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METHODS FOR SAMPLING AND ASSESSING DEPOSITS OF INSECTICIDAL SPRAYS
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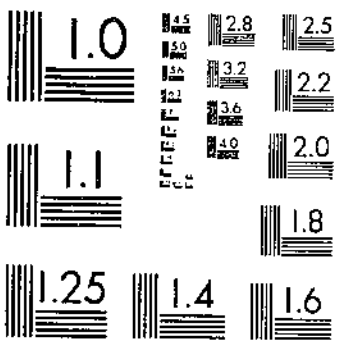

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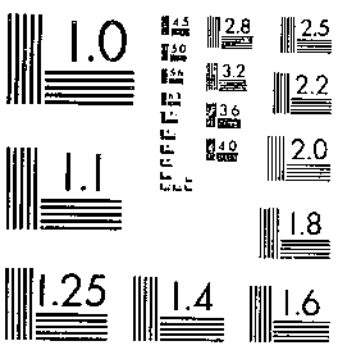

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METHODS FOR SAMPLING AND ASSESSING DEPOSITS OF INSECTICIDAL SPRAYS RELEASED OVER FORESTS

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USDA FOREST SERVICE, FOREST INSECT AND DISEASE MANAGEMENT, METHODS APPLICATION GROUP

USDA EXPANDED DOUGLAS-FIR TUSSOCK MOTH RESEARCH AND DEVELOPMENT PROGRAM

USDA EXPANDED GYPSY MOTH RESEARCH AND DEVELOPMENT PROGRAM

Preface

A Spray-deposit Assessment Workshop at Davis, California, March 16-18, 1976, sponsored by three groups--the USDA Forest Service, Forest Insect and Disease Management, Methods Application Group; USDA Expanded Douglas-fir Tussock Moth Research and Development Program; and the USDA Expanded Gypsy Moth Research and Development Program--provided an opportunity for biologists, physical scientists, and engineers to present current information on spray-deposit sampling and assessment.

The compilers wish to acknowledge the support and contributions of the three sponsoring organizations and their leaders, William M. Ciesla, Kenneth H. Wright, and Thomas McIntyre. We also thank Martha H. Brookes, Dennis D. Neill, and the contributors who are recognized throughout the book. Participants in the Spray Deposit Workshop are acknowledged as follows: Norman B. Akesson, John A. Armstrong, John W. Barry, Wayne E. Bousfield, John F. Chansler, William M. Ciesla, Robert E. Cowden, Andrew J. Culver, Jr., Jerald E. Dewey, Robert B. Ekblad, Arthur Geiser, Jack A. Henderson, Chester M. Himel, Frederick W. Honing, Kaye A. Johnson, Bohdan Maksymiuk, George P. Markin, Jack Mounts, Thomas McIntyre, John A. Neisess, Brian C. Partridge, Patrick J. Shea, William E. Slack, Richard A. Waite, Kenneth H. Wright, Wesley E. Yates, and Robert W. Young.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

The mention of products and companies by name does not constitute endorsement by the USDA, nor does it imply approval of a product to the exclusion of others that may also be suitable.

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Introduction

Purpose and User

The purpose of this book is to provide a state-of-the-art reference source on spray-deposit assessment procedures to field personnel engaged in field experiments, pilot projects, and operational control projects that aerially apply pesticides to forests. Procedures described within this guide are primarily for liquid insecticide applications.

Background

This book was prepared in response to a need for a reference source on current methods and procedures for sampling and assessing aerial sprays. Numerous methods and procedures have been used since the advent of aerial application of pesticides; seldom, however, have they been described or published. Many workers have developed their own procedures, with sophistication commensurate with their needs and understanding of the tools and methods available. Because of demands for more efficient and precise application and increasing need for spray accountability, these methods and procedures must be available to those who conduct projects that include application of pesticides. Use of standardized procedures provides spray deposit data that allow successes to be repeated and failures avoided.

As constraints on the application of pesticides become more restrictive, resource managers will be under increasing pressure to account for materials discharged into the atmosphere. They must, therefore, ensure that, for all aerial applications under their control, sufficient data are collected to meet this need.

Procedures and methods outlined range from general to specific. This is not a step-by-step instruction manual in the sense that the procedures and methods are inflexible. We provide basic information which represents the current state of the art to users in developing their plans and conducting spray deposit sampling. Sometimes, however, procedures must be followed closely if a specific answer is required.

The procedures and methods described are relatively simple to follow under field and laboratory conditions. Some new methods have been included that have not had the benefit of a long period of field use; for these we anticipate refinements as they are used.

Scope

Spray-deposit sampling and assessment are covered for field experiments, pilot control projects, and operation control projects. Because many of the described methods apply to all three types of projects, some repetition has been included for continuity.

Some workers may need training, in the form of workshops or field exercises, to use certain procedures adequately. The book is designed to serve as both a reference source and training guide.

This book consists of seven chapters and an appendix. Chapters 1, 2, and 3 are primarily introductory and descriptive, chapters 4, 5, and 6 deal with field and laboratory procedures, and chapter 7 discusses analysis of spray deposits and reporting of results. Additional details required by the reader may be obtained from contributors, whose addresses are provided in the appendix or through the literature citation section. Supplemental and reference materials are also included in the appendix.

Part I Equipment and Materials

CHAPTER 1 REQUIREMENTS FOR SPRAY-DEPOSIT DATA

William M. Ciesla and Patrick J. Shea

Introduction

In today's climate of environmental awareness and opposition to widespread use of pesticides, quality control in aerial application of pesticides is essential. As persistent, broad-spectrum chemicals are replaced with shorter lived, more selective "third generation" materials, less reliance can be placed on residual properties, and precise application to target areas will become increasingly important.

Spray-deposit assessment is the quality control mechanism designed to monitor application of pesticides. An effective assessment plan and system will provide a measure of spray accountability and keep the project director advised as to the amount of material delivered to the target. Adequate assessment will indicate whether the material is being applied evenly, sensitive areas are being effectively avoided, and the application equipment is working properly.

If deposit assessment techniques are used effectively, they will produce timely information for on-site correction of deficiencies, thus ensuring quality of application. In addition, the detailed documentation provided will assist in interpretation of biological data and evaluation of overall effectiveness. All too often a promising new material has been declared ineffective against a certain target pest - or unacceptable environmentally - during a spray project when, in fact, not the pesticide but the quality of the application was at fault.

The needs and objectives of obtaining spray-deposit data change depending on whether the project is a research field experiment, pilot control project, or an actual operational program.

Field Experiments

The primary objective of insecticide field experiments is to establish the minimum dosage required to achieve some specified degree of efficacy against a target pest. Efficacy can be expressed in such terms as percentage reduction, residual population density, or foliage protection. These are intensive studies, generally on small replicated plots, designed to test different application rates, formulations, or application modes of the same material. Deposit sampling, therefore, must be designed to fit the objectives of the experiment.

Examples of questions an adequate spray deposit assessment program will answer include: What was the coverage in the experimental area (droplets/cm^2)? What volume was deposited (gallons/acre)? What was the droplet size spectrum? Supplied with adequate data and using appropriate statistical techniques, the experimenter can begin to pinpoint treatment differences and what parameters were responsible for the differences.

Pilot Control Projects

A pilot control project evaluates, under operational conditions, a chemical or microbial insecticide shown by research to be highly promising. It is an intermediate step before full scale operational use of the new material. Normally,

in pilot projects only one dosage or treatment combination is evaluated, as contrasted to the field experiment where several treatment combinations are compared. They usually cover larger acreages than field experiments and are designed to simulate operational conditions.

As in field experiments, spray-deposit assessment in pilot control projects describes quality of the aerial application. Spray-deposit assessment attempts to answer this question: If the results were poor or erratic, was it the fault of the insecticide or the application technique? Placement of deposit cards around sample trees can determine how much spray reached sample trees or if some trees were missed. Spray-deposit data from pilot control projects add to the existing data base obtained from previous experiments on performance of the new pesticide.

In addition, spray-deposit assessment may be used on pilot control projects to monitor effects on nontarget organisms. Where drift to sensitive areas is to be avoided, proper placement of deposit samplers will indicate contamination beyond spray boundaries.

Operational Control Projects

The objective of the operationa control project is to achieve population reduction or resource protection to a given standard with a registered pesticide without serious contamination of nontarget organisms and areas. Often, large areas (sometimes millions of acres) are included in operational control programs. Magnitude alone may dictate the intensity with which deposit assessment evaluations are conducted.

Some spray deposit assessment is necessary to help answer questions such as: Were there significant gaps in the deposit within the spray block? Did sensitive areas, such as ponds, lakes, streams, crops, or beehives, receive sprays? In the event of subsequent complaints or legal action, analysis and retention of samplers provide documentation on how effectively a sensitive area was avoided, or quantifies how much material was actually deposited. These data will also be of value in planning strategy and improving quality of spray operations in future years.

Aerially applied pesticides will probably continue to be a necessary silvicultural tool in the management of our Nation's forests. The nature of the materials applied may change, and areas to which they are applied may be significantly reduced as greater portions of the Nation's forests become intensively managed, and cultural practices that increase stand resistance to pests become operational. Research and development to make available chemical and microbial insecticides will be a continuing process as registered materials are lost through continued scarcities of petrochemical or other raw materials required in pesticide manufacture, or additional adverse data on toxic effects are acquired and registrations are lost through EPA's Rebuttable Presumption Against Registration (RPAR) Program. With this continuing process, deposit assessment to ensure precise, consistent application to target areas will continue to be an integral part of pesticide research, development, and application.

CHAPTER 2 DESCRIPTION OF SAMPLERS FOR SPRAY-DEPOSIT ASSESSMENT

Deposit Cards and Collection Plates

George P. Markin

Deposit Cards

The most common method of spray-deposit assessment in forest insecticide spraying uses paper cards. Spray droplets settle on the cards and form visible spots. Compared with other methods, it is the cheapest in materials and manpower, and the cards can be examined for an immediate estimate of coverage in the field. The cards can also form a permanent record of spray-deposit.

White Kromekote® Cards

White Kromekote Cards are the most commonly used today (fig. 1).

Figure 1.—Kromekote card on metal stake. Note that the card is above the ground cover and parallel to the ground.

Printflex® cards were used extensively in the past but are no longer available. These Kromekote cards are made from a cast-coated, highly calendered stock of a finish such that droplets give a uniform spot with sharp, distinct edges. At present, three different sizes of cards are used in North America. The Canadians use a 4- by 4-inch card; researchers in the USDA Forest Service, USDA Animal and Plant Health Inspection Service. and most universities use a 4- by 5-inch card. The USDA Forest Service, Forest Insect and Disease Management (FIDM), uses a card that measures 4-5/16 by 6-5/8 inches (fig. 1).

Usually a dye must be added to the tank mix to make the spots visible on the cards. (See chapter 3 for a discussion of the types of dye.) Certain types of sprays, such as microbials, may contain ingredients that make the dye unnecessary.

A droplet landing on a spray card spreads out and forms a uniform-size spot directly related to the size of the droplet forming it. This relation is called spread factor. (See chapter 6 for methods of determining spread factors.) By measuring the diameter of a spot on the card and using the spread factor, the size of the droplet forming the spot can be determined.

A procedure that is basically the reverse of the technique described above is the use of oil-sensitive, dyed cards. These cards are treated with an oil-soluble red dye, and the insecticide droplet--in an oil

carrier such as diesel fuel--dissolves the dye, forming a visible spot. Cards of this type are usually compared against prepared standards to determine the amount of insecticide recovered. The disadvantages of dyed cards are: They are not sensitive to water base sprays; they have a tendency to fade in the field; they will not show spots formed by very small spray droplets; and they cannot usually be electronically scanned (chapter 6). The methods of manufacturing and using these cards and the procedure for preparing a set of standards against which they can be compared are described by Davis and Elliott (1953) and White (1959).

Malathion-Sensitive Cards

Malathion-sensitive cards are a modification of the oil-sensitive card. The procedure is basicially the same and consists of dipping Kromekote cards in a solution of Sudan Black BR dye. Droplets of malathion landing on the card produce visible spots. This type of card is reported to be sensitive for small droplets. The technique for making these cards and instructions for their use are given by Skoog and Cowan (1958).

Other Collectors

Kromekote cards are not the only type of collector that can be used. File cards, typing pape., white cardboard, and adding-machine tape have been tried with various degrees of success. The major disadvantages of these other types of collectors are that they do not give as clearly defined spots, nor have spread factors been determined for them.

With the recent advent of the use of several insecticides consisting of a finely ground powder suspended in a carrier, such as SEVIN® 4 Oil, Dylox®, and Dimilin®, black cards have been tried. The liquid carrier either evaporates or soaks into the card, leaving a visible spot of white. Almost any black surface may be used: construction paper, cardboard, photograph negatives, or black-dyed Kromekote cards. Because the white spot is a concentration of the insecticide and not a stain made by the oil, conventional spread factors do not apply. This does not allow determination of such values as gallons per acre deposited or volume-median diameter. Also, if these cards are collected as permanent records or are carried to a laboratory for analysis, the spots can flake from the card and the record is no longer accurate. If such recovery surfaces are used, a slotted box for storing the cards will protect them until they are read (fig. 2).

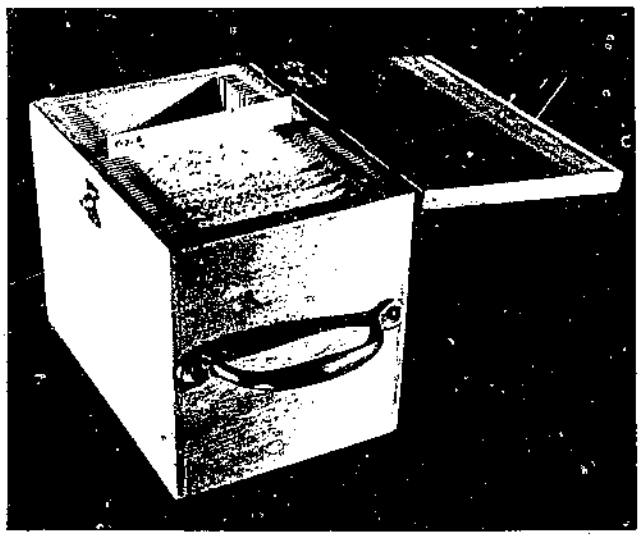


Figure 2.—Slotted box carrier for collecting and storing cards.

Collection Plates

One of the earliest methods of spray deposit assessment was to place glass plates in an area to be sprayed and examine them after spraying (Isler 1963). This method was modified in the early 1950's by addition of a known amount of red dye to the spray solution. The plates were then washed, and the solution was analyzed with a spectrophotometer. By determining the amount of dye, knowing the amount of dye originally added to the spray and the area of the collection plate, the volume of spray received, in gallons per acre, could be determined. By the mid-1950's, the glass plates had been replaced with aluminum ones. By the mid-1960's, a fluorescing dye was used, and the wash solutions were analyzed with a fluorometer (Yates and Akesson 1963).

Foliage and Insects

John W. Barry

The best sampler is the target or the substrate one is attempting to hit with the spray. Artificial samplers are subject to error in representing the actual dose received by natural target surfaces. For most forest applications, the target is either the insect or its host. Depending upon the insecticide's mode of action, insect mortality may result from droplets of insecticide impinging directly upon the insect, the insect's touching deposits on the surface of the host, the insect's consuming host material contaminated by the insecticide, or a combination of any of the three.

Foliage assessment methods generally have dealt with determining spray mass on the foliage by chemical analysis. Recently the Canadians, the British, and the USDA Forest Service (Barry et al. 1974, 1977) have investigated the relation of numbers of droplet stains on foliage and ground deposition samplers to insect mortality. Foliage assessment methods were found to be suitable for spray deposit assessment in the field.

Most dyed sprays and some undyed sprays leave visible stains on foliage and occasionally on insect larvae. SEVIN 4 Oil, for example, leaves easily detectable white stains on vegetation, which can be observed for at least a week after spraying. Except for the work on both insects and foliage reported by Himel 1969, Himel and Moore 1967, Barry et al. 1977, and Barry 1974, examination of droplets on the target has been limited to foliage. Foliage assessment may be useful on pilot or operational control projects. Examination of insects is time consuming and its practicality is limited to research.

Before this technique can be used, the following criteria must be met:

1. Dye concentrations must provide suitable contrast.

2. The droplet spread factor on target foliage must be determined.

3. The sensitivity and detection threshold of the magnifying instrument used must be known.

4. Droplets must dry in a reasonable time without excessive running.

Droplet spread factor on foliage is determined in the same manner as on cards. This is usually done by the procedures described in chapter 6.

Rhodamine B® and Automate Red B® dyes exhibit a bright stain on foliage, but some formulations--even though dyed--do not present an easily detectable stain. Each spray formulation should be checked for stain detectability in the laboratory before this technique is used.

Foliage and insect examination can yield both qualitative and quantitative data, depending upon the techniques used. Foliage and insects can be examined in the field with the aid of a magnifier to determine if spray reached the target and to assess the quality of coverage. This process can be less expensive than using cards for the same purpose.

Foliage can be examined in the laboratory under a dissecting microscope equipped with a reticle to measure size and number of droplet stains per deciduous leaf or leaflet, per coniferous needle, or per unit area of foliage surface. Stain size can be converted to aerodynamic droplet size by adjusting for the amount of spreading that occurs after impact on the leaf surface. Procedures are described by Barry and Ekblad (1978).

For quantitative measurements, both the upper and lower leaf surfaces must be examined. Under some conditions, small droplets may deposit on the lower leaf surface as reported by Barry et al. (1974 and 1977). On *Pinus*, *Abies*, and *Pseudotsuga*, the lower leaf surface is distinguished from the upper leaf surface by the preponderance of stomata on the lower surface and by cross-sectional shape.

Foliage washing is another method of deposit assessment that directly uses the foliage as a deposit collection surface for dyed formulations. In this procedure, the foliage is removed from the tree immediately after spraying, and dried. In the laboratory, the spray is washed from the foliage, and the amount of dyed formulation present is determined by spectrofiurometric analysis. This technique indicates the amount of spray deposit on the leaf surface. A description of the laboratory technique is given in chapter 6.

Examination of spray stains on larvae is basically a research tool suitable for experiments designed to investigate effects of spray droplets on insects. Droplets of water-base sprays dyed with Rhodamine B can be detected on some larvae; however, most oil-base sprays do not present a detectable stain on insects. Solid fluorescent particles as small as 5 µm (micrometers) in diameter can be detected and sized on larvae by using a microscope with an ultraviolet light source (Barry et al. 1974, 1977).

In summary, spray-deposit assessment on foliage provides another field method of assessing spray deposits and quality of application. Both use of a suitable dye in the spray formulation and foliage examination with a calibrated magnifier are required. Data including droplets per needle or unit of foliage, and droplet size can be obtained by this method.

Collection Efficiencies of Sampling Surfaces

Robert B. Ekblad

Artificial sampling devices are commonly used in pesticide spray work. A great deal of research and attention has been devoted to the surfaces and tracers that will clearly record the impacted droplets. Much less attention has been given to shape, size, position of the sampler, and wind speed. Unless these factors are considered and correctly chosen, the information gathered may be misleading or incorrectly interpreted.

Definition

A droplet that is free to fall in still air will accelerate until its aerodynamic drag is equal to gravitational force; thereafter, it will continue to fall at a uniform velocity. The terminal velocity depends on the density and size of the droplet. Some examples (based on calculations using Stokes' law) are:

Water droplet diameter (µm)	Terminal Velocity mph	km/h
40	0.10	0.16
100	0.56	0.90
150	1.05	1.69
250	2.15	3.46
400	4.03	6.49

As the flow of air approaches a sampling surface, it is deflected around the surface. Some of the droplets carried by the air will impact on the sampling surface; others will be deflected around it. The ratio of the number of droplets that impact on the sampling surface to the total number of droplets approaching the sampling surface is the collection efficiency or dynamic catch (Brun et al. 1955).

Principles

The collection efficiency is affected by (1) shape, size, and position of the sampling surface; (2) density, diameter, and velocity of the droplet; and (3) velocity and direction of the air flow. The physics and mathematics of these relations have been developed and, within certain limits, the collection efficiencies can be predicted.

Collection efficiency can be calculated for any shape after certain constants have been established. A cylinder is used for illustration. In figure 3, the flow pattern that air takes around a cylindrical rod is shown. The

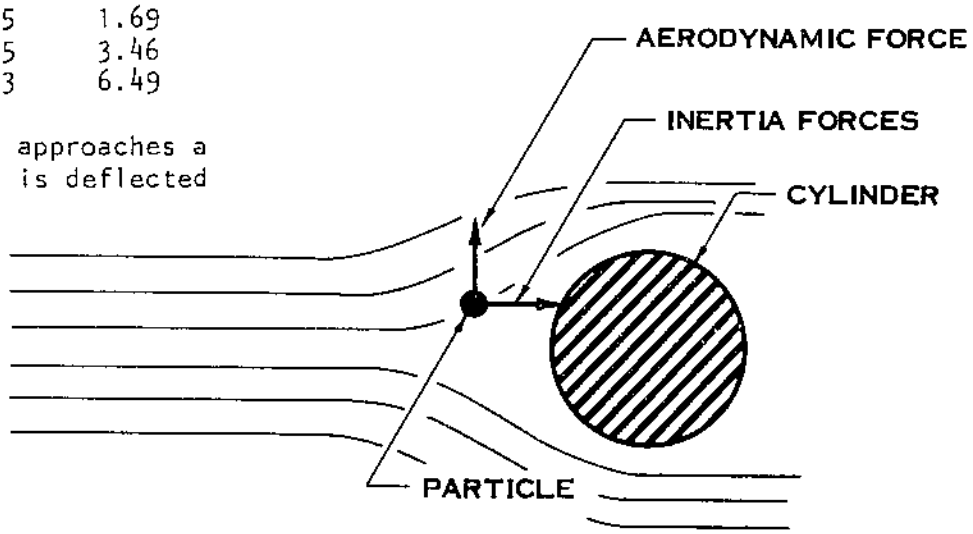


Figure 3.—Flow pattern around a cylinder illustrating relation between aerodynamic and inertial forces.

path of the droplet shown by the dotted line is governed by two forces. The inertial force is described by Newton's first law of motion: "A body will continue in a state of rest or uniform motion in a straight line unless acted upon by an external force." In a vacuum, the droplet will simply continue in a straight line until it impacts on the cylinder. The other force acting on the droplet is the aerodynamic drag (viscous force), which tends to carry the droplet along with the streamline flow of air around the sampler. The final path of the droplet is controlled by a balance of the inertial force and the viscous force. Some droplets will impact and others will miss the sampler.

Some general statements can be made about collection efficiency.

Collection efficiency can be increased by (1) an increase in wind velocity, (2) decreasing sampler diameter, (3) increasing droplet density, and (4) increasing droplet diameter (varies with square of diameter).

The collection efficiency for a given sampler differs for each size droplet.

If fine droplets are deposited uniformly across the forward surface, the collection efficiency is probably high.

Collection efficiency is more difficult to predict for complex shapes.

Larger droplets (300-400 μm) have a different trajectory than small droplets and will not fit the theory exactly.

Cylinders

Vertical cylinders have the advantage of uniform collection regardless of wind direction. To avoid end effects, the cylinders should be long compared with their diameters (at least 3 diameters in length). Cylinders can be made by wrapping cards around a cylindrical form. The deposit usually will not be uniform, so a complete horizontal segment should be assessed.

Examples of collection efficiencies for a 1/8-inch cylinder are shown in figure 4.

Spheres

Spheres have the advantage of being completely omnidirectional and can be used to indicate the angle of trajectory. Unfortunately, they cannot be laid flat for automatic scanning nor are any common spheres available with a smooth, fine-grain surface. For quick qualitative assessment, ping pong balls can be used.

Vertical Flat Cards

Vertical flat cards must face into the wind. When the cards are placed in the field, the wind direction must be accurately predicted or an array of cards facing in several directions must be used. Only the card with maximum deposit should be read. If a holder is used, some edge effects may cause a deviation from the predicted efficiencies. If a holder is not used the card may deform, which will also change the predicted efficiencies.

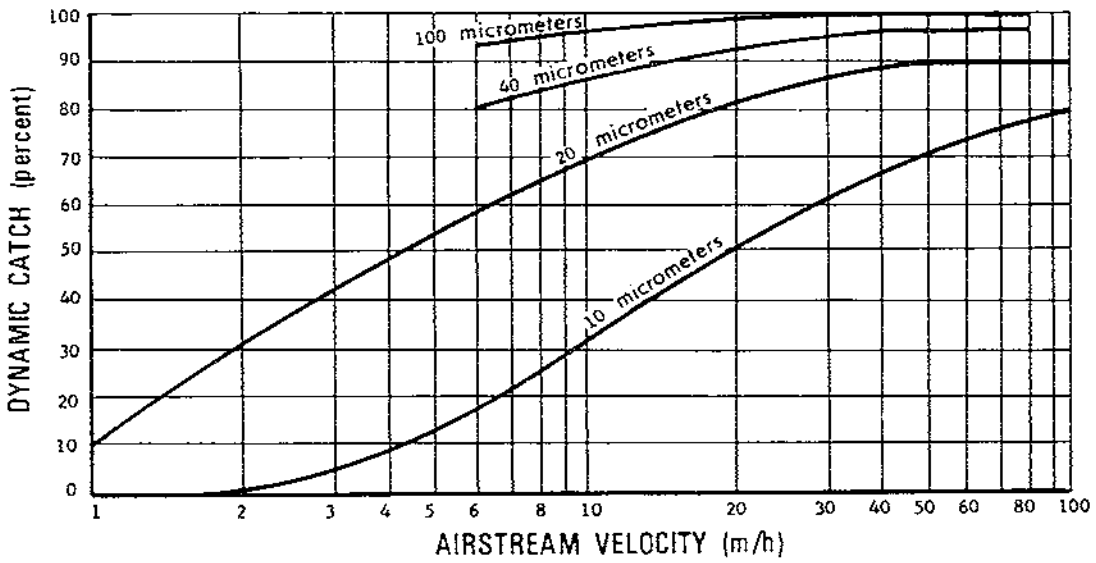


Figure 4.—Dynamic catch of droplets of 10, 20, 40, and 100 μm impinging on 1/8-in diameter cylinder at various airspeeds.

Biological Surfaces

The sampling surfaces already discussed are ordinarily used to estimate the spray reaching the target vicinity; hence, knowing if they are indeed collecting a representative sample of the spray cloud is important. Measurements on foliage or insects are usually made as a direct measure of the spray deposited on the target. For this reason, we are not usually interested in their collection efficiencies for estimating a spray cloud.

Biological samplers have a complex geometric shape, and predicting their collection efficiencies is difficult. They may also be moving by their own efforts or fluttering in the wind, which makes them more efficient collectors but harder to predict.

Horizontal Surfaces

Cards placed flat on the ground present a special case of the collection efficiency theory. No vertical wind movement can occur at the ground surface, hence no flow around the card. Collection efficiency is related primarily to the terminal velocity of the droplets and to horizontal windspeed. One study proposes that collection efficiency for horizontal flat plates can be computed by dividing terminal velocity of the droplet by the horizontal windspeed. This method was used for droplets of about 30 μm and is valid only up to 0.5 m/sec. At higher speeds, the deposition is a result of several mechanisms including turbulence. Fortunately, wind velocities near the ground are usually low.

At low windspeeds, horizontal

cards placed 18 inches above the ground, to avoid vegetative shielding, give an estimate similar to cards on the ground--from spray clouds with a volume median diameter (vmd) of about 200 μm. At high windspeeds, the cards should be placed on the ground.

Discussion

What has been said about sampling surfaces and air movements is limited to the immediate environment of the sampler, and it should not be confused with meteorological influences from the aircraft to the target.

Also, this discussion is limited to passive samplers and does not apply directly to aspirated or mechanical samplers.

In summary:

1. Horizontal surfaces near the ground are satisfactory for sampling spray clouds of medium or large droplets in low winds.

2. Vertical cylindrical samplers are recommended for sampling spray clouds of medium or fine droplets, and the sampler should be at least 3 ft above the ground.

3. Biological samplers give the most accurate target deposition information.

4. Sampling surfaces are selected based on requirements of the user as well as various limitations of handling and cost. However, when a sampler is selected, the user should understand its limitations based on size, shape, position, droplet size, and meteorological conditions.

Air-Sampling Devices

Norman Akesson and R. E. Cowden

Mechanical air-sampling devices are most commonly used to sample airborne spray particles less than 100 µm. These particles can be airborne for a significant time and travel significant distances, dependent upon wind velocity, temperature, and the intensity of air turbulence.

Thus air sampling may be essential for measuring airborne drift or for complete spray accounting. Air sampling is used to measure the material being moved through and with the air mass in which spray was released.

Any of the air-sampling and droplet-measuring devices (light scatter, filters, and various impactors) may be used for this type of monitoring. Light scatter is most effective on droplets below 10 µm, and impactors function most effectively for sampling droplets generally smaller than 100 µm in diameter. Filters will collect the broadest droplet size range from the largest airborne particles to 0.01 µm. For vapor phase (>0.01 µm), solvent bubblers and absorbent dry chemicals, such as activated charcoal, aluminum oxide, and certain resins, are used. The following describes some frequently used services and techniques for air sampling.

Rotating Collectors

Rotating rods, wires, slides, and other forms have been used to evaluate airborne material concentration, but these devices have severe limitations in that most are capable of collecting only a fraction of the particles in a practical range of 20 to 100 µm in diameter. Thus, statistical means, which can easily introduce large sample errors, are used to arrive at the total air burden.

Collection Filters

Filters are used to remove droplets from air collected by the sampling device. Glass fiber, gelatin, and cellulose filters can be obtained in a variety of pore sizes; they may also be soluble or nonsoluble in the specific chemicals used to strip or dissolve the filters for analysis of tracer chemicals. Filter efficiency is excellent, up to 95 percent for droplets down to 0.01 µm in diameter. Air volumes up to 50 ft^3/min may be sampled; this provides a high sample rate for evidence of low concentrations of materials. Some filters can be examined for droplet size as well as weighed to determine mass collected. Other multistaged filters separate different particle sizes on several successive stages of filter papers (from 0.5 to 100 µm), much as the cascade impactors do.

Commonly used filters are the Millipore® and Nuclepore®-formed filters of specific pore size (0.1 to 100 µm in diameter), available in several dimensional sizes.

Spray Assessment Sampling Equipment

A variety of equipment is available for sampling of air.

1. The Hi-Volume Staplex Air Sampler® (fig. 5) may be used with Gelman type A-E fiberglass filters. This sampler draws approximately 24 ft^3/min with about 98 percent

collection efficiency for particles as small as 0.05 µm. The sampling area is 9.62 in^2 or 62.1 cm^2.

2. The Anderson Cascade Hi-Volume Sampler® is a multistage sampler that uses four perforated type A glass-fiber filter disks with an 8x10 type A glass-fiber backup filter. This unit samples at a rate of approximately 20 ft^3/min and separates droplets into size ranges of 7 µm and above, 7 to 3.3, 3.3 to 2.0, 2.0 to 1.1, and 1.1 to 0.01 µm at the smallest end. The sampling area is 2.81 in^2 or 18.1 cm^2.

3. The Weather Measure Hi-Volume Cascade Air Sampler uses type A fiberglass filters, has a sampling rate of 20 ft^3/min, and has six stages: 8.2 and up, 8.2 to 3.5, 3.5 to 2.1, 2.1 to 1.0, 1.0 to 0.5, and 0.5 to 0.01 µm. The sampling area is 2.81 in^2 or 18.1 cm^2.

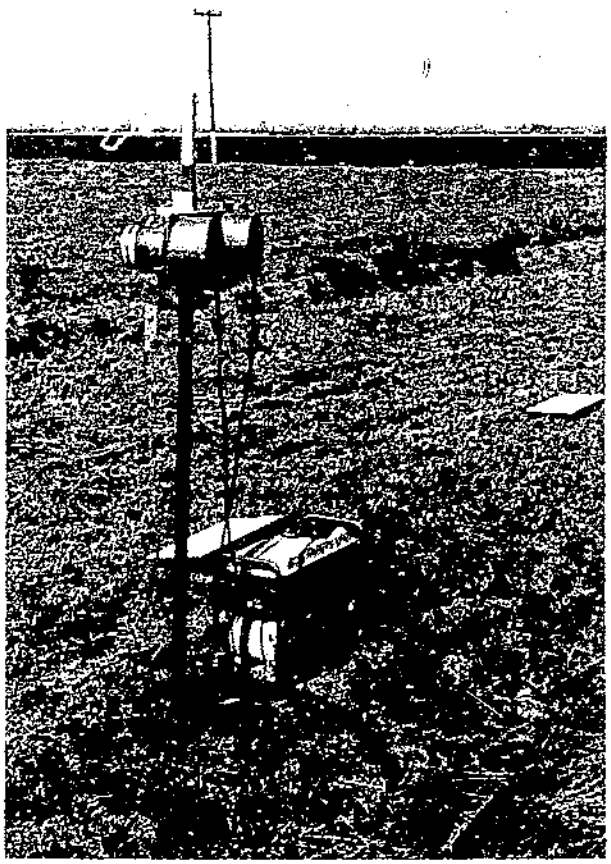


Figure 5.—Sampling equipment for air concentration and deposition of pesticide sprays. Station consists of Staplex Air Sampler with Millipore filters, and high volume pump, Mylar film for deposition, and cascade impaction sampler.

Impactors

Cascade-type impactors separate the droplets or particles collected in four to eight stages using decreasing orifice sizes. Collection is based on air velocity through the orifice, which is in turn a function of orifice size and total air volume drawn through the instrument. Large droplets (50-100 µm) are collected by the first stage with low air velocities. Small droplets (2-5 µm) are collected by the last stage.

Droplets from each stage may be counted and sized by microscope or, under constant conditions of airflow, each stage may be analyzed for dye or tracer collected. The concentration of dye indicates the number of droplets collected at each stage for its particular size range.

Sampling the air in the spray area will give a droplet size frequency analysis of the air and will indicate approximate amounts of airborne material, by weight or volume, in the spray area.

Using Air Samples

Air sampling should always be accompanied by deposit collectors, such as cards or plates, to evaluate the fallout of material (fig. 5). In this way, the mass balance may be approximated from any spray application by equating the amount of material applied to the amounts deposited in the spray swath and amounts lost downwind. Data collected on a vertical tower sampling array, up to 60 ft in height, suggests air samplers can be used to identify the air burden and potential drift hazard from specific applications. Such a tower sampler placed in a valley downslope from an application can substitute for the positioning of samples out to a mile or more, and thus simplify the air burden monitoring. The use of single station monitors strategically placed in downslope areas or valleys can aid in establishing what, if any, hazard is being presented to nontarget crops and plants or to wildlife by specific treatment of pesticides to forested lands.

Fluorescent dyes, such as Rhodamine B which comes in both water- and oil-soluble form, are used extensively. They are sensitive to 1 part per billion, stable in solution, and show up well for droplet size analysis. Some disadvantages encountered with dyes are degradation from solar radiation, and background contamination from dust or plant tissues that may mask the fluorescence of the dye.

Salt Tracers

Equally sensitive and less subject to decay are the salt tracers. With the improvements made in atomic absorption spectrophotometry, the use of these tracers has become highly effective. Detection limits for pesticides are as good as those attained by fluorometry or by gas-liquid chromatography. Salt tracers have the added advantage of not being photosensitive and, if carefully selected, have little problem with background contamination. Several different salts, such as manganese sulfate and strontium chloride, can be present in the same solution when it is analyzed, but identified separately. This allows several types of applications, each using a different salt, on the same collection substrate. Dye may be added to the solution if a visual analysis is desired. The use of metallic salts as tracers is further explained in chapter 6.

CHAPTER 3 DYES FOR WATER- AND OIL-BASE INSECTICIDES

John Neisess

Over the last 25 years, dyes or other tracers have been added to spray mixtures for measuring spray deposit in research or aerial spraying for forest insect control. At first, the dyes were principally used to study deposit patterns of different types of aircraft or spray equipment (Yuill and Secrest 1966). With the increased emphasis on deposit assessment during the last decade, fluorescent and nonfluorescent dyes and fluorescent particles (FP) have been used to varying degrees in most research and pilot projects. Dyes are usually considered too expensive for operational use, but occasionally are used for assessments in sensitive areas or for spot-checking.

When a dye or tracer is chosen for a project, the degree of spray-deposit assessment desired should be considered first. Specifically, why pay the high cost for a fluorescent dye or FP if the deposit assessment only includes counting spray droplets collected on cards? In programs where deposit assessment consists only of visual estimates or automated counting of spray droplets on cards, the least expensive, nonfluorescent dye should be used.

Nonfluorescent dyes color the spray mixture and are used primarily for qualitative assessment of the spray deposit. This assessment can be visual or conducted with an automatic spot counter if the spray was collected on a suitable surface, such as a Kromekote card. Fluorescent particles have the advantage of fluorescing when excited by UV light, thus becoming readily visible. This permits examination of insect larvae, foliage, or other sampling surfaces (Himel 1969, Himel and Moore 1967, Barry et al. 1974, and Barry et al. 1977). Because of the high density of fluorescent particles, they settle in the spray tank, thus making them difficult to use. Fluorescent dyes cause the spray droplets to fluoresce, allowing for better qualitative and quantitative analysis of the spray deposit. Fluorescent dyes have been successfully used in agriculture (Yates and Akesson 1963) and in forestry in both field experiments and pilot projects (e.g., Stelzer et al. 1975, Maksymiuk et al. 1975).

Table 1 lists some of the dyes that have been tested at the Pacific Northwest Forest and Range Experiment Station. The table includes manufacturer, class (oil- or water-soluble, fluorescent or nonfluorescent), some light-fastness data, and color index (C.I.) name (when available). The C.I. name is a simple reference for any dye and is much like the accepted common name of an insecticide.

Light-fastness is particularly important if the amount of dye is to be quantified either by fluorometric or absorption spectroscopy methods. Two fluorescent dyes that are relatively light-fast are Brilliant Sulpho Flavine® (BSF) and the Rhodamine B dyes; BSF, a light yellow dye that fluoresces yellow-green, is superior in lightfastness. The light color is a disadvantage, however, because the spray droplets can not be seen easily, except under UV light. Bird droppings, pitch, and dust fluoresce at the same wavelengths as BSF, causing

Table 1--*Water- and oil-soluble dyes*

Dye	Class	Manufacturer	Color index name	Light fastness
Automate® Red B	oil-NF[1/]	PAT[2/]	--	--
Blancophor® SU concentrate	water-F	GAF[3/]	Flu. Bri.[4/] 25	--
Brilliant Sulpho Flavine	water-F	GAF	Acid Yellow 7	1
Calcofluor® White RWP	water-F	ACY[5/]	Flu. Bri. 61	3
Calcofluor® White ST	water-F	ACY	Flu. Bri. 28	--
Calcozine Rhodamine BX Liquid	water-F	ACY	Basic Violet 10	--
DuPont® Rhodamine B Extra	water-F	DUP[6/]	Basic Violet 10	1
DuPont® Rhodamine 5 GDN	water-F	DUP	Basic Red 1	3
DuPont® Thioflavine TCN	water-F	DUP	Basic Yellow 1	--
DuPont® Uranine B	water-F	DUP	Acid Yellow 73	3
Fluoranthene	oil-F	ALC[7/]	--	3
Fluorescein	water-F	ACY	Acid Yellow 73	3
Leucophor C-6208	water-F	S[8/]	--	--
Nigrosine OPG	water-NF	GAF	--	1
Oil Color 131	oil-F	PAT	--	3
Oil Red O	oil-NF	NAC[9/]	Solvent Red 27	1
Pontamine® White BT	water-F	DUP	Flu. Bri. 28	--
Pontamine® White SP	water-F	DUP	Flu. Bri. 102	--
Rhodamine B Extra S	water-F	GAF	Basic Violet 10	1
Rhodamine B	water-F	NAC	Basic Violet 10	1
Rhodamine B	water-F	S	Basic Violet 10	1
Rhodamine B Ex	water-F	DUP	Basic Violet 10	1
Rhodamine B Extra Base	oil-F	GAF	Solvent Red 49	1
Rhodamine B Base	oil-F	DUP	Solvent Red 49	1
Rhodamine B Base	oil-F	ACY	Solvent Red 49	1
Sevron® Brilliant Red 3B	water-F	DUP	Basic Red 15	--
Sevron® Brilliant Red 4G	water-F	DUP	Basic Red 14	--
Sevron® Orange G	water-F	DUP	Basic Orange 21	--
Sevron® Yellow L	water-F	DUP	Basic Yellow 13	--
Sudan Black	oil-NF	GAF	Solvent Black 12	1
Sulpho Rhodamine B Extra	water-F	GAF	--	1

1/ F = fluorescent dye, NF = nonfluorescent dye.
2/ Morton Chemical Co.
3/ General Analine & Film.
4/ Fluorescent Brightening Agent.
5/ American Cyanamid.
6/ DuPont.
7/ Aldrich Chemical Co.
8/ Sandoz.
9/ Allied Chemical Co.

confusion in counting, or interfering with quantitative assessments. Rhodamine B is a red dye that fluoresces red to red-orange, depending on the solvent. The color of this dye makes the spray deposits readily visible on most collection surfaces. This same bright color becomes a problem if any of the spray gets on the application aircraft, cars, or houses. Care should be taken when recovering this dye from foliage samples because chlorophyll fluoresces at the same wavelength. If the solvent removes chlorophyll, inaccurate spray residue values will be recorded.

The oil-soluble Rhodamine B dyes are soluble in only a limited number of solvents and not in diesel, mineral, or crop oils, which are common diluents used in forest spraying. The dye must first be dissolved in a miscible carrier to make it soluble. Dissolving the Rhodamine B dye at a rate of 151.4 g/gal in oleic acid (a fatty acid) makes the dye soluble in any oil solvent. One qt of dye solution is added to every 9.75 gal of total spray. Bioassays of the oleic acid-dye solutions mixed with either Dylox or SEVIN showed no inhibition of insecticidal activity.

The most commonly used nonfluorescent dyes were Oil Red O and Nigrosine, for oil and water sprays, respectively. Automate Red is now being used to a large extent with oil formulations. Because this dye comes as a liquid, it is easy to mix with the spray mixture.

Two types of fluorescent particles have been used in field tests; (1) Presized particles such as zinc cadmium sulfide, which fluoresces yellow, green, or red (Himel 1969, Himel and Moore 1967); (2) Oil- or water-soluble dye dissolved in a suitable diluent and coated on absorbent, presized clay or synthetic particles (Barry et al. 1974). Both types of particles have been used successfully in the field. Particles have been counted on insect larvae and foliage with relative ease, using a UV light source and the stereo microscope.

Liquid dyes can precipitate in storage; therefore, dyes should be purchased in the powdered form if they need to be stored for a year or longer. Rhodamine B or BSF is added to the spray mixture at the rate of 3.785 g dye/gal of spray (0.1 percent weight/vol). This concentration is sufficiently high for fluorometric analysis and, when using Rhodamine B, provides enough color to the spray droplets that they can be counted with an image analyzer such as the Quantimet® (see chapter 6). Nonfluorescent dyes, such as Nigrosine OPG, Oil Red O, or Sudan Black are added at the rate of 7.57 g dye/gal of spray (0.2 percent weight/vol). The increased concentration is needed to give sufficient contrast to the spray droplets on the cards so that they can be counted by the Quantimet. Automate Red is added at the rate of 3 to 4 qts dye/50 gal of spray (1.5 to 2.0 percent weight/vol).

When powdered dyes are prepared for a spray project, the dye is weighed into 10- to 100-gal equivalents, depending on the size of the project. These lots can be packaged in either plastic bags (double-bagged) or ice cream cartons.

Generally the dye should be the first additive to the carrier and added while the mix is agitated to ensure a complete solution. Some tank mixes may require special mixing; instructions should be provided by the developers of the mixes. Liquid dyes can be added to the carrier or the final spray mixture; if they are used, the dye volume (2.0-2.5 percent) should be subtracted from the volume of carrier.

Table 2 lists the dyes and the rates that have been used with the

Table 2--*Recommended dyes and concentrations for various insecticides*

Insecticide	Project size[1/]	Dye	Concentration per gallon
Biotrol®	FE P, O	Rhodamine B, BSF Nigrosine	3.785 g 7.57 g
Dimilin®	FE, P, O P, O	Rhodamine B Nigrosine	3.785 g 7.57 g
Dipel®	FE, P O	Rhodamine B, BSF Nigrosine	3.785 g 7.57 g
Dylox® 1.5	FE P, O	Rhodamine B-Oleic Acid Automate Red	3.785 g 4 qts/50 gal
Dylox 2	FE P, O	Rhodamine B-Oleic Acid Automate Red	3.785 g 4 qts/50 gal
Dxlox 4	FE P, O	Rhodamine B Automate Red	3.785 g 4 qts/50 gal
Orthene®	FE, P O	Rhodamine B Nigrosine	3.785 g 7.57 g
SEVIN® 4 Oil	FE P, O	Rhodamine B-Oleic Acid Automate Red	3.785 g 4 qts/50 gal
Thuricide®	FE, P O	Rhodamine B, BSF Nigrosine	3.785 g 7.57 g
Douglas-fir tussock moth virus	FE, P O[2/]	Rhodamine B, BSF None	3.785 b
Zectran® FS15	FF P, O	Rhodamine B	3.785 g

[1/] Project sizes: FE = field experiment; P = pilot project; O = operational.

[2/] Assumes Shade[R] is in the tank mix.

various chemical or microbial insecticides. For the most part, these dyes have been bioassayed with the specific insecticide, against Douglas-fir tussock moth. No inhibitions have been recorded for the recommended rates. Feeding repellencies were noted for high concentrations of all the dyes. Table 2 is based on the assumption that field experiments require fluorometric analysis and that operational projects require a less complete deposit-assessment analysis.

With tie advent of automatic droplet counting, new dyes must be investigated for compatibility with the counting equipment. For example, there are Automate dyes of different colors. A blue, black, or purple dye may provide enough contrast for automatic counting, but at a lower concentration than is currently needed for the red dye. Of course, any new dye should be compatible with the chemical and toxicological properties of the active ingredient and must comply with any Environmental Protection Agency regulations.

Part II Procedures

CHAPTER 4 FIELD PROCEDURES FOR DEPOSIT SAMPLING

Sampling Design in Field Experiments

John Neisess

The scope of the experiment dictates the types of spray-deposit variables that need to be measured, and these in turn dictate the amount of sampling. In field experiments, the amount of spray-deposit sampling will be of the highest order to permit full understanding of all parameters. These data should determine the relation between the amount of spray deposited and insect mortality. The field experiment is the developmental phase for selecting suitable deposit-assessment techniques. Therefore, the deposit-sampling design used in field experiments should contain procedures that in part can be used for pilot projects. The sampling design in pilot projects should further test the specifications and procedures developed in the field experiment phase. Deposit sampling designed for operational projects should maintain the specifications developed during the field experiment and pilot control phases.

When a field experiment is being designed, sufficient spray-deposit sampling is needed to provide information as to why a particular treatment was or was not effective. For example, a treatment that caused higher insect mortality than another treatment may have had better deposit coverage. Deposit coverage should be categorized by droplet size (vmd) or droplet size spectra, droplet coverage (droplets/cm^2), volume of spray recovered at ground level, or volume or mass of spray recovered in the tree crown--and deposit sampling should be designed to measure these parameters.

Deposits collected on aluminum plates provide data in terms of volume per unit area such as gallons per acre. The cards yield coverage (droplets/cm^2), droplet size, and give an indication of volume and mass recovery (gallons and ounces per acre). The foliage provides a sampling surface that is an actual part of the insect's environment; the advantage is that the surface the insect consumes or touches is sampled. Spray droplets on the foliage can be counted to provide density values. The spray residues can be removed by washing with suitable solvents to provide volume or mass of active ingredient.

For optimum correlation between deposit and insect mortality, the ultimate sampling design should provide for sampling deposit on the surface touched by the spray, such as the foliage. Because sampling foliage may not be practical in pilot or operational control projects, correlations between deposit sampled on foliage and deposit sampled on some other surface should be developed in field experiments. With the advent of automatic droplet counters such as the Quantimet, Kromekote cards are the most practical alternative sampling surface. Cards can be subjectively analyzed in the field to determine whether an area has been sprayed, and then the cards can be sent to a laboratory for complete analysis.

The sampling design most commonly used both in coniferous and in deciduous forests requires sampling the spray with aluminum plates and cards on the ground, then collecting foliage at midcrown. A ground sampling station consists of two aluminum plates and one card. The plates and cards are held about 2.5 ft above the ground with wire and

plastic cardholders (fig. 1). Immediately after the area has been treated, the plates are collected, placed sprayed-face-to-sprayed-face, and stored in slotted boxes until they are analyzed. The cards are collected and kept from touching by storing--either with the plastic holders or without them--in special slotted boxes (fig. 2). Foliage samples consist of 10-in branch tips cut from the midcrown at the four cardinal directions of each sample tree. These four samples can be bagged (small paper bags) separately or together, depending on whether the variation in deposit within the tree crown needs to be measured.

Variation in this design depends on the placement of sample stations. For population sampling, they are placed in openings adjacent to the sample trees. These openings should be large enough that the sampling station is at least one tree height away from the nearest tree. Maksymiuk (1963b) showed that a 70 to 80 percent loss in deposit recovery results from placing plates and cards within a distance of one tree height. A variation of this design or an addition to it requires a line of ground-level samplers within the plot boundaries. These lines are perpendicular to the proposed line of flight of the aircraft. Large openings, such as roads, are used if available. These open-area samplings provide the best estimate of the deposit that reaches the target area (plot at ground level).

Another design, which includes only ground-level sampling and no foliage sampling, places cards and plates in the open, adjacent to each sample tree. One or more sampling stations are placed directly under the midcrown portion of each sample tree. The "open" and "under" sampling stations are paired so the difference in deposit should give an estimate of the deposit in the tree crown. This design is dependent on the availability of suitable openings adjacent to the sample tree. The trees will screen part of the spray deposits if the open sampling stations are too close to surrounding trees. This results in low estimates of deposit for open areas. If the open deposit value is low, the difference, or deposit assumed to be in the trees, will also be low.

Another spray-deposit sampling design that has been used requires placing cards under each sample tree at the four cardinal directions, at the drip line of the tree. Midcrown foliage samples are also collected for each tree at the four cardinal directions. This design allows for sampling the directional differences in deposit both on the ground and midcrown of each tree. Differential screening of the various sample trees may cause poor correlations between deposit data on the ground and at the midcrown.

Sampling designs for pilot control and operational projects can easily be adapted from any of the above experimental designs. Ground-level sampling has been used extensively, and if the proper correlations have been developed (fig. 6), foliage sampling need not be included in pilot control or operational projects. On the other hand, results of the experimental design may indicate

that foliage sampling provides the easiest and most direct method of deposit sampling. If so, this experimental design should be carried through to pilot control projects.

Forcing a standard sampling design onto all experiments would be unwise. The designs will vary for different insects, insecticides, host types, and research groups. Some standardization, however, should exist so that the results of different experiments can be com-

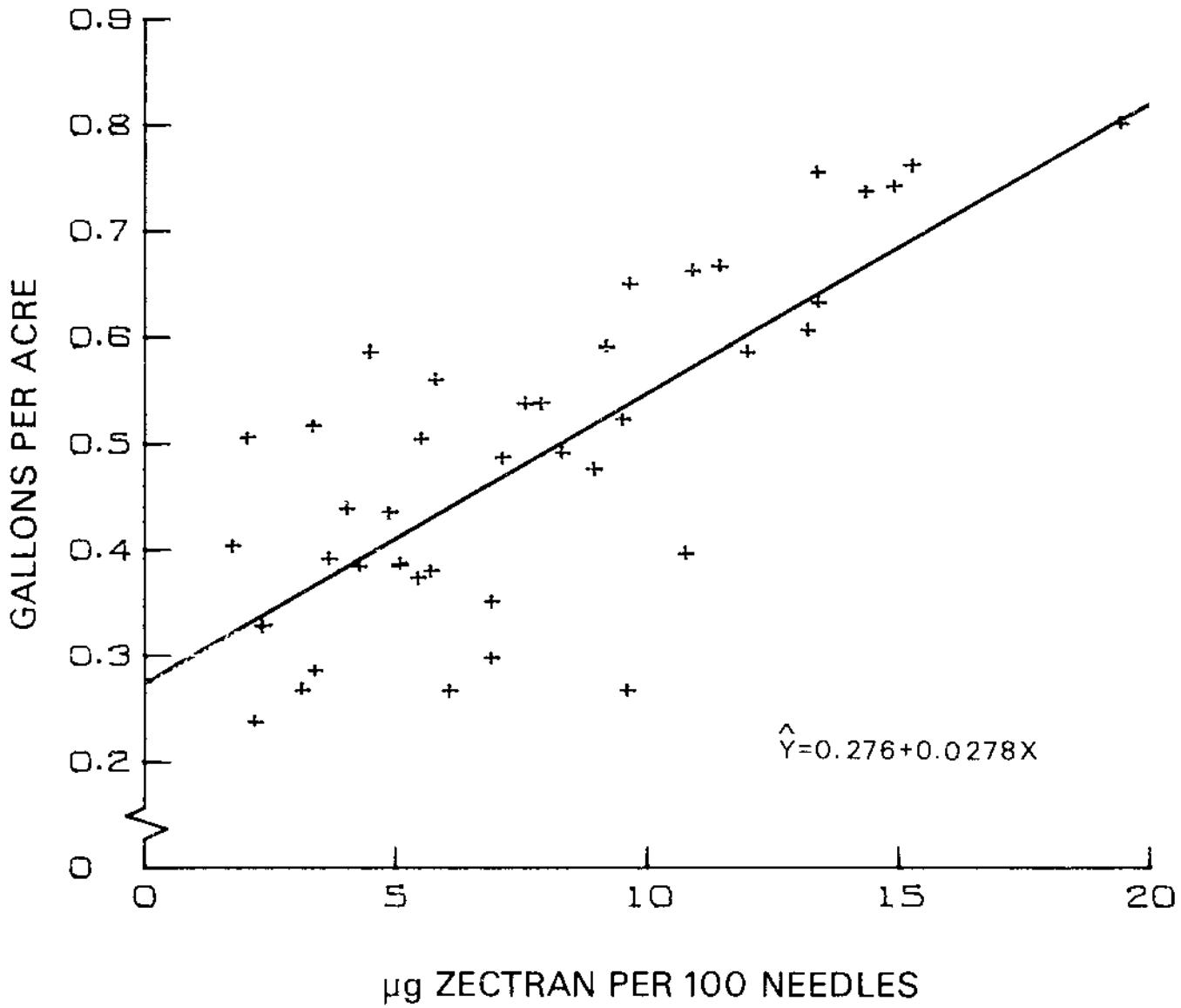


Figure 6.—The relation between deposit (gallons per acre) removed from aluminum plates that were in the open and deposit recovered from foliage (µg Zectran/100 needles) of adjacent trees.

pared. The Kromekote card method is the logical choice for a standard sampling surface because it is easy to use and provides the greatest range of data. It should, therefore, be an integral part of every deposit sampling design. Although these cards do not approximate the ultimate sampling surface, such as foliage or the actual pest, deposit data collected on cards can be correlated with that from other sampling surfaces (fig. 7). The goal of a good sampling design should be to provide data that can predict a certain level of mortality resulting from a certain number of droplets of a certain size.

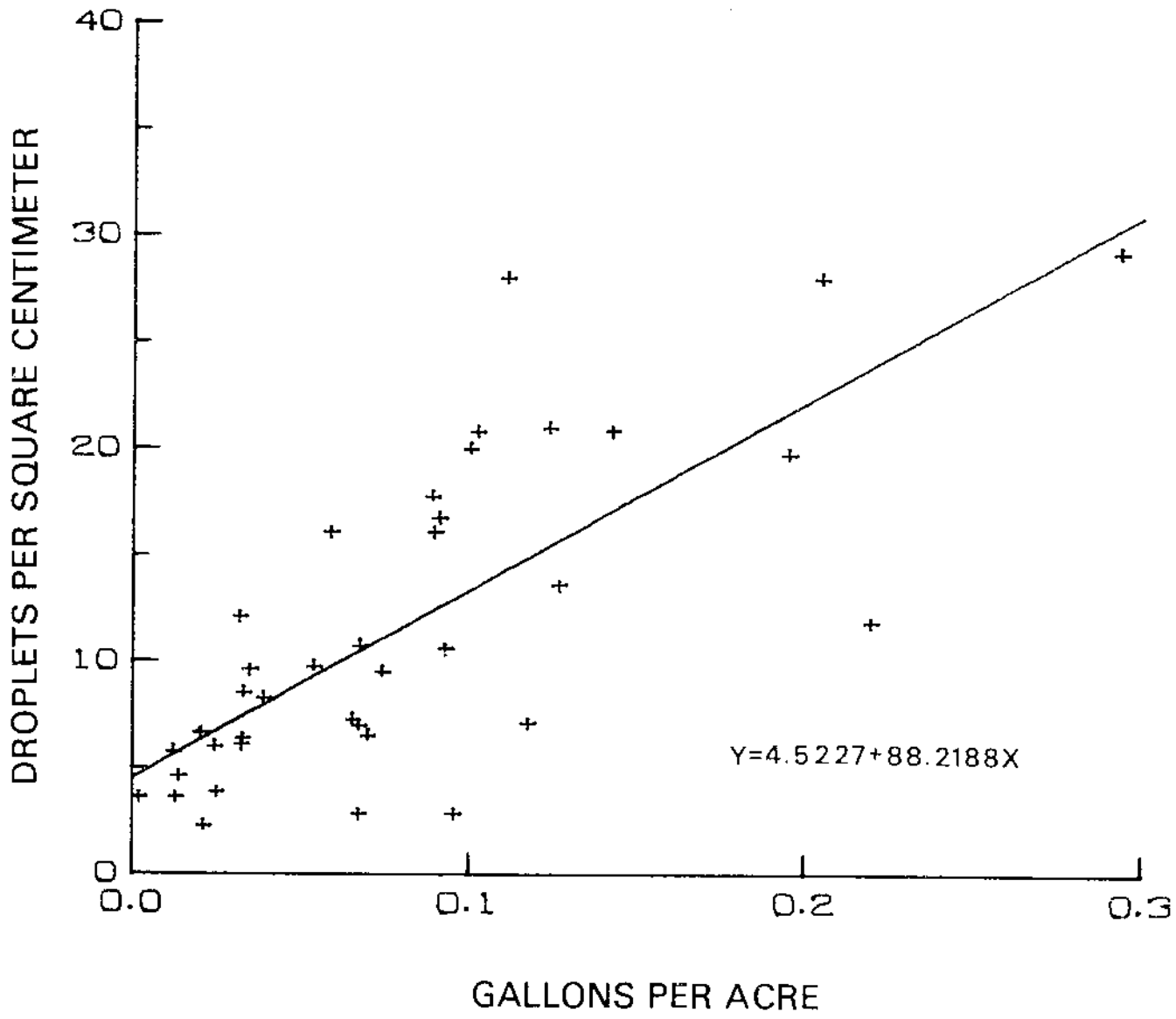


Figure 7.—The association between droplet density (drops/cm^2) and deposit (gallons per acre) removed from aluminum plates that were in open areas.

Sampling Design in Pilot Control and Operational Projects

John W. Barry

Various designs have been used to provide spray-deposit data on pilot and operational control projects. The data required dictate the design, which includes placement, positioning, number, and types of spray-deposit cards.

For some projects, such as operational control projects, we are interested only in determining if the spray reached the target area and if the application was even throughout the spray block. Sampling design for these types of data may be one of random spacing throughout the block or sample lines perpendicular to the spray swath lines. The number of cards depends on the size of the spray block; in the past, 50 to 300 cards have been used on spray blocks ranging from 40 to 6,000 acres. Ideally, a grid sampling pattern should be established within the spray block, but this is seldom practical. Therefore, random placement of samplers provides the simplest and fastest means of monitoring the quality of spray application. The project director must define, during the project planning stage, the spray-deposit data requirements.

Assessments are made for these purposes:

To determine overall quality of spray application.

To monitor spray deposition on nontargets within the spray block.

To monitor spray deposition outside the spray block.

To obtain physical characteristics of the spray such as droplet size, droplet density, and spray mass.

To obtain data correlating deposit of spray to insect mortality and tree defoliation or other damage.

To obtain data to support registration of new insecticide formulations or continued use of existing formulations.

The specific data required to serve these purposes are:

Qualitative requirements

1. Coverage of spray area: One or two sampling lines should be placed perpendicular to the planned swath lines. Samplers should not be placed directly under trees. Spray recovery on cards will indicate overall coverage.

2. Drift to nontarget or sensitive areas: Placement and number of samplers depends on the nature of the sensitive area. If drift is expected to be light, mechanical air samplers (chapter 2) may be required.

3. Coverage of sample trees: A single sampler placed near a sample tree is not a good indicator of the deposit reaching that tree because of shielding from nearby trees. Two or more samplers should be used per sample tree to establish coverage. They should be placed in an opening near the sample tree.

Quantitative requirements

1. Recovery or accountability as a percentage of total material disseminated: Total counts or recoveries of the spray deposit on

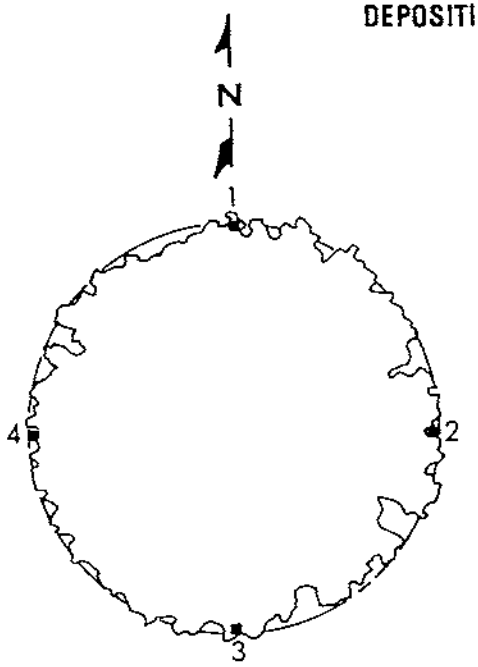
any particular group of cards (forest cards, open-area cards, etc.) can be compared with the application rate. For example, average recovery on cards in an open position is 0.4 gal/acre. Application rate was 1.0 gal/acre. Therefore, the recovery or accountability was $\frac{0.4 \text{ gal/acre}}{1.0 \text{ gal/acre}}$ or 40 percent. The validity of the procedure is contingent upon a well-calibrated aircraft, a steady application rate, and a sufficient number of samplers within the sample area.

2. Recovery beneath sample trees as it relates to insect mortality: Obtaining data on the relation of spray deposit to insect mortality is recommended and often essential. These data provide efficacy information and supplement insecticide registration data. The sampling scheme that has proved to be valid is illustrated in figures 8 and 9. Four cards should be placed at the drip line of the sample tree, one at each of the four cardinal directions. The cards should be numbered clockwise from the north. Recoveries on each card will vary by wind direction, shielding effect of the sample trees and surrounding trees, and location of the spray swath. Four cards are considered minimum to obtain data for comparing spray deposit with insect mortality. Attempts to correlate deposit data to mortality data with fewer than four cards per sample tree have frequently been unsuccessful.

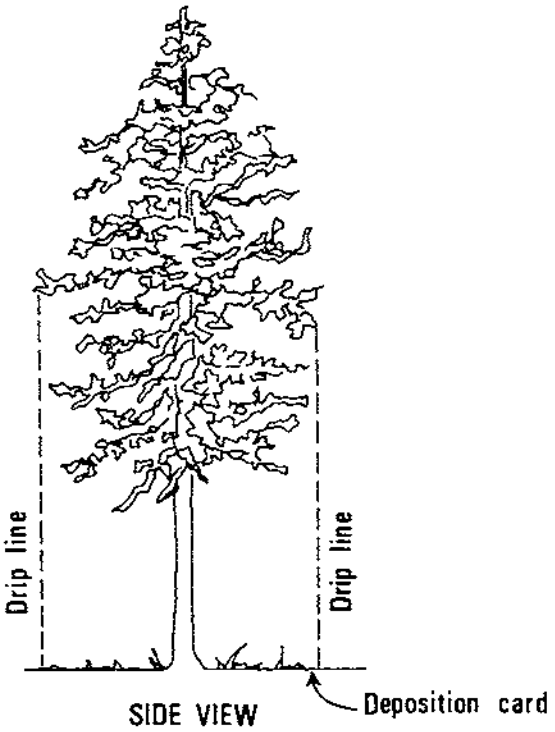
3. Canopy penetration: Canopy penetration is obtained by comparing recovery in the open to recovery beneath the canopy. Approximately 50 to 100 cards should be positioned randomly under the trees and the same number in the open. Another method is to place two cards in an opening near each designated sample tree or cluster, and compare these cards to those placed under the tree. A good open area should be at least one tree height from the nearest tree. This will allow an unfiltered spray to reach the cards. Canopy penetration is expressed in percent as a ratio; that is, recovery beneath the canopy to recovery in the open. Recovery in the open is assumed to represent what was available at the top of the canopy before the spray penetrated the canopy. Separate ratios are calculated for each droplet size category. The numbers can be obtained from the automatic spot-counting and sizing computer program printout described by Young et al. (1977).

4. Spray characteristics, including vmd, droplets per unit area, and mass per unit area: Data of this type are used to determine if previously established spray-deposit criteria have been met. They also provide a comparison of one project with another, which aids in planning subsequent projects.

DEPOSITION CARD SAMPLING

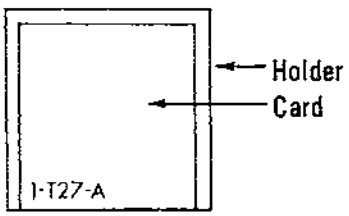


TREETOP VIEW



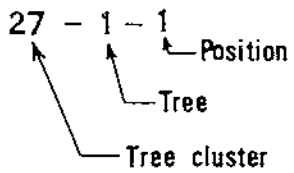
SIDE VIEW

MARKING OF DEPOSITION CARDS

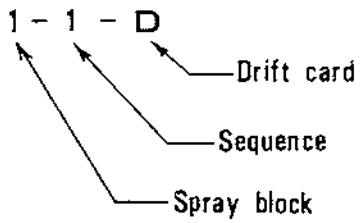


Place marking at bottom margin
¼ inch to ⅜ inch letters

MARKING CODE TREE CARD



MARKING CODE FOR DRIFT CARDS



MARKING CODE FOREST OPEN CARDS

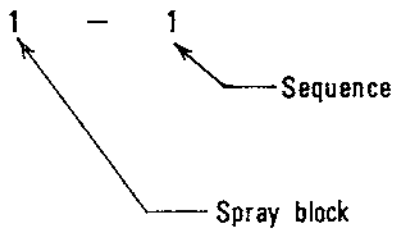


Figure 8.—Deposition card placement and numbering for pilot and operational projects. This figure has been useful for instruction of field crews.

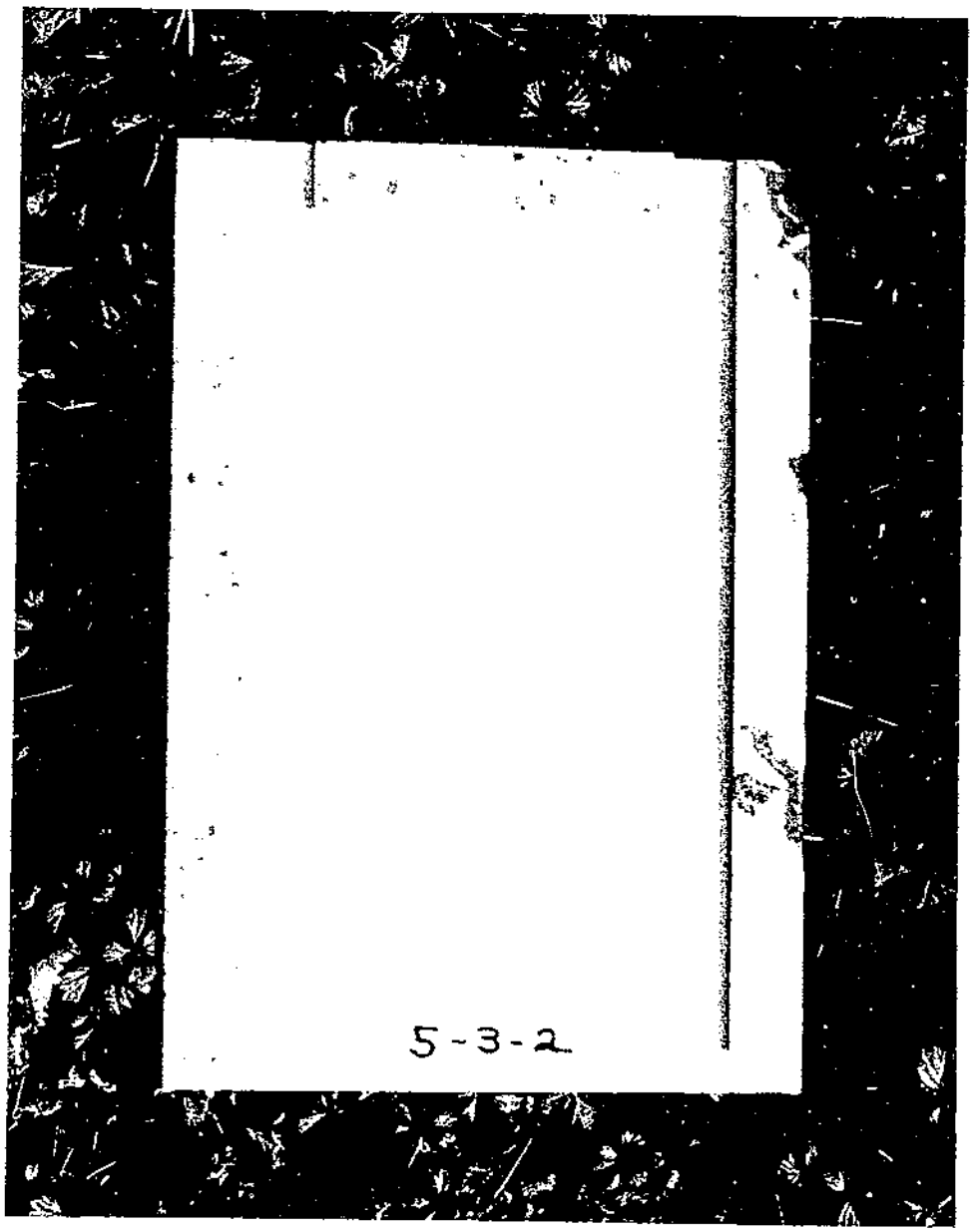


Figure 9.—Spray-deposit card in cardholder. Card identification is placed on bottom edge for identification. Note spray deposit on card.

Characterization of Spray Systems

Keith Dumbauld and James Rafferty

Characterization of the spray deposit from aircraft dissemination systems before conducting large-scale forest spray operations is important in assisting spray-project entomologists to establish the applicability of specific spray-system characteristics to particular application problems. This information also helps aircraft engineers in implementing and evaluating field changes in aircraft spray systems to improve application characteristics. The design of a sampling grid and an aircraft flight plan for establishing spray characteristics--such as the effective swath width, droplet-size spectrum, droplet densities, volume-median diameter, and other mass deposition characteristics--are described below. Techniques for analyzing spray-deposit cards to establish droplet densities, volume-median diameters, and the droplet spectrum in the field and field laboratory are discussed elsewhere in this book. Much of the material presented below was extracted from a field manual for use in characterizing spray from small aircraft using field-sampling techniques (Dumbauld and Rafferty 1977).

Site selection and design of the sampling grid are essential to obtain good quality data. Large, cleared and relatively level areas are ideal for determining spray characteristics. Building, trees, power lines, and other obstructions interfere with the placement of sampling lines, the windflow field, and the aircraft flight pattern. Because the card samplers are placed on the ground, high grass or bushes can intercept the droplets before they reach the cards; mowing or other means of removing larger plants in the immediate vicinity of the sampling lines may be required. The aircraft pilot must maintain level flight for some distance downwind of the sampling line as the aircraft approaches it and for even greater distances upwind. The requisite length of the flight line depends, as will be discussed later, on the height of the aircraft. Aircraft heights of 50 to 100 ft require characterization sites exceeding 1 mi^2. Sites where the public can easily gain access should be avoided, because some of the dyed spray material could easily be deposited on people or cars.

Grid Geometry

As noted above, an upwind flight trajectory ensures that the entire droplet size spectrum of the spray cloud can be sampled with a minimum number of samplers. The grid should be designed such that sampling lines are crosswind. Experienced field meteorologists and test personnel know that specifying a mean wind direction for a short period well in advance of a trial is extremely difficult under the best of circumstances. Therefore, the sampling grid must be designed to accommodate variations in the mean wind direction to prevent the introduction of serious errors in the data analysis; an equilateral triangle design is recommended. The design tends to limit the angle between the aircraft flight path (flown into the wind) and a sampling line to 90 $\pm$ 30 degrees. The choice of the proper flight path for any given trial depends, as explained below, on the mean wind direction measurements made just before the trial.

Knowledge of the most frequent wind directions at the site chosen for the trials will assist in orienting the triangle to ensure that sampling lines are oriented crosswind. Spray projects are normally conducted during the early morning and late evening, during fair weather. The light wind usually present during these hours is generally favorable for maximum canopy penetration and minimum offsite drift of the spray material. Strong winds and high atmospheric turbulence generally diminish spray deposition in the immediate target area and increase the possibility of downwind drift. These considerations also apply to the determination of aircraft spray characteristics. Thus, one of the sampling lines should be oriented across the wind direction expected during the early morning or late evening. A trained micro-meteorologist can often determine expected mean wind directions for these periods from a knowledge of the topography features in the area.

Length of the Triangular Sides

Each side of the triangle must be long enough to contain the swath width or contamination density of interest. Although complicated diffusion-deposition formulas can be used to determine the length (L) as a function of droplet settling velocity, planned aircraft flight altitude, and meteorological conditions, experience has shown that multiplying flight height (H) by 10 is normally sufficient to contain the swath width (L=10H). If the aircraft flies at a height of 15 m (50 ft), the length of each side of the triangle should be 150 m (500 ft).

Sampler Spacing

The sampler spacing along each side of the triangle must be sufficiently dense that statistically stable estimates of the volume-median diameter and other spray characteristics can be obtained. Modeling and field experience show that multiplying the aircraft height by 0.4 gives satisfactory spacing ($S = \frac{L}{25} = 0.4H$); where S = maximum sampler separation distance.

Aircraft Height and Spray Line Length

For the purpose of characterizing aircraft spray, it is generally desirable that the aircraft fly as low as possible to minimize sampling grid requirements while satisfying flight safety. A 15-m (50-ft) minimum altitude generally meets both requirements. The flight altitude may have to be increased, however, if the density of the stains from droplets deposited on the sampling cards is so great that spray characteristics cannot be determined.

Because the stain spread factor of droplets depends on the spray formulation and the type of sampling card, it is difficult to recommend a specific aircraft altitude before the trials. A simple one-trial experiment at an aircraft altitude of 15 m can be conducted before final specification of the grid design to determine if the cards will be covered so heavily that stains cannot be counted and sized.

On the other hand, a value for the length L of 300 m can be used in the grid design for a 30-m aircraft altitude with a sampler separation distance of 6 m appropriate for an aircraft altitude of 15 m. If the first trials indicate that a 15-m altitude results in spray densities that cannot be conveniently counted, the flight altitude can be increased to 30 m and every other sampling position removed from each side of the triangular grid. Because spray density is nearly inversely proportional to aircraft altitude, an increase in aircraft altitude by a factor of two will reduce deposition density by half.

The length of the upwind release line required to ensure that the crosswind mass recovery sampled on the grid is not affected also depends on the aircraft altitude, as well as spray characteristics and meteorological conditions. Calculations show that if much of the spray cloud mass is comprised of droplets with diameters of 50 µm or less and windspeeds are less than or equal to 4 m/s, the length of the release line upwind of the sampling grid should be about 100 times the aircraft altitude. If most of the mass of the spray cloud is comprised of droplets between 50 and 100 µm in diameter and windspeeds are less than 4 m/s, the release line length upwind of the sampling grid should be about 70 times the aircraft altitude. Finally, if most of the spray cloud mass is comprised of droplets greater than 100 µm in diameter, the release line length upwind of the sampling grid need only be 35 times the aircraft altitude. The release line must always begin at least 50 to 100 m downwind of the sampling grid. Longer distances may be required to stabilize the aircraft altitude and the flow rate in the spray dissemination system.

Dressing the Grid

After the length of the triangular sides of the sampling grid and the sampler grid spacing have been determined, a transit theodolite, or compass, and a manila rope are used to lay out the sampling lines. The manila rope is stretched taut at right angles to the most probable wind direction expected during the early morning, using the theodolite to ensure that the line segment is straight and correctly oriented. Quarter-inch-stock metal rods for marking sampler positions are then driven or forced into the ground at the predetermined sampling intervals marked by a surveyor's tape tacked to the rope. The theodolite and the rope are then used to measure the 60-degree angles and lay out the next two sides of the array. Clearing a small area around each metal rod may be necessary so that plants or other material do not intercept drops that would otherwise hit the card. Larger wooden stakes, 5 to 6 ft high and marked with bright tape, should be placed at the end of each leg of the triangle and at the center of each leg to assist in orienting the pilot to the center of the sample line.

Cards for three or more trials can be premarked and placed in cardholders before each day's operation. At a minimum, the marks placed on each card should identify the trial (or flight) number, sampling line number, and sampler location on the

line. For example, the identification 13-1-50 might indicate trial 13, sampling line 1, and the 50th card position of sampling line 1. The cards in their cardholders can be packed in ascending numerical order in the wooden boxes for transportation to the field site. One or two boxes, depending on the length of the sampling line, are sufficient to dress one side of the triangular array. The cardholders should be placed at the side of each stake so that the stake does not intercept droplets that would otherwise strike the card. The cardholder must be placed flat on the ground and care must be taken that loose soil or dust is not kicked onto the card.

Meteorological Considerations and Measurements

John W. Barry

Meteorological data are used for both research and operational purposes, and occasionally they are needed during spray drift and accident investigations.

Meteorological conditions affect spray behavior; therefore, spray deposit sampling design and field sampling must consider the influence of these conditions.

Basic meteorological measurements should include the following:

Temperature (°C) -	1 to 2 meters above ground
	top of canopy
	release height
Relative humidity (%) -	2 meters above ground
Wind direction (°) -	2-m level in the open
	top of canopy
	release height
Wind speed (m/sec) -	2-m level in forest
	2-m level in open
	top of canopy
	release height
Temperature gradient (°) -	2-m level to top of canopy and from top of canopy to release height
Barometric pressure -	vicinity of spray site
Turbulence -	top of canopy
Surface observations -	cloud cover
	soil condition (dampness)
	vegetation condition (dampness)
	precipitation

These data should be collected continually during the spray operation. If this is not practical because of lack of personnel or adequate equipment, then as a minimum, data should be collected at the start, midpoint and end of spraying.

Use of meteorological observations include:

- Making a decision to spray or not
- Interpreting spray-deposit data
- Comparing one project's results to another
- Developing and altering spray strategy
- Minimizing spray drift
- Developing spray accountancy plan
- Documenting drift incidents and accident investigations.

Placement and positioning of deposit samplers should take into consideration the scavenging effect of forests upon the spray (source depletion) and the nature of the

terrain. Cards placed under the forest canopy will receive less spray than those placed in the open. Cards placed on open ridges that usually are swept by winds may receive little or no spray deposit. Spray droplets are blown in the direction of the wind (fig. 10) and do not fall straight down (fig. 11). Sprays released over ridges will be deposited at great distances downwind. If data on spray deposit in the open areas of a spray block are needed, sampling should be conducted in an area where the influence of topographical features and wind are minimal.

Drainage Wind

These winds are referred to as mountain-valley or slope-valley wind.

During clear nights when the prevailing wind is light, the wind in a valley frequently assumes a pattern after sunset. As the slopes of the valley cool by radiation, the air immediately adjacent to the slopes cools also and becomes more dense than the air over the center of the valley at the same elevation. This dense air drains down the slopes toward the valley floor. The drainage flow from the slopes at various points along the valley will combine into a general flow toward the valley mouth.

Although greatly dependent on the slope and configuration of the valley, on the ground cover, and on the prevailing large-scale meteorological situation, down-valley flows of perhaps 5 m/s are not uncommon. The slope-valley circulation, once established, will usually extend to the height of the ridge tops. This pattern will be changed after sunrise by the heating of the slopes and valley floor (Slade 1968). This change is often dramatic and rapid. When the rays of the sun hit the eastern slopes, downslope drainage winds will weaken, direction will become variable and upslope winds can start within a short period.

On clear days with light winds, an opposite circulation pattern may develop. This upvalley, upslope flow is caused by heating of the air adjacent to the sun-warmed slopes and valley floor. This phenomenon is not as marked as the night flow. At night, turbulence in the valley is suppressed by a thermal inversion; thus the flow in the valley is comparatively undisturbed. By day, however, the turbulence induced by the heated land surface can be expected to stir the air within the valley and to cause mixing with the free flow above the ridges. This turbulence constitutes a general disruptive mechanism and hinders the establishment of a sensitively balanced circulation pattern. Therefore, although daytime upslope, upvalley patterns undoubtedly exist, they are not so common or so well marked as the downvalley flow at night (Slade 1968).

Spray operations should be completed before the upvalley winds develop. Spray strategy for the downslope winds is different from the upslope. These differences will not be discussed in this book.

Drainage winds have a pronounced effect on the spray-deposit pattern; therefore, sampling design must consider these influences.

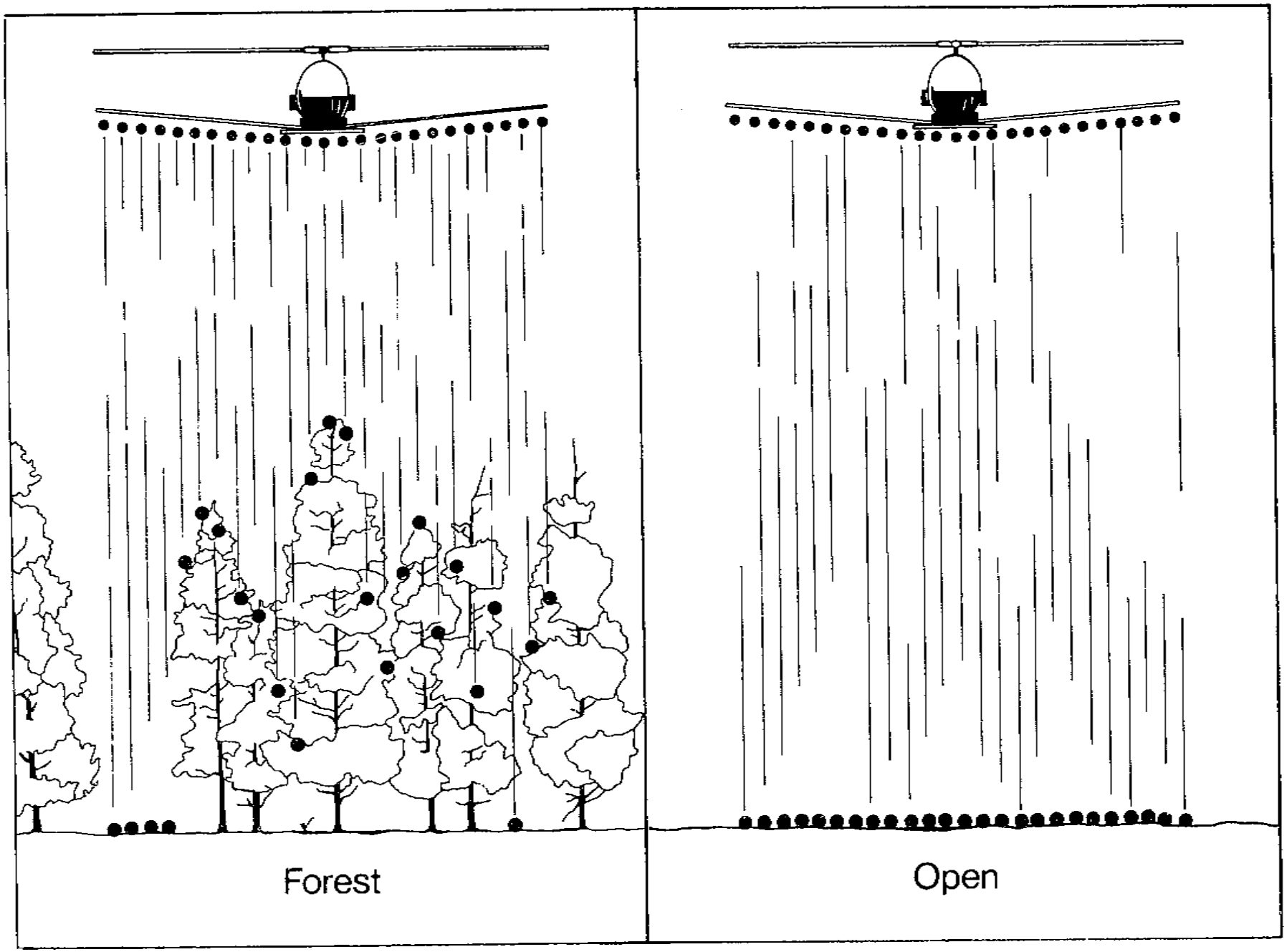


Figure 10.—Capture of droplets by vegetative elements. Penetration ratio, defined as a function of droplet size, is the number of droplets recovered under the canopy compared to the number of droplets recovered in the open. Spray droplets do not fall straight down; they angle from the vertical depending on windspeed and the velocity of the droplets.

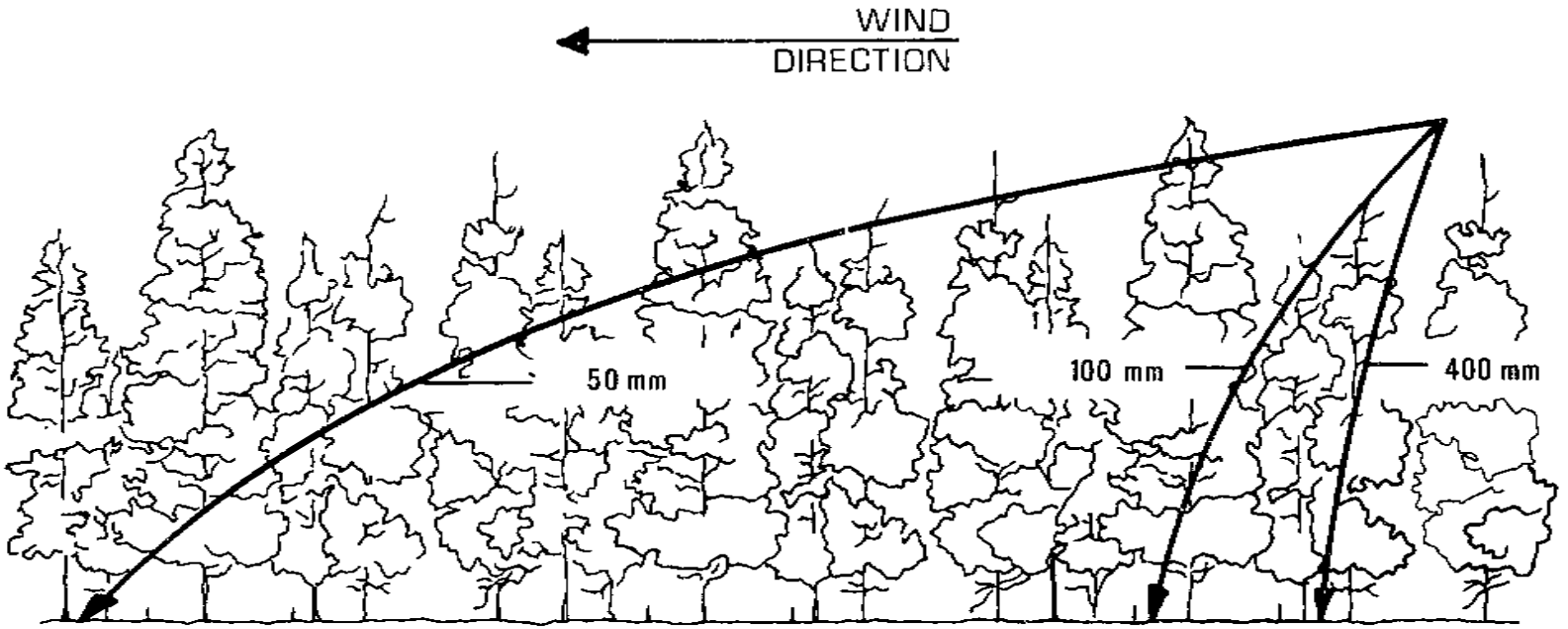


Figure 11.—Relative trajectories of various sized particles penetrating forest as function of windspeed.

Handling and Marking of Deposit Cards

John W. Barry and George P. Markin

When deposit cards are used in the field, a cardholder is used to hold the card horizontally above the ground at a predetermined height. The elevation of the card above the ground usually ranges from 18 in to 2 ft, which keeps the cards away from moist ground surfaces, keeps rodents and small animals from chewing or running off with them, and keeps the cards above underbrush or ground cover that may shade them. Underbrush higher than the cardholder being used may have to be cut down to ensure that the card is not overshadowed.

Several types of cardholders have been used. The Canadians have developed a system consisting of two aluminum plates hinged together with tape. A card is held to each plate with two rubber bands and placed on top of a wooden stake. When not in use, the two aluminum plates sandwich the cards between them, but the cards do not touch because they are separated by the rubber bands. In the United States, a wire cardholder has been used. This often contains a special wire knot at the top that is arranged in such a manner that sections of it slide over and under the card to hold it in place (Maksymiuk 1959). It has the disadvantage that the wire passing over the card produces a shadow where the wire intercepts the landing spray droplets. Another arrangement consists of a straight heavy wire with a heavy snap-type paper clip welded to hold the card. The presently recommended cardholder consists of a thin, flat, yellow plastic sheet slightly larger than the Kromekote card, with three edges folded up and over to form a lip. The Kromekote card is laid on the plastic sheet and held firmly on three edges where the plastic overlaps the card by 1 cm. To elevate the cards above the ground, they are usually mounted on top of a stiff wire with a clip (fig. 1).

In general, cards should be put out just before spraying. Occasionally this means having crews on the plots before daylight. Under high humidity, the cards absorb moisture out of the air. A moist card produces a spot that is not as distinct or sharp edged as a dry card. Also, spots spread differently on moist cards than on dry. Moist cards also tend to warp and to retain this warp after drying. Badly warped cards are almost impossible to read with some spot counting devices.

Cards should be left out for at least 15 min after the aircraft has completed treatment of the area. This is necessary to allow the very small spray droplets to settle and dry. Cards should never be left out for more than 1 hr, particularly since direct sunlight may fade the dye.

Never handle the surface of the card on which the spray will land, or let this surface get dirty. Oil or dirt picked up in handling can leave a spot that will be misread by the spot counter. In general, it is best to simply pick up the cards, blow on them or wave them to remove any needles or pollen that have collected upon them. When the cards are dry, place them together in a stack that can be stored in a paper sack.

The key to implementing proper field handling of deposit cards

lies with the field foreman, who must be knowledgeable and motivated to demand compliance to instructions from the field crew. Good field handling is dependent upon ability to communicate, organize, supervise, and monitor.

Three elements the field foreman is responsible for are:

1. Preparing and implementing field crew instructions.
2. Briefing field crews before each trial.
3. Supervising and monitoring performance of the field crew.

The foreman should prepare detailed and explicit instructions for the field crew. These instructions should include the following topics:

1. Diagram of the spray site.
2. Method and system of marking the samples.
3. Location where cards are to be picked up and returned.
4. Protection of samples during transit.
5. Positioning and placement of samplers in the field.
6. Protection of samples from sunlight, humidity, rain, dust, etc.
7. Handling of tote or carrying boxes.
8. Check list of necessary equipment and materials.
9. Special instructions as required.

Field crew briefings should be held before each trial. The field crew must understand the purpose and test objectives and any changes to written instructions. The crew unquestionably will do a better job if they understand the reasons for their efforts. These briefings deal primarily with coordination and communication or project schedules and tasks and they provide an opportunity to discuss and resolve questions and problems. They also help foster a team spirit.

A staging area usually is an appropriate place to meet and organize the field crew, equipment, and materials. Each crew should stage its materials the day before the field operation. This provides an opportunity to examine and account for necessary equipment and materials before the early morning exodus.

If deposit spots might be smeared, some type of tote or carrying box (fig. 2) for the deposit cards is necessary. These are fabricated from 1/4-in plywood. A web strap is attached for carrying.

The field foreman should monitor the field crew's performance. He should inventory the cards in the field or at the staging area to ensure proper marking and accountancy, and to identify and correct poor handling procedures.

Marking of Field Samples

The numbering system was developed in parallel with the automatic data processing program for data analysis of spray deposit cards.

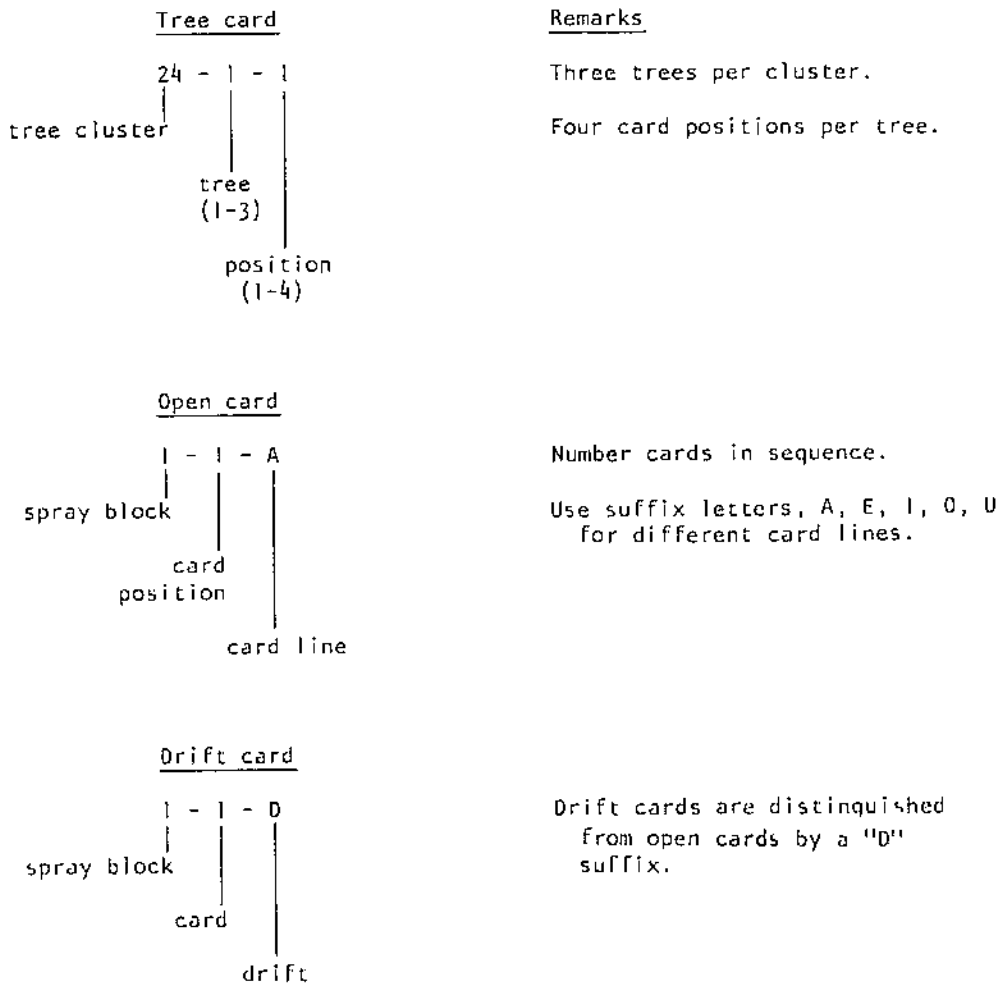
Proper identification of field samples is critical to any field project. Experience has demonstrated that this simple effort frequently is not given sufficient emphasis and, as a result, data for which the project was conducted are lost.

The field foreman and laboratory chief are responsible for establishing the marking system within the guidelines presented here and instructing the field crew. The field crew must follow the sample-marking instructions.

Kromekote cards should be marked at the bottom of the card with 3/8-in-high numbers. An example is given in figure 9. Ballpoint pens are appropriate for marking; pencils and water-soluble inks should be avoided.

Other samples--such as branches, foliage tips, membrane filters, and the like--are identified with white marking tape. The number is written on the tape and the tape strip is placed on the vial, box, bag, or branch.

A sampler marking system is outlined below:



CHAPTER 5 FIELD ASSESSMENT METHODS

Determining Volume-Median Diameter

Bohdan Maksymiuk

Introduction

The degree of pesticide spray atomization affects the effectiveness and safety of insect control. Spray atomizing devices, such as conventional nozzles and spinners, produce a range of droplet sizes--the droplet size spectrum (Maksymiuk 1964a, 1971a).

In each spectrum, the number of droplets decreases with the increased droplet size. Fine sprays can result in a higher deposit coverage (for example, in number of spray droplets per unit area) than coarse sprays, but under unfavorable meteorological conditions, fine droplets are subject to more drift, evaporation, and photodeactivation or weathering of pesticides. In addition, characteristics of the droplet size spectrum affect spray behavior, pattern of deposition, and insect mortality (Isler and Thornton 1955, Davis et al. 1956, Maksymiuk 1971b). Therefore, some measure of the droplet size spectrum is essential, for research purposes, for checking and calibrating the spray equipment on insect control projects to meet contract specifications, and for attaining more efficient, safe, and reproducible field practices.

Various parameters such as volume-median diameter (vmd), number-median diameter (nmd), and average number or droplet size, are used for characterizing droplet spectra. The vmd, known also as mass-median diameter (mmd), is the most commonly used measurement. The vmd is the droplet diameter dividing the spray volume into two equal parts--50 percent of the spray volume is in droplet sizes below vmd and 50 percent is above vmd. Standard methods for determining vmd require accurate sampling of all droplet sizes, under ideal meteorological conditions, from the entire spray swath, and the measurement of many droplets of all sizes (Maksymiuk 1964a). These methods are complicated, require special equipment and trained personnel, and cannot be used in the field for rapid determination of vmd.

In this section, a simple and rapid method for determining vmd from the largest droplet (D-max) in the continuous spectrum is described. Only the size of the five largest droplets for each single-swath test flight is needed. Spray tests can be conducted under a wide range of meteorological conditions because small droplets need not be sampled.

The development of the D-max method for determining vmd was described by Maksymiuk (1964b). Moore et al. (1964) reported on the precision and accuracy of this method. Isler and Carlton (1965) summarized use of the D-max method for research purposes in determining vmd of sprays under a wide range of test conditions. The D-max method also proved highly satisfactory for use on spray projects (Maksymiuk 1963a).

The D-max method has been successfully tested over a wide range of spray atomizations using oil-base spray formulations(Isler and Maksymiuk 1961, Isler and Carlton 1965).

Procedure

Step-by-step procedures for determining vmd of spray deposits

by the D-max method are as follows:

Spray equipment 1. Make sure all spray nozzles and nozzle tips are similar, oriented in the same direction, and in good working condition--old tips can become eroded resulting in the production of too large droplets.

2. Adjust the spray application volume so that it does not exceed 1 gal/acre. Higher application rates can result in droplets overlapping on the spray deposit cards, making determination of droplet size difficult. The application rate can be increased or reduced by changing the number of nozzles, but the spray pressure, flight speed, and nozzle angle must not be changed because they affect the droplet size. A reduction in the deposit rate may be obtained by flying the spray plane higher and crosswind so that small droplets are blown away from the center of the flight line.

Droplet sampling 1. Kromekote cards are preferable for sampling droplet sizes.

Oil-base sprays--undyed spray can be sampled on dyed oil-sensitive cards (White 1959) or dyed spray on undyed cards (Maksymiuk and Moore 1962, Maksymiuk et al. 1975, Maksymiuk and Orchard 1975).

Water-base sprays--dyed spray can be sampled on undyed cards. Use oil-soluble dyes for oil formulations and water-soluble dyes for water formulations (see chapter 3 for choice of dyes).

2. Set a line of about 40 cards on a little-used runway or in an open area, preferably aligned with the wind direction (fig. 12). Cards can be supported above ground vegetation using wire cardholders (Maksymiuk 1959), or any other supports described in this publication. Place cards as follows:

(a) at 10-foot intervals for slow-speed aircraft (about 80 to 100 mph) for example, the Stearman, Piper, and most helicopters.

(b) At 20-foot intervals for medium-speed aircraft (about 150 to 180 mph) for example, the TBM, DC-3, B-18, and the B-17.

Flight procedures 1. Spray over the cards at a right angle to the sampling line (fig. 12).

(a) Slow-speed aircraft: Spray from a height of 50 ft or more; turn on the spray about 400 ft before the line and turn it off about 400 ft beyond the sampling line.

(b) Medium-speed aircraft: Spray from a height of 100 ft or more; turn on the spray about 800 ft before the sampling line and turn it off about 800 ft beyond the sampling line.

2. Flights can be made at most any time of the day providing the air is stable enough for safe flight, the windspeed is less than 8 mph and no rain is falling. At higher windspeeds, the droplets often produce oval or streaked spots of meaningless dimensions. When crosswind flights are made, the largest droplets, from which D-max

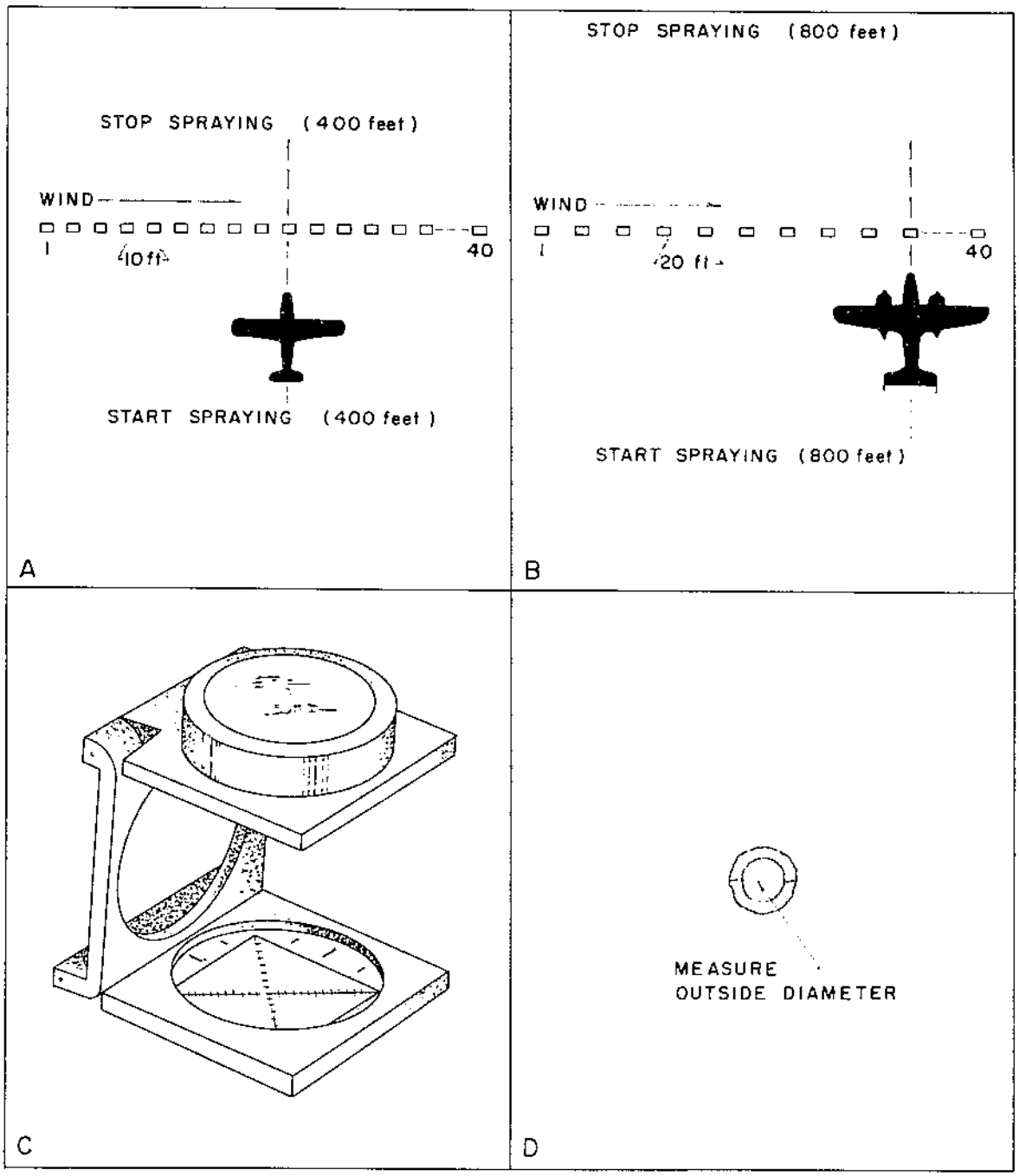


Figure 12.—A, Arrangement of sample cards for small aircraft; B, arrangement of sample cards for large aircraft; C, linen tester equipped with eyepiece reticle for measuring spot diameters; D, halo surrounding spots on dyed cards.

is selected, will fall under the airplane or will be shifted slightly downwind. The smaller droplets will be carried downwind and will not overlap or be superimposed on the larger droplets. A crosswind of from 1 to 6 mph is desirable.

Determining droplet D-max 1. Allow at least 10 minutes for the droplets to spread and dry on the cards before measuring the spots; allow more time for very large droplets or for spray formulations that evaporate slowly.

2. After the spots stop spreading, select and measure the diameters of the five largest spots, including the halo if dyed cards are used (fig. 12). Measure the spots to the nearest 100 µm (0.1 mm). The spots can be measured with a microscope eyepiece reticle, graduated in 100-µm units. This reticle can be used either in a microscope or attached with tape to the bottom of a linen tester or other magnifier. A linen tester gives a direct measurement because it magnifies both the spot and the scale at the same rate (fig. 12). Reticles and linen testers can be bought at any scientific supply house (for example: Edmund Scientific Co., Barrington, N.J.; crossline reticle, scales 10 mm in 100 parts; linen tester magnifier 6X lens diameter 1 inch). Tabulate the spot diameters in order of decreasing size, as shown in the example under step 4 below.

3. Convert the spot diameters to spherical droplet diameters by dividing the spot diameters by the proper spread factors. The spread factor shows how much the droplets spread on the cards. Spreading varies with droplet size and the components of the spray formulation. The spread factor is determined in advance for the droplet sizes, spray, and sampling surface to be used, by dividing the diameter of spherical droplets of known size into the outside diameters of the spots they produce on the cards. Methods for determining spread factor are described in chapter 6. When rough estimates of vmd will suffice, table 3 will be adequate for most oil-base spray formulations.

4. Select the D-max droplet. The D-max is the largest droplet diameter in the continuous droplet spectrum with not more than a 32-µm difference between it and the next largest droplet--going from the smallest droplet size up (Maksymiuk 1964b). In the following example, droplet D-max is 390 µm:

Spot on card			Spherical droplet diameter	Vmd, for aircraft	
No.	Diameter Micrometers	Spread factor		Slow speed	Medium speed
			Micrometers		
1	4,000	6.28	637	--	--
2	3,800	6.27	606	--	--
3	2,400	6.15	390	177	156
4	2,300	6.14	375	--	--
5	2,300	6.14	375	--	--

Droplets larger than D-max are only found occasionally. They are sometimes caused by leaks or by dripping of spray from the equipment or from the surfaces of the aircraft. If they are present, check your spray equipment.

Converting droplet D-max to vmd The conversion factors for converting droplet D-max to vmd for different speed aircraft (2.2 and 2.5) were developed by Maksymiuk (1964b) and the precision of the method is given by Moore et al. (1964).

1. Obtain vmd as follows:

(a) Slow-speed aircraft: Divide spherical droplet D-max by 2.2 or simply multiply it by reciprocal 0.454.

(b) Medium-speed aircraft: Divide spherical droplet D-max by 2.5, or simply multiply it by reciprocal 0.400.

2. Because vmd varies from flight to flight (Moore et al. 1964), use the average of not less than three test flights.

Convenient tables, similar to table 3, should be prepared by users.

Table 3--*Estimated VMD for slow- and medium-speed aircraft using spread factors for an oil spray*[1/] *on dyed Kromekote cards*

Spot diameter	Spread factor	Spherical droplet diameter	VMD, for aircraft of	
			Slow speed	Medium speed
Micrometers		Micrometers		
1 000	5.74	174	79	70
1 100	5.80	190	86	76
1 200	5.85	205	93	82
1 300	5.90	220	100	88
1 400	5.94	236	107	94
1 500	5.97	251	114	100
1 600	6.00	267	121	107
1 700	6.03	282	128	113
1 800	6.05	298	135	119
1 900	6.07	313	142	125
2 000	6.09	328	149	131
2 100	6.11	344	156	138
2 200	6.12	359	163	144
2 300	6.14	375	170	150
2 400	6.15	390	177	156
2 500	6.16	406	185	162
2 600	6.18	421	191	168
2 700	6.19	436	198	174
2 800	6.20	452	205	181
2 900	6.21	467	212	187
3 000	6.21	483	220	193
3 100	6.22	498	226	199
3 200	6.23	514	234	206
3 300	6.24	529	240	212
3 400	6.24	545	248	218
3 500	6.25	560	255	224
3 600	6.26	575	261	230
3 700	6.26	591	269	236
3 800	6.27	606	275	242
3 900	6.27	622	283	249
4 000	6.28	637	290	255
4 500	6.30	714	325	287
5 000	6.31	792	360	317
5 500	6.33	869	395	348
6 000	6.34	946	430	378
6 500	6.35	1 023	465	409
7 000	6.36	1 100	500	440

[1/] Spray formulation: 1 lb DDT plus 1 quart of Sovacide (Mobisol 544-B) plus No. 2 fuel oil to make 1 gallon of spray.

Conclusion

The D-max method for determining vmd has been tested under a wide range of conditions in the field, using different aircraft (TBM, DC-3, Ford, F4F, C-82, B-19, B-17, etc.) equipped with various spray equipment. The accuracy of the conversion factors is known only for the test conditions and sampling procedure for which they were developed and tested. For different drop-size distributions, different conversion factors might be needed.

Determining Droplets Per Square Centimeter

G. Lynne Whyte

Determination of droplet density per square centimeter on Kromekote cards in the field requires counting stains in a known area. This can be accomplished by acquiring the equipment listed below and following these procedures developed by Dumbauld and Rafferty (1976).

Equipment for Field Laboratory Analysis

Any indoor site with 110-volt power, desks, and chairs.
Cork bulletin board (18x24 in.)
Bulletin board push pins
High-intensity lamp
7X measuring magnifier with 100-µm divisions
Card templates.

Method

The template (fig. 13) and measuring magnifier are used to count droplets in the field laboratory. The 4-, 8-, and 16-cm^2 areas are arranged on the template so that the area to be counted is at the center of the card when the line at the top of the template labeled with the corresponding area is aligned with the top of the sampling card. Droplets within a 4-, 8-, or 16 cm^2 area are counted. Select an area that will include at least 200 stains. With a little experience, you can readily select the proper area to be counted by looking at the card.

Examine the area for obvious anomalies that might affect accuracy. These anomalies include smeared droplets, foreign matter on the card, or shadows (absence of droplets) where deposition has been prevented by a leaf or some other object. If anomalies occur, move the template to an unaffected portion of the card. Once an anomaly-free area has been found, anchor the template and card to the corkboard with push pins. The results of the droplet-density count are recorded on a droplet density data sheet. Record the trial number, row and line number, card number, and area being counted.

The template areas in figure 13 are divided into five columns to assist in counting the droplets. Each column is counted using the measuring magnifier. The total number of droplets for each column is noted. Stains that intersect the outer perimeter of the template area should be included in the count only if more than half their area is inside the perimeter. Stains that intersect the lines dividing the area into columns must be counted only in one column, usually by assigning them to the column at the left of the line no matter how much of the stain is contained in a column.

After the five columns are counted, the results are summed and entered in the "stain count" column on the droplet density data sheet. The droplet density is calculated by dividing the stain count by the total area in square centimeters that was counted. The result is entered in the "droplet density" column on the data sheet. All cards included in the swath width are counted.

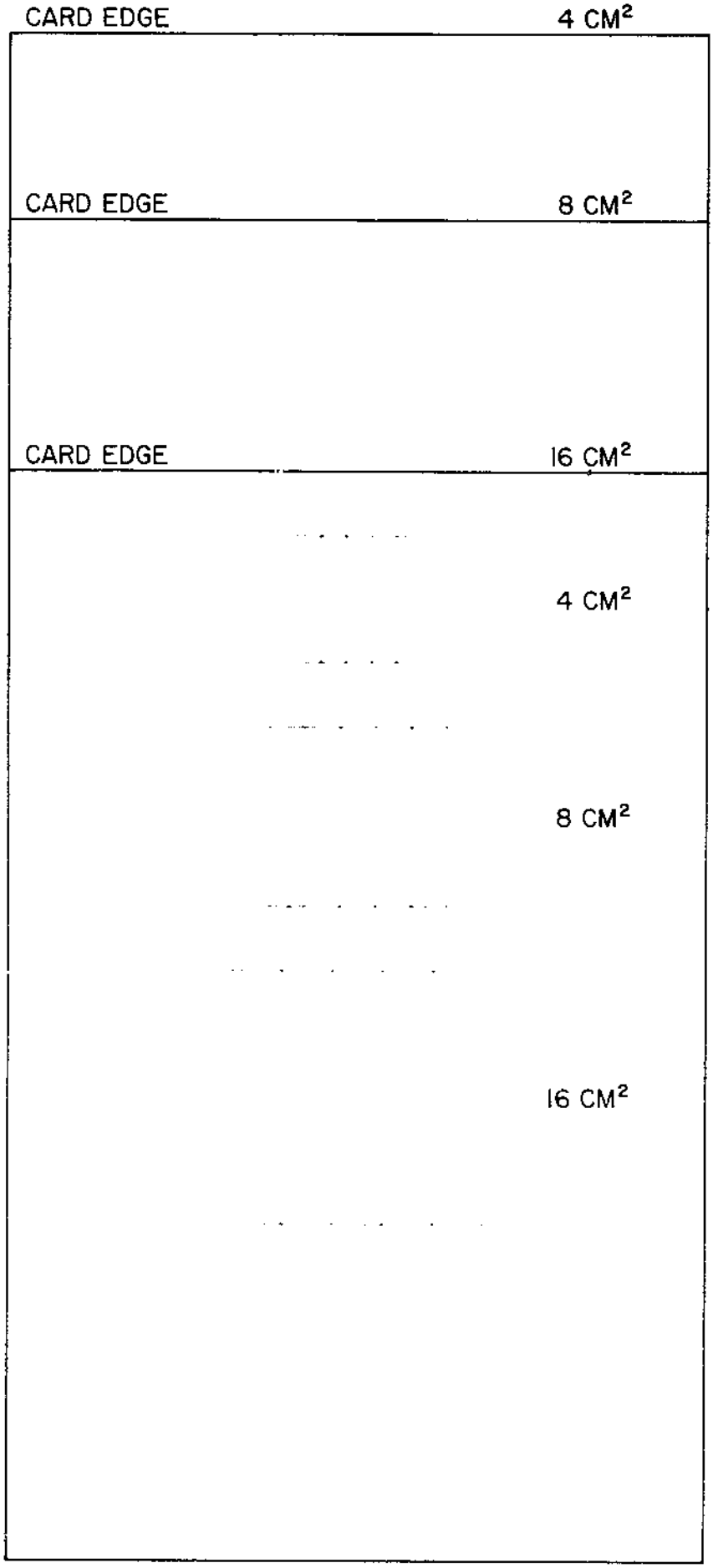


Figure 13.—Template for counting and sizing droplets on sampler cards.

Spectral Counts of Deposits on Cards

Keith Dumbauld and James Rafferty

Spectral counts of droplet stains on Kromekote cards can be used to determine the deposit characteristics of spray dissemination systems. The following paragraphs describe a field-laboratory procedure for determining the mass-median, average-mass, and number-median diameters of spray deposits on cards and the total mass deposited on cards. This description has been extracted from a field manual (Dumbauld and Rafferty 1977) characterizing the spray deposit across a swath, using field-sampling techniques and simple calculations. The ASCAS computer program, briefly described in chapter 7, is available for detailed analysis of data.

Analysis of the droplet stains on five cards located within the swath is normally sufficient to estimate the spectral distribution of droplets in the swath. The five cards are selected by taking one card from each edge of the swath, one card near the center of the swath, and one card from each side of the swath, located about half the distance between the center and the edge.

Selection of Size-Class Intervals

Before the droplets are counted and sized, droplet size categories must be specified. Normally, 8 to 10 droplet size intervals are sufficient to define the droplet spectrum. The upper and lower limits of the stain size intervals must be determined before the droplet stains on the spray-deposit cards are sized and counted. The following procedure is suggested for selecting the limits of the intervals:

1. Draw the line representing the relation between the stain and droplet diameter, derived from laboratory experiments defining the spread factor as described in chapter 6, on linear graph paper. An example of this relation for Dylox is shown in figure 14. The relation is given by the equation

$$DD = a + b(SD) + c(SD)^2$$

where DD is the droplet diameter; SD is the stain diameter; and a, b, and c are constants determined in the laboratory analysis. The line should extend from the smallest stain diameter to the largest stain diameter that can be measured on the cards.

2. Mark the position on the line of the stain vmd estimated by the D-max method described by Maksymiuk in this chapter. For example, the point marked + in figure 14 corresponds to a vmd of 600 µm and a droplet diameter of 130 µm.

3. Divide the line in figure 14 into about five intervals below the point marked + using standard intervals of 50, 100, or multiples of 50-µm stain intervals. The measuring magnifier is only accurate to 50 µm. For the example shown in figure 14, the upper limits of the stain intervals become 200, 300, 400, 500, and 600 µm as shown by the short horizontal lines. The lower limit of the smallest interval

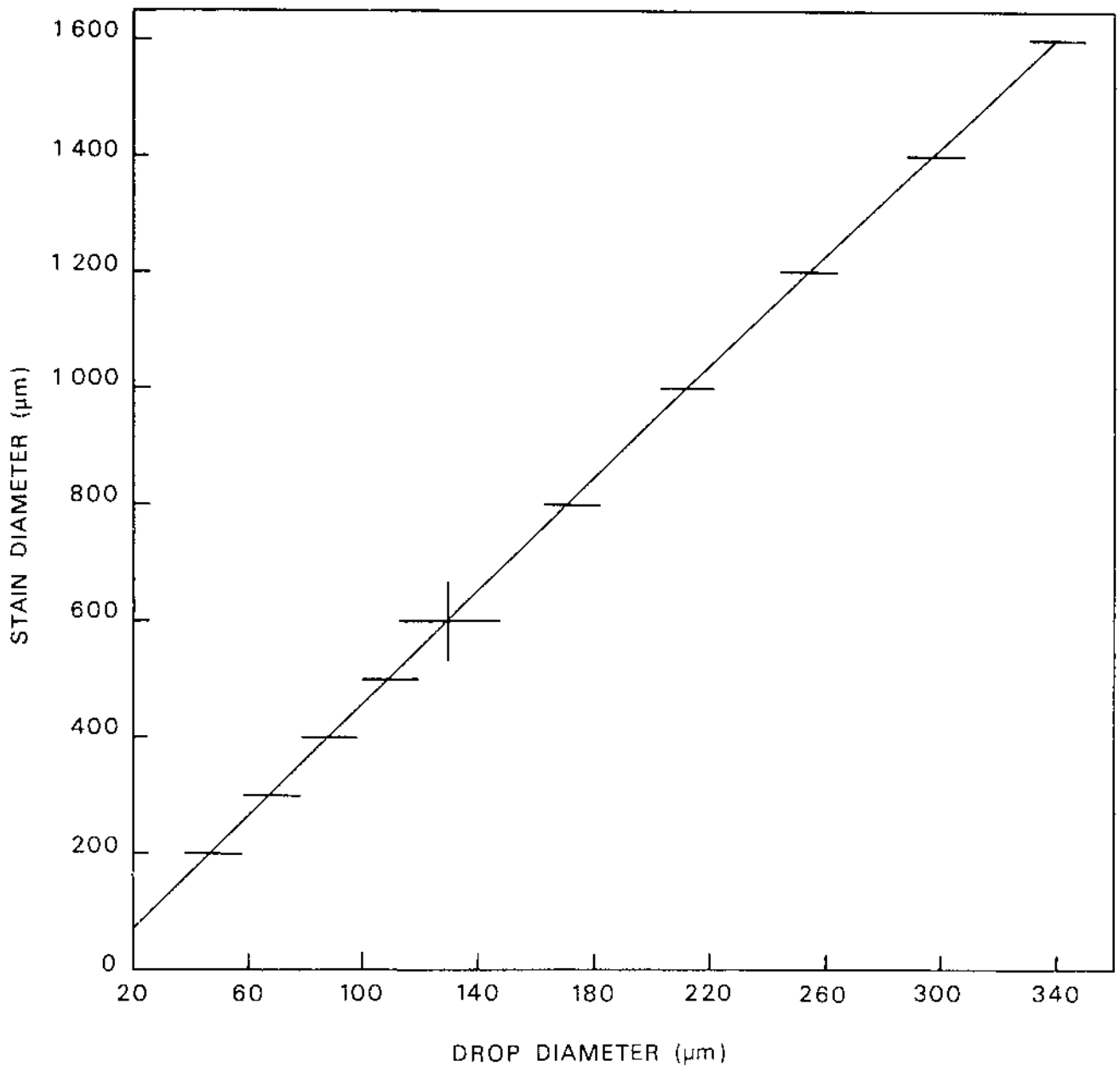


Figure 14.—Stain factor relation for example trial data. The + symbol is the stain vmd obtained from the estimated D-max field analysis (droplet diameter = a+b(stain diameter)+ c(stain diameter)^2; a = 7.68, b = 0.199, c = 5.73x10^{-6}).

should correspond to the smallest droplet in the spray-deposit density count performed according to the procedures described by Whyte in this chapter.

4. Divide the line in figure 14 above the point marked + into five intervals using standard intervals of 50 or 100 µm or other multiples of 50 µm. In the example shown in figure 14, this procedure results in stain category upper limits of 800, 1000, 1200, 1400, and 1600 µm. If the vmd estimated by the D-max method is less than 100 µm, dividing the straight line above the point marked + into more than five intervals may be necessary to obtain a representative mass distribution.

Note that the basic graph shown in figure 14 can be generated before the trials. Enter the stain class intervals on the droplet spectrum data sheet (fig. 15) and use the stain factor equation to convert the stain upper limits to droplet-size upper limits. Enter the droplet-size upper limits on the droplet spectrum data sheet.

Counting and Sizing Droplet Stains

After the droplet size categories are determined, the droplets on the cards can be sized and counted. The template used for hand counting cards in the field (see fig. 13) is also used in making the spectral counts. A minimum of 200 stains should be measured and counted to obtain droplet densities. The measuring magnifier is used to size stains and classify them according to stain size categories.

After the card and template have been secured to the corkboard with push pins, the magnifier is used to measure the droplets in each column (fig. 16). Sizing and counting is best accomplished by two people, one to size the droplets and another to record each droplet by a size-category number. After the stains in each category are sized and counted, the number of stains in each category is totaled. When the sizing and counting of droplets in all five columns of the selected

Figure 16.—Sizing and counting stains on cards with pocket magnifier.

Figure 15.—Droplet spectrum data.

Test 9 Row/Line C Spray material DYLOX Material density 1.067 (g cm^{-3})

Analyst: John Doe Stain factors: a = 7.68, b = 0.199, c = 5.73x10^{-6}

		Size category												
		1	2	3	4	5	6	7	8	9	10	11	12	Total
Stain upper limit (μm)		100	200	300	400	500	600	800	1000	1200	1400	1600		
Stain lower limit (μm)		50	100	200	300	400	500	600	800	1000	1200	1400		
Drop upper limit (μm)		27.6	47.7	67.9	88.2	109	129	171	212	255	298	341		
Drop lower limit (μm)		17.6	27.6	47.7	67.9	88.2	109	129	171	212	255	298		
CARD NO. 43 TEMPLATE AREA 16 cm^2	NUMBER OF DROPS	41	118	121	85	85	40	45	7	2	1	0		545
	DROP DENSITY (drops cm^{-2})	2.562	7.375	7.562	5.312	5.312	2.500	2.812	0.4375	0.1250	0.0625	0		34.06
CARD NO. 46 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	44	83	54	21	21	11	5	3	1	0	0		243
	DROP DENSITY (drops cm^{-2})	5.500	10.380	6.750	2.625	2.625	1.375	0.6250	0.3750	0.1250	0	0		30.38
CARD NO. 50 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	69	91	60	24	14	5	2	1	0	0	1		267
	DROP DENSITY (drops cm^{-2})	8.625	11.38	7.500	3.000	1.750	0.6250	0.2500	0.1250	0	0	0.1250		33.38
CARD NO. 54 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	44	105	84	35	25	19	5	1	0	0	0		318
	DROP DENSITY (drops cm^{-2})	5.500	13.12	10.50	4.375	3.125	2.375	0.6250	0.1250	0	0	0		39.74
CARD NO. 57 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	8	21	36	26	43	39	20	9	3	0	0		205
	DROP DENSITY (drops cm^{-2})	1.000	2.625	4.500	3.250	5.375	4.875	2.500	1.125	0.375	0	0		25.625
CARD NO.	NUMBER OF DROPS													
TEMPLATE AREA cm^2	DROP DENSITY (drops cm^{-2})													
A	Mean drop diameter (μm)	23.0	38.5	58.4	78.5	99.0	119.3	151.0	192.2	234.2	277.1	320.0		
B	Mean drop mass (mg)	6.796 x10^{-6}	3.188 x10^{-5}	1.113 x10^{-4}	2.703 x10^{-4}	5.421 x10^{-4}	9.466 x10^{-4}	1.924 x10^{-3}	3.967 x10^{-3}	7.117 x10^{-3}	1.189 x10^{-2}	1.831 x10^{-2}		
C	Sum of drop densities by size category	23.19	44.88	36.81	18.56	18.19	11.75	6.812	2.188	0.625	0.0625	0.125		
D	Average drop densities by size category (drops cm^{-2})	4.638	8.976	7.362	3.712	3.637	2.350	1.362	0.4375	0.1250	0.0[illegible]	0.025		
E	Cumulative drop densities	4.638	13.61	20.98	24.69	28.33	30.68	32.04	32.48	32.60	[illegible]1	32.64		32.64
F	Cumulative percent of drop densities	14.21	41.70	64.28	75.65	86.80	94.00	98.17	99.52	99.88	99.91	100		
G	Average deposition by size category (mg cm^{-2})	3.152 x10^{-5}	2.862 x10^{-4}	8.194 x10^{-4}	1.003 x10^{-3}	1.972 x10^{-3}	2.229 x10^{-3}	2.620 x10^{-3}	1.736 x10^{-3}	8.971 x10^{-4}	1.486 x10^{-4}	4.518 x10^{-4}		
H	Cumulative mass (mg)	3.152 x10^{-5}	3.177 x10^{-4}	1.137 x10^{-3}	2.140 x10^{-3}	4.112 x10^{-3}	6.341 x10^{-3}	8.961 x10^{-3}	1.070 x10^{-2}	1.159 x10^{-2}	1.161 x10^{-2}	1.207 x10^{-2}		1.207 x10^{-2}
I	Cumulative percent of mass	0.26	2.63	9.42	17.73	34.04	52.55	74.26	88.67	96.05	96.21	100		

area have been completed, the subtotals are added and the total number of stains in each size category are entered on the form (fig. 15) for each card analyzed.

Calculating the Droplet Size Distribution

After all five cards have been analyzed, determination of the droplet-size distribution can proceed. For convenience in explaining the calculations, the rows used in these calculations on the droplet spectrum data sheet (fig. 15) have been identified by the letters A through I.

Row A, mean droplet diameter

The volume-mean droplet diameter ($\bar{d}$) in each size category is calculated from the expression

$$\bar{d} = \left(\frac{d_2^3 + d_1^2 \, d_2 + d_1 \, d_2^2 + d_1^3}{4} \right)^{1/3}$$

where

d_1 = droplet lower limit for the size category

d_2 = droplet upper limit for the size category

For example, the entry in the first column of Row A is calculated as

$$\bar{d} = \left(\frac{(27.6)^3 + (17.6)^2 \, 27.6 + 17.6(27.6)^2 + (17.6)^3}{4} \right)^{1/3}$$

$$= 23.0 \ \mu m$$

Repeat the calculation for each size category and enter the result in the appropriate column of row A.

Row B, mean droplet mass

The mean droplet mass ($\bar{m}$) in mg for each size category is calculated from the relation

$$\bar{m} = \frac{\pi \rho}{6} (\bar{d})^3 \times 10^{-9}$$

$$= 5.236 \times 10^{-10} \ \rho (\bar{d})^3$$

where,

ρ = density of spray material in grams per cubic centimeter (g/cm^3)

For the example shown in figure 15, where the density of the spray material is 1.064 g/cm^3, the entry in the first column of row B is

$$\bar{m} = 5.236 \times 10^{10}(1.067)(23.0)^3$$

$$= 6.796 \times 10^{-6}\text{mg}$$

Repeat the calculation for each size category and enter the result in the appropriate column of Row B.

Row C, sum of droplet densities by size category

The sum of droplet densities by size category is obtained by summing the droplet density in each size category over all the cards analyzed in the swath. In the example in figure 15, the result for the first column in Row C is

$$2.562 + 5.500 + 8.625 +$$

$$5.500 + 1.000 = 23.187\ (23.19)$$

where 2.562 is the droplet density from card 43, size category 1, 5.5 is the droplet density from card 46, size category 1, and so on.

Repeat the summation procedure for each size category and enter the results in the appropriate column of Row C.

Row D, average droplet densities by size category

The average droplet density in each size category is obtained by dividing the sum of droplet densities in Row C by the number of cards included in the analysis (5, here).

For the example shown in figure 15, we get

$$\frac{23.19}{5} = 4.638$$

which should be entered in the first column of Row D for size category 1.

Row E, cumulative droplet densities

The cumulative droplet densities shown in Row E of figure 15 were calculated from the average densities recorded in Row D. The cumulative density recorded in each size category column of Row E is the cumulative sum up to and including the average droplet density recorded for that size category in Row D. For the example shown in figure 15 in Row E for category size 3, the cumulative droplet density is

$$4.638 + 8.976 +$$

$$7.362 = 20.976 = 20.98$$

Continue the summation procedure across Row D until the cumulative density for each size category has been calculated and recorded in the appropriate column of Row E. Also, enter the cumulative sum for the largest category (32.64 in fig. 15) in the total columns of Row E.

Row F, cumulative percent of droplet densities

The cumulative percent of droplet densities is calculated for each size category by dividing the cumulative droplet density for each category in Row E by the cumulative droplet density in the total column of Row E and multiplying by 100.

For the example in figure 15, the cumulative percent in the first column of Row F for size category 1 is

$$\frac{4.638}{32.64} \times 100 = 14.21 \text{ percent}$$

Calculate the cumulative percent of droplet densities for every size category and record the result in the appropriate column of Row F.

Row G, average deposition by size category

The average mass deposition by size category is calculated by multiplying the mean droplet mass in a given size category in Row B by the corresponding average droplet density in Row D. Thus, the average deposition for category 1 in Row G of figure 15 was obtained from

$$(6.796 \times 10^{-6})(4.638) = 3.152 \times 10^{-5} \text{mg/cm}^2$$

Complete the calculation for each size category and enter the results in the appropriate column of Row G.

Row H, cumulative mass

The cumulative mass for each size category shown in Row H of figure 15 is calculated from the average deposition values recorded in Row G. The cumulative mass recorded in each size category column of Row H is the cumulative sum up to and including the average deposition recorded for that size category in Row G. In figure 15 the cumulative mass for Row H, size category 3, is

$$3.152 \times 10^{-5} + 2.862 \times 10^{-4} + 8.194 \times 10^{-4} = 1.137 \times 10^{-3}$$

Continue the summation procedure across Row G until cumulative mass for each size category has been calculated and recorded in the appropriate column of Row H. Also enter the cumulative sum for the largest category (1.207×10^{-2} in fig. 15) in the total column for Row H.

Row I, cumulative percent of mass

The cumulative percent of mass is calculated for each size category by dividing the cumulative mass for each category in Row H by the cumulative mass in the total column of Row H and multiplying by 100. In figure 15, the cumulative percent in the first column of Row I for size category 1 is

$$\frac{3.152 \times 10^{-5}}{1.207 \times 10^{-2}} \times 100 = 0.026 \text{ percent}$$

Calculate the cumulative percent of mass for size category and record the result in the appropriate column of Row I.

The Mass(Volume)-Median Diameter

This is the droplet diameter that divides the spray deposition distribution into two equal parts by mass (volume). The mass(volume)-median diameter is obtained from a graph of the cumulative percent of mass from Row I of figure 15 plotted as a function of the droplet upper limit for the size category on logarithmic probability paper. Figure 17 shows the example distribution from Row I of figure 15 plotted on two-cycle log probability paper. The mass(volume)-median diameter is the diameter corresponding to the

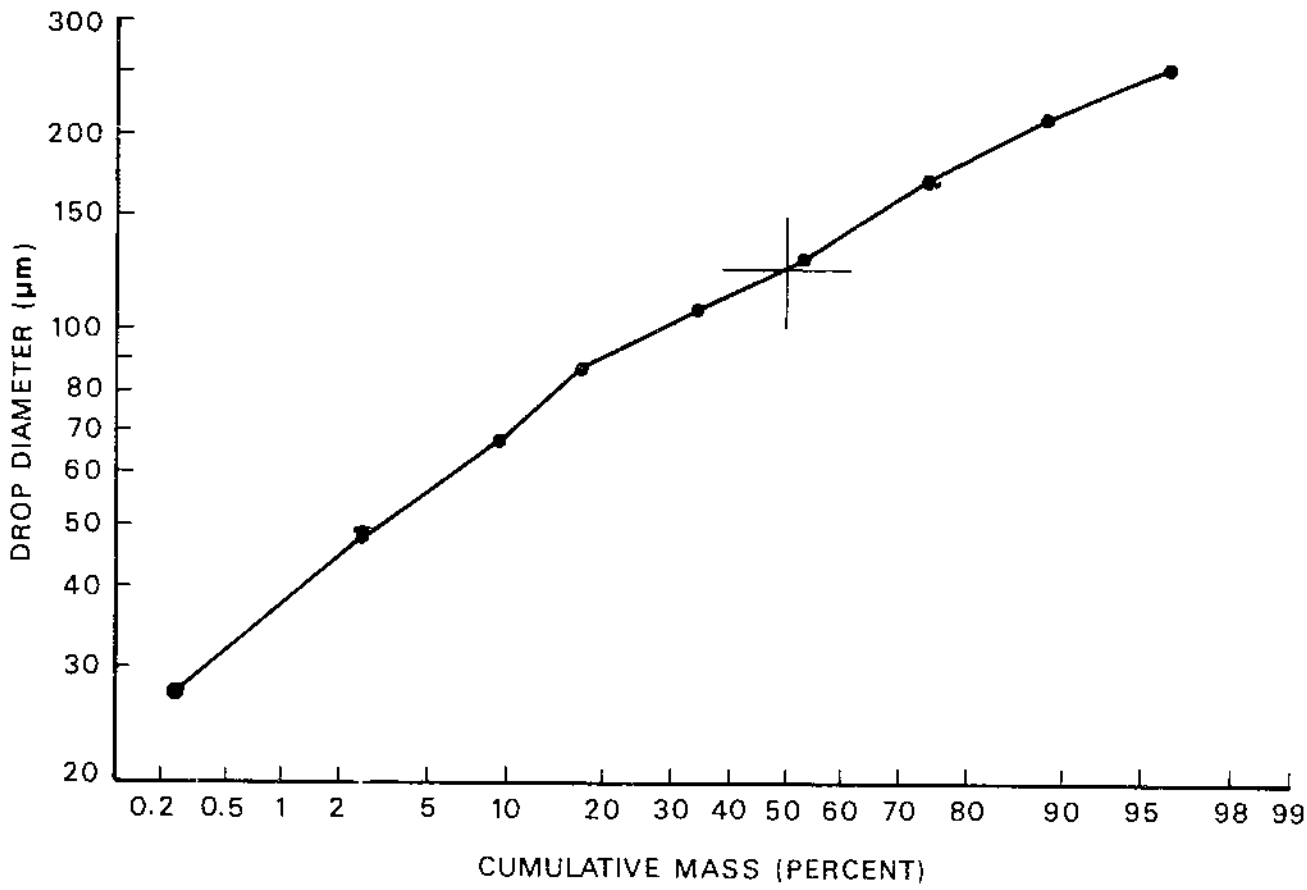


Figure 17.—Cumulative mass distribution from row I of figure 15. The symbol + marks the median of the cumulative mass distribution.

intersection of the mass distribution curve with the 50-percent line on the plot. For the example distribution, the mass(volume)-median diameter is 125 μm.

The Average-Mass Diameter

This is calculated from the expression

$$amd = 10^3 \left(\frac{6\bar{M}}{\pi\rho\ \bar{N}_D} \right)^{1/3}$$

where

$\bar{M}$ = total cumulative mass deposited on all cards from the total column of row H in figure 15.

$\bar{N}_D$ = total cumulative drop density on all cards from the total column of row E in figure 15.

Thus, for the example distribution in figure 15,

$$amd = 10^3 \left(\frac{6(1.207 \times 10^{-2})}{\pi\ (1.067)(32.64)} \right)^{1/3}$$

$$= 87\ \mu m$$

The Number-Median Diameter

This is the droplet diameter that divides the spray deposition distribution into two equal parts by the number of droplets counted. The number-median diameter is obtained from a graph of the cumulative percent of droplet densities from Row F of figure 15 as a function of droplet upper limit for the size category on logarithmic probability paper. If the cumulative percent of droplet densities from Row F for the example in figure 15 is plotted on log probability paper, the number-median diameter is about 54 μm.

Mass Deposited on Cards

The mass deposited on each card within the swath can be obtained under the assumption that the mass distribution calculated in figure 15 is representative of the distribution on each card in the swath. Under this assumption, the mean mass in milligrams of all droplets on the card is

$$\bar{m} = 5.236 \times 10^{-10}\ \rho (amd)^3$$

and the mass deposited in units of milligrams per square centimeter on the card

$$M = \bar{m} \times \text{total droplet density on the card}$$

where the total droplet density for individual cards is obtained from the total column for each card in figure 15. For example, an estimate of the mass deposited on card No. 43 is

$$M = 5.236 \times 10^{-10} (1.067)(87)^3 \times 34.06$$

$$= 1.253 \times 10^{-2} mg\ cm^{-2}$$

Field Estimation of Spray Deposit Mass From Kromekote Card Data

Keith Dumbauld

Rapid assessment of spray deposit immediately after spray operations is essential to effective use of aircraft in forest spray operations. Timely recognition that the spray deposit is unsatisfactory (for example, too spotty or of undesired density) allows the project director to take appropriate corrective action, such as rescheduling flight operations and requesting adjustments in the flow rate or other parameters affecting spray deposition. Under Contract No. 26-3843 with the U.S. Forest Service, Missoula Equipment Development Center, the H. E. Cramer Company has analyzed spray-deposit card data from selected Forest Service spray projects to determine the feasibility of using statistical relations in the development of field techniques for estimating the spray-deposit density on Kromekote sample cards. The analysis of the spray-card data and the field procedure for estimating spray-deposit mass developed from the analysis are described below.

Approach

Because analytical relations exist among basic parameters of theoretical droplet-size distributions (Herdan, 1960), the study was based on the premise that significant statistical relations between mass deposited on spray cards and easily estimated distribution parameters could be determined from historical spray data. Specifically, we decided to determine the statistical relations between the mass- or volume-median droplet diameter (mmd) on a sample card and the average mass diameter (amd). The average mass diameter is defined as the diameter of the droplet whose mass, when multiplied by the number of drops on a card, is equivalent to the total mass deposit on the card. Thus, if a significant relation between the mmd and amd could be demonstrated, the mass density on a card could be obtained from estimates of the mmd and the droplet density on the card. In a previous study, Dumbauld and Rafferty (1977) showed that the droplet density on sample cards could easily be estimated in the field and that the D-max method developed by Maksymiuk for estimating the mmd in the field laboratory (see chapter 6) could be adapted for use in the field.

Spray-deposit card data in the form of computer cards and tabulations containing deposit card spectral counts of stains in 16 size categories from five spray projects were supplied by FI&DM Methods Application Group in Davis, California. A modified version of the ASCAS program described in chapter 7 was used to calculate droplet-distribution parameters, including the mmd and amd, for each sample card, and the results were put on magnetic computer tape. A least-squares regression analysis program was then used to evaluate the constants a and b in the expression

$$amd = a(mmd)^b$$

from the card data for the various spray formulations used. The results of the regression analysis for Dylox, SEVIN 4 Oil, and the microorganism *Bacillus thuringiensis* are given in table 4. The results of the regression analysis are given for cards in open areas as well as for all

cards (including cards underneath the drip-line of trees and on sampling grids within the forest).

Estimation of Spray-Deposit Mass Density

We used the results of the regression analysis given in table 4 to calculate the ratio of the mass density on a card (expressed in units of gallons per acre) to the droplet density on the card (expressed in units of drops per square centimeter) from the relation

$$\frac{\text{gallons/acre}}{\text{drops/cm}^2} = \frac{m}{d} = 5.598 \times 10^{-9} a^3 (\text{mmd})^{3b}$$

where the mmd is in micrometers.

The solid lines in figures 18 through 23 represent the ratio m/d for the regression parameters and spray formulations in table 4. The dashed lines represent the 95-percent confidence interval about the line of regression.

The mass density on a sample card can be estimated from figures 18 through 23 if the mmd and the droplet density d on the card are known. For example, if the mmd for a card in the open area sprayed with Dylox is estimated to be 400 μm and the droplet density on the card is 15 droplets/cm^2, the mass density on the card according to figure 18 is

$$9.13 \times 10^{-2} \frac{\text{gal/acre}}{\text{droplets/cm}^2} \times 15 \frac{\text{droplets}}{\text{cm}^2} = 1.37 \frac{\text{gal}}{\text{acre}}$$

Table 4--

RESULTS OF THE REGRESSION ANALYSIS RELATING THE amd AND mmd ON SAMPLE CARDS *

Spray Formulation	Cards in Open Areas					All Cards				
	a	b	R	S.E.	N	a	b	R	S.E.	N
Dylox	1.396	.8683	.985	.009	232	1.517	.8572	.954	.014	2079
SEVIN 4 Oil	1.286	.8586	.980	.054	100	1.401	.8505	.935	.142	858
Bacillus thuringiensis	1.684	.8474	.892	.011	789	1.524	.8573	.909	.186	4261

*R = correlation coefficient
S.E. = standard error
N = number of cards used in the analysis

The confidence intervals shown in figure 18 indicate that the actual mass density could be expected to vary between 0.8 and 2.3 gal per acre 95 percent of the time for an mmd of 400 μm and droplet density of 15 droplets/cm^2.

Nomographs for Field Estimation of Mass Densities on Sample Cards

The nomographs in figures 24 through 29 have been constructed from the results of the regression analysis for use in field estimation of the mass density on sample cards. To use the nomographs, estimates of the mass-median diameter and droplet density on the card must be made. As noted above, field procedures for estimating these parameters are described by Dumbauld and Rafferty (1977). Estimates of mass density are obtained from the nomograph by using a straight-edge to draw lines connecting the droplet density estimates (left-hand scale) and mass-median diameter estimates (right-hand scale) for the card; the mass densities in units of gallons per acre are then read at the points where the lines cross the center scale. The example straight line in figure 24, drawn between an mmd of 400 μm and droplet density of 15 droplets per square centimeter for a card in the open sprayed with Dylox, indicates a mass density on the card of about 1.4 gal/acre.

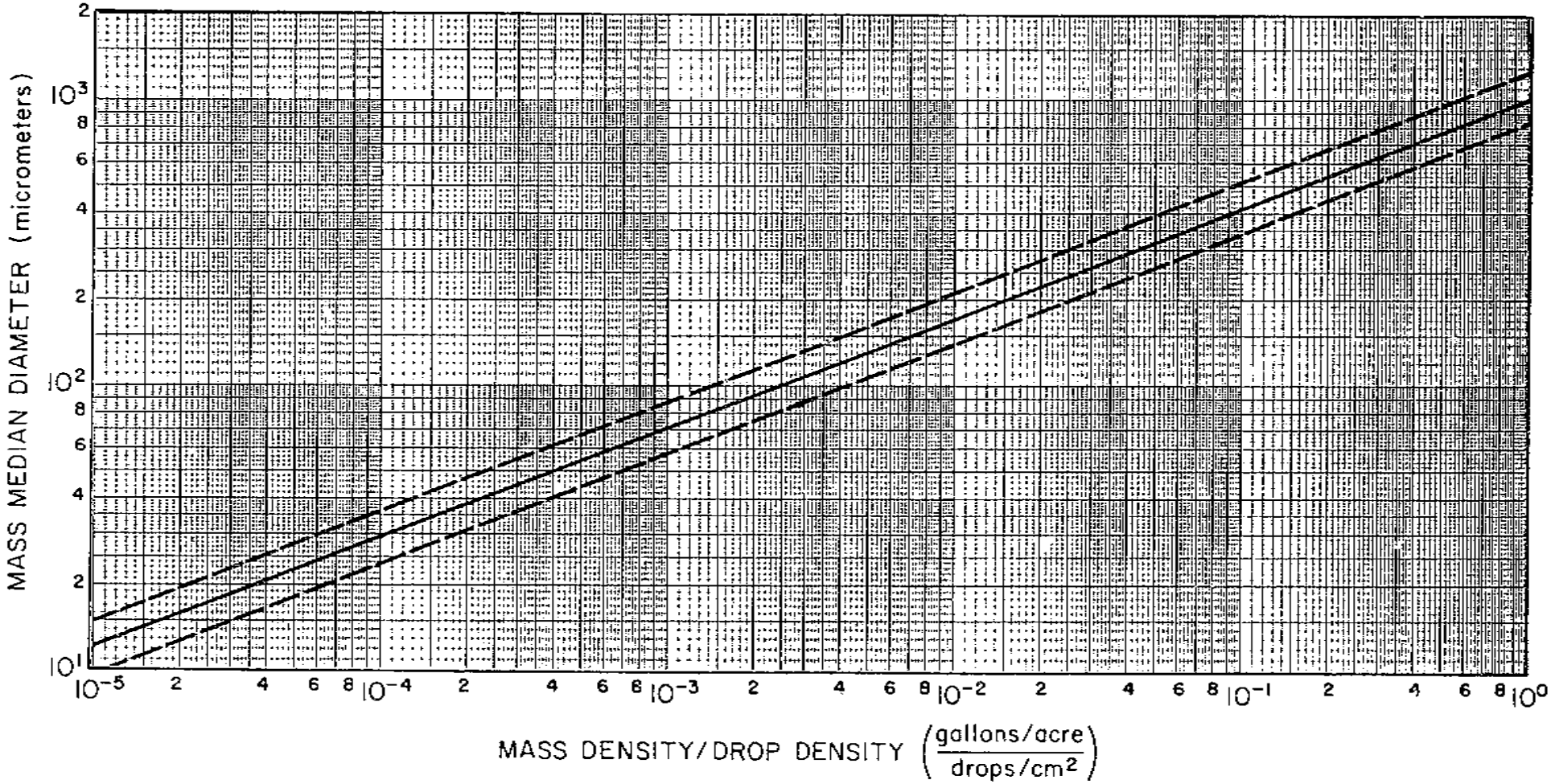


Figure 18.—Ratio of mass density and droplet density versus mass-median diameter for Dylox on sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

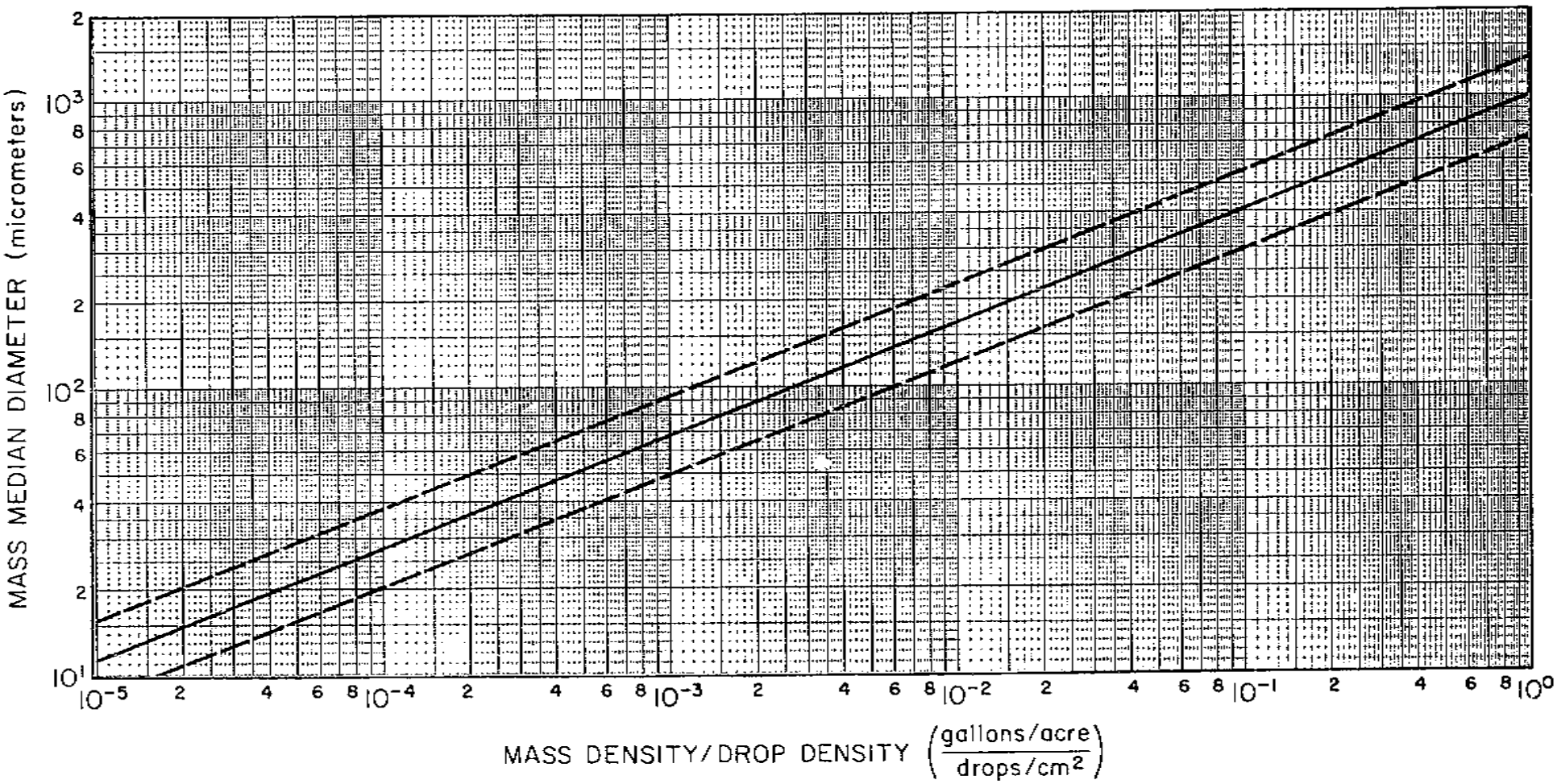


Figure 19.—Ratio of mass density and droplet density versus mass-median diameter for Dylox on all sample cards. Dashed lines represent the 95 percent confidence interval.

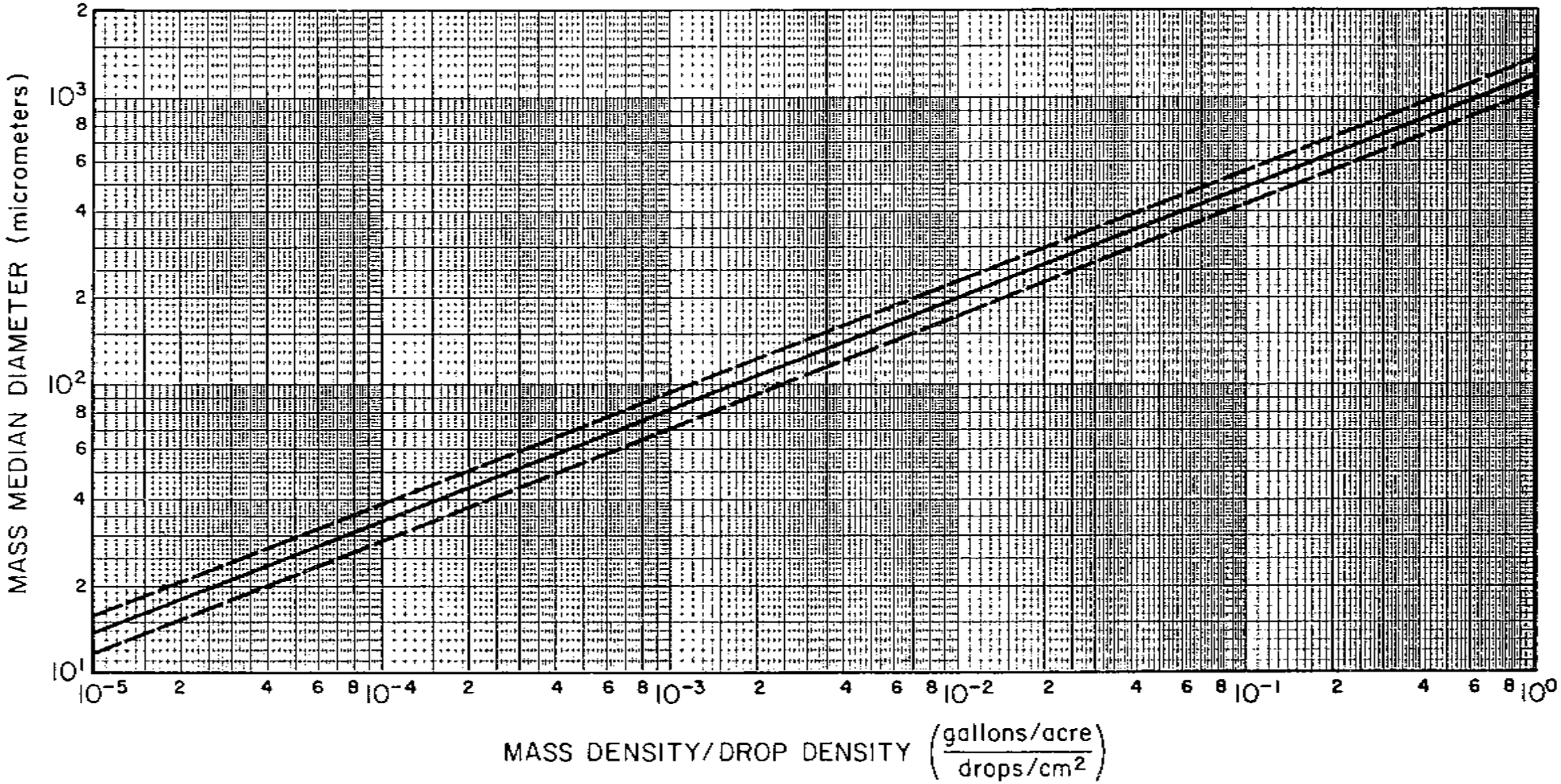


Figure 20.—Ratio of mass density and droplet density versus mass-median diameter for SEVIN 4 Oil on sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

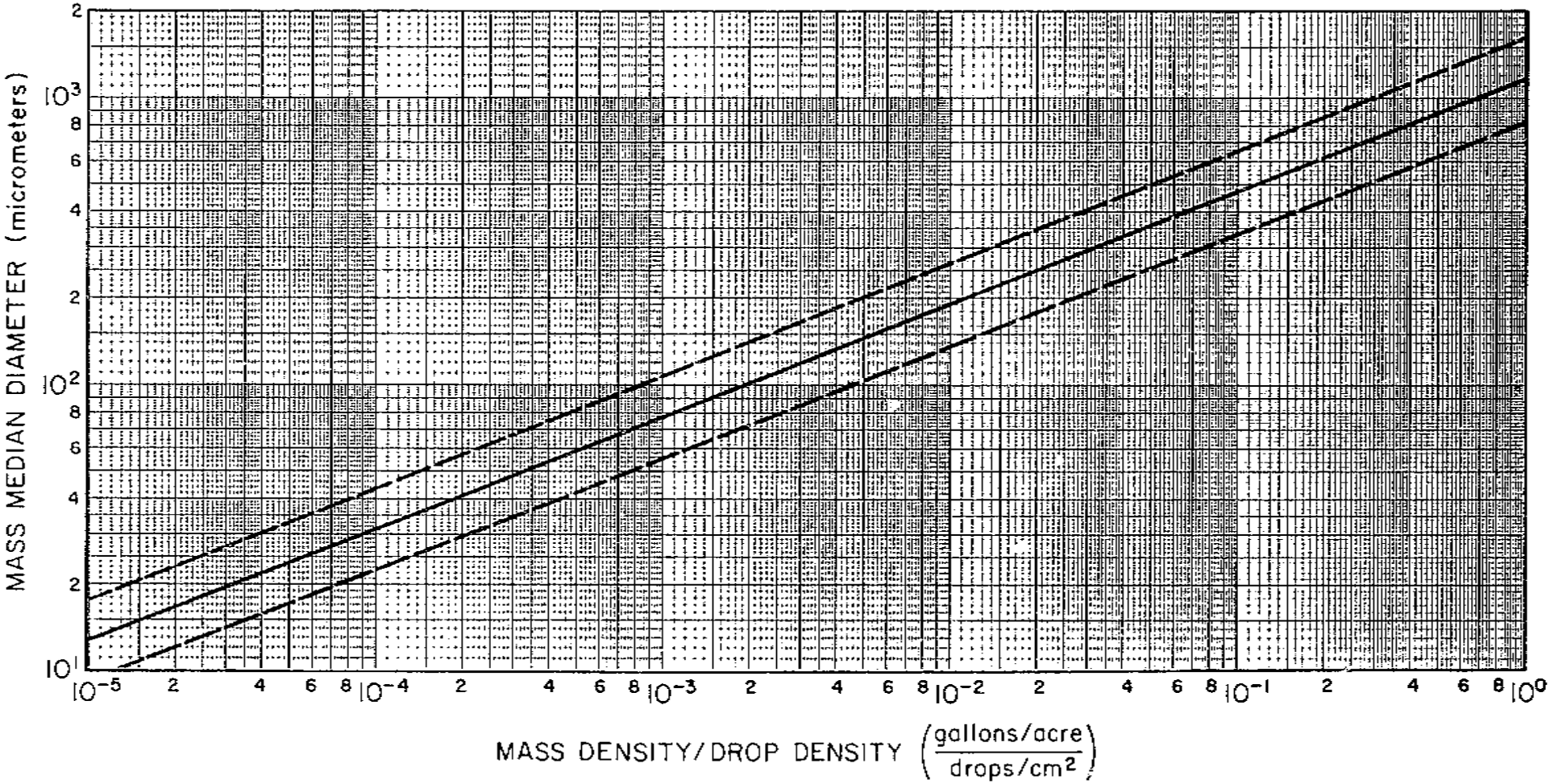


Figure 21.—Ratio of mass density and droplet density versus mass-median diameter for SEVIN 4 Oil on all sample cards. Dashed lines represent the 95 percent confidence interval.

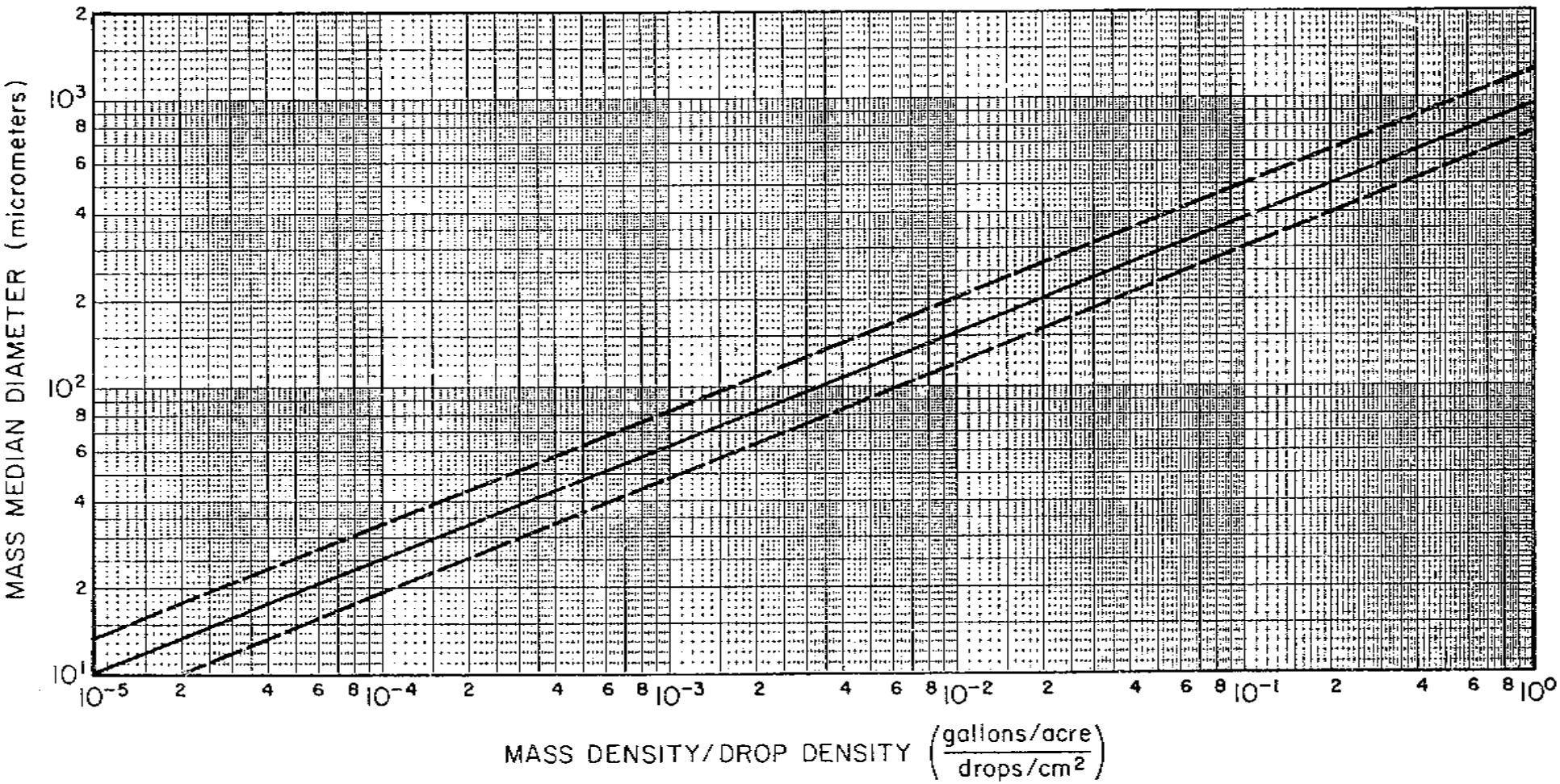


Figure 22.—Ratio of mass density and droplet density versus mass-median diameter for *Bacillus thuringiensis* on sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

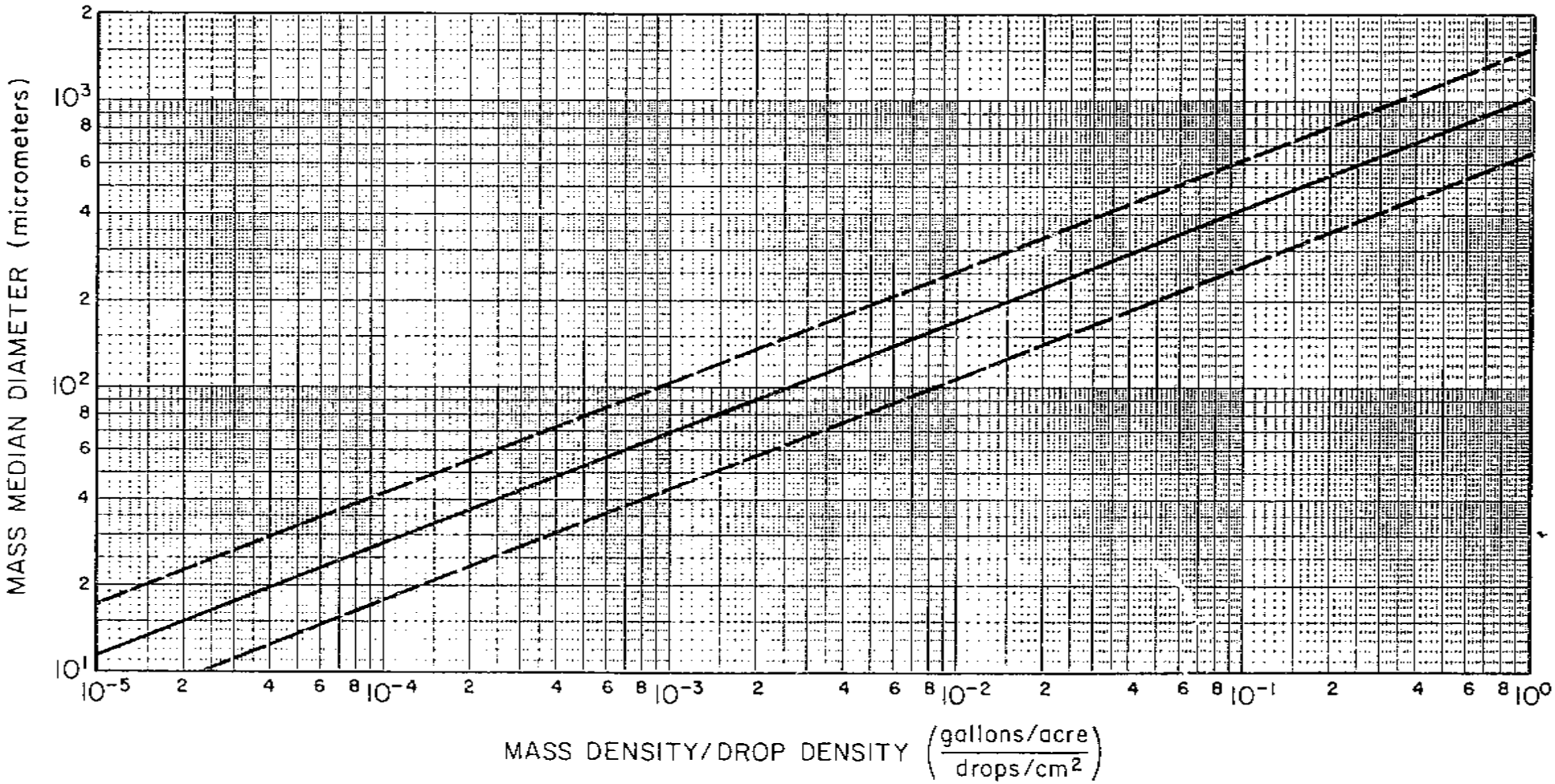


Figure 23.—Ratio of mass density and droplet density versus mass-median diameter for *Bacillus thuringiensis* on all sample cards. Dashed lines represent the 95 percent confidence interval.

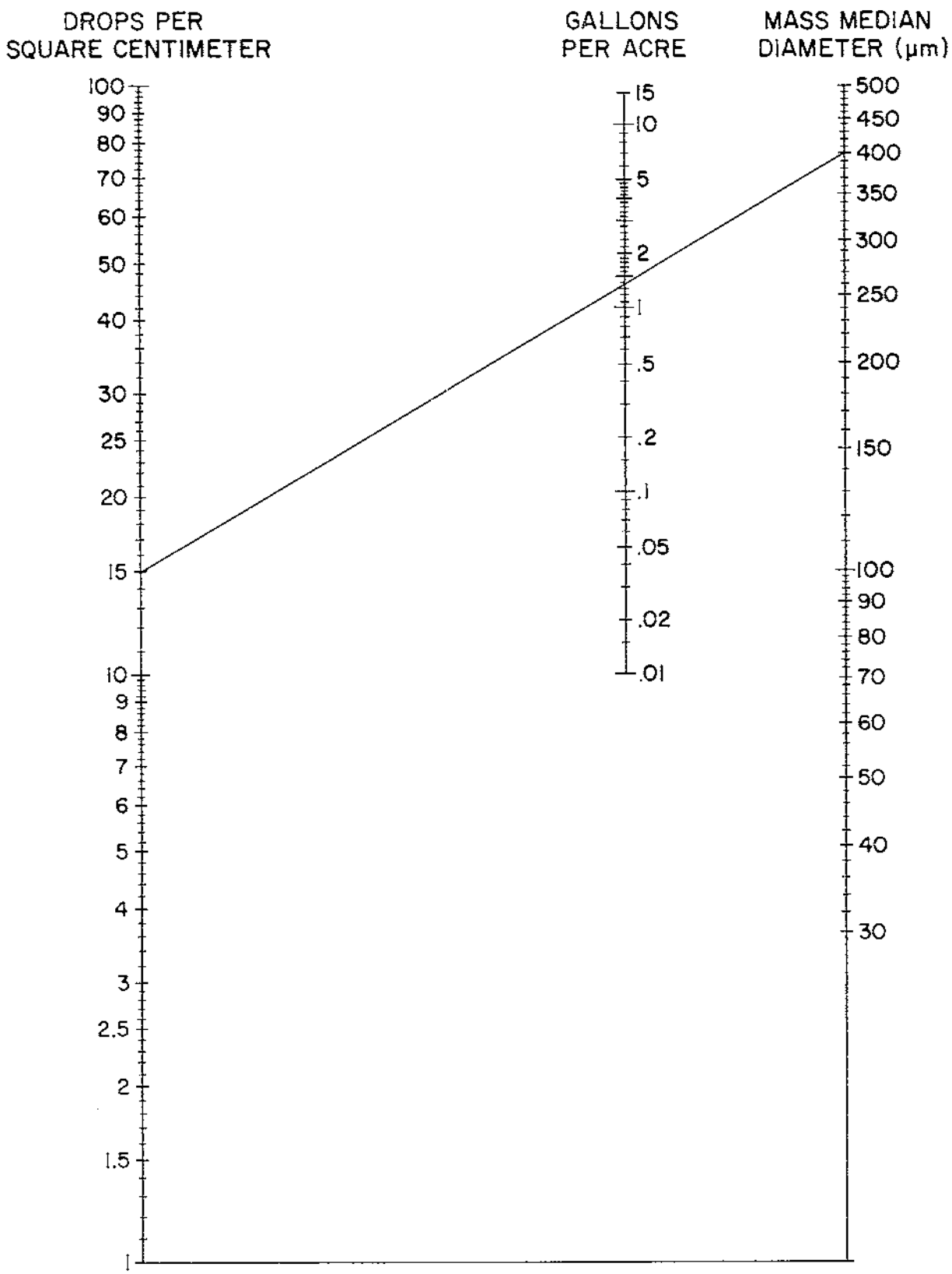


Figure 24.—Nomograph for field estimation of mass density (gallons/acre) of Dylox from the mass-median diameter and droplet density (drops/square centimeter) on sample cards in the open.

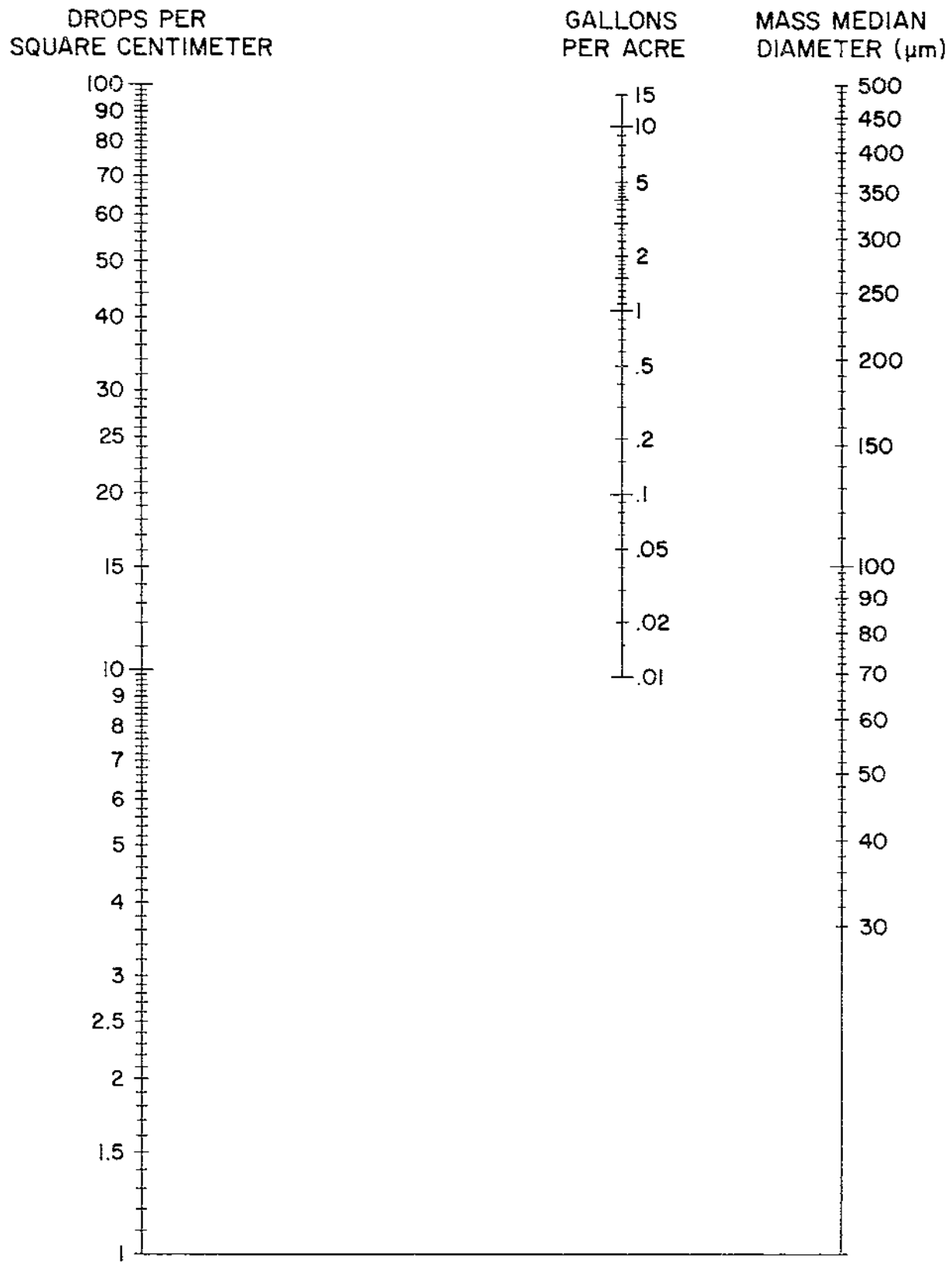


Figure 25.—Nomograph for field estimation of mass density (gallons/acre) of Dylox from the mass-median diameter and droplet density (drops/square centimeter) on all sample cards.

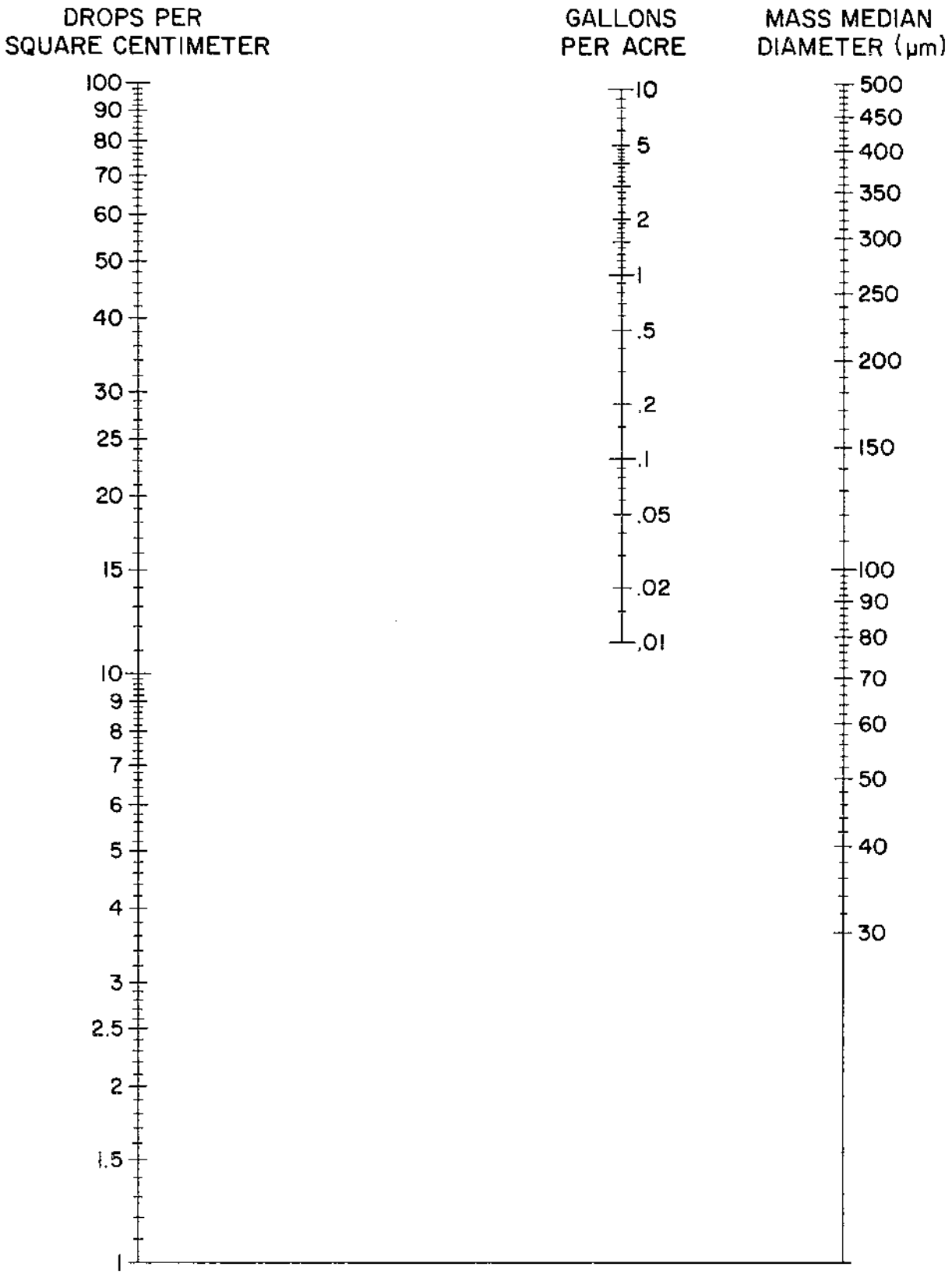


Figure 26.—Nomograph for field estimation of mass density (gallons/acre) of SEVIN 4 Oil from the mass-median diameter and droplet density (drops/square centimeter) on sample cards in the open.

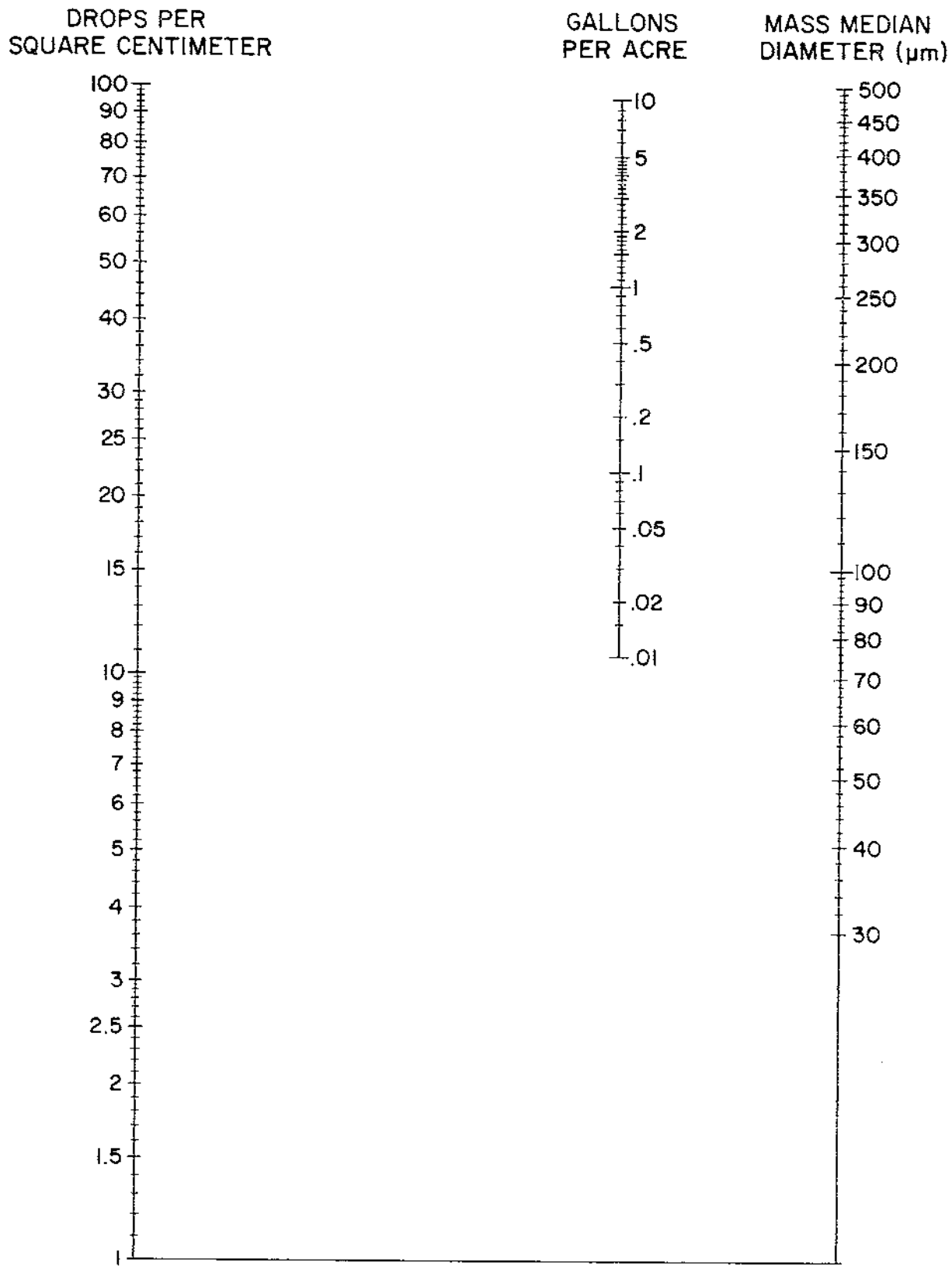


Figure 27.—Nomograph for field estimation of mass density (gallons/acre) of SEVIN 4 Oil from the mass-median diameter and droplet density (drops/square centimeter) on all sample cards.

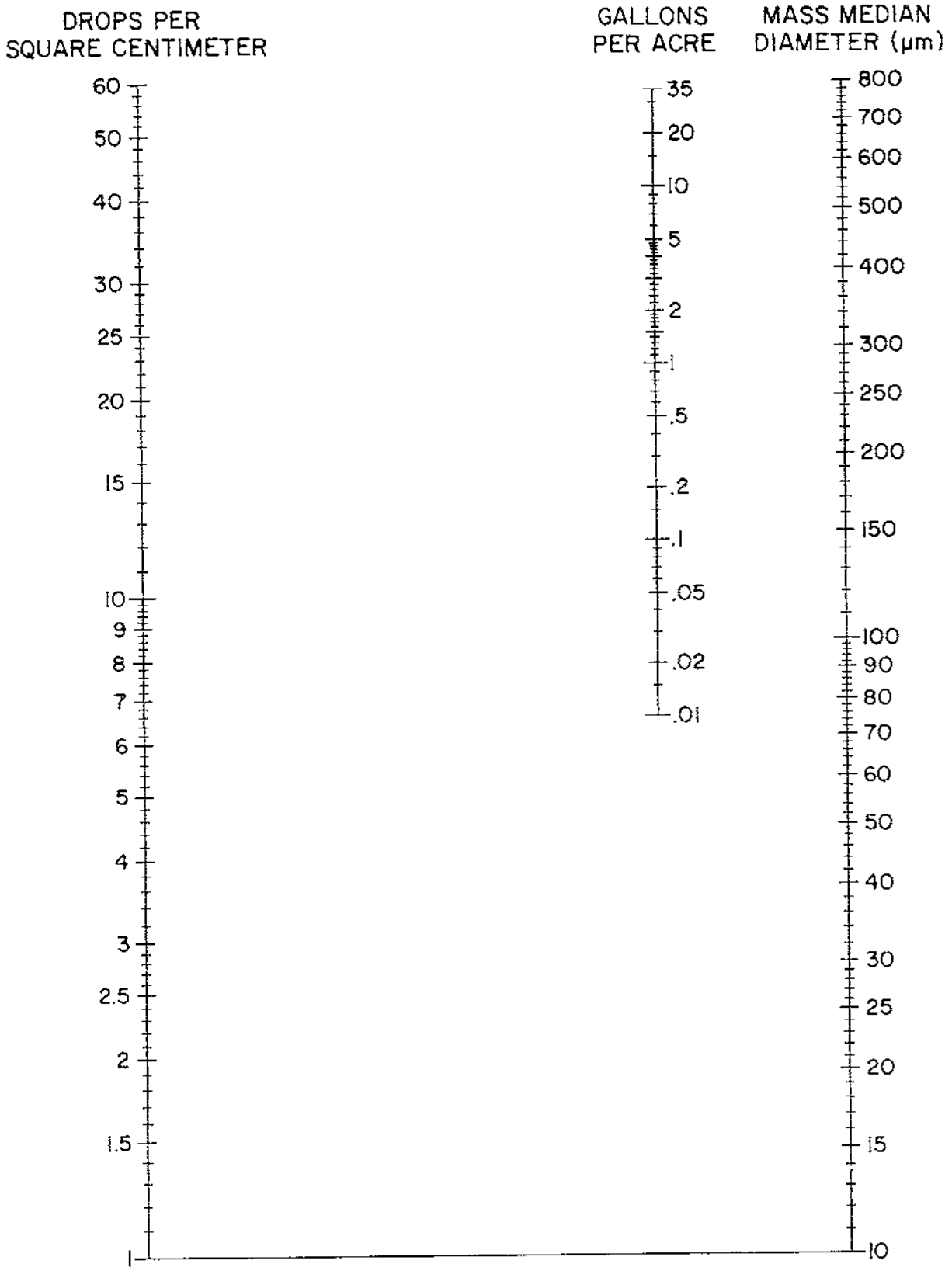


Figure 28.—Nomograph for field estimation of mass density (gallons/acre) of *Bacillus thuringiensis* from the mass-median diameter and droplet density (drops/square centimeter) on sample cards in the open.

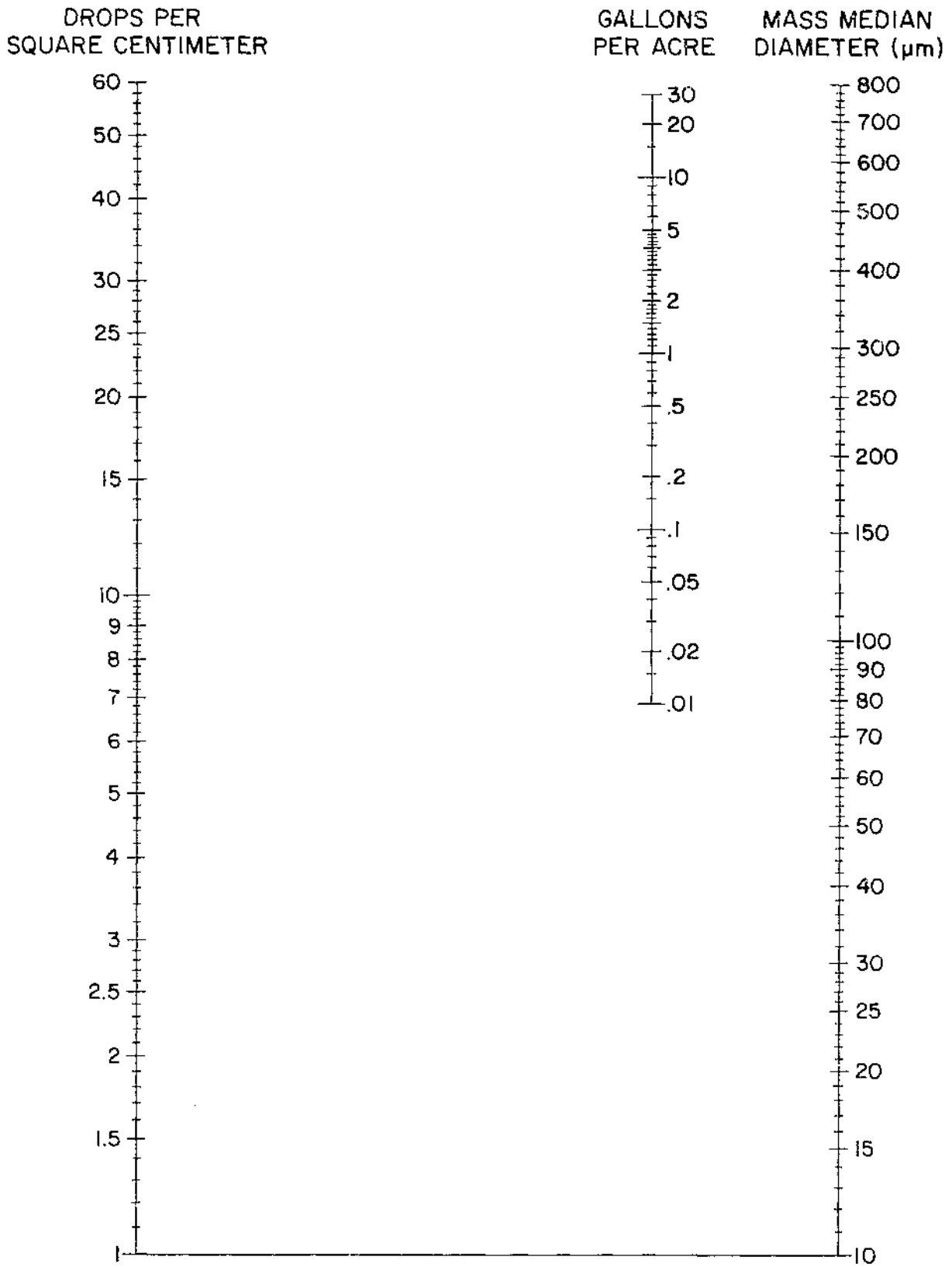


Figure 29.—Nomograph for field estimation of mass density (gallons/acre) of *Bacillus thuringiensis* from the mass-median diameter and droplet density (drops/square centimeter) on all sample cards.

CHAPTER 6 LABORATORY ANALYSIS METHODS

Spread Factor of Pesticide Spray Formulations on Cards[1,2]

Richard Waite

Introduction

To understand the effects of aerial application of pesticides, it is important to determine relationships between target effect and spray factors such as drop density, atomization, and gallons per acre. Spray-deposit assessment is the key to the determination of these factors.

Since determination of atomization and gallons per acre requires knowing actual drop diameters, we must employ a corrective spread factor to the stain marks on our sampling surface to find the actual drop size. This conversion, or spread factor, is the ratio of the diameter of the stain to the diameter of the drop causing it.

The determination of a particular spread factor involves the production, collection, and measurement of groups of uniform size droplets from which a calibration curve can be made.

This paper summarizes the spread factor determination on white Kromekote cards for various pesticidal formulations.

Materials and Methods

Uniform spherical droplets were produced by means of a vibrating reed apparatus (fig. 30) similar to that described by Davis (1951) and Maksymiuk and Moore (1962). The reed, which bore a needle affixed at the end, was vibrated at resonance to produce maximum amplitude. As the needle passed through the liquid emanating from a hypodermic syringe, streams of droplets were formed (fig. 31). A water manometer was used to provide a constant flow of liquid from the syringe. Back lighting provided easy viewing of the stream of droplets. Uniform size droplets, 50 to 500 micrometers (μm) in diameter, were produced by varying the amplitude of the reed vibration, needle size, flow rate, and reed position in the liquid emanating from the syringe.

Dyes were added to the spray formulation to make the spots visible. Mainly fluorescent dyes were used, such as Brilliant Sulpho Flavine FFA (BSF) and Rhodamine B extra S which are water-soluble, and Rhodamine B extra base, an oil-soluble dye.

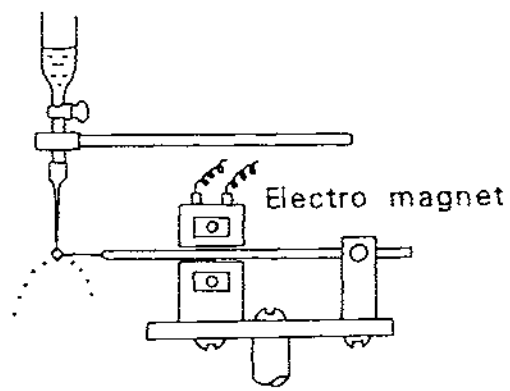


Figure 30.—Vibrating reed apparatus for generating droplets.

1/ This section is a paper published by Waite (1977).

2/ Another set of spread factor data developed by Wedding follows this section.

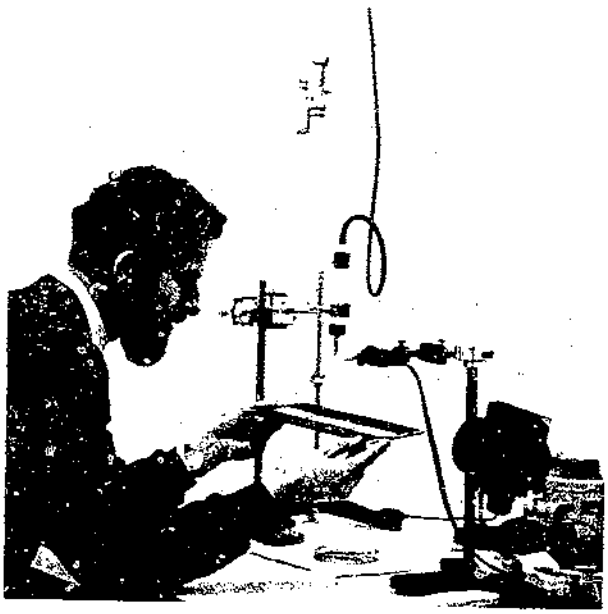


Figure 31.—Droplets produced by vibrating reed droplet generator are caught on sampling tray.

Nonfluorescent dyes, Nigrosine, a black water-soluble dye, and Sudan Deep Black, an oil-soluble dye, were also used occasionally. The dye concentration was 0.1 gm per 100 ml (0.1 percent w/v) in all the spray formulations except as noted in the tables. All of the dyes mentioned here are manufactured by General Dyestuff Division.

Spread factor was determined by passing cards and magnesium oxide (MgO) coated slides through a stream of uniform droplets produced by the vibrating reed apparatus and then performing the necessary measurements and calculations. The spherical drop diameter is the diameter of the crater formed by the droplet penetrating the MgO coating multiplied by a conversion factor of 0.86. According to May (1950) this conversion factor varies slightly with droplet size. The thickness of the MgO coating must be at least the diameter of the impinging drops. The slides and cards are viewed with a binocular microscope with a reticle containing a calibrated scale inserted in one of the oculars. With transmitted light, the inside diameters of the craters are readily visible and easily measured (in our case to the nearest 50 µm). Depending on the dye used, the spots on cards are viewed with reflected white or ultraviolet light and their outside diameters measured to the nearest 50 µm. Before measuring, sufficient time must be allowed for the spots to cease spreading. The time needed will depend on the type of formulation. Water-base formulations reach their maximum spread in less than 1 hour, whereas oil-base formulations will continue to spread for several hours.

Variation is minimized by using the mean of 10 spots or drops from each card and its corresponding slide. These values are used in the following formula for the spread factor determination of that drop size:

$$\text{spread factor} = \frac{\text{outside spot diameter on card}}{\text{inside MgO crater diameter} \times 0.86}$$

To account for the variation of spread factor with drop size, the spread factor must be determined for the working range of drop sizes. Maksymiuk and Moore (1962) found that the relationship between the drop diameter and spot diameter for fuel oil number 2 was linear for drops larger than 125 µm. A

linear regression equation can, therefore, be conveniently used to convert spot diameters to drop diameters.

Results and Discussion

Table 5 shows spread factors for microbial insecticidal formulations for *Bacillus thuringiensis* (Dipel and Thuricide) and the Douglas-fir tussock moth nucleopolyhedrosis virus (NPV). These are all water-base formulations and have spread factors in the vicinity of 2.00. Two formulations were filtered, and one was decanted because the complete formulation would not flow through the syringe needle. The data obtained for these three should not be construed as representing the complete formulation.

Table 6 depicts a variety of oil- and water-base chemical insecticidal formulations; the variation of spread factor according to the formulation of a particular insecticide is of special interest. Several insecticidal carriers are also included in table 6.

The first part of table 7 indicates that the type or concentration of dye may make a difference in the spread factor. When distilled water was used as a solvent, spread factor differences up to 17 percent were found for different dyes (0.5 percent Nigrosine vs. 0.5 percent Calcofluor) and up to 11 percent for different concentrations (0.1 percent Nigrosine vs. 0.5 percent Nigrosine). Adding a wetting agent to water greatly increased the spread factor (water + detergent + 0.1 percent Nigrosine vs. water + 0.1 percent Nigrosine). The spread factors of a few fertilizers and herbicides are shown at the bottom of the table.

Several complicating factors are evident in spread factor determination. Halo effects around spots can be caused by the unequal spreading of different ingredients in certain formulations. They can also be formed if the sampling card is damp. Precautions should be taken to prevent dampening of cards. The exact conditions of dampness for a spread factor calibration cannot be matched in the laboratory.

Another problem is that of irregular spreading of certain formulations. The drop forms an irregular or noncircular shaped spot which is measured by taking an average of the maximum and minimum dimensions.

Two problems occur with the vibrating reed droplet generator due to the type of formulation used. First, water-base formulations differ from the oil-base formulations in that they do not generally form the two streams of uniform size droplets as the vibrating reed spreads liquid from the syringe. Often it is very difficult to isolate streams of droplets of uniform size, and it becomes a matter of patience.

Second, some formulations contain particulates that settle and often plug the syringe needle. This problem can be minimized by providing constant agitation.

The tables show the linear regression equation for each formulation with the range of spherical droplet

Table 5 -- *Spread factor and linear relation between spot (y) and droplet (X) diameter for microbial insecticides on Kromekote cards*

Formulation	Dye[1]	Mean spread factor	Range (spherical drop diameter µm)	Linear regression equation	Correlation coefficient
1/2 lb Dipel WP in 25% CIB (cargill insecticide base-molasses) and H_2O to make 1 gal (filtered)	Rhod B S	1.82	80-400	$X=\frac{y+34.37}{2.02}$	0.9970
1 lb Dipel WP in 25% CIB, and H_2O to make 1 gal (filtered)	Rhod B S	1.81	112-425	$X=\frac{y+87.00}{2.22}$	.9900
1/2 lb Dipel WB in 25% CIB, 3.2% Maywood formula, and H_2O to make 1 gal	BSF	2.42	86-387	$X=\frac{y-77.26}{2.02}$	.9832
1/2 lb Dipel WB in 25% CIB, 3.2% Maywood formula, 3% Chevron sticker, and H_2O to make 1 gal (decanted)	BSF	2.65	67-344	$X=\frac{y-46.59}{2.35}$	.9873
50% Dipel LC, 50% H_2O	Rhod B S	1.95	100-325	$X=\frac{y-2.77}{1.93}$	.9808
67% Dipel LC, 33% H_2O	Rhod B S	1.77	112-475	$X=\frac{y+140.86}{2.35}$	.9749
1/2 lb Dipel WP + 25% Sorbo and H_2O to make 1 gal	Rhod B S	1.69	64-592	$X=\frac{y+19.32}{1.83}$	.9950
1/2 lb Dipel WP + 25% Sorbo + 5% w/v Shade + H_2O to make 1 gal	Rhod B S	1.56	64-688	$X=\frac{y+81.12}{2.00}$	.9897
1 lb Dipel WP in 12.5% Biofilm, + H_2O to make 1 gal	BSF	2.79	86-344	$X=\frac{y-23.21}{2.69}$	.9762
1 lb Dipel, 0.125% Biofilm	Rhod B S	1.74	75-550	$X=\frac{y+48.70}{2.04}$	.9973[2]
25% Thuricide HPC, 25% CIB, 3% sticker,	BSF	2.24	92-516	$X=\frac{y+31.45}{2.40}$	.9560
and 47% H_2O	BSF	2.06	92-516	$X=\frac{y+42.78}{2.29}$	.9590[3]
50% Thuricide 16B, 50% H_2O	Rhod B S	1.88	87-525	$X=\frac{y-130}{1.87}$	.9976
25% Thuricide 16B, 75% H_2O	Rhod B S	1.94	100-300	$X=\frac{y-5.45}{1.91}$	.9951
50% Thuricide 16B, 0.2% w/v $FeCl_3$ and H_2O to make 1 gal	No dye	2.13	97-548	$X=\frac{y-16.24}{2.04}$	.9816
33% Thuricide 24B, 67% H_2O	Rhod B S	2.17	86-387	$X=\frac{y+28.58}{2.32}$	.9910
25% Thuricide 32B, 50% H_2O, 25% Sorbo	Rhod B S	1.64	86-333	$X=\frac{y+24.69}{1.80}$	.9944
50% Sandoz V[5], 50% H_2O[4]	No dye	1.62	129-280	$X=\frac{y+46.85}{1.87}$	.9652
25% CIB, 75% H_2O[4]	BSF	1.99	43-430	$X=\frac{y-61.85}{1.57}$	.9848
25% CIB, 0.5 lb/gal Shade + H_2O to make 1 gal[4]	BSF	1.94	70-323	$X=\frac{y+10.15}{2.00}$	.9769

[1] Rhod B S is Rhodamine B extra S and BSF is Brilliant Sulpho Flavine FFA.

[2] Printflex cards.

[3] Kromekote cards with glossy coat on one side.

[4] Carrier for nucleopolyhedrosis virus (NPV) formulation for Douglas-fir tussock moth.

[5] An aerial adjunct for virus formulation from Sandoz Co.

Table 6 --*Spread factor and linear relation between spot (y) and droplet (X) diameter for chemical insecticides on Kromekote cards*

Formulation	Dye	Mean spread factor	Range (spherical drop diameter um)	Linear[1] regression equation	Correlation coefficient
Oil base:					
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100® [3] in Klearol to make 1 gal	Rhod B[2]	4.30	86-344	$X=\frac{y+46.38}{4.57}$	0.9789
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100® [3] in Panasol® to made 1 gal	Rhod B	5.70	86-237	$X=\frac{y+51.34}{6.06}$	.9519
0.1 lb/gal Pyrethrins, 5.6% Dowanol DB®,	Oil red O	6.06	129-430	$X=\frac{y+139.82}{6.74}$	.9994
89.2% heavy mineral oil, 3.6% stabilizers	Oil red O	5.64	129-430	$X=\frac{y+183.20}{6.55}$	[4] .9956
67% Dylox 1.5®, 33% Orchex 796®	Rhod B	2.20	129-688	$X=\frac{y-9.66}{2.13}$	.9948
Dylox 1.5® oil undiluted	Rhod B	2.31	64-344	$X=\frac{y-70.48}{1.91}$	.9847
Dylox 4® undiluted	Rhod B	3.91	108-688	$X=\frac{y+37.52}{4.15}$	.9976
Fuel oil No. 2	Rhod B	4.82	43-258	$X=\frac{y+42.77}{5.26}$	.9923
SEVIN 4 Oil® undiluted	Rhod B	2.18	70-194	$X=\frac{y-17.24}{2.07}$	.9742
25% SEVIN 4 Oil®, 75% No. 2 fuel oil	Rhod B	4.09	76-344	$X=\frac{y+42.56}{4.30}$	.9941
67% SEVIN 4 Oil®, 33% No. 2 fuel oil	No dye	2.13	129-297	$X=\frac{y+63.60}{2.47}$	.9519
	No dye	2.12	129-297	$X=\frac{y+47.67}{2.37}$	[5] .9526
	No dye	2.38	129-297	$X=\frac{y+4.05}{2.40}$	[6] .9513
50% SEVIN 4 Oil®, 50% No. 2 fuel oil	Rhod B	2.31	86-443	$X=\frac{y+20.59}{2.40}$	.9945
10% Sumithion®, 20% Panasol®, 70% No. 2 fuel oil	Rhod B	4.32	86-312	$X=\frac{y+235.78}{5.60}$	.9915
Dowanol TPM® (carrier for Zectran®)	Sudan Deep Black	4.93	43-301	$X=\frac{y+60.74}{5.46}$	[4] .9905
Dowanol TPM®, (carrier for Zectran®)	No dye	7.69	65-387	$X=\frac{y+202.49}{9.45}$	[5] .9944
10% Zectran FS 1.5®, 90% No. 2 fuel oil	Rhod B	4.87	65-473	$X=\frac{y+107.71}{5.60}$	.9901
	Rhod B	4.86	65-473	$X=\frac{y+70.58}{4.90}$	[4] .9893
10% Zectran FS 1.5®, 90% Chevron C	Rhod B	3.99	75-430	$X=\frac{y+123.12}{4.86}$	[4] .9957
Water base:					
0.25 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	1.99	194-441	$X=\frac{y-30.99}{1.89}$	.9737
0.5 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	1.81	129-473	$X=\frac{y-29.84}{1.70}$	.9865
1 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	2.14	86-602	$X=\frac{y+44.24}{2.32}$	.9971
1 lb Dimilin 25% WP®, 10% Ethylene glycol, in H_2O to make 1 gal	Rhod B S	2.18	86-430	$X=\frac{y+16.46}{2.28}$	.9971
Imidan IE® undiluted	Rhod B	4.57	129-322	$X=\frac{y+23.79}{4.77}$	.9991
75% Imidan IE®, 25% H_2O	Rhod B	3.97	97-473	$X=\frac{y+204.72}{5.15}$	.9995
50% Imidan IE®, 50% H_2O	Rhod B	4.90	86-280	$X=\frac{y-95.37}{4.37}$	.9918
1 lb Orthene 75SP® in H_2O to make 1 gal	Nigrosine	2.18	43-494	$X=\frac{y+49.44}{2.41}$	.9880
1 lb Orthene 75SP®, 10% Ethylene glycol in H_2O to make 1 gal	Rhod B S	1.75	86-860	$X=\frac{y+38.09}{1.89}$	.9992
1 lb Orthene 75SP®, 0.1% w/v $FeCl_3$ in H_2O to make 1 gal	No dye	2.06	86-387	$X=\frac{y+33.39}{2.22}$	.9788

[1] Modified from the publication to solve for X rather than y.

[2] Rhod B is Rhodamine B extra base.

[3] Manufactured by B. F. Goodrich Co.

[4] Kromekote cards with glossy coat on one side.

[5] Red-dyed Kromekote cards.

[6] Blue-dyed Kromekote cards.

Table 7--*Spread factor and linear relation between spot (y) and droplet (X) diameter for water, herbicides and fertilizers on Kromekote cards*

Formulation	Dye	Mean spread factor	Range (spherical drop diameter μm)	Linear regression equation	Correlation coefficient
Water:					
Distilled water + detergent	0.1% Nigrosine	2.77	75-344	$X=\frac{Y+18.17}{2.89}$	0.9779
Distilled water	.1% BSF	1.85	32-387	$X=\frac{Y-10.91}{1.76}$	.9958
Distilled water	.1% Rhod B S	1.72	75-e02	$X=\frac{Y+19.32}{1.81}$	.9951
Distilled water	.1% Nigrosine	1.63	100-500	$X=\frac{Y+57.99}{1.90}$	.9896
Distilled water	.5% Nigrosine	1.82	129-430	$X=\frac{Y-38.72}{1.64}$	.9715
Distilled water	.5% Calcofluor	2.18	118-366	$X=\frac{Y-67.14}{1.85}$	.9324
Herbicides and Fertilizers:					
1723.0 g nitrogen, and H_2O to make 1 liter	Nigrosine	2.71	65-409	$X=\frac{Y+51.35}{2.93}$	.9866
422.6 g nitrogen, and H_2O to make 1 liter	Nigrosine	2.76	129-705	$X=\frac{Y-27.17}{2.67}$	.9900
16.3 g 2,4,5-T, and H_2O to make 1 liter	Nigrosine	2.86	27-2000	$X=\frac{Y+37.78}{3.08}$	.9993
2 lb Benlate, and H_2O to make 1 gal	Rhod B S	2.42	108-731	$X=\frac{Y+92.45}{2.70}$	.9949

diameters that were measured to determine this equation. The experimental mean spread factor may be utilized as a close approximation for calculations. The spread factor does not take into account, however, the variation of spread factor with droplet size. The correlation coefficient is greater than 0.95 in all cases except one, showing an excellent correlation between drop and spot size. Most of the work was done on white Kromekote paper--coated on both sides. A few other surfaces have been used, such as Kromekote coated on one side, Printflex, oil-sensitive red-dyed Kromekote (white Kromekote dipped in acetone with red dye), and blue-dyed Kromekote.

Aerodynamic drops, on impact, will spread on Kromekote cards and on most other collecting surfaces. Spreading and the degree of spreading depend on the physical properties of the collecting surface and the spray formulation.

Because drop diameters are required for determination of atomization and quantity of spray, the stain marks on the Kromekote cards are converted to actual drop size by means of a corrective spread factor. This conversion factor is the ratio of the diameter of the stain to the diameter of the aerodynamic drop causing it. The determination of a particular spread factor involves the production, collection, and measurement of groups of uniform-size droplets from which a calibration curve can be made.

Spread Factor of Selected Insecticide Tank Mixes[1]

James Wedding

Spreading of nine tank mixes was examined on different sample surfaces (table 8). Droplets of solutions 1, 5, 6, 7, 8, and 9 were generated by use of a vibrating orifice atomizer that produces predictable and reproducible droplet sizes between 0.5 and 200 µm with a geometric standard deviation of 1.01 (Berglund and Liu 1973, Wedding 1974, 1975). For droplets larger than 200 µm, a vibrating needle was used that was a modification of the one described by Schneider (1967). Each data point in figures 32 through 39 was the result of analyzing 30 or more stain diameters on the collection surface tested. For solutions 2, 3, and 4, a pneumatic atomizer was used. This instrument develops a complete size spectrum of 20-400 µm by using an air blast to force the suspension through small openings rather than developing individual single-size droplets. Atomization is a function of test-liquid chemistry and air pressure used.

The atomizer was first calibrated by using a solution (oleic acid) and a substrate with a known spread factor (oilphobic coated glass slides) as a standard. Then, each test solution was atomized and collected on MgO-coated slides, which were compared to the oleic acid results.

Once a definite reproducible size distribution was confirmed, the test solutions were again atomized and samples collected on the different substrates as indicated (table 8). Droplet measurements were then plotted on a graph of stain size against cumulated mass (expressed as a percent).

A second curve was described on the same graph using the spot size developed from the standard. Two curves developed were based on over 400 points. The spread factor was then determined using the ratio of unknown to the standard for different amounts of accumulated mass.

1/ For the data presented in table 8 and figures 32 through 39, some experimental data points are included in the figures, along with the functional form describing the plot of spread factor against aerodynamic size. These spread factors were determined by James Wedding under USDA Forest Service contract.

Table 8--*Insecticide tank mixes*

Tank mixes	Dye	Collection material	Specific mixture
1. Malathion® technical (95%1/ Cythion® Tech.)	None	Sudan Black cards	100% Malathion as received
2. SEVIN 4 Oil®: 80% SEVIN 4 Oil and 20% No. 2 fuel oil	None	Black construction paper	400 ml SEVIN 4 Oil 100 ml No. 2 fuel Oil
3. SEVIN 4 Oil: 80% SEVIN 4 Oil and 18% No. 2 fuel oil	Automate Red 2%	White Kromekote cards	400 ml SEVIN 4 Oil 90 ml No. 2 fuel Oil 10 ml Automate Red
4. SEVIN 4 Oil: 4 parts plus 1 part diesel fuel by volume	No dye	Black construction paper and Sudan Black cards	400 ml SEVIN 4 Oil 100 ml diesel fuel
5. Dylox 4®, 50%: HI SOL®, 4-5-T 48%	Automate Red 2%	White Kromekote cards	500 ml Dylox 4 480 ml HI SOL 4-5-T 20 ml Automate Red
6. Dylox 4, 24 oz; HI SOL, 8 oz	Automate Red 2%	White Kromekote cards	709.8 ml Dylox 4 236.6 ml HI SOL 19.3 ml Automate Red
7. Orthene 75S®, 1.33 lb and enough water to make 1 gal of total material	Rhodamine B 0.15% by weight	White Kromekote cards	301.9 g Orthene 75S diluted to 1.893 liter water 2.9 g Rhodamine B
8. Herbicide 2,4-D water mixture	Rhodamine B 0.15% by weight	White Kromekote cards	103.4 ml 2,4-D 896.4 gal water 1.5 g Rhodamine B

1/ % indicates volumetric ratios.

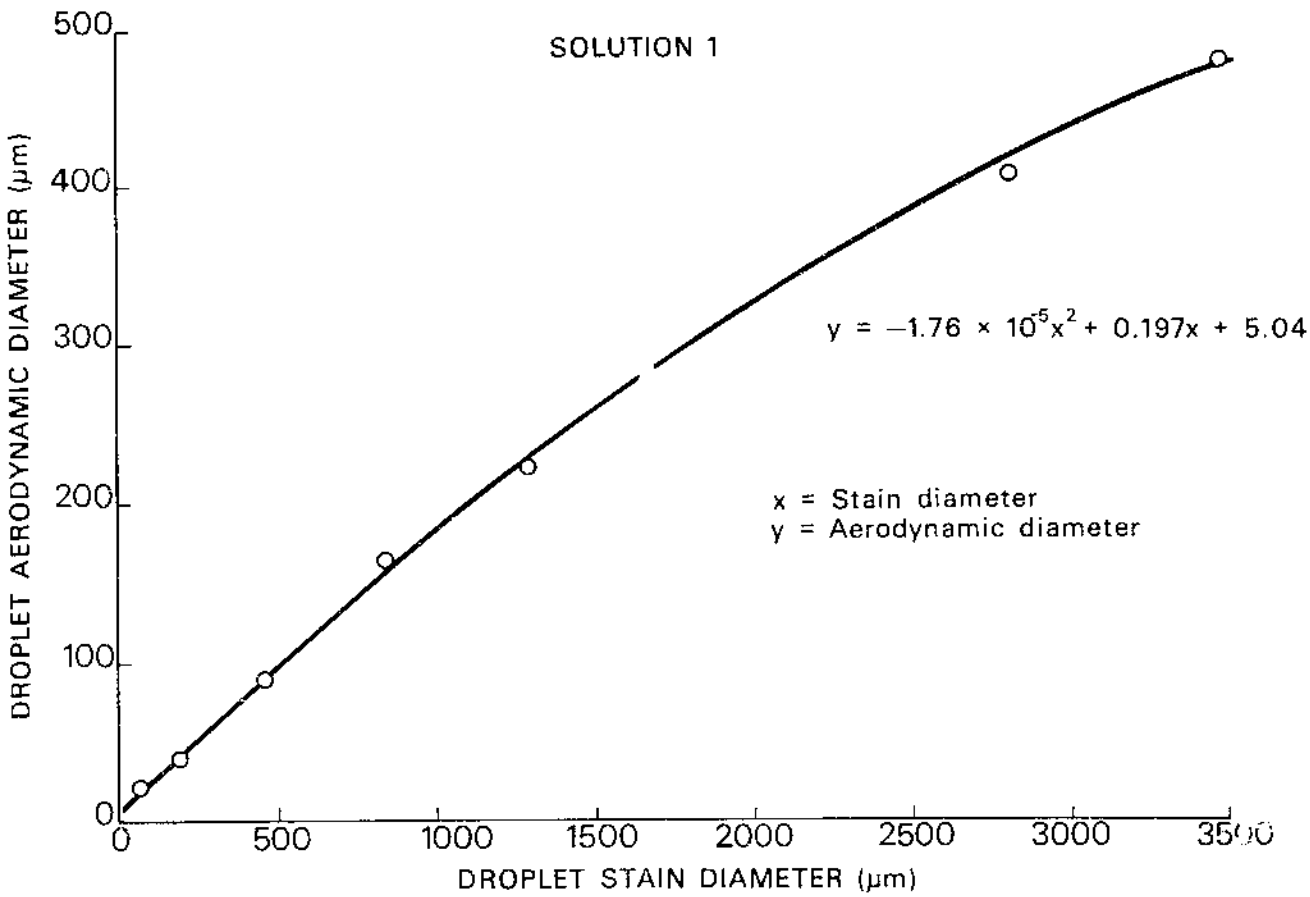


Figure 32.—Spread factor equation for malathion technical (95 percent Cythion technical) on Sudan Black cards.

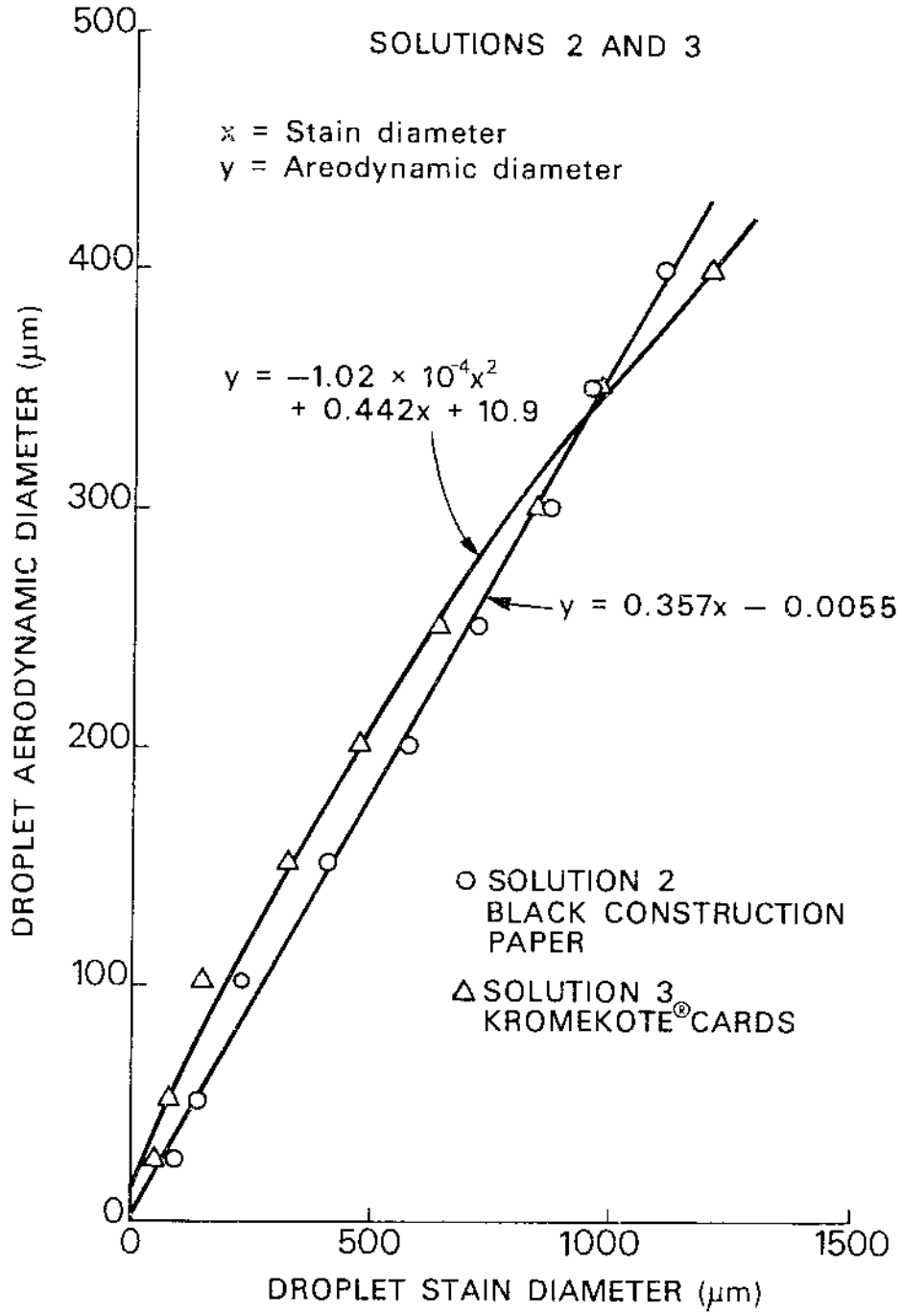


Figure 33.—Spread factor equation for SEVIN 4 Oil on black construction paper and white Kromekote cards.

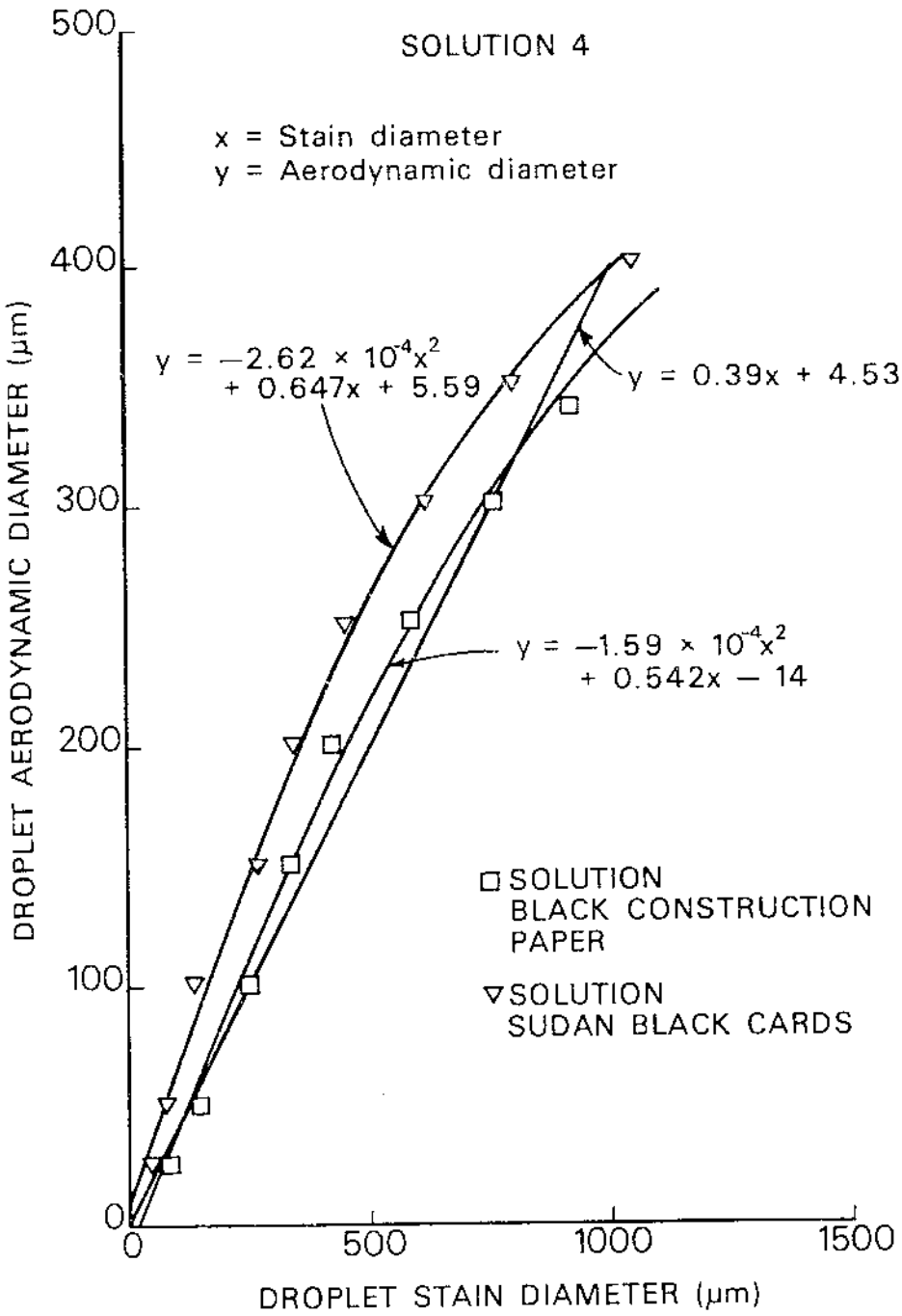


Figure 34.—Spread factor equation for SEVIN 4 Oil on black construction paper and Sudan Black cards.

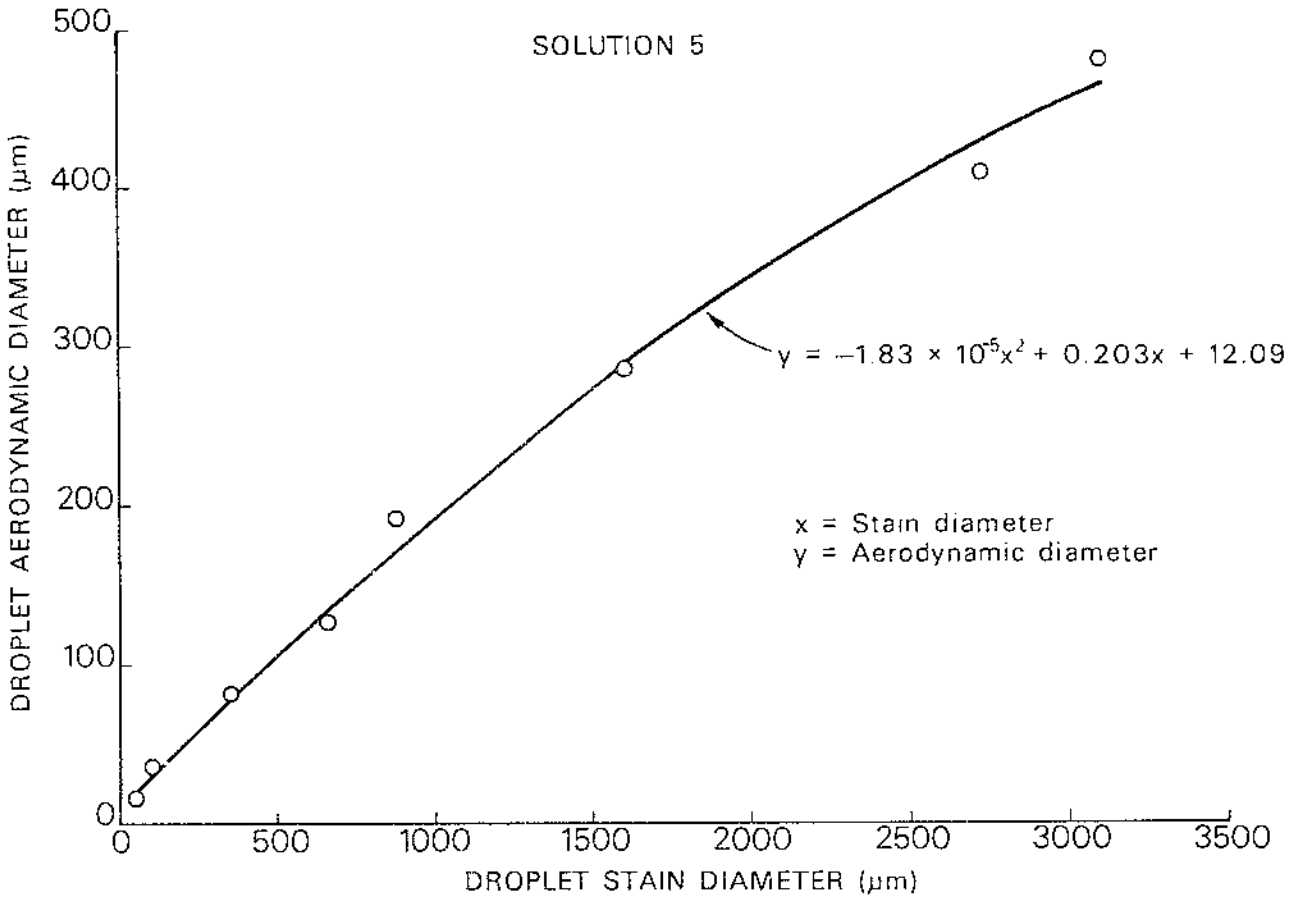


Figure 35.—Spread factor equation for Dylox 4, 50 percent, and HI SOL 4-5-T, 48 percent, on white Kromekote cards.

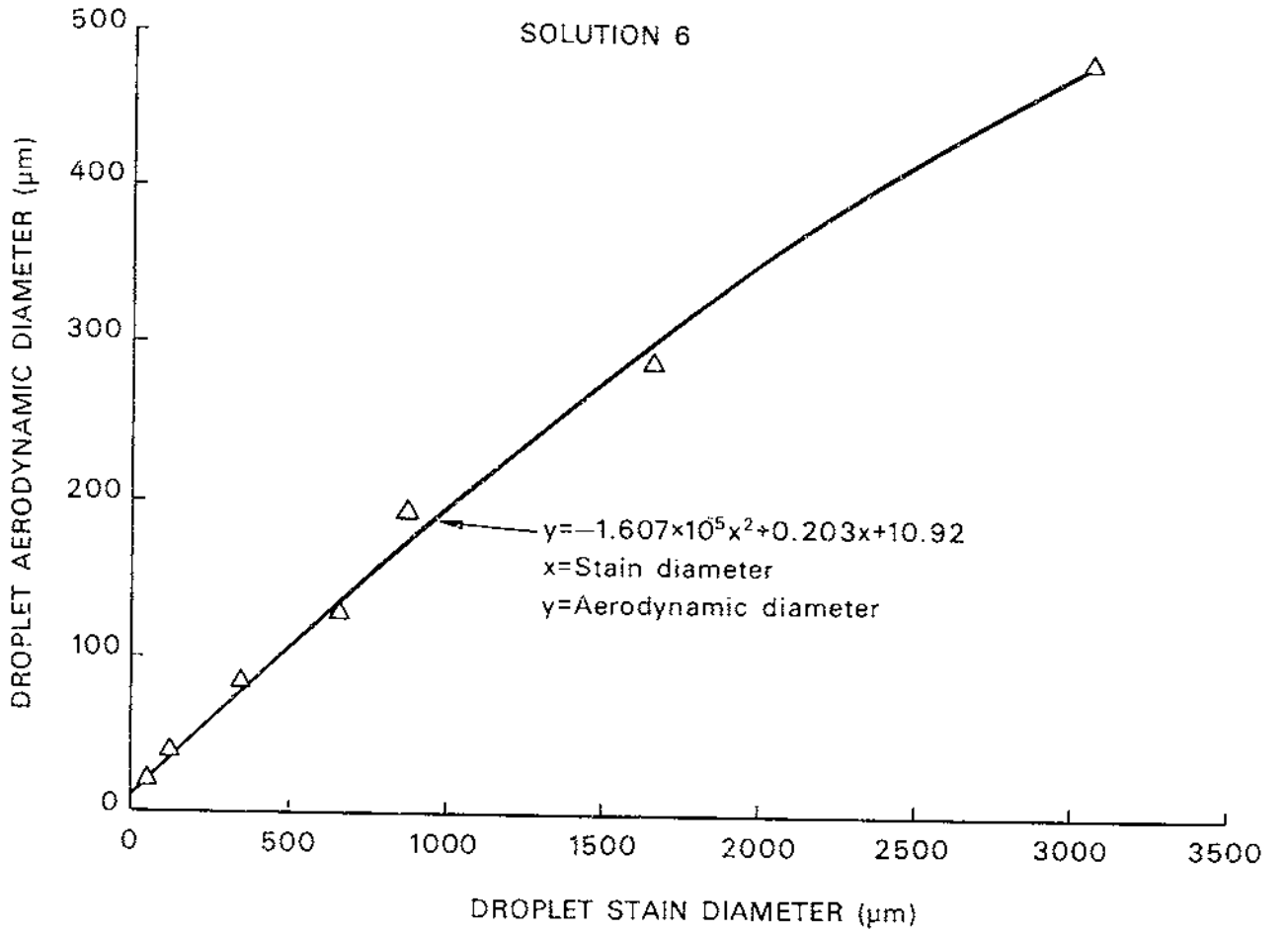


Figure 36.—Spread factor equation for Dylox 4, 24 oz, and HI SOL, 8 oz, on white Kromekote cards.

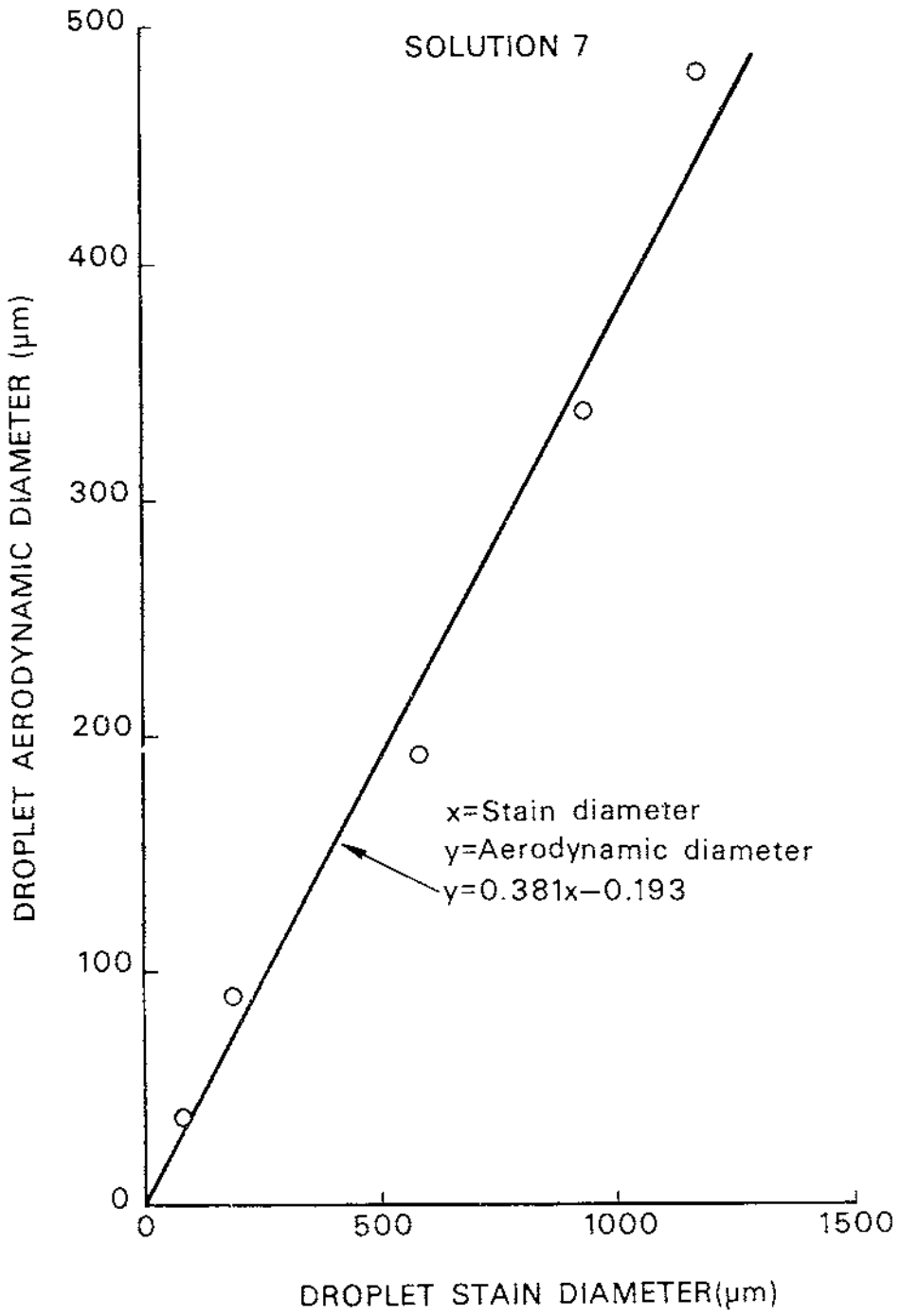


Figure 37.—Spread factor equation for 1.33 lb Orthene 75S in 1 gal water on white Kromekote cards.

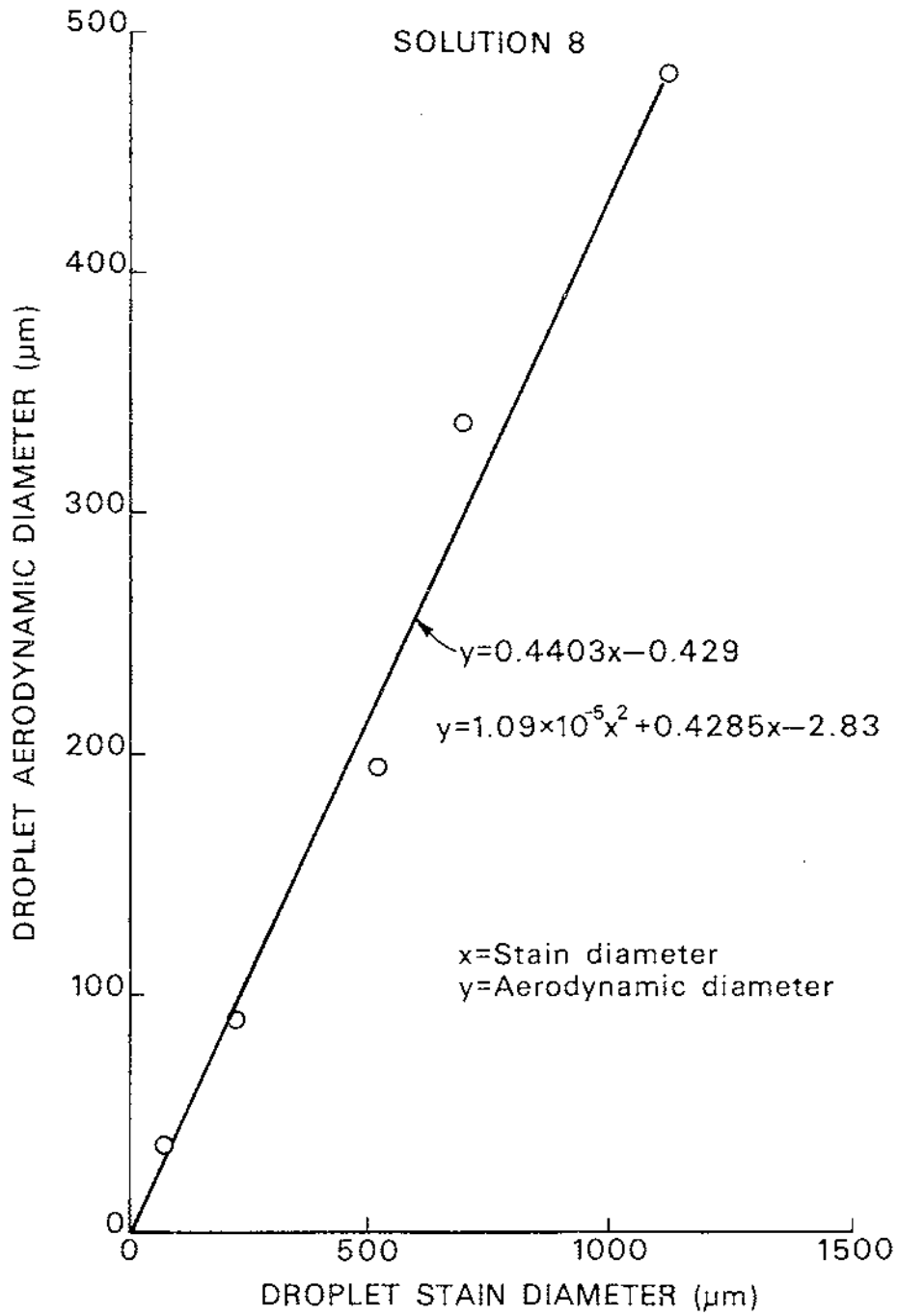


Figure 38.—Spread factor equation for 0.5 pound Orthene 75S in 1/2 gal water on white Kromekote cards.

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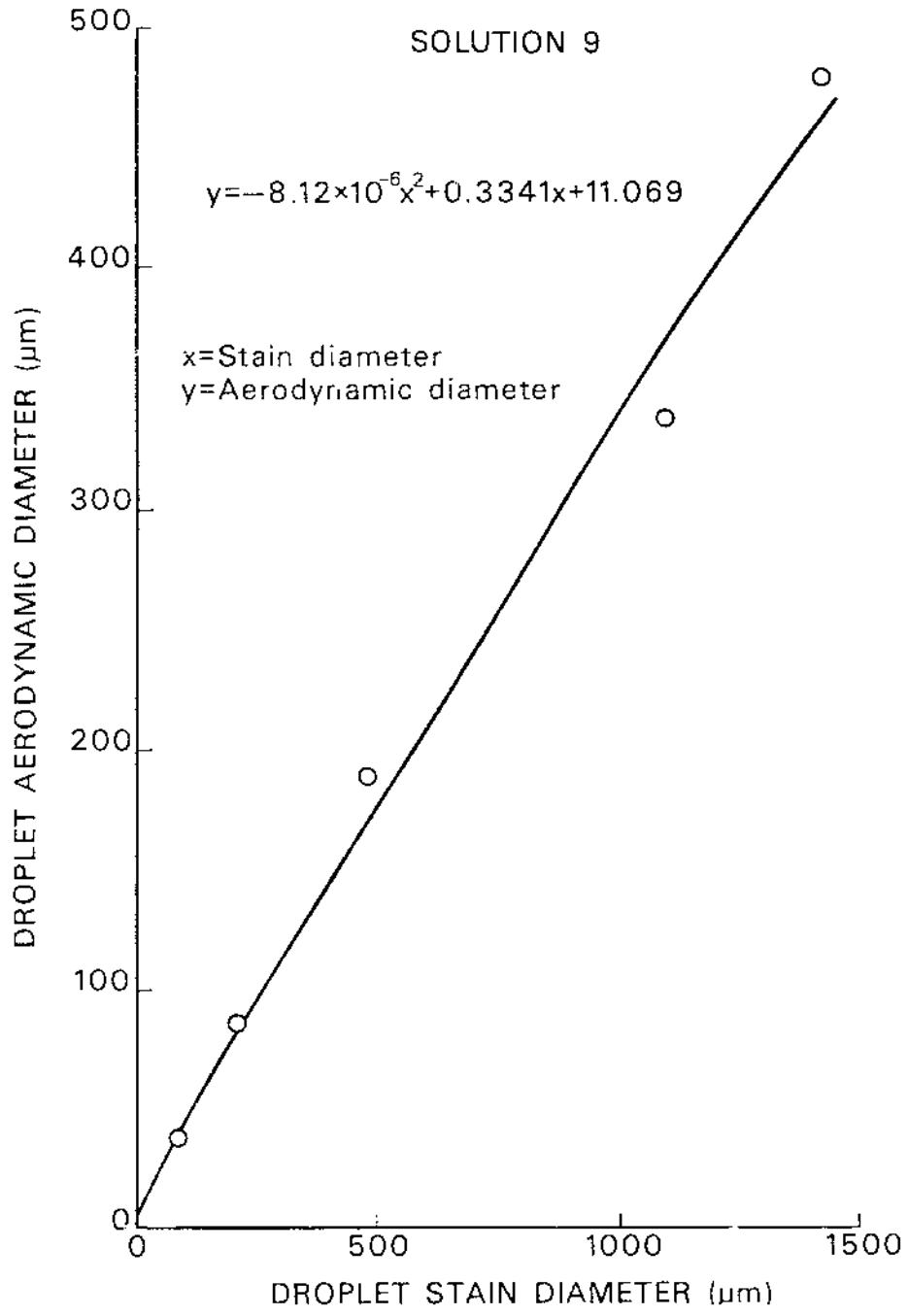


Figure 39.—Spread factor equation for herbicide 2,4-D water mixture on white Kromekote cards.

Image Analyzers for Deposit Card Assessment

Richard Waite

Automatic spot-counting instruments, called image analyzers, have been in use for several years. These instruments are capable of rapid and consistent sizing and counting of insecticide stains on deposit cards or photographic film and prints of these samples. The USDA Forest Service uses directly, or through contractors, an image analyzer computer called the Quantimet. An image analyzer computer is a sophisticated instrument that consists primarily of a closed-circuit television system with a detection unit and a computer unit (fig. 40). The Quantimet has been designed to meet a wide range of specific and individual image analysis problems. Each system consists of a particular configuration of modules, assembled to meet one or more defined, image analysis tasks. Systems can be expanded simply by adding new plug-in modules.

For sizing and counting spray-deposit stains on cards, a basic system consists of a macroviewer, a plumbicon or vidicon scanner (an improved TV camera), a system control and display unit (TV screen), a detector module, and a standard computer module. More sophisticated systems may incorporate modules that correct for uneven illumination of sampling surface, select desirable areas for analysis within the field of view, allow for automatic sizing of features, and permit area sizing.

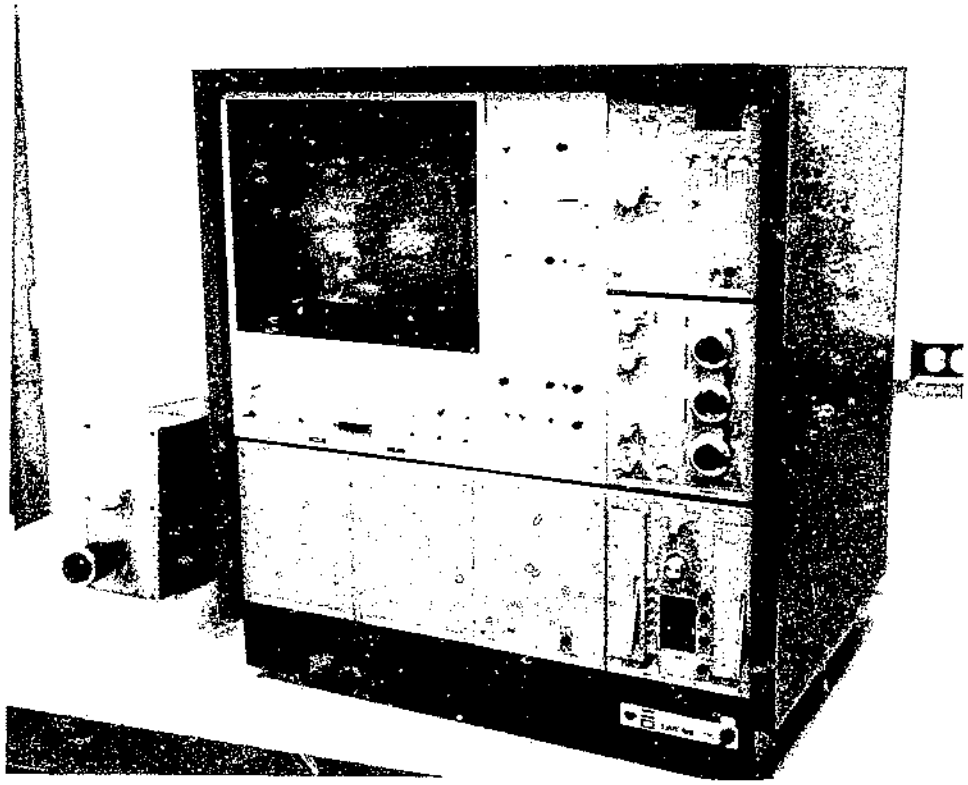


Figure 40.—Image analyzer.

The analysis procedure for a set of spray-deposit cards begins with a decision on the resolution needed and the card area required for statistical purposes. This decision on resolution determines the lens to be used on the scanner. For instance, a fine spray would be detected better by a lens with a resolution of 12 µm than a lens with only 45-µm resolution. As resolution increases, however, the number of fields of view per card must increase if the same area is to be counted. This increases the time and cost required for analysis.

The next step is to determine class size by dividing the largest spot in the series of cards to be analyzed by the number of classes desired. Ten or more classes are generally desirable to allow accurate calculations to be made. For example, class sizes would be 50 µm for a maximum stain size of 500 µm with 10 classes. A system with a sizing module would be programmed accordingly, so that each detected stain would be placed in its corresponding class. Each card is placed in the viewer, brought into focus, and evaluated. Values can be read off the screen or, at the touch of a button, all information passed to a computer.

The image analyzer has certain inherent problems. It will detect dirt, overlapping spots, and any extraneous marks along with the normal spray deposit. Also, small features or features with low contrast may not be detected because of the limit of resolution (dependent on the lens system), shading problems, or sensitivity of the threshold. Shading because of nonuniform illumination of the sampling surface causes problems, such as partial detection of features and detection of electronic noise.

The main problem encountered in card analysis is poor condition of cards. Wrinkled or curled cards have spots in different focal planes; dirt particles, fingerprints, and smears may be detected along with the spray deposit; and spots will spread on cards moistened by rain or dew. These conditions can be avoided by handling the cards carefully.

An image analyzing laboratory can be set up for rapid analysis of many cards. Each card must be clearly marked and distinctly identified to prevent confusion and errors in recordkeeping.

Foliage Examination

John W. Barry

The use of foliage as a deposit sampler is discussed in chapter 2. Procedures for measuring and counting spray droplet stains on foliage, are discussed below. Safety considerations in use of UV light with dissecting microscopes are also discussed. The procedures presented were developed and evaluated in the field in two pilot projects to assess droplets on foliage. One project, conducted in Montana in 1975, included *Bacillus thuringiensis*, trichlorfon, and carbaryl. Droplet stains also were assessed on another pilot project there of acephate and trichlorfon the following year. These exercises demonstrated the simplicity and ease of using this technique in the field.

Procedures are outlined below:

1. Collect samples with care to avoid smearing and dislodging the stains from the needle surfaces. The needle collection method is shown in figure 41.

2. Store samples under refrigeration to reduce needle drying, condensation, and fungal growth. If cold storage is not available, containers holding samples should be open.

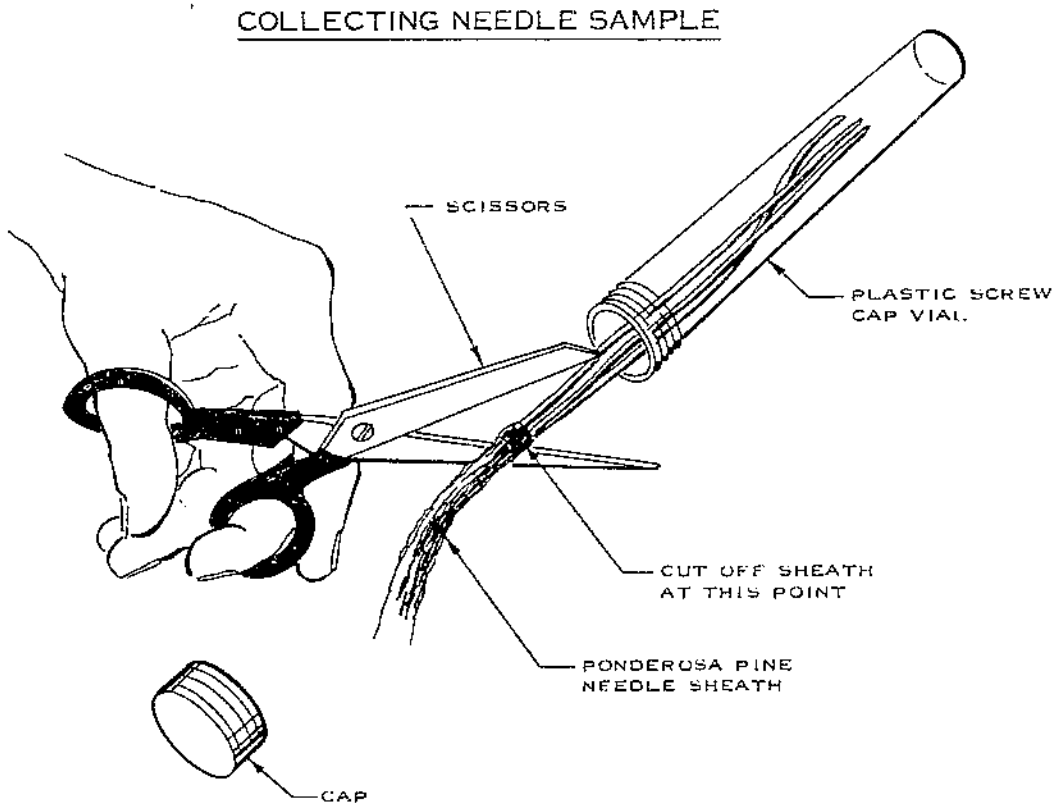
3. Make counts with a zoom type dissecting stereomicroscope with an eyepiece reticle under artificial lighting. The illuminating device should be capable of increasing or decreasing the light intensity to improve stain contrast as required. Use a UV light to count fluorescent stains.

4. Magnification should be between 23 and 30 power. The eyepiece gives 10-power magnification and the scope will zoom to 2.3 to 3 power, depending on the model used.

5. Calibrating the eyepiece is critical. Place a calibration slide in a petri dish, on the stage of the microscope. Determine the smallest increment in micrometers on the calibration slide and align the slide with the scale on the calibration slide. You may need to change the zoom dial to a lower magnification to make this alignment. When you are satisfied that the slide is aligned with the eyepiece scale, have at least one other person check it by comparing it with the calibrated slide. Tape the zoom dial to prevent movement and changes in the magnification.

6. Work in pairs, with one person counting, while the other records on the needle data sheets (fig. 42). Frequently alternating assignments between two people lessens fatigue.

7. The samples will probably be in a tube or bag. Remove the 2-in branch tip sample and select the first ten 1-year-old needles from the tip below the new needles. Try to select needles that are about the same length. Do not select broken, immature, or partially eaten needles. Remove the needles with forceps and place them in the same



1 PLACE VIAL OVER THE 3 CLUSTERED NEEDLE WITHOUT TOUCHING THE NEEDLES. CUT THE NEEDLES AT THE UPPER END OF THE NEEDLE SHEATH AND SECURE THE CAP.

2 LABEL THE VIAL BY PLOT, TREE NUMBER, AND DATE.

3 STERILIZE THE SCISSORS WITH CIGARETTE LIGHTER PRIOR TO COLLECTING THE NEXT SAMPLE.

Figure 41.—Methods of collecting needle samples to avoid direct contact with fingers. Shorter vials would be used for spruce and fir needles.

NEEDLE DATA COUNTS

PROJECT:
TRIAL NO.
TRIAL DATE:
COUNTING DATE:
COUNTER:
MAGNIFICATION:

TREE NO.	SAMPLE NO.	UPPER	LOWER	STAIN SIZE	SMEAR	NEGATIVE	REMARKS

Figure 42.—Data sheet for recording needle counts.

petri dish used to calibrate the microscope and begin counting. Keep account of the sample number and maintain a clean work area.

8. Examine the entire length of the needle on both surfaces. Record separately on the data sheet the number of stains observed on each side of the needle, entering zeros when no stains are observed. Appropriate remarks should be included on the data sheets.

9. Some stains will not appear as perfect circles. Depending on the nature of the formulation, the angle of impact, and the velocity of impact, the droplets may run or smear on the needle surface. This will be particularly noticeable on the needle margin and on the underside along the rows of stomata. Most formulations will penetrate the stomata, spread through the cells, and appear as a pink discoloration. The rules for measuring a stain are:

   (a) If the longest axis is more than two times the shortest axis, do not measure the stain. Do, however, indicate on the data sheet that the stain is a smear.

   (b) Always measure the smallest diameter of the stain.

10. Occasionally you will see that a droplet either shattered when it hit the needle or slid off the needle. Count these as smears. After a little experience, you will be able to determine when a droplet slid off the needle leaving traces of the formulation or shattered making many small droplets. Count these groups of satellite droplets as one smear.

11. Be consistent in your procedures.

Insects can be examined for the presence of spray droplets. The surface structure of insects, however, obscures the stains unless they fluoresce. Fluorescent particles are readily visible on spruce budworm larvae when a UV light is used in conjunction with a stereomicroscope following the procedures developed by Himel (1969) and Barry et al. (1974).

Several dyes and tracer particles exhibit fluorescence when excited with light energy in the 3000 Å unit range. Fluorescence provides an excellent means of detecting spray droplets and particles on foliage and insects. Droplets are more readily detectable and are easier to count and measure under UV light than natural or incandescent light. The light source usually is used in conjunction with a dissecting microscope. This requires acquisition of a UV illumination system to excite the particle fluorescence, and a means of magnifying and counting the observed fluorescing droplets.

Fluorescence is excited by near UV radiation. Mercury arc lamps are commonly used in fluorescent microscopy. They provide a high

intensity in the region of 3660 Å An illumination system ideally suited for this analysis is supplied by Metronics Associates, 2991 Corvin Drive, Santa Clara, California 95051, Ultra Violet Illuminator Model UV85-1 and Ultraviolet Illumination Power Supply Model UVPS8-1.

Ultraviolet light sources, if used improperly, can cause skin and eye damage. The harmful portion of the UV spectrum is the radiation at wavelengths roughly 1000 to 3000 Å, a wavelength band that is effectively filtered by glass. The lamp housed in this illumination system is manufactured by General Electric, Model H85A3. Although it generates UV radiation of wavelength 2537 Å, this radiation passes through three glass filters. The first and second filters are in the glass encasing the lamp and the lens at the exit port of the casing. A third filter, also on the exit port, is the Corning 7-60 UV filter, which permits the passage of near UV light. This spectral region (3600-4000 Å) causes excitation of the fluorescent droplets on the needles. The glass elements in the binocular microscope are also effective filters of mid-to-far UV radiation. Therefore, the amount of short wave radiation present when the illumination system is operating is minimal. It is comparable to that normally encountered in afternoon sunlight.

Foliage Washing

George P. Markin

Introduction

Another technique for analyzing spray deposit by washing foliage has been used successfully for both coniferous and deciduous forest foliage (Maksymiuk and Orchard 1975). The procedure consists of removing a foliage sample from the tree immediately after spraying, washing the deposit from the sample, and analyzing the wash solution fluorometrically to determine the amount of dye present.

Handling of Samples

Extendable pole pruners are used to collect foliage samples from each sample tree. Samples usually consist of 10-in branch tips for coniferous trees or 25 leaves from a deciduous tree. After they are collected, samples are carefully examined to make certain they contain no insects. The samples from each sample tree are placed in an ordinary brown paper bag, which is then stapled shut. Foliage is arranged so that it lies flat against the side of the bag; the bag is then folded flat to make as compact a package as possible. Bags from each plot are usually combined in loose bundles. When stored in a dry room for several weeks or more, foliage usually desiccates naturally and is dry enough for analysis by the time it reaches the lab. Effects of overdrying and long-term storage are not known, but for accuracy, samples should be analyzed as quickly as possible.

Laboratory Analysis

In the laboratory, if deposit is to be expressed as volume or weight per weight of dry foliage, the foliage samples should be uniformly dried in an oven. The drying needles are removed from the twigs, mixed together, and a subsample removed from the mix. The subsample can either contain 100 needles or 1 g of dry foliage. For deciduous foliage, a small cork borer is used to remove 1-cm^2 disks from leaves. Forty of these disks (40 cm^2) from the foliage from each tree are used as a sample.

The dried foliage is placed in a 150-ml Erlenmeyer flask, and 10 ml of the appropriate wash solution is added (30 percent ethylene for oil-base insecticides, distilled water for water-base insecticides). The combination is agitated on a mechanical shaker for 15 min. Excessive washing and strong solvents are not advised because they may remove pigments from the foliage that can confuse the fluorometric analysis. The wash solutions are analyzed with a fluorometer as described in the section on analyzing spray deposits on aluminum plates.

Standards of untreated foliage collected from the plots before spraying are used to give a background reading for the foliage, which can then be subtracted from the reading obtained from the washed foliage. A tank sample collected from the aircraft just before spraying is necessary to determine accurately the amount of dye in the spray solution, so that the exact ratio of insecticide to dye can be determined. Knowing the amount of dye obtained from the foliage sample, the weight (or size) of the foliage sample, and the ratio of insecticide to dye, we

can express recovery as amount of insecticide per gram of foliage; amount of insecticide per needle or per 100 needles; amount of insecticide per given foliage area (micrograms per square centimeter or parts per million of insecticide).

Comments

Preparation, washing, and analyzing the foliage sample are not only time consuming but also demand a high degree of accuracy. As a research tool, however, this technique is believed to be an accurate method of determining the actual amount of spray reaching the target insect. The samples can be collected at the same point where the population of target insects is being studied. For example, if the budworm population is being sampled at midcrown in the tree, foliage samples for analysis are collected at the same location. Verification of satisfactory recovery should be demonstrated beforehand by laboratory tests of the dyes and foliage to be used. Although foliage washing is not a suitable technique for deposit assessment on operational projects, it is probably the most accurate and useful tool for the researcher for correlating mortality with spray deposit. If foliage assessment is correlated with spray-deposit assessment on cards, cards could be used on operational projects to indicate quantity of spray reaching the foliage.

Assessment of Microbial Spray Deposits

John Neisess

Introduction

When fluorescent dyes are used to assess microbial spray deposits, one precaution should be noted. Most microbial spray mixtures now contain a sun screener, Shade®. Because it absorbs ultraviolet light well, traces of this product can reduce the effective detection energy of the fluorometer by as much as 30 percent. In essence, the fluorometer reading will indicate dye concentrations that are lower than the concentrations actually present in solution. These losses increase with sample storage time, especially if the samples are in the liquid form.

Two techniques have been used to reduce this loss of sensitivity: (1) the residue samples, both foliage and plates, are analyzed as soon after application as possible, and (2) the solutions containing the spray residues are diluted so that dye reading will be made at the more sensitive settings of the fluorometer.

In addition to the dye method of spray-deposit analysis, two bioassay methods have been used to analyze spray residues when *Bacillus thuringiensis* was the active ingredient. Because *B. thuringiensis* is a spore-forming bacterium, spray residues can be quantified using plating techniques. Spray residues can also be bioassayed with host insects. These two techniques can also be used to determine residual activity of spray residues.

Sample Collection

Foliage samples are collected and handled in the same manner as described in the "Foliage Washing" section. Foliage samples may be collected at different times to determine residual activity of the spray residues.

Laboratory Methods

Bioassay technique. The foliage samples designated for bioassay are dried, and 5 g of needles from each tree are weighed into 4-oz plastic cups. Fifty ml of distilled water is piped into each cup, and the cup agitated for about 2 min on a Maxi Mix® model M-16715 stirrer. One drop (0.025 ml) of each wash suspension is spread on the surface of artificial media in a 3-ml jelly cup. Individual day old Douglas-fir tussock moth larvae from a laboratory colony are placed on the treated diet, and the cups sealed with Parafilm®. Mortalities are recorded after the larvae are held at 26°C and 45 percent relative humidity (RH) for 14 days. Three replicates (10 larvae/replicate, 1 foliage sample/rep/treatment) are tested for each treatment and sample interval. Control groups of 30 larvae, exposed to untreated diet, should be set up for each 150 sample cups.

Plating technique. Three ml portions of the wash solution from each of the immediate postspray samples are placed in 1/2- by 2-in vials and pasteurized for 15 min in an 80°C water bath. The wash suspensions are plated on nutrient agar using standard bacteriological plating techniques. Developing colonies should be spot checked for *B. thuringiensis* endospores. Viable spore counts are expressed as spores per gram of foliage.

Certain constraints should be included for the use of deposit data from these bioassay and plating techniques. Although we have obtained excellent correlations of data from the two techniques within a single treatment, bioassay or plating data does not necessarily correlate with volume data from the dye method of spray-deposit analysis. Because the bioassay and plating methods actually measure activity, spray deposit of treatment variables that might affect insecticidal activity or residual activity should not be compared with only these assessment methods--data collected with the dye method should also be included. For example, if droplet size (large vs. small) was the treatment variable, recovering the same volume from the two applications, would be possible, but the insecticidal activity of the small droplets could be less than that of the large drops because of increased inactivation rates. Therefore, the dye method and either the bioassay or plating methods of deposit assessment are needed to show the total response of the treatments.

Collection Plates

John Neisess

Some type of fluorometer is used for the analysis of the spray residues collected on aluminum plates. Two models currently being used by USDA Forest Service laboratories are the Turner model 110 fluorometer and Turner model 430 spectrofluorometer. Most major manufacturers of scientific equipment make fluorometers or spectrofluorometers. The advantage of the spectrofluorometer is that the excitation and emission wavelengths can be set for a particular dye. Fluorometers use different filters to achieve the same effect, but finding the proper filter combination may prove difficult and time-consuming. The minimum detectable sensitivity of these instruments is about $1x10^{-10}$ g/ml, which in a water solution is equivalent to 0.1 part per billion. The sensitivity is dependent on the solvent system, fluorescent dye, and background or naturally occurring fluorescences.

Absolute dye concentrations are obtained from meter readings by using standard calibration curves. To make a standard curve, standard solutions of known dye concentration are made by diluting a field formulation that contains a dye concentration of $1x10^{-3}$ g/ml (field dose). Separate standard curves should be made for each sensitivity setting on the fluorometer. Three replicates of each dilution (concentration) are made for each curve. Dye concentrations should cover the range of $1x10^{-10}$ to $1x10^{-6}$ g/ml.

Samples should always be measured on the most sensitive range of the instrument without exceeding the available 100 scale divisions. The preparation of standard solutions should start with the total formulation, because any additives that may affect the fluorescence will be included in all the dilutions. Figure 43 illustrates the standard curve for the 100x range of the Turner model 430 spectrofluorometer. The formulation was 8 billion international units/gal of Dipel 36B mixed with water, and the dye was Rhodamine B extra S. Linear regression lines are fit to the standard curve data by conventional least squares methods. The estimated errors for calculations based on these curves are less than 6 percent of the values used as independent variables.

Because some formulations may contain sticking agents, the efficiency of washing must be determined. A microapplicator is used to apply five replicates of 5-10 µl of formulation (e.g., five 1-µl droplets) to the aluminum plates and comparable volumes to 10-ml volumetric flasks.

The volumetric flasks are brought to volume with the solvent that will be used to wash the plates. The deposit on the plates is allowed to dry for 48 to 96 hr and is then washed from the plates by the technique described below. The fluorescence of the wash solutions from the plates and volumetric flasks is measured with the fluorometer, and the dye concentrations are determined from the calibration curve. The percent recovery values are computed as follows:

$$\text{percent recovery} = \frac{\text{g/ml from aluminum plate}}{\text{g/ml from volumetric flask}} \times 100.$$

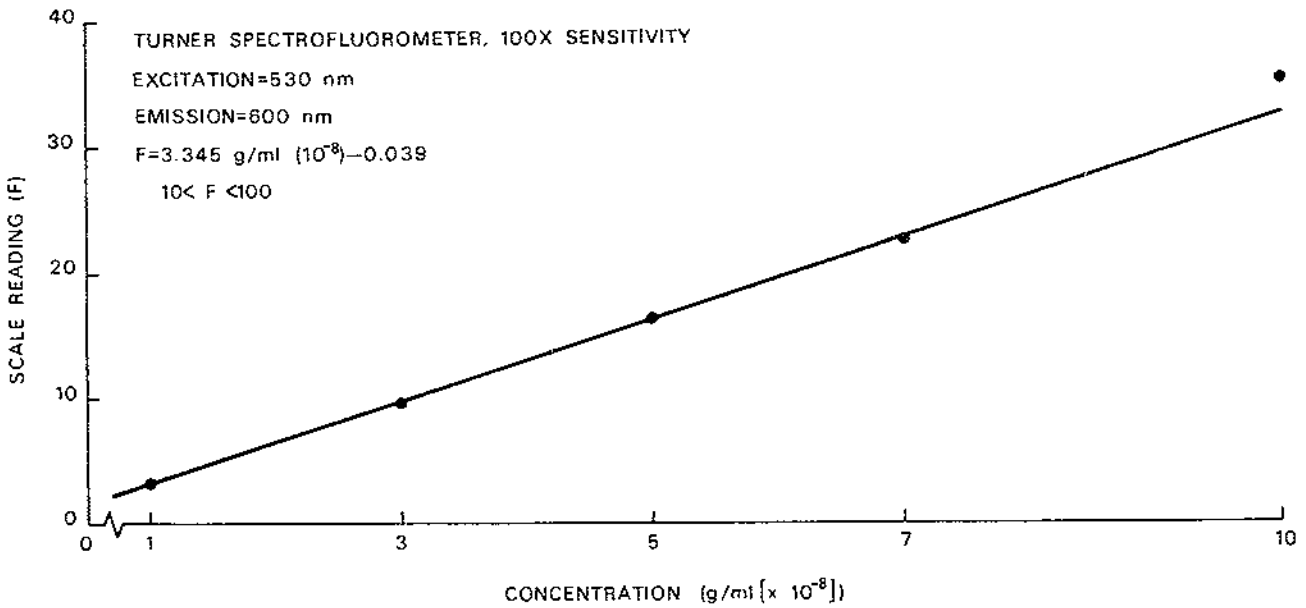


Figure 43.—Standard calibration curve for Rhodamine B extra S mixed in an 8 billion international units/gal Dipel 36B-water mixture.

For processing the aluminum plates, a holder has to be built to hold a plate almost upright. The plates are positioned on the holder so that all of the wash solution will run off one corner. A volumetric flask and glass funnel are placed under this corner to catch the wash solvent. The aluminum plate is uniformly sprayed with the wash solvent, using an Erlenmeyer-type chromatography sprayer (fig. 44). The wash process continues until the volumetric flask is about full or until the deposit is removed from the plate. The liquid in the flask is brought to volume, and the fluorescence of the solution is measured. The dye concentration is determined from the proper standard calibration curve. The volume of spray on the plate (gallons per acre) is determined by the following equation: gal/acre =

Figure 44.—Plate washing apparatus, including chromotography sprayer, plate holder, funnel, and 10-ml volumetric flask.

$$\frac{(\text{g/ml dye washed from plate minus background values}) \times \text{ml of wash} \times \text{ft}^2/\text{acre}}{\text{g/gal dye in formulation} \times \text{ft}^2/\text{plate} \times \frac{\text{percent recovery}}{100}}$$

Background contamination should be determined by placing some plates in the field before spraying, in the same manner as you place those used to collect spray deposit and for the same length of time the test plates will be exposed. These background plates are picked up before the spray application. They are then washed by the usual procedure and fluorescence readings are converted to dye concentration equivalents from the calibration curves. Background values normally range from 2×10^{-10} to 1×10^{-9} depending on the conditions of the experiment, dye, and solvent.

If a nonfluorescent dye has been mixed with the spray, deposit residues collected on aluminum plates can be assessed by quantitative absorption spectroscopy methods (Yuill and Secrest 1966). Quantitative absorption spectroscopy is not as sensitive as fluorometric analysis and should not be used to measure drift or very low deposits, such as those found in areas that were skipped or missed.

As with fluorometric analysis, a calibration curve must be prepared from a series of standard solutions to determine the relation between absorbance and dye concentration. As before, the standard solutions should approximate the overall composition of the actual deposit samples and should cover the expected range of concentrations. Deposit residues should be washed from the plates with the same equipment and techniques described for fluorometric analysis. Because each instrument has its own peculiarities, the operators' manual should be consulted for instrument setup and measurement of samples.

Chemical Analysis of Spray Deposits

Richard Roberts

Introduction

Probably one of the most accurate methods of assessing spray deposit or drift is by direct chemical analysis for the insecticide itself (Ware et al. 1969, Ware et al. 1969a, Ware et al. 1970, Ware et al. 1972, Ware et al. 1975, and Wood and Steward 1976). Present day analytical instrumentation can provide extreme sensitivity for some insecticides. Insecticide deposited on a substrate can be removed by simply washing the surface with a suitable solvent before analysis. Substrates used for studying drift and spray deposit are Mylar or acetate sheets, cards, glass plates, filters or films from various filtering or air sampling devices, insects, and foliage (see chapter 2). To establish a comparative baseline, a chemical analysis of the concentration of insecticide in tank samples is also done.

Direct chemical analysis is discussed here, as compared to indirect methods using dyes, etc., previously discussed in this chapter.

Instrumentation and Methods

Gas Chromatography (GC). Probably the best and most popular instrument utilized for the analysis of insecticides is the gas chromatograph. Gas chromatographs are unique because they come equipped with several types of detectors that are sensitive to virtually all insecticides, and under optimum operating conditions, some insecticides can be detected at the subpicogram (1×10^{-13} g) or parts per billion (ppb) level. These instruments can be incorporated into a mobile laboratory or taken into the field for continuous monitoring of environmental contamination.

High-Pressure Liquid Chromatography (HPLC) has recently come into use for analysis of insecticides. One of its advantages over GC is that no thermal degradation of the sample (insecticide) occurs. Consequently if additional analyses are needed, the insecticide can be recovered intact. Another advantage is that little cleanup and sample preparation is required. Generally, the sensitivity is not as great as with GC, but some insecticides can be detected in picogram amounts.

Sample Storage and Preparation. All samples to be analyzed should be collected as soon as possible after the spray is deposited, because some insecticides are unstable in light, heat, or both, Extracting the samples in the field into a solvent where they are less likely to degrade is best, but if this is not feasible, they should immediately be stored in the dark, and refrigerated or frozen until they can be processed for analysis. Each sample should be clearly and accurately labeled as permanently as possible, so that it can be identified and correlated to the correct collecting site.

Extracting the insecticide from the sample requires selecting a solvent in which the insecticide is soluble and one that is compatible with the method of analysis. If both these criteria can be met, it reduces the time and cost of the analysis. Extracted samples should be stored in the freezer until

analyzed. Before analysis, diluting or concentrating the samples may be necessary, depending on how far from the sprayed area they were taken.

Insecticides

The following is a partial list of insecticides currently used, or being considered for forest insect control operations, that chromatography can be used to analyze. Notes on sensitivity are included.

1. Orthene® (acephate), sensitive to 60 pg (picogram). Monitor, a major degradation product of Orthene, can also be analyzed at the same time with sensitivity to 8 pg (Leary 1974, Richmond et al. 1978). The next three insecticides require the same GC conditions and analytical procedures as Orthene.

2. Dursban® (chlorpyrifos), sensitive to less than 10 pg.

3. Reldan® (chlorpyrifos-methyl), sensitive to about 5 pg.

4. Cygon® (dimethoate), sensitive to 10 pg.

5. Furadan® (carbofuran), sensitive to 30 ng (nanogram). (Crisp 1978, personal communication).

6. Dylox® (trichlorfon), thermally degrades on the GC column to dimethyl phosphite, sensitive to 10 pg, and to DDVP, sensitive to 50 pg. The dimethyl phosphite is commonly identified in lieu of Dylox in this analysis. (Larson 1978, personal communication).

7. Lannate® (methomyl), sensitive to 10 pg (Reeves and Woodham 1974).

8. Cythion® (malathion), sensitive to 10 ng (Cook and Moore 1976).

9. Matacil® (aminocarb) and Zectran® (mexacarbate), both sensitive in the high nanogram range (Roberts et al. 1978).

HPLC is used to analyze the following insecticides. The sensitivity is also noted.

10. SEVIN® (carbaryl), sensitive to 10 ng (Pieper, 1978). A common degradation product of carbaryl, alpha naphthol, can be detected with HPLC at 5 ng (Colvin et al. 1974). Carbaryl can also be analyzed by spectrophotofluorometry; however, it must first be hydrolized to alpha naphthol. This can be done easily in the cuvette used for analysis (Pieper 1978, personal communication).

11. Dimilin® (diflubenzuron) sensitive to 5 ng (DiPrima 1977).

Recommendations and Limitations

The analyses discussed here should be conducted by persons trained in the use of these instruments, because complications are frequently encountered. In addition, preparing the samples for analysis is unsafe without certain laboratory equipment, such as fume hoods for removing the toxic solvents fumes.

Currently, the cost of analyzing samples ranges from $20 to $65 per sample, depending on the method of analysis. Some of this cost can be defrayed if the sample is extracted into a suitable solvent before sending it to the laboratory for analysis. Most cities near agricultural areas, have laboratories that analyze pesticides. Agricultural chemistry departments of universities sometimes contract this type of work. Those that do not usually can recommend where to go for it.

When should this type of analysis be used? Generally, this decision depends on several factors, such as the need for accuracy, the facilities and personnel available, funding, and the type of insecticide used. Where dangerous contamination from drift is possible, documenting the accuracy of the application and the drift pattern is important.

All the insecticides in the above list can be analyzed with sufficient sensitivity by chemical means to give an estimate of spray deposit on cards or other sampling surfaces collected within the sprayed area.

Metallic Salts as Tracers for Spray Applications

Norman Akesson and Robert Cowden

Metallic salts, soluble in water at as much as 10 percent by weight or 83 lbs per 100 gal total mixture, can be used for accurate and sensitive analysis of spray deposition. This method has been used to measure accurately the spray swath and the airborne transport portions of aircraft spray applications. The technique depends upon a highly sensitive atomic absorption (AA) flame spectrophotometer, such as the Perkin-Elmer® Model 370. This instrument's sensitivity is increased by about 20 times when used with a graphite furnace attachment, HGA-2000. Similar instruments, in the cost range of $10,000 to $15,000, are available from other suppliers such as Varian, Beckman and Fisher. These instruments with the graphite furnace are as sensitive as gas-liquid chromotography used to detect low levels of various pesticide chemicals in the range of 10-12 g (picogram or ph). This is much greater sensitivity than can be obtained from a flame spectrophotometer.

This sensitivity is but one of the desirable attributes of the AA system. The relative ease of operation, simple calibration by use of three standard solutions for any given tracer, and availability of attachments for data processing during analysis make the system quick and easy to use. Normally, the graphite furnace would only be used where microgram quantities or less were present, and straight AA flame techniques would be used for higher deposits, such as characterization of different spray-application equipment.

A wide variety of metallic salts may be used as tracer materials. Selection of tracer materials depends upon the wavelength (nanometers) of the emissions when the material is burned, and upon the amount of material necessary to emit a detectable amount of light. The principal constraints are: (1) cost of the material in usable grade or concentration of metallic anion, (2) sensitivity of the particular anion, ranging from 1 to 40,000 pg, (3) the difference between the optimum atomizing temperature of the anion and the allowable charring temperature, which is the heat needed to burn off the organic materials from the sample, (4) relative scarcity of the metallic anion in the sample area, and (5) wavelength of the light emission from the anion that could be confused with extraneous materials in the sample.

Materials suitable for tracers are listed in the operational handbook provided with the spectrophotometer. We have used technical grade strontium chloride, with detection sensitivity of 200 pg, and manganese sulfate, fertilizer grade (SO_4), with a sensitivity of 8 pg. The wavelength of the emissions are about 200 nm (nanometers) apart, which permits dual analysis of common samples. Thus, we can spray over collector substrates and air samplers with both tracers, for two tests, and separate the collector data by separate analysis of each tracer.

Sampling Techniques

Because these measurements are highly sensitive, background contamination can cause the loss of most

well-designed experiments. The utmost care must be used in handling all collection substrate materials.

The substrate should be tested with the tank mix to determine that the spray does not contain a solvent that reacts with the substrate. The plastic sheets or plates used for collection of samples are light and easily stripped of chemical residue and also readily cleaned. The collection substrates used are Mylar® plastic sheets, 6 x 18 in, for fallout samples and glass fiber filter paper (no binder materials) for high volume (20-30 ft^3/min) air samplers. Other filters such as the Millipore type may also be used. Collection efficiency of glass fiber filters is 98% for particles of 0.05 μm and larger, and Millipore (and Nuclepore) filters have specific size filter screens that range from submicron size upward. Airborne sampling systems are discussed in another section of this manual.

The filter papers are carefully placed in the holders with tweezers washed in double distilled water. The holders and filters should be bagged in clear plastic before being carried to the field. The filter holders are placed on the air samplers just before the spray runs, to avoid contamination. We carry the entire holder to the laboratory for careful removal of the filter--or remove the filter in the field and place it in a clean jar, washed as described below. With sensitivities in the range of a few pg, a dirty fingerprint can cause significant contamination.

We have used 1/2-in Celotex® boards, 12 x 24 in, to support the Mylar sheet's surface for fallout samples. This size conveniently fits a 12- x 30-in polyvinyl poultry bag used to cover it. The Celotex boards generally have one side painted white and one unpainted. The Celotex board should be placed in the plastic bag so that the white surface has a smooth surface of plastic covering it with the folds of the plastic bag on the unfinished side of the Celotex board and the ends of the bag closed, folded, and stapled. Boards should be stored in a clean box or compartment until the Mylar sheets are ready to be stapled to them.

Mylar Sheet Preparation and Processing

We have found the following method to be efficient for obtaining and processing fallout samples.

To avoid contamination, each Mylar sheet should be cleaned, stored, and processed in separate, large mayonnaise jars or similar containers (fig. 45). The Mylar

Figure 45.—Removing Mylar sheets from storage jar preparatory to stapling them to Celotex boards.

sheets can be pre-rinsed at the same time as the jars are pre-rinsed and tested. Rolls of 5 mil (0.005-in thick) Mylar, 6 in wide, are cut into 18-in lengths and placed in the 1-gal mayonnaise jars. The jars are lined up without lids on a convenient working surface or table with one Mylar sheet in each. About 1 qt of double distilled and de-ionized water is poured into the first jar. swirled around, then poured into the next jar, rotating the jar while the liquid is poured to clean the lip of the jars. This process is continued until about 12 jars and Mylar sheets have been rinsed with the original quart of distilled water. A sample of the effluent should then be tested in the atomic absorption machine. If the contamination is not more than 1 percent above the background of a sample of clean distilled water, the jars are considered clean. If contamination is greater than 1 percent, the process must be repeated. All the clean jars should be turned over, with the Mylar sheets left inside, onto a clean surface to drain.

Jar lids generally come with a wax-coated paper seal. These should be replaced with a polyvinyl seal, either by covering the paper seal with thin polyvinyl sheets or replacing the entire paper seal with a polyvinyl seal of about the same thickness. The lids may be washed with soap and water, rinsed with distilled water, and put aside to drain and dry.

The boards that were covered with the polyvinyl bags should be laid out on a clean surface, white side up. A lint-free cloth or paper tissue soaked in methanol is used to wipe the surface to which the Mylar sheet will be stapled. With clean tweezers (washed in distilled water), the Mylar sheets are removed from the jars and placed in the middle of the surface just cleaned (fig. 45). With a light staple gun, each corner is stapled (fig. 46). Two boards are placed face to face, in another 12- by 30-in polyvinyl bag, then stapled or heat sealed shut. The boards are put in a box and taped shut to keep out dust. Lids are put on the jars, and they are placed in their boxes and taped shut.

Figure 46.—Closeup of Mylar fallout sheets. Stapled to covered Celotex board.

In the field, distilled water should be available for washing several pair of 6- to 10-in tweezers, which are used to handle the Mylar sheets. A wax pencil for writing on the lids of jars is also desirable. The Mylar sheets should not be exposed to the atmosphere

until the tests are made. The laying out of sample sheets is done whenever possible from the treated end of the line to the downwind end to avoid contamination from dirt and dust raised by traversing the line. Pickup of collection substrates should be done in the opposite direction, or from the end of least contamination towards the more concentrated or treatment end.

We have also found a good experimental procedure is to expose untreated blanks to the same environment as the treated samples. This can either be done by placing them in a similar location nearby not reached by the spray or exposing them for a similar time before spraying begins. Windborne material can cause significant contamination when low levels of pesticide drift are measured.

The Mylar sheets should be carefully handled with clean tweezers. The staples are pulled from each corner with one tweezer while the Mylar sheet is held down with the other. The Mylar sheet should then be rolled up, using the tweezers, and put into one of the 1-gal jars. The time of pickup and location of the sample should be marked clearly on the jar lid with the wax pencil and the jars put back into their boxes. After pickup, hands and tweezers should be washed with distilled water before for the next run.

The Mylar and filter paper substrates should be processed as soon as possible. As many bottles as can be handled at one time (usually about 12) should be taken from their boxes, and the lids removed. Care should be taken not to mix up the lids. The best procedure is to start with only 50 ml of 0.266 N HCl solution (44.4 ml of 12 N HCl mixed with 1955.6 ml of distilled H_2O = 0.266 N HCl) to strip the samples from those samples with the lowest deposits, and the field blanks. All other samples are stripped with 100 ml of the solution. After water is put in the jars, the lids are replaced (with care not to splash material up on lids). Jars are put on a rolling machine and allowed to roll for 20 to 30 min. Then the required sample is drawn and run through the AA machine.

After a run, the boards should be stripped of the polyvinyl bags and re-covered; the bottles and Mylar should be washed in soap and water, with the Mylar sheets left in the bottles. The procedure outlined at the beginning for preparing the sheets and bottles should be repeated.

Characterization of Spray Deposits

Where the amount of material deposited is appreciably greater, as in the assessment of spray systems, we use a smaller sampling surface, such as a 3- by 6-in plastic plate with a raised edge to facilitate stripping the deposit by a hand-held wash system (fig. 47). The raised edge reduces contamination by fingers and allows more rapid handling.

The above procedure is also used for stripping air sampler filters for pesticide chemical sampling. Monitoring studies for swath coverage and drift can also easily be

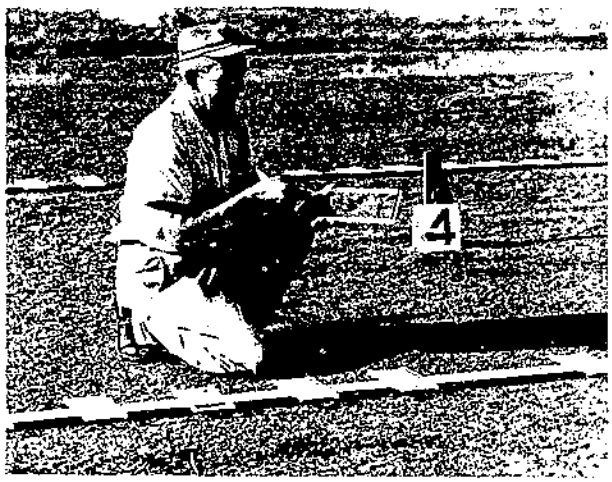


Figure 47.—Small plastic collectors for swath evaluation.

handled by collecting the pesticide on experimental spray tests (fig. 48). Highly accurate evaluations are possible, reducing the tedious work of the droplet size-frequency means and the inherent errors that accompany this analysis (fig. 49-50).

Figure 48.—Collection station showing air samplers and Mylar fallout sheets.

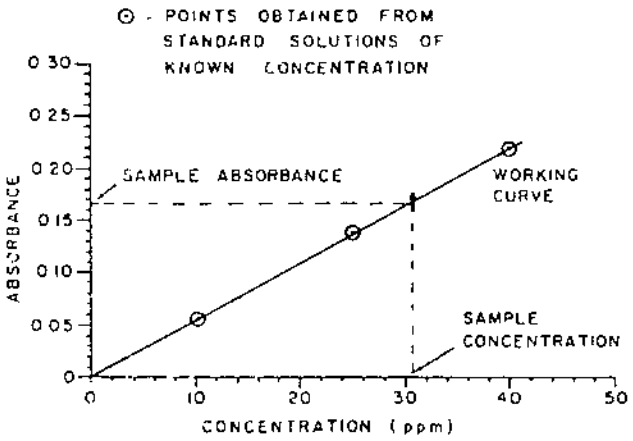


Figure 49.—Example of working curve relating absorbance to concentration for a routine analysis.

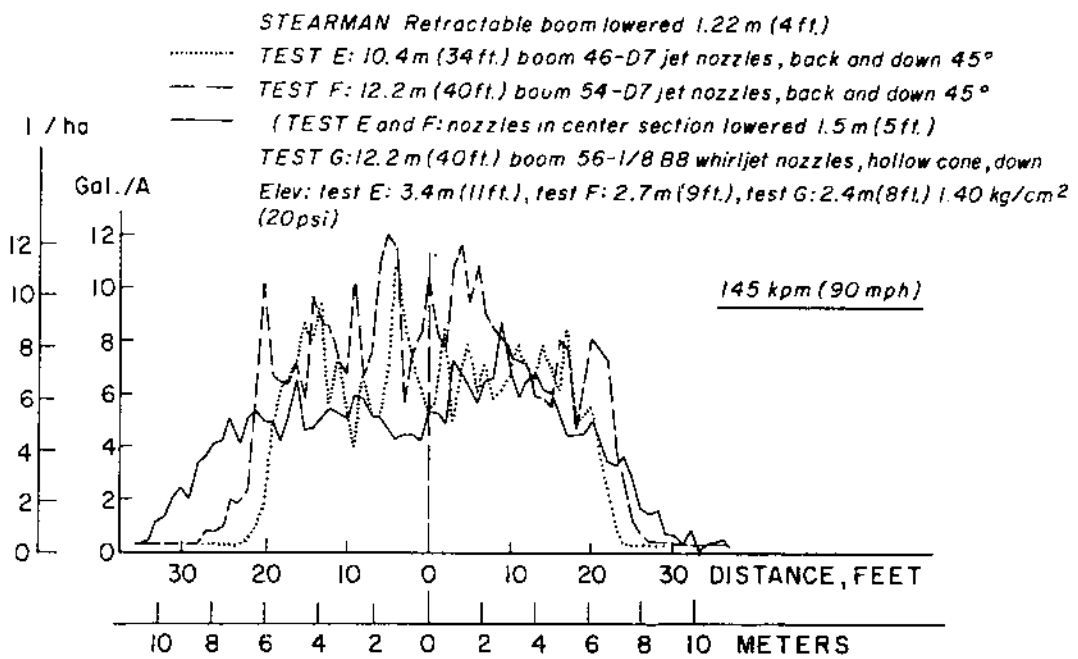


Figure 50.—Sample output showing data plotted for the spray distribution in the aircraft swath.

CHAPTER 7 DATA ANALYSIS AND REPORTING

ASCAS Data Processing Program

John Barry

USDA Forest Service Forest Insect and Disease Management (FIDM) has implemented an automatic data processing program called ASCAS (Automatic Spot Counting and Sizing Program) for processing spray-deposit data.

Introduction

Assessment of deposits achieved by application of insecticides has been increasingly important in the USDA Forest Service in recent years. Because of the increased emphasis upon spray accountability, a rapid, accurate, and standard method for evaluating spray deposit data was needed.

The ASCAS program has been used to analyze FIDM spray-deposit data since 1972, both for pilot and operational projects (Millers 1976, Taylor et al. 1972, Ciesla et al. 1976).

The ASCAS Program was originally developed by the U.S. Army Dugway Proving Ground (DPG), Utah in the early 1960's. DPG provided FIDM-Methods Application Group a copy of their ASCAS program for adaptation to their needs. The program was rewritten and documented (Young et al. 1977).

Procedures

In general, the procedure for spray-deposit assessment consists of four steps: (1) collection of spray on deposit cards in the project area; (2) sizing and counting stains or spots on a card (see chapter 5); (3) analysis of the spot-count data with the ASCAS program; and (4) evaluation of spray-deposit results through comparison of spray-deposit with insect mortality, tree defoliation, canopy penetration, spray drift, and meteorology.

Basically, the program needs punched cards containing identification and number of stains in the various size categories specified. Through input to the program, including spread factor equations and specific gravity of the tank mix, the stain diameters are converted to droplets (spheres), and the following output values are then computed: mass-mean diameter (mmd), volume-median diameter (vmd), number-mean and number-median diameters, deposition density in terms of milligrams per square meter, droplets per square centimeter, fluid ounces per acre, and U.S. gallons per acre. These values are computed and printed for each spray-deposit card and summarized for groups of cards, for example, all the cards from one spray block.

The spectrum of the spray cloud is described by giving both the counts and the mass in each of 16 droplet size categories. Fewer size categories can be used if desired. To increase flexibility and usefulness, several analysis options have been built into the program. Three different equations for expressing the spread factor are available. The output can be sent to a printer or a disk memory. Each data card contains an identifier for sorting. Intermediate summaries of results for any group of cards can be obtained from any category within the identifier. Additional summaries can be obtained by changing the identifiers

before sorting. Lastly, four options for treating cards from different type samplers with duplicate identifiers are possible.

The program is established at the Fort Collins Computer Center in Colorado. The program can be run by anyone with access to the center.

The entire process from field collection to automatic data processing printout can be accomplished in a relatively short time. A project leader must be aware of the sequence of operations and monitor each step closely. The user must be alert to errors in the printout caused by incorrect input or mechanical malfunctions of the system.

Details and documentation of the ASCAS program are provided in a FIDM Methods Application Group report (Young et al. 1977).

Sample printouts of the ASCAS Program are provided in figures 51 through 54.

USE ID CARD- NEW IN =

********** CONTROL CARDS **********

IEN = 1 IPRINT = 0 ISTMRY = 1 IDUP = 0 ISORT = 0 IORDER(I) = 1 2 0 0 0
DENSITY OF MATERIAL = 1 000 G/ML PHOTO REDUCTION FACTOR = 1 000 AREA SCANNED BY MACHINE = 2 0000 MM**2
DROP DIAM = (- 6952+00) + (5348+00)*STAIN DIAM + (0000)*STAIN DIAM**2

********** SIZE CATEGORY DATA **********

SIZE CATEGORY	SIZE SETTING	AVG SIZE	STAIN DIF UP LIMIT	STAIN DIF LOW LIMIT	AVG STAIN	DROP DIF UP LIMIT	DROP DIF LOW LIMIT	AVG DROP	MASS(GM)
1	50 0	31 5	50 0	0	31 5	26 0	0	16 4	2 313-09
2	100 0	78 1	100 0	51 0	78 1	52 8	26 6	41 1	3 628-08
3	200 0	155 7	200 0	101 0	155 7	106 3	53 5	82 6	2 953-07
4	300 0	253 7	300 0	201 0	253 7	159 7	106 8	135 0	1 288-06
5	400 0	352 8	400 0	301 0	352 8	213 2	160 3	188 0	3 478-06
6	500 0	452 3	500 0	401 0	452 3	266 7	213 7	241 2	7 347-06
7	600 0	552 0	600 0	501 0	552 0	320 2	267 3	294 5	1 327-05
8	700 0	651 8	700 0	601 0	651 8	373 6	320 7	347 8	2 204-05
9	800 0	751 6	800 0	701 0	751 6	427 1	374 2	401 2	3 382-05
10	900 0	851 5	900 0	801 0	851 5	480 6	427 6	454 6	4 921-05
11	1000 0	951 4	1000 0	901 0	951 4	534 1	481 1	508 1	6 867-05
12	1100 0	1051 3	1100 0	1001 0	1051 3	587 5	534 6	561 5	9 269-05
13	1200 0	1151 2	1200 0	1101 0	1151 2	641 0	588 1	614 9	1 218-04
14	1300 0	1251 2	1300 0	1201 0	1251 2	694 5	641 6	668 4	1 563-04
15	1400 0	1351 1	1400 0	1301 0	1351 1	748 0	695 0	721 8	1 969-04
16	1500 0	1451 1	1500 0	1401 0	1451 1	801 4	748 5	775 3	2 440-04

Figure 51.—Sample output showing control cards and size category data.

RAW DATA TABULATION

IDENTIFICATION		SIZE CATEGORIES																
1	_ 0 0 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	SUM
1	10	0	5	8	10	1	0	0	0	0	0	0	0.	0	0	0	0	24.
1	11	2	13	11	8	1	2	0	0	0	0	0	0.	0	0	0	0.	40.
1	12	2	17	14	11	9	3	1	0	0	0.	0.	0.	0.	0	0	0.	67
1	13	5	32	13	11	5.	1	2	0.	0.	0.	0	0.	0.	0.	0	0.	69.
1	14	0	28	11	7	5	8	1	1	0	0	0.	0.	0	0.	0	0	71
1	15	0	32	20	12	9	11	1	0	0	0	0	0.	0	0	0.	0.	84
1	16	0	14	4	12	8	9.	6	1	0.	0	0	0.	0.	0.	0	0.	54.
1	17	1	24	5	4	8	12	5	0	1	0	0.	0	0.	0.	0.	0	60.
1	30	1	20	6	4	2	5	1	0	0	0	0	0	0	0.	0	0.	39.
1	31	1	40	2	5	3.	5	0	0	0	0	0	0.	0.	0.	0	0	56.
1	33	1	15	7	6	2	2	1	0	0	0	0.	0	0	0	0	0.	34
1	35	1	17	8	8	4	3	1	0	0	0	0	0.	0.	0.	0.	0	40.
1	37	0	20	9	6	3	3	0	0	0	0	0	0.	0.	0	0.	0	43.
1	37	0	13	11	9	8	6	1	0	0	0	0	0.	0	0.	0	0	47.
1	38	1	10	4	3	1	0	0	0	0	0.	0.	0	0.	0.	0	0	19.
1	39	0	12	7	6	2	1	0	0	0	0	0	0.	0.	0.	0	0.	28.
1	30	1	14	4	4	1	0	0	0	0	0	0.	0	0.	0.	0	0	26.
1	31	0	14	8	4	1	0	0	0	0	0	0	0	0	0	0.	0.	29.
1	32	1	13	8	4	2	0	0	0	0	0	0	0	0.	0.	0	0	28.
1	33	0	10	6	2	0	0	0	0	0	0	0	0	0.	0	0	0	19.
1	34	1	9	6	2	0	0	0	0	0	0	0	0	0	0.	0	0.	18
1	35	1	11	5	1	0	0	0	0	0	0	0	0.	0	0.	0.	0	18.
1	36	0	11	6	[illegible]	0	0	0	0	0	0	0	0	0	0	0.	0.	19
1	37	1	11	5	2	0	0	0	0	0	0	0	0.	0.	0.	0	0.	18.
1	38	1	7	3	1	0	0	0	0	0	0	0	0.	0.	0.	0.	0	12
1	39	1	4	1	0	0	0	0	0.	0	0	0	0	0	0	0.	0	6.
1	40	1	1	0	0	0.	0	0	0	0	0	0	0.	0.	0.	0.	0.	2.
1	41	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.	1
2	16	0	5	14	7	3	4	2	0	0	0	0.	0	0	0	0.	0.	35
2	17	0	11	12	7	2	0	0	0	0	0	0	0	0	0	0.	0	32
2	18	0	40	25	9	3.	0	0	0	0	0	0.	0	0.	0.	0.	0.	77.
2	19	0	43	25	10	3	1	1	0	0	0	0	0.	0	0	0.	0.	83.
2	20	0	54	36	13	4	4	0.	0	0	0	0	0	0	0.	0.	0	111
2	21	0	62	39	9	2	0	0	0	0	0	0	0	0.	0.	0	0.	111
2	22	5	42	13	4	1	1	0	0	0	0	0	0	0.	0.	0.	0.	66.
2	23	4	40	20	3	0	2	0	0	0	0	0	0	0.	0	0	0	69.
2	24	7	51	19	7	4	2	0	0	0	0	0	0	0	0	0.	0.	90.
2	25	10	52	12	2	1	3	0	0	0	0	0	0	0	0.	0.	0.	79.
2	26	8	49	7	9	3	2	0	0	0	0	0	0	0.	0	0.	0	78.
2	27	3	37	14	10	3	0	0	0	0	0	0	0	0	0.	0.	0.	59.
2	28	4	25	14	11	1	1	0	0	0	0	0	0	0	0	0	0.	58.
2	29	5	35	18	3	1	0	0	0	0	0	0.	0	0.	0.	0.	0.	65.
2	30	5	38	30	7	0	0	0	0	0	0	0	0.	0.	0	0.	0.	80.
2	31	5	41	27	2	0	0.	0	0	0	0	0	0.	0.	0.	0.	0.	75.
2	32	7	46	19	2	0	0	0	0	0	0	0	0.	0	0	0	0	74.

Figure 52.—Sample output of raw data tabulation.

********** RESULTS FOR UNIT CARDS **********

IDENTIFICATION					DIAMETERS (MICROMETERS)				DEPOSITION DENSITY		RECOVERY RATE		AREA ASSIGNED	MASS RECOVERED
1	2	3	4	5	MASS MEDIAN	MASS MEAN	NUMBER MEDIAN	NUMBER MEAN	NO/M**2	GRP/CM**2	OZ/ACRE	GAL/ACRE	M**2	GRAMS
1	1				135.5	137.3	100.1	100.2	94.5	12.00	12.9	.10	1.00	.095
1	2				188.1	184.2	92.5	99.4	230.4	20.00	31.5	.25	1.00	.230
1	3				198.6	199.4	85.6	103.1	443.0	33.50	60.6	.47	1.00	.443
1	17				209.9	215.0	51.2	83.0	353.3	34.50	48.4	.38	1.00	.353
1	16				242.5	244.3	51.4	97.6	626.1	35.50	85.7	.67	1.00	626
1	17				229.2	214.4	80.1	107.6	722.7	42.00	98.9	.77	1.00	723
1	18				263.7	256.3	146.9	154.0	1066.8	27.00	146.0	1.14	1.00	1.067
1	19				260.3	270.4	106.8	137.1	1120.9	30.00	153.4	1.20	1.00	1.121
1	20				239.6	231.4	51.3	96.2	323.6	19.50	44.3	.35	1.00	.324
1	22				226.7	212.0	44.6	76.2	278.3	28.00	38.1	.30	1.00	.278
1	23				233.3	231.0	61.0	93.3	226.8	17.00	31.0	.24	1.00	.227
1	25				237.4	246.8	66.7	101.6	338.9	30.00	46.4	.36	1.00	.339
1	24				208.4	193.2	62.3	91.5	330.6	21.50	31.6	.25	1.00	.231
1	27				223.3	216.3	104.4	122.7	496.5	23.50	68.0	.53	1.00	.497
1	28				146.9	144.9	49.3	71.1	44.4	9.50	6.1	.05	1.00	.044
1	29				175.9	175.7	68.6	89.2	122.7	14.00	16.8	.13	1.00	.123
1	30				142.4	141.5	46.6	66.6	52.0	13.00	7.1	.06	1.00	.052
1	31				136.3	135.5	50.8	70.6	57.9	14.50	7.9	.06	1.00	.058
1	32				154.9	148.4	53.3	76.0	74.7	14.00	10.2	.08	1.00	.075
1	33				118.8	113.8	52.0	69.0	30.0	9.50	4.1	.03	1.00	.030
1	34				111.7	108.5	50.3	64.0	23.4	9.00	3.2	.03	1.00	.023
1	35				96.1	98.6	46.0	56.5	15.6	9.00	2.2	.02	1.00	.016
1	36				111.0	107.6	49.7	64.1	23.7	9.50	3.2	.03	1.00	.024
1	37				117.1	111.0	46.0	59.4	20.8	9.00	2.8	.02	1.00	.021
1	38				109.8	106.0	45.7	57.2	12.2	6.00	1.7	.01	1.00	.012
1	39				66.7	68.7	39.9	43.9	2.2	3.00	.3	.00	1.00	.002
1	40				39.1	39.6	26.6	28.7	.2	1.00	0	.00	1.00	.000
1	41				39.9	41.1	39.9	41.1	.2	.50	0	.00	1.00	.000
OVERALL					231.5	225.6	61.7	95.8	251.2	17.34	34.4	.27	28.00	7.033

Figure 53.—Sample output for unit cards and unit summaries.

********** RESULTS FOR ALL CARDS **********

	DIAMETERS (MICROMETERS)				DEPOSITION DENSITY		RECOVERY RATE		AREA ASSIGNED	MASS RECOVERED
	MASS MEDIAN	MASS MEAN	NUMBER MEDIAN	NUMBER MEAN	NG/M**2	DRP/CM**2	OZ/ACRE	GAL/ACRE	M**2	GRAMS
OVERALL	177.6	179.2	45.4	63.1	148.9	33.69	20.4	16	223.00	33.199

--------- ---------- TOTAL SUMMARY ----------

SIZE CATEGORY	NUMBER OF COUNTS OVER SPRAY AREA	MASS RECOVERED OVER SPRAY AREA (GM)	CUMULATIVE MASS (GM)	PERCENT MASS (=)	CUMULATIVE PERCENT MASS (=)	LOWER LIMIT DROP SIZE (MICROMETERS)
1	58900	.014	33.199	.04	100.00	.00
2	4490000	1.629	33.186	4.91	99.96	26.58
3	14350000	4.237	31.556	12.76	95.05	53.32
4	4580000	8.476	27.319	25.53	82.29	106.79
5	1995000	6.940	18.843	20.90	56.76	160.27
6	1170000	8.595	11.903	25.89	35.85	213.74
7	210000	2.809	3.308	8.46	9.96	267.23
8	15000	.331	.500	1.00	1.51	320.70
9	5000	.169	.169	.51	.51	374.17
10	0	.000	.000	.00	.00	427.65
11	0	.000	.000	.00	.00	481.13
12	0	.000	.000	.00	.00	534.60
13	0	.000	.000	.00	.00	588.07
14	0	.000	.000	.00	.00	641.55
15	0	.000	.000	.00	.00	695.03
16	0	.000	.000	.00	.00	748.50
TOTAL	75110000	33.199				

@ FIN

Figure 54.—Sample output for all cards.

Deposit/Mortality Data Analysis

Robert Young

General

Procedures for evaluating the effectiveness of spray application rely on statistical inference and graphical interpretation. Several methods are available to analyze and interpret relations between a spray-deposit parameter (such as vmd, droplets/cm^2, and mass) and insect mortality. One specific procedure will be outlined in this section.

The purpose of analyzing the relation between spray-deposit data and insect mortality is to determine:

1. The effectiveness of treatment on the target population.
2. Quality of application in terms of consistency and proportion of spray recovered (percent recovery).
3. Minimum deposit required to achieve a predetermined level of population reduction.
4. Spray specifications for future projects, that is, droplet size, droplet density, percent recovery.

Data Preparation

The first step in analyzing spray-deposit data and insect mortality is to prepare a summary table of insect mortality and spray deposit (table 9).

The levels of summary can be: (1) individual trees within a spray block; (2) cluster averages for a group of trees within a spray block; or (3) block averages for an entire experiment or pilot project. The term cluster implies that two or more trees in the same proximity are used as the sample unit.

Insect sampling procedures used to determine mortality generally require destructive sampling. For example, insects used to estimate prespray populations are taken from

Table 9--*Insect populations, mortalities, and spray-deposit data*

Level	Insect per sample unit			Unadjusted mortality[1/]		Spray deposit parameters		
	Prespray	Postspray sample period		Sample period				
		A	B	A	B	Vmd	Mass	Droplets/cm^2
1								
2								
.								
.								
.								
n								

[1/] Mortality = $\left\{1.0 - \frac{\text{Postspray insect per sample unit}}{\text{Prespray insect per sample unit}}\right\}$.

branches cut from the tree; therefore, the same insects and branches cannot be used to determine the populations after treatment. With that in mind, we must obtain a reliable estimate from both the pre- and postspray populations at the level of analysis (tree, cluster, or block) desired. The pre- and postspray populations should be calculated and expressed according to the insect sampling plan. Insect populations are usually expressed as number of insects/unit of habitat,--that is, insects per 100 buds, insects per 15-in branch, or insects per square meter of foliage.

A and B in the table represent time periods. For example, A could represent the number of insects per unit area 3-days postspray and B could represent the number of insects per unit 10-days postspray, followed by their respective mortalities.

In preparing the table, unadjusted mortalities must be computed for each spray time period, for each line of data. The following formula is used for this purpose:

$$\text{mortality} = 1.0 - \frac{\text{postspray}}{\text{prespray}}$$

The spray-deposit values--vmd, mass, and droplets/cm^2-- must be listed also for each line of data. Mass can be expressed in ounces per acre, gallons per acre, milligrams per square meter, or liters per hectare. Values for each spray-deposit parameter come directly from the spray-deposit assessment outputs.

Analysis

The rationale for comparing spray-deposit data with mortality is to attempt to explain, statistically and graphically, variations in insect mortality as they relate to variations in spray deposit.

An empirical relation between spray-deposit data (independent variable) and insect mortality (dependent variable) was developed by plotting the data from many previous data sets.

For example, in figure 55, as the independent variable (either droplets per square centimeters or mass) increases, mortality increases and approaches or is equal to 1.0. This relation forms a basis for the underlying mathematical model:

$$Y = 1.0 - \frac{B}{X + B}$$

where
Y is the dependent variable (mortality)

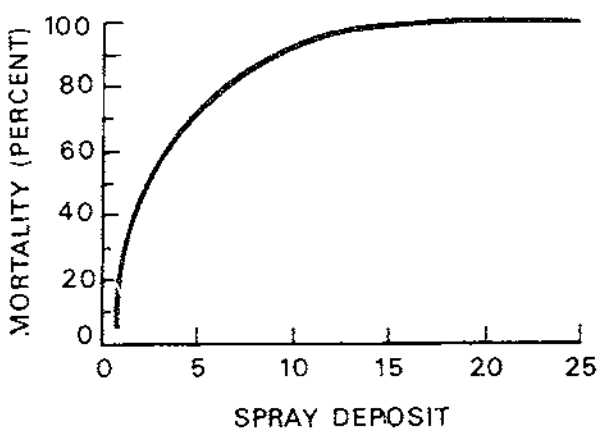


Figure 55.—The expected relation of target-insect mortality to spray deposit.

X is the independent variable (mass or droplets per square centimeter
B is the model coefficient

Because the model is not linear in parameter B, formulas using standard regression analyses for calculating B are not appropriate. The equation can be fit by using nonlinear methods to estimate B.

Other mathematical models exist that have the same general form and can be solved for their coefficients through transformations. Each model is transformed to an equation that is then linear in parameters A and B. The method of regression analysis can then be used to fit the transformed data. The models and transformations follow:

Regression model	Transformed equation	Restriction
1. $Y = A + BX$	unchanged	none
2. $Y = A + B/X$	unchanged	X 0
3. $Y = A + B\log X$	unchanged	X 0
4. $Y = AX^B$	$\ln Y = \ln A + B \ln X$	X Y 0
5. $Y = X/(A + BX)$	$1/Y = A/X + B$	X Y 0
6. $Y = A(\exp)\frac{B}{X}$	$\ln Y = \ln A + B(1/X)$	X Y 0

Goodness of fit statistics used to determine the "best" model are:

1. R^2, coefficient of determination;
2. residual error (standard error of estimate); and
3. maximum absolute residual.

Each of the above methods has a restriction in that one or both variables must be greater than zero. For most observations, the values of X and Y will always be positive. If some entries are zero, a constant (1.0, 0.1, or 0.01) can be added to all of the values before making the actual transformation. Changing just one entry from 0 to 0.01 will introduce some bias into the data.

The question arises as to which model should be used. To compare data from block to block, the same model should be used. Using the same model to compare different treatments used in the same project also has some appeal. The criteria for selecting the appropriate model follows:

1. The selected model best explains the underlying hypothesis to be tested, and

2. The model has the highest coefficient of determination, R^2.

The coefficient of determination represents the percent variation accounted for by fitting the X and Y variables. An R^2 value of 0.921

can be interpreted as; 92.1 percent of the variation can be explained by the relation of X to Y. If R^2 is 0.325, we could state that only 32.5 percent of the variation is explained by fitting X and Y. The remaining variation is unaccounted for.

Statistical Note

The intent of this paper is not to describe the statistical methodology or general model assumptions about the proper use of regression analysis. A word of caution is in order, however. In a strict sense, the use of regression analysis demands that the independent variable be independent observations, free of sampling error. This assumption is probably the most violated assumption in regression analysis. When the average value for the independent variable from a data set must be used, most statisticians agree this has not much effect when the relative sampling error of that variable is less than 10 percent: R.S.E. = $S\bar{x}/\bar{x}$ (Daniel and Wood 1971). When both independent and dependent variables are subjected to sampling error, the error can be magnified. Estimating a structural relation (both variables measured with error), the regression analysis can lead to large errors in the coefficient and erroneous conclusions.

Where block averages are used, both the dependent and independent variables are determined from average values observed within each spray block. These variables must have a relatively low sampling error.

Three examples have been prepared to assist the user. Each example demonstrates spray-deposit and mortality relations for a different level of sampling--cluster, tree, and block. All three examples were derived from spruce budworm spray-project data. Insect data were reported in larvae per 100 buds.

Example 1. Shows data reported for 25 three-tree clusters in one spray block. The cluster level values as presented for the prespray and two postspray time periods (3 and 10 days), (table 10).

Graphic analysis of 10-day mortality with gallons per acre and droplets per square centimeter is displayed in figures 56 and 57, respectively.

Example 2. Data are reported for 15 single trees in one spray block (table 11). The mortality values were computed from 10-day postspray population values. The spray-deposit parameters are mass, expressed in ounces per acre, and droplets per square centimeter.

Graphic relations are displayed in figures 58 and 59.

Example 3. Data are reported for 12 spray blocks in a field experiment (table 12) with three dosage rates and controls. Prespray and postspray insect

Table 10--*Spray-deposit data with corresponding spruce budworm mortalities for one spray block with 25 three-tree clusters sampled within block*

Cluster	Prespray (insects/100 buds)	Postspray (insects/100 buds) 3 days	Postspray (insects/100 buds) 10 days	Mortality (%) 3 days	Mortality (%) 10 days	Spray deposit Vmd (µm)	Spray deposit Mass (gal/acre)	Spray deposit Droplets (No./cm^2)
1	17.868	1.395	.112	.921	.994	239	.21	6
2	23.551	.781	.000	.967	1.000	241	.36	10
3	12.280	3.500	.361	.715	.971	172	.06	4
4	22.975	.342	.000	.985	1.000	285	.50	14
5	18.983	.195	.000	.990	1.000	304	.64	11
6	16.062	.278	.247	.983	.985	258	.25	6
7	8.466	.877	.124	.896	.985	228	.27	9
8	9.906	.111	.321	.989	.968	231	.56	18
9	7.537	.100	.000	.987	1.000	225	.26	11
10	16.695	.087	.000	.995	1.000	282	1.12	22
11	15.477	.640	.388	.959	.975	242	.23	8
12	19.968	.891	.000	.955	1.000	298	.55	13
13	16.297	.451	.157	.972	.990	217	.23	13
14	15.295	.249	.000	.984	1.000	253	.95	26
15	15.011	2.139	.465	.856	.969	303	.45	10
16	29.538	1.713	1.142	.942	.961	161	.16	12
17	31.331	2.991	.417	.905	.987	337	.42	5
18	9.868	1.806	.565	.817	.943	162	.08	6
19	23.067	5.124	5.418	.778	.765	161	.05	4
20	17.077	4.776	1.164	.720	.932	297	.08	4
21	12.462	.976	.535	.922	.957	236	.24	10
22	15.761	4.756	1.257	.698	.920	167	.10	7
23	24.866	.456	.074	.982	.997	250	.65	18
24	19.723	3.946	1.200	.800	.939	242	.14	4
25	11.260	.000	.000	1.000	1.000	277	.76	18

Table 11--*Spray-deposit data with corresponding spruce budworm mortalities for one spray block with 15 single trees sampled within a block*

Trees	Prespray (insects/100 buds)	Postspray (insects/100 buds) 3 days	Postspray (insects/100 buds) 10 days	Mortality (%) 3 days	Mortality (%) 10 days	Spray deposit Mass (gal/acre)	Spray deposit Droplets (No./cm^2)
1	6.304	1.301	2.964	.794	.530	.03	7
2	7.087	3.033	2.049	.572	.711	.05	6
3	5.732	1.691	2.239	.705	.609	.06	12
4	5.299	.702	.465	.868	.913	.11	12
5	3.759	.159	.000	.958	1.000	.16	22
6	4.050	.532	.986	.869	.757	.05	13
7	5.398	.426	.000	.921	1.000	.10	21
8	6.558	1.196	.849	.818	.871	.09	11
9	11.628	3.764	2.711	.676	.767	.07	16
10	11.449	4.745	5.734	.586	.499	.01	4
11	17.886	13.747	8.513	.231	.524	0(.01)	1
12	5.702	3.052	3.781	.465	.337	.02	7
13	6.634	1.875	1.760	.717	.734	.03	5
14	5.065	4.351	3.384	.141	.332	.01	4
15	8.244	4.661	5.128	.435	.378	.02	4

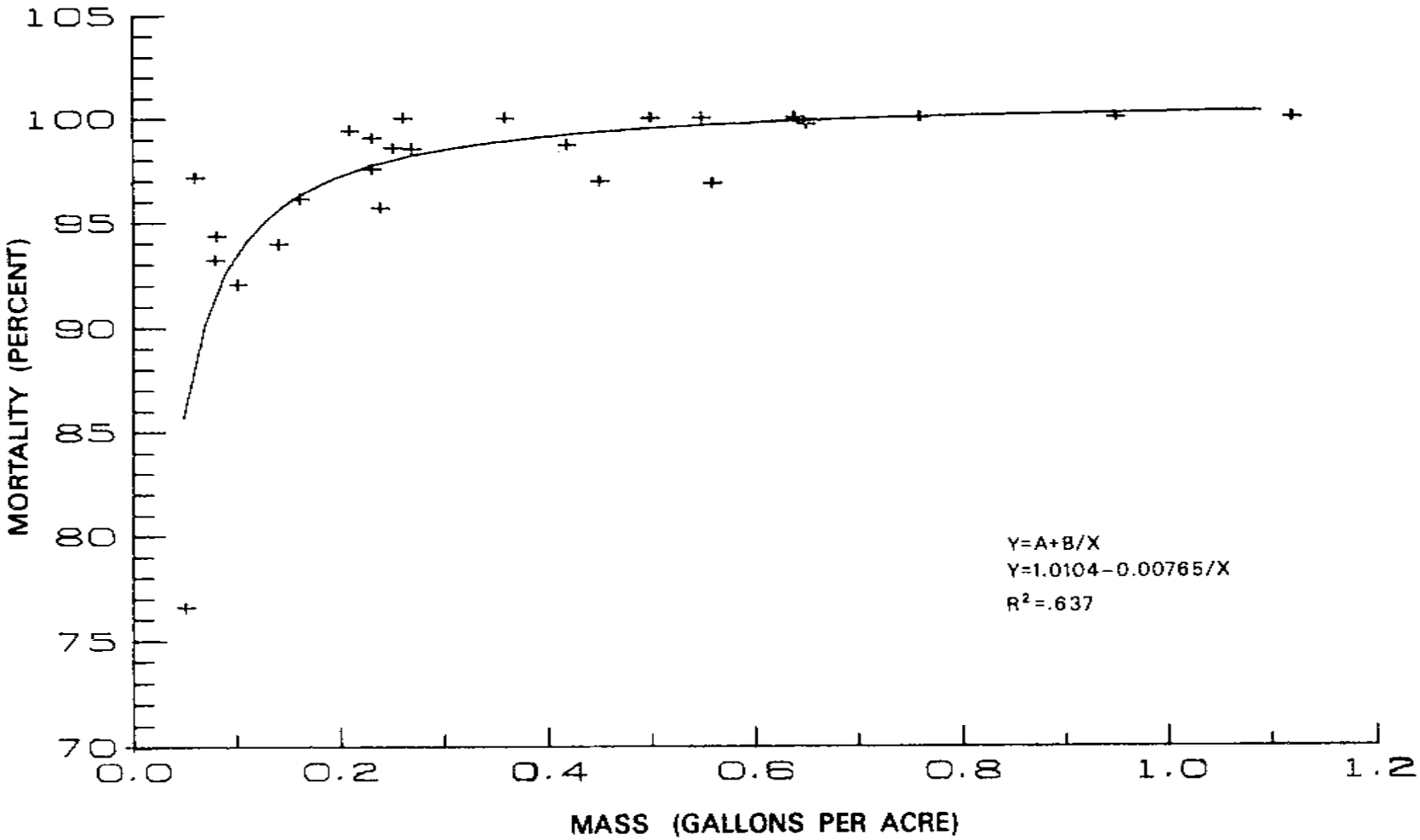


Figure 56.—Regression curve of insect mortality over gallons per acre in one spray block with 25 three-tree clusters.

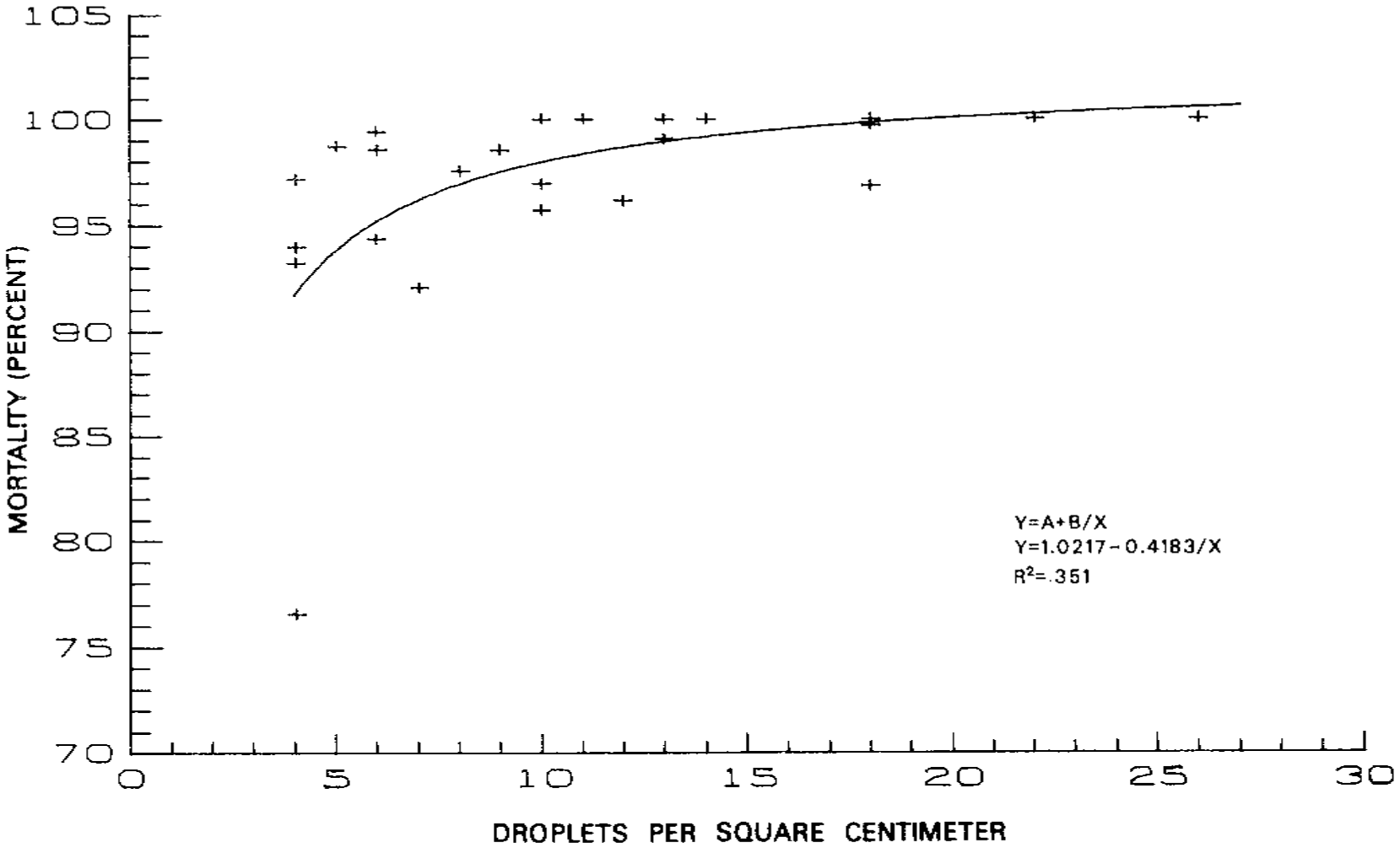


Figure 57.—Regression curve of insect mortality over droplets/cm^2 in one spray block with 25 three-tree clusters.

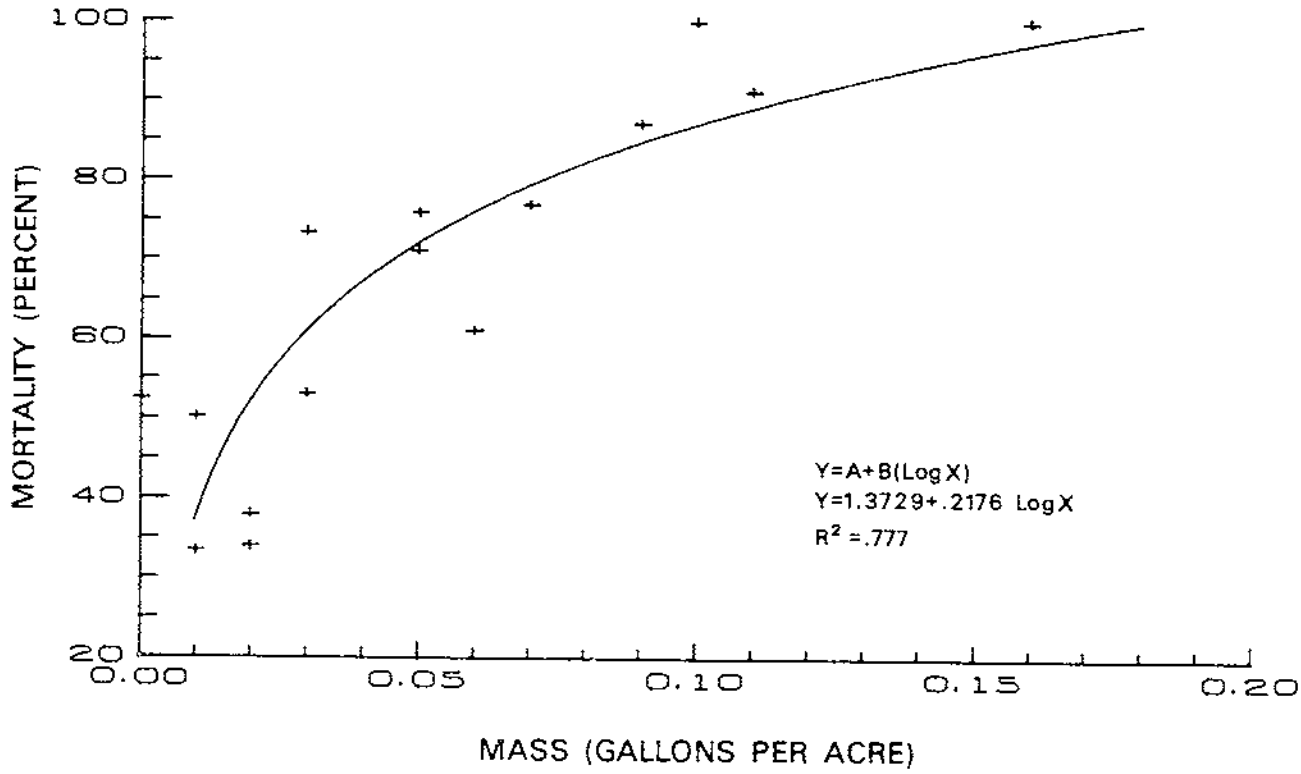


Figure 58.—Regression curve of insect mortality over mass recovery in one spray block with 15 single trees.

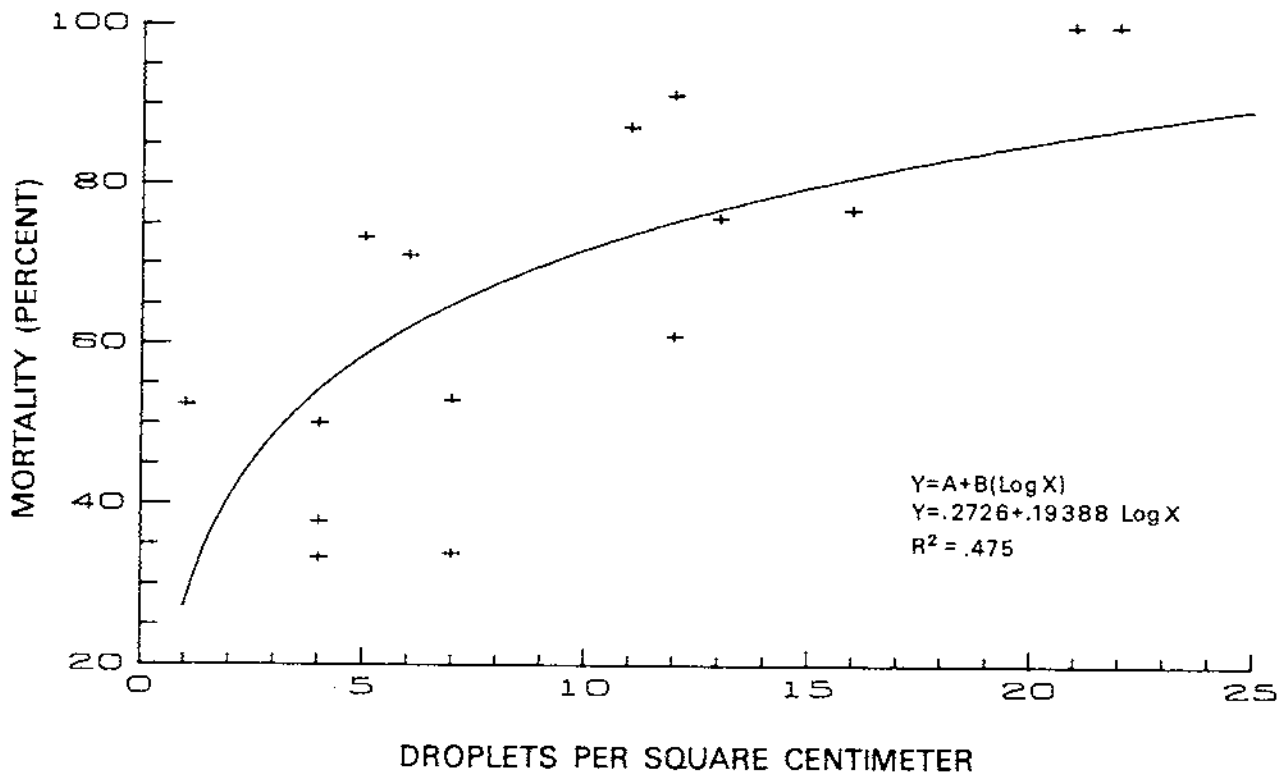


Figure 59.—Regression curve of insect mortality over droplets/cm^2 in one spray block with 15 single trees.

Table 12--*Spray-deposit data with corresponding spruce budworm mortalities for an entire field experiment using block averages for 12 blocks--three replications each using three different dosage rates and check blocks*[1/]

Block	Treatment	Prespray (insects/100 buds)	Postspray (insects/100 buds)	Mortality (%)	Spray deposit Mass (Ounces/acre)
1	A	35.1	.1	.997	1.89
2	A	22.5	.2	.991	1.86
3	A	36.5	.0	1.000	2.48
4	B	29.2	1.7	.942	1.09
5	B	33.6	2.8	.917	.95
6	B	35.9	3.4	.905	1.09
7	C	20.5	2.3	.888	.53
8	C	18.9	2.7	.857	.47
9	C	29.2	1.8	.938	.70
10	Control	26.1	10.8	.586	.0 (.01)
11	Control	31.4	10.9	.653	.0 (.01)
12	Control	35.6	14.4	.596	.0 (.01)

[1/] The control blocks did not receive any spray but are included to show the effects of natural mortality.

densities are expressed in larvae per 100 buds. Mortality values were computed for 10-day postspray population values. The spray-deposit parameter is mass, expressed in ounces per acre.

The graphic relation is displayed in figure 60.

Conclusions

These data provide the user with some insights on how well a particular spray block or series of spray blocks were treated, and on how variations in spray deposit affect mortality of the target insect. From data sets such as this, performance standards--specifying minimum deposit required for a desired level of mortality--can be derived for operational projects. In field experiments and pilot projects where less than desired mortalities are achieved, this approach can provide some indication as to whether the insecticide being evaluated was ineffective because it has an inherent low toxicity to the target insect or because the spray block received inconsistent or poor application.

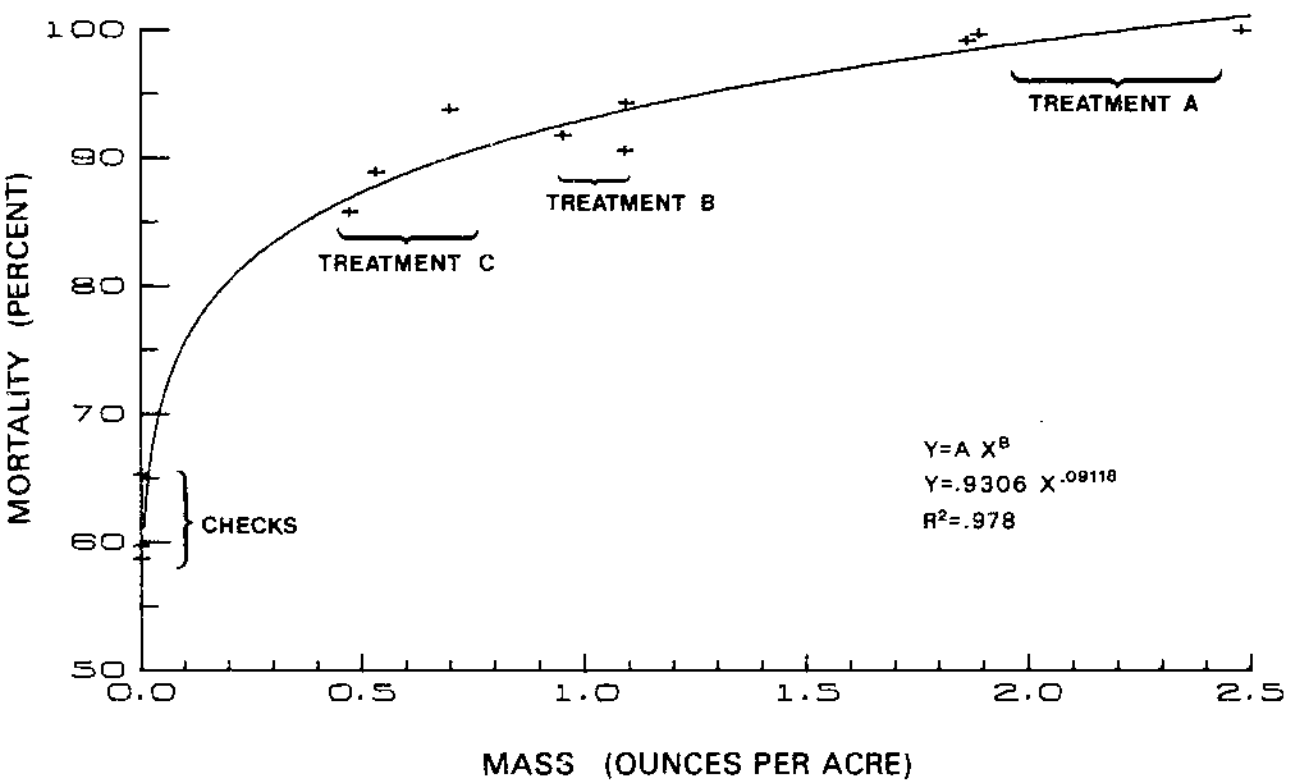


Figure 60.—Regression curve of insect mortality over ounces per acre for 12 sampled plots in a field experiment.

Reporting Spray-Deposit Data

Jerald Dewey

A common fault of many aerial spray studies or projects is a failure to report objectives, methods, and results adequately. Frequently, past project reports are reviewed by management and researchers for planning purposes or for making comparisons with other projects. They are of limited value if pertinent information is lacking.

Deposit assessment aspects of a project should be a part of the whole project report. The extent of spray-deposit reporting varies with the type of project. Field experiments and pilot projects require thorough documentation, but operational project reporting may be somewhat abbreviated. The following checklist can serve as a guide for reporting important spray-deposit information. A description of each item listed should be reported. Use of photographs is encouraged.

Aircraft

- Type
- Wing or rotor length
- Performance (load capacity)

Spray System

- Kind, size, and manufacturer of nozzles and orfices
- In-line and nozzle screens (mesh size)
- Spinning nozzle parameters (rpm, flow rate into each nozzle)
- Spacing and total number of nozzles
- Direction nozzles were facing to line of flight
- Boom length
- Type of pump (wind driven, hydraulic, electric)
- Recirculation (how much and what type)

Formulation

- Formula of active ingredient
- Concentration (amount of each ingredient in tank mix and density in g/ml)
- Carrier
- Dyes/tracers
- Physical properties of tank mix (specific gravity, viscosity)
- Spread factor for samples

Application

- Calibration (calibrated flow rate; how, when, and where calibrated)
- Characterization (how, when, and where characterized)
- Pump pressure (psi)
- Atomization (μm)
- Spraying speed
- Spraying height
- Application rate (gal/acre)
- Dosage applied (AI lbs/acre)
- Total volume of spray applied per plot or block
- Swath width
- Plot size (how determined)
- Guidance (type for boundaries and plot)

Site Characteristics

- Type of terrain
- Stand attributes (density, species, age class, ground cover)

Meteorology (see chapter 4)

- Wind speed
- Wind direction
- Ambient air temperatures
- Relative humidity
- Stability ratio

Deposit Assessment

- Sampling surface (cards, plates, foliage)
- Sampling design (number and location of samplers)
- How handled (when positioned, retrieved, stored, and read)
- Method of analysis (fluorometric, visual counting and sizing, Quantimet)

Results (droplet size, mean gallons/acre at ground level)

- Data analysis

In addition to the above items, a narrative should be prepared discussing the specific objective or objectives of the deposit-assessment effort. It should include a review of anything unusual about the equipment, application, or analysis. Keep in mind the importance of documenting the project, for future reference by persons unfamiliar with it. Recommendations for future projects are very helpful.

Graphs, tables, maps, and photographs should be used extensively in reporting deposit-assessment activities. Deposit or meteorological data may be presented in raw form in the appendix of the report.

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Glossary

AERODYNAMIC DROPLET DIAMETER--the diameter of an airborne spray droplet.

AEROSOL--a colloidal suspension of solids or liquids in air, spray droplets of less than 50 μm in diameter.

AI--active ingredient.

AIRCRAFT CALIBRATION--the process of measuring and adjusting the flow rate from the spray boom to ensure that the desired application rate is maintained.

AIRCRAFT SPRAY- SYSTEM CHARACTERIZATION--the process of determining the spray pattern, swath width, droplet spectrum, droplet numbers, spray mass, and spray volume produced by an aircraft spray system.

AIR DRAINAGE--general term for gravity-induced, downslope flow of relatively cold air; winds thus produced are called drainage winds.

APPLICATION RATE--usually refers to the amount (mass) of active ingredient (AI) of a pesticide in a given amount of tank mix per acre; for example, 1 lb of DDT per gallon per acre.

APPLICATOR--the person who actually does the spraying.

ASCAS--(automatic spot counting and sizing)--automatic data-processing program for analyzing spray-deposit data.

ATOMIZE--to break up a liquid into fine droplets by various means such as pressure, rotating discs, air blast, vibration, or ultrasound.

AVERAGE-MASS DIAMETER (amd)--diameter of a droplet the mass of which, if multiplied by the total number of droplets, will equal the total mass.

AVERAGE-NUMBER DIAMETER (and)--average droplet size of all droplets sampled. Determined by multiplying the number of droplets in each class by the size of the class and then dividing the sum of the products by the total number of droplets counted.

CANOPY PENETRATION RATIO--the ratio or percent of the amount of spray recovered under the canopy to that available at the top of the canopy.

CARDHOLDER--a device usually fabricated from plastic to protect and hold a Kromekote card.

COLLECTION PLATES--glass, aluminum, stainless steel, or plastic plates for collecting liquid sprays in the field. The spray deposit is washed from the plates and assessed chemically.

LINEAR CORRELATION COEFFICIENT--a measure of the degree of linear association between two variables, free of the effects of the scale of measurement.

COVARIANCE--a measure of the association between the magnitudes of two characteristics.

DEPOSIT CARDS--cards, Kromekote unless otherwise specified, used to sample spray deposit.

D-MAX METHOD--a method of estimating vmd as a function of the five largest droplets on a set of deposit cards.

DRAINAGE WINDS--general term for density-induced, valley and slope winds. They flow upslope during the day and downslope during the night.

DRIFT--the portion of spray cloud that is not deposited within the target area.

DROPLET DENSITY--amount of spray material that was recovered on deposit samplers, expressed in droplets per unit area, volume per unit area, or mass per unit area.

DROPLET-SIZE--size of aerodynamic droplet, commonly expressed as droplet diameter in micrometers.

DROPLET-SIZE CLASSIFICATION (SPRAY ATOMIZATION)--no classification has been agreed upon for all purposes. Maksymiuk's classification for aerial application of insecticides in forestry is as follows:

1. Aerosol spray--vmd of droplets below 50 µm
2. Fine spray--vmd of droplets from 50 to 150 µm
3. Medium spray--vmd of droplets from 150 to 250 µm
4. Coarse spray--vmd of droplets from 250 to 350 µm
5. Very coarse spray--vmd of droplets above 350 µm.

DROPLET-SIZE SPECTRUM--the range of droplet sizes.

EFFICACY--capacity of material to produce desired effects; effectiveness.

EMULSION--a dispersion of fine particles of one liquid, such as oil within another liquid, such as water. The one liquid is not

dissolved in the other, but the mixture can be stabilized with proper emulsifiers.

FIELD EXPERIMENT--field test conducted to evaluate a pesticide that showed promise in the laboratory.

FORMULATION--insecticide mixture produced and delivered by the manufacturer. Once the formulation is diluted in the field, it is referred to as tank mix.

HALO--shadow around a stain, sometimes caused by differences in spreading rates of ingredients in the spray mix. Halos also appear on cards that have been wet.

INSECTICIDE--a substance or mixture of substances or biological agents that kill insects.

KROMEKOTE CARD--cover stock manufactured by Champion International, often referred to as a deposit card sampler.

MASS-MEDIAN DIAMETER (mmd)--the droplet size diameter that divides the spray mass into equal parts; 50 percent of the mass is in droplets below the mmd and 50 percent of the mass is in droplets above the mmd.

MEDIAN LETHAL CONCENTRATION (LC_{50})--stated concentration of active material in liquid formulation, dust, mist, gas, or vapor resulting in death of half of the test subjects in a given interval.

MEDIAN LETHAL DOSE (LD_{50})--the dose of insecticidal material (chemical or microbial) producing death in half of the test subjects in a given interval. A common method of expressing the toxicity of a compound. It is generally expressed as milligrams of a chemical per kilogram of body weight of the test animal (mg/kg). An LD_{50} is a statistical estimate of the dosage necessary to kill 50 percent of a very large population of the test species under stated conditions (e.g., single oral dose of aqueous solution) or, by law, the dose that is expected to cause death within 14 days in 50 percent of the test animals treated. A compound with a LD_{50} of 10 mg/kg is more toxic than one with a LD_{50} of 100 mg/kg.

NUMBER-MEDIAN DIAMETER (nmd)--the diameter that divides the number of droplets into two equal groups--50 percent of the droplets have a diameter above the nmd and 50 percent below.

OIL-BASE SPRAY--a pesticide chemical dissolved in oil.

OIL-SENSITIVE CARD--a red-dyed, oil-sensitive Kromekote card, which shows a white spot when an oil-base spray droplet lands on the surface.

OPERATIONAL CONTROL PROJECT--a project conducted to control a forest pest.

PERCENT CONCENTRATION--the weight or volume of a given compound expressed as a percentage of the final mixture.

PESTICIDE--a chemical or agent that will kill a pest (plant or animal)--used to regulate a pest population.

PESTICIDE CONCENTRATION--the percentage or amount either by weight/weight or volume/volume of the active ingredient of a pesticide chemical in a formulation or tank mix.

PILOT CONTROL PROJECT--tests of materials and equipment or both to demonstrate and evaluate their operational aspects.

PROJECT DIRECTOR--person responsible for directing a spray project.

QUANTIMET--an image analyzing instrument, which counts spots and particles, manufactured by Cambridge Instrument Company, Inc.

RECOVERY RATE--ratio of spray recovered to amount disseminated.

SATELLITE STAINS--droplets sometimes shatter on foliage, forming satellite stains. These groups of stains should be recorded as single smears.

SPECTRAL COUNTS--number and size of droplets represented by the stains on a given sampler.

SPRAY ACCOUNTABILITY--an accounting for the spray that has been released into the atmosphere, usually expressed in percent of original amount released.

SPRAY CLOUD--spray, consisting of aerosol or particulate-size particles or droplets, generated into the atmosphere from a spray device.

SPREAD FACTOR--an expression of the amount of spreading of an aerodynamic droplet on a collecting surface, or the conversion of a sphere to a plane surface. If a 50-µm aerodynamic droplet makes a stain of 100 µm on a Kromekote card, the spread factor will be 2.

SPREAD-FACTOR EQUATION--a mathematical expression of the spread factor.

STAINS--the spots produced by droplets of spray.

SUDAN BLACK CARDS--a purple card used to detect malathion droplets.

SUSPENSION--a dispersion of small particles of a solid or an immiscible liquid in another liquid or gas. The dispersed particles have little or no affinity for the dispersion medium.

SWATH WIDTH--the area (span) in which the amount of spray expressed in various ways equals or exceeds a specified amount thought to produce the requisite pesticide effectiveness.

TANK MIX--the mixture resulting after the formulated pesticide is prepared for field application.

TEMPERATURE GRADIENT (ΔT)--difference in temperature from the ground to a specified height. ΔT are usually described as lapse (temperature decreases with height), neutral (no difference from the adiabatic rate), or inversion (temperature increases with height).

VOLUME-MEDIAN DIAMETER (vmd)--the droplet size diameter that divides the spray volume into equal parts; 50 percent of the volume is in droplets below the vmd and 50 percent is above.

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SOURCES OF MATERIALS

Kromekote cards:

Nationwide Papers
Division of Champion International
345 Schwerin Street
San Francisco, CA 94119

The Mead Corporation
Dayton, Ohio 45402

Home and Farm Chemical Co.
P.O. Box 6055
Charlotte, North Carolina 28207

Quantimet analysis:

Energy Research and Development Administration
Albuquerque Operation Office
P.O. Box 5400
Albuquerque, New Mexico 87115
(Analysis completed at Los Alamos Scientific Lab)

Kromekote cardholder specifications:

MEDC
P.O. Drawer 6
Missoula, Montana 59801

Sudan Black and oil-red cards:

Home and Farm Chemical Co.
P.O. Box 6055
Charlotte, North Carolina 28207

Fire weather instrument kit--belt type complete:

Western Fire Equipment Co.
440 Valley Drive
Brisbane, California 94005

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SOURCES OF DYES AND TRACERS

Chemical		Cost*	Source
Automate Red B		3.20/lb 40 lb container	Keystone Ingham P.O. Box 669 Artesia, Ca. 90701 or Keystone Aniline and Chemical Co. 321 N. Loomis St. Chicago, Ill. 60607
Rhodamine B Extra		11.20/lb for 1 to 24 lb lots 8.20/lb for 25 to 109 lb lots	
Rhodamine B Base		12.75/lb for 1 to 24 lb lots 10.35/lb for 25 to 109 lb lots	
Oleic acid		1.67/500 grams	ICN Pharmaceuticals, Inc. Life Sciences Group 26201 Miles Road Cleveland, Ohio 44128
Ferric Chloride	lumps powder	11.25/lb 15.63/lb	MCB Manufacturing Chemists 2909 Highland Avenue Cincinnati, Ohio 45212
Red B liquid dye		2.20/lb in 30 lb drums 1 to 9 drums	E. I. DuPont 111 Sutter St. Rm. 1429 San Francisco, Ca. 94104
Tinopal S.F.P.		4.50/lb in 110 lb containers	Ciba Geigy Corp. Dye Staff Chem. Div. P.O. Box 11422 Greensboro, N.C. 27409

*As of July 1, 1978.

COMMON EQUIVALENTS AND CONVERSION FACTORS[1/]

Approximate Common Equivalents		Conversions Accurate to Parts/Million	
1 inch	= 25 millimeters	inches x 25.4*	= millimeters
1 foot	= 0.3 meter	feet x 0.3048*	= meters
1 yard	= 0.9 meter	yards x 0.9144*	= meters
1 mile	= 1.6 kilometers	miles x 1.609 34	= kilometer
1 sq. inch	= 6.5 sq. centimeters	sq. in. x 6.4516*	= sq. centimeters
1 sq. foot	= 0.09 sq. meter	sq. ft. x 0.092 903	= sq. meters
1 sq. yard	= 0.8 sq. meter	sq. yards x 0.836 127	= sq. meters
1 acre	= 0.4 hectare	acres x 0.404 686	= hectares
1 cu. inch	= 16 cu. centimeters	cu. inches x 16.3871	= cu. centimeters
1 cu. foot	= 0.03 cu. meter	cu. feet x 0.028 316	= cu. meters
1 cu. yard	= 0.8 cu. meter	cu. yards x 0.764 555	= cu. meters
1 quart	= 1 liter	quarts (lg) x 0.946 353	= liters
1 gallon	= 0.004 cu. meter	gallons x 0.003 785 41	= cu. meter
1 ounce (avdp)	= 28 grams	ounces (avdp) x 28.3495	= grams
1 pound (avdp)	= 0.45 kilogram	pounds (avdp) x 0.453 592	= kilograms
1 millimeter	= 0.04 inch	millimeters x 0.039 370 1	= inches
1 meter	= 3.3 feet	meters x 3.280 84	= feet
1 meter	= 1.1 yards	meters x 1.093 61	= yards
1 kilometer	= 0.6 mile	kilometer x 0.621 371	= miles
1 sq. centimeter	= 0.16 sq. in.	sq. centimeter x 0.155 000	= sq. in.
1 sq. meter	= 11 sq. feet	sq. meters x 10.7639	= sq. feet
1 sq. meter	= 1.2 sq. yards	sq. meters x 1.195 99	= sq. yards
1 hectare	= 2.5 acres	hectares x 2.471 05	= acres
1 cu. centimeter	= 0.06 cu. in.	cu. centimeters x 0.061 027 7	= cu. in.
1 cu. meter	= 1.3 cu. yards	cu. meter x 1.307 95	= cu. yards
1 cu. meter	= 35 cu. feet	cu. meters x 35.3147	= cu. feet
1 liter	= 1 quart	liters x 1.056 69	= quarts
1 cu. meter	= 250 gallons	cu. meters x 264.172	= gallons
1 gram	= 0.035 ounces	grams x 0.035 274 0	= ounces
1 kilogram	= 2.2 pounds	kilograms x 2.204 62	= pounds
1 ton	= 1.016 047 0 metric tons or 1,016.0470 kilograms		

* Exact.

[1/] The Modernized Metric System. Special Publication 304A. U.S. Department of Commerce, National Bureau of Standards. Revised 1970.

[Source: Neal (1974, table 25, p. 61, used with permission).]

WEIGHT CONVERSION UNITS[1/]

Units to be converted	Multiply by figures below				
	Grains	Grams	Ounces	Pounds	Kilograms
Grains	1	0.0647	0.0022	0.00014	0.00006
Grams	15.432	1	0.035	0.0022	0.001
Ounces	437.50	28.34	1	0.0625	0.0283
Pounds	7,000.0	453.59	16	1	0.453
Kilograms	15,432.3	1000.0	35.273	2.204	1

[Source: Neal (1974, used with permission).]

LIQUID CAPACITY CONVERSION UNITS

Units to be converted	Multiply by figures below					
	Ounces, fluid	Pints	Quarts	Gallons	Milli-liters	Liters
Ounces, fl.	1.0	0.0625	0.031	0.0078	29.572	0.0295
Pints	16.0	1.0	0.5	0.125	473.167	0.4731
Quarts	32.0	2.0	1.0	0.25	946.33	0.946
Gallons	128.0	8.0	4.0	1.0	3,785.33	3.785
Milliliters	0.0338	0.0021	0.0010	0.0002	1.0	0.0010
Liters	33.814	2.113	1.056	0.264	1000	1.0

[1/] All weights are avoirdupois as opposed to troy weight for gold, silver, other precious metals, stones, and drugs.
[Source: Neal (1974, used with permission).]

METRIC UNITS AND PREFIXES

Prefixes[1/]	Symbols	Meaning	Multiples & submultiples	Decimal
tera	T	= 1 trillion	10^{12}	1,(12 ciphers)
giga	G	= 1 billion	10^{9}	1,(9 ciphers)
mega	M	= 1 million	10^{6}	1,000,000
myria[2/]		= 10 thousand	10^{4}	10,000
kilo	k	= 1 thousand	10^{3}	1,000
hecto	h	= 1 hundred	10^{2}	100
deka	da	= 10	10	10
unity		= 1	1	1
deci	d	= one tenth	1×10^{-1}	0.1
centi	c	= one hundredth	1×10^{-2}	0.01
milli	m	= one thousandth	1×10^{-3}	0.001
micro	μ	= one millionth	1×10^{-6}	0.000,001
nano	n	= one billionth	1×10^{-9}	0.(8 ciphers)1
pico	p	= one trillionth	1×10^{-12}	0.(11ciphers)1
fento	f	= one quadtrillionth	1×10^{-15}	0.(14 ciphers)1
atto	a	= one quintrillionth	1×10^{-18}	0.(17 ciphers)1

[1/] Common suffix: meter, gram, liter, etc.

[2/] e.g., myriagram = 10 kg.

[Source: Neal (1974, used with permission).]

Size, volume, and number of droplets per square centimeter by distributing 1 gallon of liquid uniformly over a surface of 1 acre

Actual diameter	Volume	Number of droplets per square centimeter
Micrometers	Cubic micrometers	
1	0.52	178,012,500
2	4.2	22,251,600
3	14.18	6,593,000
4	33.6	2,781,400
5	65.6	1,424,200
6	113.4	824,100
7	180	519,700
8	269	347,600
10	525	178,000
12	907	103,000
13.5	1 289	72,500
15	1 772	52,700
17.5	2 814	33,200
18	3 062	30,500
20	4 200	22,200
24	7 257	12,900
25	7 442	12,500
30	14 175	6,600
35	22 507	4,150
40	33 600	2,780
45	47 838	1,950
50	65 520	1,430
55	87 343	1,060
60	113 400	820
70	180 007	520
80	268 800	350
90	382 725	244
100	525 000	178
110	699 000	133
120	907 000	103
130	1 153 000	81
140	1 440 000	65
150	1 771 000	53
160	2 150 000	43
170	2 579 000	36
180	3 061 000	30
190	3 600 000	26
200	4 200 000	22
220	5 590 000	17
240	7 257 000	12
260	9 227 000	10
280	11 528 000	8
300	14 175 000	6.6
400		2.8
500		1.4
1 000		.18

Settling rates of airborne particles with a specific gravity of 1, in still air[1/]

Diameter of particles	Velocity of settling	Time required to fall 50 feet
Micrometers	Feet per minute	Minutes
0.1	0.00016	312,500
.2	.00036	138,888
.4	.0013	38,461
.6	.002	25,000
.8	.005	10,000
1.0	.007	7,142
2.0	.024	2,083
4.0	.095	526
6.0	.21	238
8.0	.38	131
10	.59	84
20	2.4	21
40	9.5	5
60	21.3	2
80	33.0	--
100	47.0	--
200	138.0	--
400	354.0	--

[1/] Falling angle is assumed to be the same for all particle sizes.

Distance of travel of 100-micrometer droplet falling 50 feet with various windspeeds

Miles per hour	Feet
0.25	22
.5	45
1	87
2	175
3	265
4	348
5	435
10	765

Spray Area Computation Table of Aircraft Speed and Swath Width[1/]

$$\text{Acres per minute} = \frac{2x \text{ swath width x miles per hour}}{1{,}000}$$

Speed	30-foot swath	35-foot swath	40-foot swath	45-foot swath	50-foot swath	75-foot swath	100-foot swath	200-foot swath	300-foot swath	500-foot swath
m/h										
75	4.5	5.2	6.0	6.7	7.5	11.2	15.0	30.0	45.0	75.0
80	4.8	5.6	6.4	7.2	8.0	12.0	16.0	32.0	48.0	80.0
85	5.1	5.9	6.8	7.6	8.5	12.7	17.0	34.0	51.0	85.0
90	5.4	6.3	7.2	8.1	9.0	13.5	18.0	36.0	54.0	90.0
95	5.7	6.6	7.6	8.5	9.5	14.2	19.0	38.0	57.0	95.0
100	6.0	7.0	8.0	9.0	10.0	15.0	20.0	40.0	60.0	100.0
110	6.6	7.7	8.8	9.9	11.0	16.5	22.0	44.0	66.0	110.0
120	7.2	8.4	9.6	10.8	12.0	18.0	24.0	48.0	72.0	120.0
130	7.8	9.1	10.4	11.7	13.0	19.5	26.0	52.0	78.0	130.0
140	8.4	9.8	11.2	12.6	14.0	21.0	28.0	56.0	84.0	140.0
150	9.0	10.5	12.0	13.5	15.0	22.5	30.0	60.0	90.0	150.0

[1/] This table shows the rate, in acres per minute, at which spray or dry material can be applied when swath width and speed of aircraft are known. For swath widths or aircraft speeds other than those shown, interpolate or use combinations of the figures shown. To find the rate of flow in gallons per minute or pounds per minute, multiply the acres per minute figure by the number of gallons or pounds per acre to be applied.

Spray Area Computation Table of Length and Width of Swath[1/]

$$\left(\text{Acres covered} = \frac{\text{Length of swath in miles x width of swath in feet}}{8.25}\right)$$

Swath length	30-foot swath	35-foot swath	40-foot swath	45-foot swath	50-foot swath	75-foot swath	100-foot swath	200-foot swath	300-foot swath	500-foot swath
Miles										
1/4	0.9	1.1	1.2	1.4	1.5	2.3	3.0	6.1	9.1	15.2
1/2	1.8	2.1	2.4	2.7	3.0	4.5	6.1	12.1	18.2	30.3
3/4	2.7	3.2	3.6	4.1	4.6	6.8	9.1	18.2	27.3	45.4
1	3.6	4.2	4.8	5.5	6.1	9.1	12.1	24.2	36.4	60.6
2	7.2	8.4	9.8	10.9	12.1	18.2	24.2	48.5	72.7	121.2
3	10.8	12.6	14.5	16.4	18.2	27.3	36.4	72.7	109.1	181.8
4	14.4	16.8	19.4	21.8	24.2	36.4	48.5	97.0	145.4	242.4
5	18.0	21.0	24.2	27.3	30.3	45.5	60.6	121.1	181.8	303.0

[1/] Example of how to determine the number of acres in a swath of given width and length. An aircraft with a 40-foot effective swath treats a strip 1 mile long. To find the number of acres, follow the 40-foot vertical column down until it intersects the 1-mile line. The answer to the nearest tenth is 4.8 acres. For swath widths other than those shown, interpolate or use combinations of the figures shown.

To determine the amount of pesticide required, multiply the acres by the desired rate of application.

FIELD REPORT

SPRAY AIRCRAFT CALIBRATION AND CHARACTERIZATION

DATE:
AIRCRAFT:
REGISTRATION NO:
PILOT:
LOCATION:

REMARKS

CALIBRATION

DATE:
TIME:
NOZZLE NOMENCLATURE:
NOZZLE REPLACEMENT:
NOZZLE NUMBER:
NOZZLE POSITIONING:
NOZZLE SPACING:
BOOM PRESSURE:
TYPE CALIBRATION:
SWATH WIDTH:
SPRAY MATERIAL:
APPLICATION RATE:

DIAGRAM OF GRID

CHARACTERIZATION

DATE:
TIME:
LOCATION:
RELEASE HEIGHT:
AIRCRAFT SPEED:
BOOM PRESSURE:
SPRAY MATERIAL:
APPLICATION RATE:
GRID DESIGN:
DEPOSIT CARD SPACING:
INWIND OR CROSSWIND:
RELEASE POINT:
LENGTH RELEASE:
WIND SPEED:
WIND DIRECTION:
RELATIVE HUMIDITY:
TEMPERATURE:
INVERSION, NEUTRAL, LAPSE:
DROPS PER CM^2:
DROP SPREAD FACTOR:
VOLUME MEDIAN DIAMETER:

WORK SHEET FOR FIELD SPECTRAL COUNTING

SPECTRAL COUNTS

Test: ..... STAIN SIZE (μm) Date: .....

Card No.	<400	<800	<1200	<1600	<2000	<2400	<2800	<3200	<3600	<4000	<4400	<4800	<5200	<5600	<6000	<6000	Total drops/cm^2

TRIAL LOG FORM

Trial Number _____ Time/Date _____ Time Zone _____

Row _____ Row Azimuth _____ ^{o} Card Separation _____ m

Number of Cards _____

I. SPRAY SYSTEM DATA

Aircraft _____

Spray Nozzle _____ Nozzle Orientation _____

Airspeed _____ (mph) Flow Rate _____ gallons min^{-1}

Flight Altitude ____ (ft or m) Aircraft Heading _____ ^{o}

Spray Material _____ Material Density _____ g cm^{-3}

Stain Factor Formula _____

Stain Factor Constants _____ _____ _____

II. METEOROLOGICAL DATA

Cloud Cover _____ % Temperature _____ ^{o}C

2-m Wind Direction _____ ^{o} 2-m Wind Speed _____ m sec^{-1}

Relative Humidity _____ %

(Optional Measurements Using Pilot Balloons and/or Tethersonde)

Wind Profile

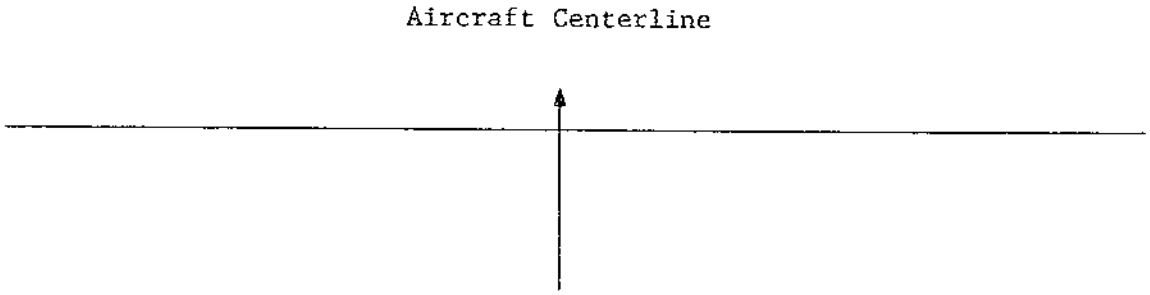
Height (m)	Direction (^{o})	Speed (m sec^{-1})

Temperature Profile

Height (m)	Temperature (^{o}C)

TRIAL LOG (Continued)

III. NOZZLE CONFIGURATION



IV. REMARKS

DATA FORM FOR

FIELD ESTIMATE OF SWATH WIDTH AND DROPLET DENSITIES

Date _____
Trial Number _____
Row/Line Number _____

Card	Area (cm^2)	No. of stains	Density (drops cm^{-2})
_____			
_____			
_____			
_____			
_____			
_____			
_____			
_____			

Card Number for Left End of Swath _____

Right End of Swath _____

Estimated Swath Width _____

DATA FORM FOR

VOLUME MEDIAN DIAMETER (VMD) ESTIMATES

Trial Number _____ Spray Material _____

Time/Date _____ Stain Factors a _____

Row/Line Number _____ b _____

Aircraft _____ c _____

Aircraft Altitude _____ Flow Rate _____

Aircraft Speed _____ Miscellaneous _____

_____

_____

Largest Stains and Drops

Card Number	Stain Diameter	Drop Diameter

Five Largest Drops

Card Number	Drop Diameter

$$VMD = \begin{cases} DD/2.2 & (80\text{–}120 \text{ mph}) \\ DD/2.5 & (> 120 \text{ mph}) \end{cases}$$

VMD = _____

DATA FORM FOR

DROP DENSITY AND MASS DEPOSIT DATA

Trial Number _____ Mass Mean Diameter _____ (μm)

Row Number _____ Mass _____ (mg)

Conversion Factor: 1 oz $acre^{-1}$ = 1.427×10^{3} mg cm^{-2}

Card Number	Template Area (cm^2)	Stain Count	Drop Density ($drops\ cm^{-2}$)	Deposition	
				($mg\ cm^{-2}$)	($oz\ acre^{-1}$)
Total					

Mass Recovery _____ ($mg\ m^{-1}$)

Deposition Efficiency _____ (percent)

METEOROLOGICAL DATA FORM

Plot _____ Date _____

Observer _____

Time of Application: From _____ To _____

Time	Temp.	RH, %	Wind		Remarks
			MPH	Direction	

Sky: Clear _____ Cloudy _____ Fog _____ Rain _____

Foliage: Dry _____ Moist _____ Dripping _____

Comments on weather or spray behavior:

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END