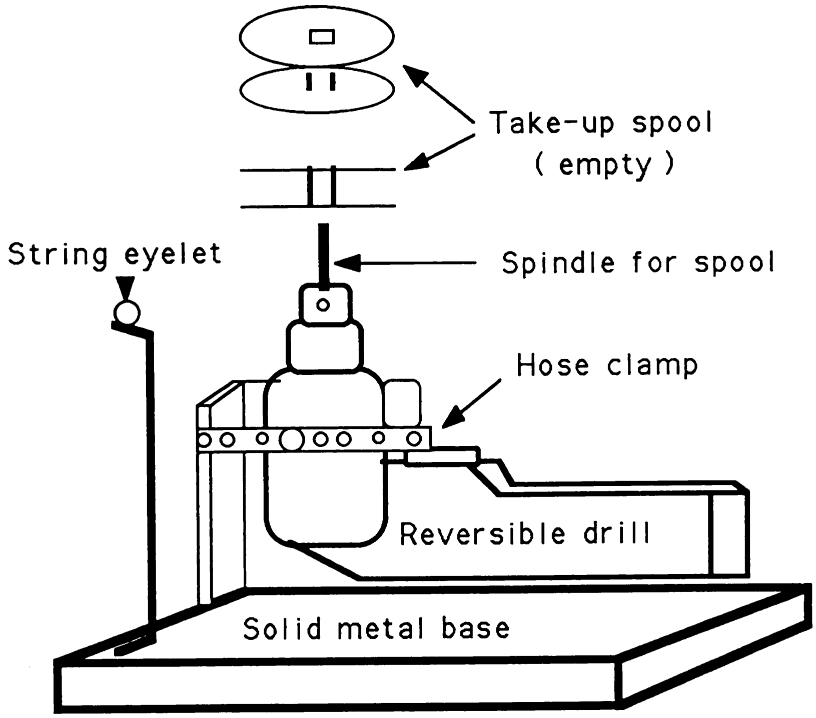
winder. This power winder was actually a reversible power drill purchased from a local hardware store and modified a little bit to hold the takeup spool. This take-up spool and the power winder and its stand are shown in Figure 3.5.

The string line running from the string dispenser through the three string supports A, B and C to the take-up winder spool was checked to see that it was free of any obstructions or entanglements. Once free flow of the string line was achieved, a 5-foot length of clean string was wound onto the spool. The take-up spool was covered with aluminum foil or plastic bag to protect the string and the spool from spray droplets. Wax paper sleeves were made to cover and protect the horizontal run of string between the string supports. Any appropriate protecting materials could be used to cover the take-up spool and the horizontal run of string from spray contaminations.

The string was then secured at the outer part of the string dispenser to maintain the tightness of the whole string line from the string dispenser to the take-up spool. The starting point and the end point of the string for each string support were marked with two different color markers for easy identification during later analysis. In these tests, red was used to mark the starting point of the string to be read by the fluorometer and blue to mark the end point of the reading for a particular string support location.

With the string in place, the trees were sprayed with the premixed spray solution containing water and fluorescent Rhodamine WT dye. Once dried, the sprayed string was wound with the power

Figure 3.5: A motorized string take-up winder and related components.



winder onto the take-up spool. It usually took one to three minutes for the sprayed string and leaves to dry. Under hot and dry condition, one minute was sufficient; under humid conditions, three minutes were typically needed for drying. It was important that the sprayed string and the leaves be dry before the string was wound onto the take-up spool so that the dye was not smeared on the string.

The sprayed string was wound until the third blue mark on the string passed the take-up point. Then 5 feet of clean, unsprayed string was also wound onto the receiving spool. The string was then cut and the take-up spool removed from the power winder. The spool was labeled and enclosed in its original canister, ready for analysis. The new string line now in place, following the take-up winding, was prepared and marked for the next spray test as previously described.

3.5 Components to Analyze the String

Analysis of the sprayed string and the graphical results were done using WRK instruments with some modifications. These instruments included an Apple IIc computer system, a filter fluorometer with a special string scanner door and a Hewlett Packard X-Y plotter to graph the results. These instruments required the use of 110 V, 60 hz electrical power. The layout of the instruments and their interconnection are shown in Figures 3.6A and 3.6B.

Figure 3.6A: Layout of instruments used in the string analysis and graphic display.

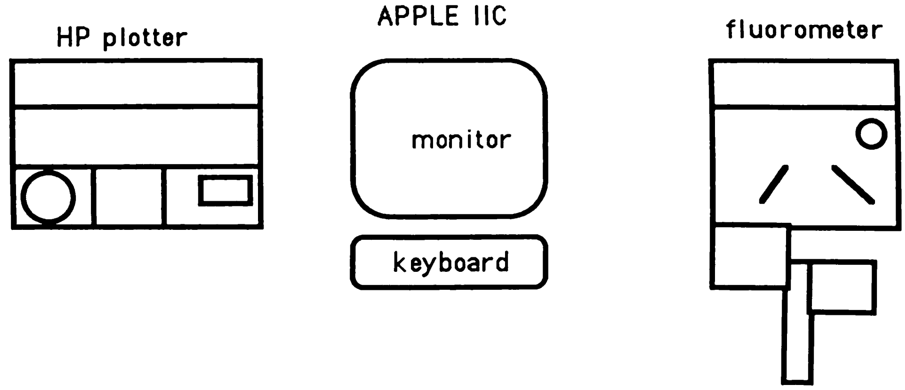
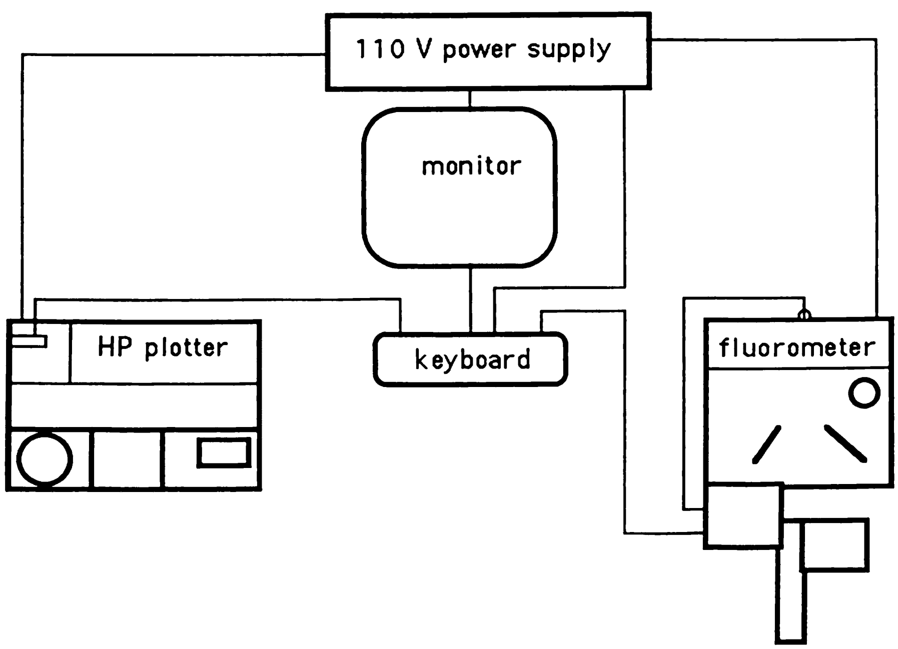


Figure 3.6B: Hookup of instruments used in the string analysis and graphic display.



3.5.1 The Computer System

An Apple IIc computer with an internal 256k RAM board, a monitor and a keyboard was used to analyze the data. An operating system disk was placed in the disk drive to load the programs into the computer memory. This disk had programs to analyze deposition on the string, calibrate the string door of the fluorometer, customize the HP plotter output and provide a graphic display of deposition patterns on the monitor screen, as well as a program to control the HP plotter to make permanent graphs of the deposition patterns and print the other pertinent data related to the test. Once the programs had been loaded, this master disk was removed from the drive and replaced with a data disk.

Instructions on the screen directed the operator in running the system. The Apple IIc keyboard controlled the starting of the string drive and analysis of the sprayed string. The unit automatically stopped when a specified length had been analyzed. The relative deposition data were recorded in the computer memory and on the data disk. As the string analysis continued, a trace of the deposition pattern appeared on the screen.

3.5.2 String Scanner Door

The string scanner door provided the means for passing the continuous string through the fluorometer for scanning. This unit was integrated into a standard fluorometer. It contained a microprocessor board, which provided the communication interface between the fluorometer, the string drive unit and the computer. This unit also kept constant the velocity of the string as it passed into and through the fluorometer for deposition analysis. The analyzed portion of the sprayed string was wound onto a larger take-up reel for discard.

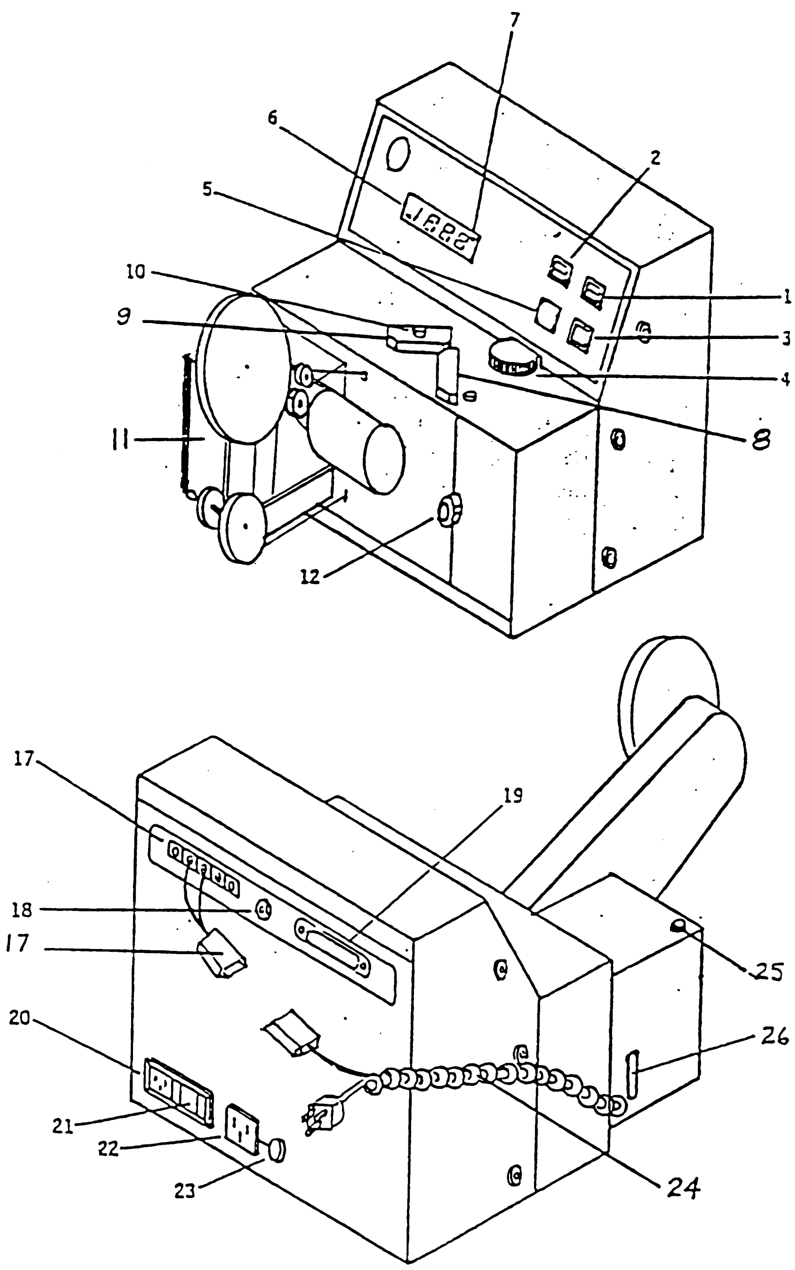
3.5.3 Fluorometer

A model 112 Sequoia-Turner fluorometer was used to measure the fluorescence values of the dye deposited on the string. A fluorescent dye, Rhodamine WT, was used as the deposition material, and a primary filter (No. 590) and a secondary filter (No. 546) were used in the fluorometer as an excitation filter and an emission filter respectively. Figure 3.7 shows the major features of the fluorometer. The fluorometer was not modified in any way -- it was used exactly as it was for the WRK system.

The fluorometer's sensitivity could be adjusted for spray application rates ranging from 0.5 gallons per acre to 300 gallons per acre. Immediately following the analysis of the string, the data were graphed with the plotter and saved for later use.

Figure 3.7: A fluorometer used in the string analysis.

1.Power switch
2.Mode switch
3.Lamp start switch
4.Coarse blank adjust
5.Fine blank adjust
6.Digital display
7.QA light
8.Excitation filter carrier
9.Emission filter carrier
10.Emission attenuator
11.The string scanner door
12.Door lock
17.Analog output connection
18.Span
19.Printer/calculator outlet
20.AC power connection
21.AC voltage connector
22.Accessory power outlet
23.Fuse
24.PC power and analog output
25.String advance switch
26.RS232 socket



3.5.4 X-Y Plotter

The Hewlett-Packard Model 7440 plotter was connected to the Apple IIc computer. Within a few minutes after the analysis of the sprayed string, the data could be recalled from the computer memory or the data disk and graphed by the plotter.

3.5.5 Image Writer II Printer

This printer was used to get a printout of the deposition values as recorded and saved on the data disk. We could also use this printer to get the deposition patterns done by the HP plotter, though the quality was very limited.

3.6 Tree Selection

One to three trees were used for testing the procedure to qualitatively measure droplet deposition. Selecting two or more trees close to or next to each other, if possible, helped reduce set-up time and possible environmental differences. Each tree selected was representative of the whole orchard in size, height and leaf density. It was desirable for the tree canopy to be nicely balanced in its shape and leaf density.

The canopy and the branches of the tree selected were open enough to allow the string supports to be nicely positioned. The cotton string threaded through the supports could move freely without obstruction or hindrance.

Brief descriptions of the selected trees were recorded to help explain deposition results. This description included the locations of the strings which might not get reasonable amounts of deposition because of possible blockage by tree branches. Foliage density was visually evaluated by estimating the amount of sunlight penetrating the canopy. A heavily foliated canopy was one that allowed almost no light to pass through. A moderately foliated canopy was one that allowed a quarter to one half of the sunlight to get through. A lightly foliated canopy was one with a few leaves or one whose leaves had just started to develop.

Once the trees were selected, the anchor units of the string supports were firmly pushed into the ground. The string was then threaded through the three string supports as described in section 3.4.4.

3.7 Types of Orchard Sprayers Used

Field tests of this modified WRK string method for evaluating spray deposition in orchard trees were done at six locations between September 1988 and August 12, 1992. These tests involved the use of eight different sprayers. Each spray run was assigned its own code to differentiate that sprayer and spray run from other sprayers and runs. Each code also contained information on the location of the support within the tree canopy from which the string was obtained. The dates, locations, crops and types of sprayers involved in the six field tests and examples of their test codes were:

i) DATES: 9/15/88-9/16/88. LOCATION: Fennville. CROP: Apple.

1. FMC air blast sprayer — Test Code Used: PEAB
2. FMC tower sprayer — Test Code Used: PETOW

ii) DATES: 9/22/88-9/28/88. LOCATION: Paw Paw. CROP: Cherry.

3. AgTec standard sprayer — Test Code Used: PEATS
4. AgTec tower sprayer — Test Code Used: PEATT
5. Air curtain sprayer — Test Code Used: PEAC
6. Myers air blast sprayer — Test Code Used: PEMY

iii) DATES: 8/30/89-9/6/89. LOCATION: Leelanau. CROP: Cherry.

7. AgTec 400 sprayer — Test Code Used: PEAN

iv) DATES: 10/4/89-10/5/89. LOCATION: MSU. CROP: Apple.

8. Turbo Mist — Test Code Used: PEMSU

v) DATES: 7/10/92. LOCATION: Clarksville. CROP: Apple.

9. Kinkelder — Test Code Used: PE1.N26W

vi) DATES: 8/5/92-8/12/92. LOCATION: Leelanau. CROP: Apple.

10. CURTEC — Test Code Used: PE1N
11. AgTec Standard — Test Code Used: PE1ATN
12. FMC — Test Code Used: PEFN

The test codes assigned to the sprayers had the following meanings:

PEAB : PEnetration test using Air Blast sprayer.

PETOW : PEnetration test using TOWer sprayer.

PEATS : PEnetration test using AgTec Standard sprayer.

PEATT : PEnetration test using AgTec Tower sprayer.

PEAC : PEnetration test using Air Curtain sprayer.

PEMY : PEnetration test using MYers sprayer.

PEMSU : PEnetration test at MSU using Turbo Mist sprayer.

The following is an example of how to read the complete test code:

PEAB2M6G.N means PEnetration test of Air Blast sprayer, operating at 2 Miles per hour and spraying at 6 Gallons per minute on N (north pole). This N pole is the same as the A pole.

Both the FMC air blast sprayer and the FMC tower sprayer were used in the deposition performance test done on apple trees at Fennville, Michigan, on September 15 and 16, 1988. Four sprayers -- namely, the MSU air curtain sprayer, the AgTec standard sprayer, the AgTec tower sprayer and the Myers air blast sprayer -- were used in the deposition performance test done on cherry trees at Paw Paw, Michigan on September 28, 1988. An AgTec 400 sprayer was used from August 30, 1989 to September 6, 1989, on cherry trees in Leelanau County, Michigan. A Turbo Mist sprayer was also tested for deposition performance on October 4 and 5, 1989, in the Michigan State University apple orchard. On July 10, 1992, a Kinkelder standard sprayer belonging to the Clarksville research station was used to determine the effect on spray deposition of changing the application rate. From August 5 to August 12, 1992, again an air curtain sprayer, an AgTec standard sprayer and an FMC standard sprayer were used to study the effect of changing sprayer speeds and changing the number and position of operating nozzles on the deposition performance of the sprayers.

The operators of each sprayer were briefed on the spraying plan. One or two practice runs were done before the actual spray runs. The actual spray runs were done when the sprayer operator and the string setup crew, agreed on the number of runs per treatment. The spray pressure, application rate and ground speed were recorded. The sprayed string was then analyzed to determine deposition performance. Based on the analysis of the string, interpretation of the sprayer's performance was done and possible remedies were recommended to improve spray deposition. Where appropriate, operators modified the spray nozzles, spray pressures, operating speed and flow rate to improve spray deposition.

3.8 Sprayer Preparation and Operation

The sprayers used for chemical deposition tests were thoroughly rinsed with water to eliminate possible chemical contamination. Any leakages or problems were corrected. Correct spray nozzles were installed and spray pressure set within the specified range.

The cleaned sprayer was filled with 50 gallons of water and one 6 ounce packet of Rhodamine WT fluorescent dye was added to the tank. The spray tank agitator was turned on to maintain an even mix of the fluorescent material in the water. Normally, the air curtain sprayer carried out skipped-row (also known as one-side or alternate-row) sprayings (Figure 3.8), while other sprayers carried out two-side or every-row sprayings (Figure 3.9). In the later studies, from August 5, 1992, to August 12, 1992, all the sprayers used did only one-side sprayings.

Operational data related to the sprayers, such as ground speed, flow rate in gallons per minute or application rate in gallons per acre, were recorded .

$$\text{Ground speed (mph)} = \frac{\text{travelled distance (ft)} \times 60}{\text{travel time (seconds)} \times 88}$$

$$\text{Total flow rate (gpm)} = \frac{\text{mph} \times \text{gpa} \times \text{spray width (ft)}}{495}$$

$$\text{Gallons per acre (gpa)} = \frac{\text{total flowrate (gpm)} \times 495}{\text{mph} \times \text{spray width (ft)}}$$

3.9 Computer Program to Analyze Data

Software written by WRK Inc., for use in aircraft spray pattern analysis was used for this spray deposition analysis. It consisted of a canopy penetration program and five subprograms designed to calibrate the string door, read the string collectors, customize the plotter output, prepare graphical outputs of the data and move data files to an emulated drive. (More details of the computer programs

Figure 3.8: A typical one-side or alternate-row spraying.

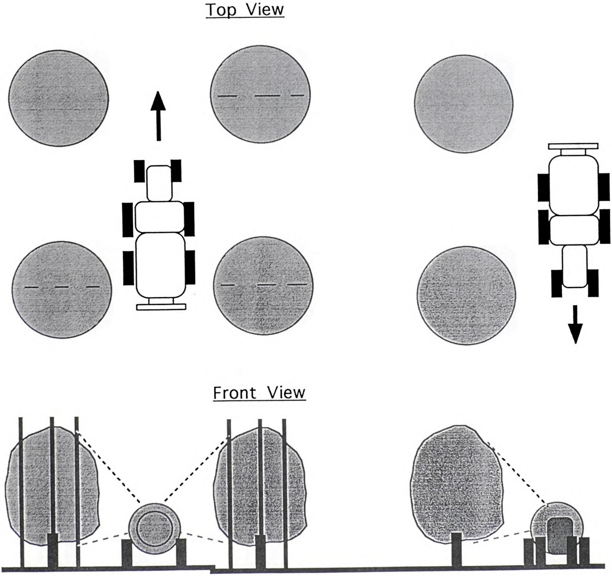
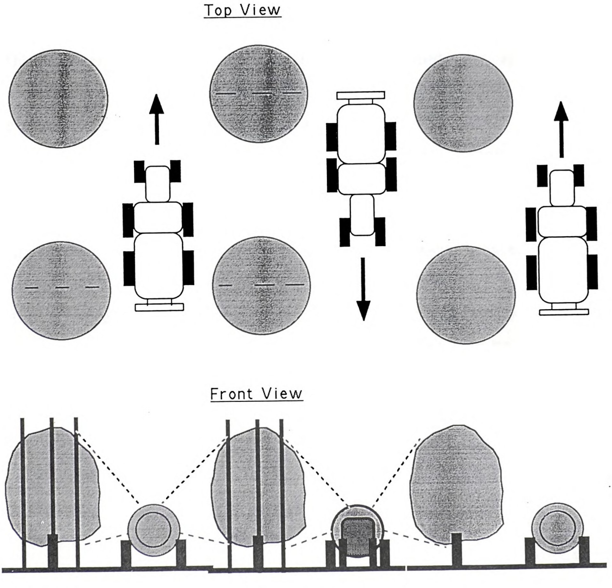


Figure 3.9: A typical two-side or every-row spraying



can be found in Appendix A).

3.10 Procedure for Analyzing a Sprayed String

With all units, the Apple IIC computer monitor and keyboard, fluorometer and plotter were correctly connected, the application program disk loaded and the power switches turned on. Step-by-step instructions appearing on the monitor screen were followed. Finally, the option Reading Penetration String was chosen from the main menu and a blank DOS formatted data disk was placed in position. A sprayed string was threaded and run through the fluorometer. The sensitivity level of the fluorometer was set at 1X or 3X and the emission filter opening was adjusted to give a maximum reading of three-quarters scale. (More information on the procedure of adjusting underscaling and overscaling can be found in Appendix B).

Hard copy of the spray patterns was obtained by choosing the Plot X-Y option from the main menu. The plotted data showed the relative fluorescence pattern of spray droplets collected by the string. If hard copy of the sprayed data was desired, the HP plotter had to be switched with the printer and the PrintData program had to be loaded and used.

CHAPTER 4
FIELD TESTING:
RESULTS and DISCUSSION

4.1 The Potential of the Modified WRK String Method for Evaluating Spray Deposition in the Orchard Canopy

This research on evaluating chemical deposition in the canopies of fruit trees made use of the modified WRK string technology that was originally developed for analyzing spray deposition patterns of spray planes. The WRK string technology has been recognized as a fast method of analyzing spray patterns produced by aircraft and helicopter sprayers. The performance of this method for monitoring the deposition pattern of aerial spraying and its advantages and limitations suggested that a modified WRK technique had good potential for monitoring spray deposition in a fruit tree canopy.

The major modification needed on the WRK string equipment was a string support to position the string vertically in the tree. The frame structure of the string support, the covered string dispenser and the motorized string winder were entirely new features. The need for smooth flow of the string through the support structure and the exposure of the string length to the spray made cotton string a good choice for spray deposition collector. The whole string length exposed to the air was the deposition target. This provided ample data throughout the entire tree height. Because the readings were almost continuous, they provided detailed, accurate and clear picture of the deposition pattern.

4.2 The Effects of Different Sensitivity Levels on the Fluorescence Reading of the Fluorometer

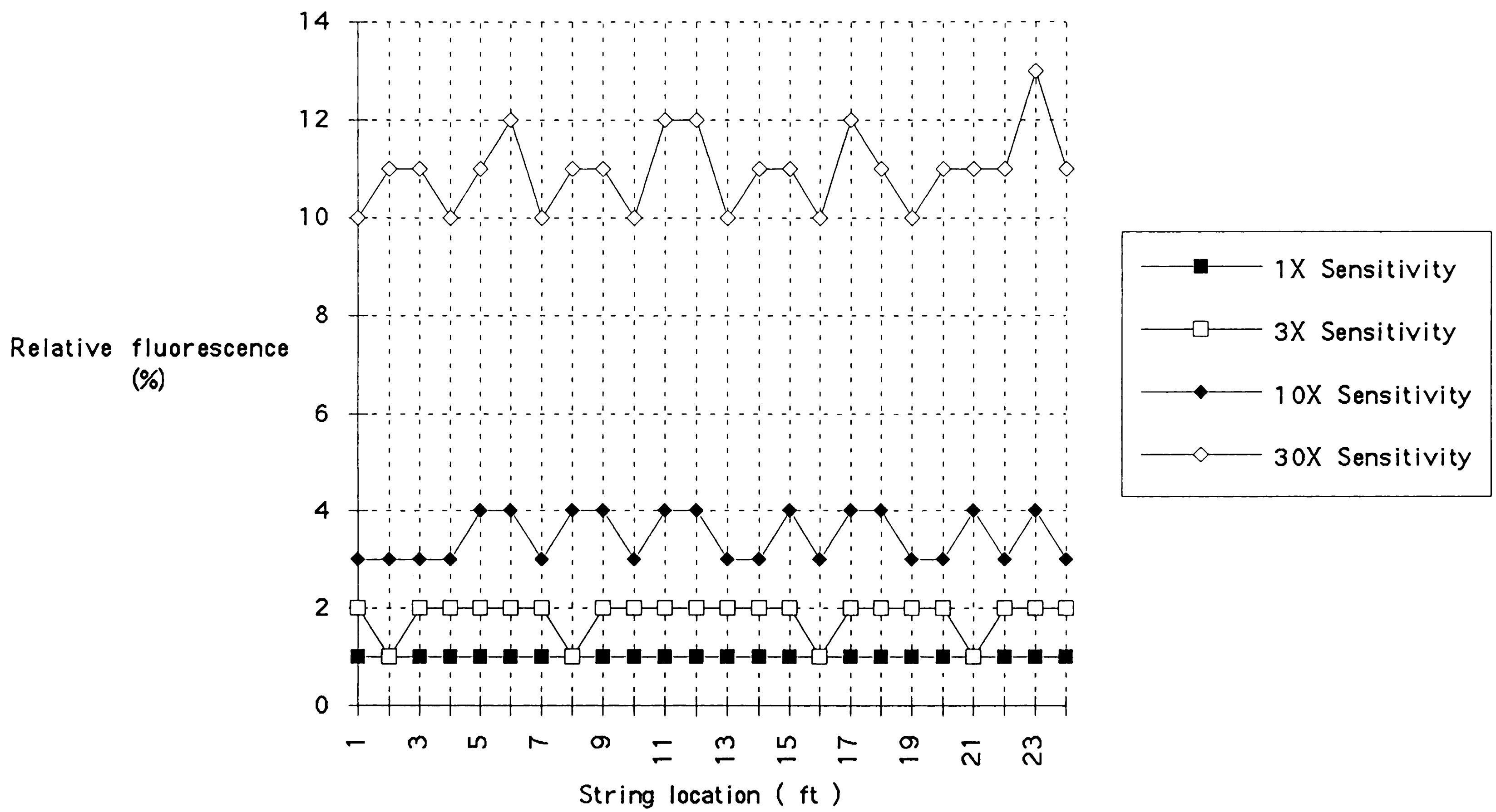
A) On Clean Cotton String

Clean, unsprayed cotton string was run through the fluorometer with the fluorometer set at 1X, 3X, 10X and 30X sensitivity levels. The results of this sensitivity study (see Table 4.1) showed that the clean (not yet sprayed) cotton string had a relative fluorescence of 1 percent when read with 1X sensitivity. Increasing the sensitivity levels to 3X or 10X or 30X shifted this 1 percent line up to 2, 3 and 12 percent, respectively, on the average, but maintained similar graph patterns. Figure 4.1 illustrates the shift in the relative fluorescence as the sensitivity levels were increased while the overall patterns stayed the same. The results of this test demonstrate that the sensitivity level setting will affect the reading of the fluorometer by shifting the baseline. Readings given by the fluorometer could be partly contributed by the blank string itself, which ranged from a value of 1 percent to about 12 percent of the flourescence readings, depending on the sensitivity level used.

Table 4.1: Summary of ranges and means of fluorometer readings on 24 feet of clean, unsprayed string at four sensitivity levels.

STRING LOCATION (ft)	1X Sensitivity Fluorescence		3X Sensitivity Fluorescence		10X Sensitivity Fluorescence		30X Sensitivity Fluorescence	
	Range (%)	Mean (%)	Range (%)	Mean (%)	Range (%)	Mean (%)	Range (%)	Mean (%)
1	1	1	1 to 2	2	3	3	10 to 11	10
2	1	1	1 to 2	1	3	3	10 to 11	11
3	1	1	1 to 2	2	3	3	10 to 11	11
4	1	1	1 to 2	2	3 to 4	3	10 to 11	10
5	1	1	1 to 2	2	3 to 4	4	11 to 13	11
6	1	1	1 to 2	2	3 to 4	4	11 to 13	12
7	1	1	1 to 2	2	3 to 4	3	10 to 11	10
8	1	1	1 to 2	1	3 to 4	4	10 to 12	11
9	1	1	1 to 2	2	3 to 4	4	10 to 12	11
10	1	1	1 to 2	2	3 to 4	3	10 to 11	10
11	1	1	1 to 2	2	3 to 4	4	10 to 13	12
12	1	1	1 to 2	2	3 to 4	4	10 to 13	12
13	1	1	1 to 2	2	3 to 4	3	10 to 11	10
14	1	1	1 to 2	2	3 to 4	3	11 to 11	11
15	1	1	1 to 2	2	3 to 4	4	10 to 12	11
16	1	1	1 to 2	1	3 to 4	3	10 to 11	10
17	1	1	1 to 2	2	3 to 4	4	11 to 14	12
18	1	1	1 to 2	2	3 to 4	4	10 to 13	11
19	1	1	1 to 2	2	3 to 4	3	10 to 11	10
20	1	1	1 to 2	2	3 to 4	3	10 to 11	11
21	1	1	1 to 2	1	3 to 4	4	11	11
22	1	1	1 to 2	2	3 to 4	3	10 to 11	11
23	1	1	1 to 2	2	3 to 4	4	12 to 13	13
24	1	1	1 to 2	2	3 to 4	3	10 to 13	11
MEANS		1		2		3		11

Figure 4.1: Effects of changing the sensitivity levels of the fluorometer on the fluorometer readings of a 24-ft Clean, Unsprayed String.



B) On Sprayed String

String sprayed with Rhodamine WT fluorescent dye was read for its relative fluorescence with the fluorometer set at 1X, 3X, 10X and 30X. It was noticed that increasing the sensitivity levels of the fluorometer had shifted up the relative fluorescent values of the same sprayed cotton string. Figure 4.2A shows the four line graphs of the same sprayed string read with different sensitivity levels. The 1X sensitivity level was found to give very low readings and a less clearly defined graph. The same sprayed string read with the fluorometer set at a sensitivity level of 3X gave reasonably higher readings, within the range, and a well defined graph. Sensitivity levels of 10X and 30X were found not suitable for use with Rhodamine WT dye at the usual spraying levels because the relative fluorescence of the sprayed string drove the reading up to the maximum and off the scale.

Sensitivity levels of 1X or 3X were found to work best with white cotton string sprayed with Rhodamine WT fluorescent dye. The final choice of sensitivity levels, between 1X or 3X, depended on the maximum reading reached when the sprayed string was read. Once the sensitivity level was chosen, it was used throughout the analysis to maintain uniformity and make possible reliable comparisons. Values that were higher than the baseline of the blank string were due to the fluorescent dye. The values contributed by the string itself diminished with increasing deposition of the dye on the string surface. The exact proportion of the fluorescence coming from the string as dye covered more of the string surface not known. A previous section has shown that the fluorescent values contributed by the clean, unsprayed string when read at 1X sensitivity level were 1 percent and when the same string was read at 3 X, 2 percent. The values of the clean string were used in calculating the standard readings.

Standard readings = fluorometer readings - string constant.

String constant at sensitivity level of 1X = 1

String constant at sensitivity level of 3X = 2

String constant at sensitivity level of 10X = 3

String constant at sensitivity level of 30X = 11

Table 4.2 summarizes the fluorometer readings and the standard readings from a 24-foot sprayed string analyzed at four sensitivity levels. The values of 100 percent and over were not useful in studying the spray patterns. Figure 4.2A illustrates the spray patterns based on the direct fluorometer readings, while Figure 4.2B illustrates the spray patterns based on the standardized readings. As shown, the effect of standardizing the fluorometer readings on the deposition patterns is very insignificant.

4.3 Repeatability of Results

Studies were conducted to see whether the modified WRK string method could produce the same deposition results when the spraying

Table 4.2: Summary of the fluorometer readings (standardized) on a sprayed string analyzed at four sensitivity levels.

STRING LOCATION (ft)	1X Sensitivity Fluorescence		3X Sensitivity Fluorescence		10X Sensitivity Fluorescence		30X Sensitivity Fluorescence	
	FR (%)	Standard (%)	FR (%)	Standard (%)	FR (%)	Standard (%)	FR (%)	Standard (%)
1	3	2	9	7	52	49	maximum	maximum
2	5	4	17	15	99	96	maximum	maximum
3	4	3	13	11	95	92	maximum	maximum
4	6	5	21	19	99	96	maximum	maximum
5	10	9	37	35	maximum	maximum	maximum	maximum
6	15	14	60	58	maximum	maximum	maximum	maximum
7	18	17	68	66	maximum	maximum	maximum	maximum
8	21	20	88	86	maximum	maximum	maximum	maximum
9	15	14	56	54	maximum	maximum	maximum	maximum
10	17	16	75	73	maximum	maximum	maximum	maximum
11	14	13	56	54	maximum	maximum	maximum	maximum
12	13	12	52	50	maximum	maximum	maximum	maximum
13	12	11	53	51	maximum	maximum	maximum	maximum
14	9	8	38	36	maximum	maximum	maximum	maximum
15	6	5	30	28	maximum	maximum	maximum	maximum
16	5	4	19	17	maximum	maximum	maximum	maximum
17	5	4	17	15	maximum	maximum	maximum	maximum
18	6	5	18	16	maximum	maximum	maximum	maximum
19	6	5	21	19	maximum	maximum	maximum	maximum
20	7	6	21	19	maximum	maximum	maximum	maximum
21	8	7	31	29	maximum	maximum	maximum	maximum
22	12	11	35	33	maximum	maximum	maximum	maximum
23	11	10	50	48	maximum	maximum	maximum	maximum
24	12	11	41	39	maximum	maximum	maximum	maximum
MEANS	10	9	39	37	maximum	maximum	maximum	maximum

Standardized readings=fluorometer readings(FR)-clean string constant
Clean string constant @1X =1 %
Clean string constant @3X =2 %
Clean string constant @10X = 3 %
Clean string Constant @30X =11 %   Fluorescent values over 100% = maximum

Figure 4.2A: Effects of changing the sensitivity levels on the sprayed string readings.

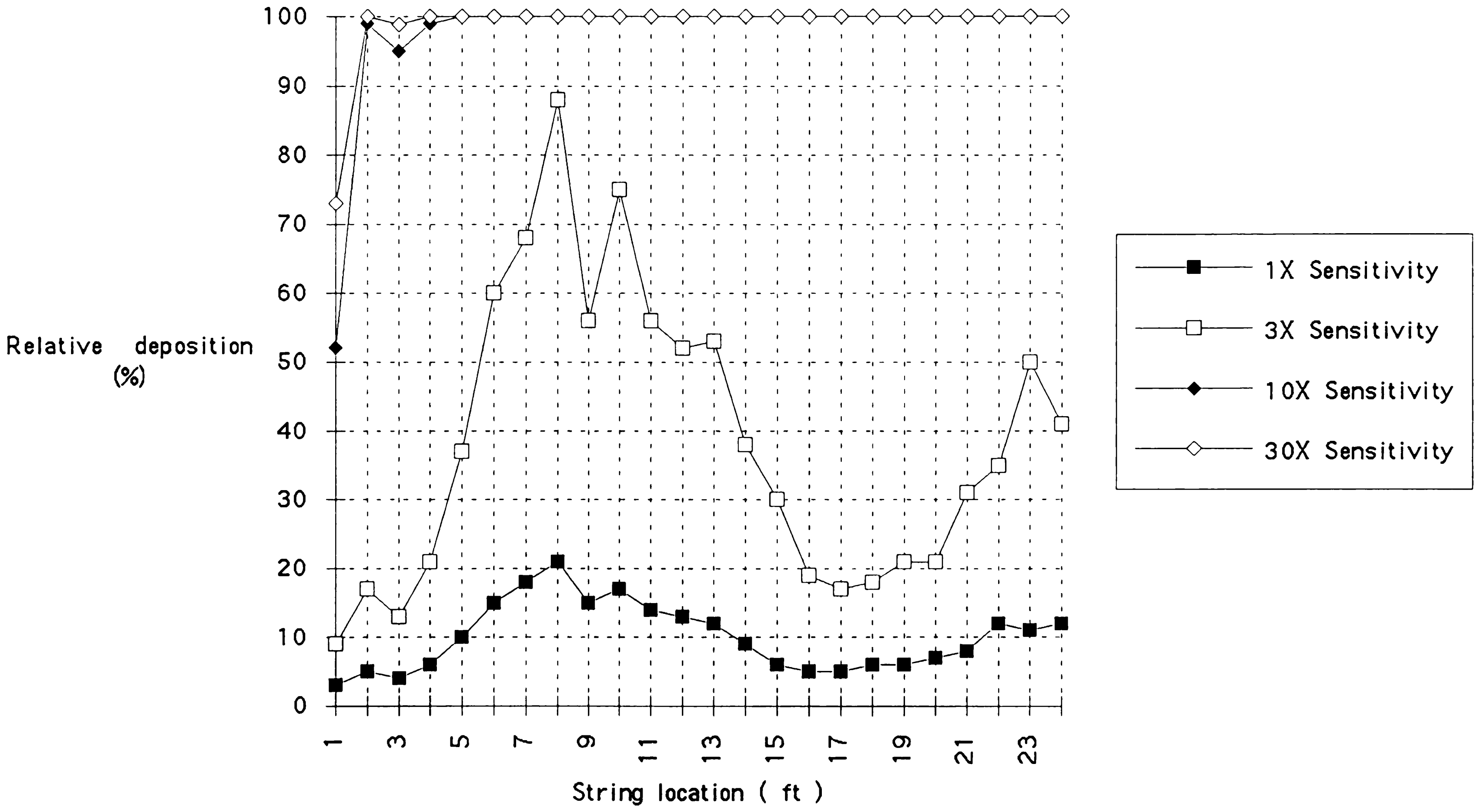
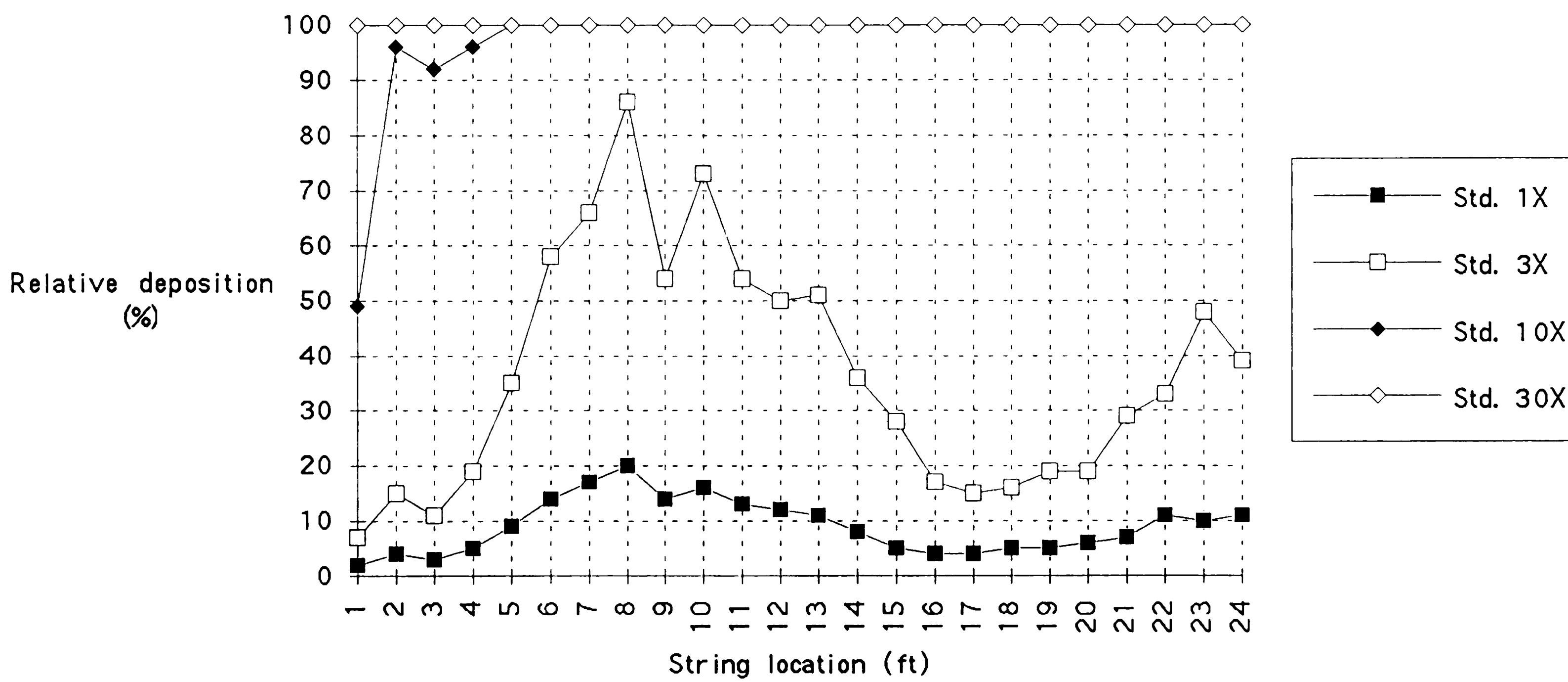


Figure 4.2B: Effects of standardizing the fluorometer readings on the relative deposition patterns .



was repeated with other factors maintained constant, including environmental factors.

In the orchard, replicated spray passes or runs were conducted within 10 minutes of one another. Figure 4.3 shows the four deposition patterns of four replicated spray passes of a CURTEC sprayer on string A (placed on the closest string support). All four spray runs maintained the same speed, 3.7 mph, and the same spray application rate, 20 gpa. The major cause of differences in the readings and patterns from one replication run to another was changing environmental factors. Figure 4.4 is the average spray pattern derived from the four replicated runs.

Because environmental factors changed frequently, especially wind speed and direction but also temperature and humidity, constant conditions were difficult to maintain. Wind played an important role in determining the direction and the distance the spray droplets travelled, so it was difficult to repeat a spray pass under exacly the same environmental conditions.

The repeatability and replication problem was solved by virtue of the double string in each support. Each string support held two vertical string lines, one going up and another coming down, approximately 1 foot apart. The closeness of the two strings and the fact that they were sprayed at exactly the same time provided an excellent replication of the deposition test at each pole.

Table 4.4 lists the 240 data point values in percent of deposition for a 24-foot string. This string was positioned at pole A, about 4 feet inside the tree canopy and was sprayed by an FMC

Table 4.3: Average fluoremeter readings of four replicated spray runs (AgTec sprayer spraying one side of apple tree at 3.5 mph and 20 gpa, analysed at 3X sensitivity and 30% filter opening -- Leelanau,Michigan).

Location above ground (ft)	CLOSEST STRING A FLUORESCENCE READING (%)					
	R1	R2	R3	R4	Total	Average
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	18	29	28	30	105	26.25
5	38	38	43	55	174	43.5
6	40	42	35	55	172	43
7	50	55	48	53	206	51.5
8	42	32	31	37	142	35.5
9	16	16	13	14	59	14.75
10	11	13	12	12	48	12
11	8	8	10	18	44	11
12	6	8	8	9	31	7.75
13	6	7	6	7	26	6.5
14	5	6	5	5	21	5.25
15	5	5	5	5	20	5
16	6	5	5	5	21	5.25
17	5	5	5	5	20	5
18	5	5	5	4	19	4.75
19	5	4	5	5	19	4.75
20	5	5	5	5	20	5
21	6	5	5	5	21	5.25
22	5	6	5	5	21	5.25
23	6	5	5	5	21	5.25
24	5	6	5	7	23	5.75
25	5	7	6	8	26	6.5
26	5	6	6	6	23	5.75
27	6	13	6	12	37	9.25
28	20	22	15	23	80	20
29	40	43	29	40	152	38
30	35	47	54	48	184	46
31	25	32	38	30	125	31.25
32	12	26	24	39	101	25.25
33	9	22	17	22	70	17.5
34	11	14	11	29	65	16.25

Figure 4.3 :Relative deposition patterns of four replicated runs (R1–R4) sprayed on the closest string in the south tree canopy (AgTec sprayer at 3.5 mph and 20 gpa, spraying one side, analysed at 3X, 30% filter opening -- Leelanau, Michigan)

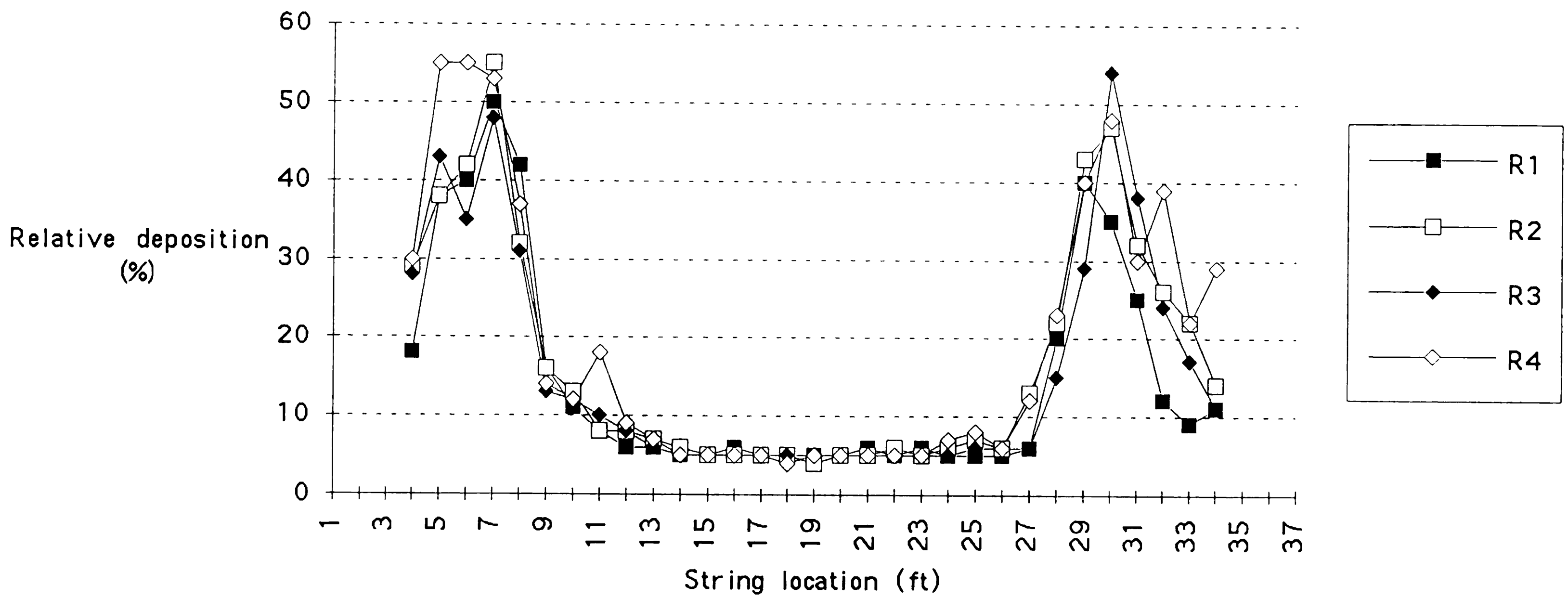
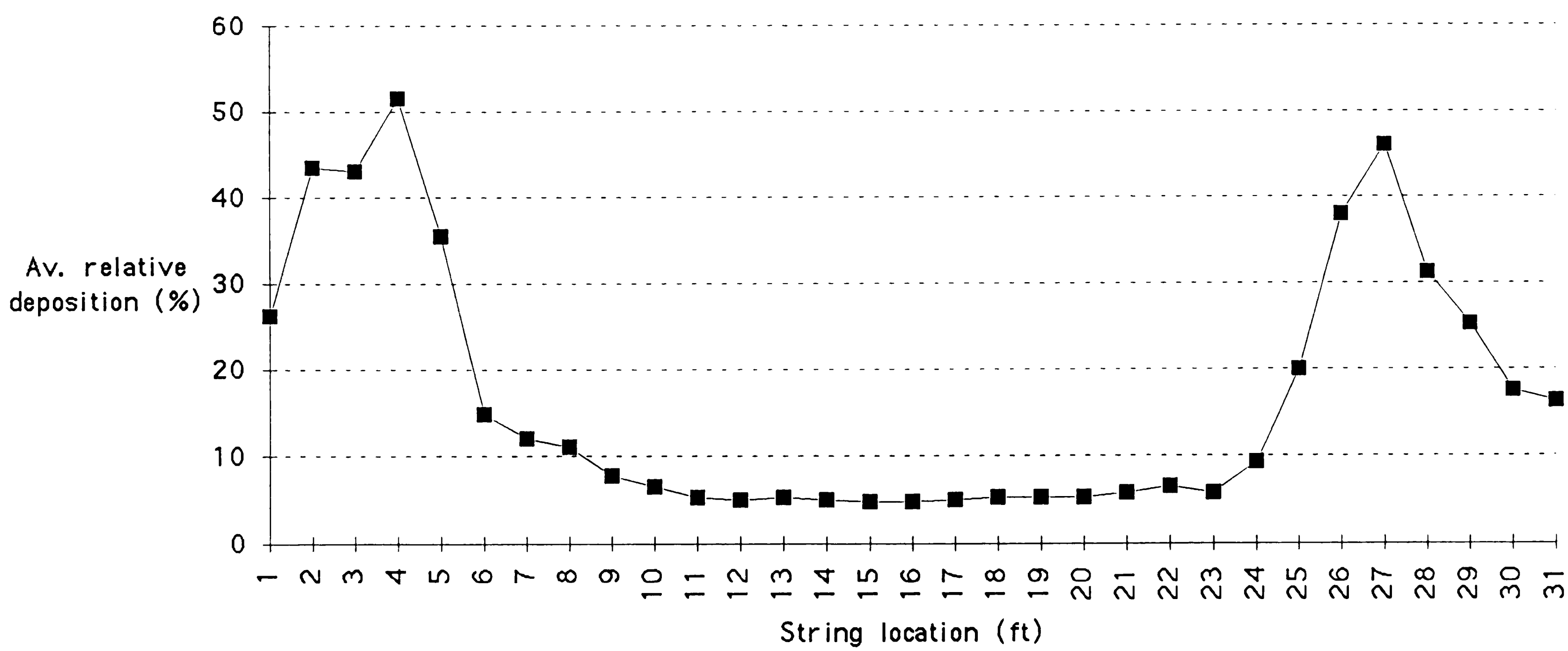


Figure 4.4 : Average deposition pattern from four replicated runs (RI–R4) of Figure 4.3 (AgTec sprayer at 3.5 mph and 20 gpa, analysed at 3X, 30% filter opening -- Leelanau, Michigan).



sprayer. The first 12 feet was the vertical string from the ground to the top of the pole. The second 12 feet (from 13 feet to 24 feet) was the descending string. There are 10 data points for each foot of string length. These are read from left to right in the table. Table 4.5A lists the fluorescence values of the 12 feet of the ascending string, while Table 4.5B lists the fluorescence values of the next 12 feet, the descending string. Figure 4.5 shows the deposition pattern of the whole string from 1 to 24 feet. Because the 12-foot point was at the top of the tree and the ascending and descending strings were parallel when sprayed, the fluorescence values plotted from 1 to 24 feet were symmetrical about the 12-foot center point. Any differences in values found between the two patterns were caused by leaves and branches that obstructed the spray and prevented equal distribution of spray on the strings .

The results from this test confirmed that the string and fluorometer method gave consistent and repeatable results as long as the same environmental factors and spray factors existed. Replications within the same spray pass resulting from the parallel string position eliminated differences due to time and environmental factors.

4.4 Reliability of the Modified Method

The reliability of any method used for evaluation work is certainly a valid concern. The reliability of monitoring the spray

Table 4.4: Fluorometer readings of a string placed 4 feet inside the canopy (FMC--Fennville, Michigan)

STRING LOCATION (ft)	Sequent FLUORESCENCE READ per 0.1 ft 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	48	51	53	58	62	65	67	67	67	69
2	70	72	74	76	76	78	77	78	79	80
3	84	86	84	84	85	85	85	85	82	77
4	74	72	70	69	70	70	68	68	66	64
5	62	58	51	43	36	33	29	24	22	26
6	30	35	39	40	40	38	36	35	34	31
7	29	29	30	30	30	31	32	34	34	36
8	36	37	39	43	38	35	32	30	31	35
9	38	40	41	41	41	41	40	39	39	40
10	38	35	32	29	26	23	22	22	21	19
11	18	16	15	14	12	11	10	9	9	8
12	8	8	7	6	6	5	5	6	6	7
13	6	7	8	9	10	10	10	11	12	13
14	15	16	17	17	18	18	18	19	21	22
15	23	23	24	25	26	28	32	34	36	40
16	42	42	41	41	39	35	36	43	47	50
17	53	51	52	51	50	49	46	42	42	40
18	37	33	32	28	28	33	38	42	44	44
19	42	39	36	35	34	32	32	33	34	36
20	38	41	39	38	43	49	52	54	55	58
21	62	64	66	66	65	66	69	72	73	74
22	76	79	79	76	73	70	68	66	63	62
23	61	59	59	60	62	66	68	70	70	69
24	72	69	65	61	51	32	18	15	20	25

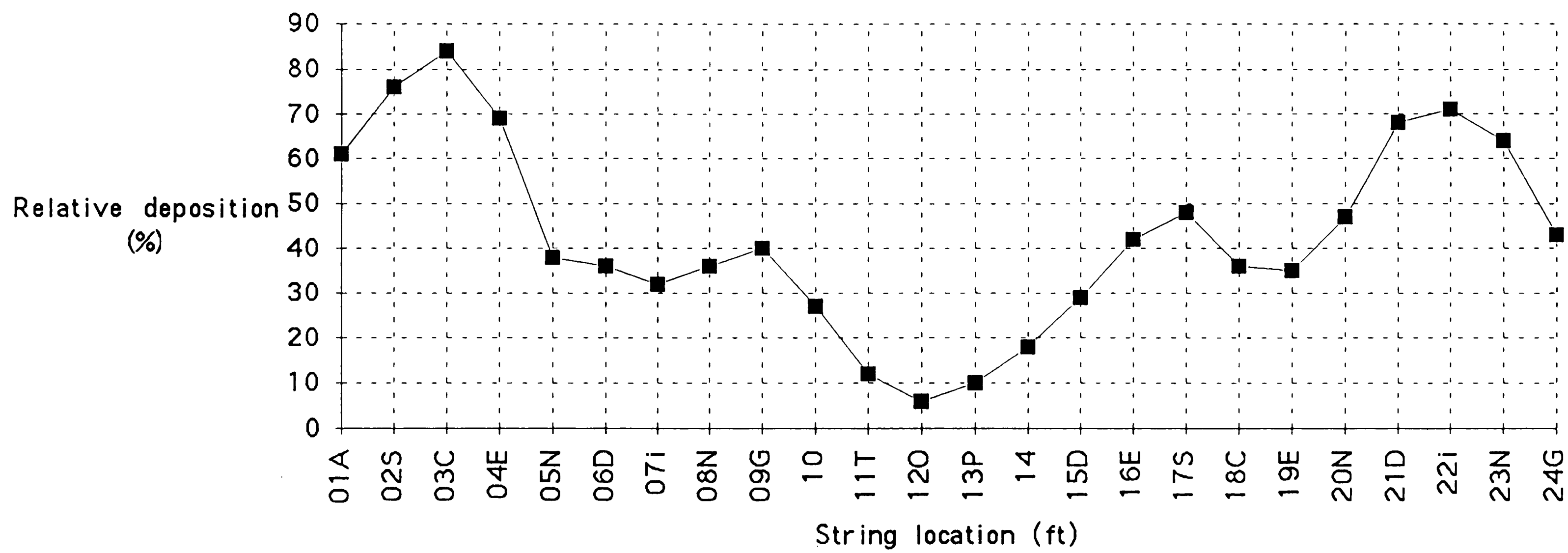
Table 4.5A:Fluorometer readings of ascending string placed 4 feet inside the canopy (FMC--Fennville,Michigan)

STRING LOCATION (ft)	Sequen FLUORESCENCE RE/ (%) per 0.1 ft 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	TOTAL	AV.	STD DEV
1	48	51	53	58	62	65	67	67	67	69	607	61	7.3
2	70	72	74	76	76	78	77	78	79	80	760	76	3
3	84	86	84	84	85	85	85	85	82	77	837	84	2.5
4	74	72	70	69	70	70	68	68	66	64	691	69	2.7
5	62	58	51	43	36	33	29	24	22	26	384	38	14
6	30	35	39	40	40	38	36	35	34	31	358	36	3.3
7	29	29	30	30	30	31	32	34	34	36	315	32	2.3
8	36	37	39	43	38	35	32	30	31	35	356	36	3.7
9	38	40	41	41	41	41	40	39	39	40	400	40	1
10	38	35	32	29	26	23	22	22	21	19	267	27	6.2
11	18	16	15	14	12	11	10	9	9	8	122	12	3.2
12	8	8	7	6	6	5	5	6	6	7	64	6	1

Table 4.5B: Fluorometer readings of descending string placed 4 feet inside the canopy (FMC--Fennville,Michigan)

STRING LOCATION (ft)	Sequen FLUORESCENCE (%) per 0.1 ft 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	TOTAL	AV.	STD DEV
12	6	7	8	9	10	10	10	11	12	13	96	10	2
11	15	16	17	17	18	18	18	19	21	22	181	18	2
10	23	23	24	25	26	28	32	34	36	40	291	29	5.7
9	42	42	41	41	39	35	36	43	47	50	416	42	4.3
8	53	51	52	51	50	49	46	42	42	40	476	48	4.5
7	37	33	32	28	28	33	38	42	44	44	359	36	5.8
6	42	39	36	35	34	32	32	33	34	36	353	35	3
5	38	41	39	38	43	49	52	54	55	58	467	47	7.3
4	62	64	66	66	65	66	69	72	73	74	677	68	3.8
3	76	79	79	76	73	70	68	66	63	62	712	71	6
2	61	59	59	60	62	66	68	70	70	69	644	64	4.4
1	72	69	65	61	51	32	18	15	20	25	428	43	22

Figure 4.5: Relative deposition of ascending and descending strings showing the symmetrical deposition pattern between the two portions of the closest string (FMC sprayer at 2 mph and 20 gpa, analyzed at 3X, 30% filter opening -- Fennville, Michigan).



deposition in a fruit tree canopy with the modified WRK string technology was confirmed by comparing the deposition results with the expected outcomes.

The expected outcomes from any method to be considered reliable should be able to meet the following criteria :

1. The spray deposition on a collector in the open area (without any obstructions) should be higher than the spray deposition on a collector in the canopy.

The spray fluorescence results from a CURTEC sprayer spraying one side of the tree toward the targeted strings placed in the open area (between trees) were compared with the results from targeted strings placed in the tree canopy . The strings were positioned on the string supports placed about 5 feet (string A), 8 feet (string B) and 11 feet (string C) away from the sprayer.

Table 4.6 lists the average flourescence values from the three sprayed strings in the open area, and Table 4.7 lists the average values from the three strings in the tree canopy. Figures 4.6 and 4.7 illustrate the corresponding deposition patterns based on the fluorescence values in Tables 4.6 and 4.7 .

The strings in the open area exhibited high deposition: 100 percent on the closest string (string A), 90 percent on the middle string (string B) and 77 percent on the far string (string C). On the average, the total percentage for the three strings in the open area was 89 percent ([100 + 90 + 77] / 3). Spray coverage was very high. This made sense because there was no foliage to intercept or divert some of the droplets .

Table 4.6: Average relative deposition (%) on strings placed in the open area 5, 8 and 11 feet away from the CURTEC sprayer (spraying from side A).

	AVERAGE RELATIVE DEPOSITION (%)		
Location above	String A	String B	String C
bottom guide (ft)	5 ft away	8 ft away	11 ft away
12	100*	100	100
11	100	100	100
10	100	100	100
9	100	100	100
8	100	100	100
7	100	100	100
6	100	100	100
5	100	100	80
4	100	68	50
3	100	57	38
2	100	59	28
1	100	95	23
TOTAL	1200	1079	919
AVERAGE	100	90	77
STD. DEVIATION	0	17	32

note: * 100 % = Reached maximum deposition = off scale

Figure 4.6: Relative deposition patterns of three strings placed in the Open Area 5, 8 and 11 ft away from the CURTEC sprayer (spraying one side at 4 mph and 20 gpa -- PawPaw, Michigan).

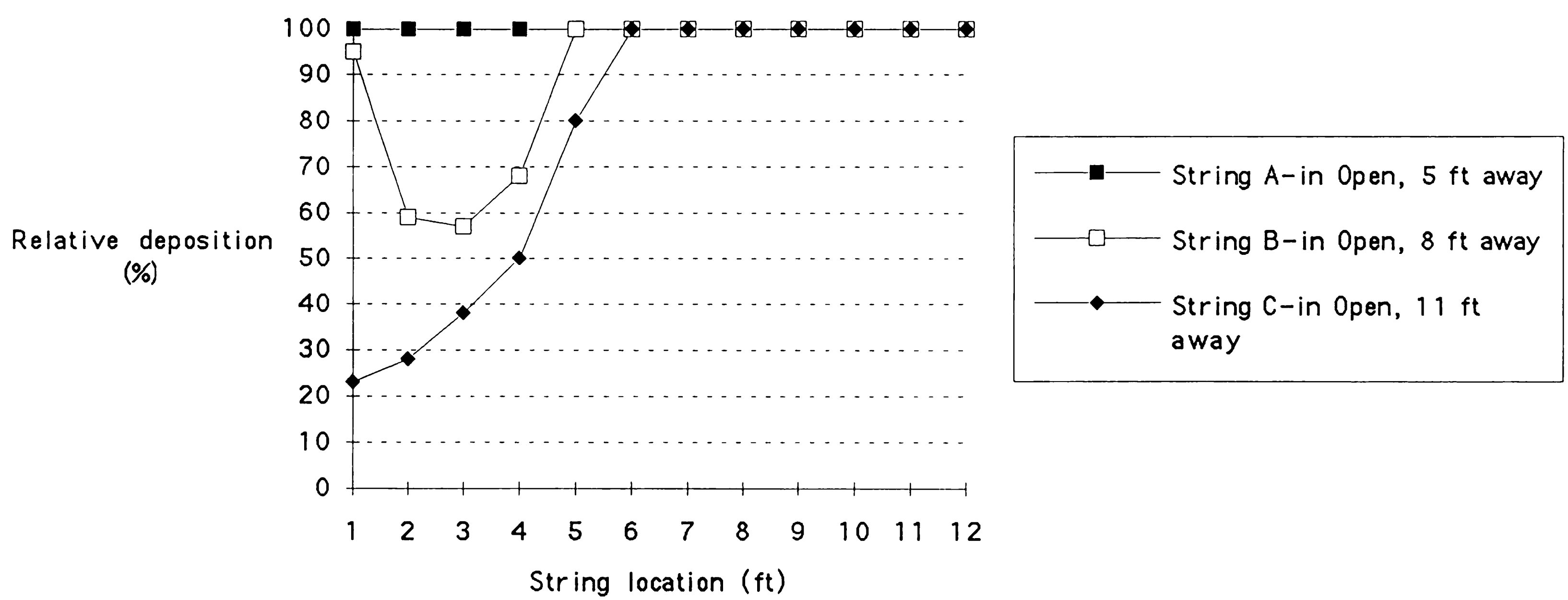
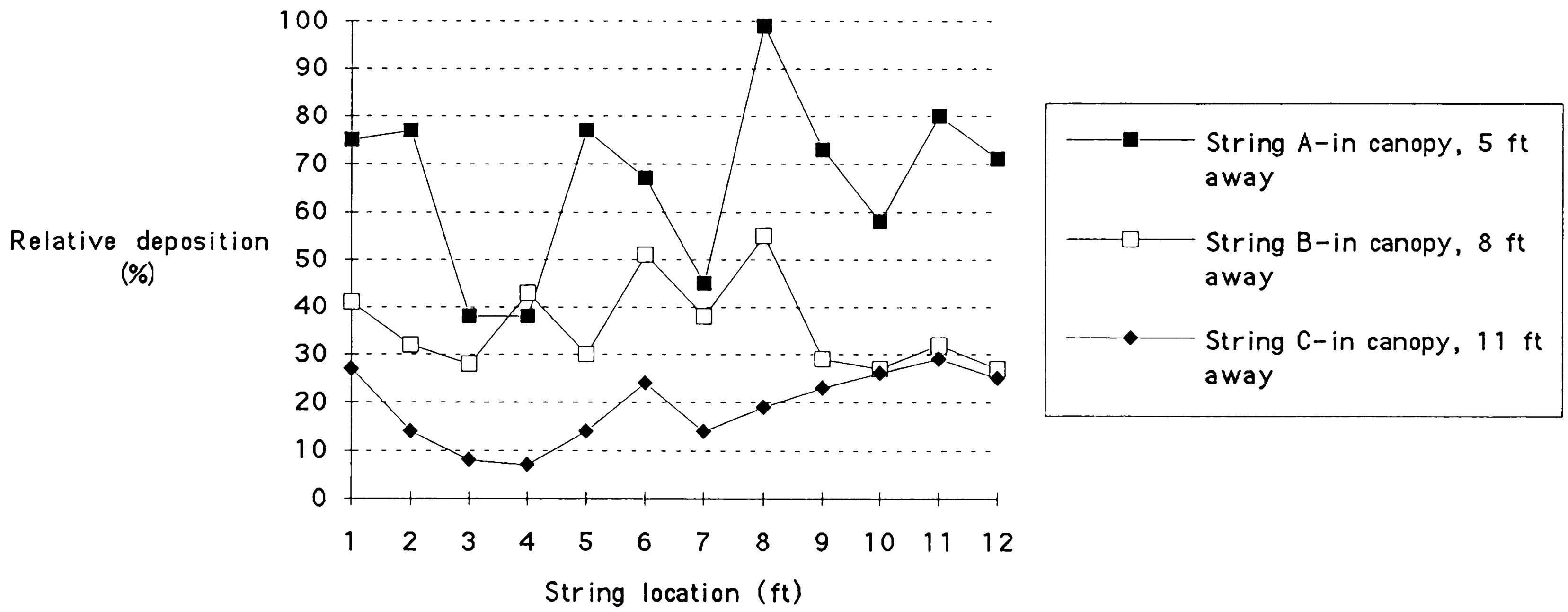


Table 4.7: Average relative deposition (%) on strings placed in the canopy 5, 8 and 11 feet away from the CURTEC sprayer (spraying from side A).

	AVERAGE RELATIVE DEPOSITION (%)		
Location above bottom guide (ft)	String A 5 ft away	String B 8 ft away	String C 11 ft away
12	71	27	25
11	80	32	29
10	58	27	26
9	73	29	23
8	99	55	19
7	45	38	14
6	67	51	24
5	77	30	14
4	38	43	7
3	38	28	8
2	77	32	14
1	75	41	27
TOTAL	798	433	230
AVERAGE	67	36	19
STD. DEVIATION	18	9	7

Figure 4.7: Relative deposition patterns of three strings placed in the Canopy 5, 8 and 11 ft away from the CURTEC sprayer (spraying one side at 4 mph and 20 gpa -- PawPaw, Michigan).



In contrast, all three strings in the tree canopy exhibited much lower deposition. The closest string in the canopy (string A) received only 67 percent deposition. This was 33 percent lower (100 - 67) than the closest string in the open. The middle string in the tree canopy (string B) also received much lower deposition: only 36 percent (its counterpart received 90 percent.), for a difference of 54 percent (90- 36). The far string inside the canopy (string C) recorded 19 percent deposition, which was lower by 58 percent (77 - 19) than deposition on the third string placed outside the canopy. The total average deposition for the three strings in the canopy was 41 percent while the average outside the canopy was 89 percent. The results obtained by the modified WRK string method showed that deposition in the canopy was lower than deposition in the open, as expected.

2. Spray depositions in the nearby zone should be higher than those farther away from the sprayer.

Previous results obtained with the CURTEC sprayer spraying one side of the target trees were again used to show that the nearby area had a higher concentration of spray droplets than the area farther away and harder to reach.

Table 4.8 shows the relative deposition on strings obtained from three string supports inside the tree canopy placed 5, 8 and 11 feet away from the sprayer. Values for the string X were the assumed values that would be expected if a string were placed just outside the canopy 3.5 feet away from the sprayer. The value of 100 percent assumed for the pole X was consistent with the values of the strings placed in the open area.

The canopy in front of pole A -- around 1 to 1.5 feet deep -- reduced the deposition of fluorescent droplets on string A to 67 percent. String B -- which was on pole B, 3 feet farther from string A and deeper into the canopy, received only 36 percent deposition. String C -- which was the farthest from the sprayer (11 feet) and the deepest inside the canopy -- received deposition reduced to just 19 percent.

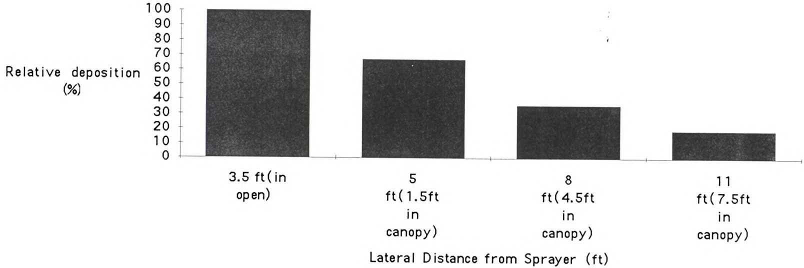
Variations in fluorescence values on the same string were caused by the presence of leaves and branches. As the lateral distance from the sprayer increased, the number of spray droplets available and deposited was reduced. This was the expected result. The air flow produced by the sprayer to carry the droplets to the targets decreased as the lateral distance increased. The forced air carrying the spray droplets lost velocity once it entered the canopy. Another factor that contributed to the decrease in deposition was the obstruction caused by leaves and branches, which intercepted spray droplets and diverted air flow from parts of the string. Under normal circumstances, the amount deposited on the string reflected the amount deposited on the tree foliage .

Table 4.8: Average relative deposition (%) of strings placed outside the canopy (3.5 ft from the sprayer) and inside the canopy (5, 8 and 11 ft from the sprayer).

	AVERAGE RELATIVE DEPOSITION (%)			
Location above	STRING X	String A	String B	String C
bottom guide(ft)	3.5 ft away	5 ft away	8 ft away	11 ft away
12	100 *	71	27	25
11	100	80	32	29
10	100	58	27	26
9	100	73	29	23
8	100	99	55	19
7	100	45	38	14
6	100	67	51	24
5	100	77	30	14
4	100	38	43	7
3	100	38	28	8
2	100	77	32	14
1	100	75	41	27
TOTAL	1200	798	433	230
AVERAGE	100	67	36	19
STD. DEVIATION	0	18	9	7

note: * 100 % = Reached maximum deposition = off scale

Figure 4.8: Average relative deposition (%) of four strings placed 3.5, 5, 8 and 11 ft away from the CURTEC sprayer (spraying one side at 4 mph and 20 gpa--PawPaw, Michigan).



3. Increasing the application rate (gallons per acre) should increase the deposition.

All the results from the field tests showed that increasing the application rate increased the fluorometer readings. A Kinkelder sprayer was used in the apple orchard at the Clarksville research station to see whether the modified WRK string method could show differences in the deposition readings of a string (W) placed 5 feet away from the sprayer and a string (E) placed 8 feet away from the sprayer when they were sprayed with several different application rates. The sprayer was spraying one side of the tree only.

The average fluorescence readings are listed in Table 4.9. For string W, the average deposition per data point was only 21 percent when spray was applied at the rate of 53 gallons per acre. Doubling the application rate to 107 gallons per acre increased the deposition reading to 37 percent. Increasing the application rate to 214 gallons per acre increased average deposition readings to only 50 percent. All the readings were taken with the fluorometer sensitivity level set at 1X and the emission filter 28 percent open. Setting the sensitivity level to 3X caused the readings for the 53 gallons per acre application rate to be in the 50 to 75 percent range and caused the fluorometer readings for the 107 and 214 gpa application rates to reach maximum and be out of the reading range. This is a limitation of the string and dye method. It is not able to measure quantitatively the amount of spray deposition as the copper method does. The fluorometer was reading only the fluorescence from the dye deposited on the outer surface of the strings -- it could not read the fluorescence of any dye embedded in the inner layer (from overlapping spray deposits). Overlapping spray deposits were probably not necessary because they contribute to overapplication of chemical on the same target. If deposition from a single layer of spray deposits was able to do a good job of protecting the plant from pest damage, then overspraying wastes chemical and may damage plants.

Table 4.9: Effect of increasing the application rates on the average relative deposition on strings (W) and (E) sprayed from side W. (Kinkelder sprayer at 1.1 mph, apple tree canopy -- Clarksville, Michigan).

Height above grd(ft)	String location (ft)	AVG. RELATIVE DEPOSITION (%)					
		STRING W			STRING E		
		53 gpa	107 gpa	214 gpa	53 gpa	107 gpa	214 gpa
10	9	17	42	50	6	15	26
9	8	19	39	54	5	9	16
8	7	28	44	64	4	5	6
7	6	35	58	66	4	6	18
6	5	41	57	74	4	3	8
5	4	28	63	63	3	2	4
4	3	16	24	54	3	2	3
3	2	3	6	18	3	1	3
2	1	3	2	5	3	1	5
Total deposition		190	335	448	35	44	89
Av. deposition		21	37	50	4	5	10

Figure 4.9A: The effect of increasing the application rates on the closest string 5 ft away in the canopy (Kinkelder sprayer spraying one side at 1.1 mph -- Clarksville, Michigan).

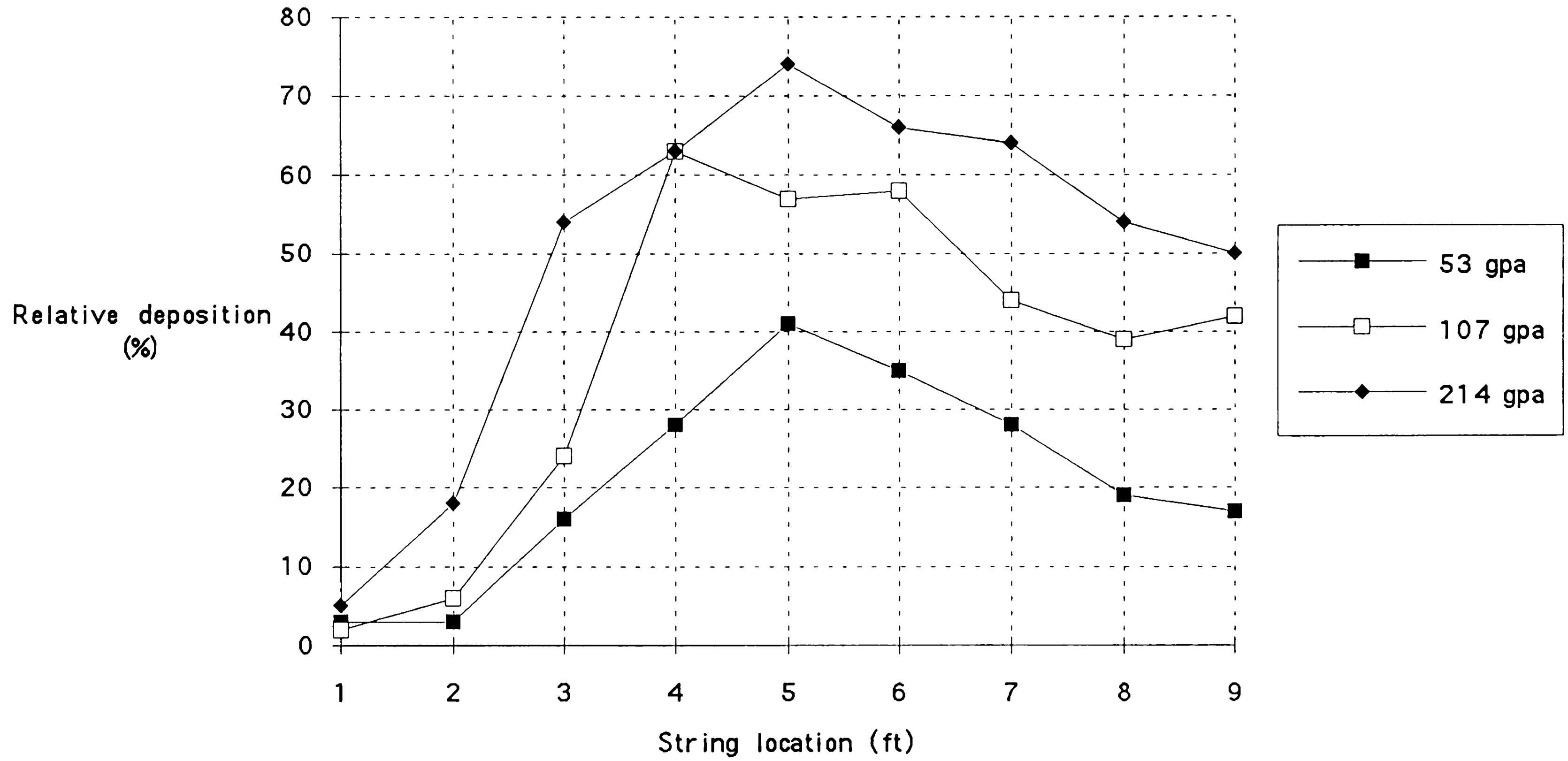


Figure 4.9B: The effect of increasing the application rates on the far string 8 ft away in the canopy (Kinkelder sprayer spraying one side at1.1 mph -- Clarksville, Michigan).

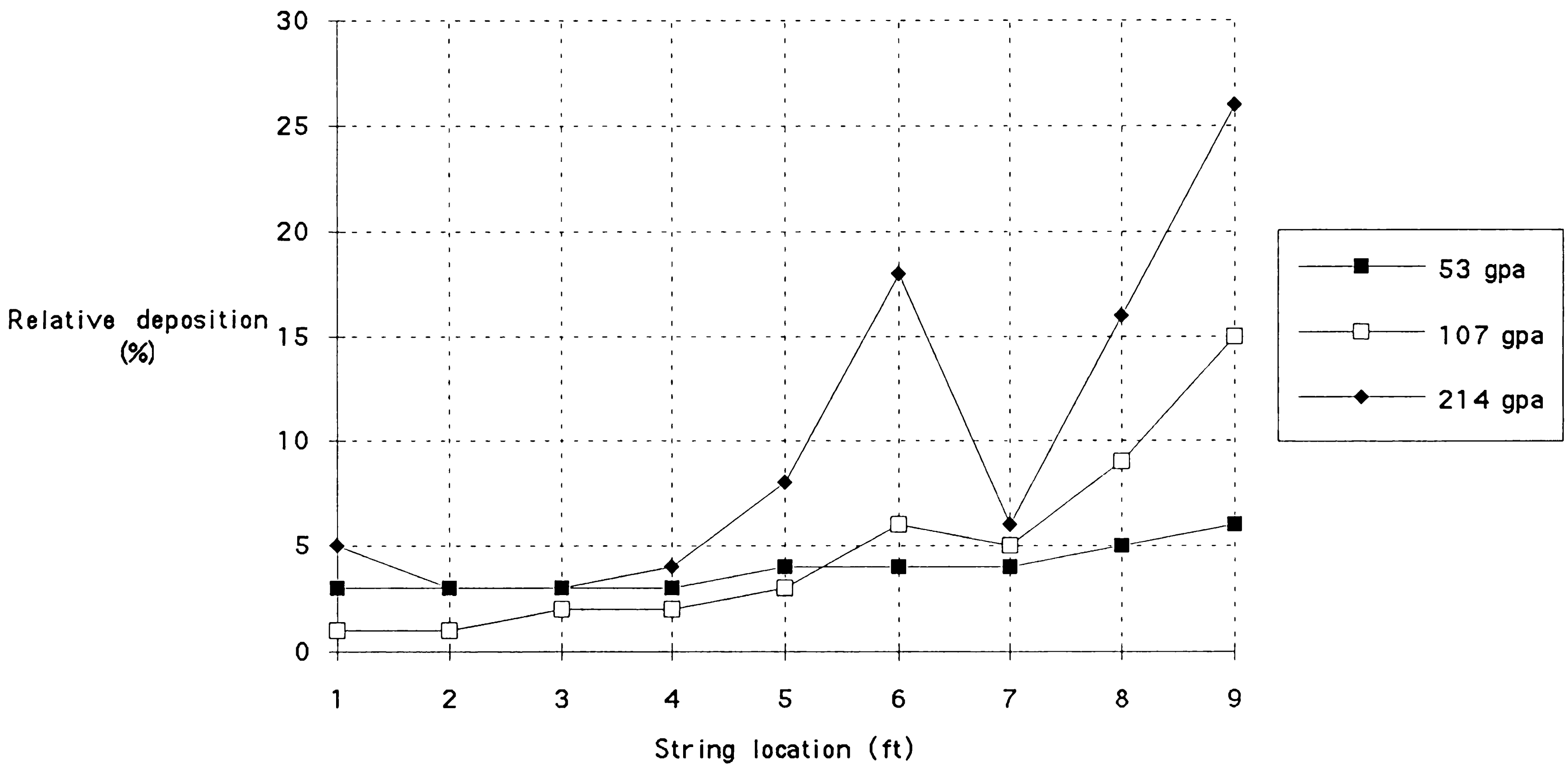


Figure 4.9A illustrates the deposition patterns of three application rates collected by string (W). Figure 4.9B shows the lower deposition patterns of the same three application rates but on string E, on the other side of the canopy. In this study, the modified WRK string method could show that deposition increased as the application rate increased. The increase, however, was not direct proportion to the increase in the application rate. The deposition patterns produced by the fluorescent dye were useful to determine the general coverage of the sprayer.

4. Reducing spraying speed (miles per hour) should increase the spray deposition.

Field tests were conducted in an apple orchard at Leelanau, Michigan, to see whether the modified WRK string method could detect differences in deposition on the strings when the spraying speeds of the sprayer were changed. Table 4.10 summarizes the relative fluorescence readings on the closest string (string A) from 4 feet above the ground to about 15 feet. The string was positioned about 1 foot inside the canopy and 5 feet away from an AgTec 400 PC sprayer.

It was observed that deposition was reasonable up to 11 feet from the ground, or the seven foot location on the string. The upper half of the tree received very low deposition at all the speeds. The poor deposition performance was due to the sprayer's inability to direct and propel the spray droplets to the upper part of the tree.

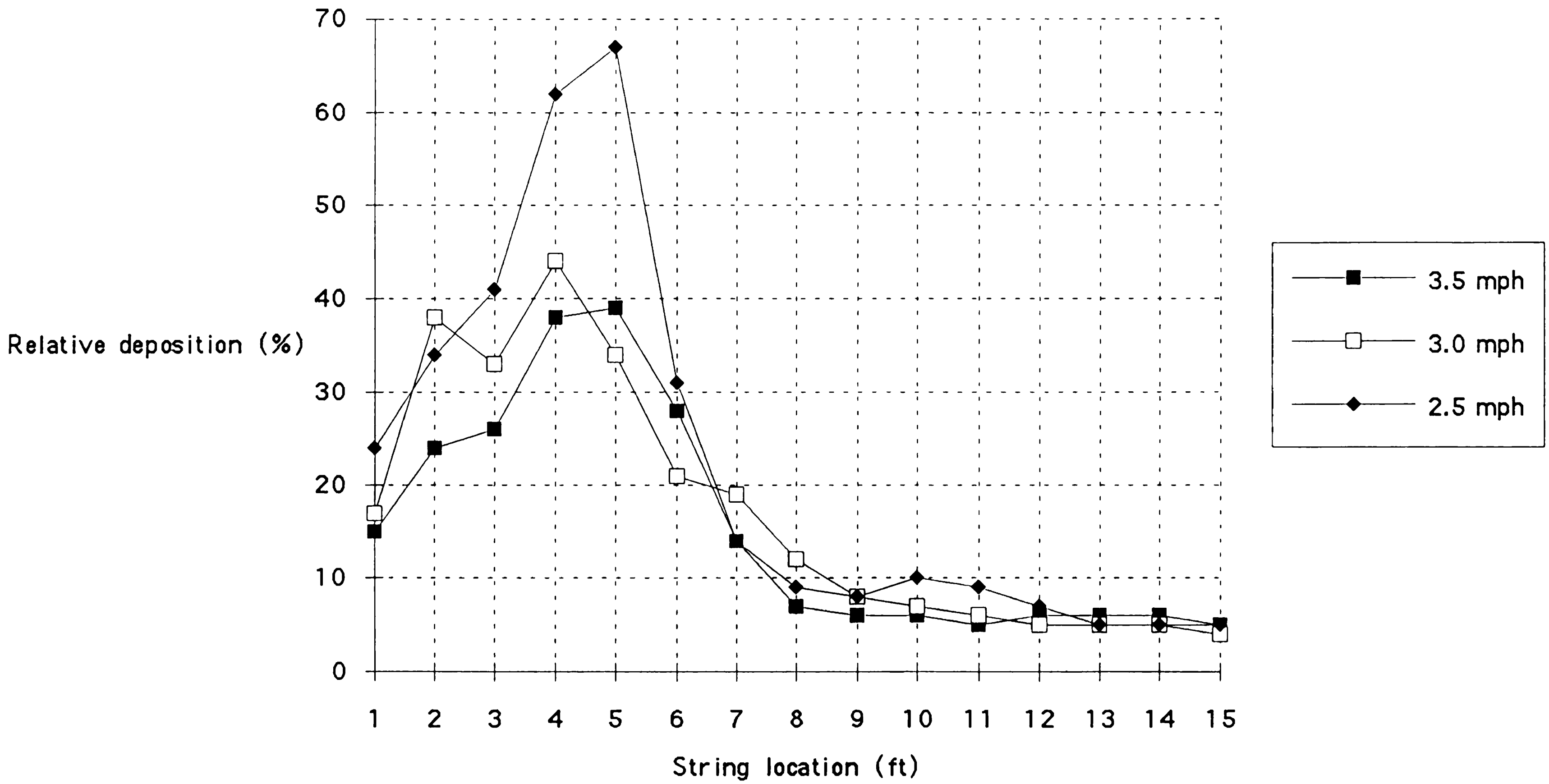
As the spraying speed was reduced from 3.5 to 3.0 mph, the average deposition increased by 2 percent, from 15 to 17 percent. Reducing spraying speed to 2.5 mph caused a noticeable increase in the average deposition, especially within the lower half of the tree. The AgTec 400 PC sprayer performed better at the slower speed of 2.5 mph than at 3.0 or 3.5 mph, achieving 22 percent average deposition for the whole tree height.

Figure 4.10 shows the three deposition patterns produced by the AgTec 400 PC sprayer spraying at speeds of 3.5 mph, 3.0 mph and 2.5 mph. All the deposition analyses were conducted at the fluorometer's 3X sensitivity level and with the emission filter open at 28 percent. The three graphs clearly showed very low deposition from the 7-foot string location upward. The 7-feet string location (7 feet above the bottom guide) was equivalent to 11 feet from the ground. This model of the AgTec sprayer was judged to be too small to cover the top half of the tree satisfactorily. Greater spray deposition was obtained between string locations of 3 to 5 feet (tree height of 7 to 9 feet). Spraying at the lower speed thus helped improve the deposition of the spray droplets .

Table 4.10: Effect of changing sprayer speeds on the average relative deposition (%) on string A sprayed from side A (AgTec 400PC sprayer operating at 3.5, 3.0 and 2.5 mph -- Leelanau, Michigan).

Height above the ground(ft)	String Location(ft)	AVERAGE RELATIVE DEPOSITION (%) 3.5 mph	3.0 mph	2.5 mph
19	15	5	4	5
18	14	6	5	5
17	13	6	5	5
16	12	6	5	7
15	11	5	6	9
14	10	6	7	10
13	9	6	8	8
12	8	7	12	9
11	7	14	19	14
10	6	28	21	31
9	5	39	34	67
8	4	38	44	62
7	3	26	33	41
6	2	24	38	34
5	1	15	17	24
TOTAL		231	258	331
AVERAGE		15	17	22

Figure 4.10: The effect of spraying at reduced speeds on the relative deposition of the closest string 5 ft away in the canopy (AgTec 400 PC sprayer, spraying one side at 20 gpa -- Leelanau, Michigan).



5. Changing the operating nozzles should effect the spray deposition pattern.

Field studies were conducted to see whether the modified WRK string method could detect the effects of changing the operating nozzles on the deposition of spray droplets. All the studies conducted showed that results from the modified WRK string method did respond accordingly.

Figures 4.11A and 4.11B illustrate the spray deposition patterns from several spray runs of a CURTEC sprayer as collected by the closest string (string A). The first run was with all four spray nozzles and fans (numbers 1, 2, 3 and 4) turned on. The second spray run had the top two nozzles and fans 3 and 4 turned on while the lower nozzles and fans 1 and 2 were turned off. The third spray run was with the two bottom nozzles and fans 1 and 2 turned on, and the top two nozzles and fans turned off. And the fourth run was with three nozzles and fans 1, 3 and 4 turned on and one nozzle and fan 2 turned off. The test clearly showed that when the top nozzles were turned off, the corresponding top portion of the string was not sprayed properly. Likewise, when the bottom nozzles were turned off, the bottom portion of the test string was not sprayed. The string targets from the modified WRK string method clearly indicated the working and non-working spray nozzles. Thus the method has potential to show whether a sprayer with its current setting of the nozzles and air deflectors is giving the expected spray performance. If it is not, appropriate adjustments can then be

Figure 4.11A: The effect of changing spray nozzles on the relative deposition patterns of the closest string 5 ft away in the canopy (CURTEC sprayer spraying one side at 3.8 mph -- Leelanau, Michigan).

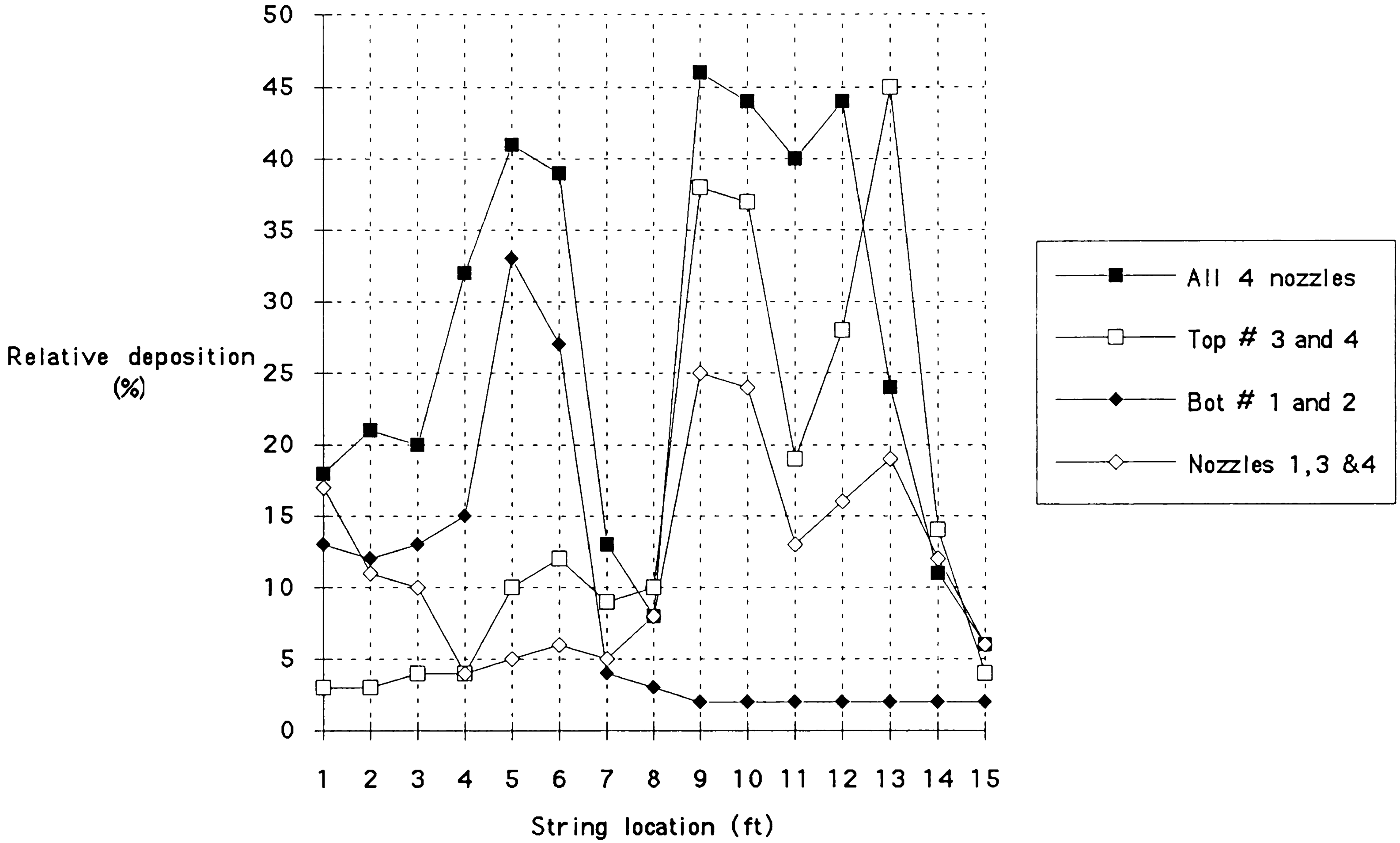
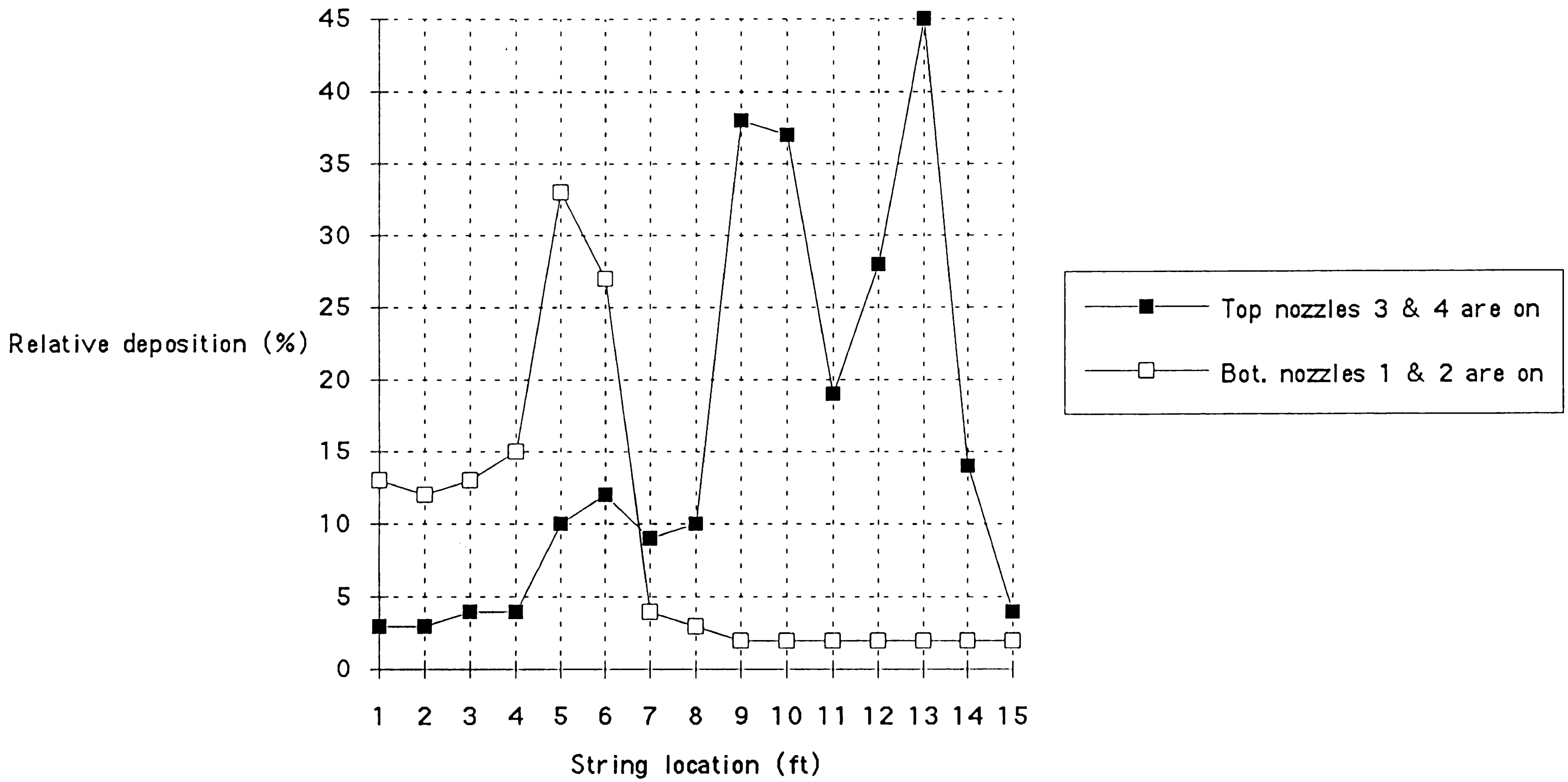


Figure 4.11B: The effect of changing spray nozzles on the relative deposition patterns of the closest string 5 ft away in the canopy (CURTEC sprayer spraying one side at 3.8 mph -- Leelanau, Michigan).



indicated the working and non-working spray nozzles. Thus the method has potential to show whether a sprayer with its current setting of the nozzles and air deflectors is giving the expected spray performance. If it is not, appropriate adjustments can then be made to improve the distribution and deposition of the spray droplets.

6. Spray patterns produced by the modified WRK string method should be similar with those of the copper colorimetry method.

Comparative deposition studies of results from the modified WRK string method and the copper colorimetry method were conducted in September 1989 and August 1992.

The first study was done on a heavily foliated cherry tree, 13 feet high and 18 feet wide using an AgTec sprayer operating at 3 mph and a spray volume of 10 gallons per acre. String and mylar targets were placed on support poles inside the canopy 4, 12 and 20 feet away from the sprayer. The string ran from 5 feet high to the top of the tree. Mylar cards were placed at 5, 9 and 13-foot locations on the vertical support poles.

The second study was done on a heavily foliated apple tree 20 feet high and 14 feet wide using both an AgTec sprayer and an FMC sprayer. The string and mylar targets were placed on support poles inside the canopy 5, 10 and 15 feet away from the sprayer. The string was run from 4 feet high to the top of the apple tree, while the mylar cards were vertically placed at 5, 10 and 15 feet above the ground on each support pole.

On both occasions, Rhodamine WT fluorescent dye and copper traces were used in the spray solution. Spraying with the copper solution was done as soon as the string sprayed with Rhodamine WT fluorescent dye had dried and been replaced with mylar cards.

The major difference between the two methods is that the modified WRK string method gives only the relative deposition reading in percentages, while the copper colorimetry method gives quantitative results in parts per million (ppm). The modified WRK string method gives an almost continuous reading throughout the entire string length, while the copper colorimetry method is limited to only a few discrete (in this case) data points on one vertical pole. The inclusion of more data points adds considerably more work.

Table 4.11A and Figures 4.12A and 4.12B reveal that both methods showed that the closest pole to the sprayer (pole A) received the highest spray deposition. As the lateral distance increased, deposition decreased. Vertically, both methods showed that the most deposition occured in the lower part of the canopy. Deposition declined as height increased.

Both methods showed that the farthest pole (C) received the lowest deposition. The modified method, however, was not able to detect the lower deposition level of the dye as well as the colorimeter detected the copper. The results showed hardly any

Table 4.11A: Relative dye depositions (%) and average copper depositions (ppm) on targets placed 4, 12 and 20 ft away from an AgTec sprayer (sprayed from side A at 3 mph and10 gpa -- Leelanau, Michigan)

Targets Location	A -- 4 ft Away DEPOSITION		B --12 ft Away DEPOSITION		C--20 ft Away DEPOSITION	
Above Ground	Dye(%)	Cu(ppm)	Dye(%)	Cu(ppm)	Dye(%)	Cu(ppm)
1 ft	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	61	1.7	24	0.9	7	0.6
6	53	-	27	-	8	-
7	30	-	28	-	4	-
8	22	-	16	-	3	-
9	5	0.4	8	0.3	1	0.2
10	5	-	4	-	1	
11	5	-	2	-	1	-
12	7	-	1	-	1	-
13	6	0.4	1	0.2	1	0.1
TOTAL	194	2.5	113	1.4	27	0.9
AVERAGE	27	0.83	12	0.47	9	0.3

Figure 4.12A: Relative dye deposition patterns inside the cherry canopy (AgTec sprayer spraying one side at 3 mph and 10 gpa--1989.Leelanau, Michigan)

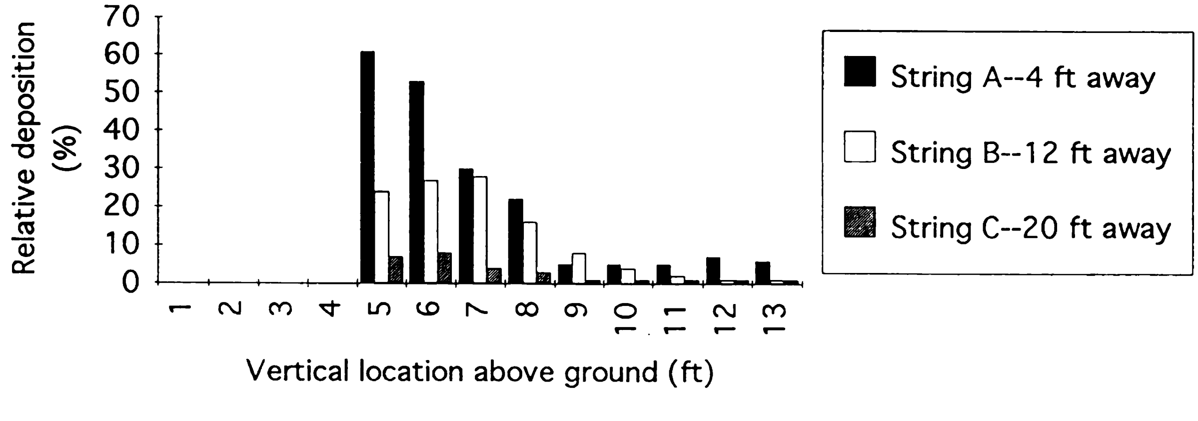


Figure 4.12B: Copper deposition patterns inside the cherry canopy (AgTec sprayer spraying one side at 3 mph and 10 gpa--1989.Leelanau, Michigan)

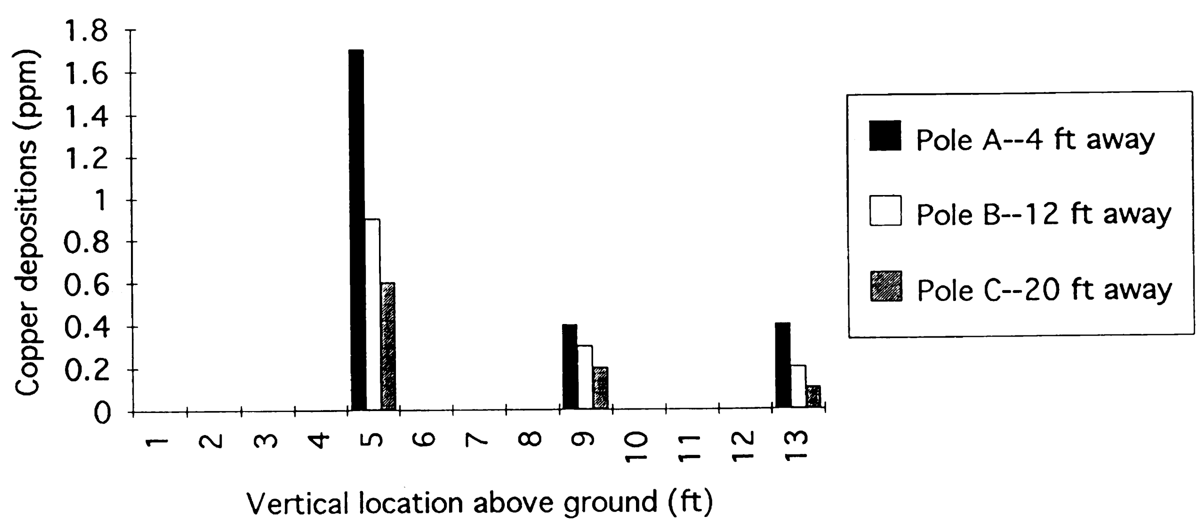


Table 4.11B: Relative dye depositions (%) and average copper depositions (ppm) on targets placed 5, 10 and 15 ft away from sprayers (FMC and AgTec sprayers, sprayed from side A at 3.4 mph and 20 gpa -- 9/1992. Leelanau, Michigan).

Location	A--5 ft Away				A--10 ft Away				A--15 ft Away			
fr Ground	Dye (%)		Cu (ppm)		Dye (%)		Cu (ppm)		Dye (%)		Cu (ppm)	
(ft)	FMC	AgTec	FMC	AgTec	FMC	AgTec	FMC	AgTec	FMC	AgTec	FMC	AgTec
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-
4	34	21	-	-	7	1	-	-	1	0	-	-
5	34	39	0.8	2	2	0	0.1	0.3	0	0	0.1	0.1
6	30	38	-	-	2	2	-	-	0	0	-	-
7	38	47	-	-	1	5	-	-	0	0	-	-
8	29	31	-	-	1	14	-	-	0	0	-	-
9	13	12	-	-	1	12	-	-	0	0	-	-
10	2	7	0.3	0.8	0	5	0.1	0.5	0	0	0	0.1
11	1	6	-	-	0	1	-	-	0	0	-	-
12	1	3	-	-	0	0	-	-	0	0	-	-
13	1	2	-	-	0	0	-	-	0	0	-	-
14	1	0	-	-	0	0	-	-	0	0	-	-
15	1	0	0.2	0.8	0	0	0.1	0.1	0	0	0.1	0.1
16	1	0	-	-	0	0	-	-	0	0	-	-
17	1	0	-	-	0	0	-	-	0	0	-	-
18	1	0	-	-	0	0	-	-	0	0	-	-
19	1	0	-	-	0	0	-	-	0	0	-	-
20	1	0	-	-	0	0	-	-	0	0	-	-
Total	190	206	1.3	1.8	14	40	0.3	0.9	1	0	0.2	0.3
Means	11	12	0.4	0.6	0.8	2.4	0.1	0.3	0	0	0	0.1

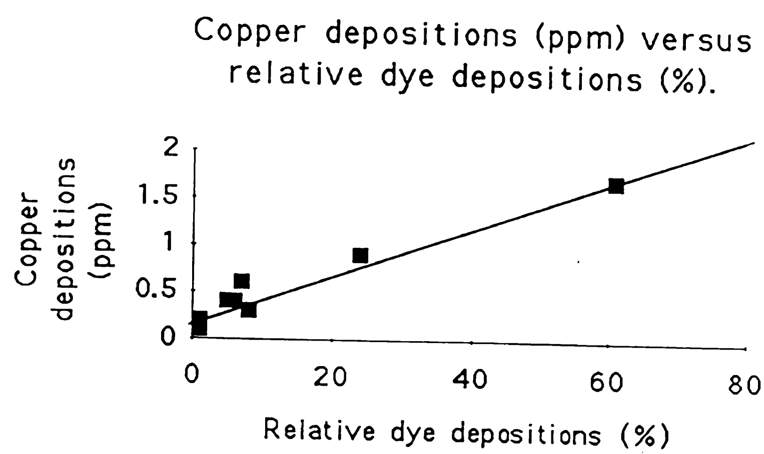
dye being deposited on the top half of the farthest string while the mylar cards were able to collect a small quantity of copper. This was the major disadvantage of the modified method compared with the copper colorimetry method. One possible reason for the absence of dye deposition at this far string position was that few dyed droplets managed to travel this distance and hit the string. The droplets that travelled this far were much drier and lighter because of evaporation and could easily miss the small, thin string targets. The situation was different for the spray droplets containing copper. Though they also lost water by evaporation, the copper traces maintained their weight. The mylar cards (2 inches by 4 inches) were able to trap a few drops of copper, enough to be detected by the colorimeter.

Table 4.11B lists the average dye and copper depositions from the second study. It further confirms the earlier findings that typical airblast sprayers such as AgTec and FMC generally were able to deliver good amounts of spray to a nearby canopy, especially the lower area. The modified string method was able to show this, as was the copper colorimetry method. But as the distance from the sprayer increased or the target area moved up the tree, the spray deposition decreased. The modified string method was not able to detect low deposition levels as well as the copper method, but well enough to warn growers of very low spray deposition on the far side of the canopy or the upper portion of the tree.

Tables 4.11C, D and E also indicate that the dye depositions are positively related to the copper depositions. The t-tests indicate

Table 4.11C: Regression analysis of relative dye deposition to copper deposition (AgTec sprayer at 3 mph, 10 gpa --Leelanau, Michigan).

Observation	Dye(%)	Copper (ppm)
1	61	1.7
2	5	0.4
3	6	0.4
4	24	0.9
5	8	0.3
6	1	0.2
7	7	0.6
8	1	0.2
9	1	0.1



Regression Statistics

Mult. R	0.976
R Sq.	0.953
Ad R Sq	0.946
Std Err	0.116
Obs	9

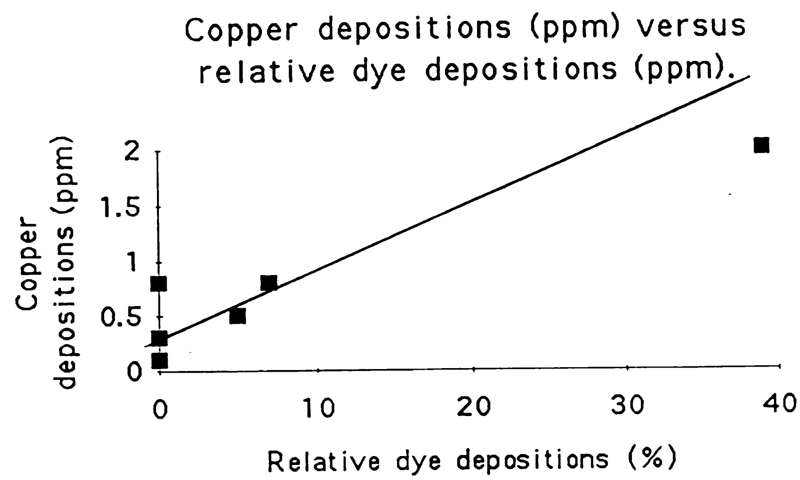
Analysis of Variance

	df	*SS*	*MS*	*F*	*Sig. F*
Regress	1	1.906	1.906	142.4	7E-06
Residua	7	0.094	0.013		
Total	8	2			

	Coefficients	*S Error*	*t Stats*	*Pvalue*	*95%*	*'Jp 95%*
Intercep	0.216	0.047	4.6	0.002	0.105	0.326
x1	0.025	0.002	11.93	2E-06	0.02	0.03

Table 4.11D: Regression analysis of relative dye deposition to copper deposition (AgTec sprayer at 3.4 mph, 20 gpa --Leelanau, Michigan).

Observation	Dye(%)	Copper (ppm)
1	39	2
2	7	0.8
3	0	0.8
4	0	0.3
5	5	0.5
6	0	0.1
7	0	0.1
8	0	0.1
9	0	0.1



Regression Statistics

Mult. R	0.926
R Sq.	0.857
Ad R Sq	0.836
Std Err	0.252
Obs	9

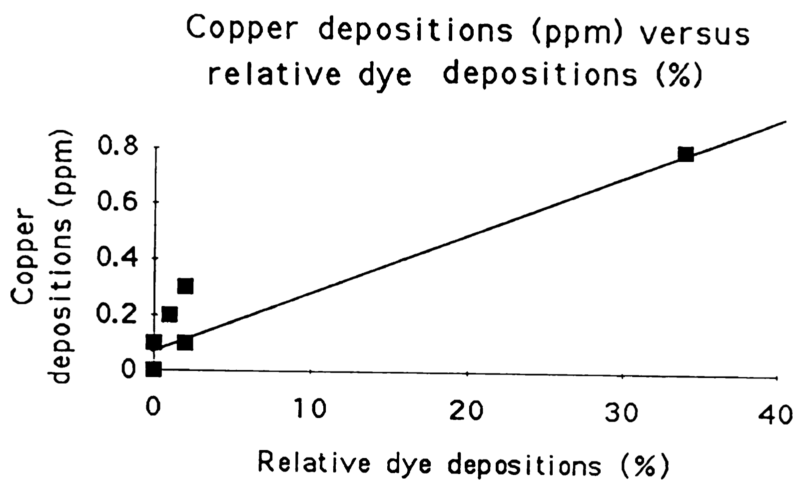
Analysis of Variance

	df	*SS*	*MS*	*F*	*Sig. F*
Regress	1	2.656	2.656	41.91	3E-04
Residua	7	0.444	0.063		
Total	8	3.1			

	Coefficients	*rd Error*	*t Stats*	*Pvalue*	*'er 95%*	*ıer 95%*
Intercer	0.278	0.093	2.995	0.017	0.058	0.497
x1	0.045	0.007	6.474	2E-04	0.029	0.062

Table 4.11E: Regression analysis of relative dye deposition to copper deposition (FMC sprayer at 3.4 mph, 20 gpa --Leelanau, Michigan).

Observation	Dye (%)	Copper (ppm)
1	34	0.8
2	2	0.3
3	1	0.2
4	2	0.1
5	0	0.1
6	0	0.1
7	0	0.1
8	0	0
9	0	0.1



Regression Statistics

Mult. R	0.953
R Sq.	0.908
Ad R Sq	0.895
Std Err	0.078
Obs	9

Analysis of Variance

	df	*SS*	*MS*	*F*	*Sig. F*
Regress	1	0.418	0.418	69.36	7E-05
Residua	7	0.042	0.006		
Total	8	0.46			

	Coefficients	*rd Error*	*t stats.*	*P-value*	*'er 95%*	*'er 95%*
Intercep	0.111	0.028	3.976	0.004	0.045	0.177
x1	0.02	0.002	8.328	3E-05	0.015	0.026

that the slope coefficients are significantly different from zero. The high R Square values for the three tables show that the variations in copper measurements correspond well with variations in the dye fluorescence. It is therefore reasonable to conclude that the dye method can be used to show the amount of spray deposition.

4.5 Speed of Fluorescence Evaluation

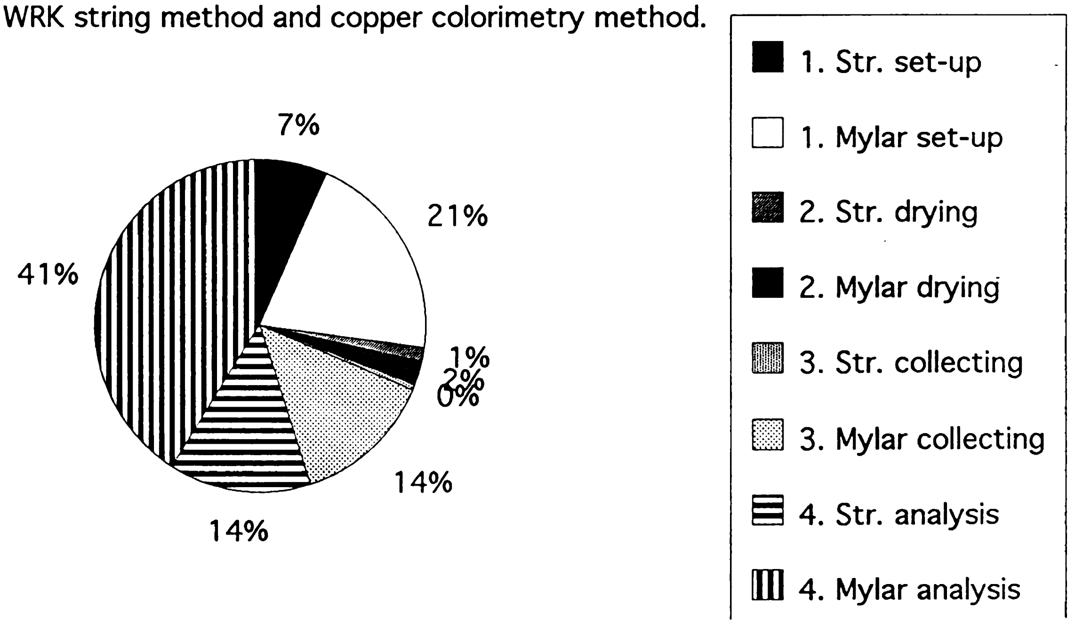
One of the objectives of developing the modified WRK string method was to speed up the overall evaluation process beginning with the preparatory stage -- spraying and setting up targets -- to the end of the process -- getting the hard copy of the fluorescence patterns.

Time and event studies were made to record the time required when using the modified WRK string method and the copper colorimetry method. Copper colorimetry was used as a comparison because it is recognized as a reliable method and is widely used to measure spray deposition. Time used to set up one string support -- including securing the pole anchor in the ground, adding the middle and top portions of the pole to reach the desired height in the tree, and threading the cotton string through all the loops of the support -- varied from 2 to 7 minutes. Thus the time required to prepare the string collectors for the whole tree canopy (three were required)

Table 4.12: Time requirements for one person using the modified WRK string method and copper colorimetry method for three target supports per tree.

ACTIVITIES	TIME REQUIREMENTS (minutes)			
	Modified WRK String		Copper Colorimetry	
	1 support	3 supports	1 support	3 supports
1. Set up supports & targets	5	15	15	45
2. Targets drying	3	3	5	5
3. Collecting dried targets	1	1	10	30
4. Analyzing targets, getting results & charts	10	30	30	90
TOTAL TIME Requirements =	19	49	60	170

Figure 4.13: Proportion of time requirements for various activities using modified WRK string method and copper colorimetry method.



averaged 15 minutes for one person working alone.

For the copper colorimetry method, the set-up time for inserting the mylar cards into the clips and positioning and anchoring a pole in the tree was found to be at least 15 minutes. Thus for the whole tree canopy, which required three poles, the time required was 45 minutes for one person working alone.

After spraying, the string required 1 to 4 minutes to dry. The mylar sheets usually required 3 to 7 minutes to dry. This variation in drying time depended on the air temperature, droplet size and the relative humidity of the air at the time the spraying was done.

Winding the dry sprayed string onto the collection spool was a fast process compared with collecting mylar targets from their stakes. With the motorized string winder, it required only 1 minute to wind the string for the whole tree, close the cap of the spool container and label the container for later analysis. In the copper colorimetry method, collecting the mylar cards from the whole tree required at least 30 minutes .

The time required to analyze the string to determine the spray deposition was about 10 minutes. The analysis included placing the spool containing the sprayed string on the fluorometer, analyzing the string and then recording the deposition values on a floppy disk. Finally, the deposition values were graphed automatically for a hard copy output.

The copper colorimetry method required a considerable amount of time and attention to tedious detail when it was used to analyze sprayer deposition on mylar cards. It took one person approximately

80 minutes to do the deposition analysis. Also, once the wash solution had been added to the sprayed mylar cards to recover the copper, the rest of the process had to be completed. Delay resulted in unreliable data readings. An additional 10 minutes were required to manually plot the graph of the deposition.

Table 4.12 and Figure 4.13 compare the average time spent for each activity in evaluating the amount of spray deposition in an apple orchard at the Michigan State University farm using both the modified WRK string method and the copper colorimetry method.

4.6 Labor Requirements

For an uninterrupted, continuous operation, the optimum number of people required to operate the modified WRK system was four. The first person was responsible for mixing the spray solution, running the sprayer and tractor, and making necessary adjustments and changes to the sprayer. The second person set up the string supports, threaded the string through the three supports and rewound the string at the end of the spraying cycle. The third person acted as a runner, taking sprayed spools to the computer operator and bringing the empty spools back to the spraying area. The fourth person was responsible for operating the computer and analyzing the sprayed string.

For a non-continuous process, two persons were considered the minimum number of operators needed to do the work satisfactorily. With a two-person team, the sprayed strings were saved for analysis later .

This study showed that the copper colorimetry method required more people to get the deposition results within the same time period as the modified WRK string method needed. For a continuous, uninterrupted process, eight people were necessary. The first person was responsible for preparing and handling the tractor and the sprayer, and other related activities. Three people were required to set up the three mylar card stakes, wrinkle the mylar cards, clip the mylar cards to the stakes, collect the sprayed cards and place them in properly labeled containers. Throughout the whole activity, care was needed not to dirty or contaminate the mylar cards. A fifth person was required as a runner to pick up the collected mylar cards, now in the labeled containers, and take them to the laboratory for analysis. Three more persons were required to analyze the depositions on the collected mylar cards. The whole process was repeated for each new set of deposition data.

For a non-continuous process, at least four persons were required to guarantee reliable results. A working crew of fewer than four people required much more time to prepare the deposition targets. Because weather conditions are constantly changing, time was an important factor in getting comparable spray runs. The four-person crew consisted of one tractor and sprayer operator and three persons to prepare targets, position them, collect the sprayed targets and place them in labeled containers for analysis later. In this non-continuous operation, the deposition analysis was delayed until all the field work was done for the day.

Table 4.13: Labor requirements of the modified WRK string method and the copper colorimetry method.

CONTINUOUS or UNINTERRUPTED OPERATION

Activity	Number of workers	
	String/dye	Mylar/copper
Tractor/sprayer operation	1	1
Set-up and collection of string	1	-
Set-up and collection of mylar	-	3
Computer/fluorometer/plotter operation (dye analysis)	1	-
Runner to bring collected targets to lab	1	1
Colorimeter operation (copper analysis)	-	3
Total number of workers	4	8

NON-CONTINUOUS or INTERRUPTED OPERATION

Activity	Number of workers	
	String/dye	Mylar/copper
Tractor/sprayer operation	1	1
Set-up, string collection and dye analysis	1	-
Set-up, mylar collection and copper analysis	-	3
Total number of workers	2	4

4.7 Simplicity of Making Evaluations

The modified WRK string method was easily understood and operated. Calculations were minimal and the operating instructions were simple .

The only chemical mixing involved was mixing dye and water in the sprayer tank. No hazardous or toxic materials were involved. There was very little handling of testing material by the operators. This limited the chance of contamination to the deposition collectors, and most importantly, the chance of human error. Once the string threaded through the three supports for the first run, it could be used for consecutive runs without rethreading. Step-by-step instructions given on the computer screen helped the operator to complete the analytical work successfully. The chance for error with the string method was significantly less than with the copper colorimetry method.

The copper colorimetry method required several preparations, and each type of preparation required that detailed instructions be carefully followed. Obtaining and mixing various chemicals at certain stages of the procedure required people who were knowledgeable about chemistry or at least someone to supervise the calculations and the mixing. A small mistake in adding and mixing the chemicals would change the results of the tests significantly. Improper handling of the mylar cards could result in contamination of the cards and thus affect the analysis results. The copper colorimetry method included many such activities done by manual labor. This increased the chances of contamination, mistakes and human errors.

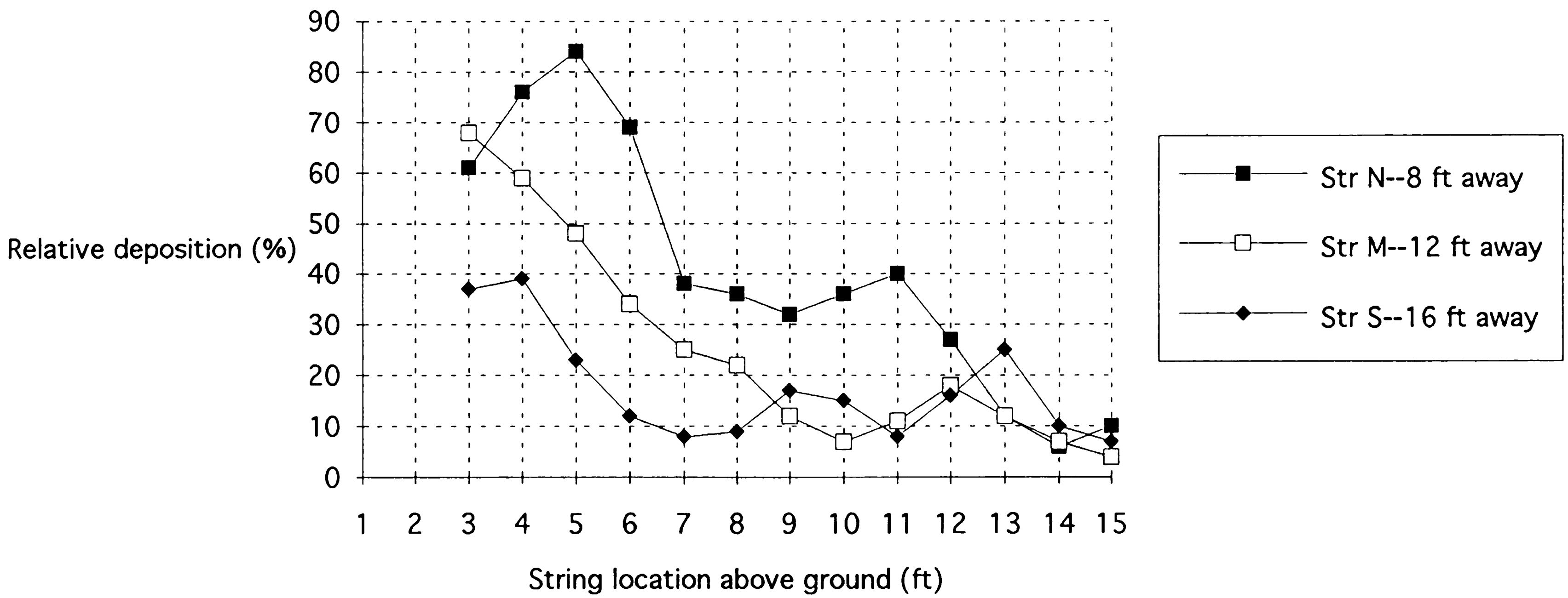
4.8 Performance of Various Sprayers

The deposition performance of each sprayer was evaluated by operating the sprayer in the orchard in a normal manner and spraying the fluorescent dye and water mixture as described in section 3.7.1. A sample of the spray was captured by the string placed in the tree canopy. The string was analyzed by running it through the fluorometer. The relative deposition values were read directly, results were traced on the computer monitor and a hard copy was produced by an HP plotter. The relative deposition values listed in each data file and the deposition patterns plotted on the paper were used to compare the deposition performance of the sprayers. The followings results and conclusions about several sprayers evaluated in the study are based on the relative deposition values and their respective deposition patterns.

1) FMC Speeds Sprayer LV400.

The FMC Speeds Sprayer LV400 was tested for its spray performance on an apple tree 15 feet high . The tree was 16 feet in

Figure 4.14: Relative deposition patterns of FMC LV400 sprayer on strings N, M and S placed in the apple tree canopy (spraying two sides at 2 mph and 20 gpa, gusty wind from N side-- Fennville, Michigan).



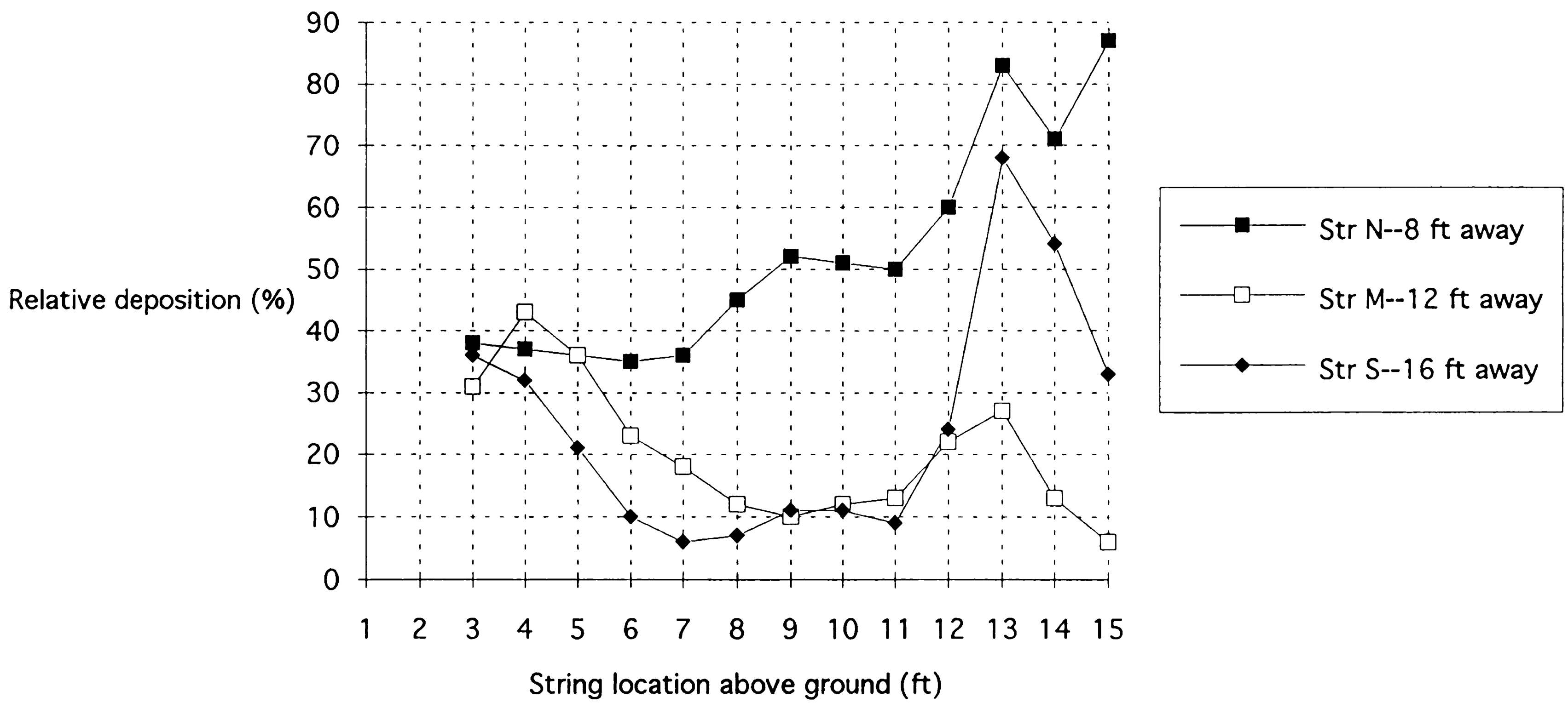
diameter and the trunk was 12 feet from the sprayer nozzle. Three string supports were placed inside the tree canopy 8, 12 and 16 feet away from the sprayer. The three string bottom guides were raised about 2 feet above the ground. The sprayer was operated at 2 mph and the application rate was 20 gpa.

The relative deposition study revealed that this particular airblast sprayer deposited higher amounts of spray droplets in the lower one-third of the canopy (up to 4 feet). This is illustrated by Figure 4.14. Deposition fell to almost half in the midsection -- 4 feet and dropped down to minimum deposition at the top part of the canopy. Horizontally, the canopy area closest to the sprayer (the N string in this example, with data file coded as PEAB2M6G.N) received the most deposition, an average of 43 percent. The middle string (M), (data file coded as PEAB3M6G.M) recorded an average of 25 percent, and the far side of the tree (S string, data file coded as PEAB3M6G.S) received an average of only 18 percent .

2) FMC Tower Sprayer

The deposition evaluation test done on the FMC tower sprayer on the same tree, spraying both sides of the tree with a sprayer speed of 2 mph and a spray rate of 20 gpa, showed improved and much higher deposition on the upper part of the tree canopy. Figure 4.15 illustrates the deposition pattern of this sprayer. The canopy area closest to the sprayer, represented by the N string and data file PETOW3M6G.N, received the most deposition, starting with 38

Figure 4.15: Relative deposition patterns of FMC tower sprayer on strings N, M and S placed in the apple tree canopy (spraying two sides at 2 mph and 20 gpa, gusty wind from N side--Fennville, Michigan).



percent at the bottom of the canopy and increasing to almost 90 percent at the top of the canopy, with an average of 46 percent. The middle (M) string area showed reasonable deposition for the first one-third of the tree height, declining deposition in the second one-third of the canopy height and decreased deposition in the top one-third of the canopy height. The average deposition for the middle string was 18 percent.

The deposition pattern on the other side of the tree (the S string, data file PETOW2M6G.S) showed the lowest deposition among the three strings at the lower half of the canopy, but then increased deposition in the last one-third for a little higher overall deposition than that recorded on the middle (M) string. The average deposition for the whole S string was 23 percent. The higher deposition on the S string than on the M string was not a surprise because the tree was sprayed from two sides on this particular run. The deposition recorded by the middle (M) string and the far (S) string showed opposite deposition behavior in the middle part of the canopy height, where depositions were the lowest.

3) AgTec Standard Air Blast Sprayer

The AgTec standard sprayer was tested for deposition performance when spraying both sides of a cherry tree at the rate of 20 gpa and a speed of 3 mph. Figures 4.16A and 4.16B show the

Figure 4.16A: Relative deposition patterns of an AgTec sprayer on strings W, M and E placed in an OPEN AREA between cherry trees (spraying 2 sides at 3 mph and 20 gpa--Paw Paw, Michigan).

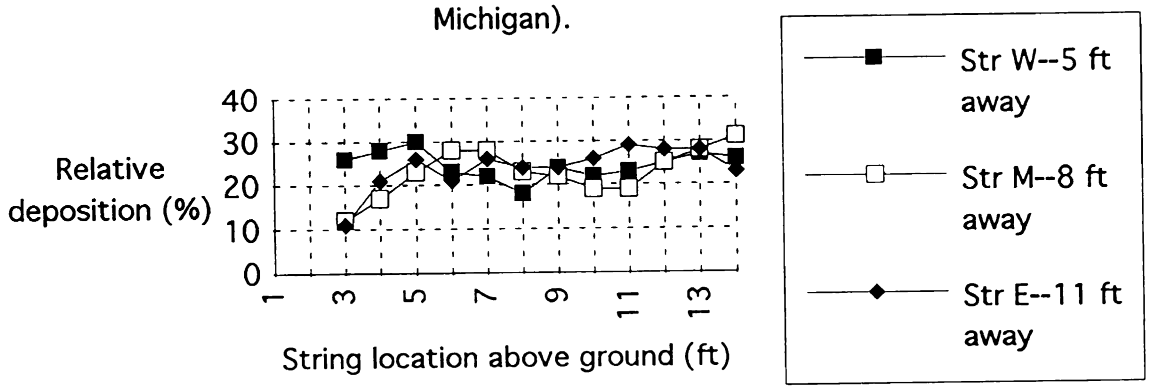
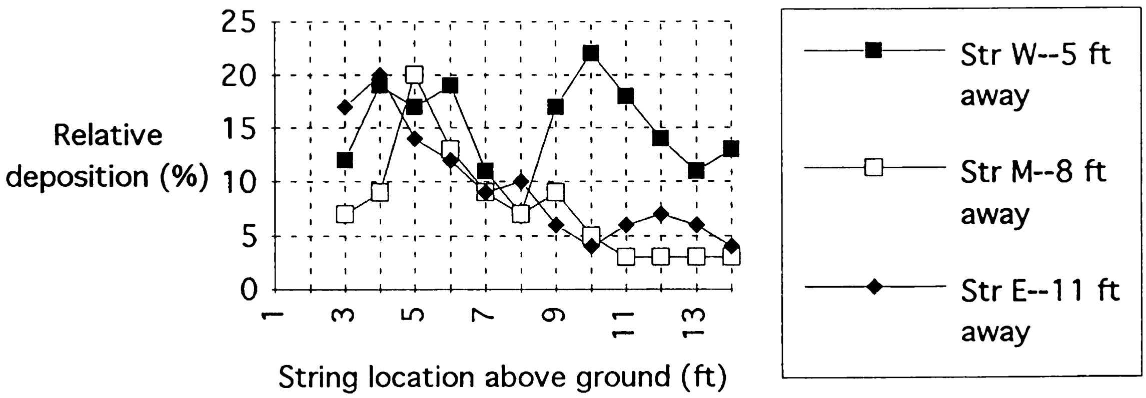


Figure 4.16B: Relative deposition patterns of an AgTec sprayer on strings W, M and E placed in a cherry tree canopy (spraying two sides at 3 mph and 20 gpa--Paw Paw, Michigan).



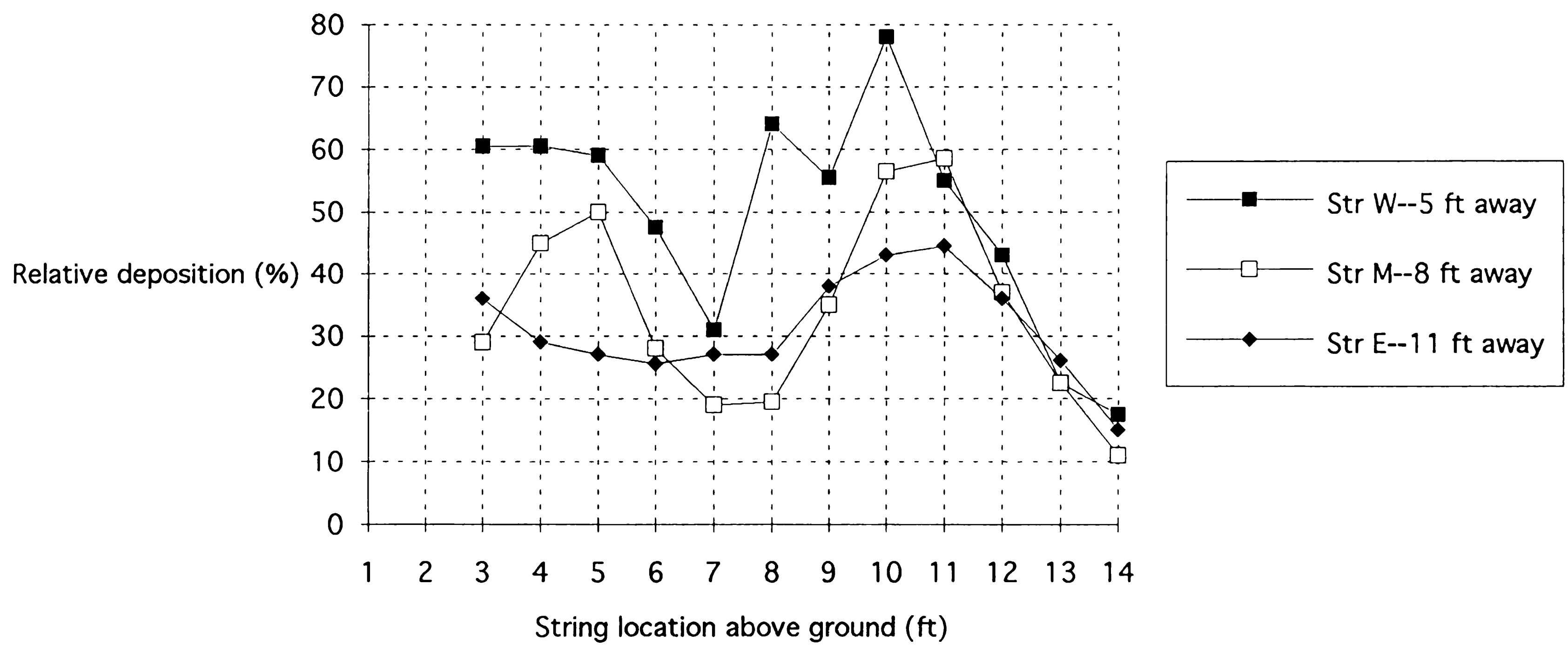
relative spray patterns of the strings placed in the open area and inside the canopy, respectively. In the open area, the strings closest to the sprayer, strings W and E, received only 22 percent and 23 percent relative deposition, respectively. In the canopy, because of foliage obstruction, the average relative deposition was even lower -- in this case, only 14 percent for the W string and 9 percent for the E string. The middle string (M) placed in the open received an average relative deposition of 22 percent, but the string placed in the middle of the canopy received only 8 percent.

Increasing the spraying rate from 20 gpa to 50 gpa while maintaining the sprayer speed at 3 mph more than doubled the deposition without changing the general spray pattern.

4) AgTec Tower Sprayer

The AgTec tower sprayer was tested for its deposition performance using the modified WRK string method while spraying both sides of the tree at the rate of 20 gpa and a sprayer speed of 3 mph. Its deposition performance was found to be much higher than that of the AgTec standard sprayer at the same application rate. Figure 4.17 illustrates the relative deposition patterns for the three string positions at 5, 8 and 11 feet from the sprayer. The sprayer demonstrated good spray droplet distribution and deposition inside the tree canopy. The average deposition on string W was found to be about 50 percent while for the middle string (M), the average relative deposition was 34 percent. String E, which was on the east

Figure 4.17: Relative deposition patterns of an AgTec tower sprayer on strings W, M and E placed in a cherry tree canopy (spraying two sides at 3 mph and 20 gpa--Paw Paw, Michigan).



side of the tree, received an average relative deposition of 31 percent.

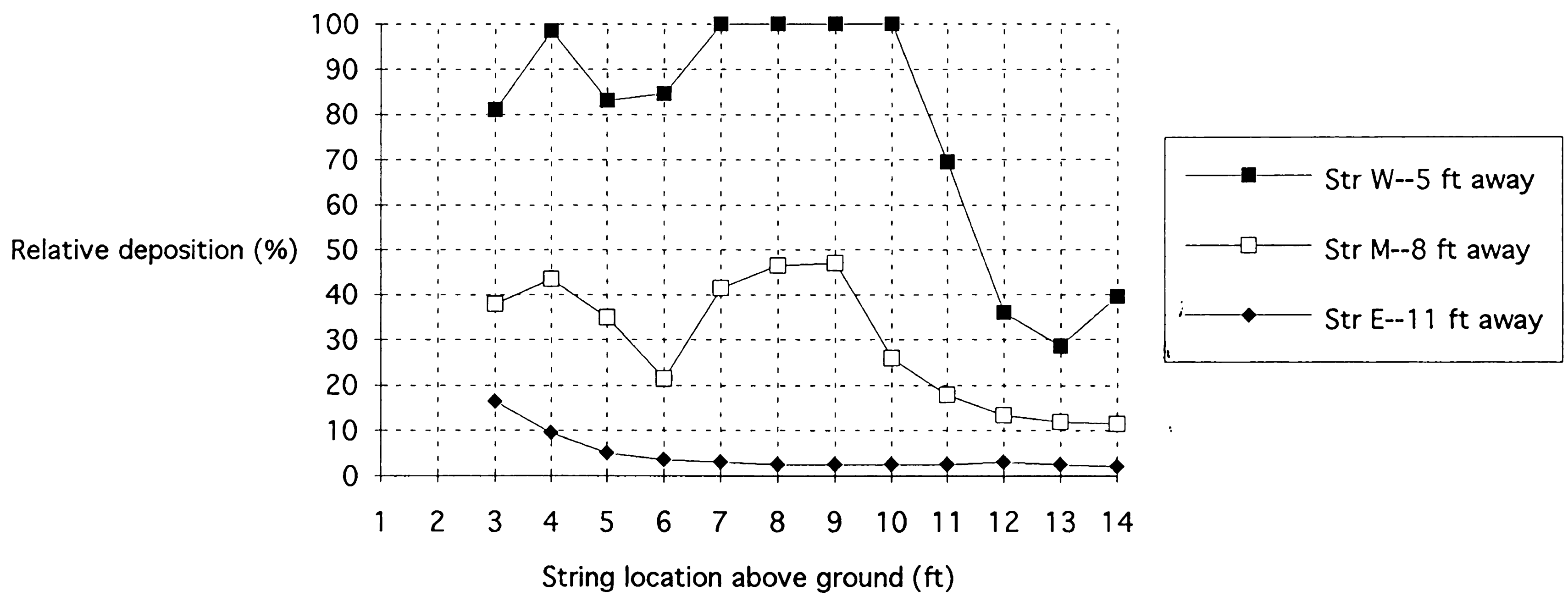
5) Myers Model 2436 Sprayer

A Myers sprayer was also evaluated for its spray deposition performance using the modified WRK string method. This sprayer was operated at 3 mph and 112 gpa and sprayed one side of the tree canopy. Figure 4.18 shows the respective deposition patterns for the three string positions. The deposition performance as shown by the relative deposition on the first string W (data file PEMY3WSNT.W) is high. The first 8 feet showed depositions of over 80 percent, while the top one-third of the tree height showed a sharp drop in deposition. The average deposition for this string was calculated at 76 percent.

The deposition on the middle string M (data file PEMY3WSNT.M) generally followed the shape or pattern of the first string but at a lower rate, an average deposition of only 28 percent. The difference -- 48 percent (76 - 28) -- was probably due to foliage obstructions. The top one-third of the tree height showed a drop in deposition, a characteristic common to standard air blast sprayers.

The deposition performance shown by string E, located on the other side of the tree trunk 11 feet away from the sprayer, was very low. The average deposition for this particular string was only 4 percent (data file PEMY3WSNT.E). The 11-foot distance, 7 feet of it

Figure 4.18: Relative deposition patterns of a Myers sprayer on strings W, M and E placed in a cherry tree canopy (spraying two sides at 3 mph and 112 gpa -- Paw Paw, Michigan).



through the canopy of thick leaves, resulted in low penetration and deposition of spray droplets produced by the Myers sprayer.

6. CURTEC or Air Curtain Sprayer

The CURTEC sprayer, spraying one side of a tree at the rate of 20 gpa and a speed of 4 mph, was found to deposit a maximum 100 percent of spray droplets on a 12-foot vertical string placed in the open area 5 feet away from the sprayer. At 8 feet distance, the relative deposition in the open area dropped to 90 percent. When the lateral distance increased to 11 feet, the deposition dropped to about 77 percent. Analyzing the strings placed inside the tree canopy 5, 8 and 11 feet away from the sprayer showed the average relative depositions dropped to 66.5, 36 and 19 percent, respectively. Figure 4.21A shows the deposition patterns of the spray droplets collected by the three strings placed in the open area, and Figure 4.21B shows the effects of the tree canopy on the deposition patterns of the strings placed within the canopy. The deposition patterns show that the CURTEC sprayer gave more uniform deposition throughout the vertical height of the string. The relative deposition was generally higher than that of other types of sprayers, even when the CURTEC sprayer was spraying only one side of the tree and moving faster.

Figure 4.19A: Relative deposition patterns of a CURTEC sprayer on strings placed in an OPEN AREA between cherry trees (spraying 1 side at 4 mph and 20 gpa--Paw Paw, Michigan).

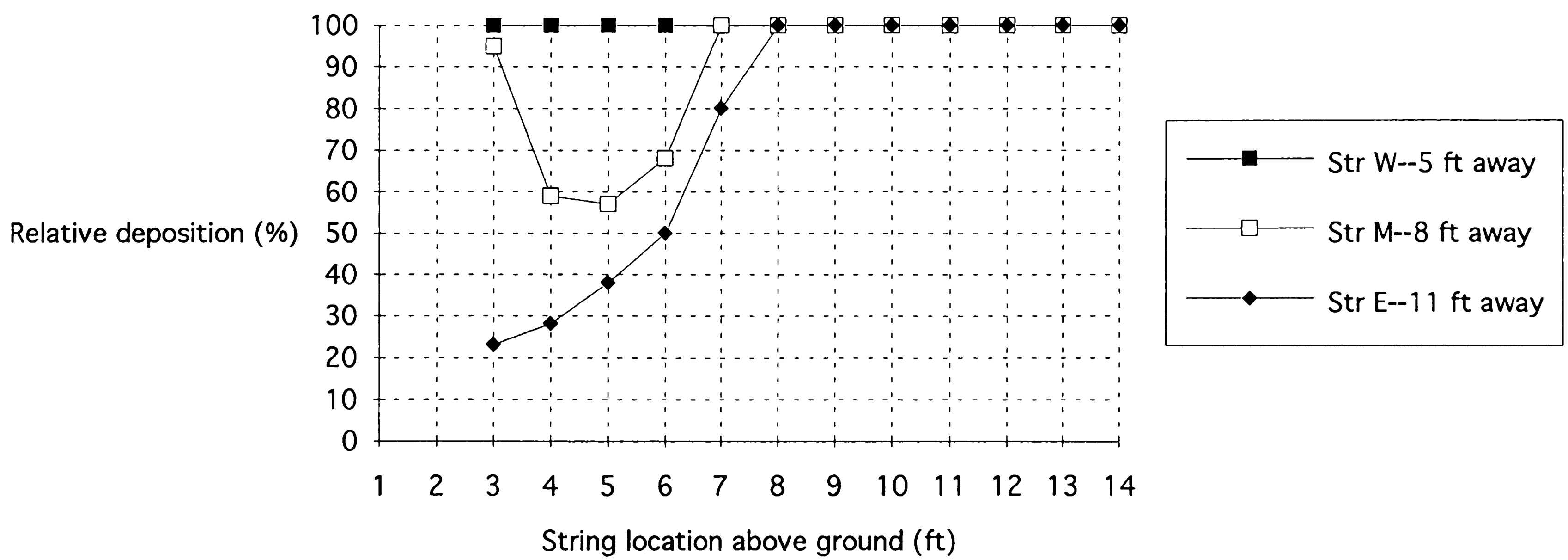


Figure 4.19B: Relative deposition patterns of a CURTEC sprayer on strings placed in a cherry tree canopy (Spraying one side at 4 mph and 20 gpa--Paw Paw, Michigan).

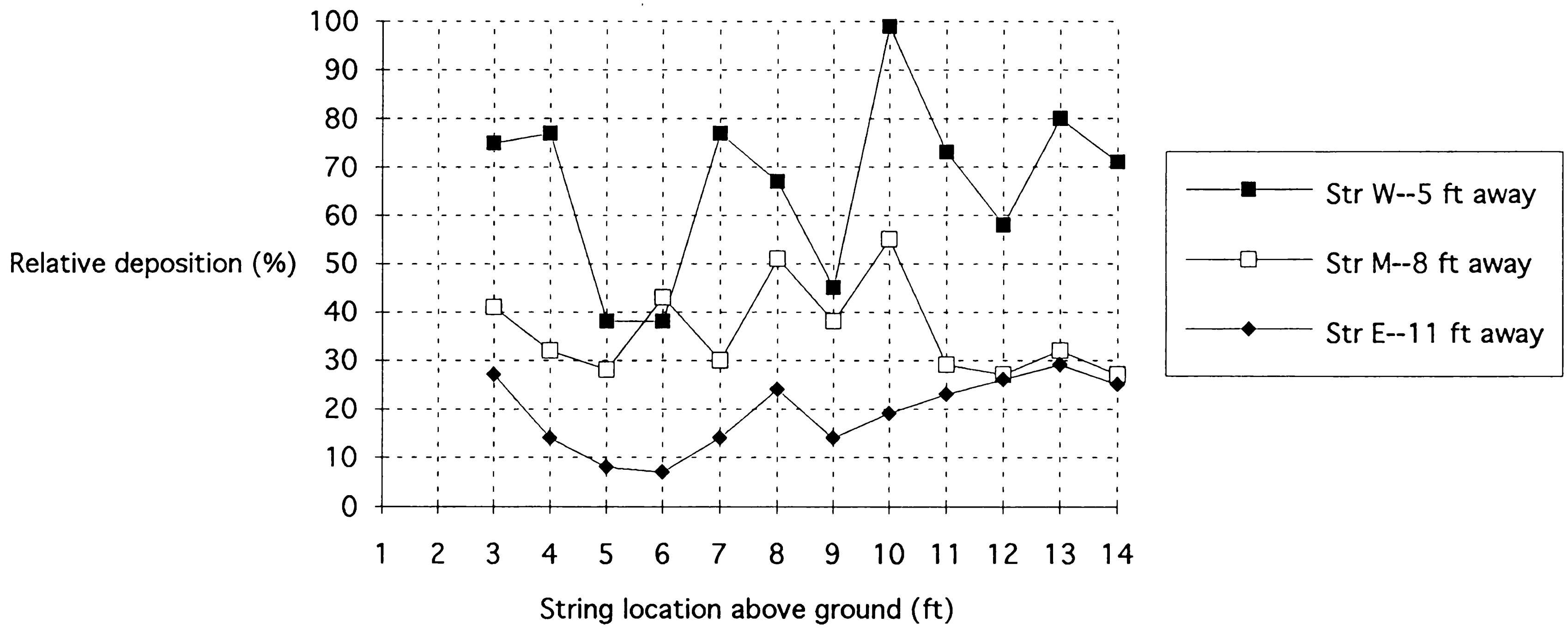


Table 4.14: Summary of the Relative Deposition Performance of Several Sprayers.

	NAME OF SPRAYER	DATA FILE	MPH	GPA	#	AVG. FLUORESCENCE at POLES A (%)	B/ M (%)	C (%)
1.	FMC LV400 Sprayer	- PEAB2M6G	2	20	B	43	25	18
2.	FMC Tower Sprayer	- PETOW2M6G	2	20	B	46	18	23
3.	AgTec Std Sprayer	- PEATS3M20GN	3	20	B	14	8	9
4.	AgTec Tower Sprayer	- PEATT3M20G	3	20	B	50	34	31
5.	Myers Sprayer	- PEMY3WSNT	3	112	S	76	27	4
6.	CURTEC Sprayer	- PEAC4M20GN	4	20	S	67	36	19

Note:

= type of sprayings :

S = spraying on a single side (one side) of a tree canopy.

B = spraying on both sides of a tree canopy.

CHAPTER 5

CONCLUSIONS

The following conclusions were drawn from the results of the research:

1. The WRK string technology, developed for patterning aerial spray deposition, was useful to evaluate and pattern the deposition of orchard sprayers in the tree canopy after some modifications were made to the original WRK equipment.

2. The new method was found to be very promising because of its simplicity and speed. This technique helped growers, sprayer operators and Extension workers visualize and understand the spray droplet deposition pattern and penetration performance. Remedial actions and changes could then be taken to improve sprayer performance before actual sprayings were done.

3. This method gave relative qualitative measurement of the spray deposition based on the fluorescence of the dye solution but not the quantitative amount of the spray.

4. The string support developed held two vertical string lines, with the ascending and descending lines providing two sets of string targets (duplications) for each pole position per spray run. This guaranteed that each set of strings received the same treatment.

Differences in the deposition patterns between the two string lines were due to leaves or tree branches blocking or intercepting the spray.

5. The whole spray deposition test can be conducted by two people without feeling overworked.

6. The reduction in time and manual handlings characteristic of the procedure reduced the chances for human error.

7. The reliability tests conducted showed that the results produced by this method were reliable in evaluating relative deposition of spray droplets inside the tree canopy.

8. The whole string length acted as a spray deposition collector, providing numerous data points (1.3 inches per data point). This produced a very detailed deposition pattern of the spray droplets at a particular location in the canopy.

9. The enclosed string dispenser and motorized string winder enabled the cotton string to be quickly and automatically reset for the next spray application, while the sprayed string portion was being wound on the take-up spool.

10. The use of ceramic eyelets on the bottom and top string guides guaranteed the smooth flow of the string lines around the string

support and long life of the unit.

11. This method required about 10 minutes to set up three string supports and thread the string for the deposition test in each tree. It took another 10 minutes for the sprayed string to dry, be rewound and be analyzed by a fluorometer and the results plotted.

CHAPTER 6

SUGGESTIONS for FUTURE RESEARCH

This research study has provided us with another tool which can quickly evaluate spray droplets in the air. The following topics are suggested for immediate exploration.

1. Using this technique to study the behavior of the air-spray droplets produced by the sprayers. The air produced by the blowers of the sprayers has a lot of effects in determining the spray deposition in the tree canopy.

2. Using the same string supports but replacing the string with narrow nylon filament which can measure the droplets size, number of droplets and the quantitive amount of spray deposition. New tracer element has to be found so that it can be washed from the narrow nylon target and be automatically quantitated.

APPENDIX A:

COMPUTER PROGRAM

The whole set of 5 programs was named Canopy Penetration. The programs were written by WRK Incorporated, 5703 Saddlerock Road, Manhattan, Kansas. They were originally designed to analyze strings that were placed horizontally for aerial spraying. The same programs were used to analyze vertical strings placed at different locations within a tree canopy, and to present the results in graphic form on a single sheet of paper. This software also gave us the option of using English units or metric units. The main menu has 5 options:

1. To calibrate string door of the fluorometer
2. To customize plotter output
3. To read a penetration string
4. To plot the data
5. To move files to emulated drive

Option 1: Program to Calibrate String Door of the Fluorometer

This subprogram enabled us to adjust the span of the fluorometer to a referenced position and to calibrate the string drive mechanism to properly measure string length. It also assigned minimum and maximum readings on the monitor screen to correlate with fluorescence readings of 0 and 100, respectively.

Option 2: Customize Plotter Output

This subprogram enabled us to customize the graphic hard copy titles, to configure the system by specifying the computer output slot, to specify the use of metric units or English units and to select the number of digits following decimal points.

Option 3: Read a Penetration String

This subprogram required us to first remove the Program Disk and inserting a Data Disk which had been formatted with DOS 3.3. It would then allow the fluorometer to read the fluorescence values of the sprayed string, tracing the fluorescence values on the monitor screen as it reads, and copying these values to the hard disk.

Option 4: X-Y Plot the Data

This subprogram enabled us to get a hard copy of the analysis. This program also retrieved the data from the data files of the data disk and incorporated title block as customized in option 2 and plotting on the paper using the HP Plotter.

Option 5: Move Files to Emulated Drive

This program enabled us to transfer files from the build-in drive to the emulated drive or to read files from build-in to emulated drive.

Each option in the main menu had sub-menu. This sub-menu had further options and instructions which were easily followed.

APPENDIX B:

PROCEDURE FOR ANALYZING THE SPRAYED STRING

Before analyzing the sprayed string from the field with the setup equipment, the following procedures were executed for guaranteeing a successful analysis and getting reliable results.

1). Procedure to prepare the fluorometer for use.

1. Carefully open the door of the fluorometer by pressing the latch lever.
2. Set the sensitivity level of the fluorometer at 1X or 3X by pulling and moving the sensitivity knob sideways to the desired setting (if previously was not set).
3. Carefully and firmly close back the door of the fluorometer while latch lever securely place in position.
4. Turn the fluorometer on and press the Lamp Start Switch to engage the Ultra Violet (UV) Lamp. Blue glow in the Lamp Indicator confirms the UV lamp is on.
5. The fluorometer is now ready to read the string.

2). Procedure to thread the string scanner door.

This is done when there is no string in the analysis chamber of the scanner door or the string has accidently been removed from the scanner door.

1. Carefully open the scanner door of the fluorometer by pressing the latch lever.
2. Insert a short length of clean string through the small top hole on the outside of the scanner door, place it over the upper string guide, then drop and guide the string carefully down through the center of the string analysis chamber, then placing it over the lower string guide and thread it back out through the lower hole in the door.
3. The top end of the string is placed around the Powered Capstan pulley and then fasten to the large string take-up reel.
4. The lower end of the threaded string is joined together with the

loose end of the sprayed string with a simple double knot. The free ends of the joined strings from the knot is clipped to about 1/2 cm. for easy passing through the String Scanner Door.

5. The spool or the reel containing the sprayed string is placed on the bottom spindle shaft and locked in place.

6. The scanner door is then carefully but firmly closed and locked.

7. Press the String Advance Switch to bring the starting mark on the sprayed string to the entrance of the door.

8. The string and the fluorometer are now ready to start the reading process.

9. Get the computer ready with the option #3 : " Read Penetration String " of the main menu selected. Follow instructions as given on the screen of the computer till screen showed a statement " Computer is ready " , " Press RETURN to begin". When followed, the string drive starts to draw the string from the smaller supply spool to the larger take-up reel through the fluorometer, creating a trace from right to left on the monitor screen. The reading process may be halted by pressing the SPACE BAR.

10. Follow further instructions as given by the computer.

3). Procedure to run the analysis.

1. Turn on the fluorometer and the fluorometer UV lamp.
2. Press the String Advance Switch located on the String Scanner Door to operate drive motor and to advance the string to the right position.
3. Install the Canopy Penetration Program Disk in the Apple 11c disk drive.
4. Turn the Monitor on.
5. Turn the Computer on. The disk should whirr while the programs were being loaded into the computer memory.
6. Remove the program disk and insert a data disk in the drive once asked by the computer.
7. Select options as listed by the Main Menu and follow instructions as given on the screen.

4). Procedure to adjust the emission attenuator.

This procedure is followed when the use of 1X or 3X sensitivity level still causes either underscaling (not sensitive enough) or overscaling (too sensitive) of the trace generated on the monitor screen when the string is being analysed. The emission attenuator provides a means of fine tuning the fluorometer sensitivity through the use of an internal shutter that alters the amount of light passing to the photo-multiplier.

a). Procedure to adjust Emission Attenuator for problem of underscaling.

1. Remove the Emission Filter Assembly from the top part of the fluorometer.
2. Turn the knob of the shutter Emission Filter Assembly clockwise to slightly open the shutter.
3. Replace the Emission Filter Assembly.
4. Run a sprayed string through the fluorometer and observe the amplitude of the trace generated on the monitor screen . The amplitude of the trace on the screen should go up and be about 3/4 of the maximum screen rectangle height where the maximum deposition occurs.

b). Procedure to adjust the Emission Attenuator for problem of overscaling.

1. Remove the Emission Filter Assembly from the top part of the fluorometer.
2. Turn the knob of the shutter Emission Filter Assembly counterclockwise to slightly shut the shutter.
3. Replace the Emission Filter Assembly to the slot.
4. Run a sprayed string through the fluorometer and observe the amplitude of the trace generated on the screen . The amplitude of the trace on the screen should come down and be about 3/4 of the maximum screen rectangle height where the maximum deposition occurs.

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