SPRAY DISTRIBUTION IN A TREE CROP

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To Joyce and Kwaku for their continuous love, care and patient endurance, during the many hours my attention was taken away from them in the course of this work, and to all those who care and sympathise with the Underdevelopment of the developing World.

ABSTRACT

Mature apple trees were sprayed using a Knapsack mistblower fitted with 3 different nozzle systems, one of which provided an induced electrostatic charge on the spray droplets.

Spray distribution was assessed by examining fluorescent tracer deposits on Kromekote cards which had been positioned in different parts of the tree canopy. Subsequently, bioassays with codling moth (neonate larvae) and formulations of cypermethrin examined the biological effect of deposits.

Small uncharged droplets (30-60µm VMD) sprayed at low volume (3.0 4.8 ml/tree) with spinning disc gave the least deposit but with an electrostatic charge, deposition was significantly improved on the outer canopy. Intermediate results were achieved when sprays were applied from an air-shear nozzle at 274.0 ml/tree. Directing spray from both sides of the tree improved spray distribution with all three nozzles.

Leaf Area Index (LAI) of the apple varieties used in the experiments was estimated in relation to tree height, and was used to calculate the volumes of spray needed to improve coverage of the canopy.

Attempts to improve penetration into canopy were made by varying the charge/mass ratio on the droplets, but a decrease in this ratio reduced deposition (ng/cm^2) within canopy.

Mortality of Codling moth was related directly to the level of deposits, so there was a decline through the canopy. When large droplets (140-152µm VMD) were applied, about 300 droplets/cm^2 were needed

to deposit 2.75 ng/cm² active ingredients (ai) to achieve at least 50 percent mortality or more. When smaller droplets (30-60µm VMD) were used the number increased to 900 droplets/cm² to give similar deposits of 4.0 ng/cm² a.i. and achieve similar responses.

Cypermethrin formulations sprayed with each nozzle on apple seedlings (variety Yarlington mill) were more persistent after artificial rain (65.3mm for 15 mins.) when small droplets (VMD = 30.70µm) were applied by spinning disc, compared with larger droplets (VMD = 90-169µm) produced by the air-shear nozzle. The under surface of leaves were more protected from the direct action of impinging rain droplets, and thus had greater mortality after rain. No significant difference was obtained between droplets by either charged or uncharged spray ($P = 0.05$).

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LIST OF ABBREVIATIONS

a.i.	Active ingredients
C.A.B.	Commonwealth Agricultural Bureaux
c.	about
cc	centimeter cube
cm	centimeter
cm^2	centimeter square
c.c.	correlation coefficient
cv	coefficient of variation
d.f.	degrees of freedom
E.C.	emulsifiable concentrate
ED	'Electrodyn '
Fig.	Figure
g, gm.	gram
ha	hectare
Kg	Kilogram
Kv	Kilovolt
l	litre(s)
l/ha	litre(s)/hectare
m	metre
m/s	metre/second
ml	millilitre(s)
min.	minimum
min.	minute
n, no.	number
ng	nanogram (10^{-9} g)
no/cm^2	number/centimeter square
ng/cm^2	nanogram(s)/centimeter square
µm	micrometer (10^{-6} m)
U.S.	United States of America
U.S.D.A.	United States Department of Agriculture
>	greater than
=	equal to

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Pest Populations in the Tropics

Agricultural crops are attacked by many insect pests and pathogens some of which may be transmitted by insects. In consequence losses occur both during crop development and post-harvest storage. In most cases such losses are greater in tropical countries, so continued effort is needed to reduce these losses and increase agricultural productivity.

The technologically advanced countries have the resources to develop adequate measures for control, but these cannot be applied uncritically in tropical countries. In temperate regions, the life cycle of most species is affected by seasonal changes in temperature so control measures, based on detailed knowledge of the species can be timed more effectively (Hill and Waller,1982).

In many tropical areas, particularly in the rain forests, temperatures do not fluctuate very much and with heavy rainfall, high relative humidity and other environmental factors, favour constant development so that all stages of pests are present most of the time. Some insecticides have little effect, since eggs and pupae generally survive contact with spray deposits which are translocated or degraded very rapidly (Le Pelley, 1968; Hill and Waller, 1982; Matthews, 1982). In perennial crop situations, it is most important to utilize natural enemies which will usually keep pest populations in check, in contrast to annual (short-term) crops where conditions as in temperate crops, are affected by cropping practices and other factors so that there is rarely sufficient time for natural enemy population to increase

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Implementation of existing technology could increase yields of many crops, but financial and other constraints affect what individual farmers are able to do, so average yields are generally lower than those that should be achieved. Biological methods of control must continue to play an important role, especially in perennial crops, where there have been successes obtained by scientists of the CAB International Institute of Biological Control, who provide expertise at a number of centres throughout the World, to evaluate pest problems, select and screen potential species and subsequently breed sufficient for release (de Bach, 1979; Hill and Waller, 1982; Matthews, 1984). Commercial requirements for top quality fruit however, require that chemical controls are also needed but as residues on crops must be minimal and taint avoided, chemical control is not easy.

1.2 Plantation Crops

Plantation crops such as citrus, coffee, cocoa and apple are subject to infestation from pests migrating from elsewhere and those which co-exist within the crop over many generations. These pests may occupy different ecological niches within the crop canopy, which can vary in size, density and complexity due to the cultivars and management of the plantation (Le Pelley, 1968; Entwistle, 1972; Morgan, 1975).

Differences in plantation crops and its pest complex, present quite distinct problems in developing control techniques and suitable equipment, but a number of principal factors are similar, i.e. tree crops, row spacing, density of canopy, etc., which are sufficiently similar to allow problems to be considered initially on one crop, and subsequently adapt the results to comparable situations in other perennial tree crops. Thus working in the U.K. it was convenient to study pesticide application on large apple trees to assess the spray distribution achieved in a crop canopy with different application equipment, with the aim of simulating large tropical trees, such as citrus and cocoa.

The pests and the application problem that arise in the control on a number of important tropical crops are discussed in the following section.

1.2.1 Citrus

The geographical origin of citrus is thought to be the Indo-Pacific region, but is now grown throughout the tropical, subtropical and the frost-free temperate regions of the World (Williams, 1975). There are many varieties of the major species, which are propagated clonally and by the use of nucellar seedlings, mostly as grafted scion material onto stock seedlings (Srivastava and Arya, 1969).

Spacing between citrus trees has traditionally been relatively wide. Ochse (1961) gives an indication of minimum and maximum planting distances used in various Citrus species based primarily on tree size, ranging from 4.5 x 4.5m for limes, to 12 x 12m for the grapefruit and pomelos. In recent years, a tendency for closer spacing for early yields, followed by appropriate thinning at a later stage has been adopted (Williams, 1975).

Morphologically, commercial citrus species vary from small trees up to 5m in height, such as most lime varieties to trees of about 10m or more in height, like the grapefruits and pomelos. Leaves are generally ovate and vary in length from 3 to 20cm; invariably with a waxy surface, and the branches conspicuously spiny. The tree tends to produce a dense foliage behind its periphery (Carman and Jeppson, 1974; Johnstone, 1970), behind which is a network of supporting branches with little foliage (Ebeling, 1959).

Over 800 species of insects occur in the citrus ecosystem, but only a few are described as pests. Among these are the scale insects, constituting the major pest problems in most citrus growing areas of the World. They are sessile in nature and can attack all parts of the tree (Ebeling, 1959; Johnstone, 1970), for example, the California red-scale (Aonidiella aurantii Mask) which causes disfigurement and loss of crop quality, is widespread and causes the death of badly infested trees (Hanna, 1968).

The Mediterranean fruit fly (Ceratitis capitata Wiedm) damages ripe fruit by abortive stinging and ovipositional punctures of the female. There is a secondary infection by some fungus spores which cause decay of the fruit (Hodgson, 1970). Mealybugs (Pseudococcus citri Risso) live on young shoots, buds and fruits and cause fruit drop, by clustering around the calyses. The associated sooty mould also results in dirty fruit (Johnstone, 1970). In Latin America, the leaf cutting ants, especially Atta insularis Guerin, are very serious pests and have caused defoliation of citrus trees overnight (Wolcott, 1933). In West Africa, the fruit piercing moths are among the most destructive pests (Cotterel, 1940; Box, 1942; Afreh-Nuamah, 1985), attacking fruits by piercing with proboscis (Hargreaves, 1936), and allowing entry of fungi.

An insect transmitted virus Tristeza which causes phloem necrosis and swellings on the stock, is causing major concern in citrus cultivation. Psorosis - a complex of viruses can cause chlorosis of leaves, scaly bark, etc.,(Broadbent, 1970). It is bud transmitted and occurs widely in South America. Other virus diseases are the Xyloporosis (Cochexia), Exocortis and the greening disease which is a virus complex, transmitted by insects (Williams, 1975).

Many fungal and bacterial diseases are described by Hanna (1969), and include the bacterial canker caused by Xanthomonas citri, Phytophora root-rot, and the citrus scab by the fungus Elsinoe fawcetti.

Control of the diseases has been by rigorous quarantine measures, use of resistant stocks and clean bud, and by vector control with various pesticides. The insect pests have been controlled essentially by use of insecticide sprays. However, the application of certain broad spectrum insecticides like DDT, have adverse effects on natural enemies of the pests, and often result in serious outbreaks of scales (de Bach and Bartlett, 1951). For example, a substantial increase in numbers of the California red scale, following the application of persistent insecticides has been recorded (de Bach, 1974). Of late, most citrus growing countries are reducing the dependence on insecticides, and giving greater emphasis on the use of biological methods of control. For example, until recently, chemical control was used extensively in Peru against the rufous scale (Selenaspidus articulatus) but a search in East Africa provided a chalcidoid Asphytis roseni, which rapidly reduced the rufous scale populations to below the economic threshold, when released from 1972-1976 in unsprayed citrus orchards (Beingolea, 1977; Matthews, 1984). Ants which tend scales, mealybugs and aphids interfere with parasitism, so by placing a sticky band around trees to stop the ants, better biological control is achieved (de Bach and Huffaker, 1971; Matthews, 1984). However, pesticides are still needed in most citrus areas, so improved application is essential to allow better integration with all possible means of control to reduce pests effectively. Pesticides must be screened, for their effect on natural enemies, and applied more selectively and quicker in response to pest numbers exceeding economic levels, to reduce costs and ensure better control.

The size and shape of citrus trees with the mass of waxy leaves, provide a complex and difficult target to spray, so several different techniques have been used, especially in the U.S.A., example (a) the "Wigwag" system of spraying horizontally from side to side, (b) a revolving motion of the spray stream, and (c) a vertical motion of spraying. Nevertheless, a combination of two or more systems, according to the shapes, sizes or density of tree foliage is most common

(Ebeling, 1959).

Penetration of the dense canopy and ensure leaves are fluttering to be treated on both surfaces, requires a large volume of air, emitted with sufficient pressure to replace the air within the canopy (Ebeling, 1959; Carman and Jeppson, 1974).

Equipment ranging from hand operated Knapsack to high pressure mechanised pumping systems on vehicles, has been used depending on the size of farm and terrain (Ebeling, 1959; Johnstone, 1970). Citrus in parts of Thailand is sprayed from a boat moving along a narrow canal between raised beds (Matthews, personal communication). In citrus areas in California, sprayers with pumps maximum capacity of from 225 to 300 litres per hectare at 600 to 1000 pounds per square inch are commonly used. Currently, however, more people are getting interested in the use of low and Ultra low volume applications (from 225 to 87 L/ha), to reduce costs and save time (Stephenson and McClung, 1966; Cohen and Cohen, 1967; Lindley, 1969; Carman and Jeppson, 1974; Johnstone et al., 1975).

1.2.2 Coffee

Coffee, one of the most important agricultural commodities in World trade, is produced in almost all tropical countries (Le Pelley, 1968). Four different species are grown to about 6.5m high under natural conditions, with marked differences in branching according to species and variety (Williams, 1975). Conventional field spacing varies from about 2.3 x 2.3m for compact arabica plants at high elevations, to 3.3 x 3.3m for robusta varieties, and up to 4 meters for the larger liberica and elcelsa species. Closer spacing gives better early yields, and wider spacing gives better prolonged yields (Deuss, 1971; Williams, 1975).

Relatively few insects cause widespread or catastrophic losses (Le Pelley, 1968; 1973). Among these are; thrips causing defoliation, sometimes quite seriously, and several species of bugs (*Antestiopsis* spp.) which attack fruit. Wood boring beetles, e.g. the large lamiids *Anthores* and *Bixadus* can kill many young trees, and seriously damage large trees. Some coccoidea can kill plants, e.g. the *Asterolecantum* in East Africa (Tothill, 1940), and the related *Cerococcus parahybensis* in Brazil (Moreira, 1921; Le Pelley, 1973).

Foliar pests include *Cephonodes*, *Ascotis* and *Epicampoptera*, larvae of which can cause serious defoliation, but in many cases outbreaks tend to be localised. When die-back follows complete defoliation, cropping is set back for at least a full season (Le Pelley, 1968).

A review of coffee diseases is given by Wellman (1961) and Waller (1972). Among the important diseases are the rust *Hemileia vastatrix* with lesions on lower surface of leaves giving off orange-coloured spores, and a translucent 'greasy' spot on the upper side (Williams, 1975). The coffee berry disease (CBD) caused by *Colletotri chum coffeanum var. virulans* has assumed epidemic proportions particularly in Africa (Waller, 1971), where it attacks *arabica* coffee varieties under wet (Woodhead, 1969; Griffiths and Waller, 1971; Waller, 1972) and cold conditions (Muthappa, 1970). Infection starts from the base of berries and the stalks as brown patches. Die-back symptoms have also been attributed to CBD (Saccas and Charpentier, 1969).

The American leaf spot caused by *Mycena flavida* is troublesome in the American tropics, where it will also attack cocoa and citrus. It attacks leaf tissues causing defoliation.Methods of applying pesticides and control of coffee pests and diseases have been reviewed (Le pelley, 1968; Gibbs, 1971; Griffiths, Gibbs and Waller, 1971; Maithia, 1981). Application methods comprise the medium and trailer-type mistblowers for large plantations of over 50 hectares applying more than 1700 L/ha, and hydraulic sprayers of various types. Sprayers for use with or on tractors are most favoured in the larger plantations of East Africa, though motorised knapsack mistblowers applying about 300 L/ha are now very popular. Small farmers, however, use the manually operated compression and lever-operated Knapsack sprayers. Bucket pumps are extensively used on peasant owned plantations.

Due to difficulties in providing water and the time involved, the present trend has been to use low volumes at high concentrations, especially with fungicides in East Africa and India, against Hemileia.

1.2.3 Cocoa

In its natural habitat, cocoa (Theobroma cacao L) is an understorey tree of the South and Central American forests, in regions of high rainfall and temperature. It is now grown in West Africa and the Far East, as an important cash crop (Richards, 1952; Williams, 1975). The various varieties of cocoa have been reviewed by Wood (1963) and Soria (1970).

Spacing for cultivation has been extensively variable. Close spacing (c. 2.3 x 2.3m, 800 trees/acre) gives higher yields than wider (4 x 4m) spacing. In cultivation without shade, closer spacing is generally used, but with more vigorous upper Amazon clones and their hybrids, a slightly wider (3.3 x 3.3m) spacing is recommended (Wood, 1964). Under coconuts in Malaysia, a spacing of two rows, 3.3m apart in the coconut avenues and 2m apart in the rows has been recommended (Leach, 1971).

The tree can reach a height of about 10m, if unpruned, and the mature trees form an almost closed canopy, at about 4-7m above the ground, in which branches held more or less horizontally, form a barrier to upward air movement.

The cocoa ecosystem has about the greatest diversity of trophically associated insects than any other tropical or temperate crop. There are more than 1,400 recorded species (Entwistle, 1972). However, only a few species are considered of major importance, of which the mirids (chiefly Sahlbergella singularis and Distantiella theobroma) have caused widespread damages to cocoa in West Africa, Java, Sri Lanka and New Guinea (Williams, 1975), by feeding on the pods and young shoots. Feeding punctures may also be infested with the fungus Calonectria rigidiuscula, leading to die back. They also contribute to cherelle wilt, which is partly associated with fungal attack.

Several strains of the deadly 'swollen shoot' virus are said to be spread by the mealybugs (Pseudococcidae) (Entwistle, 1972). This virus has caused widespread losses in cocoa in West Africa, causing swellings of fan and chupon branches.

The fungus Phytopthora palmivora which causes a range of symptoms including pod rotting (black pod), seedling wilt and leaf fall (Hislop, 1964), can spread from infected pods to invade the flower cushion and the stem, giving rise to 'canker' (Vernon, 1971). Another serious disease 'witches-broom' caused by the fungus *Marasimius persiciosius*, is endemic to the South American region. The main symptom being the production of broom-like branching of the shoots, with undeveloped leaves and enlarged branched flower cushions (Bartley and Amponsah, 1966).

Control of insect pests is based on the use of insecticides, and diseases by selection of resistant types (Youdeowei, 1971; Darkwah, 1966/67), but because it takes a long time to get a resistant variety established, reduction of shade and periodic spraying with Bordeaux mixture or other copper fungicides is practised in the short term (Hislop, 1963).

Cocoa is sprayed principally with compression sprayers, fitted with long lances, or motorised Knapsack mistblowers, which project spray into the top canopy of about 8 to 10m (Stapley and Hammond, 1951, Clayphon, 1971; Entwistle, 1972). Fogging is used in some areas, e.g. Francophone West Africa, and requires a closer spacing with more distinct canopy to retain the fog. Aerial application has been attempted in other areas, but results were not very satisfactory (Silva *et al*, 1969; Ventocilla *et al*., 1964; Entwistle, 1972).

Application volumes commonly used today for insecticides, are low volume spraying (50-110 L/ha) (Entwistle, 1972; Clayphon, 1974). Little work has been done with ultra low volume spraying, with even smaller attention to the importance of droplet size in cocoa pest control problems, though attempts to adapt the motorised Knapsack mistblower for ULV spraying have been made (Clayphon, 1974, Thornhill 1974; Macfarlane and Matthews, 1978).

1.2.4 Apple

The apple is a high value crop produced in the temperate and sub-tropical regions of the World. Trees can grow to about 8m high and 5m wide when unpruned, so traditionally they have been planted in rows 4 meters apart. However, harvesting of tall trees increases labour costs so modern intensive apple production has much smaller trees (c. 2-2.75m high and 1.5m wide), while still maintaining pathways between rows to allow access to agricultural tractors of 1.6m overall width (Morgan, 1975).

The apple orchard ecosystem like the tropical tree crops, is very diverse and complex, with over one hundred associated arthropods, small mammals and weeds and over 200 diseases being reported, 20 to 30 of which have the potential to damage the crop seriously each year (U.S. Dept. Agric. 1960).

The most serious insect pests are the Codling moth (*Cydia pomonella* L), light brown apple moths (*Epiphyas postvittana* Walk.), mites e.g. fruit-tree red spider mite (*Panonychus ulmi* Koch.). In addition the diseases apple scab (*Venturia inaequalis* (Cke) Wint) and powdery mildew (*Podosphaera leucotricha* (Elle & Eu) Salm) are major problems in all apple areas. Scab causes more losses than any other apple disease, especially in the U.S.A. (Sutton and Jones, 1981), as fruit and foliage are affected during the current season, and if extensive defoliation occurs, the number of fruit-bud formed next season is also reduced. In the U.K., apple mildew is the important disease, causing a reduction in yield and quality of fruit, especially as preferred U.K. variety Cox Pippins is susceptible to the disease (Cooke, *et al*., 1977; Gunn, 1980).

Cultural practices play an important role in the control of pests and diseases, but farmers still apply many pesticides, thus in the U.K. 8-20 sprays (Cooke et al.,1977; Gunn, 1980) and in Australia up to 12 sprays (Johnson, 1965) are often applied at 7-14 day intervals each season on apples.

Prior to the early 1950's these sprays were applied using high pressure pumps fitted with hand lances/hand guns (Lewis and Hickey, 1972), but these were replaced by the development and subsequent improvement of air carrier sprayers to reduce labour costs (Sutton and Jones, 1981). A high volume of air was more advantageous than high pressure (Randall, 1971), and this led to the development of the 'Commandair' sprayer (Gunn, 1980).

Traditionally, trees have been sprayed with large volumes of liquid (about 2000-3000 L/ha) using hydraulic, particularly cone nozzles, but with the air-carrier type machines, spray volumes were reduced to 300-1000 L/ha (Hislop, 1983). Much of the pesticide was not retained on foliage, causing adverse side effects to organisms such as earthworms in the soil, so attempts to improve efficiency of spraying were started in 1974,by substituting hydraulic nozzles on a commercial mistblower with rotary discs, to apply 45 L/ha (Cooke et al., 1976, 1977). Insects were controlled by this technique with considerable savings of insecticides but control of powdery mildew was inferior to that achieved by larger spray volumes (500 L/ha). Small droplet sizes (120 µm) were shown to have considerable advantage over larger droplets (180 µm) in disease control (Allen et al., 1978).

Whether using an electrostatically charged spray would improve spray deposition was examined initially on small apple trees. Allen et al., (1983) using a hand-held 'Electrodyn' sprays with 100 µm and 130 µm vmd droplets increased deposits on all important parts of small apple tree canopies(1.5m high) relative to high volume treatments. Deposits of charged spray were inversely related to droplet size. Powdery mildew control usually improved as deposits increased, but disease control depended on both the amount deposited and "cover index".

Low volume (< 800 L/ha) application is widely used, because it is quicker, but the spray distribution throughout a tree can be adversely affected as volumes are reduced (Brann et al., 1967; Randall, 1971). Various trials have shown that trees acquire progressively lower deposits of spray per unit area of leaf, as tree size and canopy surface area increased (Warman and Hunter, 1981). Leaves in parts of the trees further from or shielded from the sprayer acquired lower deposits, and in such zones, mildew is often poorly controlled. Subsequently, spray volume should increase with increasing tree size (Morgan, 1964). However, applying less than 100 L/ha is possible without reducing the degree of disease control (Wicks and Nitschke, 1986). Morgan (1974), using a hand directed spinning disc also reported good scab control with one tenth the conventional amount of benomyl in the U.K., while Matthee et al., (1976) controlled scab with half the normal rate of benomyl at 30 L/ha, and Barrat et al., (1981) also used normal rates of fungicides at only 9.4 L/ha.

Although scab control has been excellent in more cases where spray volumes and pesticides rates have been reduced, control of powdery mildew in the same or similar experiments has been varied

(Gunn, 1980; Umpelby, 1984; Wicks and Nitschke, 1986), with few successes (Matthee et al., 1974; Keil et al., 1980; Whan et al., 1983).

An important factor in assessing the efficacy of reduced volumes of spray is the severity of the pest or disease (Hislop, 1983). Cooke et al., (1982) showed that minimal volumes will cope satisfactorily when the innoculum pressure is slight, but fail when it is more severe.

CHAPTER TWO: GENERAL LITERATURE REVIEW ON PESTICIDE APPLICATION

2.1 Spray Application Methods

Most pesticides are applied to reduce the population of the stage of pests, which is directly responsible for damage within individual fields. Joyce (1977) has argued that such applications need to be applied economically, on a scale dictated by the area occupied by the pest, and the urgency with which that pest population has to be controlled. Increasing concern about environmental pollution due to pesticide sprays, especially, those applied on a large scale, has led to more detailed evaluation of spray behaviour, with closer attention being paid to the role of particle sizes in the spray distribution, deposition and biological effectiveness of pesticides (Hartley and Graham-Bryce, 1980).

2.1.1 Production of spray droplets

The different types of nozzles are based on the energy used to break up the spray liquid into droplets and disperse them over a short distance. Matthews, (1985) lists various types of nozzles, including:

(a) Hydraulic energy nozzles

Liquid is forced under pressure through a small opening or orifice and spreads out into a thin sheet which disintegrates irregularly into different sized droplets (Frazer, 1958) with the volume of the largest droplets being more than one million times that of the smallest. A wide range of these nozzles are manufactured to provide different application rates, spray angles and patterns.

(b) Gaseous-energy nozzles

An airstream is used to impact on and shear liquid containing pesticide into droplets. Droplet size depends on the air/liquid ratio, so large droplets are produced by increasing liquid flow or reducing air velocity. Uniform air velocity at the liquid interface is required to reduce the variation in droplet size.

(c) Centrifugal-energy nozzle

Liquid fed near the centre of a rotating surface is spread centrifugally to the edge, from which it is thrown out as single droplets. As the flow rate increases, ligaments are produced. At a particular rotational speed, there are different optimum flow rates for single droplet and ligament formation respectively to avoid the transitional phases when a wider droplet spectrum is produced. Droplet size is inversely proportional to the angular velocity of the disc (Walton and Prewett, 1949; Frost, 1981), so droplet size can be selected by adjustment of rotational speed and flow rate. The performance of spinning disc nozzles has been improved by the addition of teeth, referred to as zero-issuing surfaces, to reduce the surface to which liquid can cling by surface tension, with further development of grooves to each tooth to produce a narrow range of droplets size from ligaments, even with high flow rates.

(d) Electrostatic nozzles

The concept of charging droplets to improve spray deposition has been studied by many scientists including Law (1976), who designed a nozzle in which an air stream produces and then carries aerosol droplets (<50 µm) away from an embedded electrode, which induces an opposite charge on the droplets. Induction charging is limited to conductive liquids, and relatively low voltages (Splinter, 1968; Law, 1976).

In corona charging, a high voltage (70KV) insulated electrode ionizes the spray to give a charge of the same polarity as the electrodes. Corona charging is possible with both pressure and rotary atomisers (Moser et al, 1983). Arnold and Pye (1980) have described the resulting improved deposition efficiency, when discs are charged up to 30 KV. This system is useable with a wide range of liquids, so that conventional oil and aqueous formulations can be sprayed with them (Hopkinson, 1974; Arnold, 1979; Arnold & Pye, 1980).

The third method of contact (direct) charging, involves applying a high voltage to the spray nozzle and thus charge liquid passing through it. Coffee (1979, 1980) introduced a direct charging system, in which electrical energy atomises the liquid as well as charges the droplets. A high voltage (usually 16-30 KV) charges pesticide formulations with a resistivity in the semi-conductivity range up to 10^8ohm/m, as it is metered through a narrow gap. Although a very high voltage is required (Matthews, 1983), the power requirement is less than when small electric motors are used, so battery life is considerably extended on the new 'Electrodyn' sprayer, which has 'no moving parts'.

'Direct' charging of the liquid permits higher charges on the droplets than 'indirect' charging by field forces, as in the case of corona and induction charging (Moser et al, 1981, 1983).

2.1.2 Spraying Machines - Air carrier sprayers

Sprayers using hydraulic nozzles have been the most widely used due to the interchangeability of the nozzle tips, but other types are of increasing importance with the application of ultra-low volumes

(Matthews, 1985). The distance droplets can be projected from a hydraulic nozzle is limited, so an airstream is needed to project droplets over longer distances to the target. Air carrier sprayers are particularly useful for projecting droplets up into trees for which droplets less than 100 µm diameter are required to minimize fall out, contaminating the ground. The airstream from a powered fan may be used to produce the droplets, but hydraulic- or centrifugal-energy nozzles are often mounted in the airstream (Matthews, 1985). The later allow the use of larger volumes of air at low velocity, to displace a higher proportion of the air within a crop canopy, with air containing droplets (Randall, 1971). If droplets must be projected vertically, 6m or more, a high-velocity airstream (>60m/s) is needed, but the airstream velocity decreases rapidly on leaving the nozzle, so coverage is often difficult to achieve in the centre and top of large canopies of tree crops. Ideally the velocity should be sufficient to impact small droplets on the target with turbulence to improve distribution of the droplets, especially in dense canopies (Matthews, 1979).

(a) Knapsack mistblowers

Knapsack mistblowers are portable air carrier sprayers powered by light weight, air cooled 35cc or 50-70cc two stroke engines, with a fan directly attached, capable of applying either solids or liquid formulation of pesticides (Matthews, 1979; Sutherland, 1980).

2.1.3 Volumes of Spraying

High, medium, low, very low and ultra-low volume (NV, MV, LV, VLV and ULV) are terms used to describe the quantity of liquid used to apply pesticides, and have acquired different meanings for field and tree crops separately (Matthews, 1979; Gunn, 1980).

The target area requiring treatment may be much greater than the ground area, although most recommendations in the past have referred to ground area only. This may be true only if spraying is overhead the crop (Morgan, 1964). Some attempts to relate spray volumes to target area have been made (Matthews, 1979). Morgan (1964) referred to selection of spray volume in relation to the size of trees in orchards, and Tunstall et al.,(1961) increased the volume of spray applied on cotton according to plant height. Where spray coverage of leaves is required, Matthews (1979) suggests that the estimation of the leaf area index (LAI) (which is defined as the ratio of leaf area to ground area), is necessary. LAI varies with different crops according to the stage of plant growth. In Italy, Baraldi et al., (1984) found that the proportion of spray retained on apple trees varied directly with their respective leaf area indices. The evaluated LAI for different apple plants according to their sizes was from 0.25 to 10.58. For field crops, Matthews (1979) gives LAI figures of about 6-7, as leaves without adequate light are usually shed. According to him, if LAI is 3, and 2.5 litres is needed per hectare of foliage, then the total volume per ground hectare applied to the crop, should be 7.5 litres. It is of note however, that doubling of spray volume does not necessarily double the deposit density of each leaf (Courshee, 1967), unless placement of nozzles or some other factor improves the distribution of the spray within a crop canopy.

(a) High volume spraying

High volume spraying has been described as those which induced "run-off" of the liquid from the traget (Courshee et al., 1954). This conventional method of application has been used since spraying machines were first manufactured (Ebeling, 1959), with mostly water based sprays aimed to cover the whole area as completely as possible, with little or no attention paid to droplet size.

Over the years, a wide range of different nozzles has been used (Matthews, 1979; 1985), most of which produce a wide spectrum of droplet sizes, the smallest being subject to 'exodrift' (losses due outside the treated area), and the largest being the main components of 'endodrift' (losses to the soil at time of application (Himel, 1974; Matthews, 1979). Morgan (1974) in the U.K., calculating the fall-out volume of spray to the orchard floor from captan deposition, got as much as 1018 L/ha (45%) from HV spraying at 2250 L/ha, and 450 L/ha (80%) from mist spraying at 560 L/ha. Cooke et al.,(1977) also in the U.K., gave figures for fall-out in apple orchards as 45% for HV and 35% for low volume spraying of 560 L/ha. On the other hand, Baraldi et al.,(1984) in Italy found that the proportion of spray measured, falling to the ground, was 30% when trees had young leaves, declining to 8% at a more matured stage, when spraying at between 250-1600 L/ha.

There is overwhelming evidence that high volume spray applications, while giving effective control at recommended dose rates, are very inefficient in that a relatively low proportion of the spray applied, reaches the target (Graham-Bryce, 1977; Matthews, 1981; Hislop, 1983). Greater attention to droplet size is now essential with the trend to using smaller volumes of spray (Matthews, 1979).

(b) Ultra-low volume spraying (ULV)

The ULV application technique originated shortly after World War II in control of desert locust in East Africa (Gunn et al., 1948), with the term 'ULV' being first used by Sayer and Rainer (1958). It is defined as the minimum volume per unit area required to achieve economic control (Anon, 1971).

Most farmers and scientists have been interested in this method of application, since it was introduced to agricultural pests (Himel, 1969). However, the early use of ULV was not adapted to small-scale agriculture (Matthews, 1981), until the development of the hand-held battery operated disc sprayers (Bals, 1969; 1975).

Droplets less than 100 µm are subject to evaporation and drift, especially if the formulation is water based, so special low-volatile formulations, with non-phytotoxic solvents are preferred (Mass, 1971; Wringley, 1973; Matthews, 1981).

Knapsack mistblowers can also be adpated for concentrate ULV spraying (Claphon & Thornhill, 1974).

(c) Electrostatic spraying

The charging of droplets produces electrical forces which act between the individual droplets and the target. Droplets from 30-200 µm can be obtained, and trajectory control of charged droplets results in significantly improved deposition with greater under leaf coverage (Coffee, 1979; 1980; Law, 1980; Moser *et al*, 1982; Matthews, 1983).

Contamination of the soil underneath plants is drastically reduced at the time of spraying especially in comparison with high volume spraying (Endacott, 1983), so soil inhabiting beneficial insects are less at risk. Moreover, for a given droplet size drift for a charged spray is less with droplets being effectively deposited on foliage (Coffee, 1979, 1980; Matthews, 1981). Where penetration into dense foliage is particularly difficult to achieve and/or where drift is acceptable, Coffee (1980) has suggested the introduction of a turbulent air flow into the system.

The plant acts effectively as a neutral body until a cloud of charged droplets passes near it and induces an opposite charge on it (especially at points such as leaf tips), and attracts the droplets which being of the same polarity repel one another.

(d) Controlled Droplet Application

The concept, controlled droplet application (CDA) aims to deliver accurately the pesticide to the target by applying a narrow spectrum of droplets, of the most appropriate size and number for biological target (Himel and UK, 1975), in a minimal volume of liquid to achieve the optimum effect (Graham-Bryce and Matthews, 1981).

CDA is not restricted to any particular volume of spray, neither is it concentrate or waterless spraying. However, as small droplets evaporate quickly, part of the liquid carrier should be involatile (e.g. oil), when the optimum VMD is less than 100 µm (Graham-Bryce and Matthews, 1981).

2.2 Droplets

Sprays contain a large number of droplets, the size of which greatly influences the efficiency of pest control. Pesticidal sprays are generally classified according to droplet size spectra (Matthews, 1979). The most widely used measurement of droplet size is the volume median diameter (VMD), measured in micro-meters (µm). In a sample of droplets divided into two equal parts by volume, one half of the spray volume contains droplets that are smaller than the VMD, while the other half contains larger droplets.

The number median diameter (NMD) is another parameter that similarly divides a sample of spray droplets into two halves, but purely on numbers so the NMD is always smaller than the VMD, and is much more difficult to measure. The ratio between these two parameters is often an indication of the range of sizes, thus the more uniform the size of droplets, the nearer the ratio is to 1 (Matthews, 1979; Graham-Bryce and Matthews, 1981).

Movement of spray droplets from the nozzle to the target is greatly influenced by various factors, like gravitational, meteorological, and electrostatic forces, the magnitude of each of which are also in turn influenced by the size of droplets.

With air carrier sprayers, droplets are ideally large enough so that after evaporation, they will still impinge on the target, yet small enough to be conveyed by the sprayer airstream and provide sufficient pesticide coverage on the target (Reichard et al., 1977).

2.2.1 Movements of droplets

(a) Evaporation

The extent to which droplets of a given size evaporates in an airstream or while floating in the air has been a matter of speculation, though a number of factors are known to influence it. Potts (1958) gives the important factors as: (i) the proportion of relatively non-volatile liquids and solids in the mixture, (ii) the temperature, humidity and wind velocity, (iii) the droplet size (since small volatile droplets have relatively a large surface area and evaporate faster than larger droplets, and (iv) the length of time that droplets are airborne.

Evaporation from spray droplets is increased in areas of low humidity, but the period of travel between nozzle and crop canopy is quite short so Potts (1958) considered that deposition was unaffected whereas, Reichard et al., (1977) believed that deposition was reduced. Evaporation losses of as high as 40 per cent at eleven metres from an air carrier sprayer have been measured (Cunningham et al., 1962). Grunkel (1965) showed that at higher relative humidities of about 70% (and with 13 m/s air velocities), more spray is deposited than at lower humidities.

The sizes of the desired spray droplets are supposed to dictate the required airstream velocity, however, generally certain minimum air velocity is needed to convey the desired droplet sizes and effect impingement (Reichard et al., 1977).

(b) Effect of meteorological factors

Local climatic conditions greatly affect the proportion of spray which reaches the target (Potts, 1958; Matthews, 1979). The basic factors are temperature, wind velocity and relative humidity. These factors have been extensively discussed by Johnstone (1985).

2.2.2 Spray Coverage

The degree of spray cover which is effective on foliage is determined by the behaviour and mobility of the pest, and the mode of action of the pesticide, thus when dealing with plantation crops like citrus, cocoa or apple, with a dense canopy in which both sedentary pests like the scale insects, and very active pests like the mirids and the fruit flies occur, complete coverage of foliage is needed to achieve maximum mortality, especially of the sedentary pests. The choice of equipment becomes important in such situations for better spray penetration and distribution.

When using mistblowers the optimum droplet size for best cover may be less than that indicated by theoretical calculations, this may be due partly to a tendency of the large droplets to sediment downwards as air velocity diminishes (Potts, 1958). Also several layers of foliage from top to bottom and across the canopy, filter out the larger droplets. The best penetration and coverage of foliage is achieved by accomplishing a fairly low deposition efficiency on the first layer, but obtaining the maximum total deposition before the spray reaches the far side.

The relative distance of the nozzle to the foliage may also affect efficiency of coverage, as the air velocity is greater and readily carries spray to target within the short distance between nozzle and foliage.

When the spray nozzle is directed by hand efficiency of spray coverage depends on organization and training of operators to direct the spray to the target, (Morgan, 1972).

The slower the speed of application, the greater is the uniformity of the deposit, and the economic speed depends on the wind conditions and type of plantation (Randall, 1971; Lieftink, 1980).

2.2.3 Collection of droplets on targets

Droplets are collected on insects or plant surfaces by sedimentation and impaction (Matthews, 1979). Studies on impaction droplets have shown a complex interaction between the size of the droplet, the obstacle in its path, and their relative velocity (Langmuir and Blodgett, 1946; Richardson, 1960; May and Clifford, 1967; Johnstone, Rendell and Sutherland, 1977). Collection efficiency of an obstacle in an airstream is defined as the ratio of the number of droplets striking the obstacle to the number which would strike it if the air was not deflected. In general, impaction efficiency increase with droplet size and droplet velocity, and decrease as the obstacle increases in size (Matthews, 1979). Small droplets tend to follow in the airstream and miss the obstacle unless the size of the droplet and its momentum are sufficient to penetrate the boundary layer of the air around it. In a moving airstream a target will theoretically collect droplets with an efficiency given by the relationship $E = f\left[\frac{pV_od^2}{18nl}\right]$ where E = collection efficiency, p = droplet density, d droplet diameter, n = air velocity, l = dimension of collecting object and V_o = velocity of the droplet (May and Clifford, 1967.). With moving leaves, V_o can be expressed in terms of two relative velocities $V_o = V + V_L$, where V = horizontal velocity and V_L = velocity of leaf (UK, 1977).

Most target surfaces are not smooth and variations in the surface may cause local turbulence of the airflow (Matthews, 1979). In this way, interception of a droplet or particle may occur, if its path has only been partially altered. Impaction of droplets on leaves depends very much on the position of the leaf in relation to the path of the droplet. More droplets are collected on leaves which are fluttering in turbulent conditions and thus present a changing target pattern. If wind velocity is too great a leaf may be turned parallel with the airflow, so presenting the minimum area to intercept droplets

(Matthews, 1979).

2.2.4 Assessment of spray coverage

Fluorescent dyes like uvitex and pigments lumogen and saturn yellow have been used as tracers to observe coverage and assess deposit on different targets (Sharp, 1955; 1973; Staniland, 1959; Dean et al., 1961; Pereira, 1967). Samples of the target, often leaves, are collected and sorted out in various categories depending on the amount of cover achieved. This technique was used to assess spray deposits on cotton (Matthews and Johnstone, 1968), and was further developed by Uk and Courshee (1982), so that deposit distribution probability in conjunction with laboratory dose mortality measurements could be used to predict the likely field effectiveness of sprays.

Spray coverage has also been assessed by measuring the emission of visible light with a fluorimeter (Yates and Akesson, 1963; Stafford et al., 1970). Distribution patterns of spray deposits and spread of pesticides on leaves have also been studied by the use of the scanning electron microscope (SEM) coupled with cathodoluminescence and X-ray analysis (Hart, 1979; Hess et al., 1975; Leuthold et al., 1978; Ong et al, 1973).

2.2.5 Determination of droplet size

No method has been developed for directly measuring droplet size in the field. Usually, dyed spray is collected on a suitable surface, and the sizes calculated from measurements of stains or craters taking account of spread factors (Furmidge, 1964; Matthews, 1975).

A standard surface for collecting droplets is magnesium oxide, obtained by burning one or two strips of magnesium ribbon, each 10cm in length below a glass slide (on a metal stand to prevent unequal heating of the glass), so that only the control area is coated uniformly (Matthews, 1979). Droplets impacting on the magnesium oxide surface form a crater which is greater than the actual droplet size, the difference between which is the spread factor. The reciprocal of the spread factor is used to convert the measurements of the crater to the true size. The magnesium oxide surface is less satisfactory for smaller droplets and those above 200 µm shatter on impaction (Matthews, 1979).

Usually, Kromekote cards (Higgins, 1967) or photographic paper (Johnstone, 1960) are used for collecting droplets in the field. The most important factors that may influence stain size are (a) the absorbing power of the collecting surface, varying with the nature of surface, and dependent on the volatility, viscosity and the surface tension of the spray liquid, (b) the momentum of the droplets when they strike the surface, and (c) the angle of impingement on the surface (Furmidge, 1964).

Clearly, the use of such surfaces have several disadvantages, because surfaces cannot simulate the size, shape, surface characteristics or other biological features of a tree (Carman & Jeppson, 1974). The deposition of droplets on the card surfaces, may however provide direct evidence that the spray reached that particular tree area.

2.3 Bioassay Methods

Bioassay can be defined as the "measuring of the response in an animal to a biologically active chemical" (Way, 1949; Busvine, 1971), and laboratory bioassays assess the efficacy of chemical toxicants in a controlled environment, and are a prerequisite for the design and execution of sound field experiments, by providing basic essential information (Robertson and Boelter, 1979).

There is greater scope to adapt basic bioassay techniques to obtain more detailed information to particular pest problems, the choice of technique depending to some extent on an initial study of the life cycle of a pest to determine which stage is more accessible to control (Matthews, 1984).

Individual insects may be treated, each with a dose, a defined quantity of toxicant at one time, or in a given period of time, but application of a precise dose is not always possible, even under laboratory conditions and it is more usual to apply the toxicant to a surface or group of individuals (Finney, 1949; Busvine, 1971; Matthews, 1984).

Most assessments of pesticides involve exposure to a single dose or dosage and thus measure the effect of acute poisoning, but in practice an organism may pick up small doses over a longer period of time (Matthews, 1984).

(a) Some factors affecting pesticide efficacy

Several factors are likely to influence the apparent potency of a pesticide, these are: (1) intrinsic differences between various types of insects; (2) fluctuations in susceptibility caused by extrinsic changes in the environment, (3) experimental factors, including differences between formulations and methods of application. A critical review of these factors are found in Shepherd (1958);

Busvine (1971); and Matthews (1984).

2.4 Rainfastness

Effects of rainfall on pesticide deposits can be very severe, especially in the tropics where rain is usually associated with thunderstorms. In such places, there are two defined seasons: wet and dry seasons. Usually the fruiting period of the major tropical crops like coffee, citrus and cocoa, and their outbreak of pests and diseases coincide with rainfall.

Unfortunately, the frequent rainfalls at such times nullify the control efforts, leading to waste and reduction of effect of pesticides and increased costs. Many surfaces are extremely difficult to wet, especially those with a layer of superficial wax like citrus leaves (Brunskill, 1956; Holloway, 1970; Boize, Gudin and Purdue, 1976). Consequently, it is even more difficult to spray under wet conditions.

Rain affects spray deposits in various ways: directly through the dissolution or dislodging of the deposits from the surface of plants and extraction of systemic pesticides from plant tissues, and indirectly through lowering of surface temperatures, raising surface humidity and through physical damage and washing of leaf surfaces (Hartley and Graham-Bryce, 1980; Simmonds, 1980). The overall effects of these processes may be good, resulting in the redistribution of spray deposits and increased biological efficacy (Courshee, 1967; Matthews, 1982), but quite often the effect is negative, resulting in degradation of the deposits and their loss from the plant surfaces.

Two aspects of rainfall: intensity and duration have been observed on spray deposits. These effects differ in the tropics where rain is characteristically of high intensity but usually short duration, and in the cooler temperate areas, where it is relatively low intensity, but of longer duration. Matthews (1966) demonstrated that for any given amount of rain, loss of deposits was more pronounced when it fell over a longer period, and Taylor and Matthews (1986) observed that the longer duration of low intensity rainfall reduced the effectiveness of a bendiocarb formulation to a greater extent than the shorter duration of high intensity rainfall. On the contrary, Pick *et al.*, (1984) did not find the intensity of rain to affect the rainfastness of parathion e.c., and argued that probably, it is the speed at which a pesticide formulation penetrates the leaf surface, which determines its resistance to washoff. They found cypermethrin e.c. formulation rapidly rainfast, whereas the parathion w.p. formulation showed no signs of increased rainfastness over 2.5h periods.

The unpredictability and variability of natural rainfall necessitate the use of rain simulators to study rainfall effects on pesticides (Matthews, 1966; Polles and Vinson, 1969; Sandhu and Singh, 1977; Mass, 1971; Siddiqui, 1979; Mabbert and Phelps, 1983; Taylor and Matthews, 1986). The effect of persistency of pesticides by addition of various adjuvants and sticking agents have similarly been undertaken by use of rain simulators (Nemes and Adkisson, 1969; Phillip and Gillham, 1973; Hassall, 1982; Taylor, 1983).

2.4.1 Rain Simulators

An appropriate rainfall intensity has been one of the major problems in rainfall simulator design. Currently, available simulator nozzles approximate natural dropsize only at intensities higher than naturally occurring rain (McCool, 1979). Ideally, all droplets should reach the target travelling at their terminal velocity. Smith and Wichismeir (1962) showed that a free fall of 8 metres was required to ensure the terminal velocity for all droplet sizes. However, when hydraulic nozzles are used in a simulator, the droplets have an initial velocity as a result of the pressure of ejection from the nozzles, and thus they require less free height to ensure that their terminal velocity is achieved. In such a case, a fall of 5 metres could be considered acceptable (Taylor, 1983).

Development of simulators has followed two distinct patterns according to the type of droplet forming element used: one type uses nozzles to produce droplets, while the other relies on tubes, yarns or holes to produce a series of drips (Simmons, 1980).

(a) Nozzle type simulator

A series of nozzle simulators were produced in the U.S. for use in research in soil erosion which led to the development of the f-infiltrometer by the U.S.D.A. The spray was directed upwards from nozzles mounted on both sides of a plot six feet wide, but because the drops fell from only 2.0m, the largest drops did not reach terminal velocity (Langford, 1970).

Various downward spraying nozzles were devised, like the rain-ulator (Meyer and McClune, 1958), using standard 'spraying systems' 80100 nozzles, which delivered a flat- fan shaped spray which wetted an area of 2.5m by 0.1m. Swanson (1965) designed a simulator using similar nozzles, but with a rotating boom assembly to allow application over a large plot more evenly. Nassif and Wilson (1975) have described a simulator with horizontal slats to intercept a portion of the nozzle output to permit operation at lower intensities of rainfall.

A number of portable rainfall simulators for field use have been designed. Bertrand and Parr (1961), described a portable nozzle simulator for use on small plots. This was later modified by Rawitz et al.,(1972) by the addition of sector shutters, to intercept some of the nozzle output. Costin and Gilmour (1970) produced a portable rainfall simulator for use in field studies of infiltration and soil erosion. This consisted of a plot frame of galvanized iron (to minimize wind effects), over which rainfall was applied with a hand operated boom and nozzle. The intensity and evenness of application depended on the skill of the operator in this instance.

One of few simulators designed specifically for pesticide research is described by Simmons (1980). This employs a network of 60 plastic nozzles arranged 500mm apart in a 60 x 10 matrix, below which are fixed channels similar to those described by Nassif and Wilson (1975), and moveable shutters, driven by a servo-motor, used to reduce or increase the rainfall intensity. A moving target assembly helps reduce the spatial variation in rainfall (Taylor, 1983).

(b) Other types of simulators

A variety of other rain simulators have been developed using yarn, tubes and holes as the drop forming element. Ellison and Pomerene (1944) constructed a rainfall applicator consisting of a supply tank with a perforated bottom, below which was suspended a cloth screen. Short lengths of wool yarn, hanging from the cloth allow droplet formation.

Mounted metal capillary tubes at the base of an open tank, were used by Ekern and Muckenhirn (1947) to produce raindrops. This system was modified by Mutchlen and Moldenham (1963) with capillary tubes of internal diameters increasing in 3 steps from the diameter of the inlet. The droplet diameter could be increased by increasing the water level above the inlet to the tubes.

Romkens (1975) used hyperdermic syringes to form the drops and controlled the flow rate by causing a motor driven plate to depress the plunges of the syringes. Generally, the design of rain simulator chosen depends on the particular feature of the simulation considered important, and the reproduceability of the treatments so required (Simmons, 1980).

2.5 Codling Moth

The codling moth, Cydia pomonella L. (Tortricidae:Olethreutinae) has had several generic names: Carpocapsa Barret, Laspeyresia Meyrick, Enarmonia and Grapholitha, some of which are still used, though it is correctly placed in the genus Cydia, Pierce and Metcalfe (Brown, 1979).

2.5.1 Pest status

C. pomonella is a serious and widespread pest, the larval stages attacking the fruit of notably apples and pears (Bovey, 1966). It occurs in most temperate regions of the World (Anon, 1976). In the United Kingdom, there is one generation with an occasional second in warm summers (Alford et al, 1979; Richards, 1984). The infestation potential of codling moth is greater in warmer climates with 2-3 generations in parts of the U.S.A. (Rock et al., 1978) and 3 generations in South Africa (Myburgh et al, 1974) and Australia (Geier et al., 1983).

In areas with multivoltine development, damage due to codling moth can reach 100% in the absence of control methods (Geier, 1967). Its importance as a pest has been attributed to its ability to synchronize its seasonal activity with the presence of developing fruit on its hosts, by a larval diapause, and to exploit the full duration of the climatically favourable time of year (Geier, 1981).

2.5.2 Life History

Ovipositing females are attracted to apples (Wearing and Hutchins, 1973) and stimulated to lay eggs by a sesquiterpene, α-farnesene (Sutherland, 1972) and show a preference for humid conditions (Sutherland, 1975), presumably to reduce the danger of desiccation.

Eggs are laid singly on or near fruits. Both Geier (1963) and Wearing *et al.*, (1973) reported that over 75% of eggs laid were within 6cm of an apple fruit and 90% within 10cm. On unmanaged apple trees, Jackson (1979) found 57% of all eggs on upper leaf surfaces, 35% on lower surfaces and 8% on fruits.

First instar larvae rapidly enter fruit on hatching from eggs. Glen *et al.*, (1980) observed that larvae hatching from eggs placed on the upper surfaces of leaves usually moved within 10 min. on to the undersides, where they moved intermittently over periods varying from 2-162 min. About half the larvae then settled and fed for several hours, biting visible pits in the underside of leaves. Heriot and Waddell (1942) also observed leaf feeding. After reaching apples, larvae wander for up to two hours (Geier, 1963), though larvae may be found moving on apples two days after release (Jackson and Harwood, 1980). Larvae tend to enter apples through the calyx or through lesions or irregularities in the fruit surface as access is easier (Putman, 1963). When breaking the surface of a fruit, a larva spins a silken thread to anchor its body while chewing (Hoerner, 1925). Larvae use a plug of epidermis and frass to block feeding chambers (Jackson, 1982).

Usually, only one larva develops to maturity in each apple, though there may be up to three with increasing infestation potential (Ferro and Harwood, 1973; Geier, 1967).

On reaching the final (fifth) instar, larvae leave the fruit, generally at night when temperatures are above 10°C (Charmillot, 1976), through tunnels bored previously for the evacuation of frass (Geier, 1981). After finding a protected site in which to spin the cocoon, a larva may or may not go into diapause. The main factors inducing diapause are shortening daylength and falling temperatures, while diapause is terminated by a period of chilling followed by higher temperatures (Sieber and Benz, 1980).

CHAPTER THREE: GENERAL MATERIALS AND METHODS

3.1 Laboratory Experiments

3.1.1 Description and calibration of sprayers and nozzles

Three different spray nozzles fitted to a Wambo 50cc Knapsack mistblower were assessed:

(i) a gaseous (air-shear) nozzle, (ii) a single spinning disc;Micron-X1, providing an uncharged ULV spray, (iii) the same disc as in (ii) adapted to charge the ULV droplets by induction (Plates 1 and 2).

Later another machine (Solo GmbH) was adapted for trials work to provide a straight airjet and reduce the loss of efficiency in the airflow along the angled ducting on the standard mistblower (Plates 3 and 4).

The spinning disc was fed internally through a stainless steel shaft around which the disc rotates, and was driven by a standard 3.5cm propellor, mounted to the rear of the disc. To electrostatically charge the spray a flat thin circular metal plate (4.5cm diameter) was fitted inside the disc and connected to a 30Kv (for the Wambo GmbH) or 33Kv (for the Solo GmbH) generator, powered by a 12 volt battery controlled by a switch, so that either charged or uncharged liquid was sprayed.

(a) Measurement of Air Volumes and Velocities

Air volumes and velocities of 2 different fan capacities of Wambo GmbH 35cc and 50cc engines, and later an adapted Solo GmbH mistblowers operated at full throttle were determined with a GAP- and an ETA 3000 meter (Appendix 1.1).

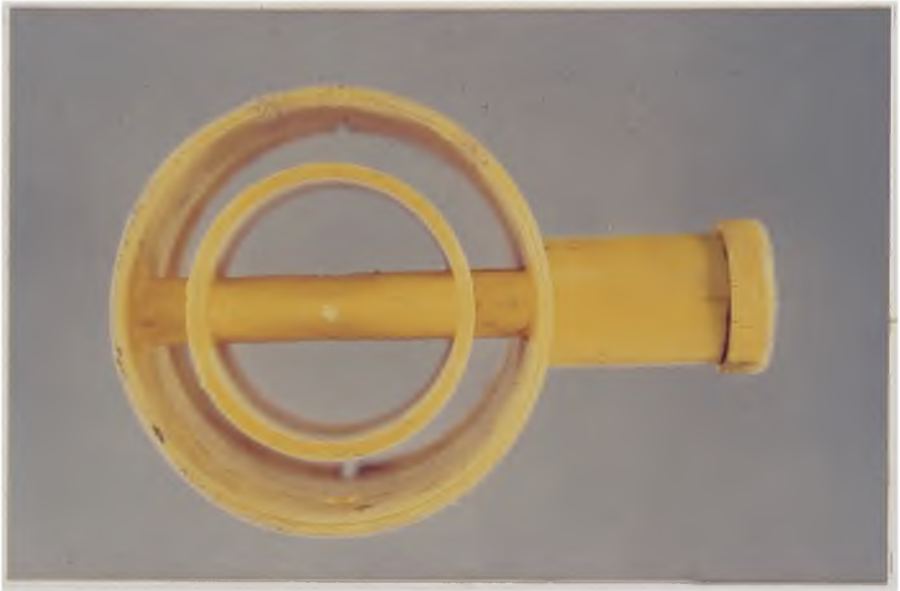


PLATE 1. Gaseous (Air-shear) Nozzle

PLATE 2. Micron -X1 spinning disc showing the flat thin circular metal plate (diameter 4.5cm) which connects to a 30Kv generator powered by a 12 volt battery for electrostatic charging of spray.

PLATE 3. Standard mistblower (50cc Wambo GmbH)

PLATE 4. Adapted Solo (GmbH) mistblower to provide a straight air jet.

(b) Determination of Spread Factor

The spread factor for Kromekote cards used to sample spray deposits was assessed for each of the different spray solutions by spraying with a microtip nozzle. Droplets were collected simultaneously on both the card and a magnesium oxide slide for analysis (Matthews, 1979) with the Optomax,assuming the spread factor on the magnesium oxide was 0.86 (Appendix 1.2.).

(c) Determination of Flow Rates of Nozzles

A known volume of spray liquid was sprayed with each of the nozzles, and the time for spraying recorded with a stop watch. The flow rate through each restrictor was calculated for each nozzle (Appendix 1.2).

3.1.2 Assessment of horizontal and vertical projections of nozzles

(a) horizontal projection: The projection of spray horizontally was assessed using Kromekote cards (6 x 2cm) fixed to an array of vertical wooden posts. Starting 3 metres from the spray line, three lines of posts 0.5m apart were positioned in 15 rows 1m apart. Cards were fixed to each post at 0.5 and 1m above the ground. The layout was screened from prevailing winds by siting it between 2 buildings, 5m apart, and tests carried out when windspeed was negligible (0 - 0.2m/s).

In each test, sprayer nozzle was set at 1m above the ground and the targets sprayed for 5 seconds. The spray solution was either 0.125 percent nigrosine and 3.0 percent sudan black in distilled water or ED formulation JF 7453 with 1% uvitex fluorescent tracer. The dye was added so that the droplets showed clearly on the white sampling surfaces. On each target the size of droplets and the amount of fluorescent tracer was measured (Appendix 1.3).

(b) Vertical throw

Kromekote cards were clipped horizontally to a rope at 0.5m intervals. The rope was raised up over an 8m vertical aluminium pole using a pulley so that the highest card was at 8m and lowest 2m from the ground. With the sprayer nozzles at 2m from the pole and 2m high, targets were sprayed for 5 seconds, with each of the nozzles, when wind speed was negligible. Targets were collected and analysed for droplet sizes and deposits (Appendix 1.4).

3.1.3 Droplet sizing

After spraying, spray droplets collected on kromekote cards were placed in plastic slide boxes lined with clean blotting papers, and were subsequently attached to glass slides (Plate 5) for analysis. The size and number (no/cm^2) of droplets were determined with an image analysing computer (Optomax).

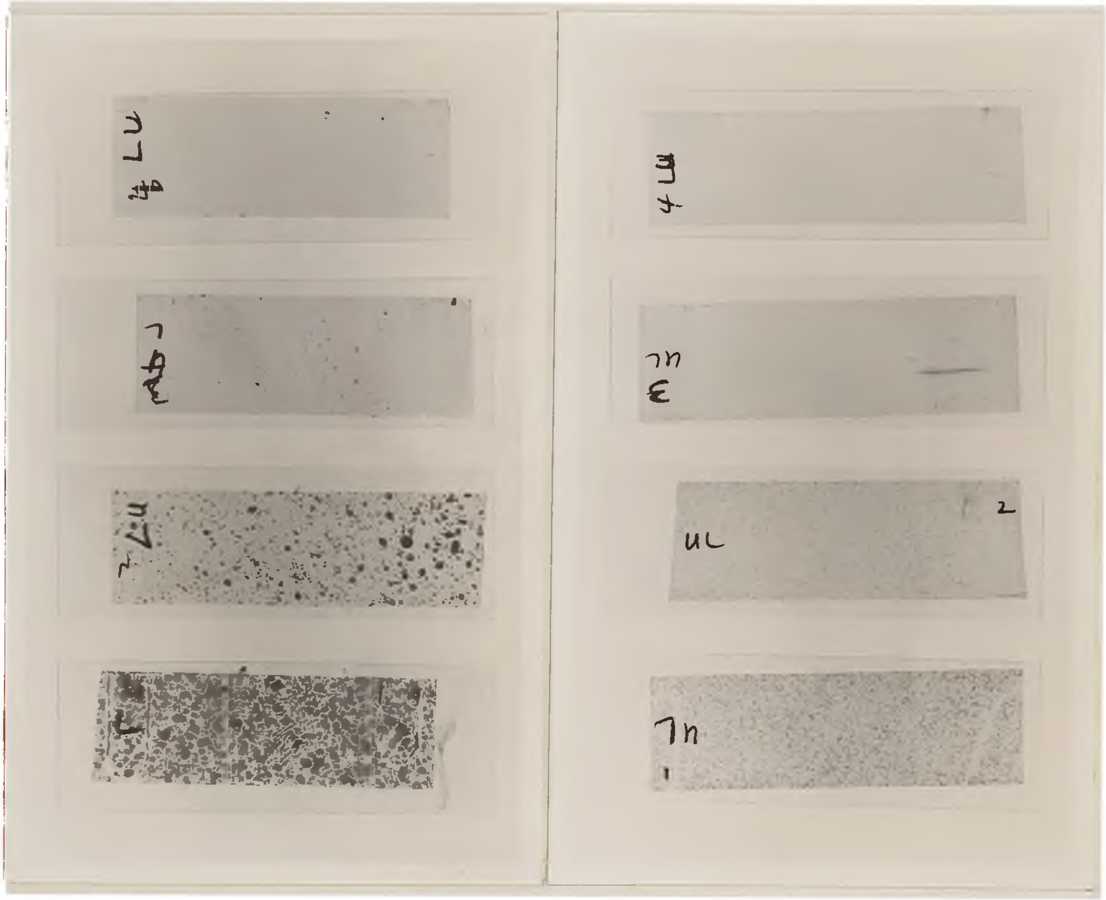
3.1.4 Reading of fluorescent tracer (Uvitex) deposits on cards

Spray deposits in these experiments were estimated by measuring the amount of fluorescent tracer on each card using a Perkin-Elmer model 1000m filter fluorimeter, calibrated using a standard series of dye concentrations (Figs. Af.1 - Af.7).

3.2 Codling Moth Rearing

3.2.1 Artificial diet preparation

Codling larvae were reared on an artificial diet described by Guennelon et al.(1981). Dry ingredients consisted of 190g maize meal, 50g yeast powder, 46g wheat germ, 7g ascorbic acid, 3g benzoic acid, 2.3g methyl para-hydroxybenzoate and 26.6g agar per litre of distilled water. To reduce microbial growth on the diet, 1.6ml of 30% formaldehyde



(a) (b)

PLATE 5. Spray droplets on kromekote cards fixed on glass slides, showing degree of coverage through canopy (outer to rear canopy: bottom to top of plate). with (a) gaseous nozzle, and (b) charged spinning disc, on Wambo mistblower.

was added to each batch of diet, Agar was dissolved in 600mls boiling water, and mixed at 70°C with the dry ingredients and remaining water in a blender, and the diet poured into trays to solidify. Diet was kept at 4°C and thawed before use.

3.2.2 Maintenance of continuous culture

A permanent culture of codling moth was established at the Silwood Park constant temperature room 25, from Laboratory stocks supplied by Dr. Chris Payne (Glasshouse Crops Research Institute) and Dr. Frances Hunter (Department of Microbiology, University of Reading).

Neonate larvae (1st instar), were reared in two's on blocks of diet in plastic "polypots" (No. 10 crystal polypots, A.R. Horwell Ltd., London) and kept at 24°C with an 18h photoperiod to prevent larval diapause. 5-6ml diet per pot was sufficient for maintenance of two insects from first instar larvae to adults, taking 28-34 days. Adults were removed from pots and kept in ventilated clear plastic bags for 5 days, with about 50 adults per bag (c. 1 litre volume). Bags were changed daily and the eggs laid on these fumigated for six hours in 450cm^3 glass jars with 100 µl 5% (w/v) formaldehyde to inactivate any virus contaminating the egg surface (Payne, 1981, Richards, 1984).

3.3 Bioassay Methods

3.3.1 Studies of bioassay on leaf surfaces.

Leaves sampled from trees and seedlings, sprayed by each application method were cut into discs of 22.0 sq cm. and placed on wetted blotting paper in a 6cm diameter bioassay plate and covered. Ten neonate larvae of codling moth were put on each leaf disc with 3 leaf discs per treatment as replicates.

Preliminary studies showed that the effect of the cypermethrin on the larvae was so rapid that 100 percent mortality was recorded after 1½ hours. During the main experiments therefore, mortalities were assessed 2 hours after larvae were put on the leaves.

3.4 Field Work

3.4.1 Selection of site and suitable apple trees

The Ashurst apple orchard at Silwood Park, consists of 41 varieties of apple, spaced out in 5m x 5m diagonal rows. Two varieties, the Keswick codling and Red victoria were selected for the experiments, the Red victoria was the larger of the two varieties, with more foliage on the canopy.

Two trees of each of these were used during the trials with the fluorescent tracer sprays (Section 3.7). Ten trees (variety Keswick codling) were used for the trials in which cypermethrin formulations were sprayed (Section 3.8).

3.4.2 Tree and leaf area measurement

Measurements of tree height, planting distances between and within rows, girth width, height of canopy from the ground, canopy height and width, and number of branches were taken. Leaf area was also measured for each tree variety, at both bud burst and full canopy (Appendix 1.5).

3.4.3 Division of trees into 'levels' and 'regions' for spray coverage assessment

Each tree was divided into two levels: top and bottom at 3m and 2m high respectively for the Keswick, and at 4m and 3m high for the

Red victoria (Sec 3.7). For each level, 'sampling regions' at distances 0, 1, 2 and 3m from the front of the canopy were marked with a tape measure. At each 'region', seven leaves at 0.5m apart, along the row were sampled. There was an additional sampling region 4m from the front of canopy, for the *Red victoria*. Upper and Lower leaf surfaces were sampled separately in each tree. The "upper" leaf surface being the side facing the direction of the spray (Figs. 3.1 and 3.2).

For the spray application with cypermethrin, one level at 2.5m high was assessed. The regions were at 0, 1, 2 and 3m from the front of the canopy, and 3 leaves in a region, a meter apart were sampled for bioassay assessment in the laboratory. Leaves were picked an hour after each spray application.

3.5 Timing of Spray Application

The time taken to spray individual trees during each spray application was measured, for a pre-determined distance from one end of each canopy to the other. An average speed of 0.5m/sec was maintained. In this way the amounts of spray liquid, and consequently the quantity of Uvitex deposited could be calculated for each nozzle.

3.6 Measurement of Meteorological Factors

The windspeed, temperature and relative humidity were measured on each occasion.

3.7 Spray Application with Unitex in Spray Solution

(a) Fixing of Kromekote cards on leaf surfaces

Kromekote cards (2 by 6cm) were clipped to leaf surfaces for assessment of spray deposits and coverage. The cards were taken to and

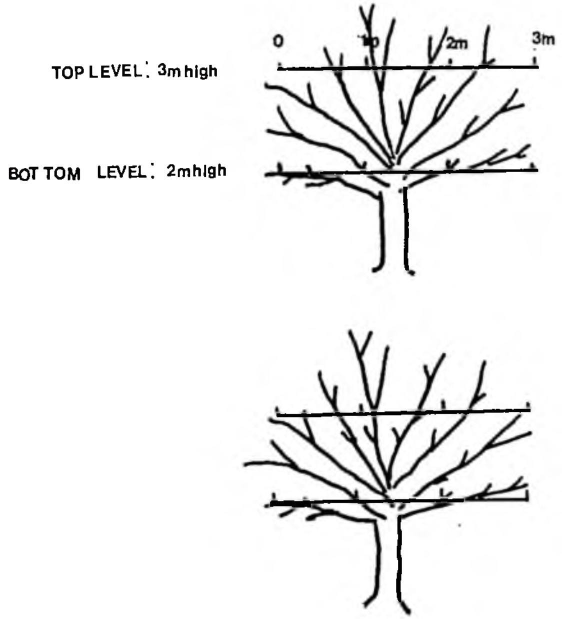


FIGURE 3.1 Apple trees variety Keswick codling(4m.high) showing sampling positions at distances 0,1,2 & 3m from outer canopy surface at 2 levels top and bottom of 3 and metres high respectively.

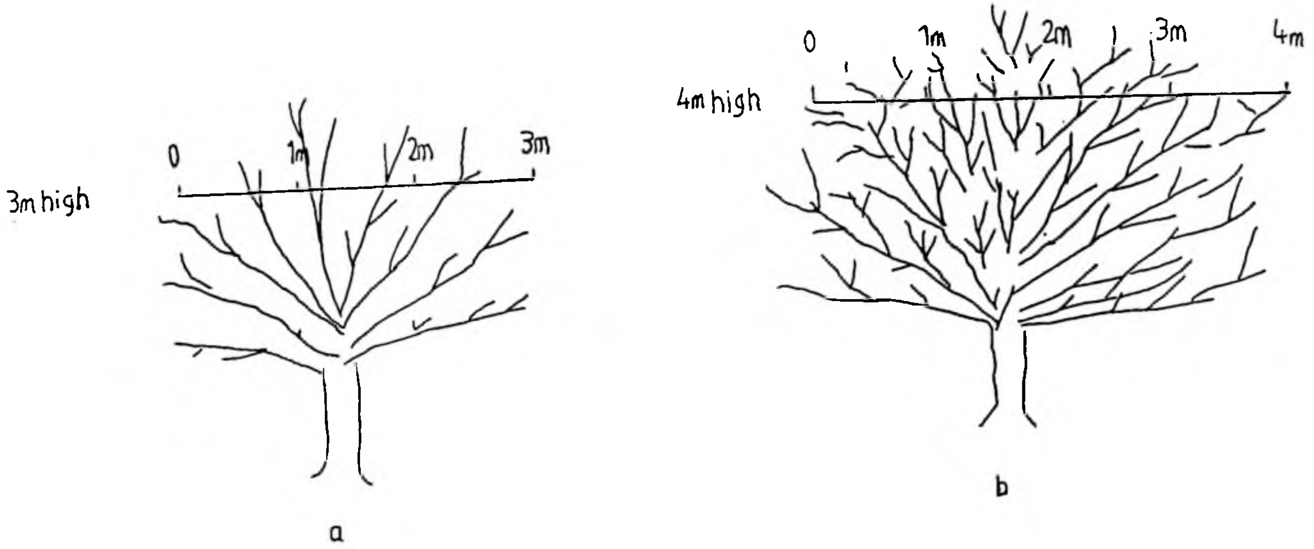


FIGURE 3.2 Apple trees variety (a)*Keswick codling* and *Red victoria* showing sampling positions within canopy at 3m for the *Keswick* and 4m for the *Red victoria*.

from the field in plastic boxes (6 x 12cm).

(b) Determination of droplet fall-out

To determine the amount of spray falling out during the spray application similar kromekote cards were placed on the ground immediately below the canopy and up to 12 meters downwind from the tree trunk.

3.7.1 Trial 1: Effect of canopy density on spray distribution

(a) Spraying at bud-burst and full canopy - one side only; and at full canopy from both sides

An electrodyn blank formulation JF 7453 containing Uvitex and 3% Sudan black, and distilled water also containing Uvitex (stardust) and 0.125% nigrosine black, were used as the spray solutions for the spinning discs and the gaseous energy nozzles respectively.

Spraying was done with each of the nozzles in turn at bud-burst and full canopy from one side only. There was an additional application at the full canopy, when spraying was from both sides of the canopy. Nozzles were maintained at 2.5m away from the canopy.

3.7.2 Trial 2: Effect of nozzle distance from canopy on spray distribution

(a) Spraying with nozzle at 1m and 3m from canopy

Spraying was carried out with each of the nozzles at a distance of 1m and 3m respectively from the canopy, from one side of canopy only; at full canopy.

3.7.3 Trial 3: Effect of tree height and shape on spray distribution

Two trees each of Keswick codling (4m high) and Red victoria (6m high) were sprayed with each of the nozzles at a distance of 2.5m from canopy, at full canopy from one side only.

3.8 Spray Application with Cypermethrin Formulations

3.8.1 Preliminary experiments to find appropriate dosage for trials

The bioassay was to determine an appropriate dosage for the trial work. Initially different concentrations of 3 cypermethrin formulations ('EC', 'ED', ULV) and their blanks were sprayed in a Potter Tower on 22.0cm^2 leaf discs, to determine LD_{50} and thus dosage for trials. However, it was later realised that there were not enough Larvae to go through all that and for the main experiments, so was abandoned. 35cm high apple seedlings were also sprayed with each of the nozzles, using the same concentrations of cypermethrin formulations.

A week before main experiments, leaves were sampled from selected trees for bioassay, to determine the background contaminations on leaf surfaces.

3.8.2 Spray application in the field

Spray solution of 0.1 percent cypermethrin was prepared for each of the three formulations. Blanks of the ULV and an 'ED' formulations were used as control applications for the uncharged and charged nozzles respectively, and distilled water for the E.C. formulation.

Before each spray application, leaves were sampled from the various tree regions, for the background contamination assessment. Trees were sprayed at full canopy from one side only and from both sides of canopy.

(a) Bioassay of sprayed leaves in the laboratory.

Sprayed leaves were sampled from the trees an hour after application for laboratory bioassay determination with neonate larvae of codling moth (Section 3.3), and results of corrected mortalities analysed in a 4-way Genstat analysis of variance.

3.9 Rainfastness

3.9.1 Maintenance of a culture of apple seedlings

Ninety nine apple seedlings of Yarlington mill variety were collected from Long Ashton Research Station (University of Bristol), and transplanted into 15cm diameter plastic pots in a glasshouse. They were used, when they had attained an average height of 34-35cm with 8-10 leaves.

3.9.2. Rainfall simulator

Rainfall was produced, using a simulator, consisting of four $\frac{1}{4}$G10 solid cone hydraulic nozzles, 80cm apart, fitted on a square frame. The nozzles were then mounted onto a 8m tower of aluminium scaffolding, to allow the 'rain' drops achieve terminal velocity as in natural rainfall (Simmons, 1980). The whole structure was covered on all four sides by overlapping, heavy-duty plaited-plastic sheets (Plate 6), to eliminate wind and its shearing effect on the rain drops as they fell.

Water was connected to the nozzles by hose from the mains supply, via an 8460 diaphragm pressure regulating valve, adjusted to deliver water at constant working pressure of 40 p.s.i.

Two sets of aluminium v-shaped channels were used to trap and channel off some of the water as it fell, leaving only the required intensity of 'rain' to fall down onto the target area of 1.5m², provided by the arrangement of nozzles. The channels were fitted 6mm apart in two wooden frames with v-shaped notches, inclined at 5°, one above the other (Plate 7). Water collected by the aluminium channels was drained into plastic gutters at the side of the tower.

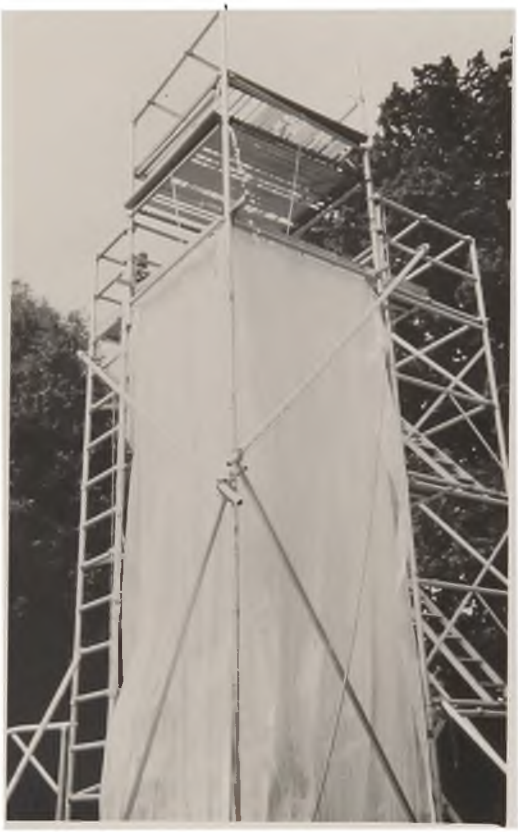


PLATE 6. Raintower covered on all four sides by over-lapping heavy duty plaited-plastic sheets, to eliminate wind.

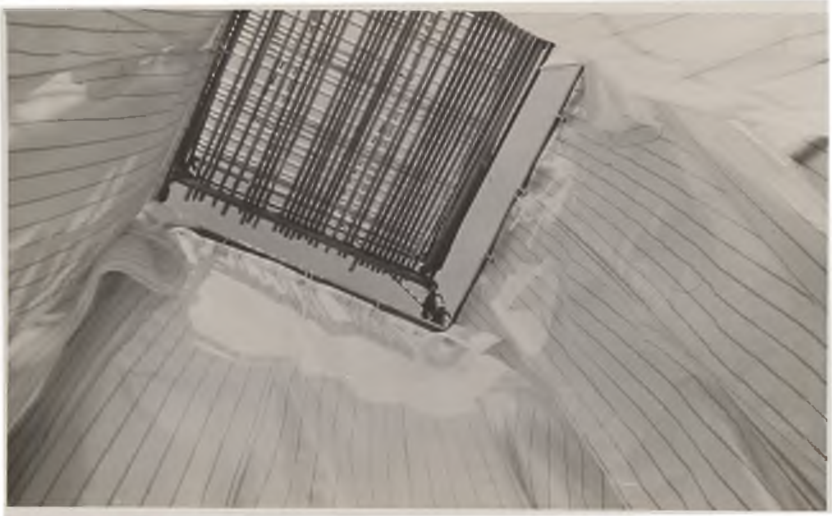


PLATE 7. Arrangements of aluminium V-shaped channels at top of rain tower

The rainfall intensity needed for a particular experiment was achieved by changing the number of the channels. The intensity was recorded with a 20cm diameter raingauge and a measuring cylinder.

Rainfall distribution at the target area, was determined by measuring the water collected over 15 minutes in twenty one 150ml beakers, placed in a regular grid pattern over the entire sampling area. When necessary, the amount of rainfall was adjusted by changing the position of the nozzles or arrangements of the channels (or both), to achieve a more even distribution.

An intensity of 65.3mm / 15 mins. was used to simulate high rainfall intensity typical of the tropics.

Seedlings placed 2.5m from the mistblower nozzle were sprayed with 0.1 percent cypermethrin formulations and their blanks, and left to dry for one hour before rain was applied to them. In each treatment five plants were placed in the target area. Four were arranged in a square pattern around a central plant. This arrangement was intended to cater for splash and shading effects as occurring in the field. Excess water was shaken off the plants which were left to dry for another hour before the laboratory bioassay was started.

Data was analysed using the 4-way Genstat analysis of variance.

CHAPTER FOUR

4.1 Spray Application with Fluorescent Tracer Solution

Introduction

Comparisons of spray performance must finally be made in terms of biological effects, such as mortality of a pest. However, a number of parameters such as the amount of spray deposited, droplet size and distribution of pesticide, all influence the biological effect. Initial studies examined therefore, the influence of nozzle type, applying different volumes, on distribution of spray within a crop canopy. Full details of spraying methods and treatments employed in the trials are given in Table 4.1.

4.1.1 Results

(a) Effect of canopy density on spray distribution

A 4-way Genstat analysis of the data, indicated that mean deposits (ng/cm^2) of fluorescent tracer (Uvitex) were significantly greater ($p = 0.05$) on the outer leaves and decreased across the tree canopy irrespective of which nozzle was used on the mistblower. Similarly deposits at the bottom of the canopy were greater than in the upper part (Tables 4.2 - 4.3). The least spray was deposited on leaf surfaces near the centre of the tree, unless the canopy was sprayed from both sides when interaction between the spray patterns achieved a more uniform deposit on both leaf surfaces (Fig. 4.3; Table 4.4).

Spraying with the charged spinning disc at an average of 4.5ml /tree gave significantly greater deposits (p 0.05) at all levels in the outer regions than the other nozzles, but the decrease in deposits within the canopy was significantly greater with charged

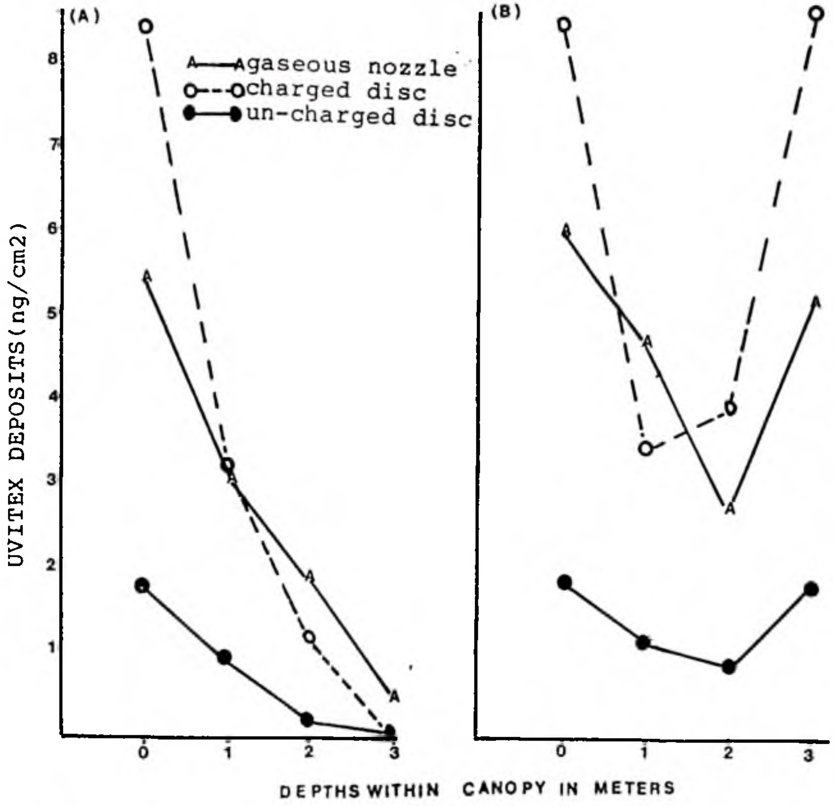


FIGURE 4.3 Mean fluorescent tracer(uvitex) deposits(ng/cm2) through apple tree(variety Keswick codling)canopy,using Wambo mistblower:spraying from(a)one side only,and (b) both sides,of the full canopy.

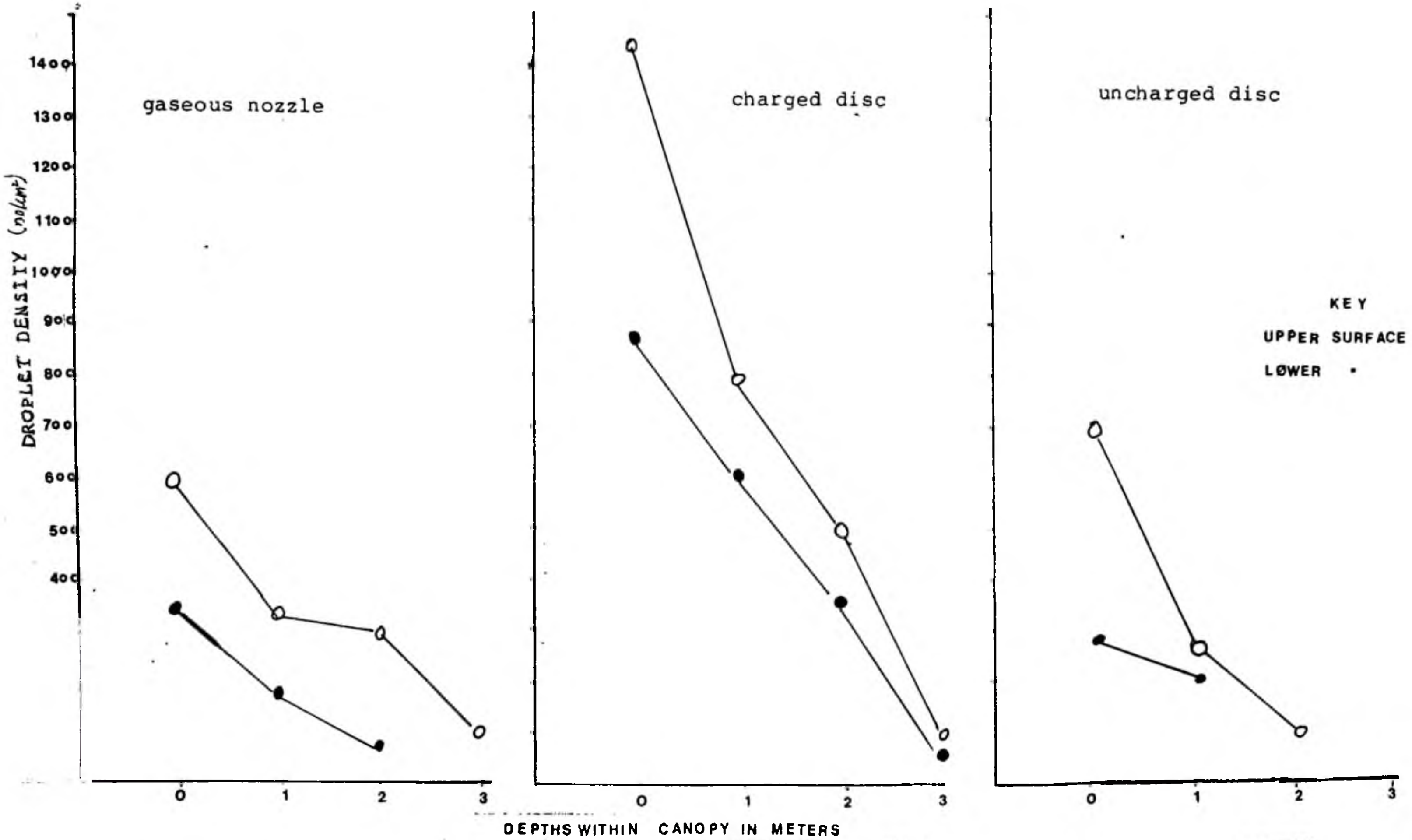


FIGURE 4.4 Variation in droplet density(no/cm2) on surfaces(upper or lower),through canopy using different spray nozzles on Wambo mistblower.

TABLE 4.1

Details of spraying methods and treatments employed in the trials.

(1) Spraying methods

Treatment	Litres/ha	%ai/ha	Trials (Keswick codling)
(a) Wambo mistblower			
Gaseous nozzle	193.0	0.1	bud burst, single sided spraying
Charged disc	3.1	0.1	" " " " "
Uncharged disc	.3	0.1	" " " " "
Gaseous nozzle	193.8	0.1	Full canopy, single sided spraying
Charged disc	3.1	0.1	" " " " "
Uncharged disc	3.3	0.1	" " " " "
Gaseous nozzle	385.5	0.1	Full canopy, both sides
Charged disc	6.2	0.1	" " " "
Uncharged disc	6.6	0.1	" " " "
(b) Solo mistblower			
Charged disc	2.10	0.1	Full canopy, single sided spraying
Uncharged disc	2.10	0.1	" " " " "
Charged disc	4.25	0.1	Full canopy, both sides
Uncharged disc	4.25	0.1	" " " "

(2) Spray volume (ml/tree) with different nozzles

	Single side spraying		Spraying both sides	
	Keswick	R. victoria	Keswick	R. victoria
Gaseous nozzle (air shear)	274.0	435.0	550.0	874.1
Charged disc (Wambo)	4.5	6.98	9.0	14.0
Uncharged disc (Wambo)	4.8	7.48	10.0	15.1
Charged disc (Solo)	3.0		6.0	
Uncharged disc (Solo)	3.0		6.0	

TABLE 4.2

Mean fluorescent tracer (Uvitex) deposits through canopy as percentage of outer leaf deposits, using Wambo mistblower: Spraying from one side only.

	Distance from outer surface			
Treatment	1m.	2m.	3m.	Trial
	(a) Top Level			
Gaseous-nozzle	91	78	46	Bud burst
	70	34	0	Full canopy
Charged-disc	52	23	16	Bud burst
	37	13	0	Full canopy
Uncharged-disc	76	44	29	Bud burst
	44	0	0	Full canopy
	(b) Bottom Level			
Gaseous-nozzle	86	64	29	Bud burst
	52	37	13	Full canopy
Charged-disc	55	24	17	Bud burst
	38	15	0	Full canopy
Uncharged-disc	70	50	28	Bud burst
	57	12	0	Full canopy
	(c) Average for Top and Bottom			
Gaseous-nozzle	88	69	35	Bud burst
	58	35	7.6	Full canopy
Charged-disc	54	24	16.5	Bud burst
	38	14	0	Full canopy
Uncharged-disc	72	47	28	Bud burst
	50	9.7	0	Full canopy

TABLE 4.3

Mean deposits (ng/cm^2) of fluorescent tracer (Uvitex) within canopy using charged or uncharged disc on Wambo and Solo mistblowers. Spraying from one side only.

(a) Bottom (2m)

Nozzle	0m	1m	2m	3m
Charged disc (Wambo)	9.5	4.8	2.1	0.0
Uncharged disc (Wambo)	5.7	1.7	1.1	0.0
Charged disc (Solo)	11.1	4.2	2.2	0.7
Uncharged disc (Solo	3.9	2.6	1.5	0.5
(b) Top (3m)				
Charged disc (Wambo)	8.4	3.3	0.3	0.0
Uncharged disc (Wambo)	3.6	1.5	0.2	0.0
Charged disc (Solo)	10.5	2.9	1.0	0.0
Uncharged disc (Solo)	9.6	1.1	0.4	0.0

Least significant difference 1.787.

TABLE 4.4

Mean deposits (ng/cm^2) of fluorescent tracer (Uvitex) within canopy at different heights (3m and 2m) with different nozzles on Wambo. Spraying from both sides of *Red victoria*.

Height	Depth Nozzle	0m	1m	2m	3m	4m
top (3m)						
	Gaseous	3.7	3.7	3.1	3.2	2.9
	Charged disc	3.0	2.0	1.0	2.1	3.1
	Uncharged disc	1.2	0.6	0.6	0.6	1.0
Bottom (2m)						
	Gaseous	7.1	6.6	4.2	5.9	6.6
	Charged disc	3.7	2.4	1.1	2.7	4.0
	Uncharged disc	2.0	1.0	1.0	1.0	2.0

LEAST SIGNIFICANT DIFFERENCE (LSD) 0.405

sprays, thus deposits at the far side of the canopy were only 16.5 percent of those on the outer region nearest the sprayer at bud burst when leaves were small. Later when leaf area doubled, no deposits were detected at this region. Applying a much greater volume (274.0ml/tree) with the air-shear nozzle gave better distribution with a gradual decline in deposits across the canopy. The innermost region received an average of about 35 percent and 7.6 percent of the outer deposits, at bud-burst and full canopy stages respectively. The lowest deposits were produced by the uncharged spinning disc at 4.8ml/tree, when only 28.0 percent of the outer surface deposits reached the innermost canopy during the bud-burst stage and none was detected at the full canopy (Table 4.2c).

Spray distribution with the spinning disc was improved when the air flow was increased by using an adapted Solo mistblower. The average amounts of spray reaching the furthest part of the crop were 2.0 and 5.0 percent of the outer deposits for uncharged and charged disc respectively (Table 4.3c). Decreasing the charge/mass ratio of spray droplets did not improve penetration in the canopy (Tables 4.5-4.6). These changes in spray deposits were reflected in the droplet numbers recorded, with a decline through the canopy. More droplets (no/cm^2) were on the upper surface of leaves at all sites (Fig. 4.4). However, in each situation the charged disc deposited more droplets (i.e. about twice as many) than the other nozzles, especially at the first two regions, at each level in the canopy (Fig. 4.5).

Droplet diameter decreased from the outer to the inner region, with all three nozzles. Similarly droplets at the 3m level of canopy were larger than at 2m for the gaseous nozzle, with no significant

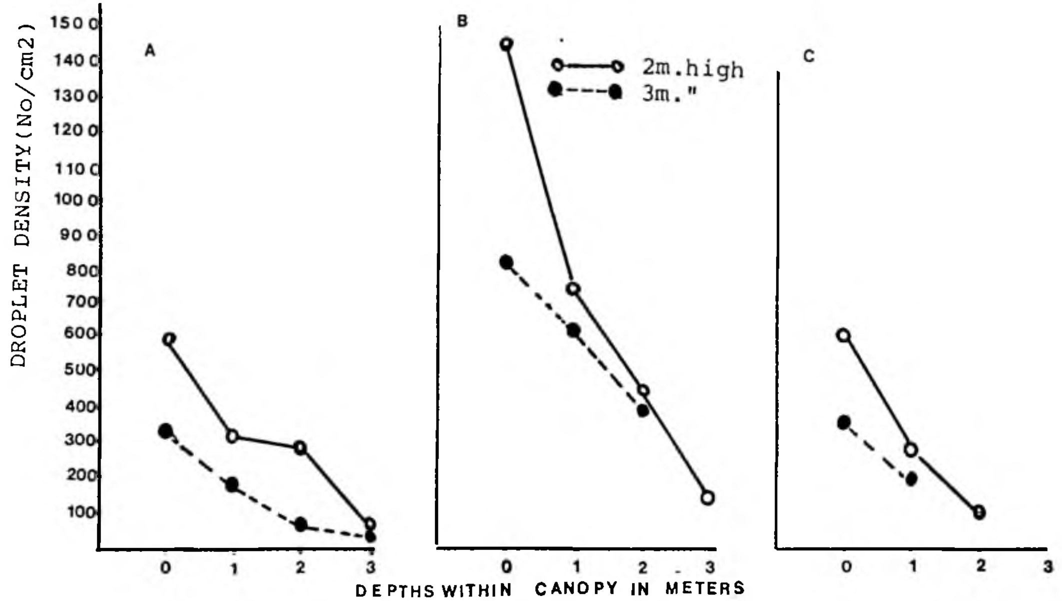


FIGURE 4.5 Variation in spray droplet density(no/cm2),within apple tree canopy for Wambo mistblower application (A) gaseous nozzle,(B) charged disc,(C)un-charged disc,at 2 levels 3m & 2m high respectively.

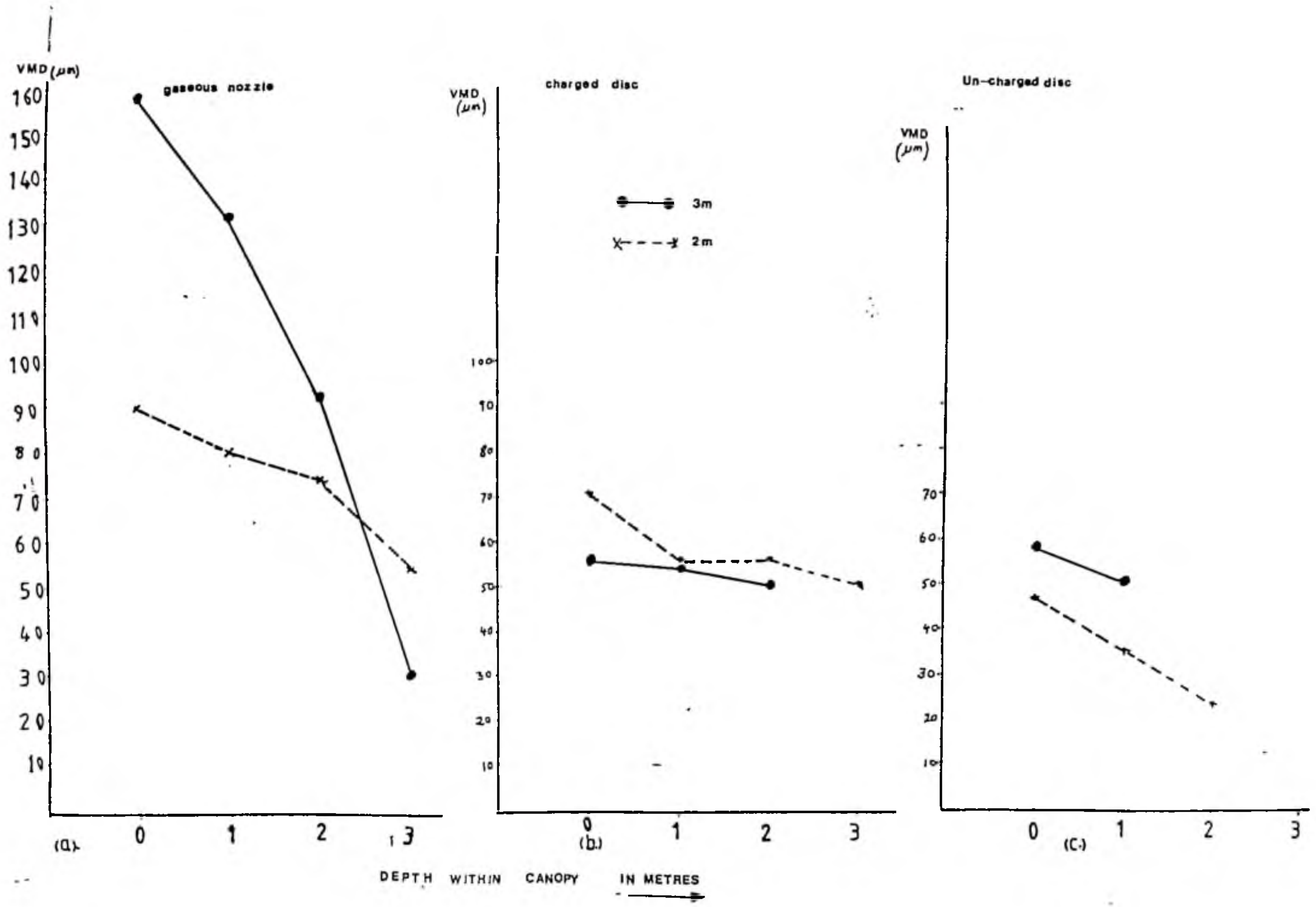


FIGURE 4.6 Average VMD(um) distribution through canopy at different heights with different nozzles on the Wambo mistblower

TABLE 4.5

Variation in fluorescent tracer deposits (ng/cm²) within canopy at different levels (3m and 2m) with Solo mistblower application at varying voltages from one side only.

Height	Depth	0m	1m	2m	3m
Bottom (2m)	Spray				
	0Kv	9.3	2.6	1.5	0.5
	10Kv	9.1	3.4	0.8	0.2
	10Kv	8.6	2.6	1.2	0.2
	30Kv	11.1	4.2	2.2	0.4
Top (3m)					
	0Kv	6.8	0.7	0·0	0.0
	10Kv	9.6	0.9	0·0	0.0
	20Kv	9.6	1.1	0·4	0.0
	30Kv	10.5	2.9	1·0	0.3

LEAST SIGNIFICANT DIFFERENCE (LSD) 1.787

TABLE 4.6

Variation in fluorescent tracer deposits (ng/cm²) within canopy on surfaces (upper and lower) with Solo mistblower application at varying voltages, from one side only.

Surface	Depth Spray	0m	1m	2m	3m
Upper	0Kv	11.5	3.0	1.5	0.5
	10Kv	13.2	3.2	0.8	0.2
	20Kv	12.2	2.8	1.5	0.2
	30Kv	14.0	4.2	2.1	0.8
Lower					
	0Kv	4.6	0.0	0.0	0.0
	10Kv	5.5	1.1	0.0	0.0
	20Kv	5.9	1.9	0.0	0.0
	30Kv	7.6	2.9	1.2	0.3

LEAST SIGNIFICANT DIFFERENCE (LSD) = 1.787.

TABLE 4.7

The variation in VMD (μm) of spray deposits within an apple tree canopy for Wambo and Solo mistblower application

Treatment (Spray)	Depth 0m	1m	2m	3m
Bottom (2m)				
Gaseous nozzle	90.0	80.3	73.8	53.8
Charged disc (Wambo)	70.7	55.5	56.2	50.0
Uncharged disc (Wambo)	47.3	35.0	23.0	-
Charged disc (Solo)	34.0	29.0	29.3	28.8
Uncharged disc (Solo)	39.0	38.8	31.5	32.8
Top level (3m)				
Gaseous nozzle	159.2	131.0	91.5	29.5
Charged disc (Wambo)	56.0	54.0	50.0	-
Uncharged disc (Wambo)	58.5	50.0	-	-
Charged disc (Solo)	43.0	40.0	-	-
Uncharged disc (Solo)	39.0	25.0	-	-

LEAST SIGNIFICANT DIFFERENCE (LSD) = 19.544.

difference between those of the charged and uncharged disc (Fig. 4.6). The decrease in droplet size across the canopy was greater for the air-shear nozzle with only the smallest droplets penetrating towards the rear of the canopy, especially at the 3m level (Fig. 4.6). In contrast the change in droplet size across the canopy for the charged disc was not significant (p 0.05). The uncharged disc produced intermediate results (Table 4.7).

Most droplets deposited on the upper surfaces of leaves and were larger from the air shear nozzle than with other nozzles, VMD's being 90-160 µm. There was no significant difference (p 0.05) between the VMD's of droplets from either the charged or uncharged disc, on either leaf surface (upper or lower), (Fig. 4.7).

Spray deposited on the ground, i.e. "fall-out" (ng/cm^2) was significantly decreased ($p = 0.05$) when charged droplets were sprayed and did not extend as far away from the treated tree (Table 4.8). Droplet diameter did not change with distance from tree (p 0.05) for the spinning discs (Fig. 4.8), but with the air-shear nozzle, smaller droplets travelled further.

(b) Effect of tree shape and size on spray distribution

A 4-way Genstat analysis of data indicated that deposits were greatest on the outer leaves but decreased sharply across each tree canopy (Fig. 4.9). The charged spinning disc spraying at 3.0 and 5.2 ml/tree, for the *Keswick* and *Red victoria* varieties respectively, produced greater droplet numbers confirmed by fluorescent tracer deposits using the adapted mistblower (Table 4.9). Similar results were obtained with the standard mistblower, though the amount of spray liquid per tree was greater (Table 4.10).

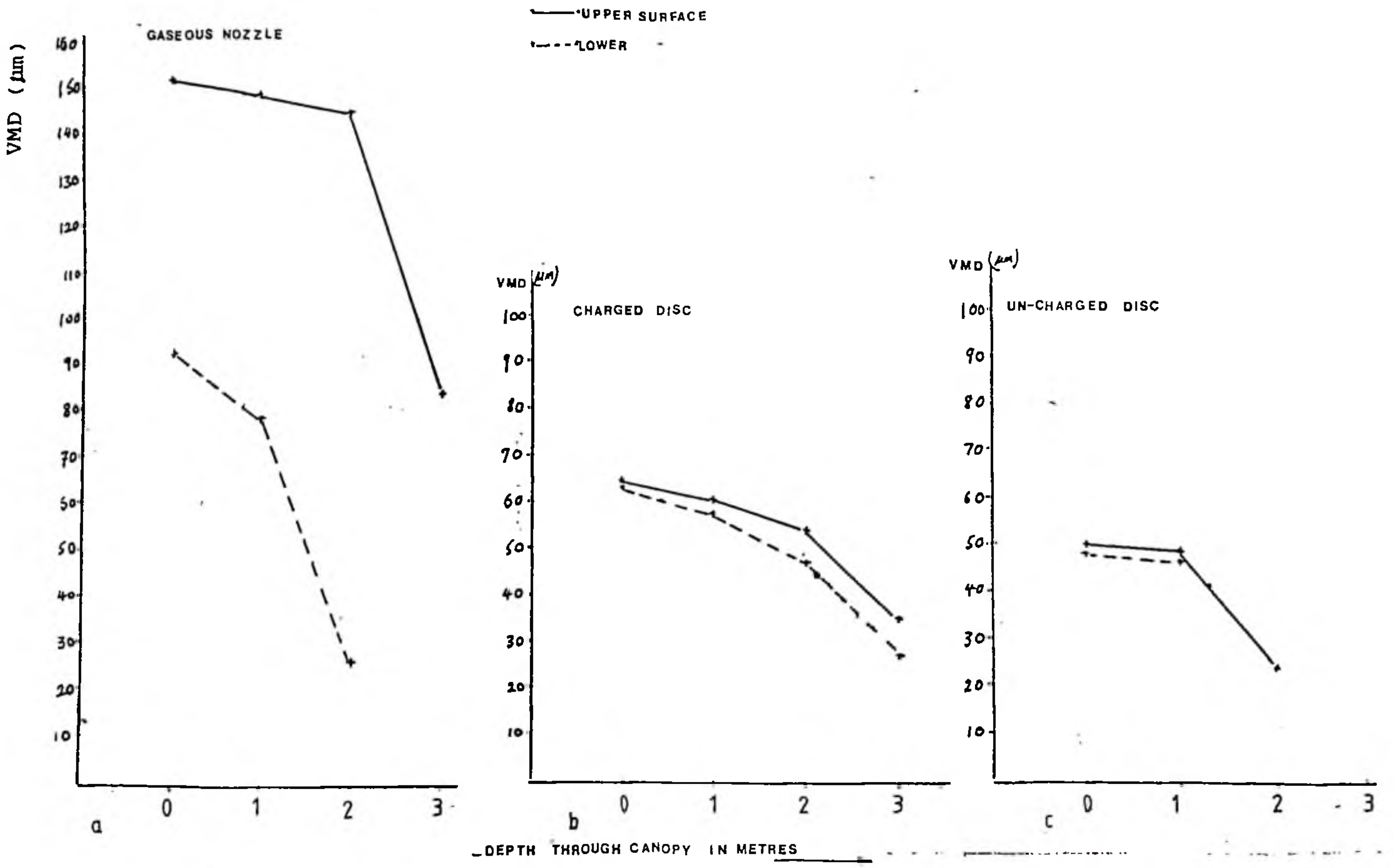
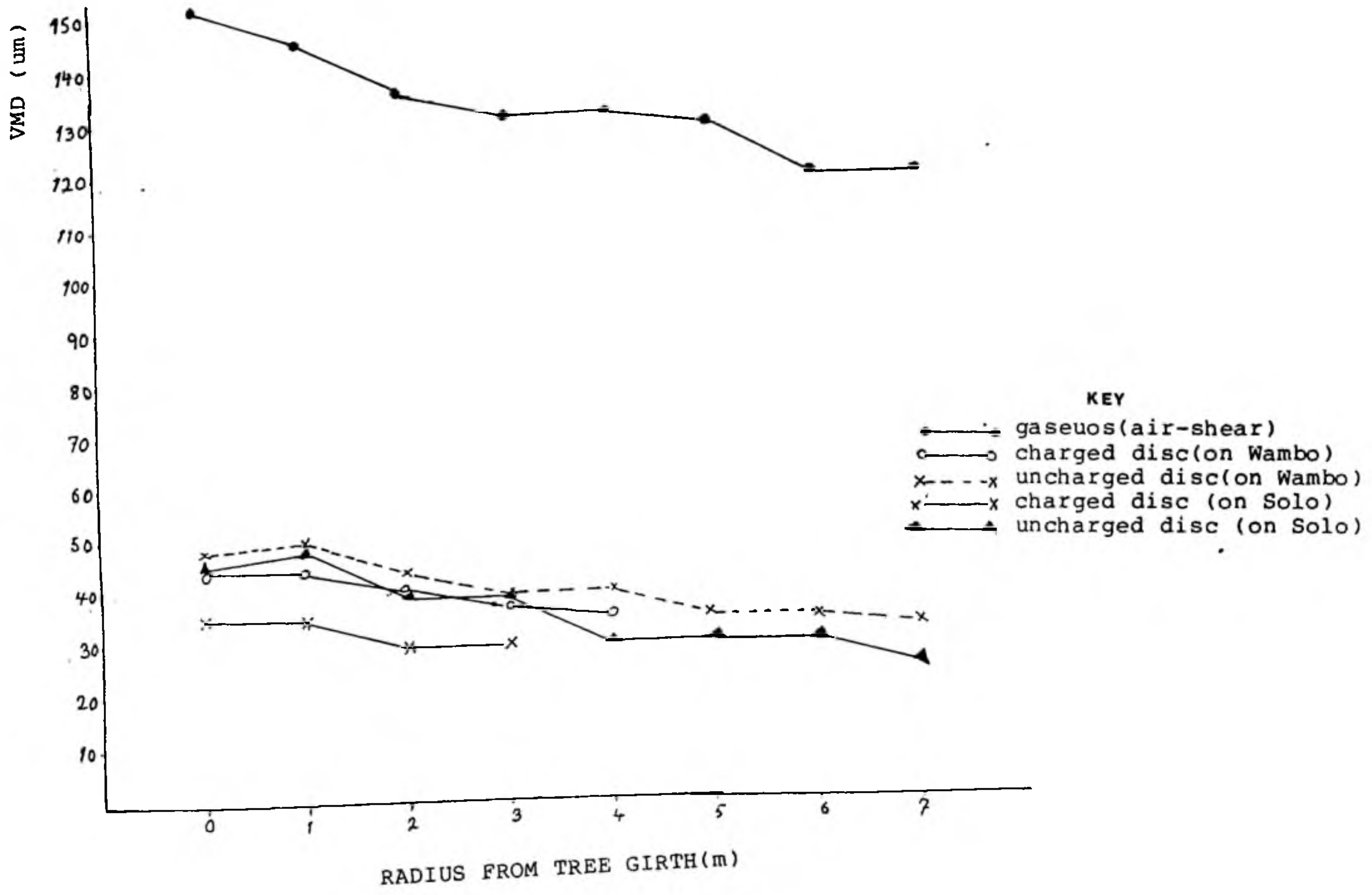


FIGURE 4.7 The variation in VMD(um) of spray deposits on surfaces with in canopy using 3 different nozzles fitted on the Wambo mistblower.

FIGURE 4.8 Variation in VMD(um) of spray droplets `fallout' under tree immediately after spray application.



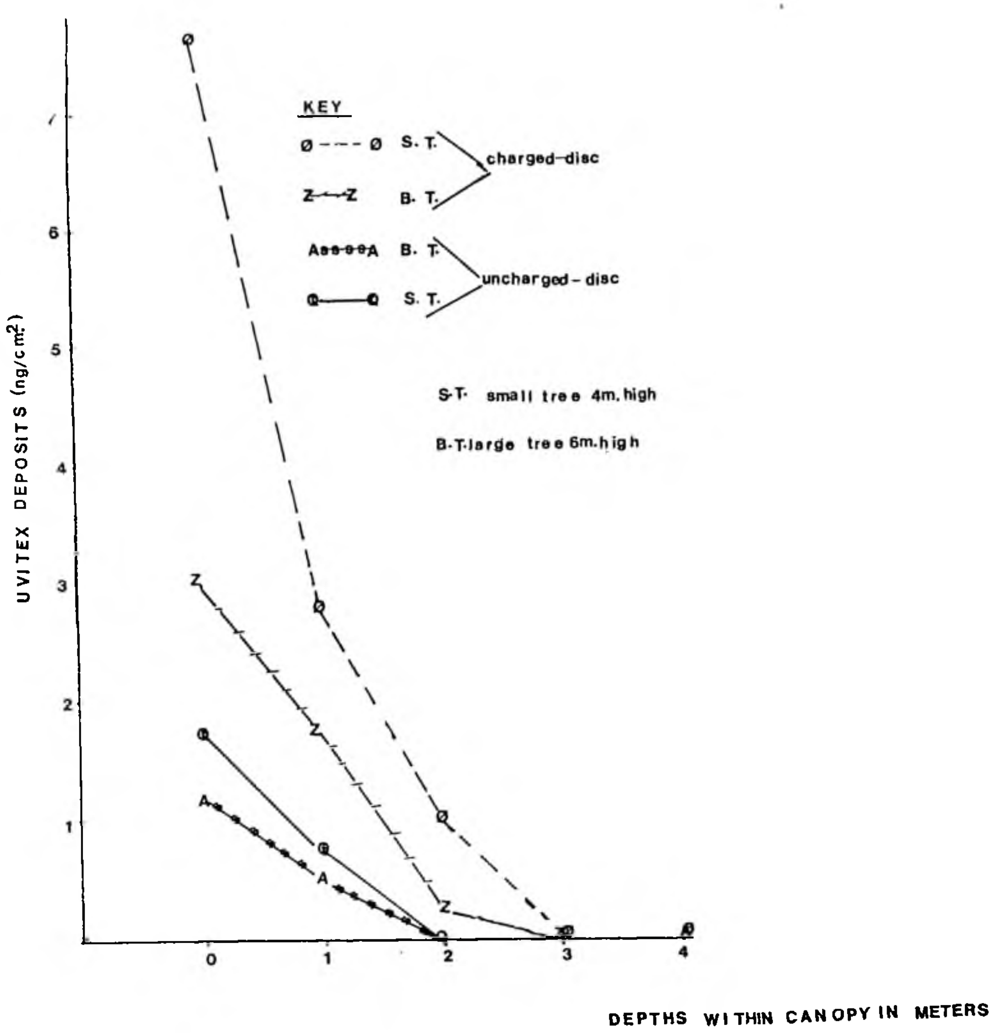


FIGURE 4.9 Variation in Fluorescent tracer(uvitex) deposits(ng/cm2) within canopy of apple trees variety <u>Keswick</u> and <u>Red victoria</u> using Solo mistblower.

TABLE 4.8

Average Uvitex fall-out (ng/cm²) on ground immediately after spraying using 0.1 percent fluorescent tracer (Uvitex) in each of the spray solutions with the different nozzles (1 side only).

	Radius from tree girth (m)						
Nozzle	0	1	2	3	4	5	6
Gaseous nozzle	6.0	8.0	6.0	6.0	2.0	1.8	1.8
Charged disc (Wambo)	0.5	2.0	1.0	1.0	0.5	-	-
Uncharged disc (Wambo)	2.5	5.0	4.5	3.5	3.0	3.0	2.5
Charged disc (Solo)	1.0	1.5	0.7	0.6	-	-	-
Uncharged disc (Solo)	2.5	4.8	3.9	3.9	3.8	2.5	2.0

LEAST SIGNIFICANT DIFFERENCE (LSD) = 0.224

TABLE 4.9

Variation in spray droplet density (no/cm²) within canopy of apple varieties *Keswick codling* (4m. high) and *Red victoria* (6m. high) with Solo mistblower application from one side only.

	Depths within canopy (m)					
Spray	0	1	2	3	4	Tree variety
Charged disc	1500	761	454	144	-	Keswick
	834	629	380	30	0	Red victoria
Uncharged disc	613	282	53	0	-	Keswick
	355	182	0	0	0	Red victoria

LEAST SIGNIFICANT DIFFERENCE (LSD) = 27.573.

TABLE 4.10a

Mean Uvitex deposits (ng/cm²) within canopy of *Red victoria* (6m) and *Keswick codling* (4m high) using different nozzles on Wambo mistblower (from one side of canopy only).

Spray	Depth 0m	1m	2m	3m	4m	Tree variety
Gaseous	5.5	3.7	1.6	0.2	-	*Keswick*
	3.5	1.8	1.3	0.1	0	*Red victoria*
Charged disc	7.3	3.0	0.9	0.1	-	*Keswick*
	2.7	2.0	0.6	0.1	0	*Red victoria*
Uncharged disc	1.5	0.7	0.1	0	-	*Keswick*
	1.1	0.3	0.1	0	0	*Red victoria*

LEAST SIGNIFICANT DIFFERENCE (LSD) = 0.213

TABLE 4.10b

Details of treatment employed. Spray volume (ml/tree)

Nozzle	*Keswick*	*Red victoria*
Gaseous	271.2	446.2
Charged disc	4.4	7.1
Uncharged disc	4.8	7.7

The larger variety (Red victoria) required about 50 percent more spray liquid, but distribution was still lower than that achieved by the smaller Keswick variety.

(c) Distance of nozzle from canopy and spray distribution

The results are given in Tables 4.11 - 4.14. The mean deposits of fluorescent tracer (Uvitex) were not significantly different for either uncharged or air-shear nozzles, irrespective of distance from target. Similarly, capture of droplets on either surface (upper or lower) was not significant with distance, for the two nozzles (Tables 4.11 and 4.13). However, the deposition of charged droplets 1m from targets was significantly greater ($p = 0.05$) at outer leaves than at 3m nozzle distance (Tables 4.12 and 4.14). On the other hand, spray penetration within canopy (at least a meter further) was significantly better ($p = 0.05$) with the nozzle at 3m, for all nozzles (Tables 4.11 and 4.13).

4.1.2 Discussion

Effect of canopy density, tree size and shape and nozzle distance from canopy on spray penetration and distribution

Chemical control of apple pests and diseases like those of other crops depends largely on the level of spray deposits retained on certain critical parts of the tree canopy. Not only is the amount per unit area on the target surface important, but also its distribution and persistence with weathering. The volume of spray retained is dependent on a combination of factors, such as ambient meteorological conditions, spray-droplet size and velocity, and the geometry of the tree (Morgan, 1964, Herrington et al., 1981; Warman and Hunter, 1981). Difficulties in achieving good spray coverage of large trees have been

TABLE 4.11

Mean deposits (ng/cm²) of fluorescent tracer on leaf surfaces within canopy at 3m high using different nozzles on the Wambo mistblower at 1m and 3m from canopy. (Spraying from one side of tree canopy).

Height (3m)	Depth Nozzle	0m	1m	2m	3m	Nozzle Distance
Upper surface	Gaseous	6.6	3.4	1.2	0	1 metre
		6.8	3.5	1.5	0.9	3 metres
	Charged disc	11.4	3.8	1.4	0.0	1 metre
		9.5	5.4	1.1	0.2	3 metres
	Uncharged disc	2.8	1.6	0	0	1 metre
		2.2	1.1	0.4	0	3 metres
Lower surface	Gaseous	3.8	2.3	0.8	0.0	1 metre
		3.5	2.5	0.9	0.0	3 metres
	Charged disc	4.8	3.8	0.9	0.0	1 metre
		2.9	2.5	0.4	0.0	3 metres
	Uncharged disc	0.7	0.3	0.0	0.0	1 metre
		0.5	0.3	0.0	0.0	3 metres

LEAST SIGNIFICANT DIFFERENCE (LSD) = 0.475

TABLE 4.12

Mean deposits (ng/cm²) of fluorescent tracer on leaf surfaces at 2m high, using different nozzles on Wambo at 1m and 3m away from canopy. (Spraying from one side of tree canopy).

Height (2m)	Depth Nozzle	0m	1m	2m	3m	Nozzle Distance
Upper surface	Gaseous	8.7	4.2	3.0	1.1	1 metre
		7.6	5.9	2.6	1.2	3 metres
	Charged disc	14.7	4.9	1.9	0.0	1 metre
		10.4	4.8	1.5	0.3	3 metres
	Uncharged disc	3.0	1.7	0.5	0.0	1 metre
		2.5	1.3	0.6	0.2	3 metres
Lower surface	Gaseous	4.3	2.6	1.7	0.0	1 metre
		4.4	4.0	1.6	0.2	3 metres
	Charged disc	8.4	3.0	0.9	0.0	1 metre
		5.0	3.5	1.5	0.0	3 metres
	Uncharged disc	0.9	0.4	0.2	0.0	1 metre
		0.5	0.3	0.0	0.0	3 metres

LEAST SIGNIFICANT DIFFERENCE (LSD) = 0.273

TABLE 4.13

Mean deposits (ng/cm²) of fluorescent tracer within canopy at heights 2m and 3m, using varying voltages on Solo mistblower, with nozzles 1m and 3m away from canopy. (Spray from one side of tree canopy).

Heights	Depths Nozzle	0m	1m	2m	3m	Nozzle Distance
Top (3m)	0Kv	4.5	0.4	0	0	1 metre
		3.0	0.7	0	0	3 metres
	10Kv	9.1	0.6	0	0	1 metre
		9.6	0.9	0	0	3 metres
	20Kv	10.8	0.9	0	0	1 metre
		9.6	1.1	0·4	0	3 metres
	30Kv	14.3	6.0	0	0	1 metre
		10.5	2.9	1.0	0	3 metres
Bottom (2m)	0Kv	5.3	5.4	0.0	0	1 metre
		4.0	2.6	1.5	0	3 metres
	10Kv	10.2	2.9	0.02	0	1 metre
		9.1	3.4	0.2	0	3 metres
	20Kv	10.2	5.4	0.01	0	1 metre
		8.6	2.6	1.1	0.2	3 metres
	30Kv	14.9	5.9	0.03	0	1 metre
		10.1	4.2	2.2	0.7	3 metres

LEAST SIGNIFICANT DIFFERENCE (LSD) - 0.402

TABLE 4.14

Mean deposits (ng/cm²) within canopy on leaf surfaces using varying voltages on spray with Solo mistblower at 1m and 3m away from canopy. (Spraying from one side of tree canopy).

	Depth	01	1m	2m	3m	Nozzle Distance
	Nozzle					
Upper	0Kv	5.7	3.6	0	0	1 metre
		3.9	3.0	1.5	0.4	3 metres
	10Kv	11.7	2.9	0	0	1 metre
		13.2	3.2	0.6	0.1	3 metres
	20Kv	18.2	3.7	0	0	1 metre
		12.2	2.8	1.4	0.1	3 metres
	30Kv	36.1	4.4	0.3	0	1 metre
		14.0	2.9	2.2	0.5	3 metres
Lower	0Kv	4.3	1.8	0	0	1 metre
		2.6	0.9	0	0	3 metres
	10Kv	6.6	1.2	0	0	1 metre
		5.5	1.1	0	0	3 metres
	20Kv	7.7	1.8	0	0	1 metre
		5.9	1.9	0	0	3 metres
	30Kv	13.1	2.0	0	0	1 metre
		7.6	2.9	0.9	0.1	3 metres

LEAST SIGNIFICANT DIFFERENCE (LSD) = 0.402

The Least Significant difference (LSD) for the figures were calculated from a 3-way analysis of variance, by the relationship:

LSD - Standard error of difference (SED) x t (for P - 0.05 of residual degree of freedom).

The Height, Spray, Depth interaction term was statistically significant ($P < 0.001$, f test).

reported (Morgan, 1972; Cooke *et al*., 1976; 1977), there being a large variation in spray distribution at different stages of tree growth from bud burst to the full canopy. Palmer and Jackson (1977) indicated that for small Cox apple trees, leaf area may increase by about 40 per-cent from late May to late July, with a slight decline in early August. This study confirmed that the average leaf area for apple tree varieties *Keswick codling* and *Red victoria* increased from 13.6cm^2 and 11.9cm^2 at bud burst (in May) to 27.8cm^2 and 33.8cm^2 at full canopy (in July) respectively. In consequence, there was a significant decrease in spray penetration, and overall distribution significantly decreased (p 0.05).

Within the canopy, the level of deposit varied and decreased significantly ($p = 0.05$) with height and crop density into the interior of trees. This decrease was particularly evident during the full canopy stage of the larger *Red victoria* variety, where the large variation was similar to that reported by Byass (1965), and Warman and Hunter (1981). The distribution within the canopy of the smaller *Keswick codling* variety was significantly better than that within *Red victoria* trees. The total amount of spray emitted as the sprayer passed a tree was proportional to the width of tree measured in the direction of travel of the sprayer (Warman and Hunter, 1981). However, the height of the canopy (i.e. difference between bottom of canopy and tree height) was an additional important factor, and to a large extent determined the total amount of spray volume used for each of the apple varieties. This confirms the suggestion by Morgan (1964) that the volume of spray should be proportional to the volume of the canopy (height and spread) with the adaption of the term 'sprayed area' used for plantation crop spraying, instead of 'Land area' as used for field crops. Subsequently an estimated leaf area index (LAI) for this study was equated to the height of the canopy. This took into consideration the movement of the sprayer from one end of the canopy to the other.

Simply increasing the spray volume in respect of tree size, and continuing to spray from one side of the tree only, may still result in insufficient penetration of the canopy. Furthermore there may be a large overdose on leaves along the edge of the canopy as spray fails to reach the interior of the canopy. The amounts of spray liquid reaching the inner canopy depend on air capacity and the density of the crop that must be treated (Randall, 1971; Lieftink, 1980). Subsequently, air must penetrate the thickest part of the foliage and retain sufficient velocity to transport droplets to target surfaces, but air velocities within canopies are more erratic and lower than in the open flow - thus the decrease in penetration of more closed up canopy (Reichard _et al_., 1977). In consequence, it is more appropriate to spray from both sides of tree canopy in such situations for an even distribution of spray within canopy.

With trees like the cocoa and mango where tree size could be larger and taller at up to about 10m, the applicator could go under the canopy and direct the spray straight up into the foliage on stem and fruits (or pods) for a direct hit of target pests, as recommended by Stapley and Hammond, 1951.

The significant decrease in capture of droplets on surfaces when the distance of the charged disc from canopy was increased from 1m to 3.0m suggests that it is convenient to direct that nozzle closer to the canopy for a more effective coverage (Coffee, 1979, 1980; Law, 1976; Arnold and Pye, 1980). Better penetration through canopy with uncharged sprays requires the nozzle to be held a reasonable distance away from the canopy, so that the air jet can spread out as wide as possible and its velocity to decrease sufficient to achieve effective results.

Attempts made to increase the penetration of canopy by charged droplets, by varying the charge/mass ratio on the spray droplets did not give any significant improvement. Decreasing the charge/mass ratio, decreased the total amount of deposits (ng/cm^2) captured by the crop, and so likely to decrease the effectiveness of electrostatic sprayers.

The movement of droplets of different size within the canopy was affected by the structure of the crop canopy, thus the VMD of droplets was significantly affected when measured at different positions. Sayer (1972) suggested two distinct planes of distribution - namely from top to bottom and across the canopy. Large droplets that remained in the air jet could be projected to the upper canopy, and fall back on to the upper surface of exposed leaves. Some of the large droplets were intercepted at the nearest leaves, leaving smaller droplets to pass through the canopy across to the rear, where they were collected by turbulent or stagnant air.

The performance of the charged droplets in reducing droplet 'fall-out' was a significant improvement over the conventional methods of application. There is the further implication that there is less wastage of pesticides, and less risks and hazards to the environment, particularly to beneficial insects and worms, in the soil.

4.2 Spray Application with Cypermethrin Formulations

The biological efficacy of the spray deposits discussed in the previous section (4.1) was studied by treating leaves with different formulations of cypermethrin and assaying the residue deposits with neonate codling moth larvae.

Studies on the biology of this pest indicate that neonate larvae usually wander at random for at least 30 minutes on leaves, petioles and twigs after hatching, and before beginning to penetrate the skin of apple fruit (Jackson, 1976; Fisher and Menzies, 1979). So they were the most likely stage to contact a residual deposit.

4.2.1 Results

The mortality responses (Appendix 4.1) were corrected with the Abbot's correction formular: $P_T = \frac{Po-Pc}{100-Pc} \times 100$ where P_T = corrected mortality, Po = observed mortality and Pc - control mortality (all in percentages) Pc was calculated from the relationship $Pc - P_{blank} - P_{bare\ leaf}$ (P_{blank} mortality on leaf surfaces with blank formulation, $P_{bare\ leaf}$ = leaves picked prior to any spray application). A two-way Genstat analysis of variance and a regression test of the results (Tables 4.15 and 4.16) showed that mortalities were related directly to the deposit parameters, thus the highest mortalities were found at regions of the crop canopy which had the most spray deposited on it and better spray coverage per unit area on leaf surfaces. There was no significant difference between the performance of the charged spinning disc and the spray from the air-shear nozzle. However, the responses due to the deposits by the uncharged ULV spray were significantly lower than the others ($p = 0.05$).

TABLE 4.15

Corrected percentage mortality of codling moth (neonate larvae) on leaves sampled from various regions within canopy, after spray application with cypermethrin formulations.

(a) Spraying from one side of tree canopy.

	Depth within canopy (m)			
Nozzle	0	1	2	3
Air-shear	88.5a	83.0a	47.4b	32.0c
Charged disc (Wambo)	87.0a	76.2a	37.1c	20.0d
Charged disc (Solo)	86.5a	77.1a	41.3c	13.3d
Uncharged disc (Solo)	58.1b	44.8c	31.0c	8.6d

S.E.D. (d.f. 30) = 3.3 C.V.% 4.7

Figures followed by same letters are not significantly different (p = 0.05) by 2-way Genstat analysis of variance.

(b) Spraying from both sides of tree canopy.

	Depth within canopy (m)			
Nozzle	0	1	2	3
Air-shear	91.0a	87.0a	86.0a	93.0a
Charged disc (Wambo)	90.0a	85.0a	85.0a	92.0a
Charged disc (Solo)	92.0a	84.0a	83.0a	90.0a
Uncharged disc (Solo)	65.0b	50.0b	52.0b	64.0b

S.E.D. (d.f. 30) 4.0 C.V.% = 4.1

Figures followed by same letters are not significantly different (p = 0.05) from 2-way Genstat analysis of variance.

Table 4.16

Relationships between spray droplet deposits (ng/cm²) droplet density (no/cm²), droplet size (VMD) and Percentage mortality of Codling moth (neonate larvae) (spraying from one side of tree).

(1) Air-shear nozzle (E.C. formulation)

	depth within canopy (m)				Regression test
	0	1	2	3	Correlation with P. mortality (C.C.)
% mortality	85.5	83	47	32	C.C. = 1.0
deposits (ng/cm²)	7.6	5.9	2.6	1.2	C.C. - 0.98
droplet density (no/cm²)	590	330	290	90	C.C. _ 0.85
droplet size (VMD)	152	148	140	85	C.C. = 0.84

(2) Charged disc (Wambo) (ED formulation)

	0	1	2	3	Correlation coefficient
% mortality	87	76.2	35	20	1
deposits (ng/cm²)	10.4	4.8	1.5	0.3	0.77
droplet density (no/cm²)	1430	790	490	90	0.81
droplet size (VMD)	65	60	55	35	0.86

(3) Charged disc (Solo) (ED formulation)

	0	1	2	3	Correlation coefficient
% mortality	86.5	77.1	41.3	13.3	1
deposits (ng/cm²)	13.98	4.2	2.05	0.78	0.80
droplet density (no/cm²)	2000	920	290	35	0.90
droplet size (VMD)	34	29	29	29	0.63

(4) Uncharged disc (Solo) (ULV formulation)

	0	1	2	3	Correlation coefficient
% mortality	58.1	47	30	8.6	1
deposits (ng/cm²)	3.8	2.0	1.48	0.04	0.96
droplet density (no/cm²)	900	350	150	30	0.89
droplet size (VMD)	39	38	32	32	0.91

4.2.2 Discussion

Several studies with droplets of insecticide of known size deposited on leaf surfaces have indicated that small droplets are more efficient at controlling certain pest species (Himel and Moore, 1967; Munthali, 1981; Omar and Matthews, 1987), so that less pesticide might be applied, although consideration must also be given to persistence of deposits. Part of the effectiveness of small droplets is due to the increase in the number of them for a given deposit level, so that coverage of a surface is greater. Coverage is also improved by increasing the number of directions that spray is projected into a crop canopy. Thus, when spray was directed into the canopy from one side of the tree canopy only, penetration was poor. Some regions which received greater deposits on which more larvae died than those on leaves further in the canopy with fewer droplets and thus less spray deposit.

Where only a few small droplets penetrated the canopy, percentage mortality was significantly reduced (Figs. 4.10 - 4.13). When large droplets (141-152 µm, VMD) were applied, it needed about 300 droplets/cm^2 to deposit 2.75ng/cm^2 active ingredients (a.i.) to achieve at least 50 percent mortality or more. When small droplets (30-60 µm VMD) were used, the number needed increased to 600-900 droplets/cm^2 to give a similar deposit of 2.72 ng/cm^2 - 4.0 ng/cm^2 a.i. and achieve similar results, as illustrated below:

	Size	a.i.	No./droplets/cm^2	
decrease	150 µm	2.75 ng/cm^2	300	increase
x2.5	60 µm	2.72 ng/cm^2	600	x2
x2	30 µm	4.0 ng/cm^2	900	x1½

Thus about 2-3 times more ULV droplets (30-60 µm (VMD) were required and 1-1.5 times deposit of active ingredients/cm^2 to achieve mortality

FIGURE 4.10 Relationship between droplet density(no/cm2), droplet deposits(ng/cm2), droplet size(VMD) and percentage mortality of codling moth(neonate larvae) using air-shear nozzle

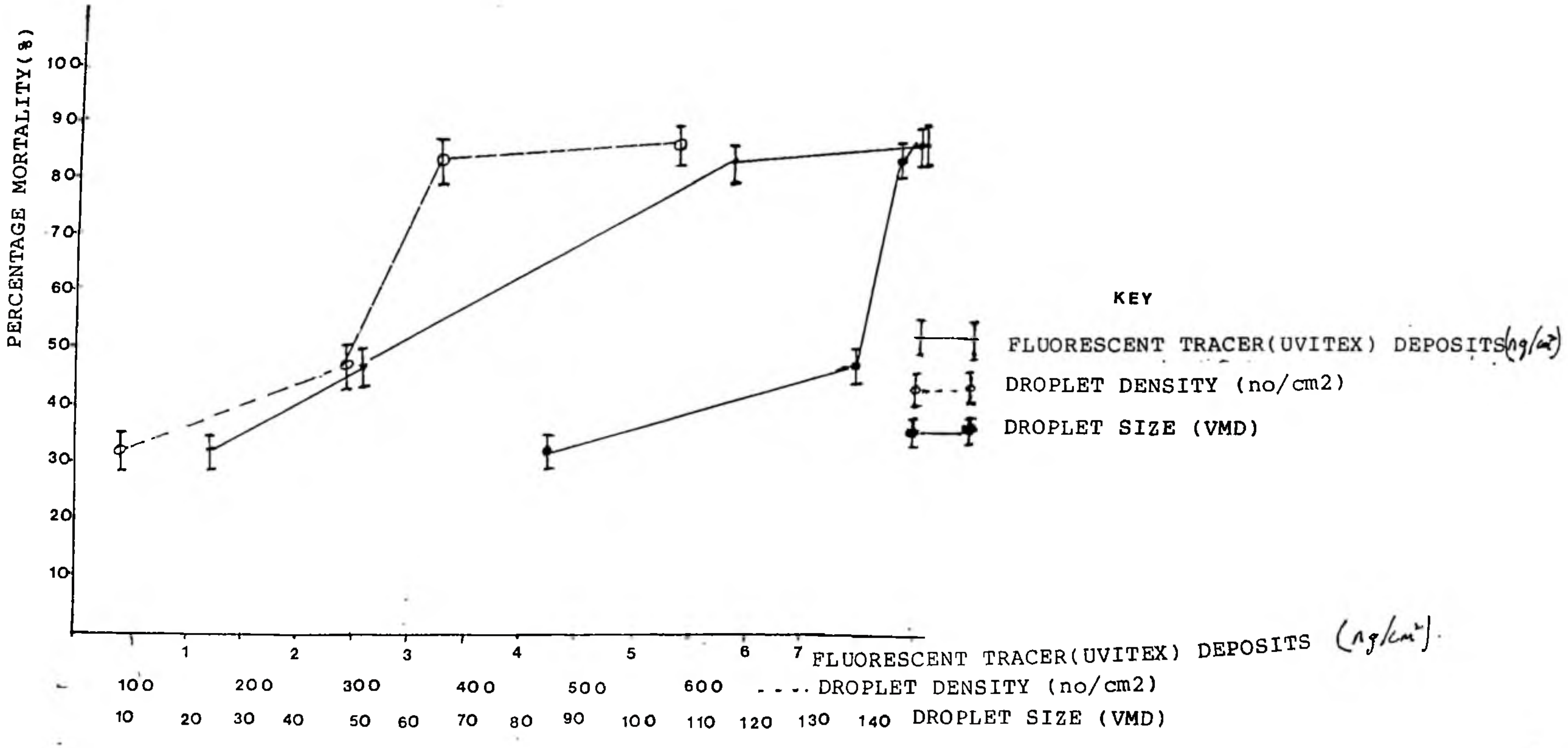


FIGURE 4.11 Relationship between droplet density(no/cm2) droplet deposit(ng/cm2) droplet size(VMD) and percentage mortality of codling moth(neonate larvae) using charged disc on Wambo.

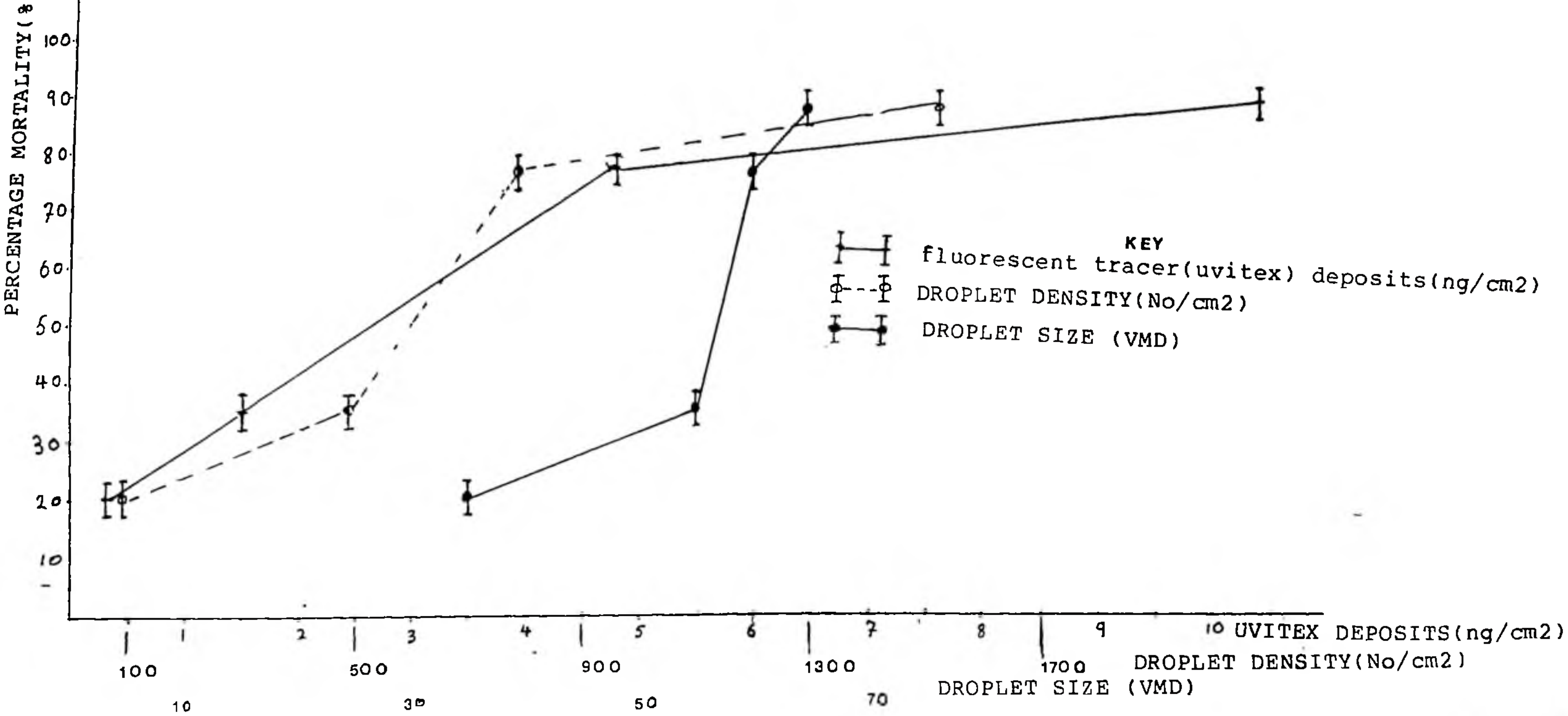


FIGURE 4.12 Relationship between droplet density(no/cm2) droplet deposit(ng/cm2) droplet size(VMD) and percentage mortality of codling moth(neonate larvae) using charged disc on Solo.

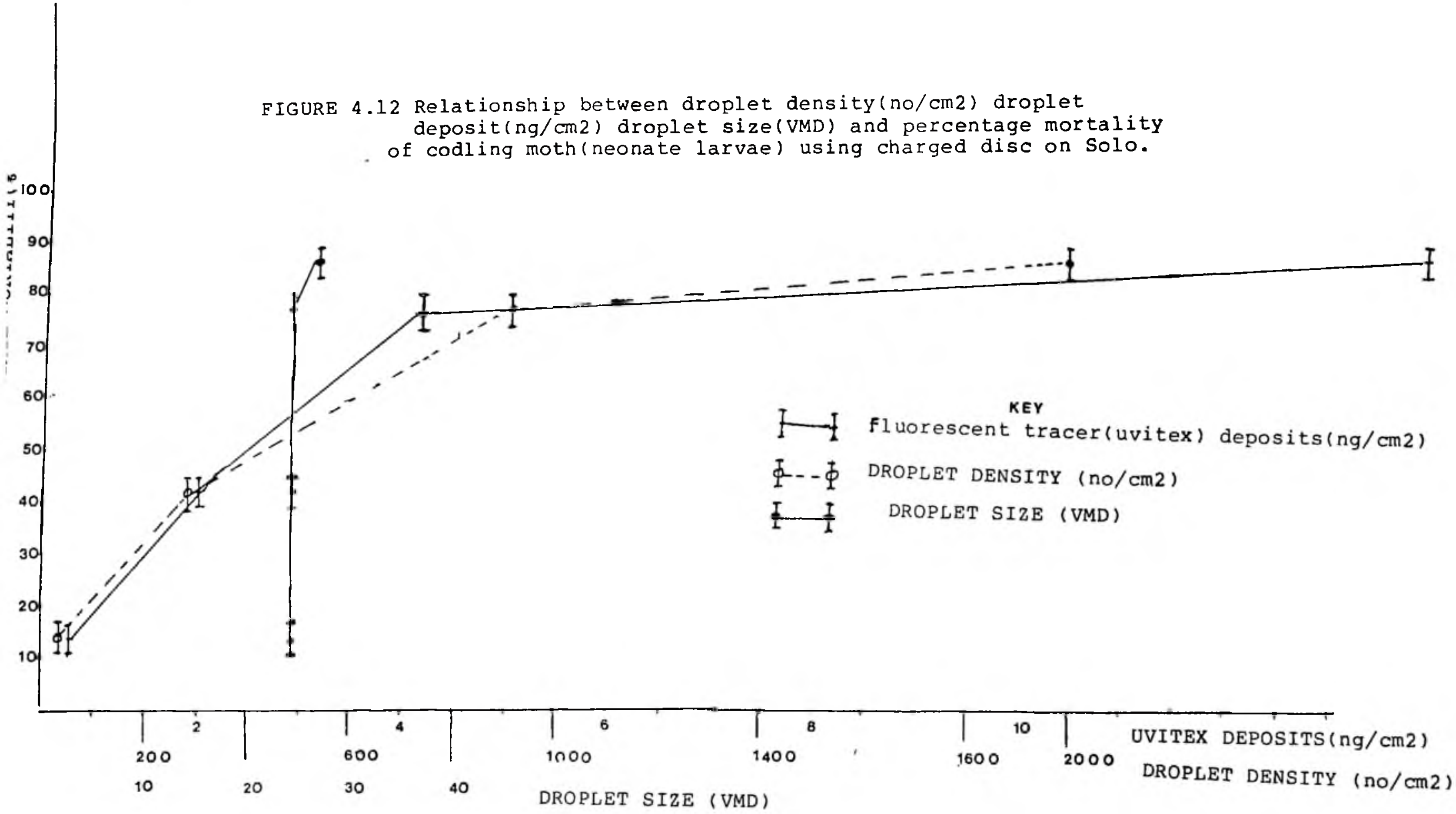
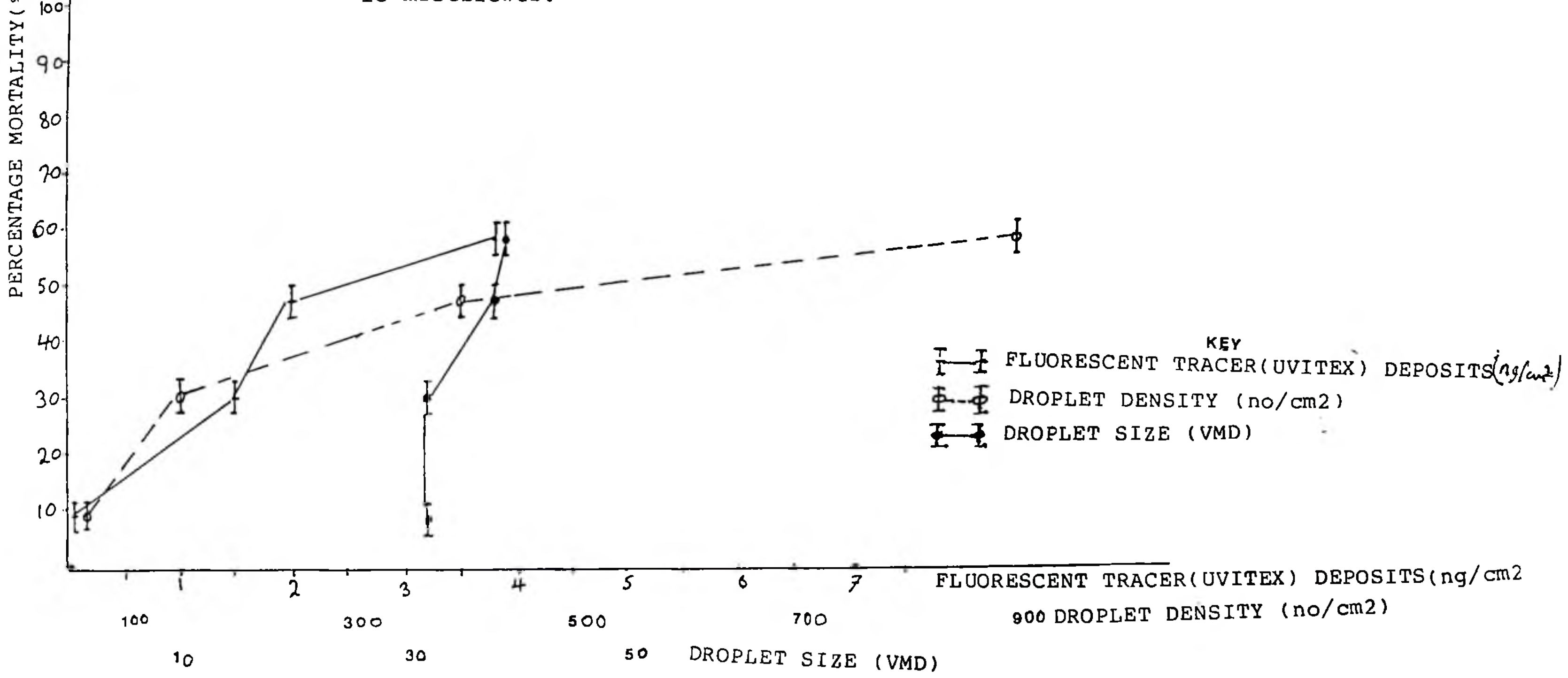


FIGURE 4.13 Relationship between droplet density(no/cm2) droplet deposit(ng/cm2) droplet size(VMD) and percentage mortality of codling moth(neonate larvae) using uncharged disc on Solo mistblower.



comparable to that with large droplets (150 µm VMD), but this was significantly less than the theoretical increase of 8-16 fold, indicating that if small droplets can be deposited where the larvae are, less volume of spray should be more efficient.

When spraying was done from both sides of the tree canopy, the improved coverage achieved resulted in significantly increased mortality throughout the canopy, with each of the nozzles ($p = 0.05$) (Table 4.15b).

The quantity of active ingredient in a spray is a function of the initial concentration in the spray solution, and determines the effectiveness of spray deposited on targets (Johnstone, 1973). Subsequently, the same concentration was maintained for each of the cypermethrin formulations as a measure of efficiency in droplet production, distribution and deposition, by the different nozzles on leaf surfaces. Thus, the comparable responses in mortality achieved by deposits from the charged ULV spray and the spray application with the air-shear nozzle was very significant. It indicated that it could be possible to achieve good responses with reduced spray volumes when trees are sprayed using the normal recommended rates of application.

This study confirms the results of Morgan (1953) who showed that the same quantity of fungicides applied to leaf surfaces in different droplet sizes and number (no/unit area) gave different degrees of protection from fungus disease. Fisher and Hanzell (1964) working on the toxicity of dicofol to the two spotted spider mite (Tetranychus telaruis (L.)) also suggested that the mite may be able to avoid discontinuous deposits on the leaf surfaces. Similarly, Fisher and Morgan (1968) observed that mite mortality increased and oviposition decreased markedly as droplet numbers increased, and that increasing the concentration of the pesticide used (i.e. dicofol), above the normal field strength (0.046 percent) had relatively little effect. Fisher and Menzies (1979) on the other hand, found that spray deposits of phosmet were 5 times more toxic in small droplets (160 µm VMD) than in large droplets (350 µm, VMD) to first instar larvae of codling moth, but that the smaller droplets required 2.5 times the number of droplets per unit area.

Smaller droplets (if deposited), thus, ensure better coverage and increased probability of contact (greater for large numbers of small droplets than a few large ones) with the pest. In addition, both the nature of the surface and the formulation of oil-based pesticides affected the spread of pesticides from droplet deposits (Abdalla, 1984), with the greater toxicity of oil-based residues being due partly to greater contamination of the insect, resulting from enhanced penetration (Busvine, 1971).

The effective responses obtained in these trials when less volume and active ingredients was applied increased the efficiency of the application process. This confirmed the potential for improving precision and economy of pest and disease control of tree crops, and for a reduction in the environmental hazards.

4.3 Rainfastness

Three different formulations of spray containing 0.1 percent cypermethrin were applied on seedlings of apple variety Yarlington mill, placed 3 meters from the nozzle using blank formulations as control. Four seedlings were used for each treatment, replicated three times. Sprayed seedlings were allowed to dry for 1 hour and two seedlings from each treatment chosen at random and subjected for 15 minutes to 65.3mm artificial rainfall from a rain tower. The other two seedlings from each treatment were not subjected to rainfall. One hour later, leaves were picked at random from both groups of seedlings (with and without rainfall), and the effectiveness of deposits retained tested in the laboratory with neonate codling moth larvae. Responses in mortality obtained (A4.2) were corrected by Abbot's formular as in Chapter 4, Section 2.. Results were analysed with paired t-test of means and by the 1-way Amstat 1 analysis of variance.

4.3.1 Results

Without rainfall, the effect of the three cypermethrin formulations was uniform. The loss of deposits after rainfall was applied decreased mortality. Deposits of small droplets (30-70 µm VMD) were more rainfast than those applied as large droplets (90 - 160 µm VMD). In addition, deposits on the lower leaf surfaces were more persistent than those on the upper surfaces (Table 4.17). No significant difference ($p = 0.05$) was obtained between droplets from either the charged or uncharged spray.

4.3.2 Discussion

Better retention of small droplets after rain was considered to be due to the larger area of contact area between smaller droplets and the leaf cuticle (Poltes and Vincon, 1969; Busvine, 1971; Mass, 1971; Mabbert and Phelps, 1983; Taylor and Matthews, 1986). The greater persistence of droplets from the ULV and 'Electrodyn' formulations could also be influenced by the differences in formulations,

Table 4.17

Percentage mortality of Codling moth on leaf surfaces sprayed with Cypermethrin formulations, before and after 65.3mm of rain.

Paired t-test of mortality, with and without rainfall percentage mortality ± standard deviation (S.D.).

	EC		'ED'		ULV	
leaf surface	no rain	after rain	no rain	after rain	no rain	after rain
Upper	100 a	43.3±5.7 a	100 b	63.0±5.6 b	80 d	51.9±11.0 d
Lower	100 b	63.0±6.1 b	100 c	74.0±4.0 c	80 d	63.0±5.6 d

Figures followed by same letters under 'after rain' are significantly different from those under 'no rain' with same letters (a = p = 0.0001; b = p = 0.0004; c p = 0.0002; d = p = 0.003) from paired t-test of means.

the oil-based droplets being bonded to the surface waxes of leaf cuticle as well as possible increased penetration. Pick, Van Dyke and de Beer (1984) suggested that the speed at which a pesticide penetrates the leaf surface probably determines its resistance to wash-off.

Greater mortality on the undersurface of leaves after rain was due to these surfaces being more protected from the direct action of impinging rain droplets, although rainwater may also get on the lower surface as in the field, wind action often makes the undersurface of one leaf touch the upper surface of another leaf. Thus, except in situations of storm and high wind (to expose all surfaces of leaves to rainfall), there still could be pesticide deposits sufficient enough to achieve good control of pests, even after rainfall.

CHAPTER FIVE: FINAL DISCUSSION

Traditional methods of spraying tree crops have generally been effective although failure to deposit sufficient pesticide at the tops of tall trees often occurs. Penetration of spray into dense canopy was achieved principally by increasing the volumes of spray up to 2000 L/ha, and the pressures. However, these methods are often time consuming and much of the chemical is wasted, so growers are anxious to have improved methods of application.

Reduction in spray volume has been considered particularly with arable crops, but relatively few studies have considered the problems of treating tree canopies with less spray. A major advantage of ULV sprays is that with less transport of water, it should be possible to treat an area quicker as soon as a pest infestation occur. This is particularly important where wind and rain may restrict the time available for application, and large areas may need rapid treatment. However, with ULV sprays, much of the small droplets fail to deposit, probably due to evaporation or drift (Amsden, 1962; Law and Brown, 1966). Consequently, there is the need to charge ULV spray droplets electrostatically, for improved deposition, and hence coverage of plant surfaces.

When hydraulic nozzles were used, they had to be mounted on vertical booms specially positioned around the canopy with individual nozzles angled to direct spray between branches (Matthews, 1983). For example, 'hockey sticks' used on coffee in Kenya (Pereira, 1972). Research had shown that penetration into trees and the uniformity of spray deposition could be achieved if a large volume of slowly moving air was used to create turbulence so that leaves were moving while spray was deposited

(Randall, 1971). For larger trees, the critical area is the centre and top of a spreading canopy, so most spray should be directed to all parts. In consequence, spray should be from both sides of tree canopy to achieve adequate coverage, and the volume of spray liquid used should be proportional to tree height and spread of canopy. Generally, however, the mobility of insects and mites, or the redistribution of a pesticide over the plant surface by rain, dew or evaporation could reduce the need for complete coverage of plants.

Ideally biological studies are needed initially to determine what amount of coverage in different parts of a crop is required.

In the U.K. and elsewhere, more farmers are replacing their large trees with more dwarf trees to maximise yield while facilitating picking, spraying and pruning. Tropical farmers could gain a similar advantage if research was directed towards breeding dwarf-type trees. At least more attention could be given to pruning trees, and farms properly managed for increased efficiency of spray application, and reduced incidence of pests and diseases. For example, with crops like cocoa and coffee, regular pruning and removal of side growths is very essential for higher yields.

A sound knowledge of biology and life history of pests and diseases is very important prior to the application of any pesticide. Accurate timing of treatments to control the susceptible stage of the pest or disease can reduce the dosage needed, to ensure maximum efficiency of pesticide sprays.

In recent years, there has been considerable interest in the development of supervised and Integrated Pest Management programmes in pest control. These techniques aim to reduce the number and rationalise the choice of sprays applied to crops, with the implementation of other methods of control, wherever possible. As with diseases, certain pests (particularly aphids and mites) are becoming increasingly resistant to commonly used chemicals. In addition, the indiscriminate use of pesticides is harmful to beneficial insects, offsetting the 'biological balance of nature', thus causing resurgences of pests, hitherto held in check by their natural enemies. Discriminate use of pesticides is therefore essential. Implementation of large scale pest management programmes, for example, in the USA and Central America, has cut down the use of insecticides by more than 50 percent on crops such as cotton, citrus and grapes (Kumar, 1984). Thus, the solution to the crop-pest situation of tropical tree crops, lies in the ability to understand each problem and device a solution acceptable in terms of overall economic, environmental and social gains. Further, Governments should implement policies which will encourage more ecologically orientated pest management programmes. In addition, funding for research on all aspects of pest management programmes should have priority, and alongside research, more training is required at all levels (Matthews, 1984).

Indeed, pest management will have to evolve to respond to the infinite challenges that pests will continue to offer man.

5.2 Summary

When the tree canopy was sprayed from one side only:

5.2.1 Mean deposits (ng/cm^2) of fluorescent tracer (Uvitex) were significantly greater on the outer surfaces ($p = 0.05$) and decreased across the tree canopy irrespective of which nozzle was used on the mistblower.

5.2.2 Deposits on the lower foliage closest to the nozzle was greater than in the upper part of the canopy.

5.2.3 Spraying with the charged spinning disc at an average of 4.5ml/tree deposited significantly more at all levels in the outer crop canopy than with the other nozzles, but the decrease in deposits within the canopy was significantly greater with charged sprays. Deposits at the far side of canopy were only 16.5 percent of those nearest the sprayer at budburst when leaves were small and were undetected later when leaf area had doubled.

5.2.4 Applying a much greater volume (274.0 ml/tree) with the air-shear nozzle gave better distribution with a gradual decline in deposits across the canopy. The innermost region of the canopy received an average of about 35 percent and 7.6 percent of the outer deposits, at budburst and full canopy stages respectively.

5.2.5 The least amount was deposited by uncharged spinning disc at 4.8 ml/tree; only 28.0 percent of that on the outer foliage reached the inner canopy at budburst, and none was detected at the full canopy.

5.2.6 Spray distribution with the spinning disc was improved, when the volume of airflow was increased.

5.2.7 Decreasing the charge/mass ratio of the spray droplets did not improve penetration in the canopy.

5.2.8 Changes in spray deposits (ng/cm^2) were reflected in the numbers of droplets recorded.

5.2.9 The size of droplets decreased progressively from the outer to the inner part of the canopy, with all three nozzles.

5.2.10 The decrease in droplet size across the canopy was greatest for the air-shear nozzle; only the smallest droplets penetrated towards the rear of the canopy.

5.2.11 Droplets deposited on the upper leaf surfaces were larger than on the lower surfaces for the air-shear nozzle than with other nozzles, VMD's being 90-160 µm.

5.2.12 Droplets at the 3m level of the canopy were larger than at 2m level for the gaseous nozzle. There was no significant difference between droplet sizes from the charged and uncharged discs.

5.2.13 Spray deposited on the ground under the tree, i.e. fallout (ng/cm^2) was significantly decreased ($p = 0.05$) when charged droplets were sprayed and less was deposited further away from the treated tree.

5.2.14 The larger apple variety *Red victoria* required about 50 percent more spray liquid, but deposits were still lower than that achieved by the small *Keswick* variety with all three nozzles.

5.2.15 Average leaf area for apple tree varieties *Keswick codling* and *Red victoria* increased from 13.6cm^2 and 11.9cm^2 at budburst (in May) to 27.8cm^2 and 33.8cm^2 at full canopy (in July) respectively. In consequence there was a significant decrease in spray penetration, and overall distribution significantly decreased (p 0.05).

5.2.16 An estimated leaf area index for this study was equated to the height of the canopy, and was used to calculate the volumes needed to improve coverage of canopy.

5.2.17 Directing spray from both sides of the tree improved spray distribution with all three nozzles.

5.2.18 Mortality of codling moth (neonate larvae) was related directly to the level of deposits, so it declined through the canopy. Percentage mortality with the charged ULV and air-shear nozzles were not significantly different, but it was significantly lower for the uncharged ULV spray.

5.2.19 Cypermethrin sprayed with each nozzle on apple seedlings (variety *Yarlington mill*) were more persistent after artificial rain (65.3mm for 15 mins.) when small droplets (VMD = 30-70 µm) were applied by spinning discs compared with larger droplets (VMD = 90-160 μm) produced by the air-shear nozzle.

5.2.20 The under surfaces of leaves were more protected from direct action of impinging rain droplets. Thus except in situations of storm and high wind (to expose all surfaces of leaves to rainfall), there still could be pesticide deposits sufficient enough to achieve good control of pests, even after rainfall.

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Appendix Table 4.1

Uncorrected mortality of Codling moth, after bioassay with Cypermethrin formulations (spraying from one side)

(a) Control

bare leaf	blank water	blank E.D.	blank ULV
17.5%	22.5%	30%	30%

(1) Replicate 1. Mean mortality (%) within canopy

Spray	0m	1m	2m	3m
air-shear nozzle	90	85	50	37.75
charged disc (Wambo)	90	80	40	30
charged disc (Solo)	90	80	50	22.5
Uncharged disc (Solo)	70	50	40	20

(2) Replicate 2.

Spray	0m	1m	2m	3m
air-shear nozzle	100	75	50	30
charged disc (Wambo)	80	70	45	25
charged disc (Solo)	80	90	45	20
Uncharged disc (Solo)	60	50	40	20

(3) Replicate 3.

Spray	0m	1m	2m	3m
air-shear nozzle	80	80	50	35
charged disc (Wambo)	100	85	50	35
charged disc (Solo)	100	70	50	22
Uncharged disc (Solo)	60	55	45	15

Appendix Table 4.2

Uncorrected mortality of Codling moth, before and after 65.3mm artificial rain

(1) No Rain

(a) Control

	Bare leaf	blank water	plant 'E.D.'	blank ULV
percent mortality	10	10	20	20

(b) Pesticide application (Cypermethrin formulations)

Leaf surfaces	air shear/'E.C.'	charged disc/'E.D.'	uncharged disc/ULV
Upper	100	100	80
Lower	100	100	80

(2) After artificial rain (65.3mm)

Leaf surfaces (3 replicates)

Spray/formulation	Upper	Lower	Upper	Lower	Upper	Lower
air-shear/'E.C.'	40	60	50	70	40	70
charged disc/'E.D.'	60	80	50	70	70	70
uncharged/ULV	60	70	70	80	60	60
Controls						
bare leaf	0	0	0	0	0	0
blank water	0	0	0	0	0	0
blank 'E.D.'	10	10	10	10	10	10
blank ULV	10	10	10	10	10	10

Appendix Table 1

A1.1 Calibration of Sprayer and Nozzles

	Wambo 35cc	Wambo 50cc	Adapted Solo 35cc
Air volume (m^3/min)	5.9	9.5	5.9
Engine speed (R.P.M.)	6500	6500-7000	6500
disc speed (R.P.M.)	9000	9800	9350
Air velocities (m/s) at nozzle	15++	15++	15++
" " 1m away	13-15	13-15	13-15
" " 3m away	5-6	8-10	6-7
" " 6m away	3-4	3-5	3-4
" " 9m away	1-3	2-4	1-3
Noise level (at operators ear)	107dB	106dB	99dB

A1.2 Flow rate and spread factor

	Average readings	Spread factor
Wambo 50cc (air shear)	33.3ml/sec	0.60
Wambo 50cc Charged disc	0.58ml/sec	0.56
Wambo 50cc Uncharged disc	0.53ml/sec	0.56
Solo 35cc Charged disc	0.25ml/sec	0.50
Solo 35cc Uncharged disc	0.25ml/sec	0.50

A1.3 Horizontal projection

(a) Uvitex deposits (ng/cm^2)

	Distance from Sprayer nozzle (m)												
	3	4	5	6	7	8	9	10	11	12	13	14	1
Gaseous	5.4	4.0	3.5	3.0	2.7	2.5	1.5	1.5	.15	.1	.1	.07	.
Charged disc (Wambo)	7.5	6.5	5.1	2.5	2.1	1.2	0.7	0.5		-	-	-	
Uncharged disc (Wambo)	5.2	3.5	3.0	1.2	0.8	0.8	0.5	0.4	-	-	-	-	
Charged disc (Solo)	8.0	7.0	5.0	2.5	2.0	1.2	0.8	0.5	-	-	-	-	
Uncharged disc (Solo)	5.0	4.0	3.5	1.0	0.9	0.7	0.4	0.3	-	-	-	-	

(b) VMD distribution (µm)

	Distance from Sprayer nozzle (m)												
	3	4	5	6	7	8	9	10	11	12	13	14	15
Gaseous	166	169	164	164	155	153	154	153	119	119	95	95	90
Charged disc (Wambo)	74	74	72	72	60	52	53	53	51	-	-	-	-
Uncharged disc (Wambo)	78	78	75	68	67	62	57	55		-	-	-	-
Charged disc (Solo)	71	70	65	47	42	38	39	38	38	-	-	-	-
Uncharged disc (Solo)	61	59	42	40		35	33	34	32	-	-	-	-

Appendix Table 1 (Continued)

A1.4 Vertical projection

(a) Uvitex deposits (ng/cm²).

	Height above ground (m)					
	3	4	5	6	7	8
Gaseous	3.3	3.0	2.3	1.3	0.8	0.6
Charged disc (Wambo)	7.7	4.5	2.5	2.2	1.2	0.6
Uncharged disc (Wambo)	4.8	3.1	2.0	1.7	0.5	6.3
Charged disc (Solo)	9.5	7.0	4.0	3.0	1.5	-
Uncharged disc (Solo)	5.0	3.5	2.5	2.0	0.9	-

(b) VMD distribution (μm)

	Height above ground (m)					
	3	4	5	6	7	8
Gaseous	-*	166	152	137	130	130
Charged disc (Wambo)	90	90	76	66	60	60
Uncharged disc (Wambo)	89	78	77	75	68	52
Charged disc (Solo)	79	69	46	38	38	
Uncharged disc (Solo)	60	55	53	43	44	

* = saturated

A1.5 Apple tree measurement

	Red victoria	Keswick codling
Height of tree (m)	6.0	3.9
Height of canopy from ground (m)	2.8	1.6
Height of canopy (m)	3.2	2.3
Width of canopy (m) N-S	6.0	4.0
Width of canopy (m) E-W	5.5	3.5
No. of branches	9	5
Leaf area (cm²) bud burst	11.9	13.7
Leaf area (cm²) full canopy	33.8	27.8

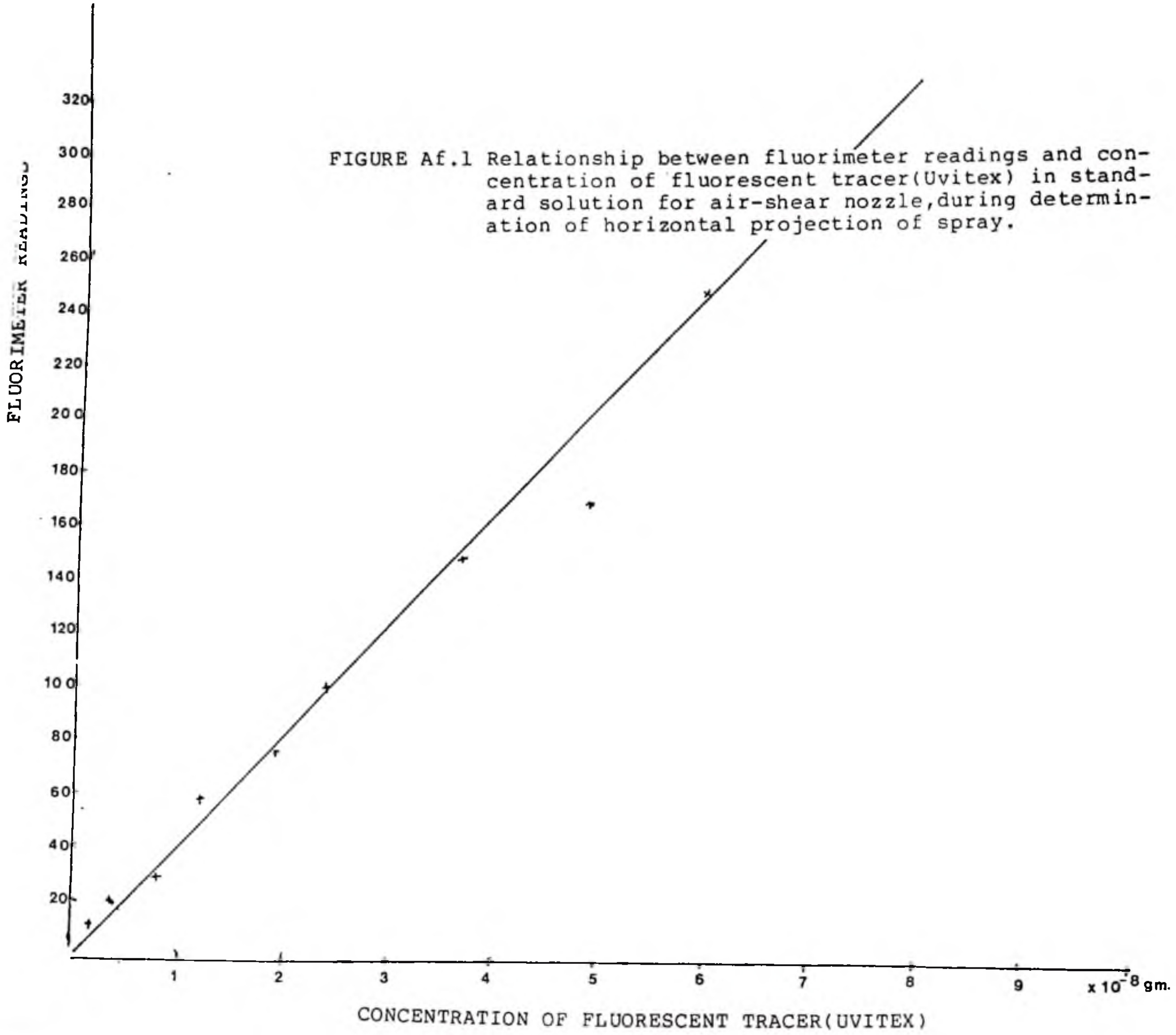
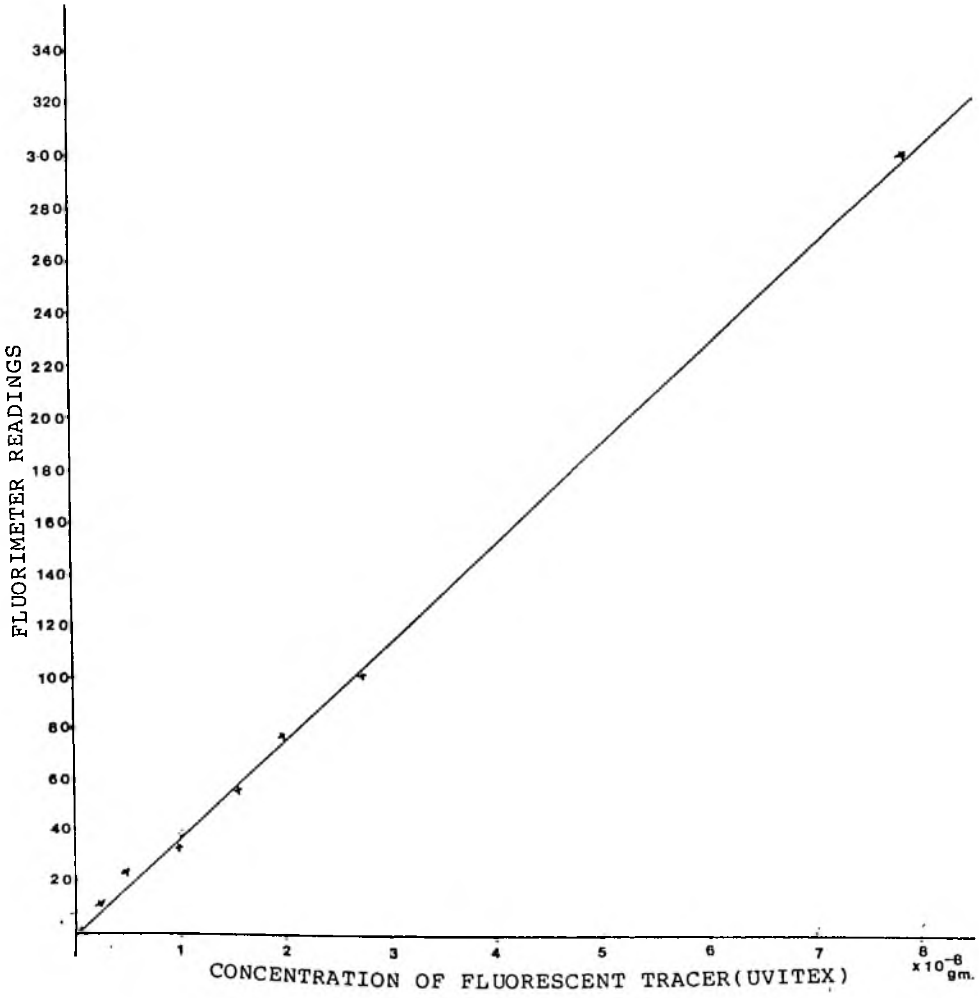


FIGURE Af.1 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in standard solution for air-shear nozzle,during determination of horizontal projection of spray.

FIGURE Af.2 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in standard solution during horizontal projection determination of spinning discs(charged and uncharged).



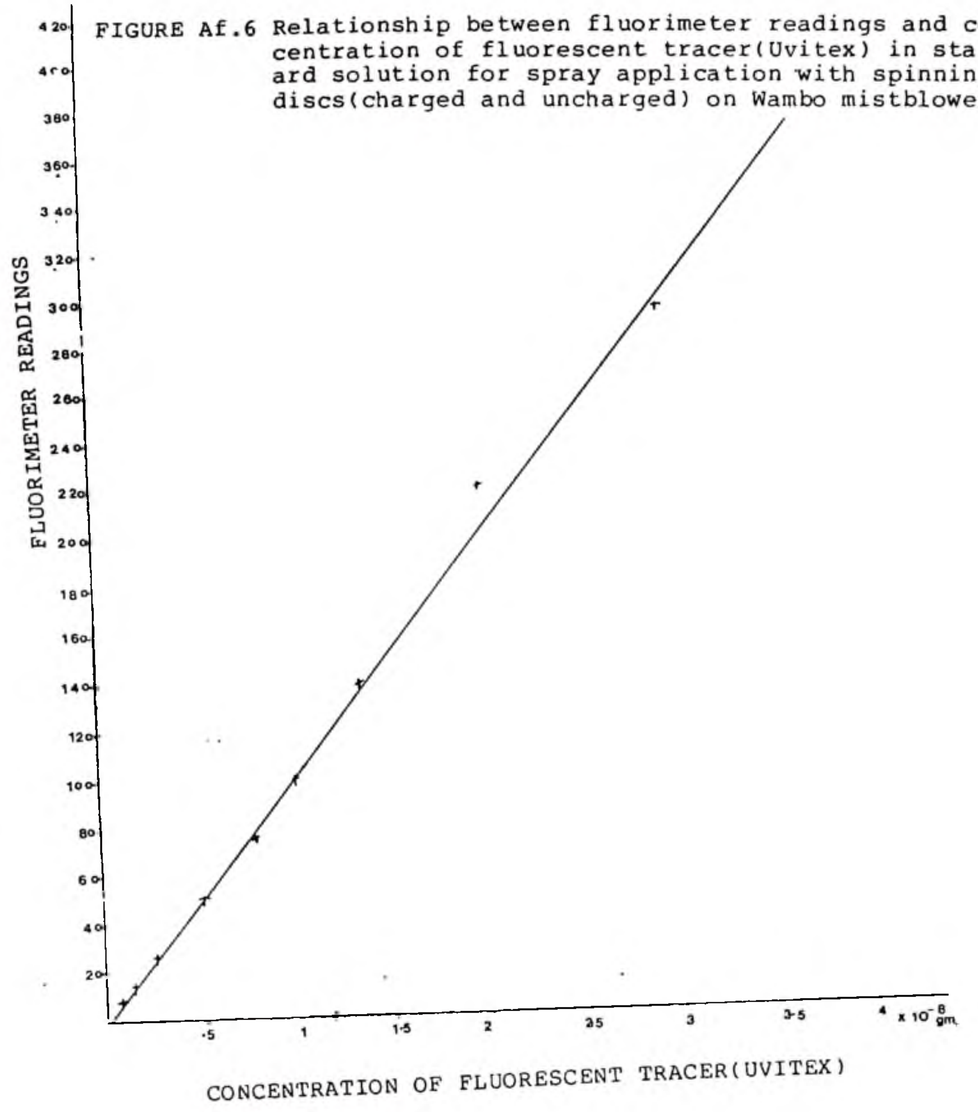


FIGURE Af.6 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in stardard solution for spray application with spinning discs(charged and uncharged) on Wambo mistblower.

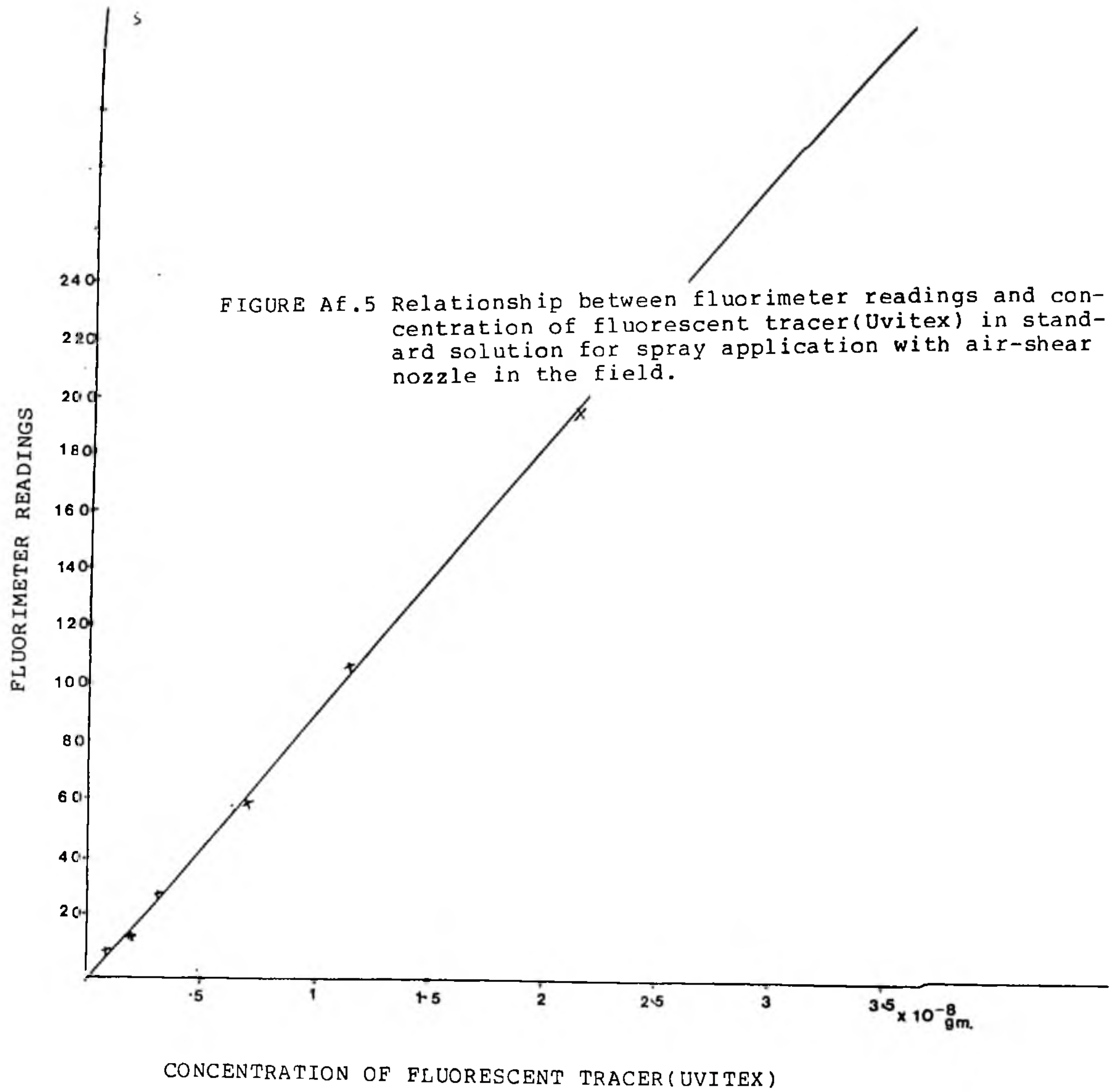


FIGURE Af.5 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in standard solution for spray application with air-shear nozzle in the field.

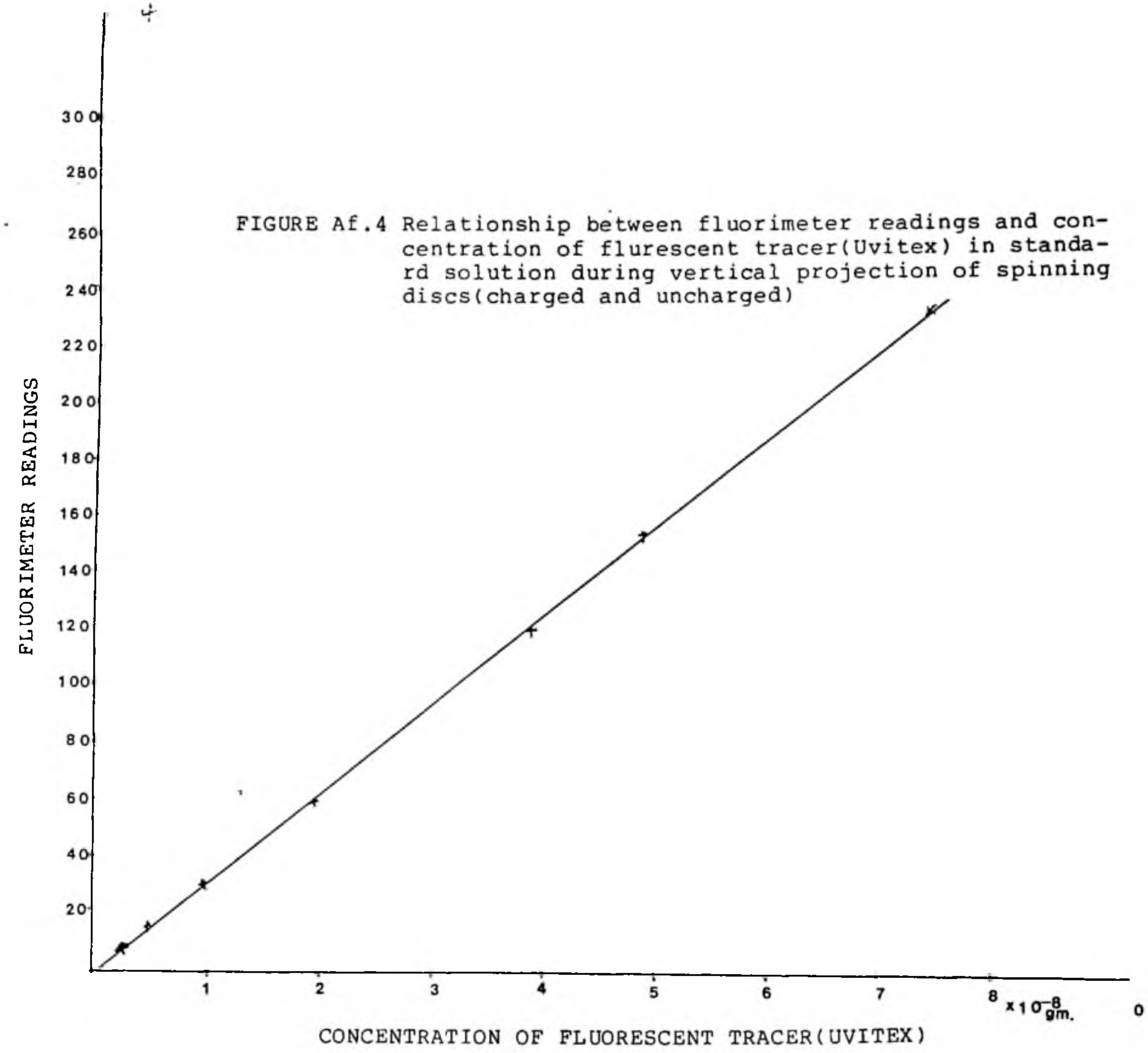
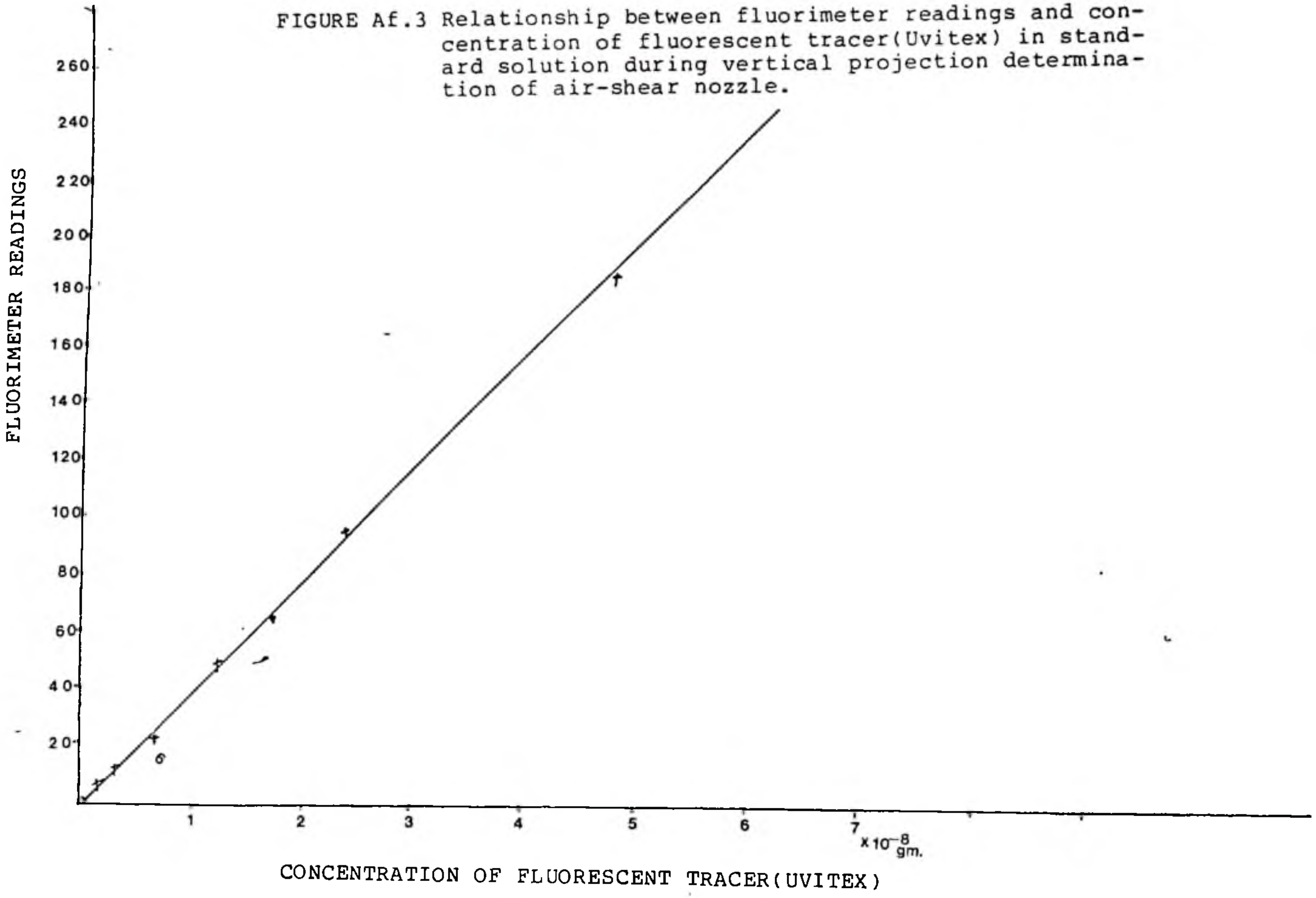


FIGURE Af.4 Relationship between fluorimeter readings and concentration of flurescent tracer(Uvitex) in standard solution during vertical projection of spinning discs(charged and uncharged)

FIGURE Af.3 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in standard solution during vertical projection determination of air-shear nozzle.



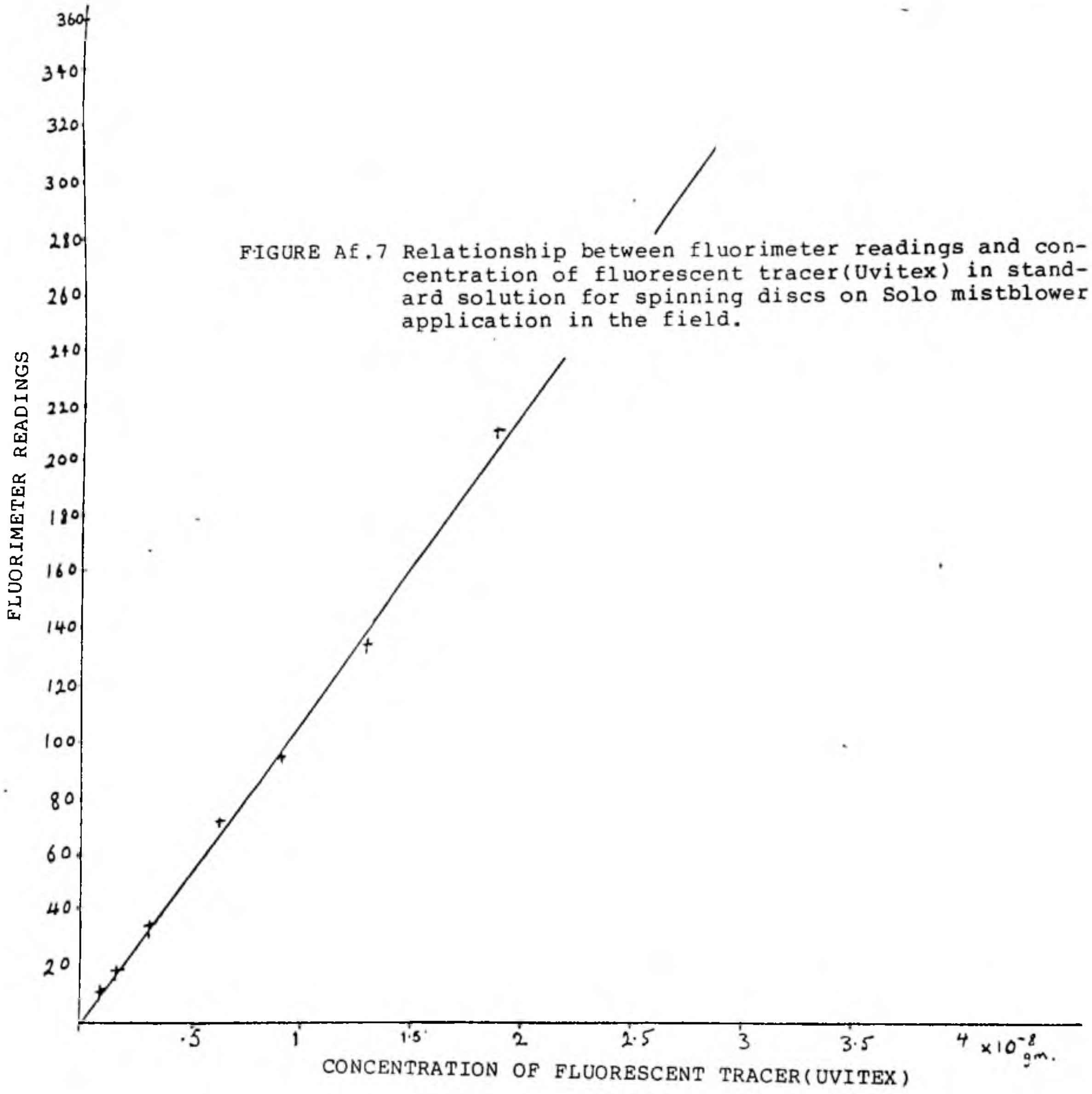


FIGURE Af.7 Relationship between fluorimeter readings and concentration of fluorescent tracer(Uvitex) in standard solution for spinning discs on Solo mistblower application in the field.

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