CONTROLLED DROPLET APPLICATION OF PARTICULATE SUSPENSIONS OF A CARBAMATE INSECTICIDE.

by

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ABSTRACT

Three distinct strategies for applying insecticides with hand-held rotary atomisers were identified: Ultra Low Volume (ULV) spraying of oil-based (UL) formulations, water-based CDA using very low volume application rates and water-miscible formulations, and modified water-based ULV application using molasses or other evaporation retarding adjuvants. Thiodicarb is virtually insoluble and must be sprayed as a particulate suspension, a property it shares with certain other biologically specific insecticides. The application of these formulations with rotary atomisers was therefore investigated, assessing especially their suitability for smallholder farmers.

Oil-based ULV suspensions (SUs) with a practical storage stability were more viscous than conventional UL formulations, and their flow through many commercial rotary sprayers was unacceptably low. Bimodal droplet size distributions occurred with UL formulations and aqueous mixtures containing pure molasses atomised at low disc speeds and flow rates. Liquids containing particulate matter were often atomised into unimodal, narrow droplet spectra at equivalent settings. Under normal operational conditions, sprays produced by different aqueous fluids had average droplet diameters that were little different from one another. The addition of surfactants, suspended particles and molasses, caused small but significant reductions in spray size. Disc speed is more important than other factors, unless they cause transitions between modes of atomisation.

During field trials in Zimbabwe, all sprays applied to cotton crops were in response to egg thresholds. Differences in formulation, dosage and droplet size of thiodicarb, applied at full (approximately 400 g.a.i./ha.) and half the recommended mass

application rates, did not significantly affect insect mortality and crop yield, even after heavy Heliothis oviposition. During similar trials in Malaŵi, halving the dosage rate always significantly reduced the yield. Oil-based thiodicarb formulations generally performed well; however efficacy was impaired at one site, when applied as a spray of approximately 100µm rather than 70µm VAD, at 1 l/ha. The numbers of bollworm larvae often accounted for yield differences, but control of sucking pests including Paurocephala was also important. No significant biological differences were detected between the performances of two water-miscible formulations (suspension concentrate and water dispersible granules).

Water-based CDA obviates problems of low stability and high viscosity associated with SUs, and provides smallholders with a versatile, reliable and cost-effective method of crop protection, but wear of atomisers is increased. Apparatus was therefore developed for assessing the durability of spinning disc sprayers.

Key Words

CDA, thiodicarb, cotton, IRM, rotary atomisation, particulate formulations, droplet sizing, sprayer durability.

To my parents, John and Kathleen, in memory of all their love and encouragement; and to my ludic friend Eric Turner, who was unable to chuckle over the gaffes in later drafts of this thesis.

To Mai,

Một hai nghiêng nước nghiêng thành,
sắc đành đòi một tài đành họa hai.
Thông-minh vốn sẵn tĩnh trời,
pha nghề thi họa đủ mùi ca ngâm. §

and to Victoria and Michael.

§: Nguyễn Du (1765-1820) Truyện Kiều.

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LIST OF ABBREVIATIONS

ADV: Volume of droplet represented by VAD in pico-litres (pl.)

a.i.: active ingredient

CDA: Controlled Droplet Application

C.V.: Coefficient of Variation

d.a.e.: Days after (cotton) emergence

DF: Degrees of freedom

IPM: Integrated Pest Management

IRM: Insecticide Resistance Management

$l.s.d._{95}$: Least significant difference (p = 0.05)

n./a.: not assessed

NMD: Number Median Diameter (µm.)D(n,0.5): approximated by D(1,0)

PSA: Particle size analyser

r: correlation coefficient (linear)

r.p.s. = $rev.s^{-1}$: revolutions per second (i.e. R.P.M./60)

RSM: Red spider mites

ULV: Ultra Low Volume (less than 5 l./ha. for field crops)

VLV: Very Low Volume (5-50 l./ha.)

VAD: Volume Average Diameter (µm.): D(3,0)

VMD: Volume Median Diameter (µm.): D(v,0.5)

Formulations

Throughout this thesis formulation names have been standardised to those listed in GIFAP monograph No. 2 (1984 revision). The text refers to the following:

EC: Emulsifiable Concentrate

SC: Suspension Concentrate (equivalent to FW: "Flowable")

SU: Ultra low volume Suspension

UL: Ultra low volume Liquid

WG: Water dispersible Granules (equivalent to DF: "Dry Flowable")

WP: Wettable Powder

Species Names

Current scientific names have been used wherever possible. Many taxonomists now refer to Heliothis as Helicoverpa although there has been considerable confusion in the nomenclature of this genus (Nye, 1982). Since Heliothis is more familiar to most field workers, it has been used throughout this text.

Measurements

Units used in this text mostly conform to the Systeme Internationale (SI). Rotational speeds of discs are given in $rev.s^{-1}$ for practical reasons (see section 2.2.) rather than $radians.s^{-1}$, or the more familiar R.P.M. Although flow rates should strictly be given in $ml.s^{-1}$, they have usually been expressed here in ml. per minute, being more practical for the normal range of rotary atomisers and familiar to field workers.

CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

Hand-held spinning disc sprayers, for Controlled Droplet Application (CDA) of insecticides, have been in field service for over twenty years, and are now used extensively for cotton growing in Africa. Centrifugal energy nozzles (or rotary atomisers) provide a reliable means of producing uniform (monodisperse) droplets, the size of which can be adjusted by the rotational speed of a spinning disc or cup, therefore enhancing the efficacy of applying minimal volumes of pesticides. CDA, with its emphasis on droplet size, is not strictly synonymous with Ultra Low Volume (ULV) spraying, which for field crops is usually understood to mean less than five litres of spray are applied per hectare (Bals, 1975; Matthews, 1979).

Early developments with CDA included the application of carbaryl, dimethoate and organochlorine insecticides (Matthews, 1973), but during the past decade it has increasingly been associated with the application of pyrethroid insecticides (e.g. Cauquil, 1985). Contact toxicity is an important mode of action for all of these chemicals, and few show any substantial selectivity in the groups of insects killed. They can be dissolved in organic liquids, to prepare oil-based ULV (UL) formulations that do not require mixture with water. It has been especially straight-forward to make UL formulations of pyrethroids since relatively small quantities of active ingredient are required. However there is widespread concern about the use of these highly active compounds due to development of insecticide resistance in some areas.

Thiodicarb is a carbamate stomach poison with a demonstrably

specific action (see section 1.7.2.), making it appropriate for integrated pest management (IPM) programmes, which aim to minimise deleterious effects of insecticides to natural enemies. It is virtually insoluble in water and organic solvents normally used to prepare UL formulations, and is therefore most economically sprayed in the form of particulate suspensions. Certain other insecticides have similar properties including: some carbamates (e.g. MIPC), acyl-urea chitin inhibitors, bacterial and virus preparations. With a growing perception of the importance of IPM, there is a need to investigate spray characteristics and other implications of applying particulate suspensions with rotary atomisers. Formulations of thiodicarb provide such an opportunity, and particular attention has been paid to their suitability for small-scale farmers in African cotton-growing countries.

1.2. ROTARY ATOMISATION: GENERAL PRINCIPLES

1.2.1. Modes of Liquid Disintegration

Johnson and Walton (1947) were amongst the first to note that the homogeneity of droplets produced by liquids fed at low flow rates to spinning discs. Previous investigators had concluded that droplet distributions were comparable to those produced by hydraulic nozzles - probably because liquid flow rates were too high and caused what was later known as sheet formation. Walton and Prewett (1949) defined a formula for deriving the droplet size (d) from the diameter (D) and angular velocity (w) of the atomiser, together with surface tension (γ) and density (ϱ) and a constant (k); this was measured as 3.8, being a mean value for various liquids and rotational speeds:

$$d = k \cdot \frac{1}{w} \cdot (\gamma/D\varrho)^{\frac{1}{2}}$$

Although Walton and Prewett have commonly been credited with this formula, Friedman et. al. (1952) point out that it is very similar to one reported by Bär, who worked in Germany in the 1930s, and produced a value of k that was 22% higher. All these authors considered that the most important and controllable factors that determine the size of droplets produced are the mechanical forces exerted on the liquid at the edge of the disc, and that surface tension and density of the liquid play a relatively minor role in determining droplet size. Viscosity was not thought to be a major factor, although Walton and Prewett observed that higher viscosity liquids produced an increased proportion of satellite droplets, and reduced the maximum flow rate at which homogeneous drops are formed. They did not observe any differences in droplet size with various profiles at the edge of the spinning top, however Frazer (1958) found a variation of up to 13%. This early data was based on measurements of the main droplets, and the smaller satellite droplets were ignored. A further discussion on droplet size will be found in chapter 2.

Hinze and Milbourn (1950) identified three types of disintegration that took place beyond the edge of a spinning cup. As flow rate increases, a transition takes place between the formation of:

i. single droplets,

ii. ligaments,

iii. a single film (or sheet) of liquid.

They examined the factors that influence transitions between these phases both experimentally and theoretically: especially those of ligament and sheet formation.

1.2.2. Single Droplet Formation

Frazer (1958) clarified Walton and Prewett's formula, giving the droplet diameter in μm, and a value for k as 6000 when disc

speeds are expressed in rev.s^{-1}. Bals (1970) simplified the relationship for the 87mm. diameter plastic discs used on the small hand-held rotary atomisers then in production:

$$d = 600{,}000/R.P.M. \text{ (or } 10{,}000/rev.s^{-1})$$

Bals (1970) also provided a rationale for moulding 360 half-pyramidal teeth or zero issuing points onto the periphery of these discs, particularly when applying very small volumes to produce single droplets. By minimising the surface from which the liquid was atomised, smaller droplets could be produced for a given force (i.e. rotational speed) and the risk of forming satellite droplets was reduced. Subsequently, discs were designed with radial grooves to feed each tooth evenly with liquid, and this significantly increased the flow rate at which transition to ligament formation occurred. When the atomisation of a flat toothless disc was compared with a similar study on a "Herbi" disc (Lake et. al., 1976), Frost (1978) observed that flow rate might be increased five times.

Sprays produced by single droplet formation are the most homogeneous of the phases of rotary atomisation (Boize and Dombrowski, 1976), and this is exploited principally with herbicide sprayers, where it is important to eliminate satellite droplets that are prone to downwind drift. In contrast, rotary atomisation of insecticides at normal flow rates is usually by ligament break-up. Small single cup rotors, such as the 55mm. "Mini Ulva", were developed to produce fine droplets but they are incapable of producing sprays with VMDs of less than 40 μm. under normal operating conditions (Johnstone and Johnstone, 1976). In order to generate fine aerosol droplets, (<25μm), very high disc speeds (>400 rev.s^{-1}) with very low flow rates (<0.5 ml/min.) are needed to ensure single droplet formation (e.g. Latigo, 1983).

1.2.3. Transition Between Single and Ligament Droplet Formation

The forces acting on the periphery of a spinning disc are proportional to its rotational speed and for a given liquid, the transition from single droplet to ligament formation therefore decreases with increasing disc speed and flow rate. Thus there is an optimum flow rate for a given rotational speed which decreases as speed increases. Hinze and Milborn (1950) listed the following factors which promote a transition from single to ligament formation:

1. increased flow rate (Q)
2. increased angular speed of cup (w)
3. decreased cup diameter (D)
4. increased density of liquid (ϱ)
5. increased dynamic viscosity of liquid (μ)
6. decreased surface tension of liquid (γ)

Boize and Dombrowski (1976) used high speed photography to study the effects of flow rate, disc speed and viscosity of four oils delivered to a Micron 'Ulva' at flow rates ranging from 0.125 - 4.0 ml/s. They had interpreted Hinze and Milborn's data to determine the transition between single droplet and ligament formation as follows:

$$\frac{Q}{D} \cdot \left\{\frac{\varrho}{\gamma D}\right\}^{0.5} \cdot \left\{ wD \cdot \left(\frac{\varrho D}{\gamma}\right)^{0.5} \right\} \cdot \left\{ \frac{\mu}{(\varrho \gamma D)^{0.5}} \right\}^{0.167} = k_t$$

(Single droplet formation should occur when $k_t < 4.55 \times 10^{-3}$.) They found this relationship inappropriate when they compared expected lines with data obtained for the 'Ulva' atomiser. Generally ligaments predominated at higher disc speeds and flow rates, irrespective of the liquid. Dombrowski and Lloyd (1974) noted that, as flow rate is increased to near the point where

transition into ligaments occurs, satellites increase in both size and number.

1.2.4. Ligament Formation

Hinze and Milbourn (1950) stated that the number of ligaments formed on the periphery of a smooth cup may be affected by the six factors listed above and the shape (cone angle) of the cup itself. They considered the main variables to be: flow rate, disc speed and liquid viscosity. Liquids of higher viscosity were observed to produce thicker ligaments. Boize and Dombrowski (1976) showed that longer ligaments were produced with liquids of higher viscosity. Maas (1971) also found a strong positive correlation between viscosity and droplet size in laboratory experiments, using hydraulic nozzles and emissions from a capillary tube in a flow of air.

Dombrowski and Lloyd (1974) showed that droplets separating from ligaments were typically accompanied by satellites and that the relationship between droplet size and operating conditions differed from that of single droplet formation. Boize and Dombrowski (1976) considered that above 25 $rev.s^{-1}$, flow rate and viscosity were "non-significant factors". Within a fairly broad range of flow rates and a small range of density and surface tension, droplet size diminished with increase of disc speed according to the following correlation:

$VMD = 0.0107/n^{1.09}$ metres $(= 10700/n^{1.09}\ \mu m)$: where $n = rev.s^{-1}$

They quoted rather large standard errors of +38.5% and -27.8%.

Heijne (1978) measured the droplet sizes of water and a wetting agent (0.1% Teepol), sprayed from a large cup with 180 teeth fed by grooves (Micron 'Battleship', equivalent to the 'Micromax'), using a Malvern particle size analyser; for a given

disc speed, larger droplets were produced as flow rates were increased up to 23 ml/s..

There appears to be a lower limit to the size of droplets produced by ligament formation. Spillman (1988) was unable to produce droplets of less than 100 μm. VMD with a 100 mm. disc fed at 2 ml/s., irrespective of the number of peripheral teeth. These measurements were carried-out using a Knollenberg PMS, and the actual droplet size limit should be considered with reference to sections 2.5.3. and 3.3.

1.3. ROTARY ATOMISATION OF PARTICULATE SUSPENSIONS

Sheets of liquid formed from flat fan nozzles disintegrate more rapidly if suspended particles are present in high concentrations or in a form that cannot be wetted; low concentrations of wetted particles have little affect on droplet size (Matthews 1979). Liquid formulations containing suspended particles are likely to be viscous, with non-Newtonian flow characteristics (see Appendix I). Matsumoto et. al. (1985) modelled the rotary atomisation phase transitions of emulsions and a suspension, and noted that there are few detailed studies on the atomisation of non-Newtonian liquids, although some authors have referred to such effects.

The physical properties of various formulations, including some pseudoplastic particulate suspensions, have been studied by Sundaram et. al. (1987a & 1987b) using rotary cage (Micronair AU 5000) equipment. There was generally a strong positive correlation between apparent viscosity and the size of droplets recovered on Kromekote cards. Comparison between oil- and water-based formulations of hexacarbate corroborated this trend,

although volatility was considered the most important factor affecting droplet recovery. Application of highly viscous Newtonian formulations produced spray deposits with very wide droplet spectra, and high proportions of droplets greater than 200µm, whereas the narrowest spectra were recovered from sprays of a clear light oil and Dipel 88: a pseudoplastic suspension of Bacillus thuringiensis (Sundaram and Retnakaran, 1987). They concluded that the atomisation of pseudoplastic formulations is very suitable for ULV applications with rotary cage sprayers, but omitted to point out though that the recovered droplet density of the bacterial suspension was low, and this formulation appeared to produce one of the lowest volume recovery rates (using the method described in section 2.7. for analysis of their data).

The viscosity of a pseudoplastic fluid is high at very low shear rates but is reduced with agitation, so this enables the formulation to have good storage properties combined with a low working viscosity when applied through a nozzle. This might be useful for hydraulic nozzles and Micronair sprayers, where the liquid is delivered under pressure, but flow rate may be inadequate in gravity-fed spinning disc sprayers.

1.4. A REVIEW OF C.D.A. SPRAYING WITH HAND-HELD MACHINERY

1.4.1. History and Background

Rotary atomisation can be said to date from the last century when Lodeman (1896) describes an animal-drawn potato sprayer in which the pesticide mixture was gravity fed onto a pair of wide revolving brushes. Modern agricultural rotary atomisers are almost all derived from the work of E.J. Bals and have usually consisted of either rotating cages - such as the Micronair atomisers, usually mounted on aircraft - or hand-held sprayers with spinning discs or cups mounted on long handles and usually powered by batteries. This thesis will be concerned primarily with insecticide application by small spinning discs designed since 1968 when the Turbair X was first tested in the field.

Manual spraying is very tedious, time consuming and may cause considerable pesticide contamination. Farmers using hydraulic sprayers often have to transport up to 300 litres of water to their fields, although other members of the family often assist in this task. Innovations such as the knapsack and tailboom (Tunstall et. al., 1965), reduced pesticide exposure to operators in African cotton fields, because they could constantly walk away from the inter-row area they have just sprayed, although this device was designed primarily to improve distribution within the canopy and on the under-leaf surfaces.

High Volume manual sprayers are still commonly used and especially have a place where versatility and low costs are important (Matthews, 1989b). They are even undergoing a revival in Malaŵi, where the cost of "D" cells for ULV sprayers is becoming prohibitive; farmers may however be unaware of "hidden costs" involved in spare part supply (G. Nyirenda, pers. comm.).

Application at very- or ultra-low volumes of spray have enabled farmers to treat their crops effectively without using enormous amounts of time and effort. Spinning disc sprayers provide a means of reliably atomising liquids into relatively even-sized droplets, at very low flow rates, with tolerably lightweight machinery; only 0.5-15 l/ha. of pesticide mixture are normally needed to treat a crop. This method of insecticide spraying now can now be considered proven in the tropics, and is used extensively in many African cotton growing regions.

1.4.2. Controlled Droplet Application Techniques

1.4.2.1. Oil-based ULV

Many initial trials evaluated the efficacy of standard Ultra Low Volume spraying where 2-3 litres of specific oil-based (UL) formulations were typically applied per hectare (Maas, 1971, Matthews 1973, Beeden 1974). These studies usually compared ULV applications with hydraulic spraying, and there were no consistent differences between techniques where spraying had been carried out by the same operators. Morton (1973) however showed how significantly improved yields could be achieved when the new technology is accompanied by good technical support.

No further mixing of pesticide is required by farmers, and in this respect one hazard in the spray operation has been reduced, although many farmers risk contamination by refilling the sprayer container from a larger drum. UL formulations are often more readily absorbed through the skin than the wettable powders, and typically are approximately three orders of magnitude more concentrated than diluted sprays. If badly executed, ULV spraying may be more hazardous than conventional methods, but spray operators are trained to keep the atomiser

downwind, so that droplets drift away from them and into several rows of the crop. If the formulation is relatively non-evaporative, wide swaths are possible (achieving high work rates), especially when the plants are small. Pyrethroid-based ULV insecticide mixtures (oil based UL formulations which usually also contain organophosphates) are used throughout francophone West Africa. Attempts to lower costs by reducing volume application rates to 1 l./ha. involved atomising UL formulations into smaller droplets and widening swaths, but yields have sometimes proved less reliable, especially for control of sucking pests (Cauquil, 1987).

1.4.2.2. **Economics and the Water-based CDA Technique**

Several workers have noted that, at a given rate of active ingredient per hectare, ULs may be considerably more expensive than equivalent quantities of more conventional formulations (see below). The possibility of lowering the cost of CDA, by rotary atomisation of aqueous mixtures containing the cheaper wettable powder formulations, was examined in Malaŵi (Mowlam et. al., 1975), and subsequently in the Gambia (King, 1976). This technique was initially called water-based ULV or "WULV", but it has subsequently been referred-to as Very Low Volume (VLV) spraying since up to 16 litres of spray mixtures are applied per hectare to fully grown cotton. The technique uses narrower swaths and is effectively placement rather than drift spraying. The flow rate is increased to 90 ml/min. causing the atomiser disc to revolve more slowly, and thus produce larger droplets to reduce the effects of evaporation (Nyirenda, 1980). This "bucket-full of water per smallholding" is negligible compared with conventional knapsack spraying, but the battery consumption may be more than doubled.

Table 1.4.1.

Cost comparisons for CDA and Conventional Low Volume (CLV) techniques.

Country Ref.	Percentage of cost of technique compared with oil-based UL: **Total cost (§1)**	**Formulation**	Insecticides as % of total cost	Batteries as % of total cost
Malawi Huntington & Johnstone (1973)	"WULV" **74**	number of sprays: 8 12	8 12	
	DDT: **36**			
	carbaryl: **53**	UL: 78 84	5 3	
	dimethoate: **11** (§2)	"WULV": 56 64	12 9	
	(12 sprays, cash prices)			
Malawi Matthews (1973)	CLV **82** tailboom	**68**	UL: 76 CLV: 63	4 -
Malawi Mowlam, Nyirenda & Tunstall (1975)	"WULV" **57**	**44**	UL: 88	3
	CLV **62** tailboom (12 sprays)		"WULV": 68 CLV: 74	13 -
	(N.B.: CLV used 18% more chemical than "WULV")			
Botswana Morton (1973)	CLV **68** tailboom	**60**	UL: 90 CLV: 79	3 -
Zimbabwe Gledhill & Madende (1974)	MULV **91**	**88**	UL: 91	9
	CLV **98** tailboom (14 sprays)		MULV: 88 (§3) CLV: 91	12 9
The Gambia King (1979) Unpublished	"WULV" **80**	**62**	UL: 78 "WULV": 60	1 8
	(§4: 5 sprays UL vs. 19 sprays "WULV")			
Paraguay Morton (1981)	CLV **56**	**56**	ED:	1?
	(§5: vs. 'Electrodyn')		CLV:	-

NOTES

§1: Comparative cost of spray operation per hectare.

§2: Dimethoate UL formulation only available in 100 ml. bottles.

§3: Farm trials in Zimbabwe (Rhodesia): Molasses cost 0.8% of the total cost. Battery costs were combined with those of labour. Basic spray programme was of endosulfan and carbaryl; ULV plots also sprayed with triazophos rather than dimethoate for knapsack and tailboom.

§4: Comparison of 5 sprays of cypermethrin + dicrotophos UL formulation with 19 sprays in a DDT/carbaryl/dimethoate programme consisting of WPs in sachets applied as "WULV".

§5: "Insecticide costs" only, cypermethrin and dimethoate ED compared with "various pyrethroids and organophosphates".

Comparisons between application techniques have been made both in Malawi and elsewhere, and are summarised in Table 1.4.1. Huntington and Johnstone (1973) pointed out that "The most economic method of spraying is not necessarily the cheapest, but is the method that gives the highest margin of return over costs, i.e. the method which provides the most effective pest control and maximum increase in yield for the minimum expense." Both they and Matthews (1973) considered that the difference might be smaller when all aspects of the spray programme were calculated, but formulation costs are probably most apparent to many farmers. The cost of batteries has been cited as a constraint on spinning-disc spraying; "WULV" is particularly likely to increase farmers' awareness of this component, even when the technique as a whole is more cost-effective than ULV with oil-based formulations.

1.4.2.3. **The "Aquamol" Technique**

In Zimbabwe a modified ULV technique, referred-to as 'aquamol' or MULV spraying, was developed by adding cane molasses to aqueous mixtures as an adjuvant to reduce the effects of evaporation on droplets (Gledhill and Brettell, 1980). The first recommendations had been made in 1974 (Gledhill, 1975), where the use of molasses with ground-based CDA equipment was adapted from recommendations for aerial spraying. Adjuvants of this type are subsequently referred-to as "anti-evaporants".

The farmer may benefit as the maximum volume he need apply is about 5 l/ha., and because wider swaths are possible by drift spraying, the work-load and power consumption is lower than the ordinary "WULV" technique. Rather more detailed farmer training is needed because three components (insecticide, molasses and water) have to be measured, mixed, filtered and poured. Using this technique, more equipment is required compared to spraying

oil-based formulations. Debris in the molasses can easily cause blockages in the gravity-fed restrictor, so like ordinary water-based spinning-disc spraying, the spray mixture **must** be filtered to remove any large suspended particles. On the other hand, water-miscible formulations are easily washed off the sprayers and the farmer is not required to use paraffin or other cleaning materials which may be considered as an additional expense. The addition of molasses also enhances the activity of some insecticides, including carbaryl, by stimulating certain pests, including Heliothis, to eat the active ingredient (see 1.5.3.3.). The economic justification for this technique was similar to that of ordinary water-based spraying, and as molasses was originally considered virtually a "waste-product" in Zimbabwe, its use added less than 1% of spraying costs.

1.4.2.4. **The 'Electrodyn' Sprayer**

The 'Electrodyn' (R) sprayer was first announced by Coffee (1979), although the principle on which it is based was observed by Lord Rayleigh (1882), who reported that liquids subjected to high electrical charges were "thrown-out in fine jets" (ligaments). Monodisperse charged droplets could thus be produced, and with the advent of modern electronics and plastics it was possible to develop a system that sprays pesticides by this method. Because there are no moving parts, the energy required by the hand-held 'Electrodyn' (ED) sprayer is very low and thus alleviates problems due to the cost and availability of batteries. One set of four "D" cells can last for 60 hours (possibly a whole crop season); battery costs with rotary atomisers are typically at least three times higher. Apart from this advantage, it is primarily an achievement of functional design; it has been developed particularly for small-holder

farmer, being very robust and easy to use (Smith, 1988).

Because electrostatic forces impact droplets onto nearby foliage, it is essentially a method of placement spraying in its present form. Swath widths on cotton are typically 1-2 rows, and the actual spraying time is therefore comparable to the "WULV" technique, although less time is needed to prepare for spraying. Packaging pesticides in a "Bozzle" precludes mixing, measuring, pouring and much of the sprayer cleaning needed with other spraying equipment. The idea of supplying insecticides in individual containers that fit the sprayer was foreseen by E.J. Bals, but agrochemical companies have yet to commercialise a similar system for spinning disc sprayers in developing countries. Low volume application rates - which may be as little as 0.25 l/ha. - are achieved by very low liquid flow controlled by the air-bleed mechanism. Unfortunately the current range of pesticide products is limited and these are all oil-based solutions, packaged by one company (Matthews, 1989b).

1.4.3. Comparisons of efficacy

Comparisons of bollworm infestations and cotton yields, resulting from equivalent treatments with different but established application methods, have rarely shown conclusive differences (Matthews, 1973; Beeden, 1974; Matthews & Mowlam, 1974; Mowlam and Nyirenda, 1975; King, 1976; Gledhill et. al., 1975; Nyirenda, 1986). Significant differences have been difficult to obtain because of the non-uniformity of the crop, however it has often been possible to show contrasting yields due to other factors, especially: active ingredient and swath width. Claims of higher profitability for 'Electrodyn' (e.g. Morton, 1981) have assumed improved yields, which were probably mostly

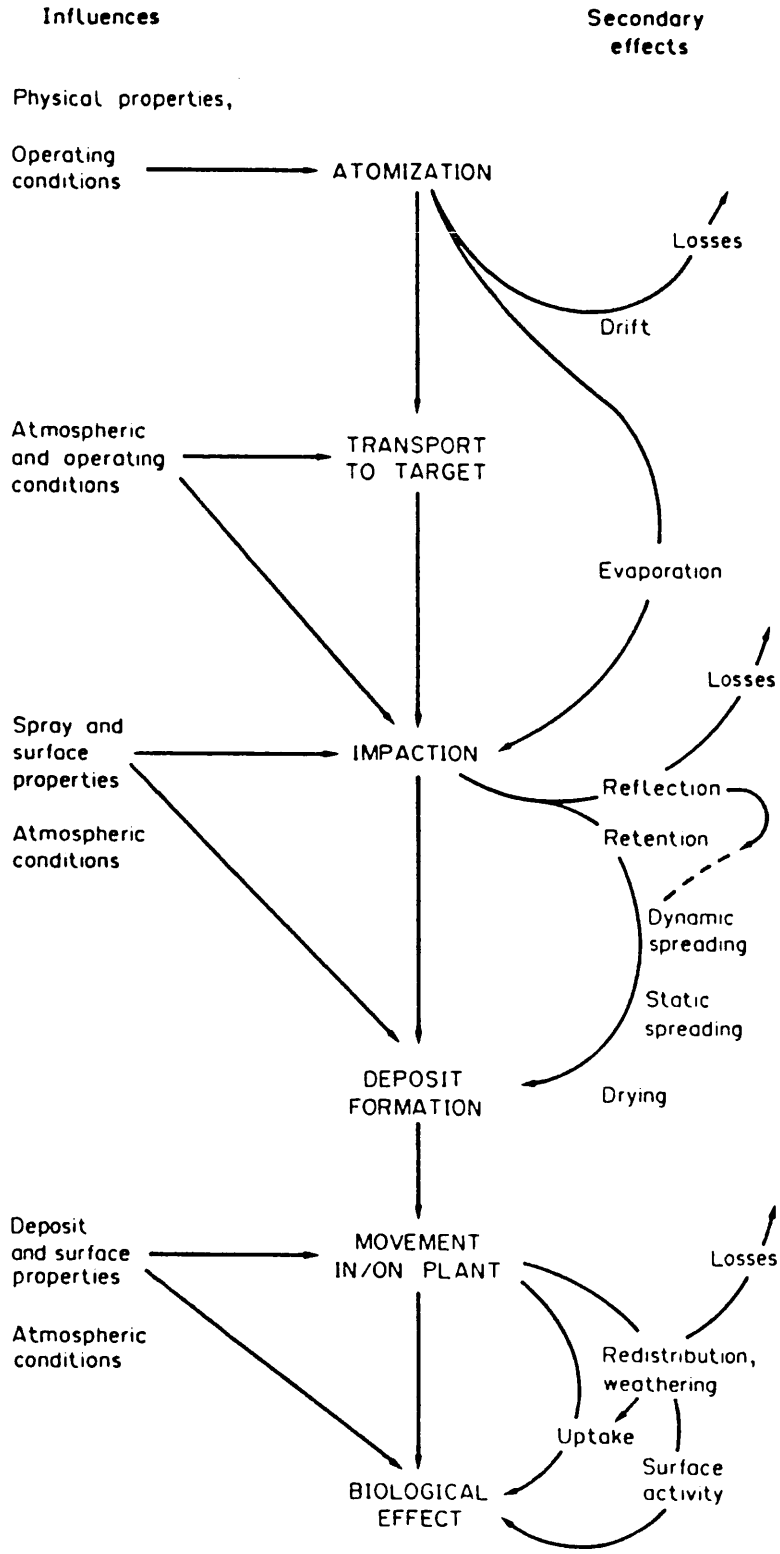
due to the accompanying extension effort. Nyirenda (1986) showed that cotton yields are generally comparable to those obtained using rotary and hydraulic atomisers, but poor insecticide penetration may give inferior control of pests such as Diparopsis and Dysdercus that reside lower in the crop canopy. Recent trials in Kenya have indicated however that effective Dysdercus control may be achieved with the 'ED' technique (Matthews pers. comm.).

1.5. THE TRANSFER OF INSECTICIDE TO ITS SITE OF ACTION

Some of the difficulties associated with comparison of field performance and detailed studies in the laboratory, have been reviewed by Merritt (1989). Young (1986) has illustrated the complexity of processes (Fig. 1.5.1.), and noted that changes in atomisation technology have taken place, with consequences to deposition efficacy that were "not adequately anticipated."

E.J. Bals (1969) stated that "The scientific work involved to determine the ideal droplet size for each purpose involves many thousands of permutations ... (which) have all to be taken into consideration - a lifetime task for a new generation of scientists and computers, to be completed sometime in the 21st century". It seems improbable that the "ideal" is an achievable goal, and it would be more practical to strive for robust compromises identifying the principal factors which govern droplet size.

Fig 1.5.1. The interactions of the spray application process. From Young (1986).



1.5.1. **Droplet Size and Efficacy**

Because of the relationship between droplet diameter and volume, there should be a cubic increase in numbers of droplets produced, proportional to any reductions of average diameter. Potts (1946) was one of the first authors to recognise the efficacy of smaller droplets. During early investigations into spraying pesticides, at higher concentrations and lower volumes than hitherto, he considered that the most appropriate sizes for ground application were 30-80 µm.. Bals (1975) discusses the concept of producing small uniform pesticidal droplets to achieve adequate control with "ultra-low dosage" combined with ultra-low volume. Graham Bryce (1977) elaborated on the relationships between dose, droplet size and efficacy, and exemplified the inefficiency of existing sprays with foliar treatments against sucking insects, where only 0.02 - 0.03% of the insecticide was utilised on the target. The most efficient dose transfer quoted was 6% for aerial spraying of locust swarms.

Himel (1969) was another early proponent of the efficacy of aerosols for efficient agricultural spraying, and suggested that droplets of a contact insecticide in the 20-30 µm. range were optimal for control of spruce budworm, and cotton pests including Heliothis zea. Having used a fluorescent tracer method to assess droplet recovery in the field, Uk (1977) considered that if most insecticidal activity against lepidopteran larvae is by direct contact action, the optimum range of droplets is likely to be 50 µm. or smaller, provided this was in the protected environment of the foliage.

Control of the glass-house whitefly, Trialeurodes vaporariorum was better with 18 µm. VMD droplets containing resmethrin, than with mists of 78 µm. (Mboob, 1975). Munthali

and Wyatt (1986) intensively studied droplet size and concentration of dicofol against Tetranychus urticae eggs on leaf discs, and demonstrated that 20 μm. oil-based droplets were most effective and the optimum concentration of active ingredient was approximately 1%. Reduction of droplet size has likewise been shown to improve the efficacy of a contact insecticide (permethrin) against mobile lepidopterous larvae. Reay and Ford (1977) demonstrated 80 μm. droplets produced higher mortalities of Spodoptera littoralis than those with a mean diameter of 120 μm. Omar (1987) not only showed that activity against Plutella xylostella was optimal at the smallest size assessed (50 μm.), but as with Tetranychus, knockdown doses may be minimised with low concentrations of UL formulations.

These laboratory and glass-house observations have not always been borne-out elsewhere, especially during field trials. Matthews (1973) compared the efficacy of ULV sprays against bollworms, with swath widths of 1,2, and 5 rows (0.9 - 4.5 m.), and the concentration adjusted to give equivalent mass application rates; he concluded that total dosage was the most important factor, provided that droplet density was not seriously reduced. Smith et. al. (1976) assessed the performances of monodisperse droplets containing Bacillus thuringiensis against Trichoplusia ni and Baculovirus heliothis against Heliothis zea. The correlations between mortality and mass application rate were much higher than for concentration, droplet density or droplet size (between 90, 180 and 270 μm.), although it was significantly less advantageous to use the largest size. Although surveys have been made of the quality of sprays produced by new rotary atomisers (Arnold, 1983), no references were found indicating that biological efficacy was adversely affected by differences

due to the quality of their construction or maintenance. Since high volume knapsack and tailboom spraying has often given superior control than ULV spraying with wide swaths (e.g. Matthews, 1973), optimising crop coverage perhaps remains the most important practical aim for control of many pests.

1.5.2. Size of Droplets and their Transport to the Crop

Droplet size may be especially important where evaporation affects the recovery of droplets containing water, although the total surface area of a spray is inversely related to droplet diameters by the same order of magnitude (see Appendix IIa). Detailed studies similar to those developed by Pickin et. al. (1980) for water-based CDA on rice have yet to be carried-out on cotton.

Apart from its influence on evaporation and convection, wind speed essentially has two effects on droplet deposition. Firstly a cross wind is needed to distribute droplets across the swath, but not severe enough to cause the spray to drift out of the area to be treated (exo-drift). The normal recommendation is to spray when wind speeds are in the range of 3-15 km./hour (1-4 m /s.: Anon, 1975).

Small droplets with diameters of <40µm. require increasingly strong air velocities in order to impact on even the smallest of targets, (May and Clifford, 1967). Wind strength significantly affects the deposition of particles with diameters <150µm. (see Appendix III), but sedimentation forces become increasingly important with larger droplets, which are deposited predominantly on the upper surfaces of leaves at the top of the canopy. Droplets of approximately 20 µm. VMD require electrostatic charging as well as air assistance to achieve adequate impaction

and penetration on crops as shown with glasshouse-grown tomatoes by Adams and Palmer (1986).

1.5.3. Selection of Formulations and Droplet Sizes

1.5.3.1. Oil-based spraying

Oils have been chosen as carriers and diluents for ULV application because of their low volatility, so formulations can be atomised into much smaller droplets than with water-based sprays. Oil-based droplets are retained on water repellent surfaces such as insect cuticles and many plant surfaces, and being lipophilic, subsequent spread and penetration of the active ingredient is better than with water-miscible formulations. Although an oil formulation may be more rain-fast than a water-miscible formulation (Nemec and Adkisson, 1969), deposits of a contact insecticide may become less available to an insect walking over the plant surface if penetration occurs too rapidly; this effect may be reduced by application of formulations containing particulate active ingredients or high viscosity oils (Crease et. al. 1985).

Recent research has concentrated on the pyrethroids, which are very active at extremely low dosages. The small quantities that are needed dissolve readily in organic solvents and are relatively easy to prepare as UL formulations for spinning disc sprayers, and meet the more exacting Electrodyn (ED) specifications, for which viscosity and resistivity are within narrow limits.

1.5.3.2. Residual efficacy of water-miscible formulations

Ebeling (1963) reviewed early literature on the persistence of pesticides. Both he and other authors have considered that

residual deposits of wettable powders (WPs) are generally more efficaceous than emulsifiable concentrates (ECs). Where initial contact action is important however, better cuticular penetration into insects (aphids were commonly cited) could be achieved with the oil content of ECs. WPs may however be more repellent to insects, as Wildey (1981) found by placing the stored product pest Tribolium castaneum in two-choice arenas. Three reasons given by Ebeling for the superior residual activity of WPs against more active insects:

i. reduced loss of surface deposit due to penetration of plant cuticles,

ii. greater accumulation of deposits by pests because active material is transferred in discrete particles,

iii. sunlight more rapidly degrades or volatilises oils and solvents.

Pick et. al. (1985) found that a carbaryl WP was less rain-fast on cotton then two EC insecticides, however Matthews and Tunstall (1966) found no significant differences in yields after spraying with both formulations of DDT and endosulfan in Malaŵi. They wished to replace DDT EC with a micronised wettable powder formulation in order to reduce the risk of phytotoxicity, and to standardise on packaging pesticides for small-holders.

1.5.3.3. **Water-based CDA and "Aquamol" Spraying**

As with hydraulic spraying, these techniques require measurement and mixture of pesticides. Dry formulations such as wettable powders are especially difficult to measure in the field, so Malaŵian farmers were provided with sachets containing sufficient for one 15 l. knapsack sprayer load (Gower and Matthews, 1971); this system subsequently worked equally well with 1 l. spinning disc sprayer bottles. The efficacy of a

pesticide may be affected by water quality; bore-hole water can be especially alkaline (occasionally reaching pH 10) and more work may be required on developing formulations with appropriate buffers for these special conditions (Bennett, 1980). A water sample with a pH of 8.1 was reduced to 5.8 on addition of 10% molasses (Gledhill and Brettell, 1980).

In Zimbabwe, a concentration of 15-25% molasses was initially selected but this recommendation was later adjusted (to a maximum of 35%), so that all formulations gave a standard flow rate of 60 ml/min. with the Taurus Hi-spin. The viscosity of molasses may however be variable, consequently affecting the flow rate. The minimum concentration needed to stabilise droplet size was considered to be 12.5% as molasses is virtually non-volatile, and 1/8th of the total spray volume results in the diameter of spray droplets being reduced by no more than half their original diameter (Gledhill and Brettell, 1980). Spillman (1988a) found that droplets of aqueous 10% molasses initially evaporate at the same rate as pure water, but this abruptly stops before the overall concentration has increased by 20%; he thought that this was due to an in-flight encapsulation process, where the molasses forms a viscous, non-evaporative skin around each droplet.

The primary function of adding molasses to CDA sprays was to minimise the effects of evaporation, but several workers had previously shown that molasses enhanced the activity of certain insecticides. Carbaryl was considered to have very little effect against Heliothis, but the addition of molasses to hydraulic sprays significantly improved control (Lincoln et al., 1966, Tunstall, 1968, Matthews, 1972). Increasing the concentration of molasses up to 20% caused a progressive reduction in the number of larvae and percentage of damaged seed cotton and an increase

in moth mortality and yield (Tunstall, 1968). There are conflicting reports about the degree of enhancement when molasses is added to organochlorine insecticides. Tunstall showed a small but insignificant improvement in yield with the addition of 10% molasses to DDT, while trials in Kadoma (Anon., 1972) showed a marked decrease in the number of Heliothis armigera larvae, when the concentration of molasses in endosulfan was increased. Nemec and Adkisson (1969) could not improve rainfastness by adding molasses to monocrotophos; but in previous reports they had demonstrated an increased residual toxicity of methyl parathion to H. zea, although this may have been due to ULV application (Nemec et. al., 1968). Rain is often considered the most severe of the weathering agents, although this depends much on the nature of the formulation (Ebeling 1963,). Pick et. al. (1985) also found considerable variations between formulations, and showed that rainfastness increased over a period of time after spraying cotton.

Tunstall (1968) reported that molasses did not cause phytotoxicity or encourage the growth of sooty moulds, however it may have adverse effects on the properties of spray mixtures, especially in humid environments. Insecticide deposits recovered on bean leaves were reduced with higher molasses concentrations and the wetting time of carbaryl WP was increased (Abbott, 1986). In some regions, cane molasses is no longer readily available, as it is now used in the production of ethanol. Concentrated molasses solubles (CMS) is the residue from ethanol production, and it has been proposed as an alternative (Jowah, 1983).

1.5.3.4. **Addition of other anti-evaporants.**

"Lovo" (an amine stearate adjuvant) was found to effectively preserve droplets in-flight and considerably increased the adhesion and rainfastness of copper oxychloride and carbaryl deposits (Amsden, 1962). Matthews (1966b) showed that 2% "Lovo 190" mixed with 0.5% technical carbaryl, produced a 58.3% mortality of Dysdercus after the equivalent of one inch (25 mm.) of rain, whereas without this adjuvant, carbaryl was inactivated by weathering. A highly micronised wettable powder formulation was found to be reasonably effective, and eventually recommended. "Lovo" was not commercially successful partly because it made machinery difficult to clean, but principally because it was only suitable for mixture with technical material, as rainfastness was neutralised by surfactants present in formulated products.

Other anti-evaporants have been commercial products based on oils mixed with emulsifiers, which have other putative adjuvant properties. Taylor (1983) demonstrated that rape-seed oil mixed with an emulsifier (marketed as "Codacide") could be applied either at ULV in an undiluted form or added to high volume sprays, improving the rainfastness and efficacy of bendiocarb against Plutella larvae. Wogadeneh and Matthews (1981) showed that the addition of 20% mineral oil ("Ulvapron") increased the number of droplets recovered downwind across the swath.

1.6. COTTON PEST MANAGEMENT IN CENTRAL SOUTHERN AFRICA

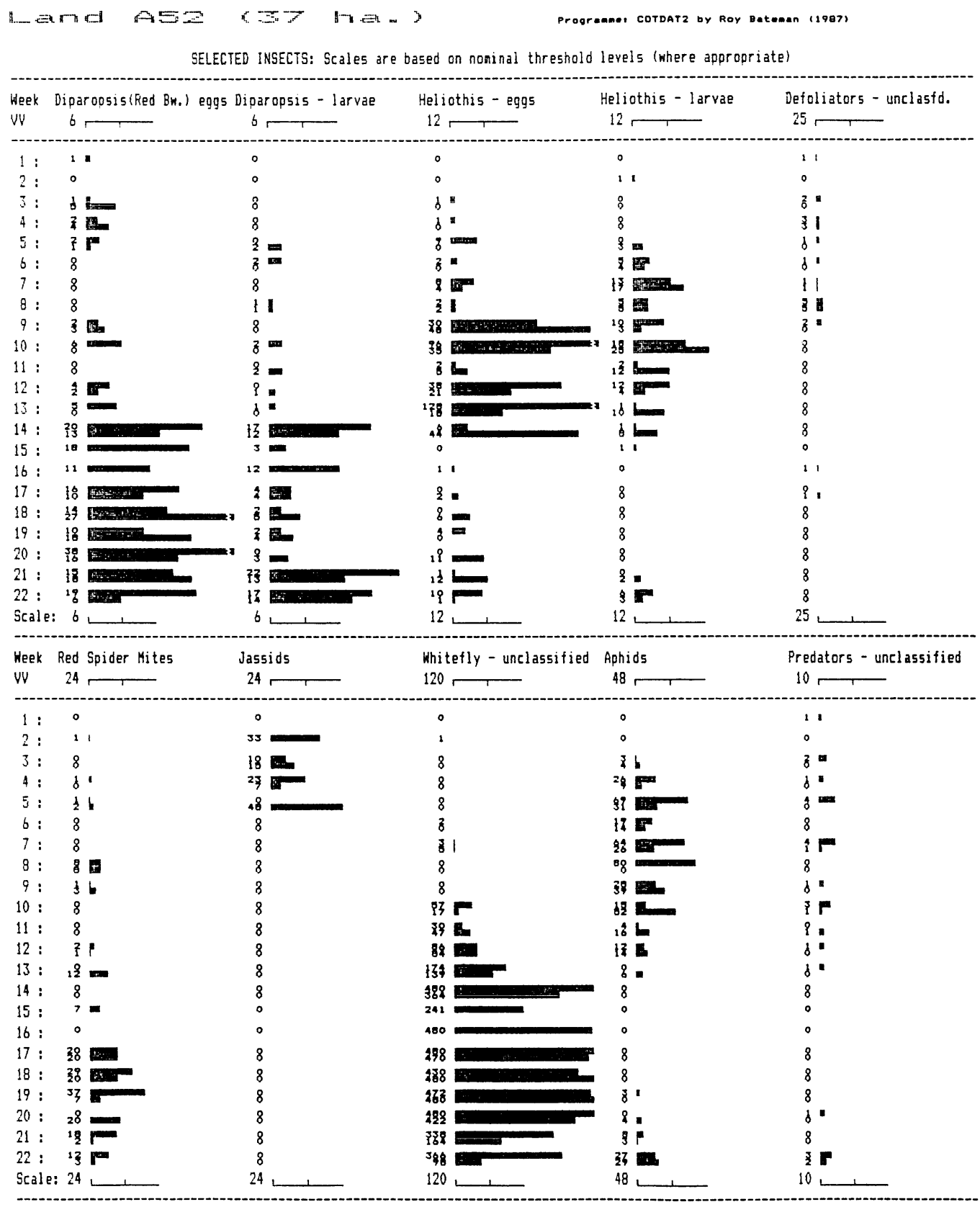
Insect pests are a major cause of yield loss on cotton, and natural enemies provide only a limited control. There seem to be no major success stories of "classic" biological control programmes working on this crop (Greathead, 1988), however Matthews (1988) reviews several cases of inappropriate pesticide usage, where severe resurgences of certain pests have hampered cotton growing. On the other hand, appropriately applied pesticides can more than double yield over untreated plots and prevent damage to the lint (Tunstall and Matthews, 1966). Integrated Pest Management (IPM) of this crop usually consists primarily of a combination of judicious chemical control with appropriate agronomic practices - involving the planting of resistant varieties at optimal times and good crop sanitation.

1.6.1. Thresholds

Economic thresholds were established for the major pests (Matthews and Tunstall, 1968) and, after minor modifications, now form the basis for much of the pesticide application decision making in Zimbabwe (Anon, 1985). A highly developed infrastructure for pest scouting exists in this country with the Cotton Training Centre for pest scouts in close proximity to the Cotton Research Institute (Burgess, 1983).

Records are routinely kept by commercial farmers using scouting pads provided by chemical companies, and a system of check scouting should quickly rectify any data collection inaccuracies. Fig. 1.6.1. is a graphic representation of scouting records taken from one farm in the lowveld, and illustrates the sequence of pest attack in this region.

Fig. 1.6.1. Example of Lowveld scouting data. From "A cotton insect pest database system" (Bateman, 1987, unpublished).



Most spraying is against bollworms which takes place in response to egg counts. Smallholder farmers in the region can scout for Diparopsis and Heliothis bollworm eggs with the aid of pegboards such as the one described by Beeden (1972), and with the shift from commercial to communal farming in Zimbabwe, research is taking place into the acceptability of alternative designs of pegboard, to include the addition of larval, aphid and red spider mite scoring (P. Jowah, 1986 and pers. comm.).

1.6.2. The Principal Pests and Natural Enemies

This is a brief review, with emphasis on the arthropods found during field trials in this study and their control by insecticides. Further information on biology and pest management reference may be obtained from Pearson (1958) and Matthews (1989).

1.6.2.1. **The Bollworm Complex**

Four genera of bollworms are of economic importance in the region. The polyphagous Heliothis armigera Hb. readily attacks cotton and other crops, and is probably the most important cotton insect pest in the region. The "American bollworm", is also referred-to as the "corn earworm", the "tobacco budworm", and the "tomato fruitworm", as well as infesting soya, sunflowers, and sorghum. It can survive on irrigated crops such as wheat and citrus flowers, before infesting rainfed crops. Although the damage to maize cobs is less serious than that caused by H. zea in North America, staple food crops provide an enormous reservoir of this pest, and populations can increase significantly before infesting cotton.

As a target for pesticide applications, Heliothis is

fortunately more exposed than other bollworms. Eggs are laid at the top of the cotton canopy, and frequently on the upper surfaces of leaves (Beeden, 1974; Joyce, 1981). Larvae often wander during the day, and even when feeding on bolls, the rear part of their bodies are exposed. Before the advent of pyrethroids and thiodicarb, organochlorine insecticides - including DDT and endosulfan - were used to control this pest.

Being polyphagous, these insects have numerous multi-functional oxidase enzymes which may facilitate the rapid development of insecticide resistance (Joyce, 1981). Daly (1988) lists alternative insecticides recommended in Australia as part of a resistance management rotation; they include the oganophosphorus compounds: parathion, profenofos and sulprophos, of which only the latter was registered in Zimbabwe, but made redundant by the synthetic pyrethroids (Brettell, 1983).

Diparopsis castanea Hmps. is oligophagous being totally restricted to cultivated and wild cotton (Gossypium spp.), and a rare wild host plant: Cienfugosia hildebrandtii Garcke. The main infestation occurs during mid to late crop stage, and as the pupae can undergo diapause, the pest readily survives the dry season. In the presence of a continuous supply of food plant material populations can increase and cause severe crop loss. Low level, persistent infestations represented by 1 egg observed for every 10 plants may cause significant losses (Nyirenda, 1986); in Zimbabwe, the normal threshold is 6 eggs on 24 plants (Anon, 1985), but is supplemented by recommendations to accumulate numbers of eggs over three consecutive counts, or project scores for increasing bollworm oviposition over two counts (see Fig. 4.2.1.).

A close season, during which farmers' fields must be cleared of all cotton plant material for at least two months, has been mandatory in Zimbabwe since the 1930s and in Malawi since 1965. The sky blue eggs are laid singly on stems leaves and bracts and are more evenly distributed throughout the plant than Heliothis, so spray penetration is more important for good treatment (Matthews and Mowlam, 1974). The most effective sprays are those that are directed against the eggs and first instar, because after this stage the larvae remain inside the bolls (Matthews, 1966c). Diparopsis is readily controlled by well timed insecticide applications, and carbaryl has been recommended since 1960; more recently, additional chemicals have included the pyrethroids and thiodicarb.

Eggs of spiny bollworms (Earias spp.) and pink bollworm (Pectinophora gossypiella Saund.) are considerably more difficult to detect in the field. Insecticidal control of Pectinophora is especially difficult since the first instar larvae bore into the bolls or flowers immediately after emerging from the eggs, which are usually laid on the immature bolls and buds themselves. The enforcement of a strict close season has limited the spread of this pest and practically eliminated severe infestations. Whereas chemical control of Pectinophora is difficult, high populations of Earias larvae are effectively controlled by sprays directed against Diparopsis and Heliothis, especially since like the latter, they tend to occur in upper zones of the cotton plant (Matthews and Johnstone, 1968).

1.6.2.2. **Red Spider Mites**

A number of species of Tetranychus infest cotton (Smith Meyer, 1987), but for the purposes of pest management, growers

need not identify them beyond genus (Matthews, 1989). Infestations usually occur late in the season, and are generally most serious in hot, dry years. Scarification of leaves initially causes yellow mottling, which progresses to a leathery appearance. In severe infestations defoliation may follow reddening of leaves, but this may be beneficial if it occurs near harvesting. Monitoring is based on a scoring index (see Appendix IVa), and in Zimbabwe an initial acaricide treatment is recommended as soon as red spider mites are recorded. Until the bolls split open the aim of further spraying is to keep population scores below 48 on 24 plants; spot treatments of localised infestations are feasible.

The Zimbabwean voluntary acaricide rotation scheme was developed after the appearance of red spider mites resistant to dimethoate (Duncombe, 1975). The country was divided into three cotton growing zones, and farmers within a certain region were subsequently advised to spray acaricides of one chemical type for only two seasons, before changing to one of two other groups.

The importance of mites greatly increased after the introduction of insecticide spraying, as predicted by Pearson (1958). Spider mites are repelled by sub-lethal doses of most classes of insecticides; e.g. fenvalerate was shown to repel Tetranychus urticae Koch, inducing aerial dispersion or walking off treated inert surfaces (Margolies and Kennedy, 1988). Re-distribution and increased reproductive potential caused by DDT and pyrethroid sprays has often been cited as a contributory factor to resurgence. In Zimbabwe the recommendation for two pyrethroids (cypermethrin and deltamethrin) was withdrawn in 1984, after trials had consistently demonstrated that they were associated with resurgences of red spider mites (Brettell, 1985).

All subsequent registrations of compounds within this group have been provisional and subject to further field trials, together with data from bioassay tests; the pyrethroids that are currently recommended in Zimbabwe are: fenvalerate, fluvalinate, lambda cyhalothrin, flucythrinate and bifenthrin.

1.6.2.3. **Sucking Insects**

Infestations of Aphis gosypii Glov. normally occur early in the season, and are most severe in dry seasons, causing leaf curling and honeydew formation which may encourage sooty moulds. Provided natural enemies have not been eliminated by broad spectrum insecticides, populations normally decrease dramatically by mid season, especially with the onset of heavy rain (Matthews, 1989a). Aphicides include dimethoate, ethiofencarb, pirimicarb and triazophos, which are frequently mixed with "bollworm" insecticides: by the farmer in C.S.Africa, or manufacturers where UL formulations are sprayed in Francophone Africa

Paurocephala gossypii Russell is the only psyllid known to infest cotton. Adults and nymphs may be found particularly on the under-sides of leaves, feeding from the veins and secreting honeydew. Infestations may be accompanied by a disorder called psyllose which is thought to be caused by a mycoplasma-like organism. Sprayed plants may also become infected, with intense reddening of the leaves that may be followed by defoliation and complete yield loss (Nyirenda, 1986). Pearson (1958) considered Paurocephala to be a pest only in Zaire, but warned that it might spread. Although the insect was recorded in Malaŵi in the 1929, the cotton disorder were first reported by McKinley (1965). Psyllose seems to be localised to areas with a high rainfall and 500m. above sea level in the centre of the country. The insect may be controlled by recommended insecticides including carbaryl

and DDT (Anon., 1975)

Other sucking insects include Jassids (Empoasca spp.) which attack early in the season. Growing pubescent varieties provides adequate control, and is especially important where few farmers use chemicals. The pest status of the cotton lygus (Taylorilygus vosseleri Popp.) is unclear, but the characteristic tattering of leaves may cause concern to farmers. Sprays applied against other pests will also limit jassid and lygus damage.

Late in the growing season, whitefly (Bemisia tabaci Gennadius) may infest the centre of the cotton plant, and secreted honeydew severely downgrades the lint quality by causing stickiness and discoloration. Dimethoate has been recommended against this pest in C.S. Africa, but due to the position of whiteflies on the plant, good spray penetration is required to give adequate control. This may be especially difficult in luxuriant irrigated crops.

Feeding of cotton stainers (Dysdercus spp.) may shrivel up boll tissues, but the principal damage is due to transmission of Nematospora - and in Malaŵi - Aspergillus spp. fungi (Nyirenda, 1986), which cause yellow staining and weakening of the cotton lint. In Malaŵi, carbaryl is recommended against this pest, although dimethoate and triazophos may also be efficaceous at increased application rates (Anon, 1976; Anon, 1985). Aerial and ULV - especially 'Electrodyn' - treatments may provide inferior control to tailboom or mistblower spraying because of poorer spray coverage (Anon, 1985; Nyirenda, 1986).

1.6.2.4. **Other pests**

Subterranean termites may produce large mounds and destroy cotton in patches extending over several metres. Where only individual plants have been killed, adjacent cotton can compensate for small gaps, and replanting is not justified if over 40% of the original stand survives (Matthews, 1988). Termites frequently attack plants that have been damaged during weeding, and spot treatments may be effective. Soil incorporation of cyclodiene insecticides have been used in research stations and where risk of severe losses is high; however this is not normally recommended for IPM programmes because of the effects to natural enemies.

Defoliators include the grasshopper Zonocerus elegans (Thnb.) and several species of lepidopteran leafworms including: Cosmophila flava (F.) and Xanthodes graelsii (Feisth.); Spodoptera spp. are rarely important on cotton in this region. Where infestations are severe, these pests are usually killed by the insecticides in the bollworm spray programme.

1.6.2.5. **Natural Enemies**

As well as pest species, spiders, chrysopids, coccinellids, and syrphids can all be identified by trained scouts; on Malaŵian research stations, mummified aphids are also scored. Although these are mostly of benefit against sucking pests, spiders (e.g. Cheirocanthium and Peucetia spp.) may take bollworm larvae up to the third or fourth instar (Brettell, pers. comm.). Tunstall (1962) considered that ants were the most important natural enemies of bollworms in Malaŵi. It is however difficult to demonstrate the beneficial effects of specific insecticides towards natural enemies during field trials (e.g. Brettell, 1984), and some farmers have doubted the value of natural enemy

assessments (recorded as "total predators"), since the benefits are not always apparent.

1.6.3. Selection of Pesticides

Cotton is grown principally by small-scale farmers in Central Africa, and even on the commercial farms manual spraying is carried out by poorly-protected labourers. From the outset, there was a policy to recommend only relatively non-hazardous pesticides (Matthews, 1966a, Brettell, 1983). In Malaŵi the only insecticides used for many years were DDT, carbaryl and dimethoate wettable powders (Gower and Matthews, 1971); certain pyrethroids and thiodicarb have now been added to this list, and in spite of their relatively low toxicity in comparison to many liquid formulations, there is a fear that poisoning cases will increase. All pesticide containers in Zimbabwe are now marked with triangles coloured according to the toxicity class of the formulation, and less toxic replacements for pesticides such as endosulfan are to be recommended in communal areas.

A strict pesticide registration scheme applies in both countries. Pesticides are only recommended for use on cotton after at least five years of screening in Malaŵi and two years in Zimbabwe. The procedures for introducing new insecticides (Matthews, 1966a) are still in use by the Cotton Research Institute in Zimbabwe (Brettell, 1983). Four stages of tests take place before recommendation of bollworm compounds:

i. Initial screening of insecticides by application to eggs.

ii. Assessment of spray deposits on bollworm larvae placed on single potted plants. This may however be complicated by the necessity to assess insect behaviour, where irritability of formulations may increase wandering times and result in

test insects receiving sub-lethal doses (Matthews, 1966).

iii. Field trials (randomised block design) in research stations.

iv. Extension trials consisting of paired comparisons of sprayed and unsprayed (or standard) treatments throughout the region.

In Zimbabwe, low rates are possible because crop scouting enables farmers to spray at early stages of pest infestation, and thus treat eggs, first and second instar larvae. Spray volumes vary according to crop height, and since mixing rates remain constant throughout the season, dosage rates are tailored to the plant growth stage. Table 1.6.1., adapted from Brettell (pers. comm.) and thiodicarb technical data sheets, illustrates how this policy has achieved pesticide application rates that are frequently considerably lower than those for many other cotton-growing countries.

Table 1.6.1.

Dosage recommendations for two insecticides

Insecticide	Dosage rates in g.a.i./hectare for plant heights:				
	Zimbabwe			Australia	U.S.A.
	< 40 cm.	40-90 cm.	> 90 cm.	all	all
Thiodicarb	130	260	395	935	670
Fenvalerate	13	27	40	140	110

After the lesson of red spider mite resistance in Zimbabwe, the policy of insecticide resistance management (IRM) was extended to delay similar problems with other pests, especially Heliothis, by limiting pyrethroid sprays on all crops to a nine week period (reckoned to be equivalent to three generations) coinciding with peak cotton boll formation (Brettell, 1983). The effectiveness of different IRM strategies for cotton has been discussed by Sawicki and Denholm (1987). In contrast, a voluntary strategy implemented in Australia after the onset of resistance has an uncertain future (Daly, 1988).

Maintaining a diversity of active ingredients within several chemical groups has been considered a long term expedient, but there is a fairly limited choice of insecticides that are safe and practical to use, as well as being truly effective against the major lepidopterous pest species. Before the advent of pyrethroids and thiodicarb, no single compound could control all species of the bollworm complex satisfactorily (Matthews, 1966c). Emphasis was placed on pest identification by the farmer, and insecticide mixtures were never recommended in this region (Matthews and Tunstall, 1966), unless the pest situation warranted such action (e.g. levels of both bollworms and sucking pests above the economic threshold).

1.7. THIODICARB

Thiodicarb is a carbamate insecticide and molluscicide, with a registered trade name of Larvin and code named UC51762 (Sousa et. al., 1977, Yang and Thurman, 1981). It was first registered for agricultural use in the USA in 1982, a considerable time after pyrethroids had been introduced, and is now available in many other countries, including those of C.S. Africa.

1.7.1. Properties and Formulation

Thiodicarb is a white, crystalline solid which is practically insoluble in water (35 mg/l.) and has a relatively low solubility in common organic solvents (0.8% w/v. in acetone, 15% w/v. in dichloromethane) and other organic materials commonly used to prepare emulsifiable concentrate (EC) and oil-based UL formulations. For this reason, "Larvin" formulations consist of dry materials or particulate suspensions, of which currently the most widely available is the aqueous suspension concentrate (SC) or "flowable" containing 375 g.a.i./l.. Other water-miscible

formulations have included water-dispersible granules (WG or "dry flowable: DF"), and wettable powders (WP) (Anon, 1984).

Thiodicarb acts primarily as a stomach poison; it has relatively low contact toxicity and practically no vapour action (4.3×10^{-5} mm Hg = 5.1 mPa at 20°C). The molecule effectively consists of two methomyl molecules joined together by a sulfenyl bond; it is degraded by hydrolysis, photolysis and metabolic processes to produce methomyl, and later methomyl oxime and other degradation compounds that are thought to be of little biological significance (Yang and Thurman, 1981). Methomyl, unlike thiodicarb, has contact action and is capable of being translocated by plants, and is highly poisonous; it also has a slight vapour action (v.p. 6.65 mPa at 25°C: cf. Gamma HCH: 5.6 mPa at 20°C). Thiodicarb is considered a "not unduly persistent" compound, and after correct application, active doses of SC typically last from 5 to 14 days with field residues becoming undetectable after 3 to 6 weeks. At 25°C it is stable at pH6, 96% being recoverable after 9 days in an aqueous buffer solution; however at pH3 only 48% remained, and it is rapidly hydrolysed in alkaline media (1% remained at pH9). Hydrolysis and other chemical degradation of thiodicarb also rapidly occurs in the presence of copper, nickel, iron, zinc, aluminium, other heavy metal ions and certain fungicides (e.g. maneb, mancozeb).

1.7.2. Biological Activity

(with special reference to the Arthropoda of African Cotton)

Thiodicarb, applied at 0.2 to 1.0 kg. a.i./ha., is effective against many Lepidopterous pests as well as some Coleoptera, Diptera and Homoptera. Because of the mode of uptake, this insecticide is considered to be selective (Allen et. al., 1986), being less harmful to bees and certain natural enemy groups such

as hymenoptera and predatory heteroptera (Geocoris, Nabis and Orius). Table 1.7.2. is based on bioassay studies carried out by Brettell (1979, 1984 and in preparation), and demonstrates the low activity of thiodicarb on a chrysopid and spider species.

Table 1.7.2.

Effects of various pesticides on beneficial insects of cotton.

Pesticide/group	Formulation	LC_{50} as expressed as % of a.i.	
		Mallada boninensis	Cheiracanthium sp.
ORGANOCHLORINE			
D.D.T.	75% WP	0.079	n.a.
Endosulfan	35% MO §	1.35	0.014
ORGANOPHOSPHORUS			
Dimethoate	40% EC	0.26	n.a.
Triazophos	40% EC	0.016	0.27
CARBAMATE			
Carbaryl	85% WP	4.39	0.013
Pirimicarb	50% WP/WG	> 10.0	0.043
Thiodicarb	**37.5% SC**	**> 19.0**	**2.58**
PYRETHROID			
Cypermethrin	20% EC	0.020	n.a.
Fenvalerate	20% EC	0.19	0.11
Flucythrinate	10% EC	0.42	n.a.
Fluvalinate	25% EC	n.a.	0.015
ACARICIDES			
Amitraz	20% EC	> 10.0	0.036
Binapacryl	50% WP	> 10.0	n.a.
Tetradifon	8% EC	n.a.	> 4.0

§: "Miscible Oil" - equivalent to an EC.

From a farmers point of view, thiodicarb shares an advantage with the pyrethroids in that it controls both the major bollworm species - unlike carbaryl, DDT or endosulfan. In the southern African region the typical application rate of thiodicarb for bollworm species is 375 or 400 g.a.i./ha. for fully grown cotton, and cotton stainers, jassids and defoliators (e.g. Spodoptera,

Xanthodes spp.) are all controlled by this insecticide at normal rates. This compares with typical application rates of 10-50 g.a.i./ha. for pyrethroids, 500 g. for endosulfan, and 1kg.a.i./ha. for carbaryl and DDT (Anon. 1976, 1985). Comparisons of efficacy between thiodicarb and pyrethroids have been made in this region by Brettell (1979,1980,1983).

Pitts and Pieters (1980) showed that thiodicarb has an ovicidal activity against Heliothis virescens that was equivalent to chlordimeform (their standard), although methomyl was consistently the best ovicide amongst the chemicals tested. Awareness of the value of egg scouting has occurred only recently in the USA, where it is considered to improve the efficacy of sprays and possibly minimise selection for pyrethroid resistance (Bacheler and Bradley, 1989). Unless resistance becomes a problem pyrethroids will continue to be preferred in North Carolina, since control of H. zea larvae is currently superior and more cost effective than thiodicarb. This chemical has however been successfully tested as an ovicide at rates from 0.14-0.17 kg.a.i./ha., especially in tank mixes with pyrethroids for control of larvae (J.S. Bacheler, pers. comm.; Anon, 1988).

The degree to which thiodicarb causes resurgence of red spider mites remains controversial. Over a six year period, in which three formulations were included in field trials in Kadoma (C.R.I. Annual reports 1978-84), high populations of red spider mites were noted in three seasons; however two instances (1977/8, 1978/9) followed applications at 700 g.a.i./ha., and populations were low during IPM trials (in 1984/4) where thiodicarb sprays were followed with spider mite inhibiting pyrethroids later in the season. Like carbaryl, thiodicarb may also aggravate whitefly populations (Brettell and Masuna, 1984).

1.8. SUMMARY OF OBJECTIVES

In section 1.4.2. three well-tried strategies for spraying insecticides with spinning disc sprayers were reviewed:

i. ULV spraying with oil-based formulations,

ii. VLV application of water-miscible formulations ("WULV"),

iii. modified water-based ULV: e.g. the MULV technique.

Because existing practice in central southern Africa included the use of aqueous mixtures, it was possible to incorporate thiodicarb into CDA programmes at an early stage. Problems of extension and equipment cleaning would hinder similar forms of adoption in countries where oil-based spaying is commonplace, so the manufacturing company endeavoured to prepare ULV suspension (SU) formulations. This study was initially an investigation into the compatibility of these SUs with commercial rotary atomisers. The effects of flow rate and disc speed on the atomisation of water-based mixtures were evaluated, and following shortages of molasses in Zimbabwe during the 1987-88 season, the atomisation of sprays incorporating alternative evaporation inhibitors was examined. Other issues associated with water-based CDA strategies included power consumption, wear of nozzles and fate of droplets after leaving the sprayer.

Field trials in Zimbabwe and Malaŵi took place over two seasons. Application and formulation strategies were compared, in multifactorial designs which incorporated variations of droplet size and dosage. Analyses of the practical factors associated with rotary atomisation were required, since these have been neglected in the literature. An understanding of the mechanisms governing flow rate is primarily of operational use, but droplet spectra may be consequently affected in conditions close to where transitions between modes of atomisation occur.

CHAPTER 2

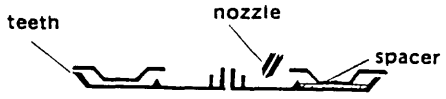
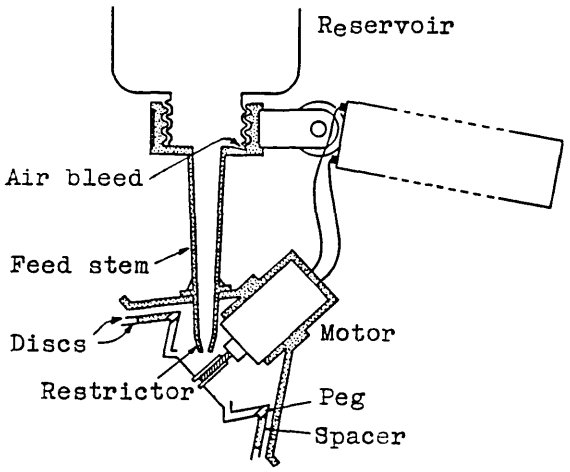
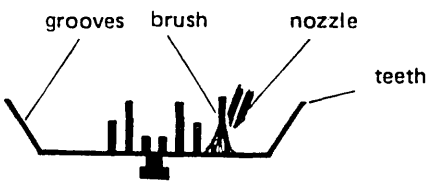
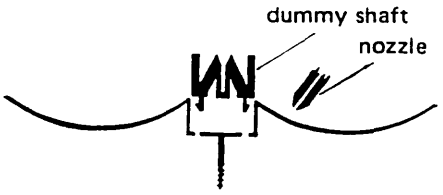
MATERIALS, METHODS AND CALIBRATION

2.1 INTRODUCTION: THE SPRAYERS

Of the spinning disc insecticide sprayers that are now commercially available (Anon, 1980,1981; Arnold 1983), four representative atomiser designs were selected for laboratory work, and the essential features of each are given Table 2.1.1. Many disc designs have 360 circumferential teeth, but the Taurus 'Hi-spin' has 344 and the Berthoud C8 has none (although a previous version had a rimmed cup with 360 teeth).

The air-bleed mechanism usually consists of a narrow hole, or a discontinuity at the base of the socket with an incomplete thread along the screw connection with the reservoir. A choice of restrictors was originally intended for adjustment of flow rate with respect to formulation viscosity. Older sprayers of the Ulva and Turbair XJ type, were designed for applying formulations at approximately 60 ml/min., but the 'Mini-' and 'Micro-Ulva' series were designed for oil-based insecticides at about 30 ml./min. The 'Micro Ulva' and the hexagonal restrictor insert on the 'Mini Ulva 78' (Mk. II) have a soft brush to improve continuity of liquid flow to the teeth and prevent sprays from "pulsating". The Turbair 'X' and Taurus 'Hi-spin' have restrictors which are screwed into the feed stem, and not usually changed. Sprayers with plastic restrictors are colour-coded according to orifice size (Table 2.1.2.); the flow-rates, for a given liquid and orifice size, may differ considerably between air-bleed and liquid head arrangements in alternative nozzle designs of the same make.

Table 2.1.1. **Rotary Atomiser Designs**

	Generic disc design §1	Diameter (mm.)	Typical machines	Restrictors and air-bleed mechanism
i.	flat disc with splash plate attached by three spacers, no grooves 	88	Turbair X, Turbair XJ, Taurus Hi-Spin Mk I.	On Turbair 'XJ', brass hexagonal restrictors, (ranging from 0.9-2.1 mm.), may be changed on the detachable feed stem. Air bleed is along screw thread.
ii.	stacked pair of corrugated discs, separated by eight pegs; both have teeth but no grooves. 	88	The Ulva series: the "8" and "16" models have identical atomisers.	Colour-coded restrictors are combined with feed-stem and a screw connection for the reservoir bottle. On current versions, air bleed is along screw thread and a discontinuity in the bottle seating (as illustrated); earlier models had a 'U' shaped hollow needle set into the plastic restrictor.
iii.	shallow cup with grooves. The version of 'Mini-Ulva' with colour-coded restrictors has no brush. 	52	Mini-Ulva Mk. II §2, Micro-Ulva	The 'Mini Ulva' had a grooved hexagonal plastic insert but this was superseded by colour-coded restrictors, as with the 'Micro Ulva'. Airbleed down screw thread (with notches on the base plate in the 'Micro Ulva').
iv.	disc with smooth, internal surface, and attached to a dummy shaft 	87	Berthoud C8	Colour-coded plastic and stainless steel restrictors. The airbleed consists of a narrow hole connecting the base of the reservoir to an opening at the rim of the reservoir housing.

§1: Illustrations are taken from Arnold (1983) except the 'Ulva': adapted from Boize and Dombrowski (1976) showing modification.

§2: The Mk. 1 Mini Ulva described by Johnstone and Johnstone (1976) had a deep cup which was 55mm. in diameter. Low-voltage motors are available for the current 'Mini Ulva' series.

Table 2.1.2. **Restrictor Colour Codes.**

colour	Micron range	Berthoud
blue:	0.78	
yellow:	1.0	1.5
orange:	1.3	
red:	1.56	1.8
grey:	2.0	
green:	2.9	2.2

In Zimbabwe, the "Hi-Spin Mk. 2" consists of a Micro Ulva head which has been attached to a tubular metal handle. This assembly was selected for the critical thiodicarb trials at Kadoma since a wide range of droplet sizes could readily be selected by adjusting the voltage. The original Hi-Spin, was used for a simpler formulation and active ingredients trial (No. 5), and the Turbair XJ for all the Malawi trials.

In many comparative experiments, sprayers have been run in tests at voltages commensurate with the power source provided (Arnold, 1983); for example, a sprayer with a battery pack fitting 8 'D' cells would be measured at 12 volts. This is a perfectly valid comparative measure, however during normal operation ordinary batteries rapidly run down. Cells with a nominal voltage of 1.5v. may initially discharge at 1.6v., but this is soon reduced to less than 1.2v within 10% of their service life (Ever Ready Ltd., 1980); thus a 12v. motor would actually be run at less than 10v. for much of the useful life of a set of cells. Unless stated otherwise, durability tests and flow rate measurements on double-disc atomisers were therefore carried out with the disc running at an arbitrary 7/8 of their nominal voltage. Droplet spectrum analysis with formulations took place at a range of disc speeds representing the normal output of a set of batteries.

2.2. MEASUREMENT AND CONTROL OF DISC SPEED

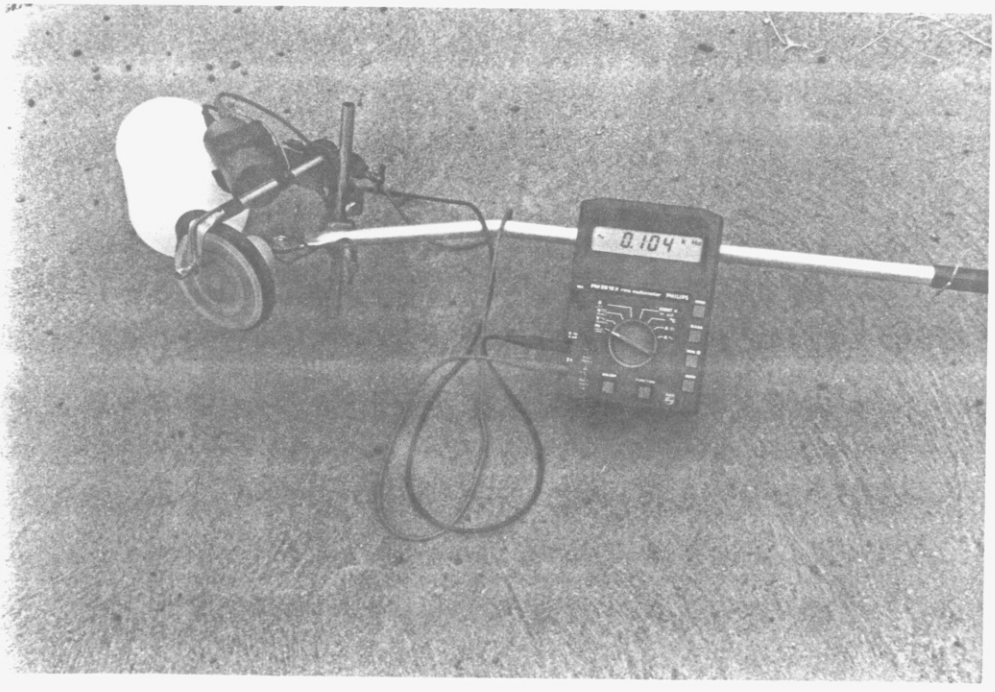
Disc speed is consequential to the condition of the motor and the voltage applied, and is the most satisfactory method of adjusting droplet size. At speeds where most rotary insecticide sprayers produce droplets of approximately 100μm diameter, small reductions in voltage and disc speed cause relatively large increases in droplet size. Robust systems were needed for monitoring and pre-setting trial sprayers at required speeds rather than voltages; an approach taken by many other workers including Boize (1978). Two simple devices were developed for this task, and having prepared calibration graphs for the droplet sizes in the laboratory, the aim was to continuously produce sprays of a specified size in the field. These could readily be selected and maintained by adjusting a pre-set potentiometer in a voltage control pack to produce a constant, measured disc speed.

2.2.1. Adjustable Power Pack

An adjustable voltage regulator (Arnold 1979) was fitted in place of one 'D' size cell in the standard battery pack of a Turbair XJ (Fig. 2.2.1.). A length of 1 inch (25 mm.) copper lightning conductor strip was cut and double bent to a size similar to that of a 'D' cell, and a threaded hole was made at one end so that it could be attached to the casing with one of the electrical terminals. As well as having a mechanical function this part also acted as a heat sink for the semiconductor (positive variable voltage regulator No. 317T). The positive supply from the cells was insulated from the heat sink with a piece of copper laminated board glued to the heat sink, and since the circuit also required a negative supply, an external switch was fitted.

Fig. 2.2.1. Adjustable power pack.

Fig. 2.2.2. Disc speed of a Taurus Hi-Spin being monitored with a magnetic tachometer.



2.2.2. A Tachometer Using A Digital Magnetic Pick-up

Optical and other tachometers, such as the 'Vibratak' which is based on a vibrating needle, can be used for checking the rotational speed of a disc when it is unloaded or spraying blank liquids. In this study however, it was essential to develop a tachometer that could monitor disc speed remotely while spraying formulations which might be opaque and noxious.

A small steel object such as a piece of razor blade was attached to the disc, and the detector was temporarily attached to the sprayer head using suitable clamps. The latter consisted of a digital magnetic pick-up (RS components no. 304-172) and associated circuitry (a battery and a protective diode). The device (Fig. 2.2.2) was used with a suitable meter with a logic device, to produce a meter reading in Hertz, therefore results were expressed in revolutions per second ($rev.s^{-1} \pm 1\%$). The principal disadvantage of this method is that the maximum distance between the detector and the disc is about 3mm. (preferably 2mm.), and it must be rigidly fixed in a suitable position. It did not work well at lower disc speeds, but these were outside the range normally used for insecticide spraying.

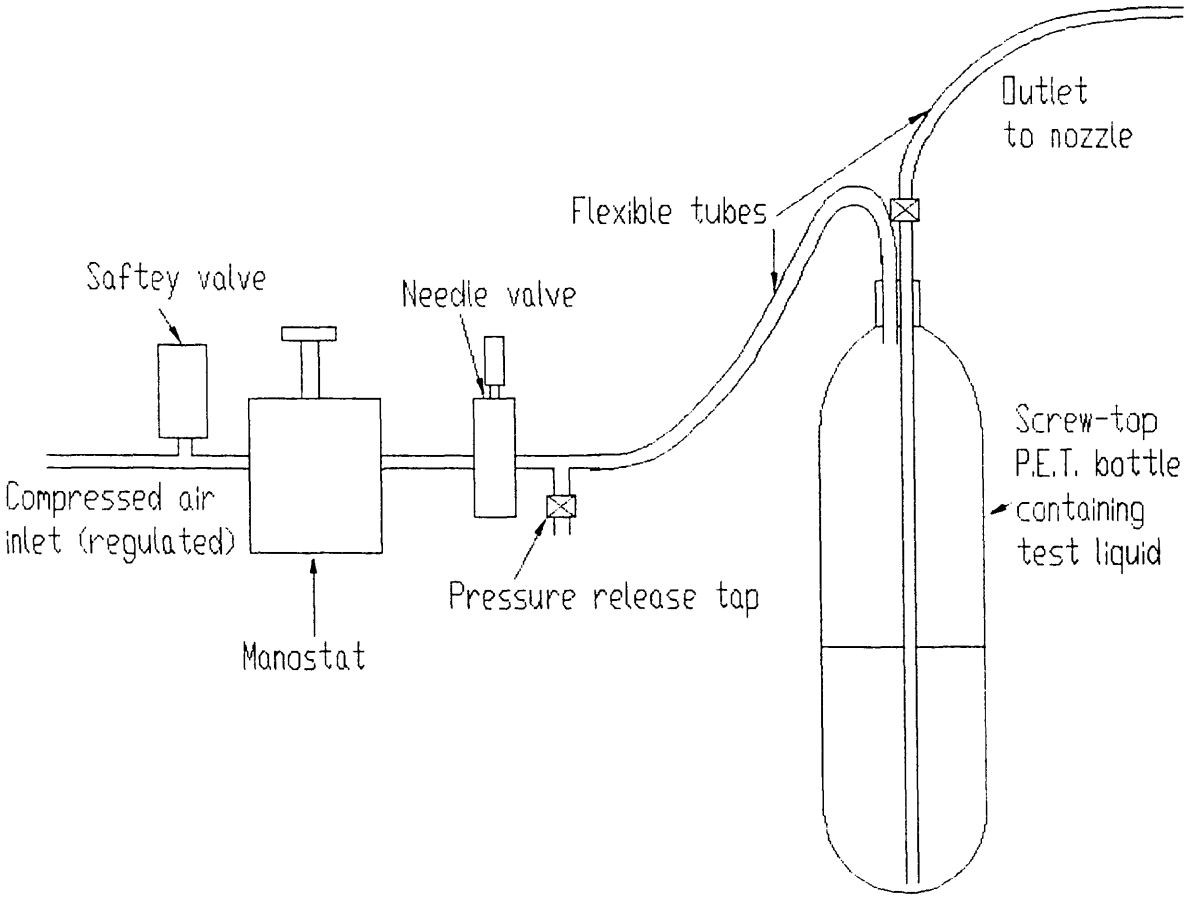
2.3 METHODS FOR MEASURING AND CONTROLLING FLOW OF FORMULATIONS

In the laboratory, flow rates were measured electronically because there was a special need to evaluate consistency of flow at low throughputs and different disc speeds, with certain atomisers. A plastic cowl was constructed to capture all the spray, without severely disrupting air-flows near the nozzle. The cowl was placed on an electronic top-pan balance weighing up to 2 kg. Sequential weight readings were recorded at 10 second intervals by a microcomputer, linked via a serial network system;

after subtraction and division by the liquid density, flow rate readings were stored electronically. This microcomputer was also interfaced with the Malvern particle size analyser (PSA), which was controlled by the same programme (see Appendix II).

Formulations were delivered to the atomiser, at constant flow rates, by a steady ingress of compressed air displacing the formulation under test in a 2 l. P.E.T. bottle with a dip tube. The pressure upstream of a flow-controlling, low range needle valve was regulated by a manostat (see Fig. 2.3.1). This method produced flow with a measured tolerance of $\pm$ 10% at 30 ml./min.; this was larger at lower flow rates, and could be reduced to less than $\pm$ 5% at 60 ml./min.. A flexible delivery tube was attached to a restrictor which could be quickly transferred from flow rate monitoring to an atomiser mounted in front of the PSA.

Fig. 2.3.1. Device for controlling flow rates of formulations.



2.4. PROCEDURES FOR EVALUATING FORMULATIONS WITH SPRAYERS

Rapid measurements of droplet size are possible with light diffraction techniques, enabling sequences of measurement at different disc speeds and flow rates. In practice, the supply voltage is relatively easy to alter on sprayers where the batteries are inserted into a detachable pack (e.g. the Turbair XJ) or a handle of adjustable length (e.g. the Micro Ulva). A series of preliminary experiments, with blank formulations, were required in order to understand better the complex interacting processes in spinning disc nozzles (see Fig. 5.1.), and assess the droplet sizing method (sections 2.5.2. - 2.5.3.).

After carrying-out initial comparisons between machines, much subsequent laboratory work centred on the Micro Ulva. From an experimental point of view, this atomiser head has two advantages: it is versatile, capable of producing a wide range of droplet sizes including mists, and has a simple disc design. This contrasts with atomisers such as the Ulva with an uneven liquid feed to the periphery of two discs separated by connecting pegs, (Boize & Dombrowski, 1976), however measurements for the Turbair XJ and Taurus 'Hi-spin' were required for support of the field trials.

Laboratory work on formulations comprised three parts:

i. Flow-rate studies: water-based mixtures vary little in flow characteristics, and most work centred on the dilution and delivery of very viscous oil-based formulations.

ii. Droplet spectrum analysis with water-based mixtures: the influence of addition of suspended particles, anti-evaporants and other adjuvants.

iii. Droplet spectrum analysis with oil-based formulations.

In conformity with normal field practice, the majority of measurements on water-based mixtures were at a flow rate of 60 ml./min., and oil-based liquids at 30 ml./min.. Four readings - between 100 and 160 $rev.s^{-1}$ for the Micro Ulva - were considered a useful working range for two reasons. These ranges were designed to span the vagaries of battery depletion and nozzle wear and include lower speeds which might produce droplet sizes more suitable for water-based spraying.

Droplet size measurements normally took place with the atomiser housed in a 50 cm. cubic box, made from capillary matting attached to an angle girder frame. Spray was emitted from a 10 cm. square window cut adjacent to the LASER beam. The edge of the disc was typically situated 10-20 cm. in front of the beam, and slightly tilted so that the light passed though the top and bottom of the spray plane. On the opposite side of the beam, a 15 cm. tube connected to an extractor fan, created a suction with a flow of approximately 5 m./s. at the centre of the opening. This device prevented contamination of the Malvern lenses and re-circulation of small droplets; otherwise it had little influence on measurements. More than one droplet spectrum reading was made for each mixture/flow-rate/disc-speed combination. Replication of readings is discussed below in section 2.5.2.1.

2.5 DESCRIPTION AND MEASUREMENT OF DROPLET SAMPLES

2.5.1. Introduction: Descriptive Parameters

The parameters that are suitable for characterisation of agricultural spray droplets have been reviewed by Rathburn (1970), Matthews (1975 and 1979) and Johnstone (1978). In practice, the experimentalist requires two measures: an estimate of droplet size and a description of spray quality, or homogeneity of droplet spectrum. Appendix IIa contains further notes on droplet parameters and their calculation.

Volume Median Diameters (VMD) and Number Median Diameters (NMD) represent respectively the diameter (in microns) at which half the liquid volume, and half the number of droplets are smaller. They are probably the most commonly-used parameters; VMD in particular has become the most widely accepted way of expressing droplet size. The Volume Average Diameter (VAD) is the diameter of droplets representing the total volume of atomised liquid divided by the number of droplets. A parameter indicating the volume of liquid (in pico-litres) represented by the VAD has been devised in this study: the Average Droplet Volume (ADV) will be discussed further in section 5.1.2.1.

NMD readings on their own are of limited practical value, however VMD/NMD ratios give some indication of the uniformity of droplet size. Results were initially illustrated by two parameters: VAD to give a practical indication of size and VMD/NMD ratios. Attempts to investigate trends were carried out with statistical analysis of VMDs and Coefficients of variation. Where such differences result from transitions between different phases of atomisation, whole droplet distribution histograms from sequences of consecutive readings are illustrated.

2.5.2. Droplet Analysis Using The Malvern (R) Particle Sizer

2.5.2.1. Configuration of Instrument

Measurements of droplet size were taken with a Malvern type ST1800 Particle Size Analyser (P.S.A.). The accuracy of this version is stated by the manufacturer to be within 4%, for a mean diameter calculated using the Rosin Rammler model. Further notes on Malvern PSA analysis may be found in Appendix IIb.

The instrument was fitted with a 799mm. focal length lens for all measurements - suitable for general purpose evaluation of agricultural spray nozzles, since droplets with diameters from 15-1500μm can be detected. Each reading consisted of 500 scans, and therefore can be considered a statistically adequate sample. True replication consisted of readings taken on completely separate occasions, or at least followed a new background reading and a shift in the position of the sprayer. Inconsistencies were often noted, and measurements are not necessarily "typical"; they should be considered as comparisons of contrasting fluids and nozzle settings, experimentally arranged in consecutive sequences.

Since many readings were of ligament breakup of liquids with rotary atomisers, bimodal droplet distributions could be expected and in transitional states between different phases of atomisation, trimodal spray distributions were possible. "Model Independent" analyses were therefore considered most appropriate.

2.5.2.2. Compensation for Artefacts

Under certain circumstances, nonsensical readings occurred with very high volume fractions calculated for the uppermost size classes. This was especially common where heat ripples, air turbulence or vapour concentrations caused fluctuations of the LASER beam. Such diffractions were small, and similar to those

produced by very large droplets (i.e. the 0.7 - 1.5 mm. range with the 799 mm. lens), which are observably not actually present in CDA sprays. Later versions of Malvern instruments enable the operator to compensate for this effect by setting readings for detector elements 1 and 2 to zero; the MSC programme makes this nullification option available to ST1800 users.

Such measures are perfectly legitimate when applied judiciously (i.e. to compensate for an obvious artefact). An inferior a posteriori adjustment (which should be used with great care) may be made simply by deleting the values for the uppermost size class before calculation and printing-out of results. Table 2.5.1. illustrates differences that may occur if such adjustments are not made, and the complete data may be found in Appendix IIb. Extremely high volume fractions in the largest size class may be produced by spraying a highly atomised, volatile liquid in a strong air-stream. Such measurements should be confirmed by repetition - in the examples shown the calculated parameters were similar. The Rosin Rammler model produce notably consistent distribution curves, with calculated parameters which are comparable to adjusted model independent analyses.

Table 2.5.1.

Malvern ST1800: VMDs (and NMDs) obtained under various conditions.

Liquid - rev.s^{-1} - droplet suction			Rosin Rammler		Model Independent		
			Normal	Nulln.	Normal	a-post.	Nulln.
Tap water	160	No	78 (47)	78 (47)	79 (43)	78 (43)	77 (45)
Tap water	200	No	64 (32)	64 (32)	66 (37)	64 (37)	65 (39)
20% acetone	160	Yes	61 (38)	61 (38)	67 (44)	60 (44)	61 (45)
20% acetone	200	No	49 (30)	49 (30)	53 (36)	50 (36)	51 (36)
20% acetone	200	Yes	53 (31)	52 (33)	644 (38)	31 (38)	54 (39)
20% acetone	200	Yes	52 (29)	52 (29)	58 (37)	51 (37)	53 (37)

These data are six examples of sprays produced by a Micro Ulva, analysed in five different ways; complete analyses of four examples may be found in appendix IIc. Both of the available models were used to analyse the normal and nullified (nulln.) detector array, as well as the crude a posteriori adjustment.

2.5.3. Calibration of Droplet Sizing Methods

The Malvern (R) particle size analyser has undergone several modifications since the prototype instrument was first described by Swithenbank *et. al.* (1975). All versions rely on spatial sampling, where assumptions are made about the diffraction of a LASER beam passing through a cloud of droplets (Appendix IIb).

Temporal sampling techniques count and measure individual droplets as they pass through LASER light. They include two instruments that have become available during the same decade and are often used for agricultural spray research. The Knollenberg Particle Measuring System (PMS), has a short, single beam that passes between two probes that extend from a robust mechanism case. The apparatus used in this study was fitted with a OAP-260X one dimensional type probe, and calibrated with a 50-500μm. graticule. The Aerometrics phase/doppler analyser (P/DPA) interprets interference patterns produced by droplets passing through the intersection of a split beam. The P/DPA can also measure droplet speed, and consequently transform the results to simulate spatial sampling.

Polydisperse sprays frequently appear to be smaller when measured with spatial sampling techniques (Frost and Lake, 1981). Smaller droplets tend to move more slowly, and therefore remain in the scanning beam longer than larger droplets. Parkin (1988) pointed out that results should be similar when narrow droplet spectra are measured. To enable comparison of these results with similar work in other laboratories, a series of calibration experiments were conducted in order to:

i. indicate confidence intervals for Malvern ST1800 readings,

ii. compare model independent output with Rosin Rammler analyses and investigate differences with later Malvern versions.

iii. indicate how data compares with PMS and P/DPA droplet sizing.

The digital magnetic pickup, described in section 2.2, was incorporated into a device for producing a narrow stream of fairly uniform droplets. Originally designed for bioassay work, this laboratory test-rig was used to compare droplet sizing methods. A new Micro Ulva atomiser was attached to a perspex base plate so that the cowl of a Micron Herbaflex (a sectorial, rotary, herbicide applicator) could be attached, thus limiting the spray to narrow band; excess formulation was simply allowed to drain away. The magnetic pickup was mounted inside the cowl with a right-angle bracket, and connected to a protective diode, battery and pair of sockets, all mounted on the base plate (see Fig. 2.5.5.). An aqueous solution of 0.1% Agral was fed to the disc at a standard rate of 60 ml/min., using a metered gap valve controlling the liquid flow from a pressurised soft-drinks tank (Cornelius "Spartan"). The motor was connected to a stabilised power supply and the disc rotation was monitored at speeds ranging from 100 to 200 rev.s^{-1}.

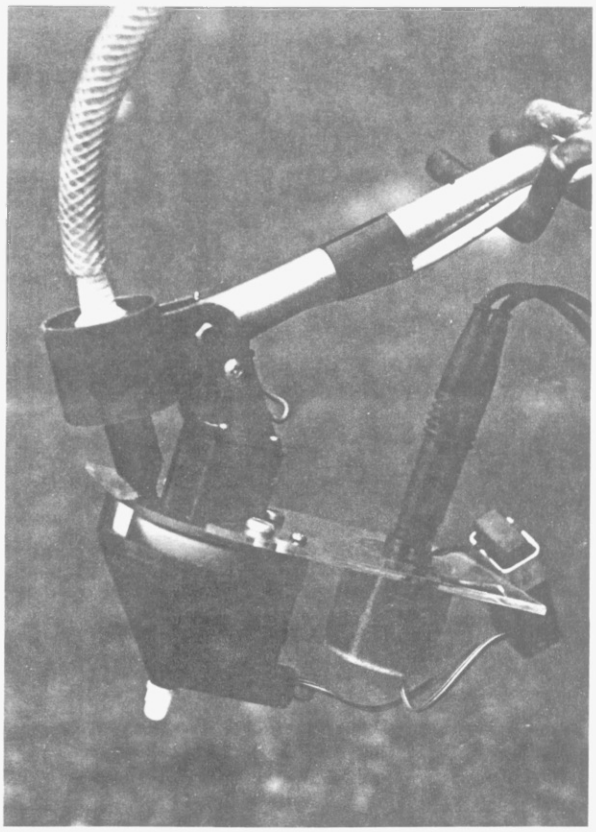


Fig. 2.5.5.
Apparatus for Producing a Narrow Stream of Rotary Atomised Droplets

2.6. SPRAYER DURABILITY

2.6.1. Context of Study

Sprayers are primarily farmers' tools and it is vital that they be constructed robustly; this factor is however more difficult to evaluate impartially than the technical aspects of atomisation. Apparatus to evaluate the durability of manually operated machinery has been previously developed by Matthews et. al. (1969) for lever-operated knapsack sprayers and WHO (1971) for pressurised hydraulic sprayers. A lever-operated knapsack sprayer should give 500 hours of service before it passes the durability test: believed to be equivalent to three seasons of repair-free use for an individual farmer. Cost comparisons for rotary atomisers (e.g. Huntington and Johnstone, 1973) have also been based on the assumption that they would give three hectare-seasons use before replacement of motors.

No analogous procedures for the assessment of CDA machines have previously been described; the development of a prototype laboratory apparatus arose from the need to assess whether water-based sprays might have a deleterious effect on sprayer performance, due to longer operation times and higher flow rates than with oil-based ULV spraying. Water-based mixtures may also be intrinsically more corrosive on moving parts. Shah (1987) initiated investigations into the compatibility of formulations and rotary atomiser materials. A test designed to assess the effect of dropping a spinning disc sprayer might also be considered, since this is a common cause of breakage in the field, however this may prove more difficult to standardise than the procedure for pressure-retaining compression sprayers (WHO, 1971).

2.6.2. Durability of Spinning Disc Head Assemblies

The aim was to operate sprayer heads to destruction (defined by power consumption measurement), under conditions that were as reproducible and realistic as possible. Atomisers were operated under load at 7/8 of their nominal voltage, thus if the battery pack normally held nine cells, the voltage was set to 10.5v. (see section 2.1.1.). A timer switch activated the head in a cycle of 20 minutes on and 10 minutes off: in order to simulate the periods of spraying then rest, while refilling the container.

A perspex spray box, sealed with a silicone filler, was constructed in a proprietary angle girder frame, so that the base slightly tilted towards an effluent hole, with a pipe leading away to a drain (see Fig. 2.6.1.). Two spinning disc heads were fixed to an attachment girder situated in front of 11 cm. circular holes in the cover. These were positioned so that the periphery of each disc was in a plane separated from the inside of the cover by approximately 2 cm.; perspex rings could be inserted into the holes, to prevent spray escaping from smaller nozzles. The heads were positioned 60 cm. apart and each was fed by an independent water and power supply. The cover was detachable and tilted at 45°; large service holes, each with a cover, were situated under the sprayer positions so that flow rate could be easily monitored.

One of the major problems encountered during the development of this test equipment was the maintenance of an even flow of water to the nozzles. Tap water was gravity-fed at a nominal rate of 60 ml./min., with each supply regulated by a needle valve, and regular checks were made on flow rate. In an earlier prototype, a solenoid valve switched the flow on and off together with the atomiser motors; this was discontinued because such

interruptions reduced the throughput after only a few on-off cycles. An 18 l. reservoir with cistern gave a 2m. head of liquid above the sprayers, and obviated problems of pressure fluctuations and short breaks in the mains supply. In 1987, the water had a stated mean hardness of 311 mg./l. $CaCO_3$ (see Appendix Ib), and a proprietary de-scaling liquid was regularly required for cleaning the spray box.

Mains power was time-switched to two independent, adjustable voltage regulators. Each supply was then connected to the sprayer heads via a control/counter box constructed by A.C. Arnold; two in-line 2A. fuses both protected the circuitry and indicated complete motor stalling. Voltages could be measured using a pair of sockets connected near each head. Current was monitored across a 1 ohm resistor in the control box. The latter consisted of a high-low window discriminator which indicated three possible states of current flow:

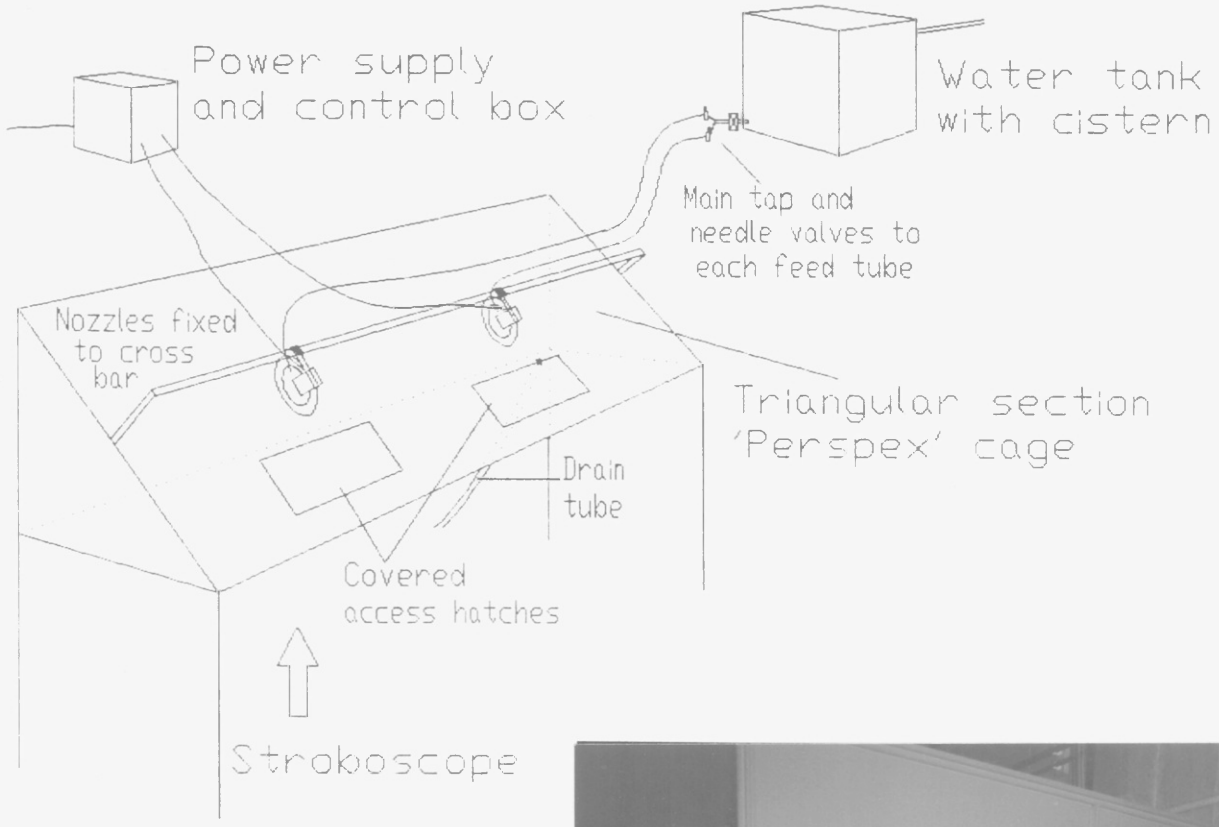
i. a minimum limit was set as low as possible to establish whether or not current was drawn by the motor.

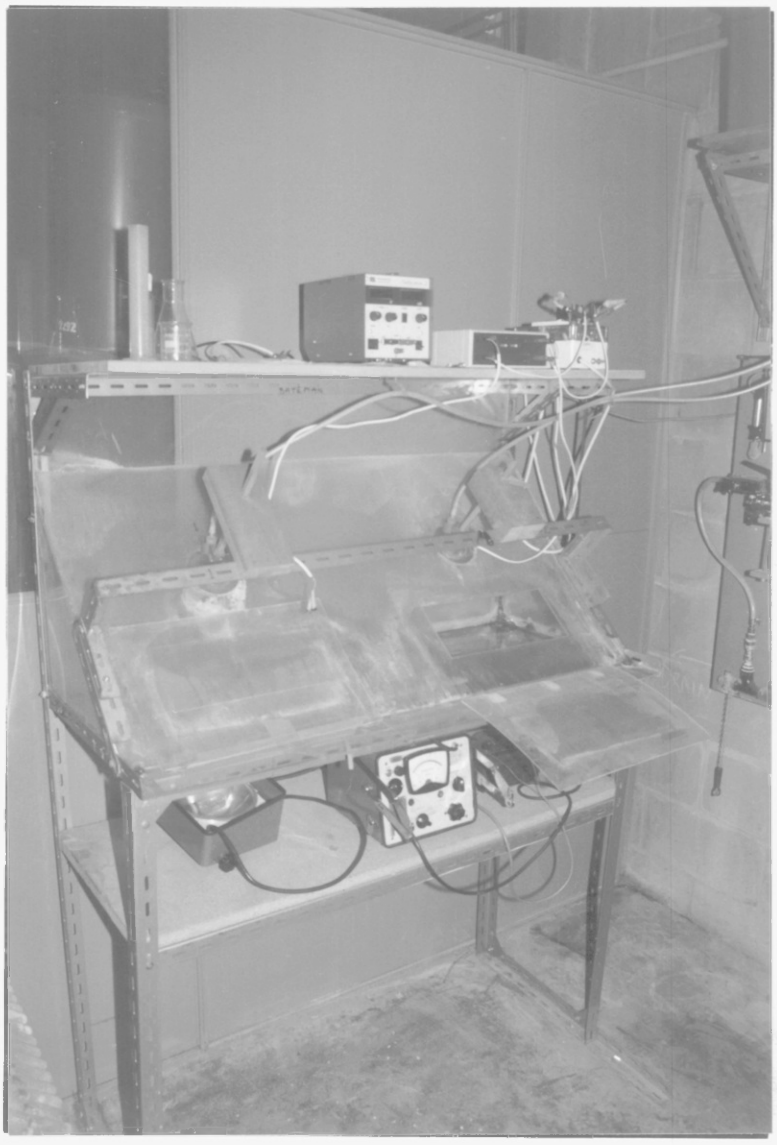
ii. power consumption within the operating range was recorded on a time elapsed meter.

iii. an upper limit was set at 150% of the initial measured current consumption, in order to stop further recording in the case of a motor stalling.

Before mounting, discs were marked with an indelible black line to facilitate measurement of rotational speed with a stroboscope situated on a shelf below the spray box. Disc speed was regularly monitored (at least twice weekly), and recorded on a log sheet (see Appendix Id). An atomiser was considered to have failed if its speed was less than 75% of that when new. This figure was based on droplet size measurements of the Micro Ulva; reducing the disc rotations from 160 to 120 $rev.s^{-1}$ frequently incurred a doubling of average droplet volume.

Fig. 2.6.1. Prototype Rotary Atomiser Durability Test Rig.





B. Arrangement of the 'Perspex' cage, control devices and stroboscope.

2.7. FIELD TRIAL METHODS

2.7.1. General Aims and Procedures

A series of field trials were carried out on cotton in Malaŵi and Zimbabwe to assess the efficacy of thiodicarb formulations applied with controlled droplet application techniques. Three types of biological evaluation were considered appropriate for thiodicarb:

i. cotton yield,

i. efficacy against principal pests,

ii. monitoring of other possible effects, including secondary pest resurgence and toxicity to natural enemies.

Several multi-factorial trial designs were used to quantify the relative importance of adjustable components such as formulation, dosage and droplet size. These were augmented by some preliminary investigations into spray recovery.

2.7.1.1. Trial Sites

In Zimbabwe, plots were laid-out at Itafa farm - part of the Cotton Training Institute - which is adjacent to the Cotton Research Institute, Kadoma in an area typical of Middle-veld growing conditions. Similar trials in Malaŵi were carried-out in both seasons at Makoka Agricultural Research Station, at Toleza (in the Upper Shire valley) and at Chitala (near Salima in the lake-shore region). An additional trial was planned at Kasinthula (lower Shire valley), but the crop was very uneven and land was limited, so a trial in 1988 was reduced to a basic comparison of three formulations, at full mass application rates. Paired comparisons of two water-miscible formulations were also carried-out in farmers' fields in the North of the country: with five small-holders in Mzuzu Agricultural Development Division (A.D.D.) and six in Karonga A.D.D.. Table 2.7.1. gives details of the

sites of the eight trials carried out in research stations.

Table 2.7.1.

Field Trial Sites.

Trial	Station	season	longitude	latitude	altitude (m.)
1.	Kadoma	1986-87	29°53'E	18°19'S	1156
2.	Makoka	1986-87	35°14'E	15°31'S	1000 (approx.)
3.	Toleza	1986-87	35°00'E	14°58'S	550 "
4,5.	Kadoma	1987-88			
6.	Makoka	1987-88			
7.	Chitala	1987-88	34°25'E	13°45'S	600 "
8.	Kasinthula	1987-88	34°47'E	16°04'S	100 "

2.7.1.2. **Formulations**

The suspension concentrate formulation of thiodicarb ("Larvin 375") is registered in all southern African countries, and constituted the standard thiodicarb treatment in all trials. In Zimbabwe the recommended "MULV" mixture contains 21% suspension concentrate by volume, with 17.5% molasses, and water; 5 l./ha. of this mixture is applied to fully-grown cotton. In Malaŵi, molasses is rarely added to sprays, and since storage problems occur with SCs at very high temperatures (which could for instance arise in the Shire valley), trials were carried-out with "WULV" mixtures containing the water dispersible granule (WG or "DF") formulation. Although provisional recommendations for oil-based ULV spraying still stand in both countries, the principal purpose for their inclusion in these trials was to assess their efficacy for use in francophone Africa. Thus comparisons were between the following techniques:

i. "WULV" containing the 37.5% SC formulation,

ii. Either in Zimbabwe: suspension concentrate MULV,
or in Malaŵi: thiodicarb 80% WG applied as a "WULV".

iii. Oil-based suspension (SU): UCLF8 in 1987, and UCLF5 diluted with Shellsol K during the 1988 trials. Where necessary, viscosity was adjusted with a vegetable oil.

2.7.1.3. **Dosage rates**

As well as spraying according to the normal recommendations, half rates were included for three reasons: firstly as an attempt to reduce the application cost of this rather expensive insecticide, secondly to investigate the consequences of reduced dosing by farmers, and thirdly because subtle differences between formulations and application methods are most likely to be observed at lower dosages. The normal rates for fully-grown cotton vary slightly between countries in the region; one litre of suspension concentrate represents 375g.a.i./ha. and many farmers spray at this rate, although treatments of up to 500 g.a.i./ha. are recommended in Malaŵi, and 400 g.a.i./ha. for fully grown cotton in Zimbabwe.

2.7.1.4. **Droplet Sizes and Disc Speeds**

There is approximately a three-fold order of difference in droplet volume between "small" and "large" droplets with diameters of 70µm. and 100µm. Variation within this range can be encountered in practice, and may affect pesticide recovery. Effects of formulation (see Chapter 3) are compounded by at least three factors that are directly attributable to machinery:

i. The characteristics of new atomisers may differ (cf. the Taurus Hi Spin with the Micro Ulva).

ii. Disc speeds may be considerably reduced towards the end of battery life - especially when sprayers are powered by disposable cells and financial restraints make farmers reluctant to discard them.

iii. Disc speed may vary significantly in poorly maintained or worn sprayers.

A further reason for investigating the efficacy of enlarged droplets is that there may be an interaction between droplet size

and evaporation, possibly giving improved recovery of large droplets with water-based sprays.

The smaller droplets were produced with nominal voltages of 12v. for the Turbair XJ, and 9v. for the Micro Ulva; battery packs containing a full complement of alkaline manganese cells maintained disc speeds (under load) of 130-140 rev.s^{-1} and 160-170 rev.s^{-1} respectively, throughout the seasons. Larger droplets were produced by slower disc speeds, adjusted with the voltage control pack described in section 2.2. Micro Ulva atomisers were adjusted to 110 rev.s^{-1} and Turbair XJs to 60 rev.s^{-1}; measured disc speeds were found to have altered by less than 2 rev.s^{-1} at the end of the season. In the trial sprayed with Taurus Hi-spins connected to 12v. accumulators, rotational speeds of 110-115 rev.s^{-1} were typical.

2.7.2. Experimental Designs

Trials containing drift spraying techniques are more difficult to execute than equivalent chemical efficacy evaluations, and very large areas of land are required in order to create representative droplet deposits. Classical block-type field trials are possible, but large plots (of at least 200m^2) and wide guards are essential to minimise downwind contamination to adjacent plots (Ciba Geigy 1981). Experiments described in section 4.1 were helpful for determining suitable plot sizes and sampling areas for the critical field trials.

The number of replicates and plot size were made as large as possible in relation to the available labour and land. Details for each trial are given in Appendix VI. All trials at Makoka took place on terraced fields with the ridges following the

contour of the slope. Plots were 20-24 ridges wide, and separated either by 5m. gaps or terrace embankments. Sampling zones were situated in the centre of each plot, to allow for changes in wind direction, and always at least 5m. from the periphery of the sprayed area. In Zimbabwe, a 6m. x 6m. central assessment area remained marked-out for the duration of the trials and the number of plant rows within the plot was always a multiple of 1,2,3 and 4 (i.e. of 12). Studies on droplet deposits (see section 4.4) indicated that the distance between plot sampling areas should not be significantly less than 30m., even to conform with the fairly imperfect criteria of less than 10% contamination to the adjacent downwind zone.

2.7.2.1. **Check Plots and Other Comparative Treatments**

In Malaŵi controls are routinely included in most experiments whereas in Kadoma they are not. The 1987, all trials contained plots sprayed with water or blank oil mixtures. During this season, two other standards were included: thiodicarb SC was applied at conventional low volume (CLV) with a knapsack and tailboom, and a commonly-applied pyrethroid. Since only one droplet size spectrum could possibly be created, CLV only accounted for half the normal number of plots. In Zimbabwe, the pyrethroid sprays consisted of fenvalerate ('Agrithrin' 20%EC) mixed with 25% molasses, and the standard full rate was 40 g.a.i./ha.. In Malaŵi, cypermethrin EC (20% 'Ripcord') was applied as a WULV at a standard rate of 40 g.a.i./ha.

In 1988, the designs were simplified, made completely multi-factorial and comparisons with other standards were not repeated. Data for untreated controls were obtained either from adjacent trials, or from a minimal number of unsprayed plots within the trial itself. In trial 5, lambda-cyhalothrin was included as a

complete factor.

2.7.2.2. **Scouting and Timing of Treatments**

In Zimbabwe, insecticide applications took place according to the recommended thresholds. For the purposes of the trial, spray timing was based on the mean pest scores for all plots (e.g. bollworm egg scores from 12 plants scouted in each plot were all added-up and expressed as a proportion of the 528 plants scouted in a 44 plot trial).

Other pest species were recorded and in Malaŵi, jassids, aphids and psyllids were also treated according to the bollworm schedule. In Zimbabwe, dimethoate MULV sprays were applied for aphid and red spider mite control, according to normal practice. In 1987, the plots in which they occurred were carefully recorded and both replicates of badly affected treatments only were treated. This made interpretation of results more complicated, and during the 1987-88 season, blanket sprays were applied to the whole trial. A brief description of scoring and evaluation techniques for these species is given in Appendix IVa.

2.7.2.3. **Volume Application Rates**

In order to make the comparison of the three CDA techniques more manageable, swath widths were altered according to two categories of plant height, rather than the three normally recommended for farmers (Anon., 1976, 1985).

In 1986-877 flow rates, swath widths and insecticide concentrations were adjusted according to the size of droplets, so that three times more liquid was applied in large droplet sprays than for fine sprays (see Table 2.7.2.). In the following season similar volume application rates were used for both disc speeds, partly because large discrepancies in the spray

logs indicated that such a complicated experiment was difficult to manage. Another reason was that applications of oil-based formulations at volumes up to 6 l./ha. were not commercially realistic, and in 1987-88 application rates were reduced to 1.1-1.6 l./ha. to improve their competitive potential. Although better than the previous season, the analyses of spray logs illustrate the difficulty in obtaining applications that accord with the target, when making-up mixtures of such different composition. The small differences that did occur during the second season were less likely to affect subsequent variability.

Table 2.7.2. Volume Application Rates in 1986-87.

Formulation/ application method	Target volume application rates (l./ha.: for fully grown cotton) Large droplets	Small droplets
"WULV" (Malaŵi)	16.7	5.6
"WULV" and MULV (Zimbabwe)	12	4
Oil-based	6	2
CLV tailboom	200	

2.7.2.4. **Summary of Trial Designs and Analysis**

Table 2.7.3. Summary of trial designs

Trial Treatment:	Formulations 2	3	Pyrethroid	CLV and Control	Design (§1)
1.	MULV	UCLF 8 }	As fourth	SC with tailboom	44 2,R
2.	WG	UCLF 8 }	main	and controls were	44 2,R
3.	WG	UCLF 8 }	treatment	blank formulations	44 2,R
4.	MULV	UCLF 5	None	} From trial	48 4,B
5.	MULV	UCLF 5, 1-Cyh. UL	Lambda-cyhalothrin as a second factor	} in adjacent C.R.I.	24 4,B
6.	WG	UCLF 5	None	Untreated control	40 3,R
7.	WG	UCLF 5	None	from adjacent trial	48 4,R
8.	WG	UCLF 5	None	untreated control	16 4,R

§1: Total number of plots in trial, number of replicates, and design: B. - blocks, R. - completely randomised.

The treatments used in all eight field station trials have been summarised in Table 2.7.3. All designs contained a "WULV"

mixture, with the 37.5% SC formulation listed as the first formulation factor.

Analyses of Malawi data are of total insect scores, summed for the whole spraying period; much of the Zimbabwean data has been analysed with assessment days incorporated as a separate factor. The most note-worthy observations are included in the main body of text with ancillary data shown in Appendix VI. Pests or natural enemies not included in the appendices were not present in numbers that were large enough for statistical analysis. Little reference is made to individual results where 95% probability significance levels (*) are indicated, since there is one chance in 20 that any such difference is simply fortuitous.

2.7.3. Estimation of Droplet Survival to the Cotton Canopy

Assessments of the number of spray droplets deposited in different parts of a crop are needed to determine coverage on the target and contamination outside the treated area. The technique used needs to be:-

i. objective,

ii. versatile and simple to use in the field,

iii. as non-destructive to the crop as possible.

Speed of assessment is desirable: to reduce carelessness derived from fatigue, to enable large numbers of observations to take place under conditions of limited manpower, and also where a marker dye is used which is quickly absorbed into the leaf cuticle, degraded by sunlight or washed off by rain.

2.7.3.1. Assessment of Deposited Droplet Numbers

The method described here is adapted from a gauge that was first used in Viet Nam (Bateman, 1985), and was modelled on a

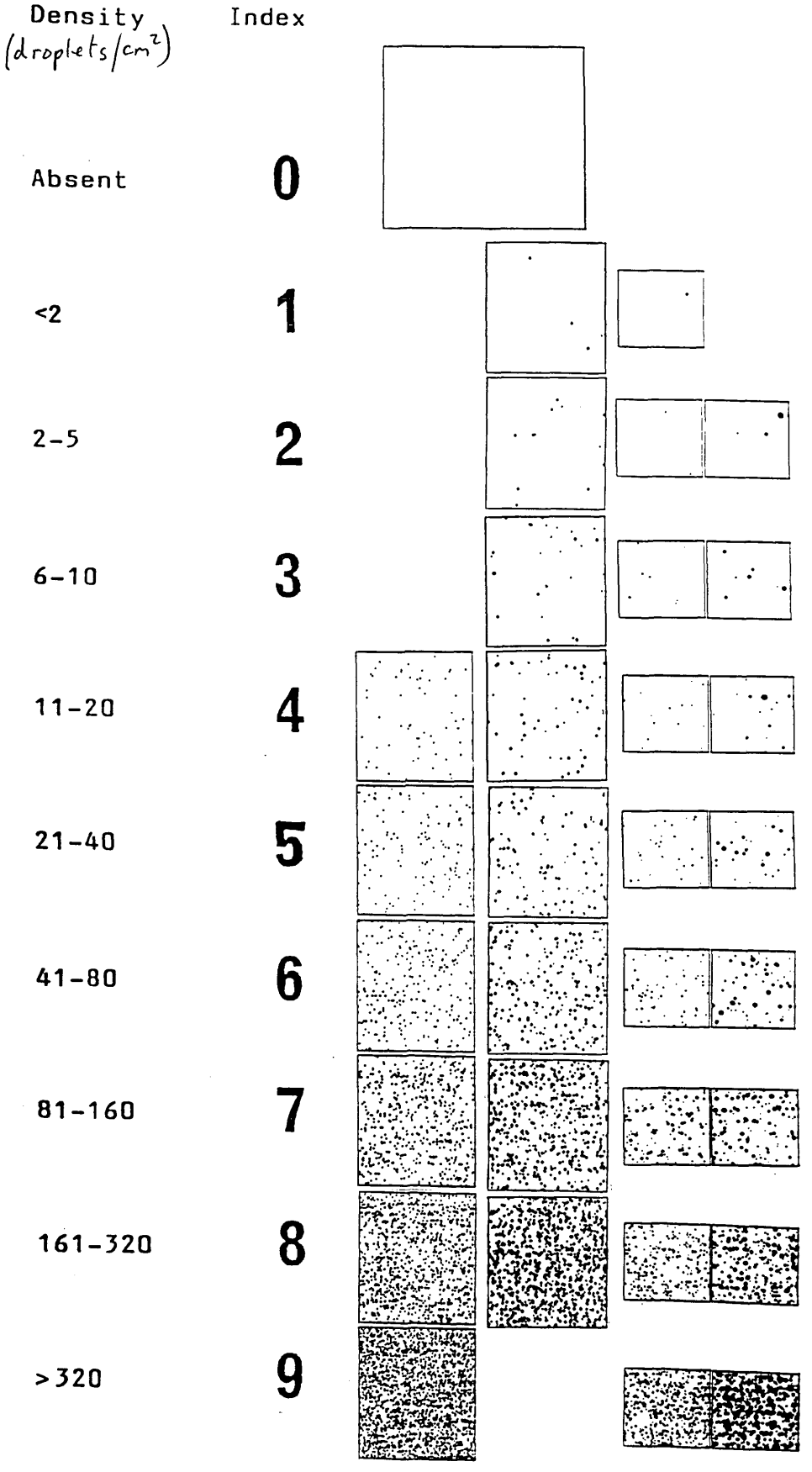
standardised 0-9 scoring system for recording observations such as pest infestations (IRRI, 1980). The numbers of marked droplets on artificial targets or plant material are compared with a sheet containing dotted areas which increase in a doubling progression with each index number.

For convenience and familiarity, the units are droplets per cm^2 (100 mm^2), however studies on deposited herbicide droplets carried out by Clipsham (1980) have indicated that wherever possible, the minimum assessment area should be $4cm^2$. The index may be converted back into actual droplet densities with the aid of computer spreadsheets or a specific computer programme (see Appendix III). Each index (I) represents a range rather than a specific droplet density, but is related by the formula:

$$\text{Equivalent mean droplet density} = 2^I - 1$$

Fig. 2.7.1. is a modified version of the original gauge, with each example produced by computer. Droplet sizes of the more heterogeneous examples are based on the normal distribution. Coalescence of droplets should be scored with a 9; scores at the upper end of the scale may therefore be poor estimates with large droplets. The gauge has been developed for insecticide work, but may be helpful for assessment of fungicide deposits. At lower droplet densities, (such as those associated with herbicide experiments), further categories between 0 and 1 may be required; indices consisting of decimal fractions, calculated in the same manner as above, could be converted into droplets per 1000 square centimetres (e.g. an index of 0.5 would represent about 41 droplets/ 100 cm^2.). The gauge also works with droplets deposited on the crop itself, when marked with fluorescent tracer materials (Staniland, 1959), but with ultra violet light, it is easier to work with a photocopy on transparent film.

Fig. 2.7.1. A Droplet Density Gauge (version 3). Computer-simulated examples: columns represent different stain sizes, and rows approximate median densities for each range.



2.7.3.2. **Downwind Spray Deposit Trials**

When evaluating drift sprays it has become common practice to apply formulations containing a marker material along a single swath line and then to measure droplets deposited at various distances downwind. The same track may be re-traced in order to improve droplet densities and compensate for wind fluctuations. The procedure described here is based on methods described by Pickin in Heinrichs et. al. (1981), but has been simplified so that useful field assessments can be made without sophisticated and expensive instruments. It assumes that estimates of pesticide deposit may be calculated from droplet numbers and average droplet volume (ADV) measurements, and therefore is restricted to C.D.A.

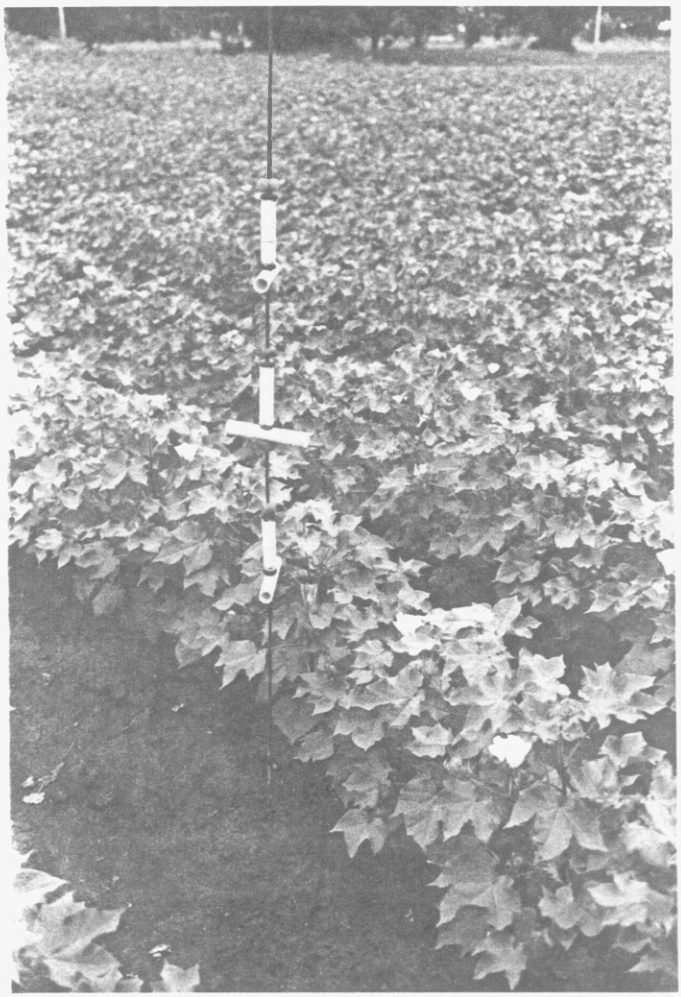
Spray deposit trials were carried-out at Kadoma during both trial seasons. Droplets were produced by a Micro Ulva at flow rates exceeding 40 ml/min. in order to reduce the risk of bimodal droplet spectra. The atomiser head was held approximately 0.5m. above crop, and the walking speed was approximately 1 m/s. Formulations or mixtures were coloured with a dye, and collected on 70 x 25 mm. Kromekote (R) cards (cf. 3x1 inch microscope slides) mounted horizontally, and vertically in the windward and leeward directions, on sampling posts in the upper crop canopy (Fig. 2.7.2). These were situated along the spray path, 0.5 and 1m. upwind and downwind, and 2,4,8,16 and 32m. downwind; in 1988 further sampling posts were positioned 2m. upwind. Rhodamine B dye was used in 1987 but this dye coagulated UCLF8 so plain mixing-oil (blank) was tested instead; in 1988 waxolene red was mixed with 70% UCLF5. Samples were taken from 3 stations in each assessed row. Assessments of large and small droplets for a given liquid were carried-out consecutively so that they were

deposited under similar meteorological conditions.

Fig. 2.7.2.

Sampling posts for mounting 'Kromekote' cards:

Only the lower tubes were used for assessment at the top of the cotton canopy, which was approximately 0.7m. tall for the 1987 tests and 0.9m. in 1988.



CHAPTER 3

LABORATORY STUDIES

3.1. INTRODUCTION

This chapter describes laboratory investigations into the flow and atomisation characteristics of oil and water-based suspensions with spinning disc sprayers. The general evaluation procedures were given in section 2.4..

Clear liquids were included as standards: in the case of water-based mixtures this was water and 0.1% Agral. Because the viscosity of oil-based formulations was more variable, comparative tests were carried-out on a range of materials including: Shellsol K, Risella EL oil, commercial UL formulations and Orchex 796. Unless stated otherwise, measurements took place at room temperature (20°C $\pm$ 3°). A brief review on viscosity measurement, and further details about the formulations tested, may be found in Appendix I.

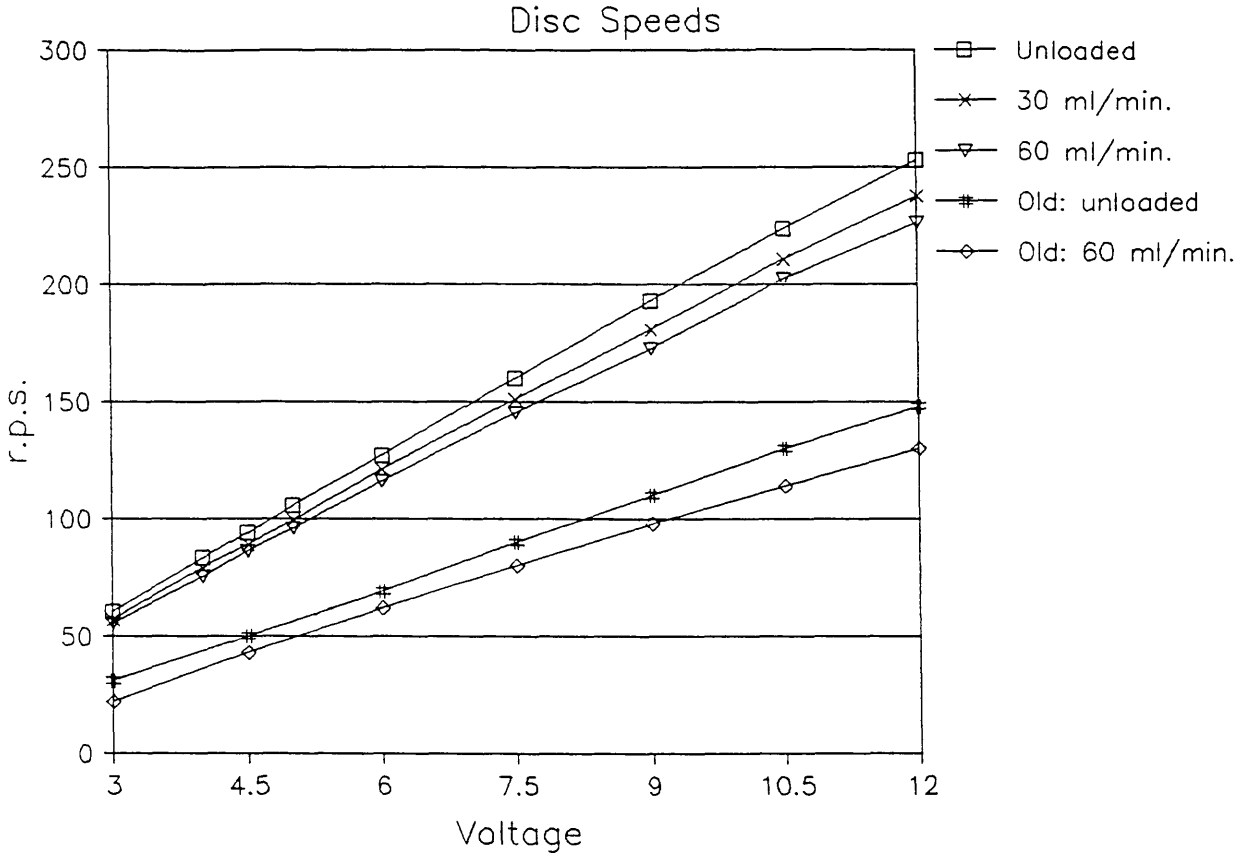
3.2 FORMULATION FLOW

3.2.1. Atomiser Design, Disc Speeds and Flow Rates

Rotational speeds of discs decrease at higher flow rates, especially with smaller atomisers such as the 'Micro Ulva'. Ageing appears to be a more important factor however, and is further investigated below (section 3.5). An atomiser that was evaluated after one seasons use in the field, rotated at 57% of the normal disc speed and 50% at 4.5v.; it consumed 65% more power than new motors at 9v., and 73% more at 4.5v. (Fig. 3.2.1.). Disc speeds and power consumption of the Turbair XJ are less affected by flow rate and age; Fig. 3.2.2. shows effects of increasing: (A) water flow rate and restrictor size with the motor operating at a fixed 10.5 v, and (B) voltage.

Fig. 3.2.1. Disc speeds and power consumption of the 'Micro Ulva':

New atomisers (average from sample of 5 nozzles) had been used only in the laboratory, the old nozzle was taken from Kadoma after one season of spraying.



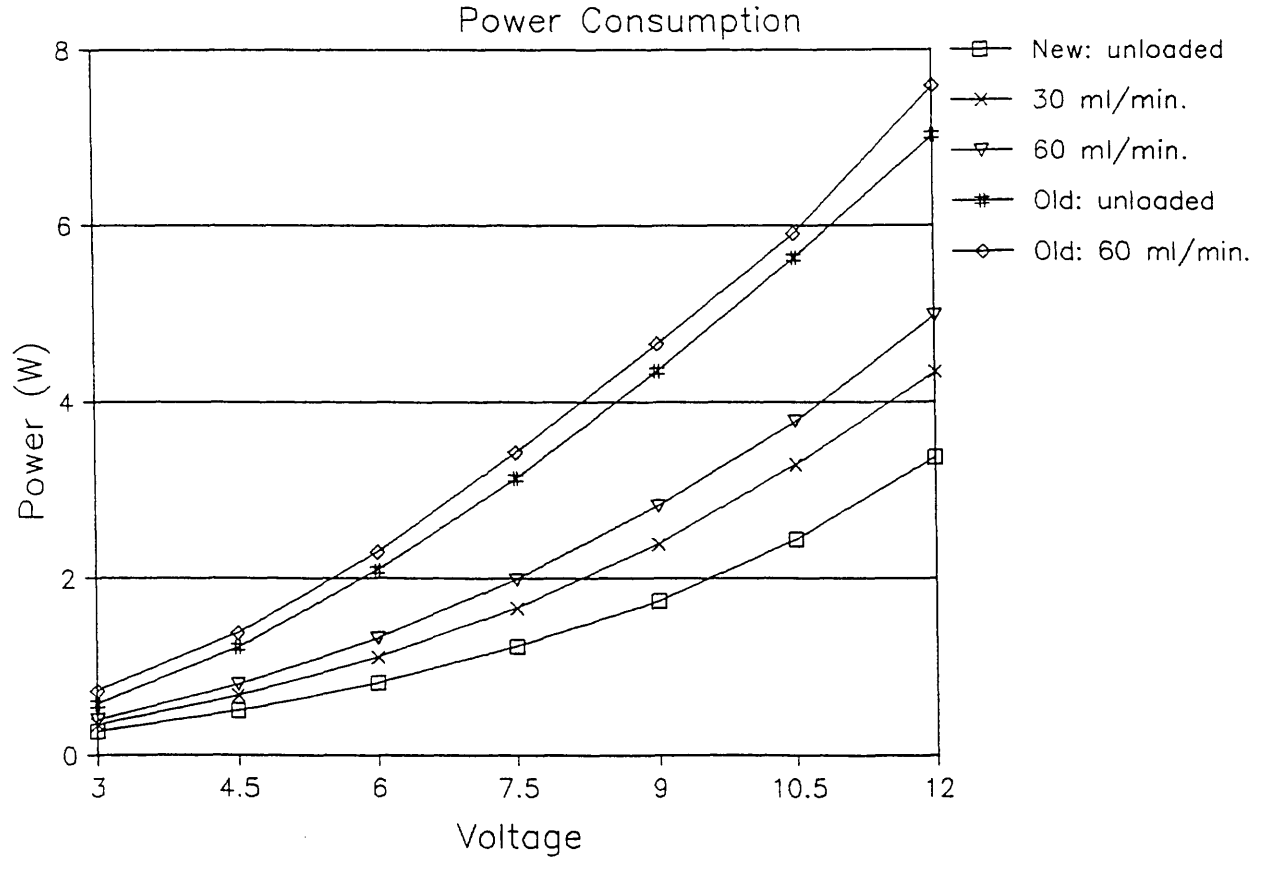
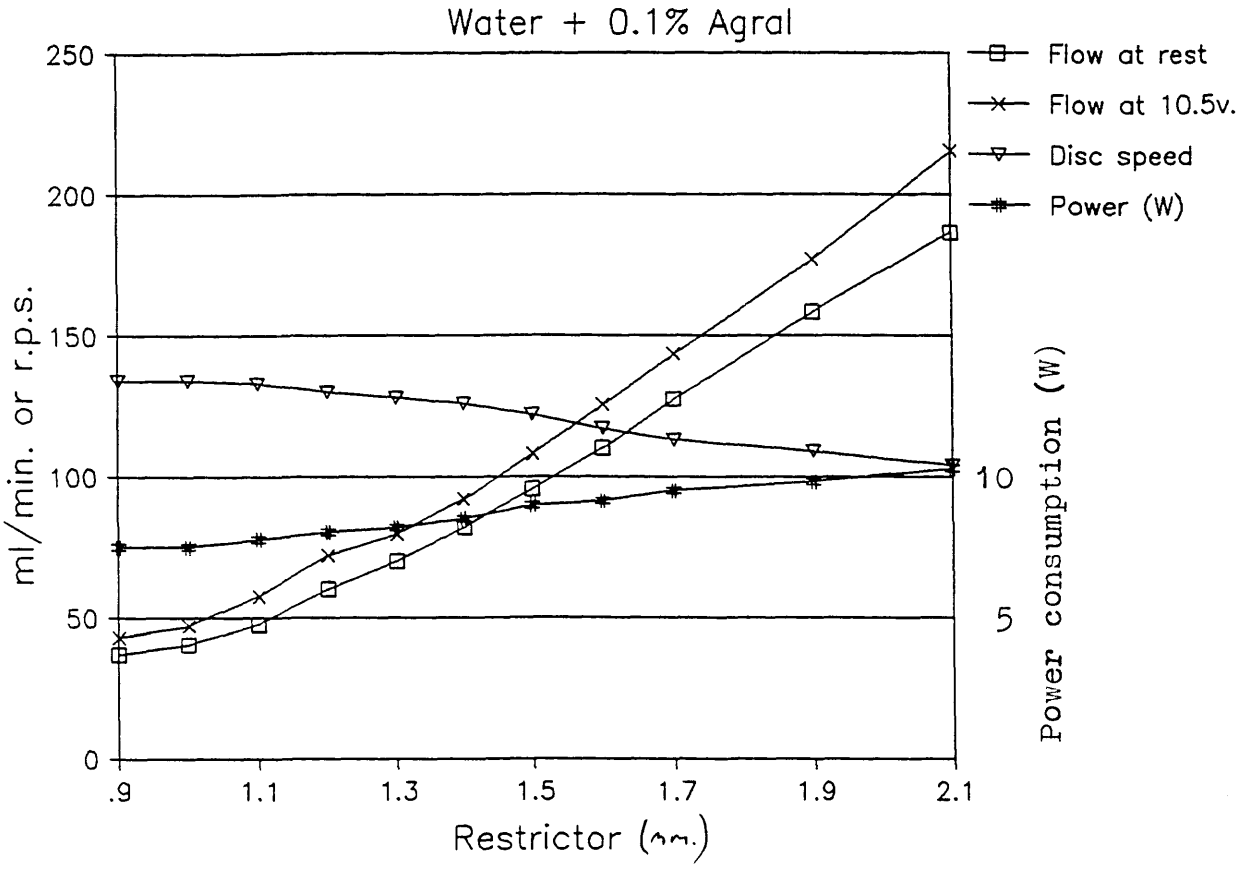


Fig. 3.2.2. Turbair XJ: A. Flow rate and restrictor size.

B: Voltage, disc speed, power consumption and flow rate: the old nozzle was taken from Makoka after two seasons of spraying.



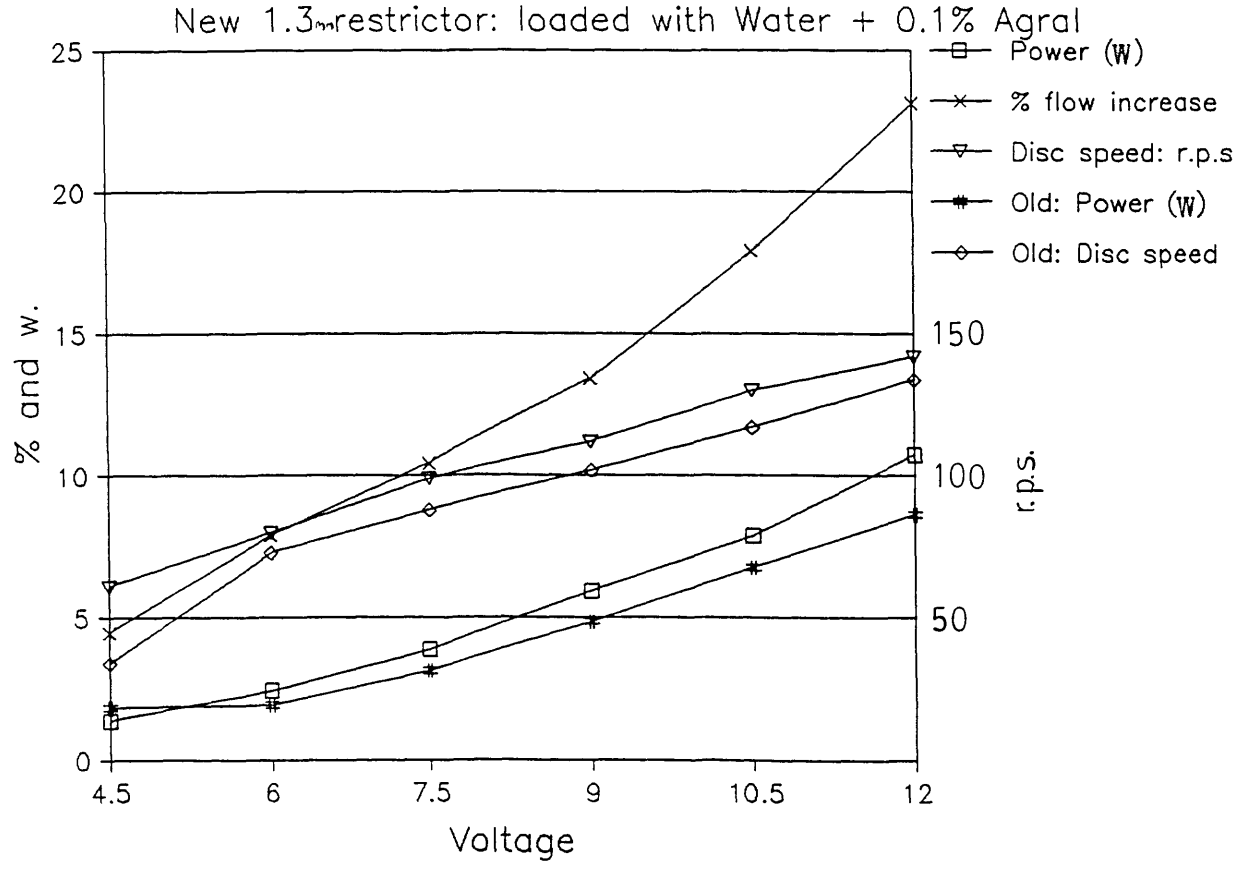
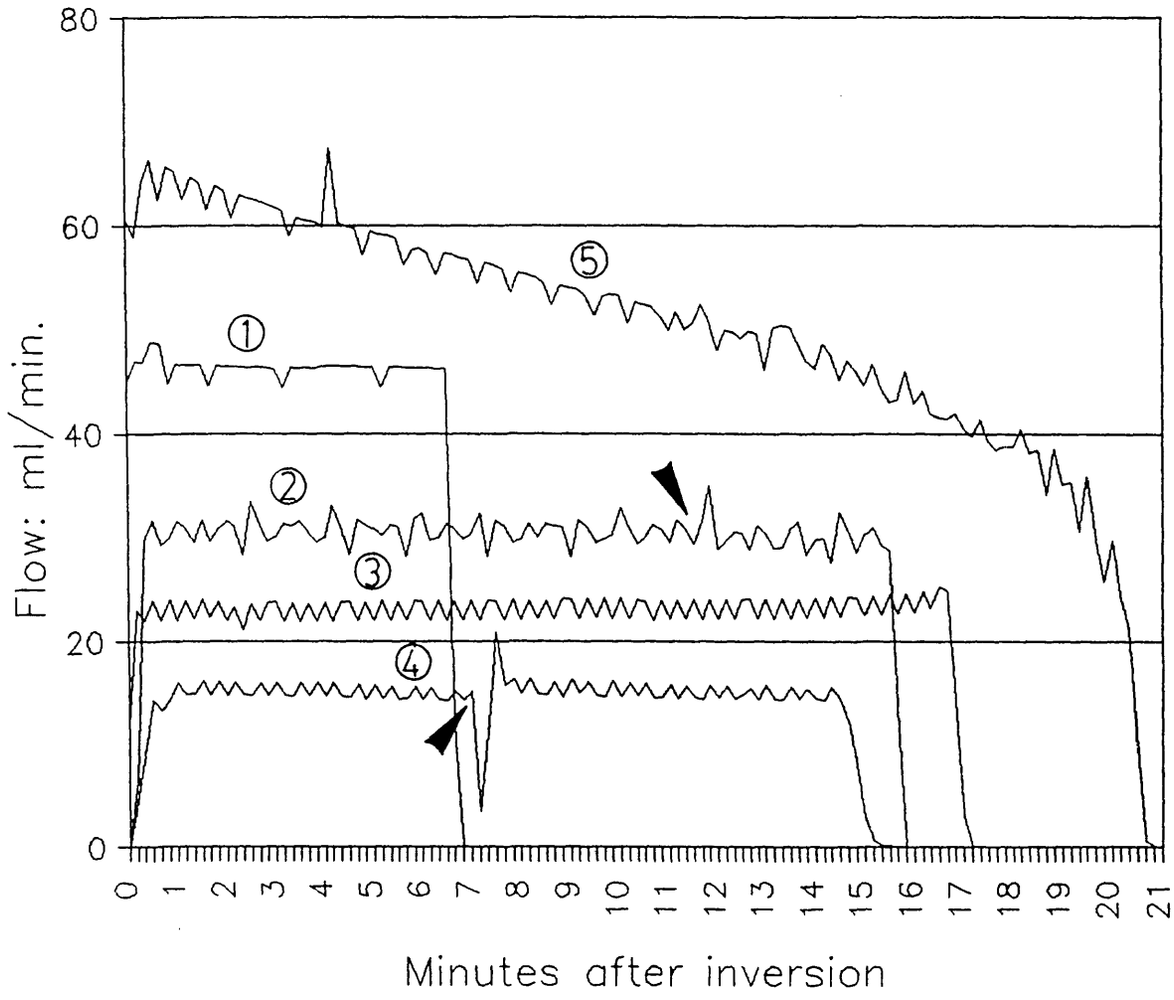


Fig. 3.2.3. Flow rates with reservoir emptying.

1: Micro Ulva, 1.3 mm. restrictor, Water + 25% Molasses.
2: Micro Ulva, 1.0 mm. restrictor, Water + 0.1% Agral.
3: Micro Ulva, 1.56 mm. restrictor, 11-DLM-Y-26-2 (see below).
4: Micro Ulva, 1.56 mm. restrictor, soyabean oil (250ml. only).
5: Aspee CDA, restrictor fixed, Water + 0.1% Agral.

Arrows indicate when the atomiser was switched on (to 7.5v.).



Because of reduced pressure at the restrictor orifice, the flow rate of the Turbair XJ increases proportionally with rotational speed, and with the motor operating at 12 v. water flows approximately 23% faster than simply inverting the reservoir and detached feed stem. A nozzle tested after two seasons of field use, typically revolved at 91% of the speed and consumed approximately 22% more power than new atomisers, (within the normal operating range of voltages).

Fig. 3.2.3. depicts four examples of flow rate being monitored, at 10 second intervals, during the emptying of the 500 ml. reservoir of the 'Micro Ulva'. Although the 'Aspee CDA' sprayer was not otherwise involved in laboratory or field work, the fifth line has been included to illustrate the consequences of a direct connection between the air space in the reservoir and the atmosphere. The 'Micro Ulva' was normally evaluated with the motor not running and the disc removed, since flow rates in single disc atomisers are little affected by rotation. This is shown by the second and fourth lines, where the disc was left on a sprayer which was mounted in a cowl for collecting droplets, and the motor was switched on at the times indicated.

3.2.2. **Water-based Mixtures**

Table 3.2.1. shows some average readings for flow rates with Micro Ulva restrictors and aqueous mixtures. Malaŵian style unmodified water-based CDA mixtures usually contain less than 10% formulated product. The measurements with 10% thiodicarb SC took place on a different occasion to the others, and represented a "WULV" mixture to be sprayed at approximately 11 l./ha. Small inconsistencies with water + Agral indicated that differences between individual restrictors and bottle tightening are more important than the change in viscosity of the mixture itself.

Table 3.2.1.

Flow rates of some aqueous mixtures with the Micro Ulva.

Restrictor	Flow rate (in ml./min.) of water with: 0.1% Agral	10% thiodicarb SC	35% molasses	molasses: % reduction
Red (1.56mm)	78	78	71.5	8.3
Orange (1.3mm)	52	53	46	8.0
Yellow (1.0mm)	28	29	25.5	9.0
Blue (0.78mm)	17.5	15.5	n/a.	

In Zimbabwe, "MULV" mixtures with EC formulations normally contain 35% molasses. Flow rates were measured using molasses obtained in the UK, and were 8-9% lower than water + 0.1% Agral. The viscosity of such mixtures may vary with the source of molasses and some batches, like the 23° brix concentated molasses solubles (CMS), may flow at rates that are little lower than plain water. The recommended mixture containing 21% thiodicarb SC and 17.5% molasses was slightly more viscous than those for EC formulations (Table 3.2.2.), and the 'Larvin' content was reduced to 20% for the field trials.

Table 3.2.2.

Characteristics of Water-based Mixtures

Fluid	Density	Efflux time *1(s)
Water	1.00	11.9
35% molasses (Zimbabwe, 1987-88 batch)	1.10	12.1
35% molasses (purchased in UK)	1.15	13.3
23° C.M.S. (Zimbabwe)	1.08	12.0
21% thiodicarb SC, 17.5% Molasses	1.12	13.6

* BSS 1733, Type B4 cup at 25°C.

3.2.3. Oil-based Mixtures

Measurements made by the VC4 or B4 cup are usually expressed simply in terms of the total efflux time in seconds (Walters, 1980). Adequate flow - in the order of 30 ml/min. - seems to be achievable with most sprayers (with an appropriate restrictor fitted) when formulations can pass through a VC4 cup in less than

20 seconds.

Table 3.2.3. Characteristics of Oil-based Fluids

Fluid	Density	Efflux time §1
Shellsol K	0.785	11.9
75% Soyabean oil + Shellsol K §2	0.888	18.2
78% Cottonseed oil + Shellsol K §2	0.885	18.8
2.5% Cypermethrin UL (ICI)	0.897	13.5
L-cyhalothrin UL (Karate) blank	0.936	19.5
Orchex 796	0.834	19.6
Risella EL oil	0.871	20.4
Soyabean oil	0.920	25.7
UCLF8	0.912	18.4
70% UCLF5 in Shellsol K	0.994	18.6
11-DLM-Y-26-2	0.916	22.5
UCLF5	1.017	41.1

§1 Time in seconds in VC4 cup at 18°C $\pm$ 2°
§2 Equivalent to mixing oils used in 1987 and 1988 trials

The formulating company prepared a series of oil-based ultra low volume suspensions (SU) of Thiodicarb which are referred-to by their codes. Three of these - UCLF 8, 11-DLM-Y-26-2 and UCLF 5 - proved to have an acceptable shelf life and provided a useful range of apparent viscosity. UCLF5 was originally formulated for application by aircraft, with the intention that it be diluted with oils such as diesel fuel, and kerosene. Samples were subject to settling, although with vigorous agitation the particulate matter could be re-suspended in the straw coloured solvent. On dilution with both deodorised kerosene and Shellsol K, a yellow crystalline solid (probably sulphur) precipitated-out. Since this could cause blockages or uneven flow, the normal procedure was to allow dilutions to stand for a few minutes, before decanting off the useful portion. Increased dilutions settled faster, and more vigorous agitation was required to achieve re-suspension.

A problem associated with very viscous liquids is illustrated in Fig. 3.2.4. Immediately after inverting the

atomiser head into the spray position, it may take more than 30 seconds for the flow rate to reach its maximum, and may be accompanied by an early flow surge with even a secondary diminution. Consistant flow only occurs when the air pressure in the reservoir has reached an equilibrium, and liquid has cleared from the air-bleed. Although of secondary importance when treating large fields, this effect could influence treatments in critical spray trials and smallholder's fields, with frequent turning at the ends of swaths. Of all the sprayers tested, only the 'Ulva' has a restrictor-airbleed system capable of applying undiluted UCLF5. To achieve a flow rate of 60 ml/min. would require a new restrictor to be moulded - the orifice diameter being between that of the grey (2.0 mm.) and the green (2.9 mm.). The maximum possible flow on the Turbair XJ is in the order of 20 ml./min. and is limited by the air bleed; the flow rate of the example illustrated (with a re-drilled restrictor: a Number 33 clearing hole is equivalent to 2.87 mm.) was similar to that of a 2.0 mm. orifice. Because of its air bleed design, it was not possible to produce any consistent flow with undiluted UCLF5 in the Berthoud C8.

Fig. 3.2.4. Flow of UCLF5 in the 'Ulva' and Turbair 'XJ'.

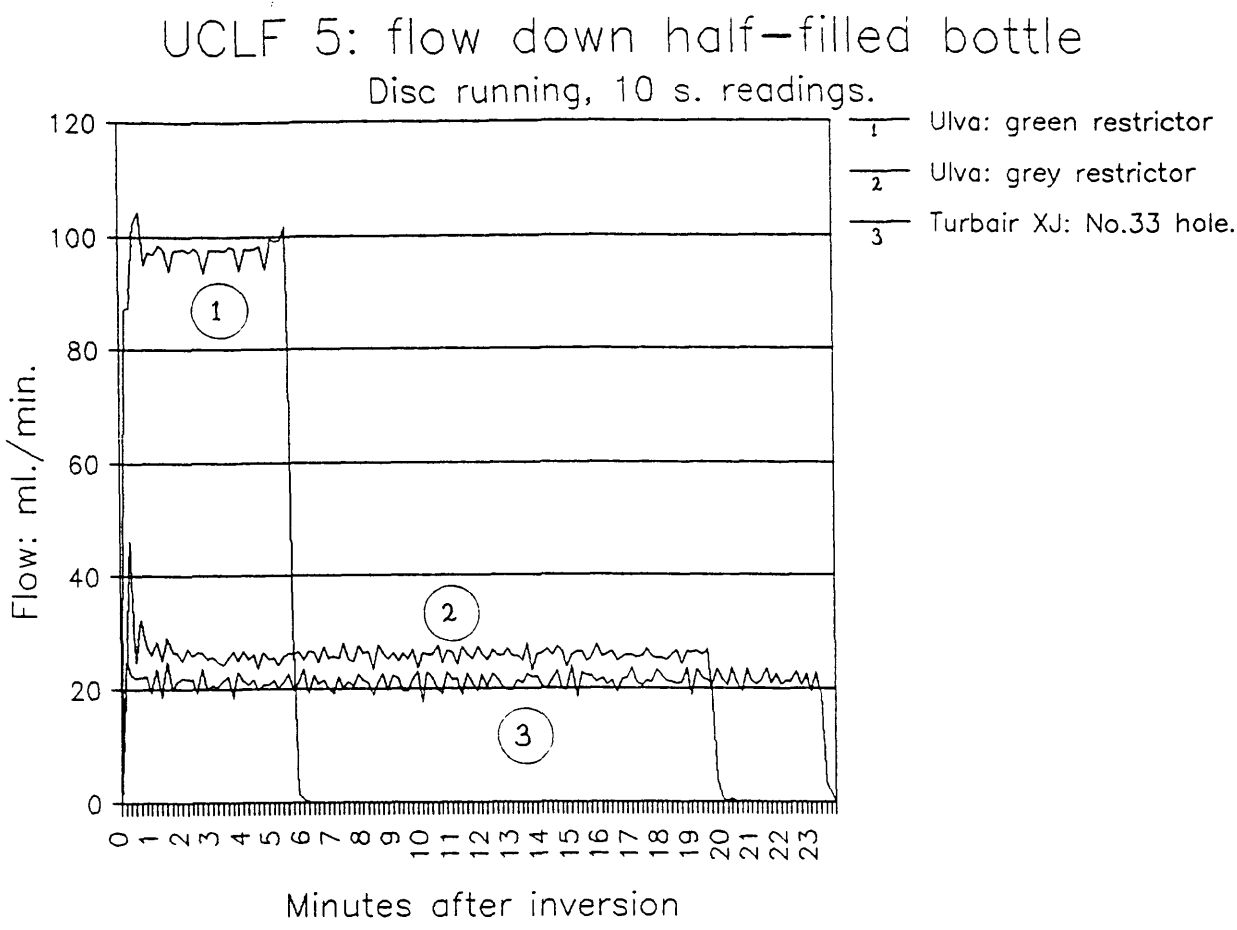
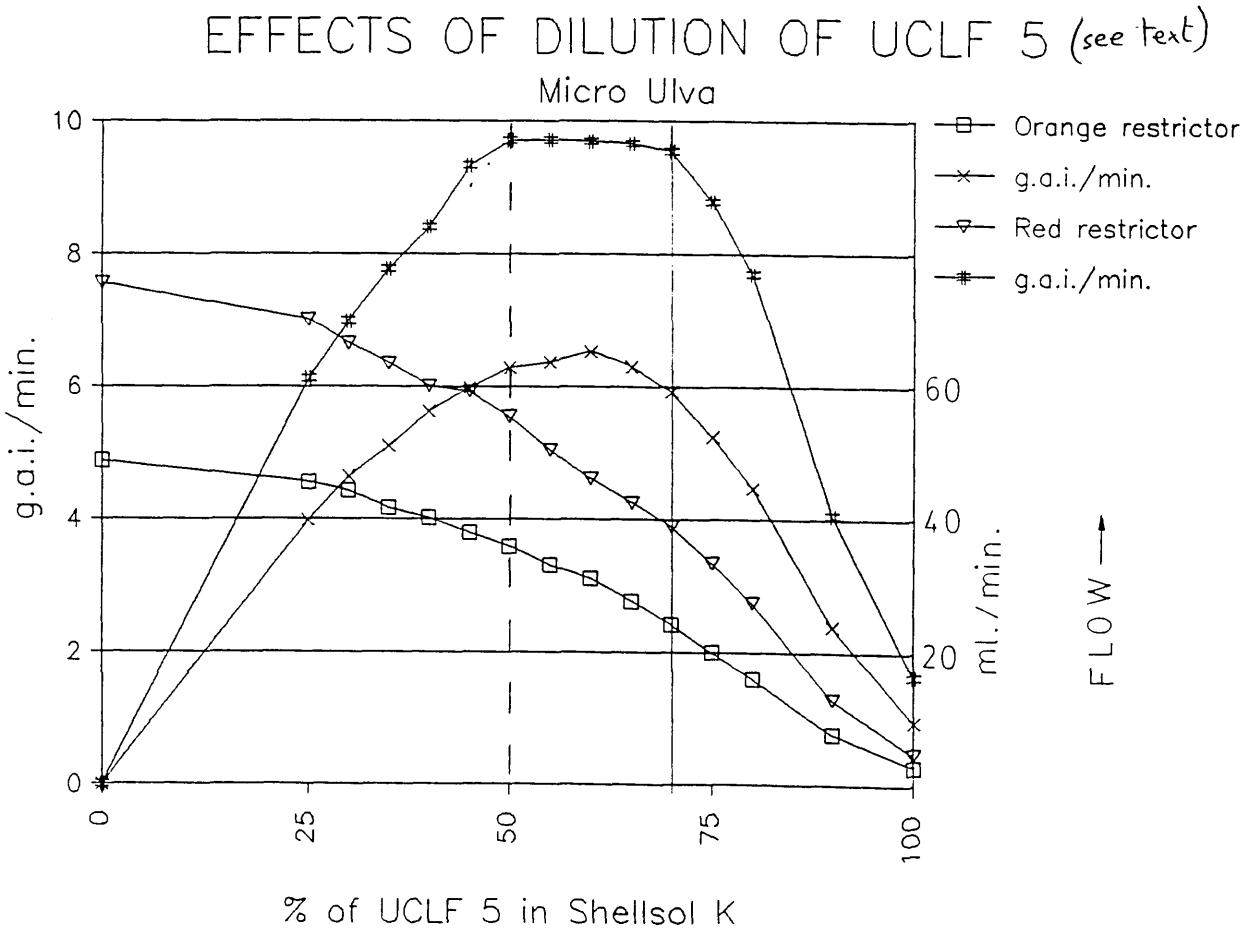


Fig. 3.2.5. Effects of dilution of UCLF5 on liquid and a.i. flow.



The principal formulating constituent in UCLF 5 is Orchex 796: a highly refined petroleum oil. Compared with Shellsol K, it has a higher distillation range (208-253 vs. 190-225°C), aromatic hydrocarbon content (10.2 vs. <0.5%) and viscosity (12.42 cp. @ 37.8°C vs. approximately 1.5 cp. at 20°C). Shellsol K was more easily obtainable in the trial countries, has a proven low phytotoxicity for all practical droplet sizes (Coutts, 1974), and is a constituent of other ULV formulations, such as those marketed as part of the Turbair system. (P. Fuller Lewis, Pers. Comm.).

Fig. 3.2.5. shows an example of the relationship between flow rate and increasing Shellsol K content. As insecticide content (% a.i./l) was decreased, curves for flow rate of active ingredient (g.a.i./min) show marked "plateaux". A 'Micro Ulva' fitted with a red restrictor would apply dilutions of UCLF5 between 50% and 70% at increasing volume application rates, but similar dosages (g.a.i./ha.). Maxima are in the order of 10 g.a.i./min for the Micro Ulva with a red (1.56 mm.) restrictor and 7 g.a.i./min. if the orange (1.3 mm.) restrictor is fitted. The plateaux become more marked at higher flow rates (obtained by further drilling-out the restrictor orifice). Dilutions containing less than 50% UCLF5 must be re-homogenised by prolonged, vigorous shaking before use; if medium-term storage is necessary, mixtures for field trials should contain not more than 30% Shellsol K.

3.3. CALIBRATION TEST RESULTS

The aspect of the disc was important as shown in Figs. 3.3.1.. The normal disc orientation of rotary insecticide atomisers is approximately 45° to the horizontal, and discs were positioned at this angle ($\pm$ 10°) during the course of the formulation studies. For the purposes of comparison between instruments, the test rig was normally positioned in a horizontal plane. In three separate comparative experiments, (e.g. Fig. 3.3.2.) small but significant increases in VMD (up to 8%) and heterogeneity took place when air extraction was turned off. Variations such as aspect of disc and its juxtaposition to the LASER beam and suction device therefore compounded any discrepancies due to the method of measurement. For simplicity, four sets of readings for disc speeds between 120-180 rev.s^{-1} are illustrated. High variability occurred at 100 rev.s^{-1} (ST1800 model independent analysis: VMD = 109, l.s.d. = 6.3), presumably because small differences in formulation, flow rate and disc speed determine whether the spray distribution is unimodal or bimodal.

Analyses of trends in VMD measured with the Malverns ST1800 and 2600 are illustrated in Fig. 3.3.3.; averaged parameters are summarised in Table 3.3.1. where comparisons are also made with single readings from other instruments. Individual readings from three versions of Malvern instrument are illustrated in Figs. 3.3.4.-6. Number distributions from the 2200 and 2600 series are shown both analysed by the standard procedure, and re-analysed from size class distribution data with the 0 to 15.5µm. classes set to zero. Droplet distributions measured with the two temporal sampling instruments are shown in Figs 3.3.7. - 3.3.8..

Table 3.3.1.

Comparison of LASER droplet sizing techniques.

DROPLET SIZING TECHNIQUES CALIBRATION Micro Ulva test rig @ 60 ml/min.

Disc speed: r.p.s.	120				140				160				180			
parameter	VMD	Span	ADV	NMD	VMD	Span	ADV	NMD	VMD	Span	ADV	NMD	VMD	Span	ADV	NMD
Malvern ST1800	(estimated from volume distribution)				(12 replicates)											
model independent:																
mean	86	1.34	162	53	72	1.27	86	39	66	1.23	66	35	60	1.19	54	34
l.s.d.	1.58	0.11	12.02	3.65	1.99	0.16	6.71	3.86	1.89	0.17	5.51	3.60	1.83	0.16	3.61	2.52
Maximum	90	1.67	207	65	76	1.71	110	50	71	1.90	82	43	65	1.62	65	40
Minimum	81	1.01	140	43	66	0.76	73	29	61	0.72	53	27	55	0.73	46	28
Rosin Rammler:																
mean	86	0.70	152	50	71	0.68	95	44	65	0.71	65	37	60	0.71	52	35
l.s.d.	2.09	0.10	39.99	10.04	1.98	0.08	25.59	7.71	1.72	0.09	19.31	7.43	1.90	0.08	14.46	6.57
Maximum	95	1.10	254	72	76	0.96	188	67	70	1.03	135	58	65	1.06	104	53
Minimum	81	0.48	15	10	65	0.41	18	15	61	0.49	10	10	54	0.52	5	8
Malvern 2200 (MI)	86	0.86	20	8	72	0.72	7	8	64	0.72	6	8	60	0.63	4	8
estimate: size ranges >15.5 µm.			236	68			154	60			115	55			98	53
Malvern 2200 (RR)	88	0.65	192	58	73	0.62	120	51	65	0.59	92	48	61	0.61	73	44
Malvern 2600	Malvern calculations (3 replicates)															
model independent:																
mean	78	0.77	135	52	70	0.53	75	39	63	0.63	4	8	59	0.60	4	9
l.s.d.	0.33	0.06	0.94	0.43	1.31	0.06	42.62	15.60	0.83	0.06	3.08	3.31	1.31	0.00	0.44	0.35
Maximum	79	0.80	136	52	71	0.60	102	48	64	0.70	6	9	60	0.60	5	9
Minimum	78	0.70	134	51	69	0.50	27	22	62	0.60	1	4	58	0.60	4	8
Example, estimated from volume distribution:																
Malvern calculation	79	0.80	134	52	70	0.60	27	22	62	0.70	5.1	9.3	58	0.60	4.1	8.8
estimate §	79		138	54	71		90	44	62		6	8	58		5	8
estimate: size ranges >15.5 µm.			138	54			90	44			97	53			76	48
Rosin Rammler:																
mean	82	0.60	114	45	72	0.53	87	43	66	0.53	76	44	61	0.60	20	20
l.s.d.	0.91	0.00	79.26	23.95	2.02	0.06	59.43	21.97	1.06	0.06	20.15	7.66	1.95	0.00	13.09	6.62
Maximum	83	0.60	161	59	73	0.60	129	57	67	0.60	91	49	63	0.60	34	27
Minimum	82	0.60	26	19	70	0.50	22	19	65	0.50	54	36	59	0.60	12	16
Knollenberg PMS (1D) (1)	131	0.59	473	77	120	0.65	402	73	117	0.67	357	68	115	0.65	331	65
(2)	139	0.59	703	92	135	0.69	647	89	113	0.72	266	57	144	0.60	613	83
Aerometrics: temporal	87	0.76	276	71	73	0.78	176	62	68	0.79	135	57	61	0.73	102	52
" spatially reduced	83	0.80	263	68	70	0.78	150	59	65	0.78	114	53	59	0.72	86	48

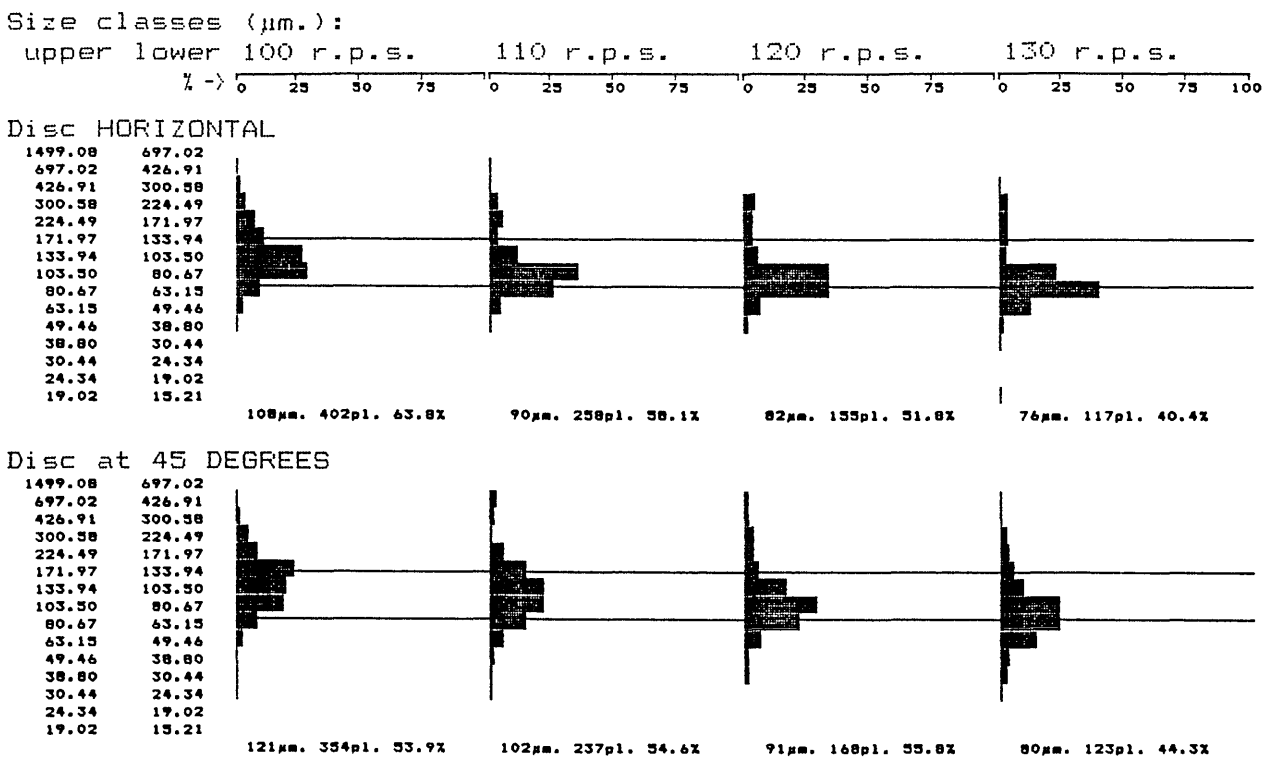
§: estimated from volume distribution data only

Malvern 2200 and Aerometrics: one set of readings only

SPAN: $\frac{D(v,0.9) - D(v,0.1)}{V.M.D.}$

Fig. 3.3.1. Test rig: effects of disc orientation.

Malvern ST1800 P.S.A.
Test Rig Orientation Study.
Percentage distributions by VOLUME



Parameters are: VMD (µm.), VADV (pl.), and estimated % droplet volume between 75 - 150µm.

Orientation at lower disc speeds (model independent only).

VMD

Source	Sum of Squares	DF	Mean Squares	F	Significance
Test Runs	63.27	2	31.63	1.902	N.S.
Disc Speeds	6007.87	4	1501.97	90.299	*****
Orientation	1241.63	1	1241.63	74.647	*****
Di. x Or.	243.20	4	60.80	3.655	*
Contrasts					
Linear	5742.82	(1)	5742.82	345.260	*****
Quadratic	264.30	(1)	264.30	15.890	***
Cubic	0.60	(1)	0.60	0.036	N.S.
Quartic	0.15	(1)	0.15	0.009	N.S.
Residual (Error)	299.40	18	16.633		
TOTAL	7855.37	29			

Coefficient of Variation = 4.5%

Fig. 3.3.2. Effects of droplet suction and other experimental conditions (Malvern ST1800).

Micro Ulva, 60 ml/min

VMD

Source	Sum of Squares	DF	Mean Squares	F	Significance
Tests [blocks]	21.59	1	21.59	11.275	**
Analysis type	3.40	1	3.40	1.776	N.S.
Suction	88.65	1	88.65	46.302	*****
Liquid	2288.18	1	2288.18	1195.119	*****
Disc speed	746.17	1	746.17	389.727	*****
An. x Su.	0.03	1	0.03	0.014	N.S.
An. x Li.	1.07	1	1.07	0.557	N.S.
An. x Di.	1.87	1	1.87	0.978	N.S.
Su. x Li.	1.30	1	1.30	0.678	N.S.
Su. x Di.	0.21	1	0.21	0.112	N.S.
Li. x Di.	46.81	1	46.81	24.451	***
An. x Su. x Li.	0.01	1	0.01	0.005	N.S.
An. x Su. x Di.	0.25	1	0.25	0.130	N.S.
An. x Li. x Di.	0.14	1	0.14	0.075	N.S.
Su. x Li. x Di.	0.00	1	0.00	0.001	N.S.
An. x Su. x Li. x Di.	0.00	1	0.00	0.000	N.S.
Total (all treatments)	3178.10	15	211.87	110.662	*****
Residual (Error)	28.72	15	1.915		
TOTAL	3228.41	31			

Coefficient of Variation = 2.2%

No.	Analysis type	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: droplet size: microns				0 70.00
1	Model Independent	63.86	2.52	1.587	
2	Rosin Rammler	63.21	2.67	1.798	
	Suction				0 70.00
1	no suction	61.87	2.51	1.628	
2	suction	65.20	2.60	1.665	
	Liquid				0 70.00
1	plain tap water	71.99	1.69	0.636	
2	water +20% Acetone	55.08	1.03	0.307	
	Disc speed				0 70.00
1	160 r.p.s.	68.37	2.55	1.523	
2	200 r.p.s.	58.71	1.96	1.045	

C.V.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Tests [blocks]	0.00	1	0.00	1.373	N.S.
Analysis type	0.37	1	0.37	166.329	*****
Suction	0.01	1	0.01	4.857	*
Liquid	0.01	1	0.01	4.406	N.S.
Disc speed	0.01	1	0.01	2.925	N.S.
An. x Su.	0.01	1	0.01	3.447	N.S.
An. x Li.	0.00	1	0.00	0.242	N.S.
An. x Di.	0.01	1	0.01	3.674	N.S.
Su. x Li.	0.01	1	0.01	3.467	N.S.
Su. x Di.	0.01	1	0.01	3.123	N.S.
Li. x Di.	0.00	1	0.00	0.364	N.S.
An. x Su. x Li.	0.00	1	0.00	1.603	N.S.
An. x Su. x Di.	0.00	1	0.00	1.019	N.S.
An. x Li. x Di.	0.00	1	0.00	1.121	N.S.
Su. x Li. x Di.	0.00	1	0.00	0.393	N.S.
An. x Su. x Li. x Di.	0.00	1	0.00	0.005	N.S.
Total (all treatments)	0.44	15	0.03	13.132	*****
Residual (Error)	0.03	15	0.002		
TOTAL	0.47	31			

Coefficient of Variation = 7.3%

No.	Analysis type	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: homogeneity indices				0 0.70
1	Model Independent	0.76	0.02	0.007	
2	Rosin Rammler	0.54	0.01	0.003	
	Suction				0 0.70
1	no suction	0.63	0.03	0.019	
2	suction	0.67	0.03	0.028	
	Liquid				0 0.70
1	plain tap water	0.67	0.03	0.023	
2	water +20% Acetone	0.63	0.03	0.025	
	Disc speed				0 0.70
1	160 r.p.s.	0.63	0.04	0.033	
2	200 r.p.s.	0.66	0.03	0.015	

Fig. 3.3.3. Trends in VMD analyses of Malverns ST1800 and 2600.

Micro Ulva Test Rig (see text)

Malvern ST1800 readings.

VMD

Source	Sum of Squares	DF	Mean Squares	F	Significance
Test Runs	1274.58	11	115.87	4.489	****
Disc Speeds	50019.78	5	10003.96	387.538	*****
Analysis Type	79.51	1	79.51	3.080	N.S.
Di. x An.	9.12	5	1.82	0.071	N.S.
Contrasts					
Linear	44836.33	(1)	44836.33	1736.893	*****
Quadratic	4605.26	(1)	4605.26	178.401	*****
Cubic	548.27	(1)	548.27	21.239	****
Quartic	0.33	(1)	0.33	0.013	N.S.
Quintic	29.58	(1)	29.58	1.146	N.S.
Residual (Error)	3123.51	121	25.814		
TOTAL	54506.49	143			

Coefficient of Variation = 6.8%

No.	Disc Speeds	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
Units (untransformed) are: Droplet diameters (um)					0 — 110.00
1	100 r.p.s.	110.21	2.24	1.090	
2	120 r.p.s.	87.04	1.17	0.380	
3	140 r.p.s.	72.08	0.63	0.134	
4	160 r.p.s.	66.00	0.69	0.174	
5	180 r.p.s.	60.33	0.64	0.162	
6	200 r.p.s.	55.12	0.68	0.199	
Analysis Type					0 — 110.00
1	Model Independent	75.87	2.34	5.209	
2	Rosin Rammler	74.39	2.27	4.992	

Malvern 2600 readings.

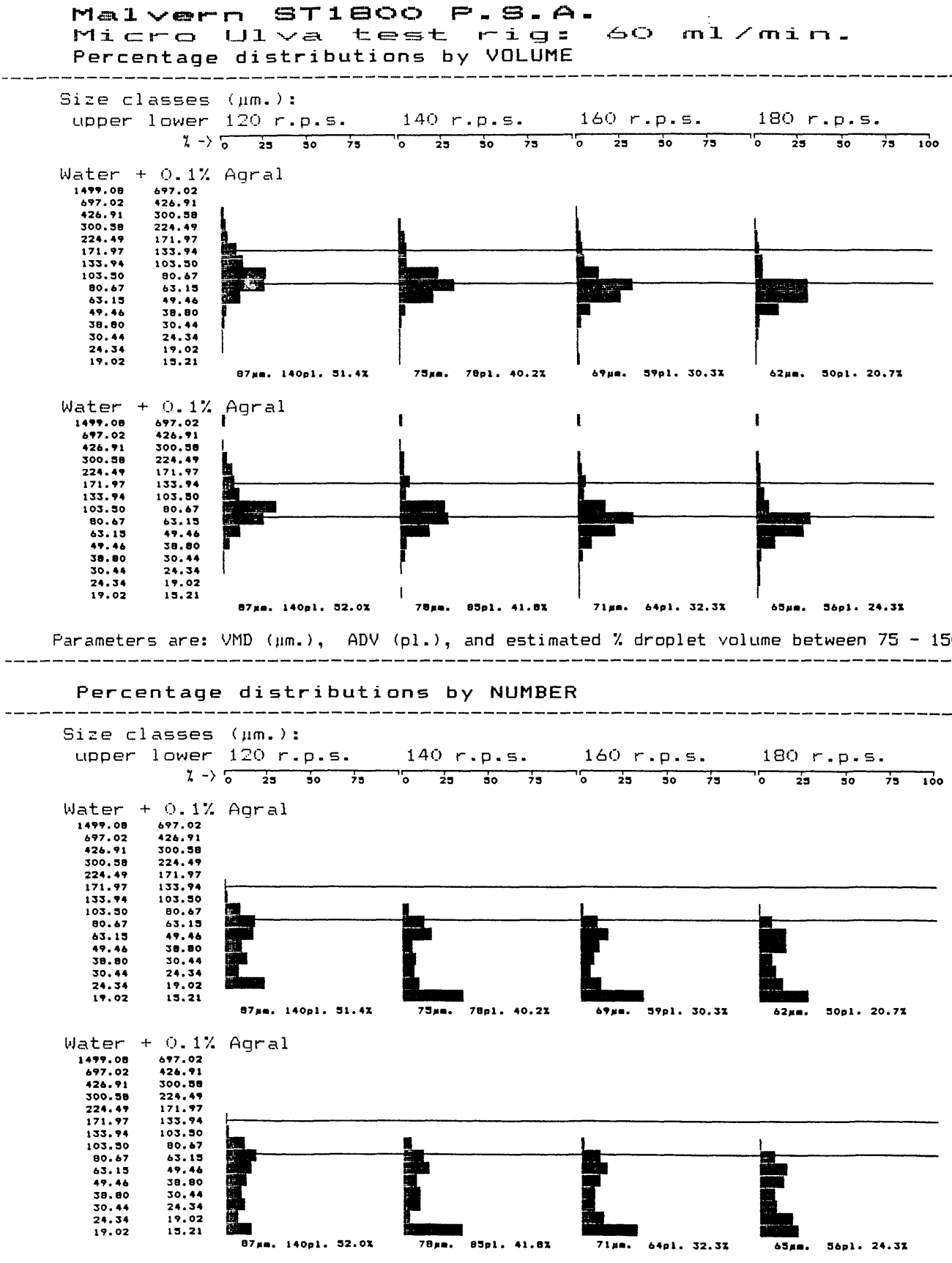
VMD

Source	Sum of Squares	DF	Mean Squares	F	Significance
Test Runs	31.23	2	15.61	5.417	*
Disc Speeds	8872.19	5	1774.44	615.606	*****
Analysis Type	44.44	1	44.44	15.419	***
Di. x An.	6.26	5	1.25	0.434	N.S.
Contrasts					
Linear	7796.79	(1)	7796.79	2704.942	*****
Quadratic	911.26	(1)	911.26	316.145	*****
Cubic	148.22	(1)	148.22	51.423	*****
Quartic	11.37	(1)	11.37	3.944	N.S.
Quintic	4.55	(1)	4.55	1.577	N.S.
Residual (Error)	63.41	22	2.882		
TOTAL	9017.53	35			

Coefficient of Variation = 2.3%

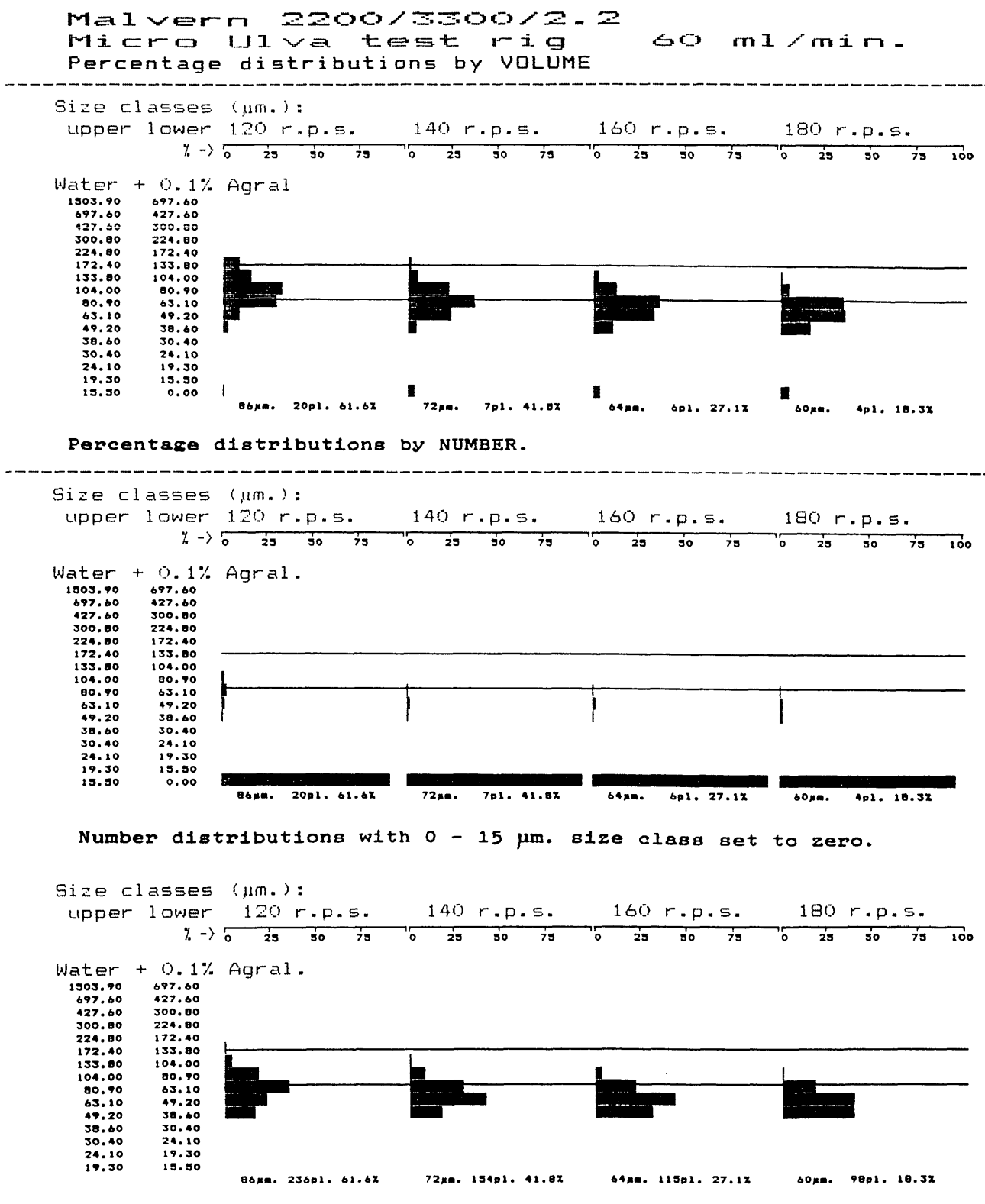
No.	Disc Speeds	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
Units (untransformed) are: Droplet diameters (um)					0 — 100.00
1	100 r.p.s.	102.85	1.19	0.083	
2	120 r.p.s.	80.35	0.88	0.057	
3	140 r.p.s.	70.93	0.69	0.040	
4	160 r.p.s.	64.18	0.69	0.045	
5	180 r.p.s.	60.23	0.76	0.058	
6	200 r.p.s.	55.95	1.06	0.120	
Analysis Type					0 — 100.00
1	Model Independent	71.31	3.85	3.735	
2	Rosin Rammler	73.53	3.81	3.557	

Fig. 3.3.4. Calibration of droplet sizing methods: Malvern ST1800.



These are two groups of readings taken on separate occasions.

Fig. 3.3.5. Calibration of droplet sizing methods: Malvern 2200.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.3.6. Calibration of droplet sizing methods: Malvern 2600.

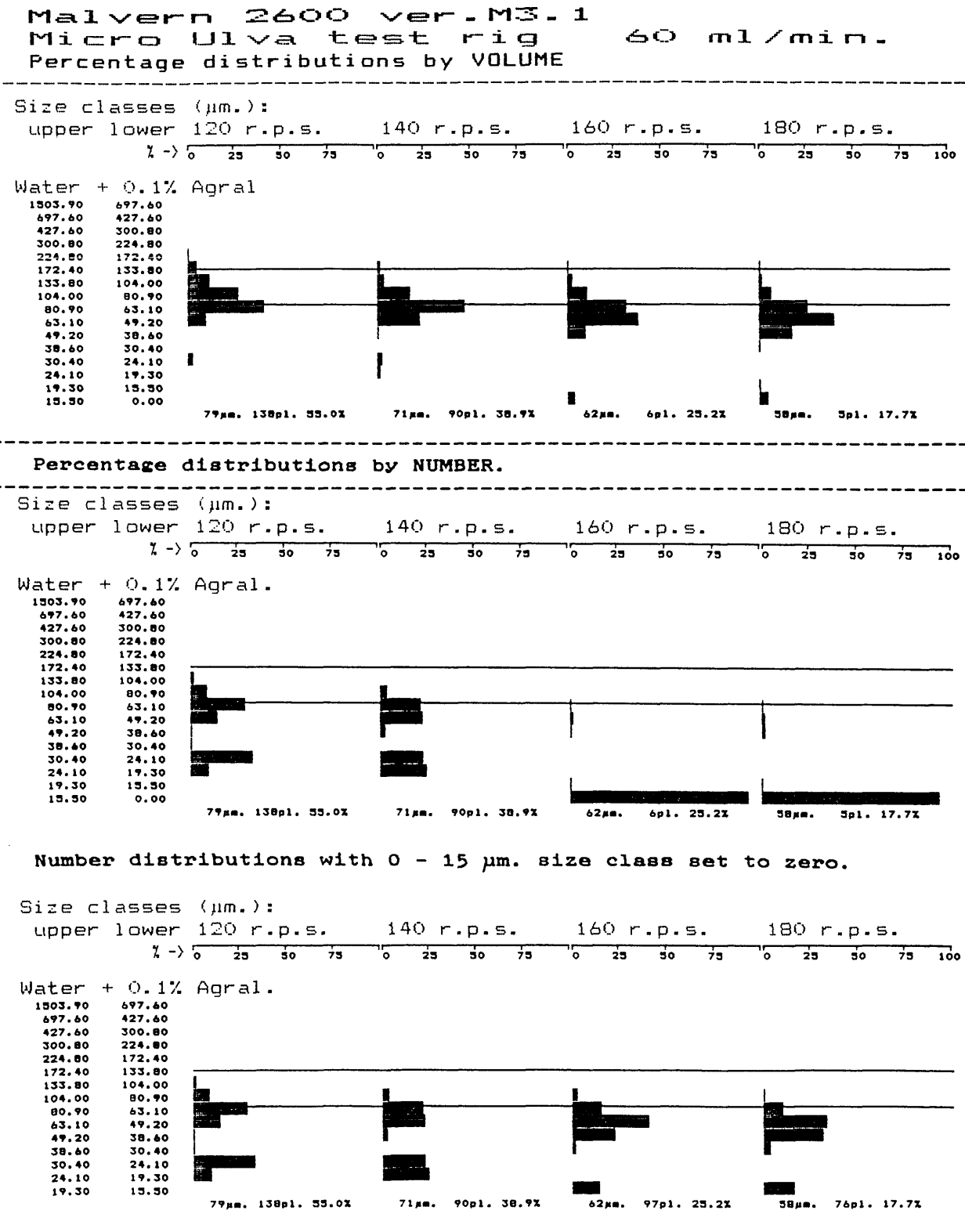


Fig. 3.3.7. Calibration of droplet sizing methods: Knollenberg.

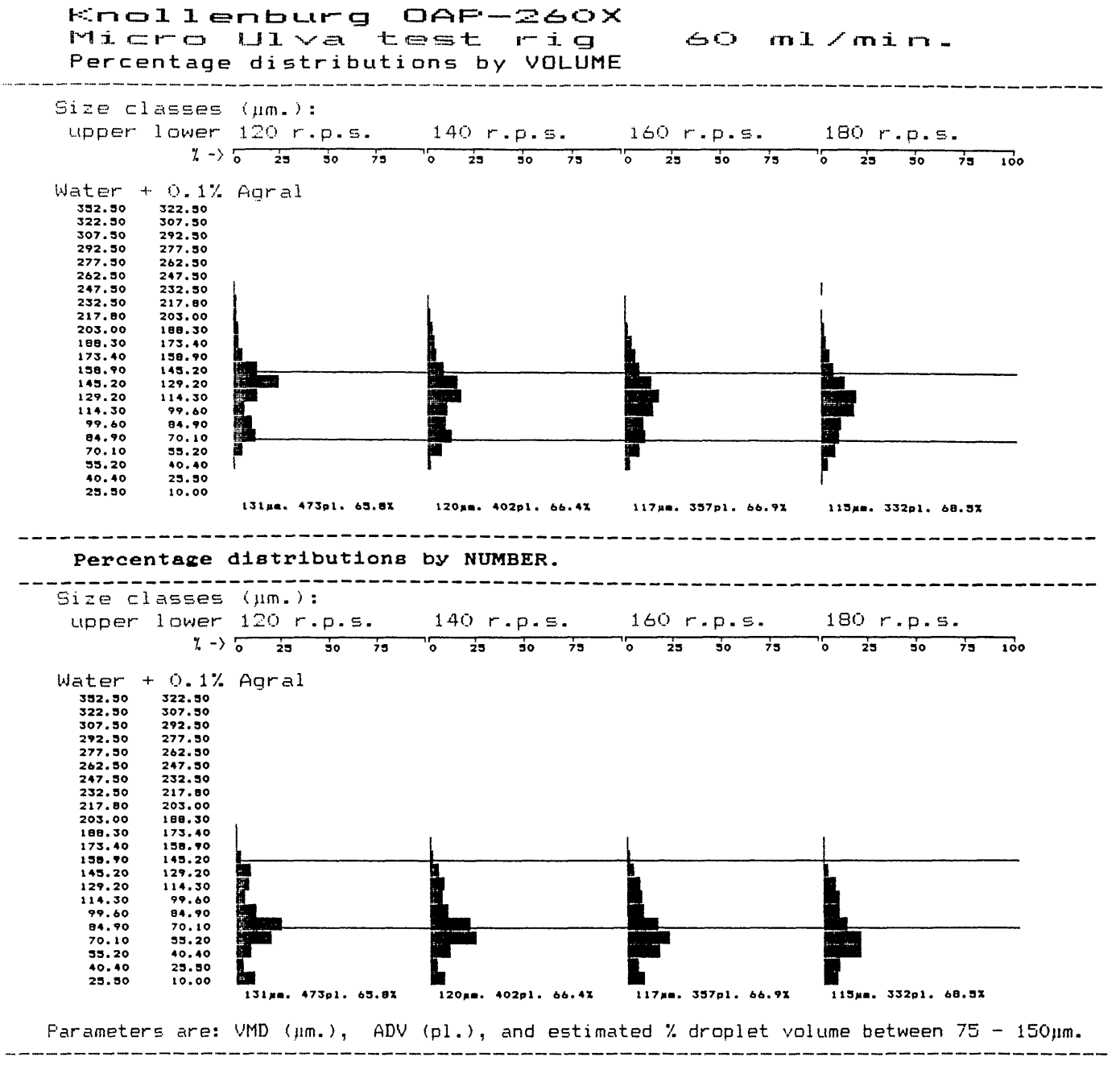
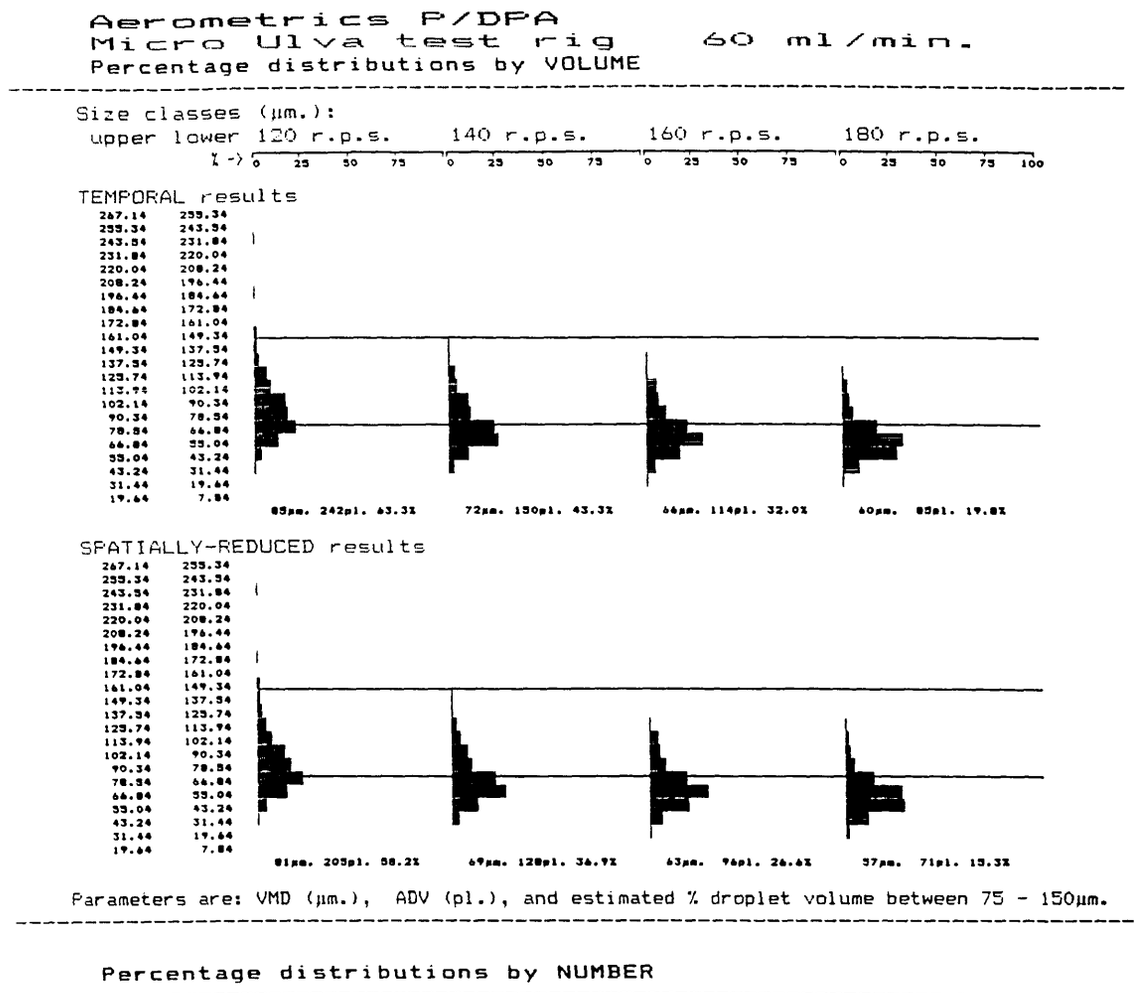
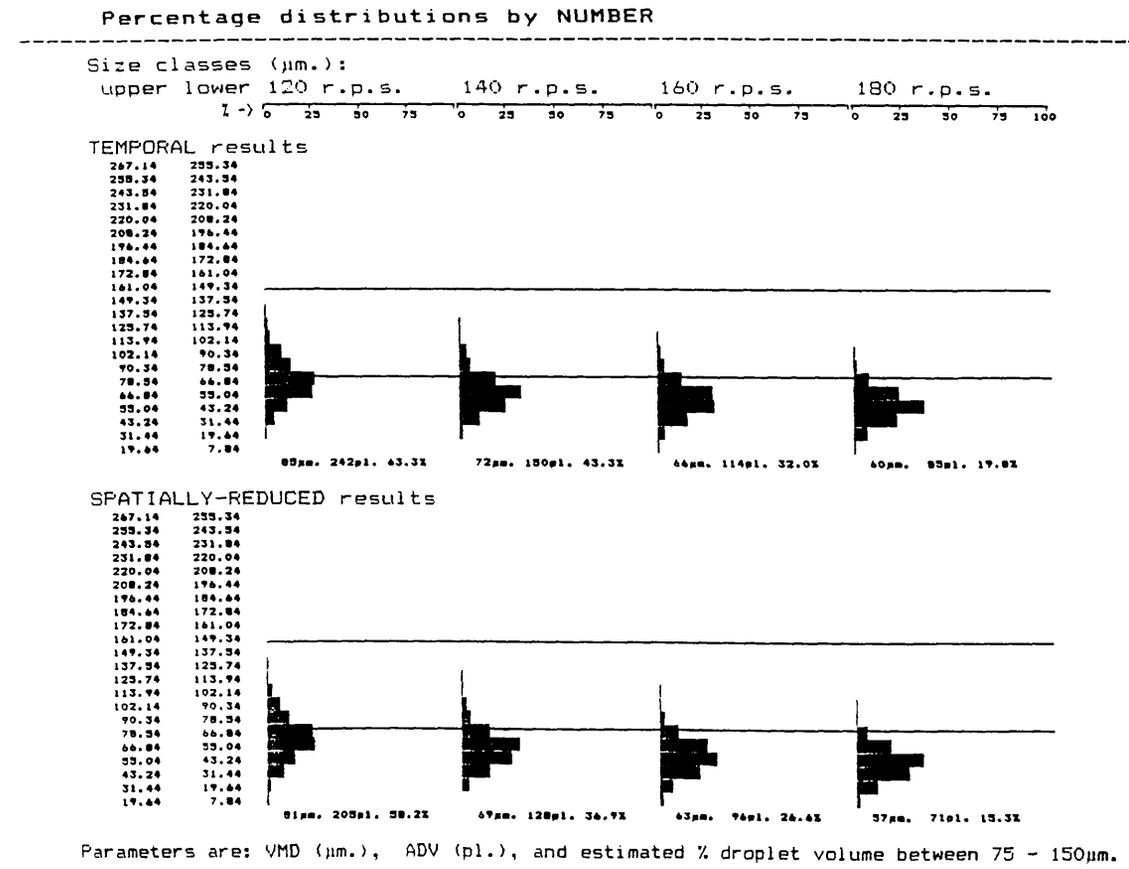


Fig. 3.3.8. Calibration of droplet sizing methods: Aerometrics P/DPA.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

3.4. ATOMISATION OF PARTICULATE SUSPENSIONS AND CLEAR LIQUIDS

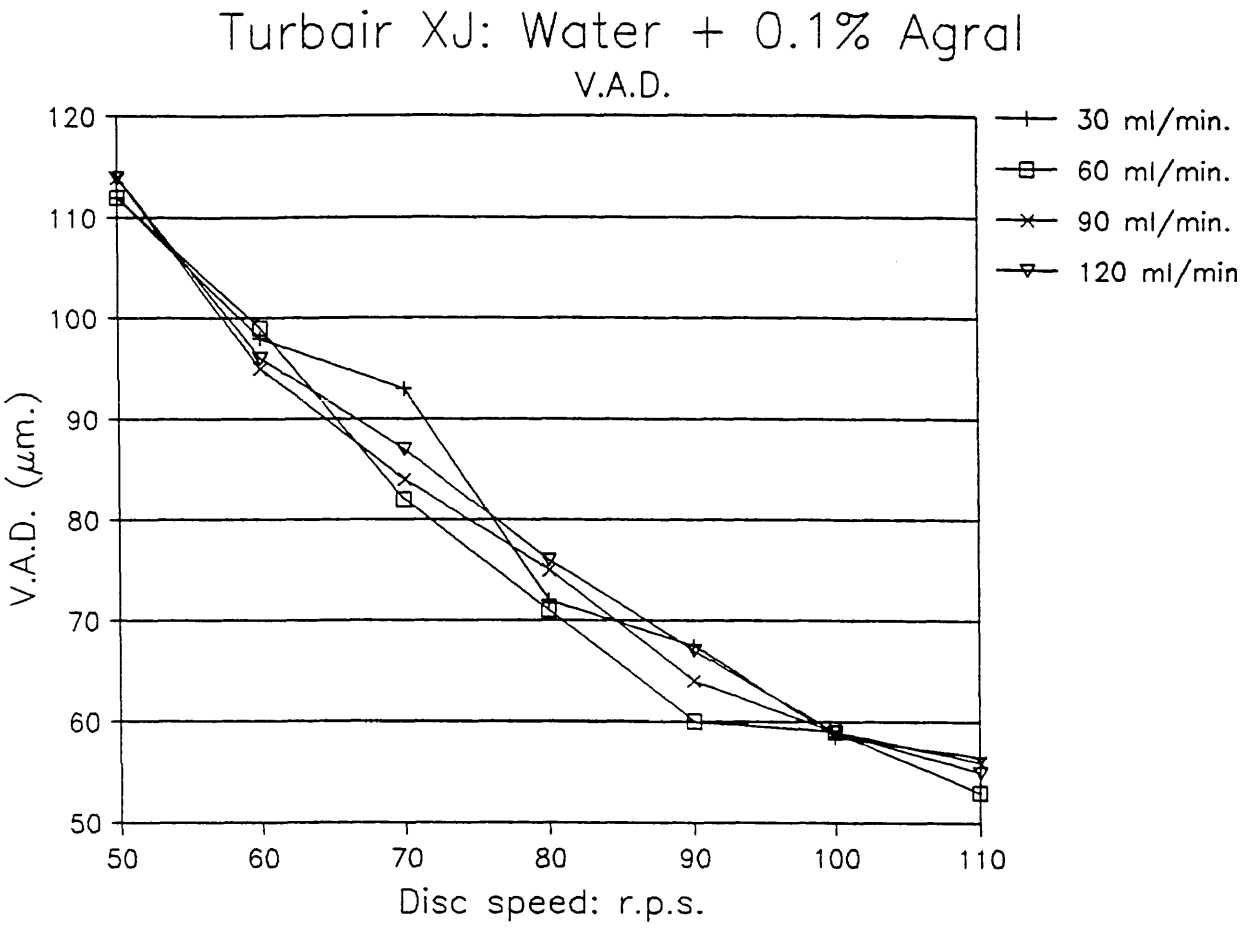
3.4.1. Water-based mixtures.

Water with 0.1% 'Agral' was used as a standard, and for initial evaluations of different machinery. Fig. 3.5.1. shows a study carried out on the 'Micro Ulva', and Fig. 3.4.1.1. shows droplet data for the Turbair XJ. Within their normal working ranges (30-70 ml/min. = 0.5-1.2 ml/s.), the droplet sizes from these two atomisers are little affected by flow rate; spray quality was acceptable where enlarged droplets were required (see section 2.7.1.4.).

3.4.1.1. Effects of Flow Rate

The effects of increasing flow rate at six rotational speeds with 52 mm. ('Micro Ulva') discs are shown in Fig. 3.4.1.2.. Droplet size increases with flow rates greater than 60 ml/min (1.0 ml/s.), however discontinuity at lower disc speeds appeared to be caused by the onset of bimodal size distributions (Fig. 3.4.1.3.). These results are largely consistent with Heijne's (1978) observations. Tests carried out on three 88 mm. disc designs, at two rotational speeds, likewise indicated that flow rate plays a significant part in determining VMD, although disc speed was considerably more important (Fig. 3.4.1.4.). Increased flow rates and disc speeds are accompanied by significant decreases in droplet quality, although this may be less important than the quality of disc moulding: the Taurus 'Hi-spin' produced significantly poorer sprays than the other two atomisers. Flow rates in the region of 40-120 ml/min. have been used for water-based mixtures, and with all types of 87-88 mm. discs, 60 rev.s^{-1} apparently produces sprays suitable for 'WULV'. Poorer quality atomisation may result in smaller proportions of spray droplets within the 75-150 μm. limits (Fig. 3.4.1.5.).

Fig. 3.4.1.1. Droplet size calibration for the Turbair XJ.



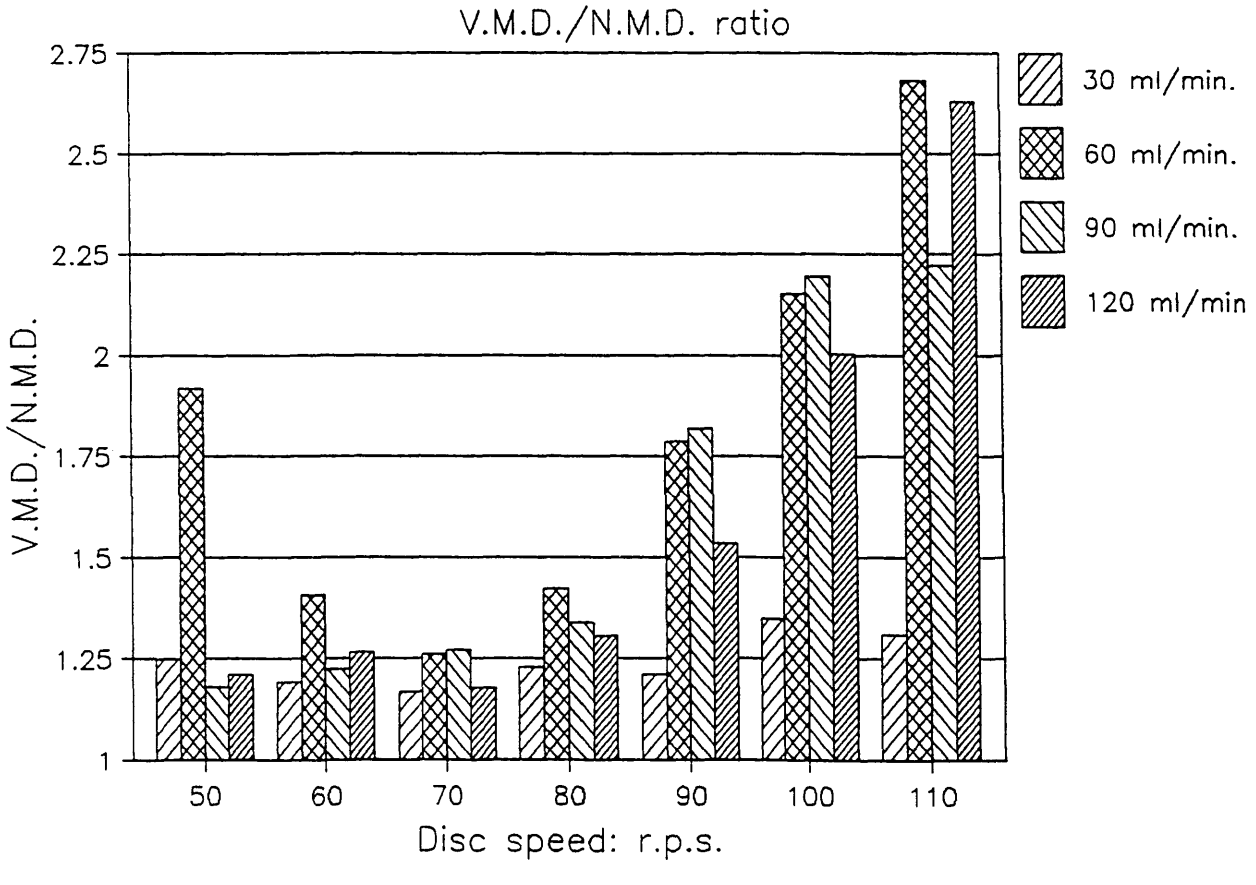
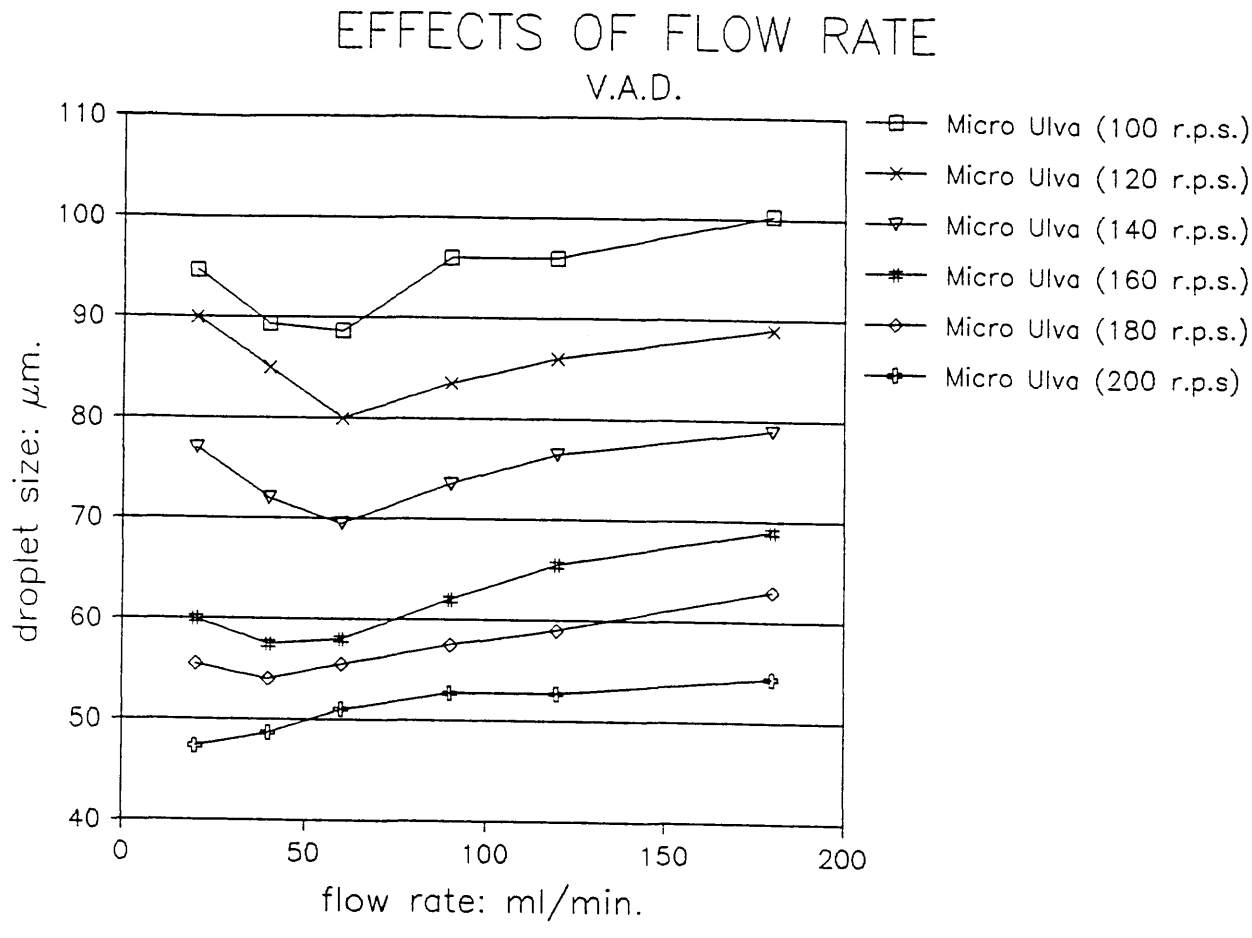


Fig. 3.4.1.2. Effects of flow rate: Micro Ulva, Water + 0.1% Agral.



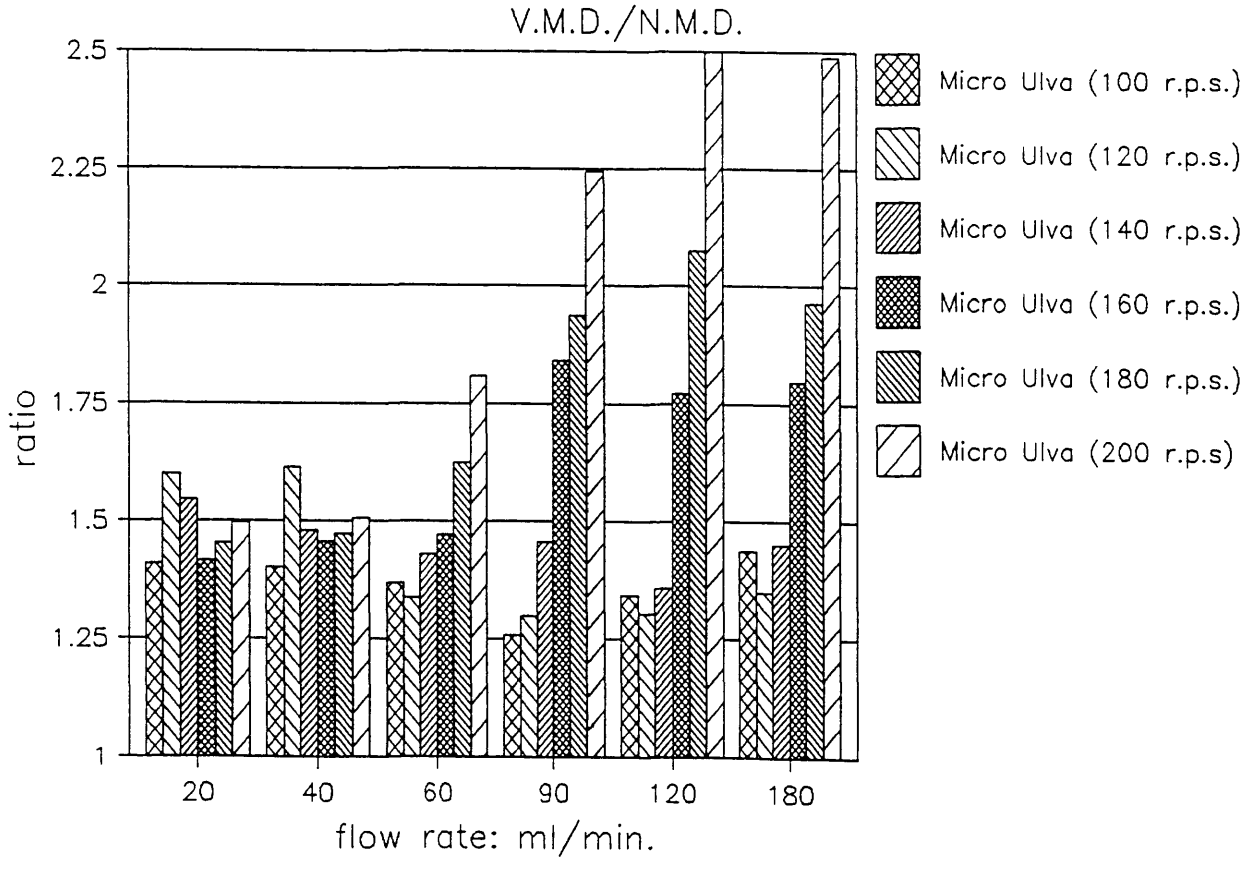
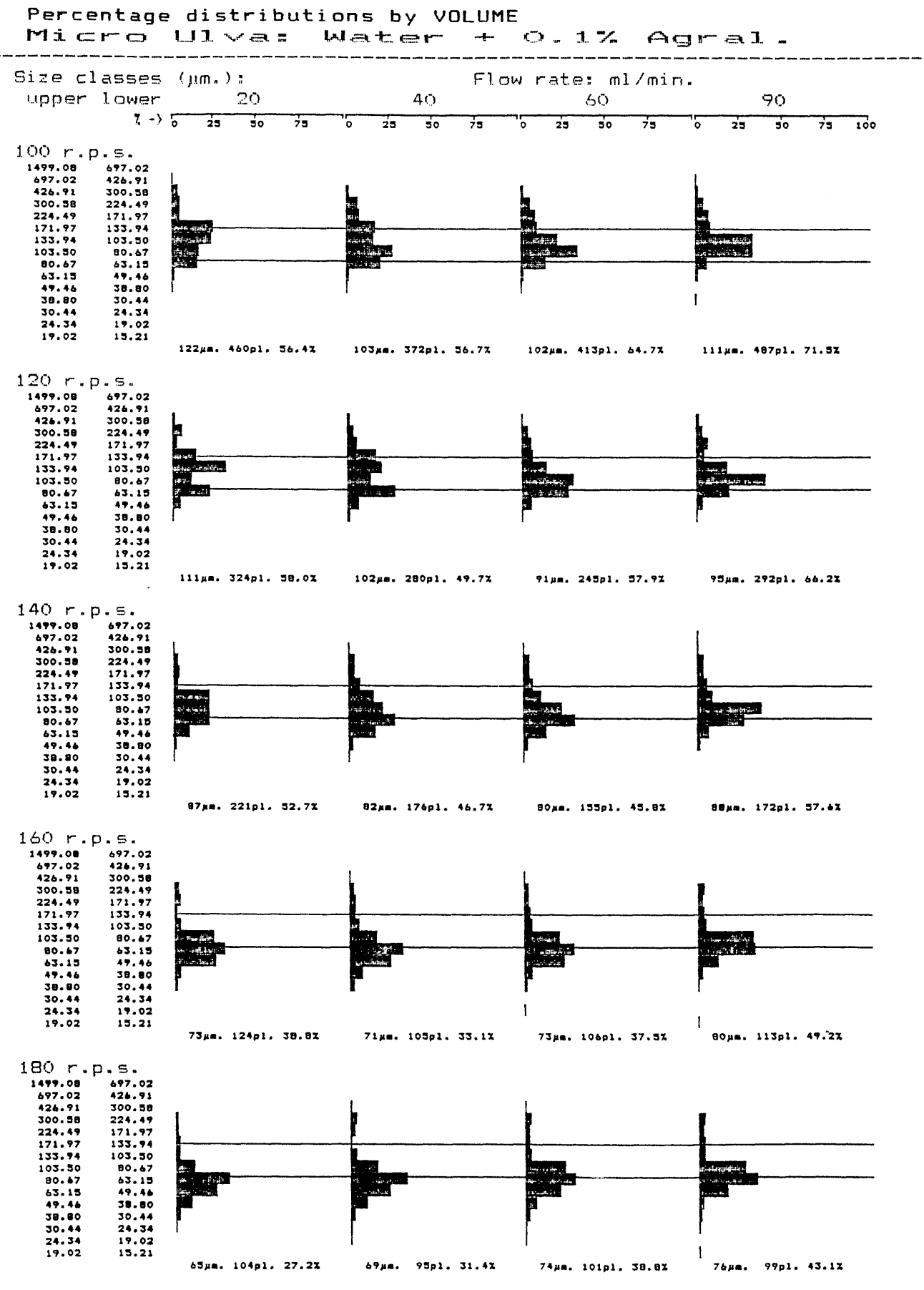


Fig. 3.4.1.3. Sample droplet size distributions from Fig. 3.4.1.2.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.4.1.4. Effects of flow rate and sprayer type: analysis. Water + 0.1% Agral.

88mm. Double Disc Sprayers

V.M.D.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Flow Rates	3503.12	6	583.85	6.468	****
Disc Speeds	36255.59	1	36255.59	401.637	*****
Atomiser heads	1499.50	2	749.75	8.306	***
Fl. x Di.	662.25	6	110.37	1.223	N.S.
Fl. x At.	796.36	12	66.36	0.735	N.S.
Di. x At.	947.71	2	473.86	5.249	**
Fl. x Di. x At.	751.17	12	62.60	0.693	N.S.
Residual (Error)	3791.32	42	90.270		
TOTAL	48207.01	83			

Coefficient of Variation = 10.6%

No.	Flow Rates	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: droplet size: microns				0 110.00
1	20 ml./min.	82.05	6.97	7.104	
2	40 ml./min.	84.00	7.07	7.136	
3	60 ml./min.	85.81	6.94	6.737	
4	90 ml./min.	87.49	5.79	4.605	
5	120 ml./min.	88.09	5.25	3.755	
6	180 ml./min.	96.11	8.39	8.781	
7	240 ml./min.	101.47	7.78	7.155	
	Disc Speeds				0 110.00
1	slow: 60 r.p.s.	110.06	2.44	2.279	
2	fast: 120 r.p.s.	68.51	0.98	0.593	
	Atomiser heads				0 110.00
1	Turbair XJ	86.43	4.21	5.732	
2	Taurus Hi-spin	95.26	5.40	8.556	
3	Micron Ulva	86.17	3.87	4.867	

Coefficient of Variation

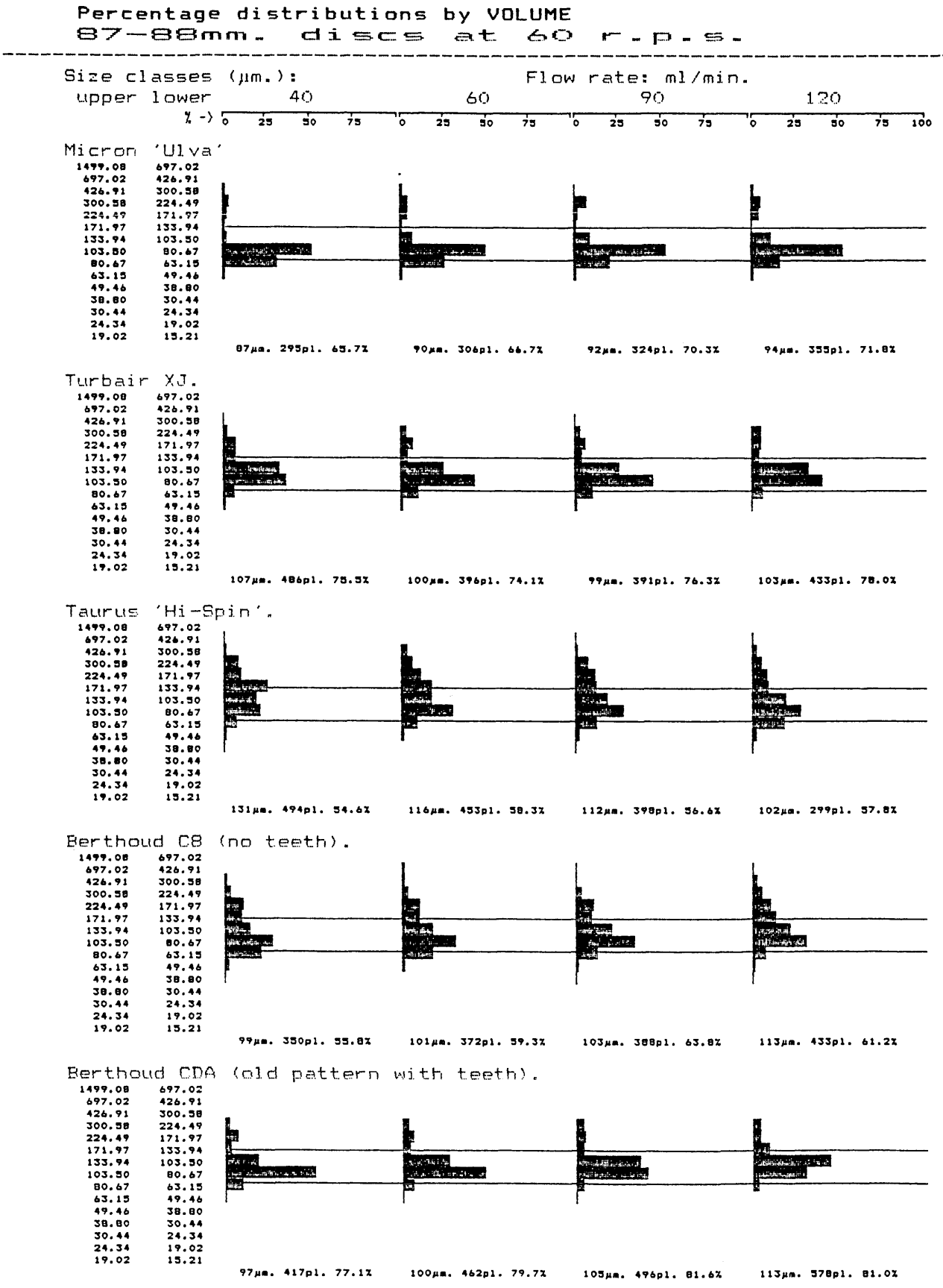
Source	Sum of Squares	DF	Mean Squares	F	Significance
Flow Rates	0.92	6	0.15	5.258	***
Disc Speeds	0.03	1	0.03	1.095	N.S.
Atomiser heads	2.05	2	1.03	35.077	*****
Fl. x Di.	0.04	6	0.01	0.227	N.S.
Fl. x At.	0.23	12	0.02	0.644	N.S.
Di. x At.	0.11	2	0.05	1.819	N.S.
Fl. x Di. x At.	0.22	12	0.02	0.633	N.S.
Residual (Error)	1.23	42	0.029		
TOTAL	4.83	83			

Coefficient of Variation = 20.5%

No.	Flow Rates	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: homogeneity indices				0 1.10
1	20 ml./min.	0.75	0.07	0.070	
2	40 ml./min.	0.77	0.07	0.075	
3	60 ml./min.	0.75	0.06	0.063	
4	90 ml./min.	0.81	0.07	0.076	
5	120 ml./min.	0.78	0.06	0.060	
6	180 ml./min.	0.92	0.06	0.048	
7	240 ml./min.	1.05	0.06	0.042	
	Disc Speeds				0 1.10
1	slow: 60 r.p.s.	0.85	0.04	0.077	
2	fast: 120 r.p.s.	0.81	0.03	0.063	
	Atomiser heads				0 1.10
1	Turbair XJ	0.66	0.03	0.046	
2	Taurus Hi-spin	1.04	0.03	0.028	
3	Micron Ulva	0.80	0.04	0.055	

Fig. 3.4.1.5. Sample droplet size distributions for five large disc atomisers. Water + 0.1% Agral.

N.B. Berthoud readings were not congruent with the others.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

3.4.1.2. **Effects of Formulations**

Fig. 3.4.1.6. is a comparison of atomisation of the water and Agral standard with ten miscellaneous water-based mixtures, at a representative 60 ml./min. flow rate. Although not comprehensive, this selection was judged to be representative of water-based CDA, and these measurements were carried out in support of the field trials. Aqueous thiodicarb mixtures included: 7.2-10% suspension concentrate similar to those used in Malawi, an equivalent a.i. concentration of the water dispersible granules (3.3% w./v.), and the recommended Zimbabwean mixture containing 21% SC and 17.5% molasses. In response to shortages of molasses in Zimbabwe, three other anti-evaporant additives were included in an investigation into modified WULV:

i. Molasses at 35% - the typical Zimbabwean concentration.

ii. Concentrated Molasses Solubles (CMS): the concentrated residue from the fermentation of molasses to produce alcohol (source: Triangle, Zimbabwe). The 21.8° brix descriptor indicates the remaining level of complex reducing sugars.

iii. 'Derimin' (Hoechst AG.): a waxy suspension mixed at the recommended rate of 2.5%, and 5.0% v/v.

iv. Codacide oil (Microcide Ltd.): a blend of 95% rape-seed oil and emulsifier. No clear recommendations on the mixing rate are given by the manufacturer, and 20% is an arbitrary rate. This adjuvant has been described as a carrier, and is normally added in proportion to the quantity of pesticide.

Addition of molasses and CMS appeared to reduce the VMD of sprays, whereas 'Derimin' caused a significant increase over the standard. Addition of Codacide oil or SC and molasses produced droplet spectra with a strikingly greater uniformity over the range of disc speeds. Reducing disc speed to 100 rev.s^{-1} causes many mixtures start the transition to bimodal droplet

distributions; in the readings illustrated (Fig. 3.4.1.7.) this is most marked with Molasses and 'Derimin'. In retrospect, it appears that water and Agral provides a useful standard with rotary atomisers, since sprays are not atypical. Table 3.4.1. indicates the influence adjuvants may have on the average droplet volume, and thus the number of droplets obtained from a unit volume of liquid. Using 'Derimin' rather than molasses as an anti-evaporant may result in a doubling of droplet volume at lower disc speeds.

Table 3.4.1.

Droplet Sizes Obtained from a 'Micro Ulva':
fixed position: flow 60 ml/min. Numbers are mean ADVs. in pl.

Disc speed (rev.s^{-1}): Formulation	100	120	140	160
2.5% 'Derimin'	819	420	243	136
5.0% 'Derimin'	751	362	239	126
Water + 2% Karate EC	671	359	234	156
Water + 10% Larvin SC	653	288	235	129
Water + 20% Codacide oil	574	344	220	148
Water + 0.1% Agral	573	295	229	145
35% Molasses	417	235	150	118
21% SC, 17% Molasses	414	291	215	138
21.8 brix CMS.	397	215	153	110

Addition of formulations or small proportions of surfactant is known to considerably reduce the static surface tension of water. Plain hard water was included in a series of evaluations of typical field mixtures of thiodicarb, with three atomisers (Figs. 3.4.1.8-11.). Although the droplet spectra produced by the 'Micro Ulva' and Turbair XJ were similar with and without Agral, the absence of surfactant was conspicuous with the 'Ulva' (Fig. 3.4.1.11.). Mixtures containing thiodicarb SC appeared to produce smaller droplet spectra with the 'Micro Ulva' (Fig. 3.4.1.8.). The presence of molasses appeared to be more influential for lowering the VAD with larger discs, and 7.2% v./v. thiodicarb SC produced sprays with relatively high ADVs.

Miscellaneous water-based mixtures

Micro Ulva, 60 ml./min.: V.M.D.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Mixtures	4372.91	10	437.29	8.564	*****
Disc speeds	21257.73	3	7085.91	138.765	*****
Mi. x Di.	2672.73	30	89.09	1.745	*
Contrasts					
standard vs. 35% Molasses	263.92	(1)	263.92	5.168	*
" 21.8 brix C.M.S.	374.34	(1)	374.34	7.331	**
" 21% SC + 17.5% mol.	62.49	(1)	62.49	1.224	N.S.
" 2% l-cyhalothrin EC	150.91	(1)	150.91	2.955	N.S.
" 20% Codacide	113.51	(1)	113.51	2.223	N.S.
" 3.3% WG blank	89.41	(1)	89.41	1.751	N.S.
" 3.3% thiodicarb WG	99.93	(1)	99.93	1.957	N.S.
" 10% thiodicarb SC	22.09	(1)	22.09	0.433	N.S.
" 2.5% Derimin	593.28	(1)	593.28	11.618	**
" 5.0% Derimin	682.37	(1)	682.37	13.363	***
Residual (Error)	2246.82	44	51.064		
TOTAL	30550.19	87			

Coefficient of Variation = 7.8%

Micro Ulva, 60 ml./min.: Coefficient of Variation (droplets)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Mixtures	0.86	10	0.09	12.393	*****
Disc speeds	0.93	3	0.31	44.566	*****
Mi. x Di.	0.71	30	0.02	3.372	***
Contrasts					
standard vs. 35% Molasses	0.02	(1)	0.02	2.528	N.S.
" 21.8 brix C.M.S.	0.01	(1)	0.01	0.898	N.S.
" 21% SC + 17.5% mol.	0.31	(1)	0.31	44.573	*****
" 2% l-cyhalothrin EC	0.07	(1)	0.07	10.139	**
" 20% Codacide	0.27	(1)	0.27	39.246	*****
" 3.3% WG blank	0.09	(1)	0.09	12.774	***
" 3.3% thiodicarb WG	0.03	(1)	0.03	3.770	N.S.
" 10% thiodicarb SC	0.01	(1)	0.01	1.937	N.S.
" 2.5% Derimin	0.01	(1)	0.01	1.305	N.S.
" 5.0% Derimin	0.00	(1)	0.00	0.051	N.S.
Residual (Error)	0.31	44	0.007		
TOTAL	2.81	87			

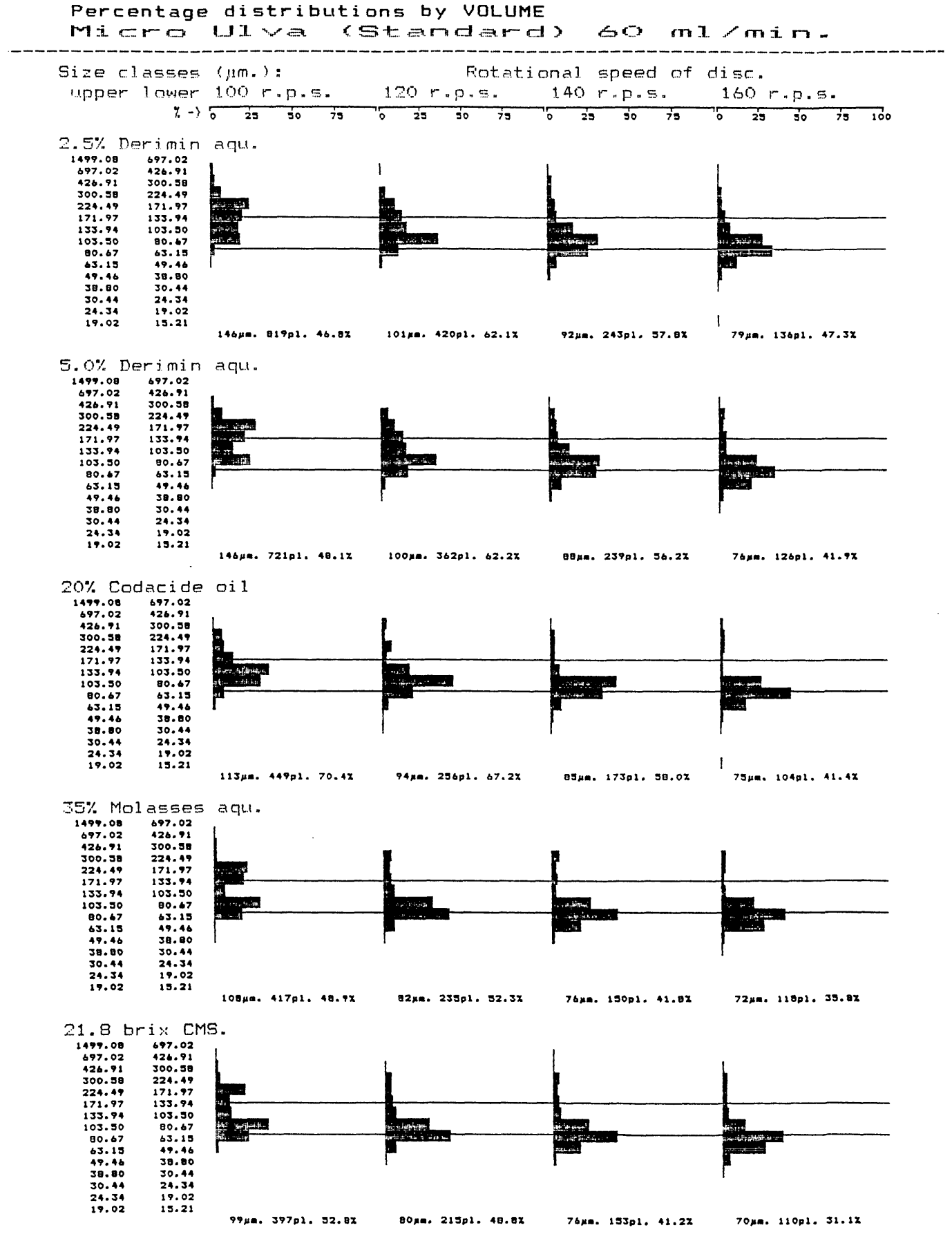
Coefficient of Variation = 11.1%

No.	Mixtures	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: droplet size: microns.					0 120.00
11	5.0% Derimin (R)	102.36	10.59	8.760	
10	2.5% Derimin (R)	101.48	9.14	6.590	
5	2% l-cyhalothrin EC blank	95.45	6.10	3.121	
6	20% Codacide (R) oil	94.63	5.54	2.592	
8	3.3% thiodicarb WG	94.30	6.81	3.935	
7	3.3% thiodicarb WG blank	94.03	5.55	2.618	
9	10% thiodicarb SC	91.65	6.80	4.041	
1	Water + 0.1% Agral	89.30	5.26	2.476	
4	21% thiodicarb SC + 17.5% molasses	85.35	3.66	1.258	
2	Water + 35% Molasses	81.18	4.83	2.301	
3	21.8 brix C.M.S.	79.63	4.00	1.607	
Disc speeds					0 120.00
1	100 r.p.s.	116.60	3.80	2.722	
2	120 r.p.s.	92.37	1.73	0.712	
3	140 r.p.s.	82.59	1.30	0.449	
4	160 r.p.s.	75.49	1.01	0.295	

No.	Mixtures	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: homogeneity indices					0 0.90
4	21% thiodicarb SC + 17.5% molasses	0.57	0.03	0.016	
6	20% Codacide (R) oil	0.58	0.03	0.012	
7	3.3% thiodicarb WG blank	0.69	0.03	0.009	
5	2% l-cyhalothrin EC blank	0.71	0.04	0.018	
8	3.3% thiodicarb WG	0.76	0.05	0.029	
2	Water + 35% Molasses	0.78	0.10	0.093	
9	10% thiodicarb SC	0.79	0.08	0.066	
3	21.8 brix C.M.S.	0.80	0.10	0.099	
11	5.0% Derimin (R)	0.83	0.03	0.007	
1	Water + 0.1% Agral	0.84	0.03	0.008	
10	2.5% Derimin (R)	0.89	0.02	0.005	
Disc speeds					0 0.90
1	100 r.p.s.	0.91	0.04	0.045	
2	120 r.p.s.	0.76	0.03	0.027	
3	140 r.p.s.	0.68	0.03	0.024	
4	160 r.p.s.	0.65	0.02	0.018	

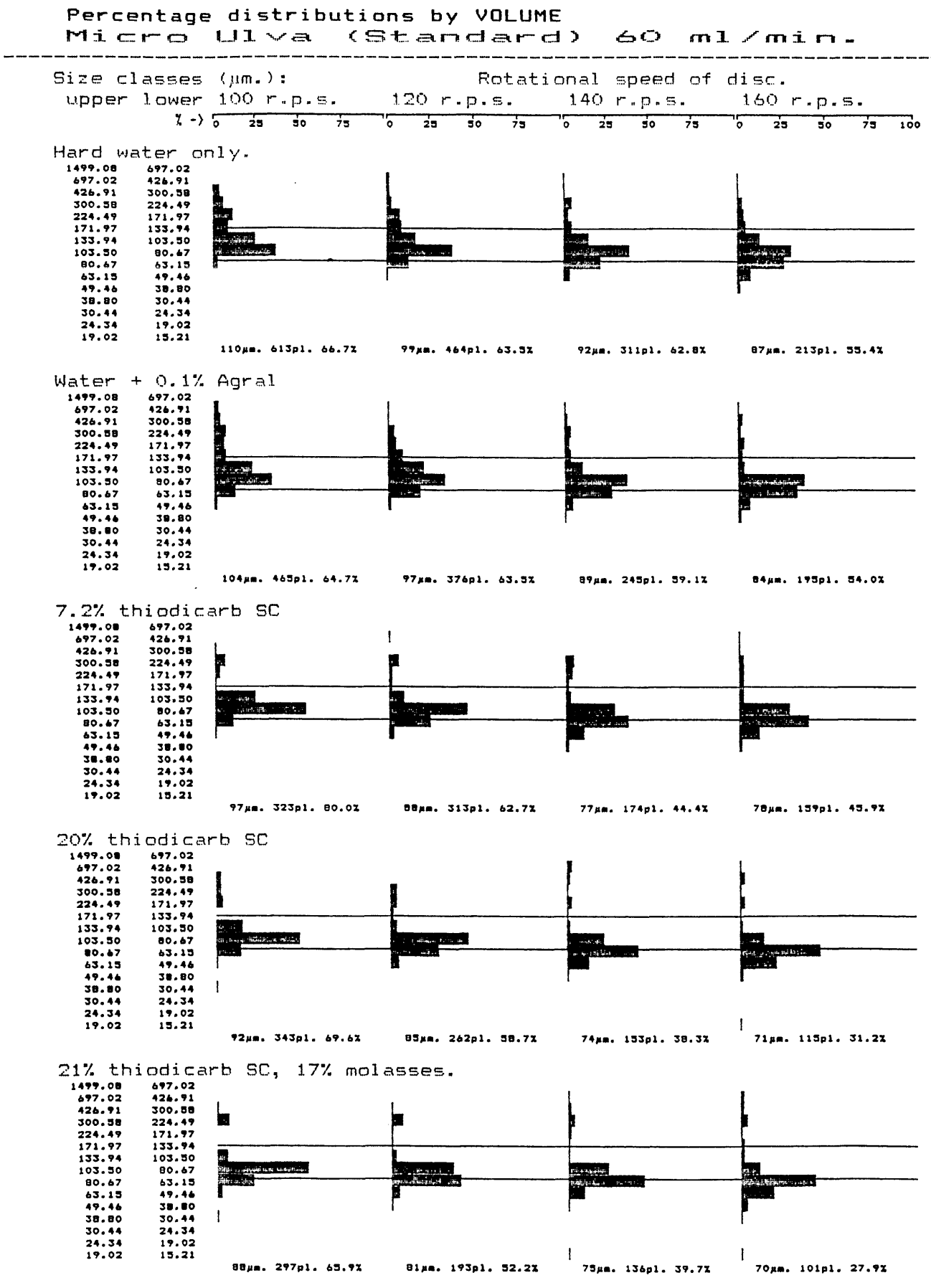
Fig. 3.4.1.6. Micro Ulva: analysis for various water-based mixtures.

Fig. 3.4.1.7. Sample droplet size distributions from Fig. 3.4.1.6. (1) Effect of four adjuvants.



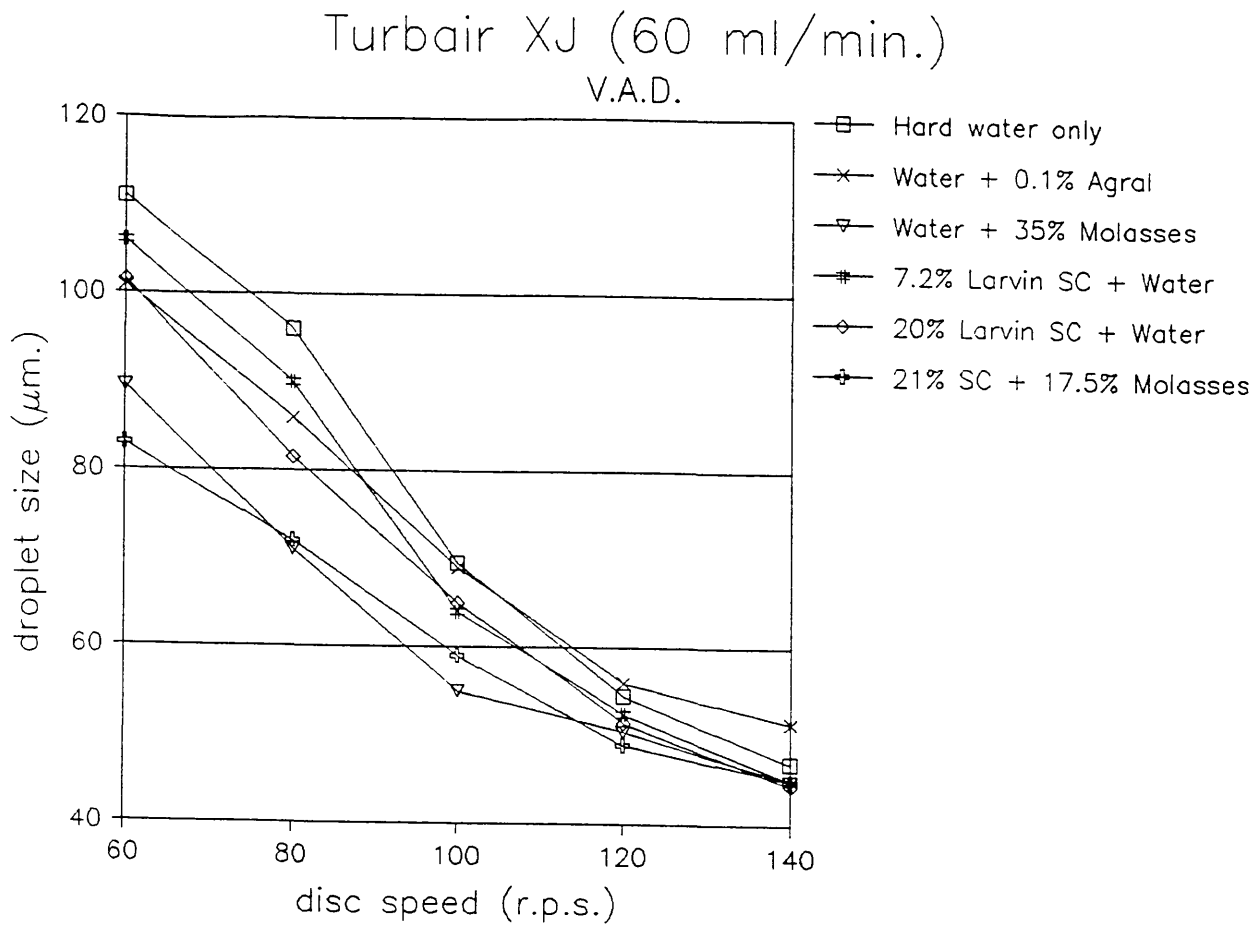
Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.4.1.8. Sample droplet size distributions from Fig. 3.4.1.6. (2) Effect of surfactant and thiodicarb SC mixtures.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.4.1.9. Turbair XJ: effects of surfactant and thiodicarb SC mixtures.



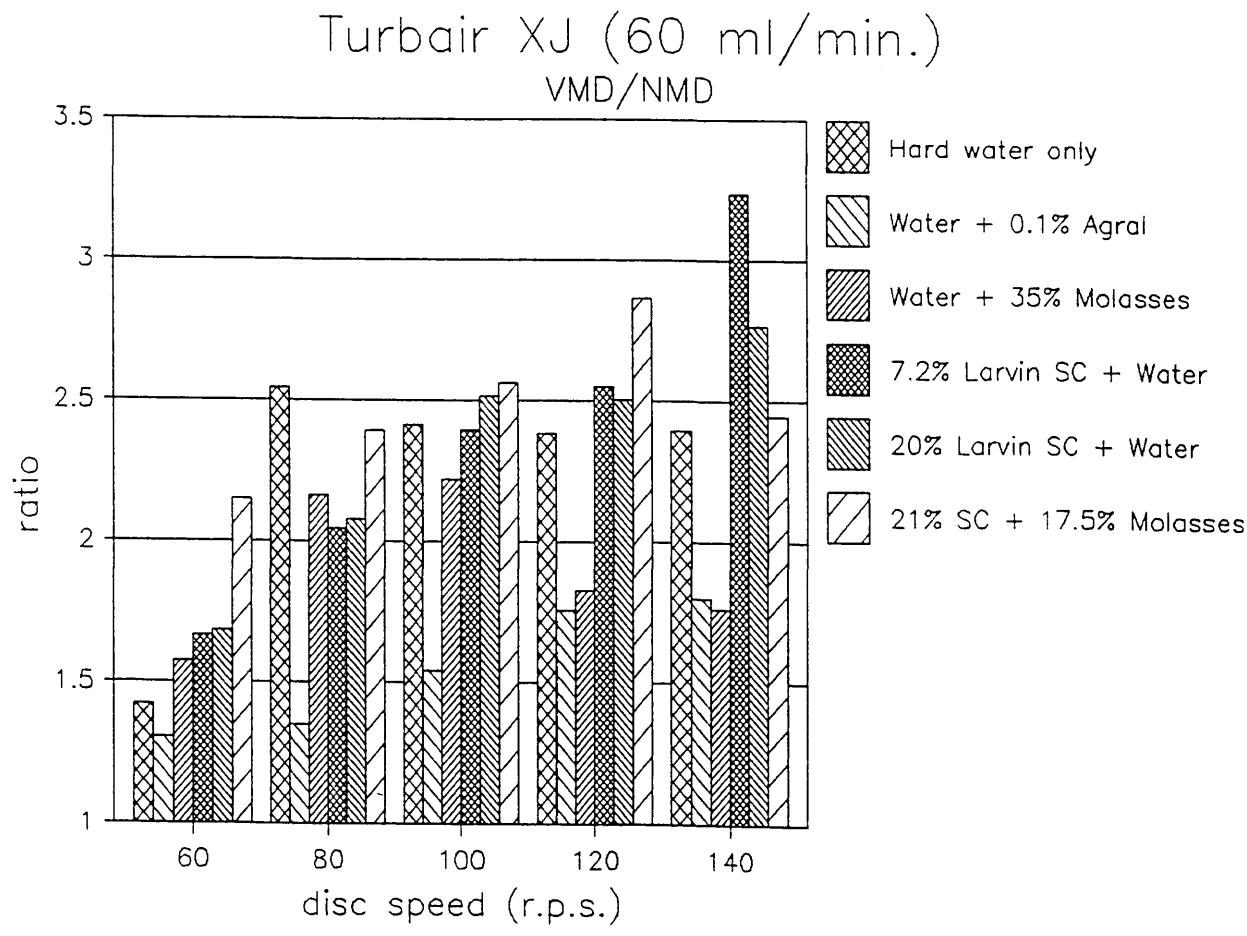
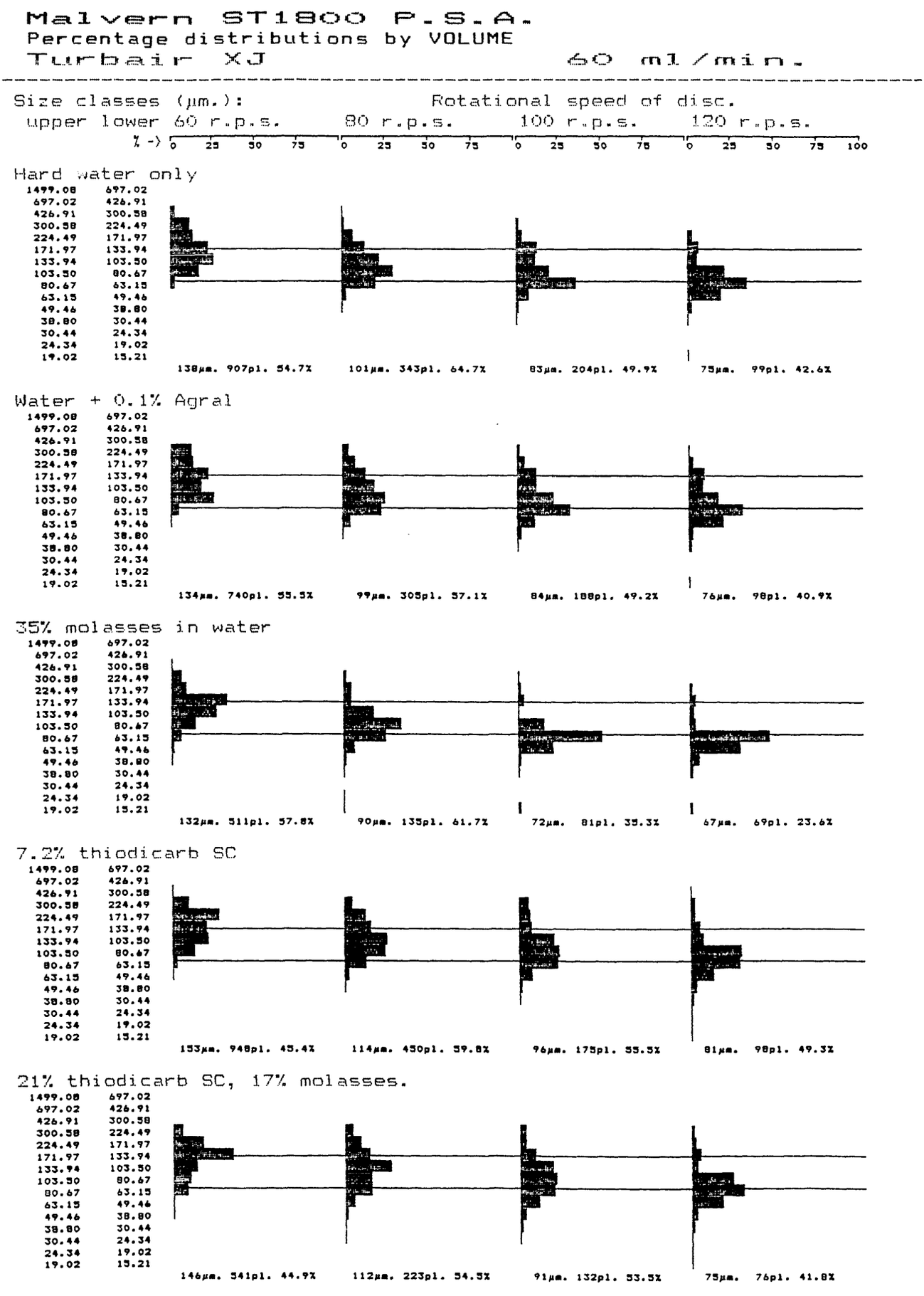
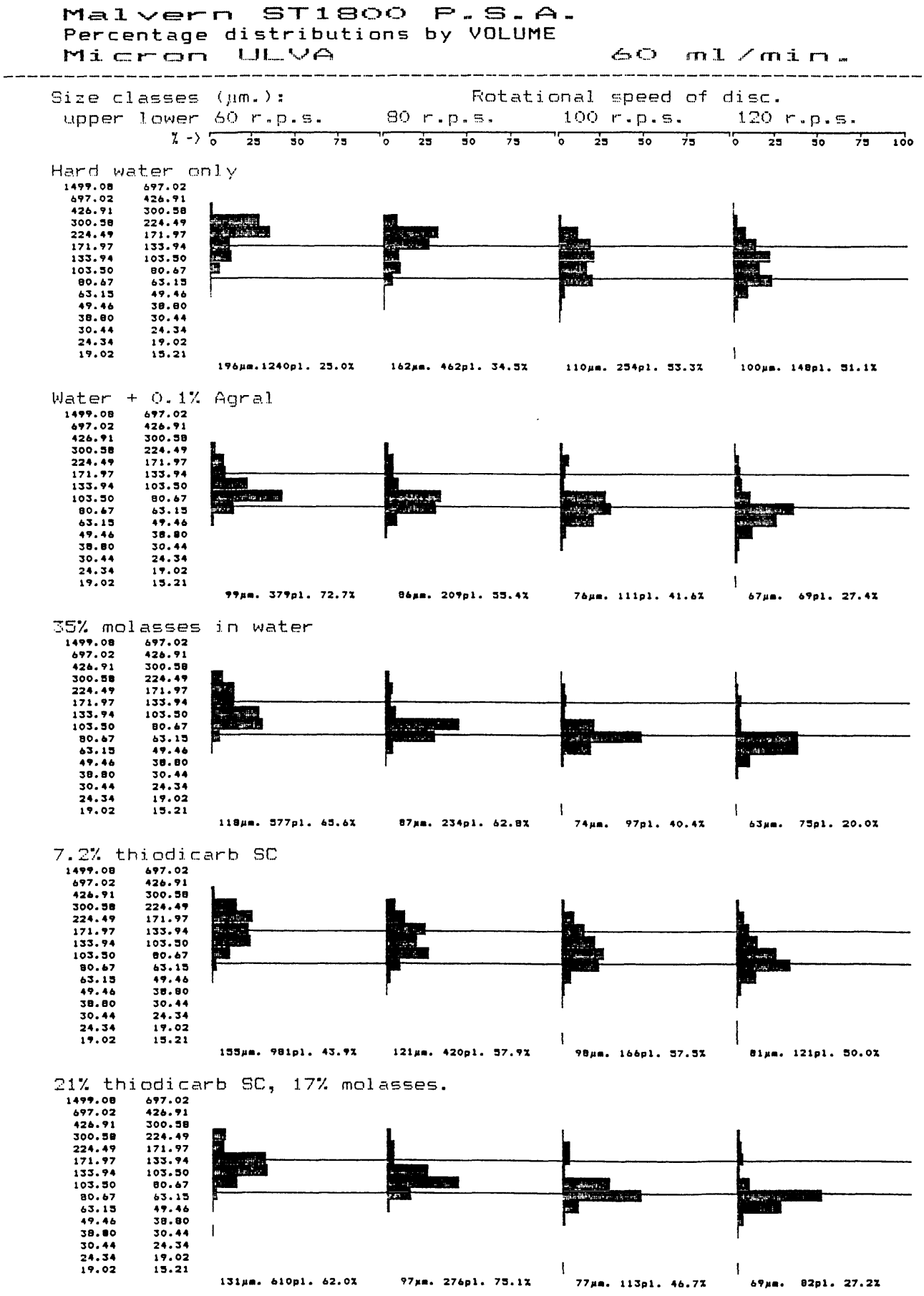


Fig. 3.4.1.10. Sample droplet size distributions from Fig. 3.4.1.9.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.4.1.11. Sample droplet size distributions for the Micron Ulva. Effect of surfactant and thiodicarb SC mixtures.



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

More intensive examination of two types of mixture took place with readings at a reduced flow rate of 30 ml/min., as well as the more representative 60 ml/min.; this was to highlight any differences in zones of transition to bimodal size distributions.

A. Particle Addition (WGs)

The 80% water dispersible granule formulation was available as a clear blank solution (7-DLM-Y-62A), with the thiodicarb particle content replaced by water. A multi-factorial comparison illustrated effects of particle concentrations and how they might be distinguished from those of surfactant concentration.

Although the presence of particles made the VMD of sprays smaller (typically by 6%) they had no distinguishable effect on quality (Fig. 3.4.1.12.). Increasing proportion of formulation from 5% to 20% had a more important influence: decreasing both size (by more than 12%) and droplet heterogeneity. It should be emphasised that all these differences were small, and differences between volume distributions are not conspicuous (Fig. 3.4.1.13.).

B. Water-miscible anti-evaporant additives

i. Prominent interactions take place between additive and disc speeds, especially at reduced flow rates (Fig. 3.4.1.14.). At the lowest disc speed, mixtures containing 'Derimin' produced larger droplet spectra: probably associated with a shift to single droplet atomisation (Fig. 3.4.1.15.).

ii. Mixtures containing Molasses or CMS produce droplets that are smaller than the standard. This is consistent with observations made by Gledhill and Brettell (1980) who considered this to be a surface tension effect. Compared with 'Derimin', these additives complete the transition to ligament formation at lower flow rates and disc speeds (Fig. 3.4.1.15.).

Fig. 3.4.1.12. Effects of particle addition: analysis.

Micro Ulva (standard) 60 ml/min.

Thiodicarb - aqueous WG formulation: V.M.D. (M)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Readings: block	138.95	1	138.95	30.222	****
Disc Speeds	5311.08	3	1770.36	385.062	*****
Particulates	364.68	1	364.68	79.320	*****
Concentration	965.67	2	482.83	105.018	*****
Di. x Pa.	13.01	3	4.34	0.943	N.S.
Di. x Co.	457.34	6	76.22	16.579	*****
Pa. x Co.	1.67	2	0.84	0.182	N.S.
Di. x Pa. x Co.	35.27	6	5.88	1.279	N.S.
Contrasts					
Linear	5119.66	(1)	5119.66	1113.551	*****
Quadratic	187.03	(1)	187.03	40.679	*****
Cubic	4.39	(1)	4.39	0.956	N.S.
Total (all treatments)	7148.72	23	310.81	67.604	*****
Residual (Error)	105.74	23	4.598		
TOTAL	7393.41	47			

Coefficient of Variation = 2.4%

No.	Disc Speeds	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: droplet size: microns.				0 100.00
1	100 r.p.s.	105.03	3.07	1.074	
2	120 r.p.s.	91.30	1.55	0.317	
3	140 r.p.s.	82.88	1.74	0.441	
4	160 r.p.s.	77.04	0.96	0.144	
	Particulates				0 100.00
1	WG formulation	86.31	2.53	1.782	
2	Clear Blank	91.82	2.52	1.654	
	Concentration				0 100.00
1	5% w/v.	95.15	3.91	2.576	
2	10% w/v.	87.57	2.62	1.252	
3	20% w/v.	84.47	2.15	0.874	

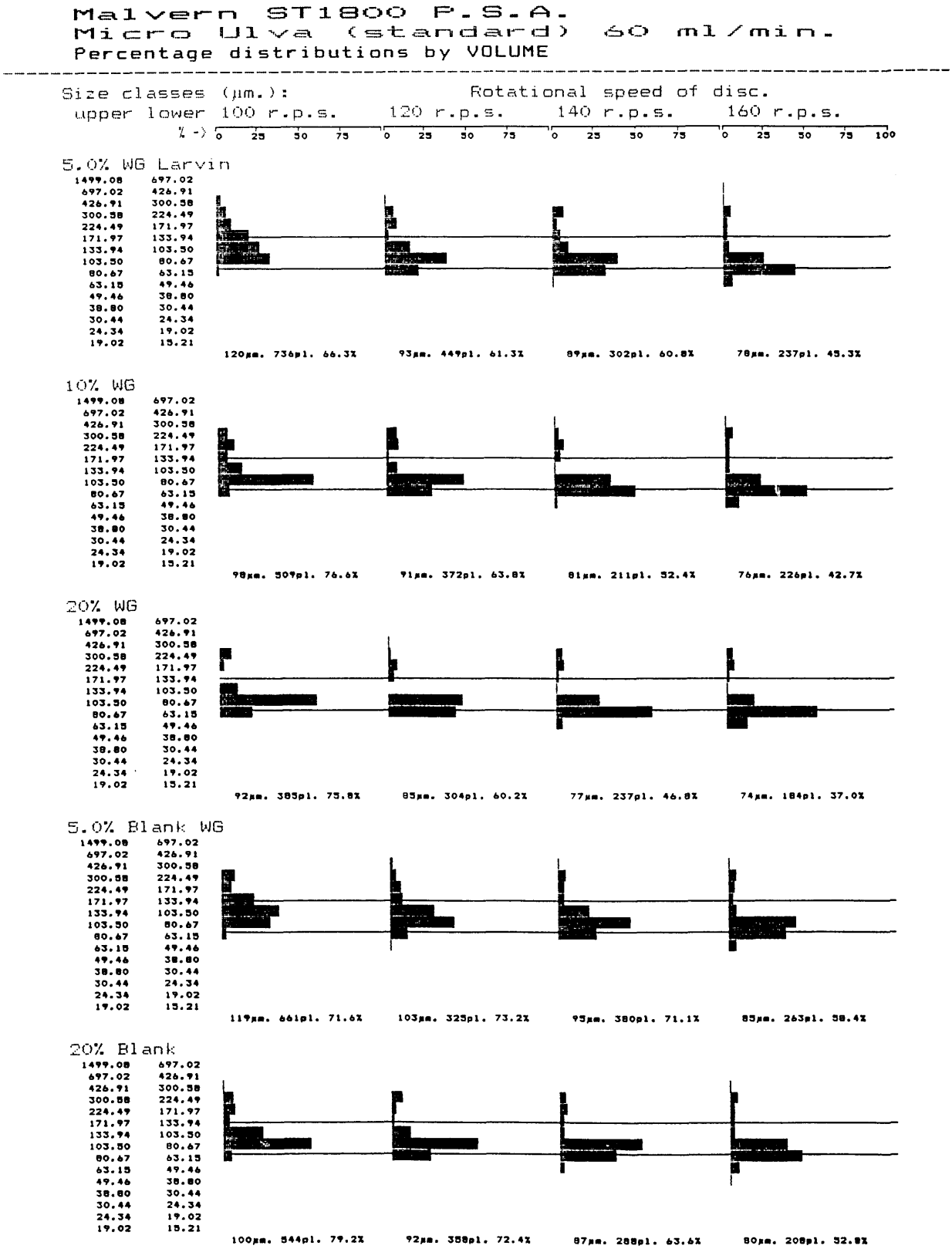
Thiodicarb - aqueous WG: Coefficient of variation (M)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Readings: block	0.02	1	0.02	1.160	N.S.
Disc Speeds	0.24	3	0.08	6.146	**
Particulates	0.00	1	0.00	0.336	N.S.
Concentration	0.34	2	0.17	13.288	***
Di. x Pa.	0.00	3	0.00	0.027	N.S.
Di. x Co.	0.10	6	0.02	1.319	N.S.
Pa. x Co.	0.08	2	0.04	3.122	N.S.
Di. x Pa. x Co.	0.05	6	0.01	0.688	N.S.
Contrasts					
Linear	0.20	(1)	0.20	15.623	***
Quadratic	0.02	(1)	0.02	1.770	N.S.
Cubic	0.01	(1)	0.01	1.046	N.S.
Total (all treatments)	0.82	23	0.04	2.770	**
Residual (Error)	0.30	23	0.013		
TOTAL	1.14	47			

Coefficient of Variation = 18.3%

No.	Disc Speeds	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: homogeneity indices.				0 0.80
1	100 r.p.s.	0.72	0.04	0.022	
2	120 r.p.s.	0.65	0.06	0.062	
3	140 r.p.s.	0.55	0.04	0.034	
4	160 r.p.s.	0.56	0.02	0.013	
	Particulates				0 0.80
1	WG formulation	0.61	0.04	0.056	
2	Clear Blank	0.63	0.02	0.023	
	Concentration				0 0.80
1	5% w/v.	0.73	0.03	0.018	
2	10% w/v.	0.62	0.04	0.040	
3	20% w/v.	0.52	0.03	0.029	

Fig. 3.4.1.13. Effects of particle addition: volume distributions. Flow rate: 60 ml/min



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

Fig. 3.4.1.14. Atomisation of anti-evaporant mixtures: analysis.

Effects of Anti-evaporants: Micro Ulva.

Effects of anti-evaporants on V.M.D.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Additives	14220.87	4	3555.22	114.203	*****
Flow Rates	5013.13	1	5013.13	161.035	*****
Disc Speeds	41241.74	3	13747.25	441.598	*****
Ad. x Fl.	2912.84	4	728.21	23.392	*****
Ad. x Di.	1573.74	12	131.14	4.213	***
Fl. x Di.	2809.64	3	936.55	30.084	*****
Ad. x Fl. x Di.	3572.99	12	297.75	9.564	*****
Contrasts					
Water + Agral vs others	403.84	(1)	403.84	12.972	***
Agral vs Molasses	331.93	(1)	331.93	10.663	**
Agral vs C.M.S.	129.69	(1)	129.69	4.166	N.S.
Agral vs 2.5% Derimin	7406.12	(1)	7406.12	237.904	*****
Agral vs 5.0% Derimin	50.37	(1)	50.37	1.618	N.S.
Molasses vs C.M.S.	46.66	(1)	46.66	1.499	N.S.
2.5% vs 5.0% Derimin	6234.99	(1)	6234.99	200.284	*****
Residual (Error)	1245.23	40	31.131		
TOTAL	72590.18	79			

Coefficient of Variation = 5.4%

No.	Additives	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
Units (untransformed) are: droplet size: microns.					0 — 140.00
1	Water + 0.1% Agral	99.41	5.13	4.242	
2	Water + 35% Molasses	92.97	8.12	11.340	
3	Water + 21 Brix C.M.S.	95.39	8.21	11.316	
4	Water + 2.5% Derimin	129.84	6.15	4.660	
5	Water + 5.0% Derimin	101.92	6.76	7.170	
	Flow Rates				0 — 140.00
1	30 ml./min.	111.82	5.10	9.301	
2	60 ml./min.	95.99	4.16	7.216	
	Disc Speeds				0 — 140.00
1	100 r.p.s.	138.56	5.98	5.155	
2	120 r.p.s.	109.21	5.14	4.848	
3	140 r.p.s.	88.15	3.34	2.531	
4	160 r.p.s.	79.71	3.03	2.296	

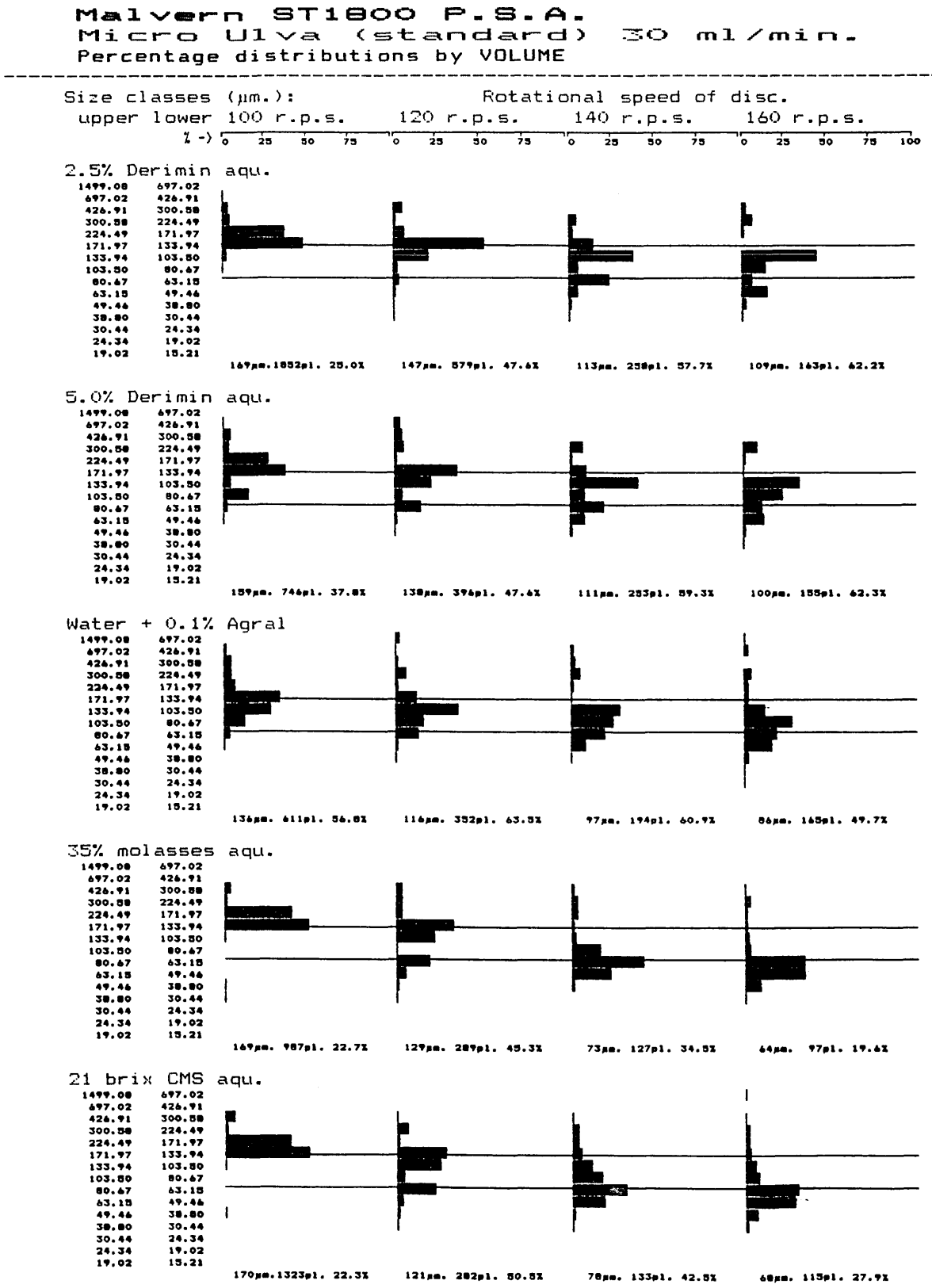
Effects of anti-evaporants on Coefficient of variation

Source	Sum of Squares	DF	Mean Squares	F	Significance
Additives	0.36	4	0.09	11.226	*****
Flow Rates	0.10	1	0.10	12.798	***
Disc Speeds	0.07	3	0.02	2.773	N.S.
Ad. x Fl.	0.11	4	0.03	3.332	*
Ad. x Di.	0.43	12	0.04	4.404	***
Fl. x Di.	0.50	3	0.17	20.545	*****
Ad. x Fl. x Di.	0.76	12	0.06	7.841	*****
Contrasts					
Water + Agral vs others	0.02	(1)	0.02	2.569	N.S.
Agral vs Molasses	0.08	(1)	0.08	9.663	**
Agral vs C.M.S.	0.00	(1)	0.00	0.309	N.S.
Agral vs 2.5% Derimin	0.10	(1)	0.10	12.861	***
Agral vs 5.0% Derimin	0.04	(1)	0.04	4.759	*
Molasses vs C.M.S.	0.05	(1)	0.05	6.518	*
2.5% vs 5.0% Derimin	0.27	(1)	0.27	33.266	*****
Residual (Error)	0.32	40	0.008		
TOTAL	2.65	79			

Coefficient of Variation = 11.8%

No.	Additives	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
Units (untransformed) are: homogeneity indices.					0 — 0.90
1	Water + 0.1% Agral	0.79	0.03	0.017	
2	Water + 35% Molasses	0.70	0.06	0.077	
3	Water + 21 Brix C.M.S.	0.78	0.06	0.076	
4	Water + 2.5% Derimin	0.68	0.04	0.030	
5	Water + 5.0% Derimin	0.86	0.02	0.007	
	Flow Rates				0 — 0.90
1	30 ml./min.	0.73	0.03	0.042	
2	60 ml./min.	0.80	0.03	0.043	
	Disc Speeds				0 — 0.90
1	100 r.p.s.	0.78	0.06	0.108	
2	120 r.p.s.	0.78	0.03	0.028	
3	140 r.p.s.	0.76	0.03	0.018	
4	160 r.p.s.	0.71	0.03	0.021	

Fig. 3.4.1.15. Anti-evaporant mixtures: volume distributions. Flow rate: 30 ml/min



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 75 - 150µm.

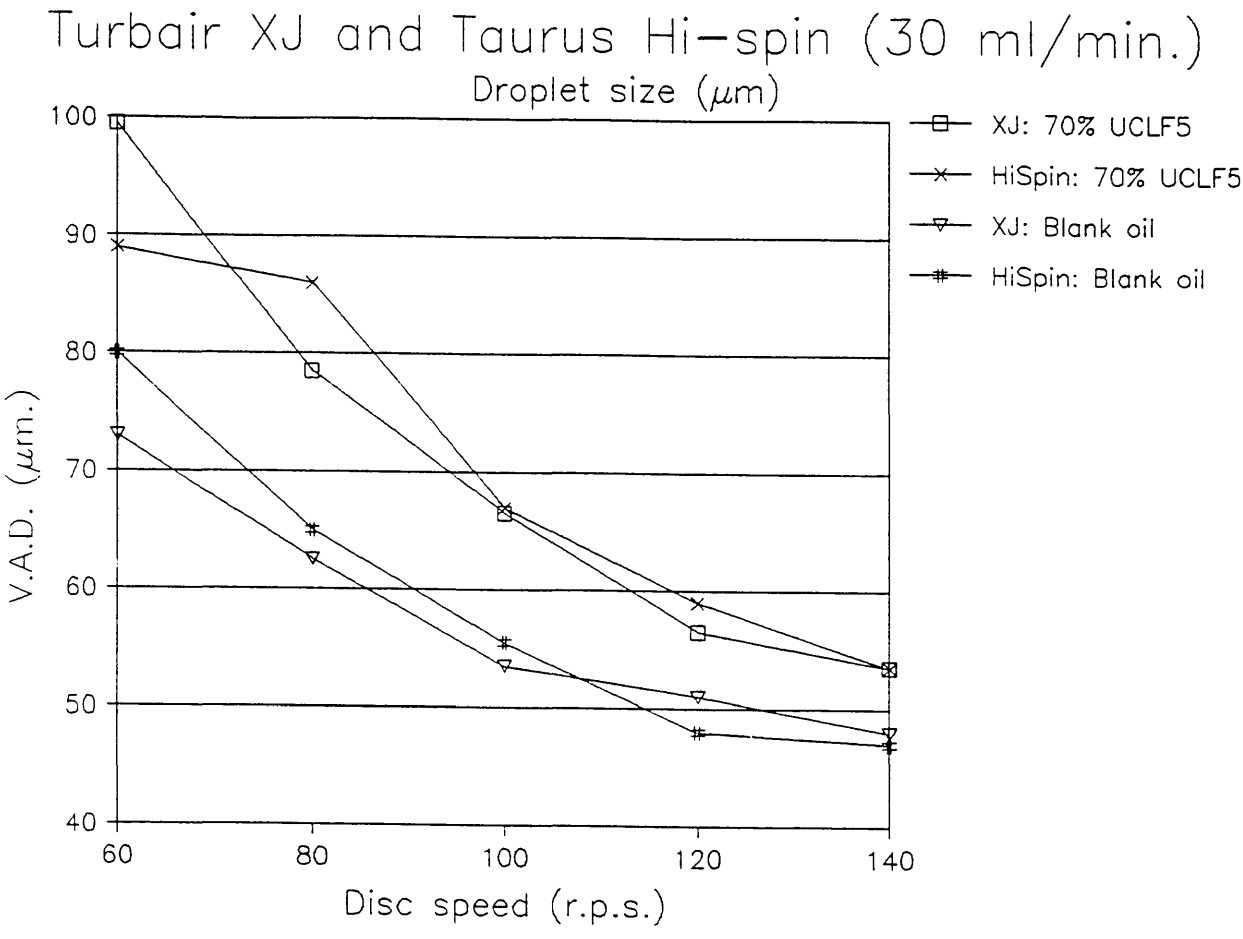
3.4.2. Oil-based Formulations

Fig. 3.4.2.1. was prepared for field trial 5; it shows two liquids of equivalent apparent viscosity which passed through sprayers at approximately the same flow rate. Fig. 3.4.2.2. is a comparison of sprays produced by the Berthoud C8 and Micron 'Ulva', with a commercial UL formulation (2.5% cypermethrin) and the higher viscosity UCLF8. At 30 ml/min., the 'Ulva' produced poor quality sprays with the UL formulation, indicating bimodal droplet distributions, with high VADs at low disc speeds. Within their normal operating range of flow rate, nozzles with 87-88 mm. discs tended to produce more uniform droplet spectra of larger average diameter with oil-based suspensions compared with transparent oils.

All readings described below have been obtained with a 'Micro Ulva' atomiser. Fig. 3.4.2.3. illustrates a series of liquids with a range of properties showed a general correlation between droplet size and viscosity - apart from some ambiguity with low viscosity oils at the lowest disc speed. Figs. 3.4.2.4-3.4.2.6. are comparisons of clear oils and suspensions, at typical (30 ml/min. = 0.5 $ml.s^{-1}$) to low flow rates (10 ml/min. = 0.17 $ml.s^{-1}$); these groups of readings are arranged in pairs for the sake of clarity only. Fig. 3.4.2.4. is a comparison of extremes, with Shellsol K apparently undergoing transitions between phases of atomisation as flow rate and disc speed are increased. Fig. 3.4.2.5. may be representative of commercial UL and SU formulations, with lambda-cyhalothrin blank compared with the most stable of the low viscosity thiodicarb preparations. Fig. 3.4.2.6. shows the contrast between UCLF8 with Orchex 796 (which has a higher apparent viscosity); at all flow rates the SU produced larger and more even droplet spectra than the clear oil.

Fig. 3.4.2.7. illustrates droplet distributions by volume for Shellsol K and Risella EL. At 10 ml/min., Shellsol K produced large unimodal droplet spectra, with virtually all the spray in 2-3 size classes. Bimodal distributions appeared at 20 ml./min., as disc speed was increased. At 30 ml/min. unimodal distributions re-appeared with speeds greater than 120 rev.s^{-1}; VMDs were 40-50 μm. smaller than with equivalent readings at 10 ml/min., and droplets were distributed in a greater number of size classes. Risella EL oil appeared to undergo transitions at 10 ml/min., which was broadly consistent with Orchex 796 or lambda-cyhalothrin UL blank (Fig. 3.4.2.8.). This figure further confirms that the SU formulations produced more uniform droplet spectra than clear oils at low flow rates. At 30 ml/min. the SU formulations continued to produce more homogeneous sprays, with most droplets in 2-3 size classes (Fig. 3.4.2.9). Sprays produced by the least viscous SU (UCLF8) were less homogeneous than UCLF5, and this at least partially accounts for lower VAD readings (e.g. Fig. 3.4.2.3).

Fig. 3.4.2.1. Oil-based formulations: Tests for field trial 5. UCLF5 and 78% raw cotton-seed oil diluted with Shellsol K.



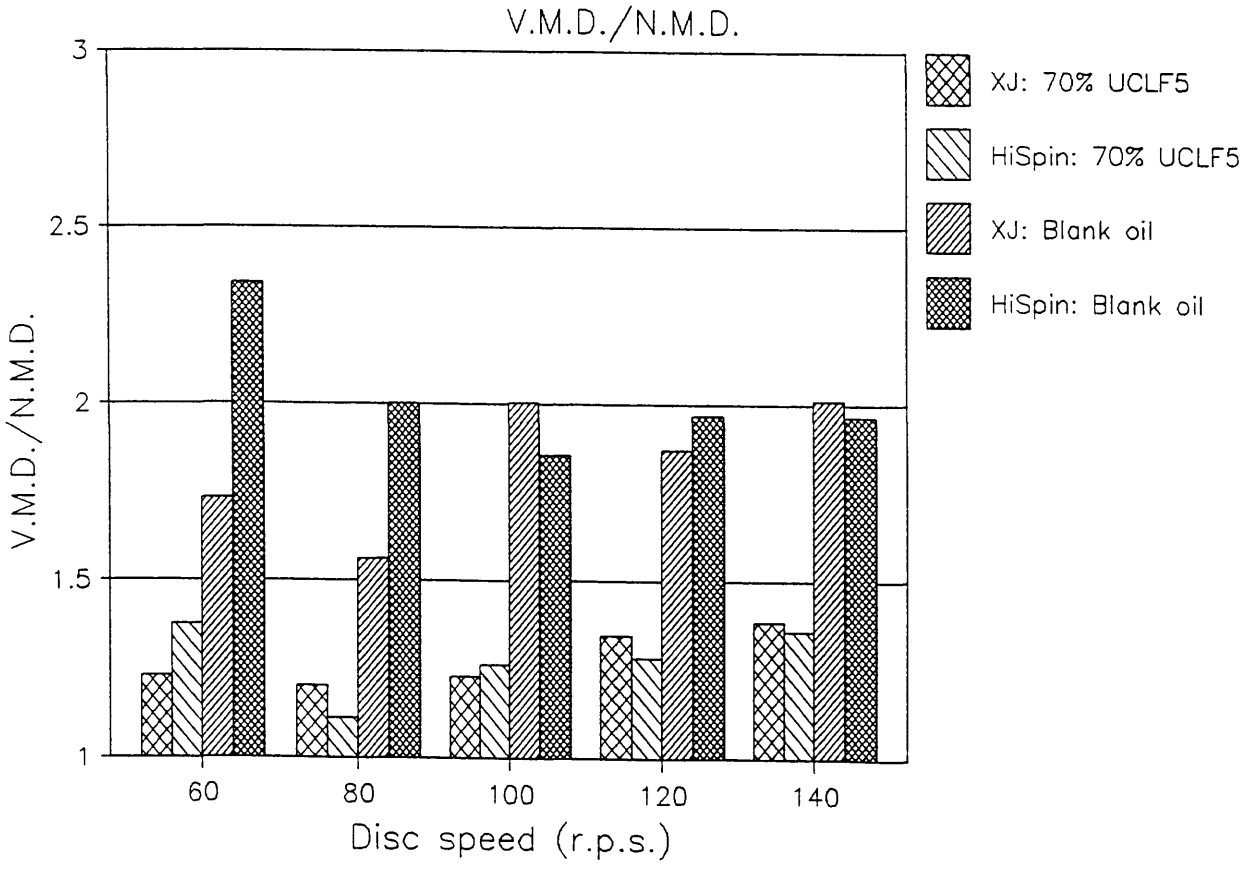
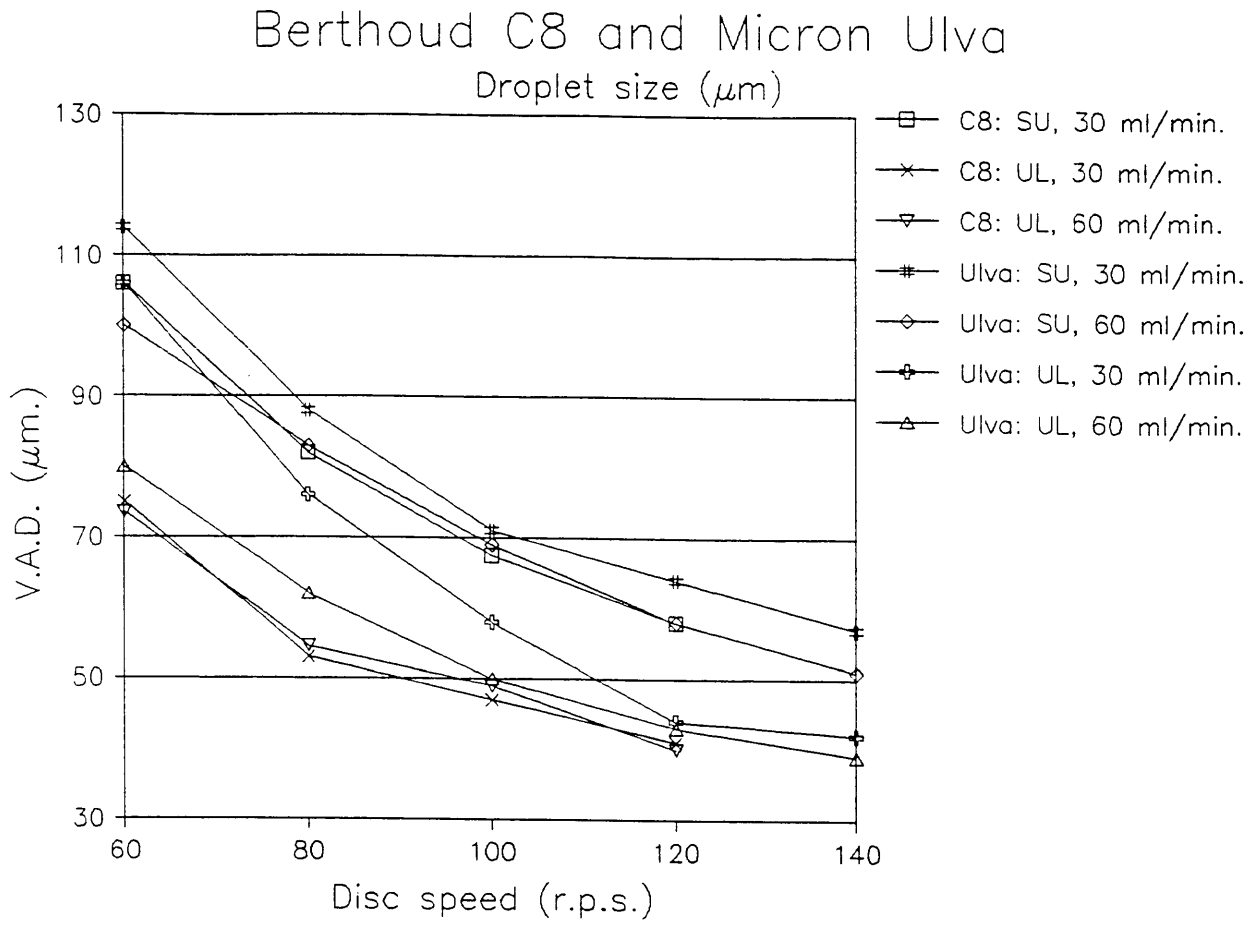


Fig. 3.4.2.2. Oil-based formulations: Berthoud C8 and Micron 'Ulva'.
SU: UCLF8; UL: 2.5% cypermethrin UL.
(N.B. 60 ml./min. is unobtainable for UCLF8 with unmodified C8)



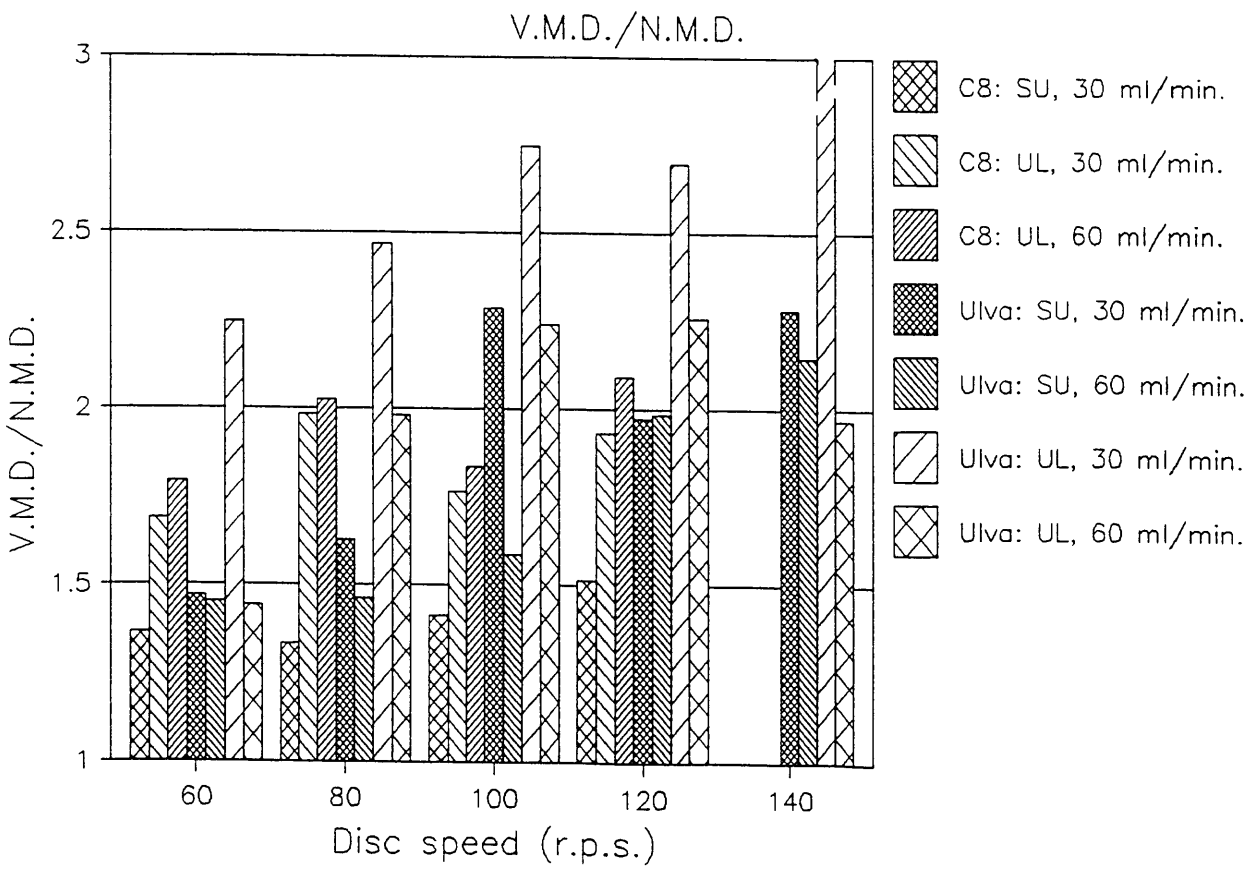
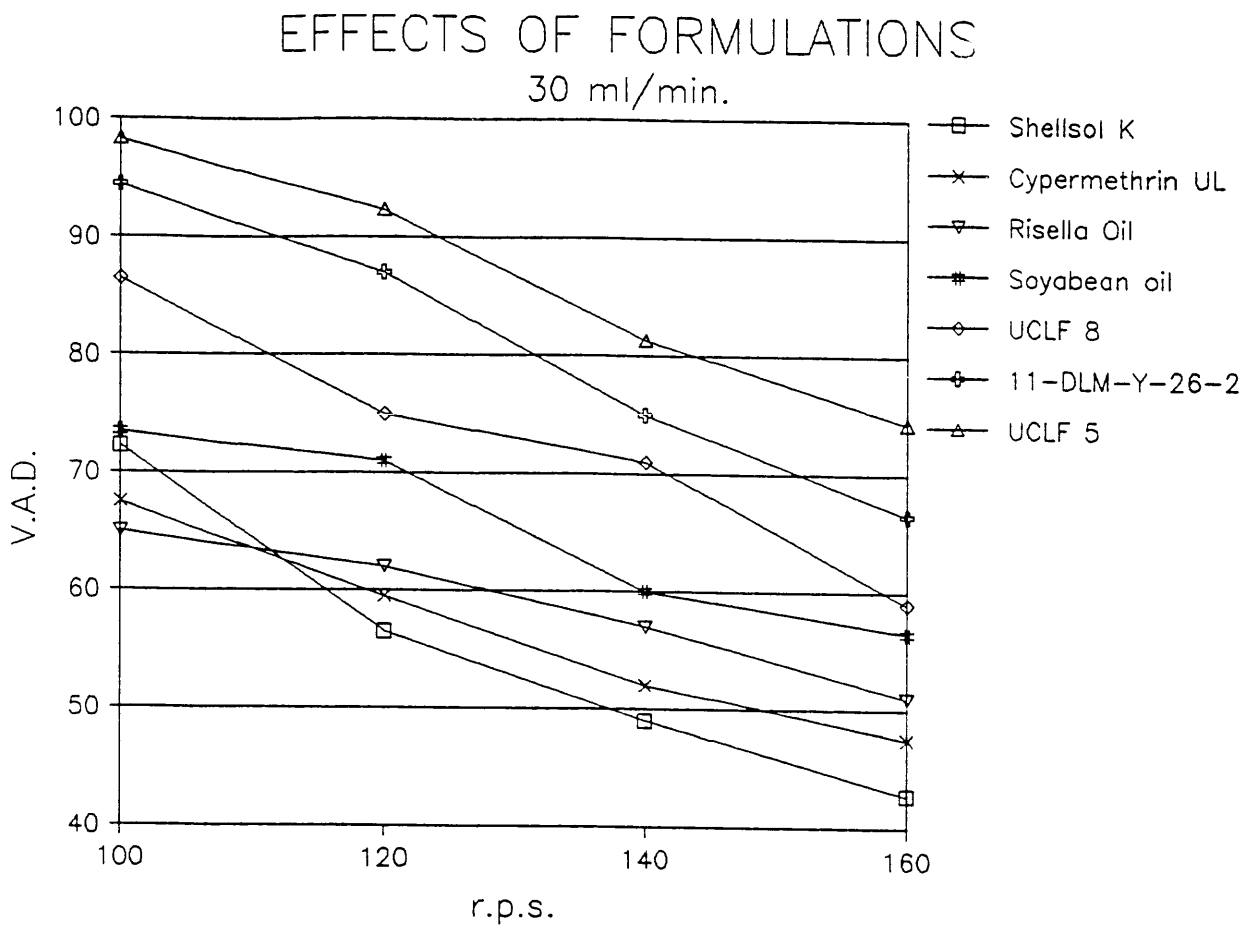


Fig. 3.4.2.3. 'Micro Ulva': fluids of increasing apparent viscosity.



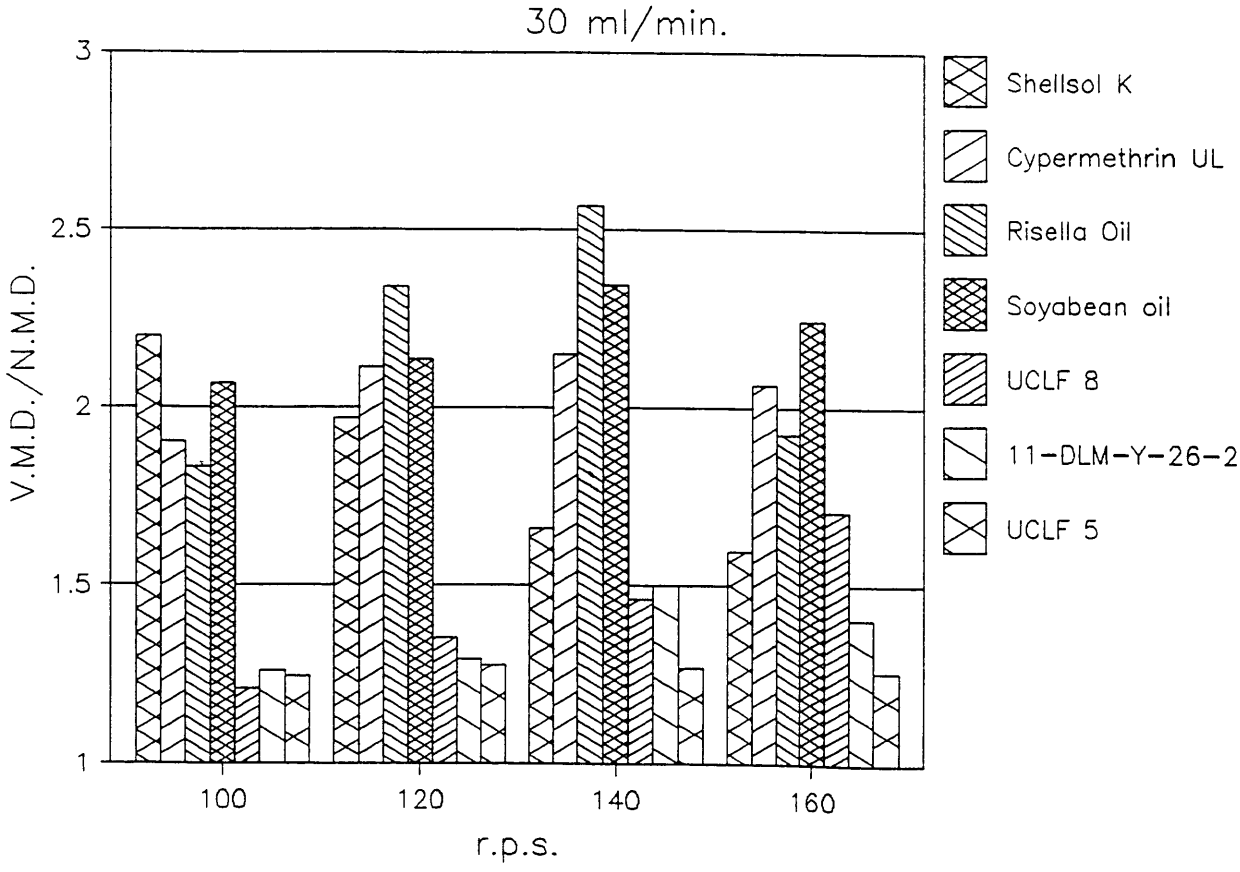
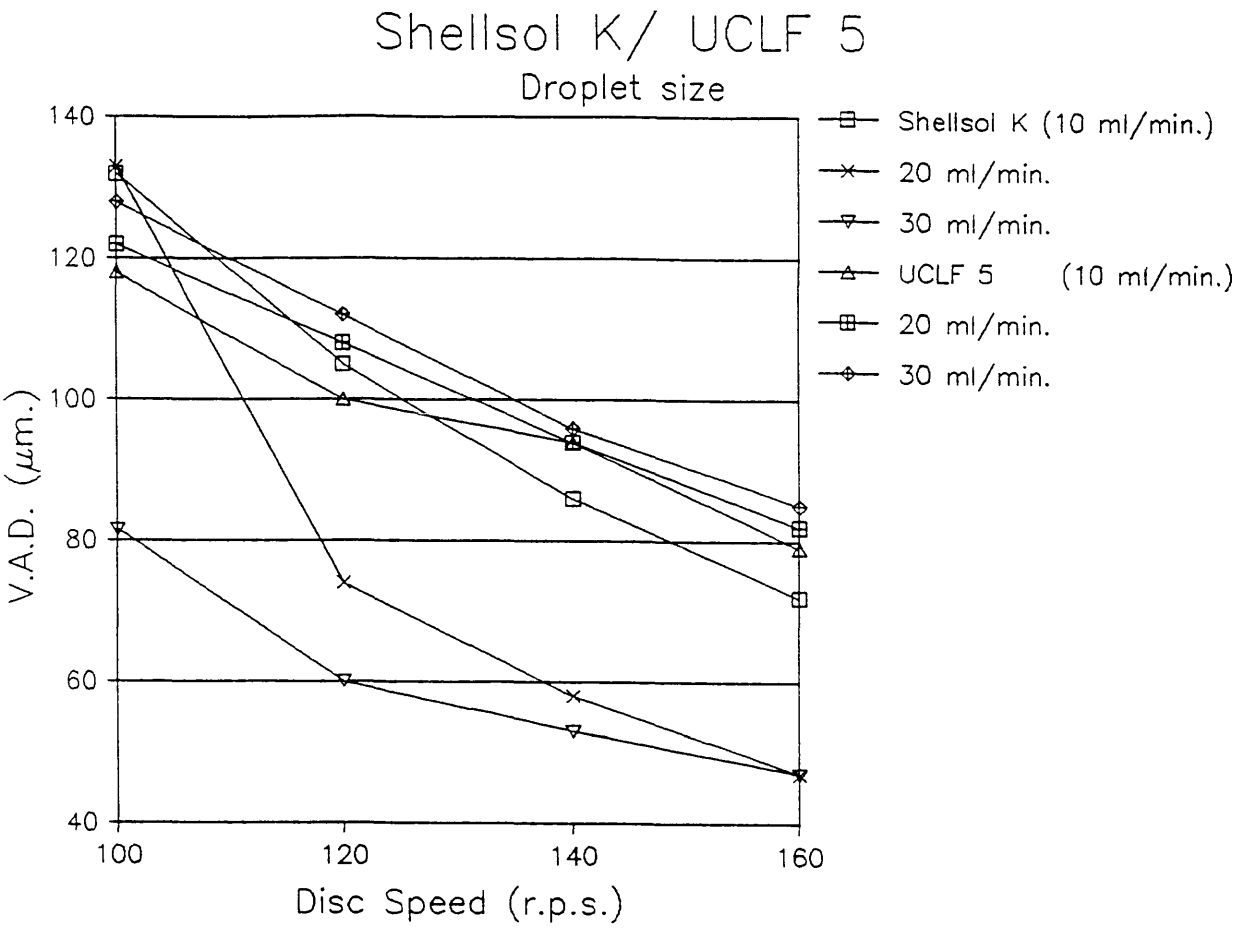


Fig. 3.4.2.4. 'Micro Ulva' (1): Atomisation of Shellsol K and UCLF5



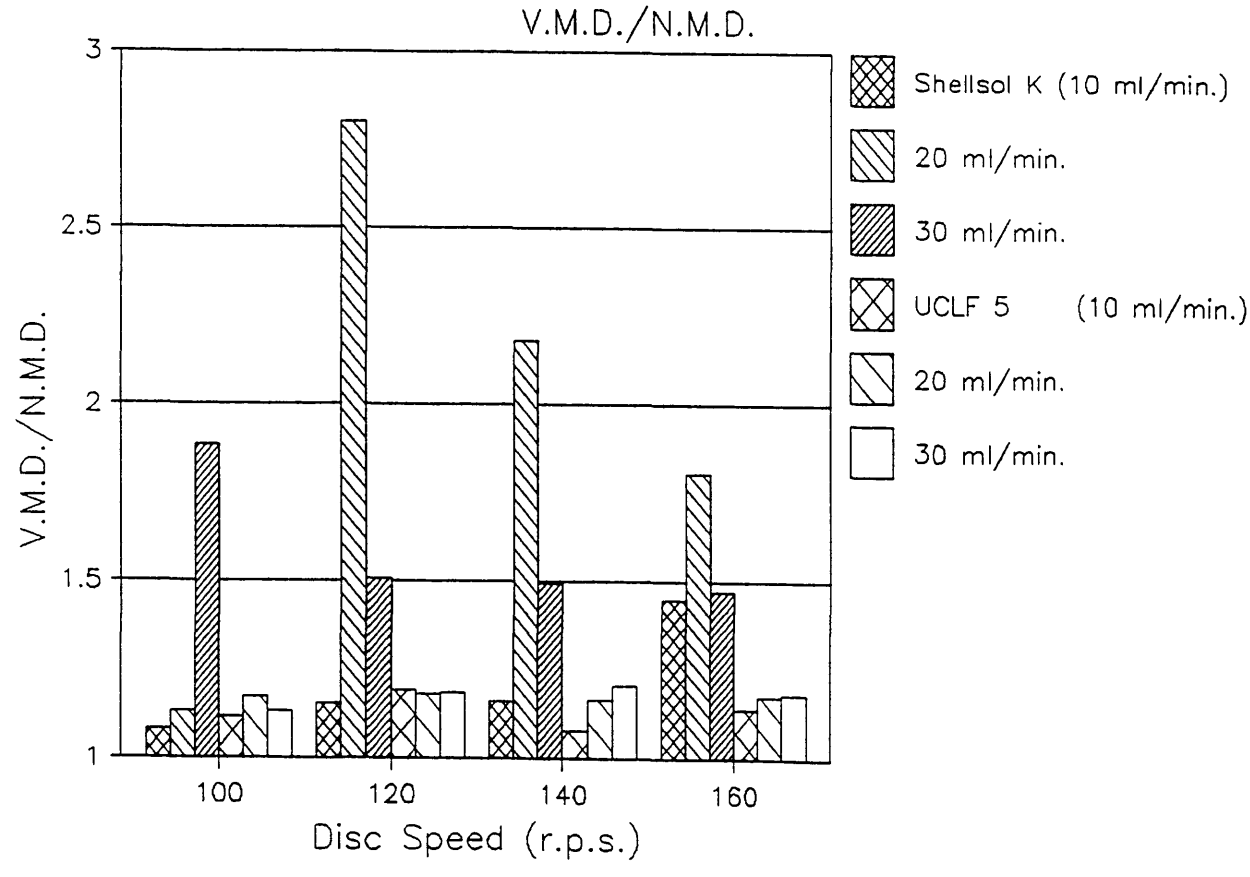
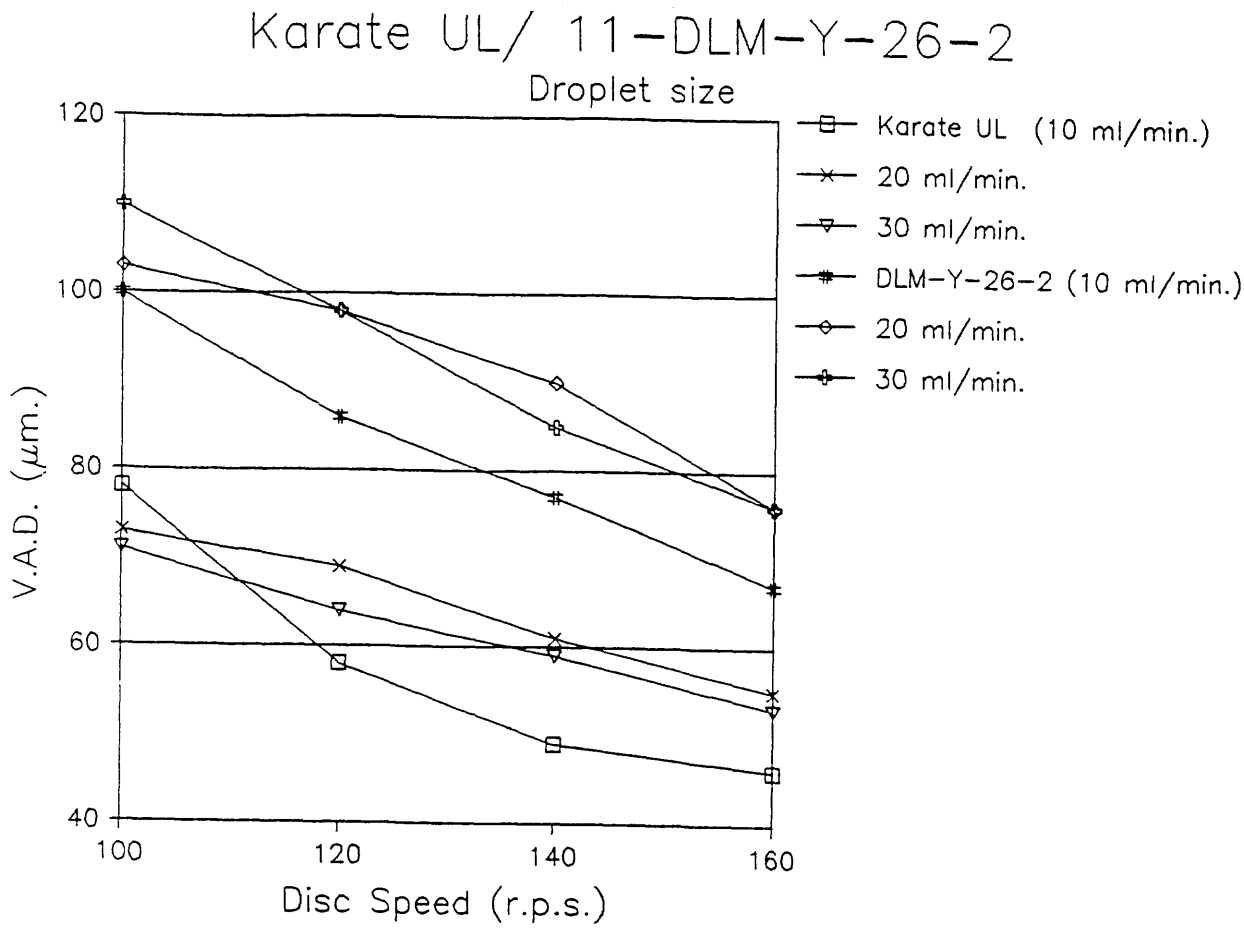


Fig. 3.4.2.5. (2): Atomisation of L-cyhalothrin UL and 11-DLM-Y-26-2



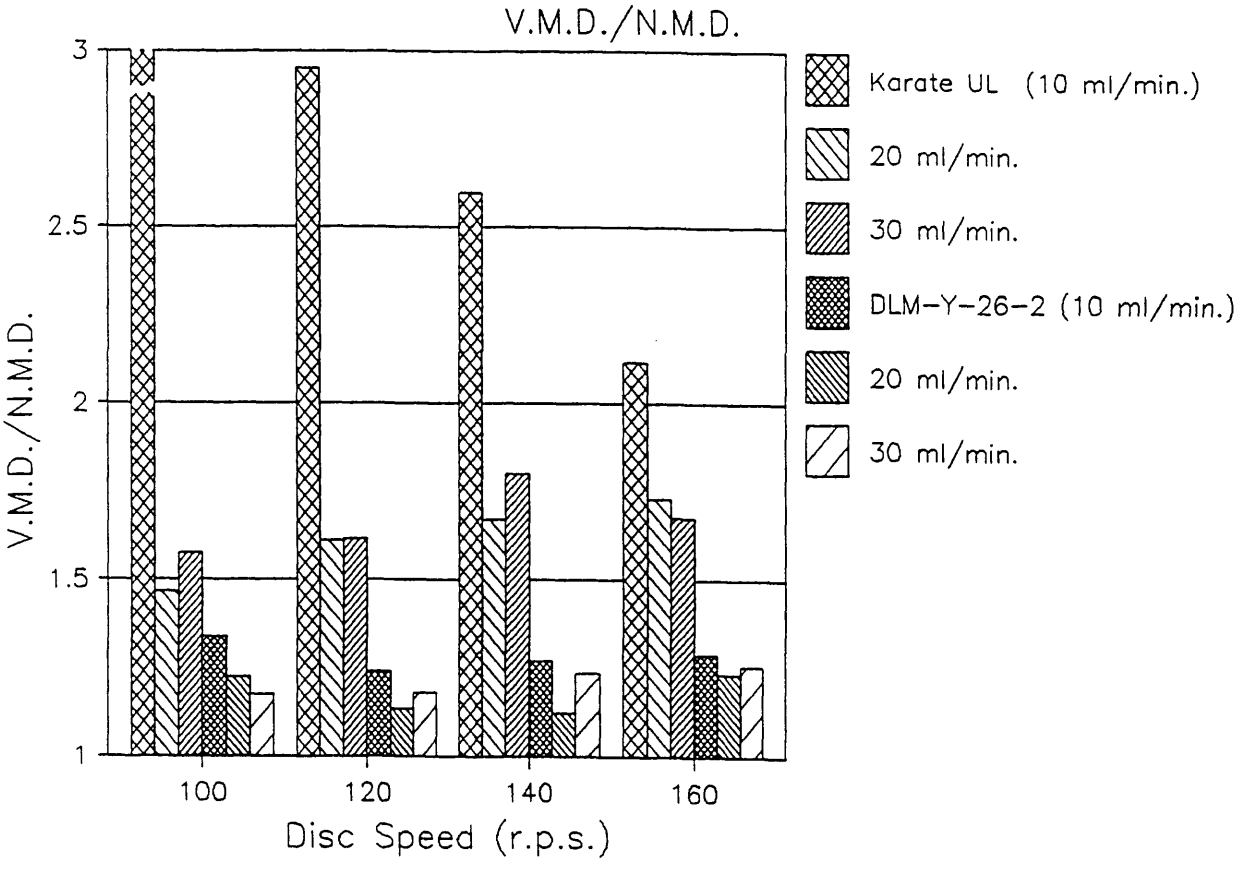
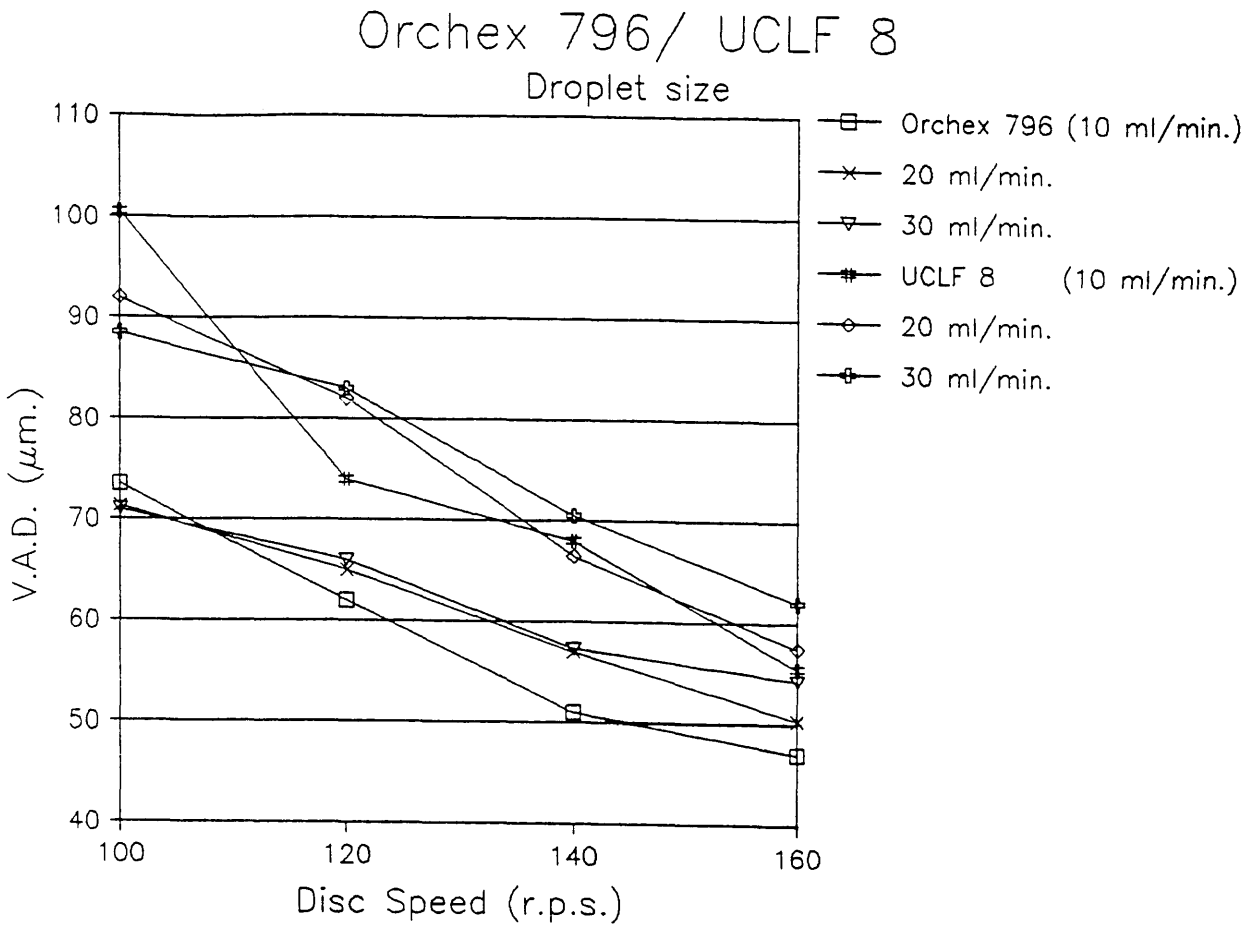


Fig. 3.4.2.6. (3): Atomisation of Orchex 796 and UCLF8



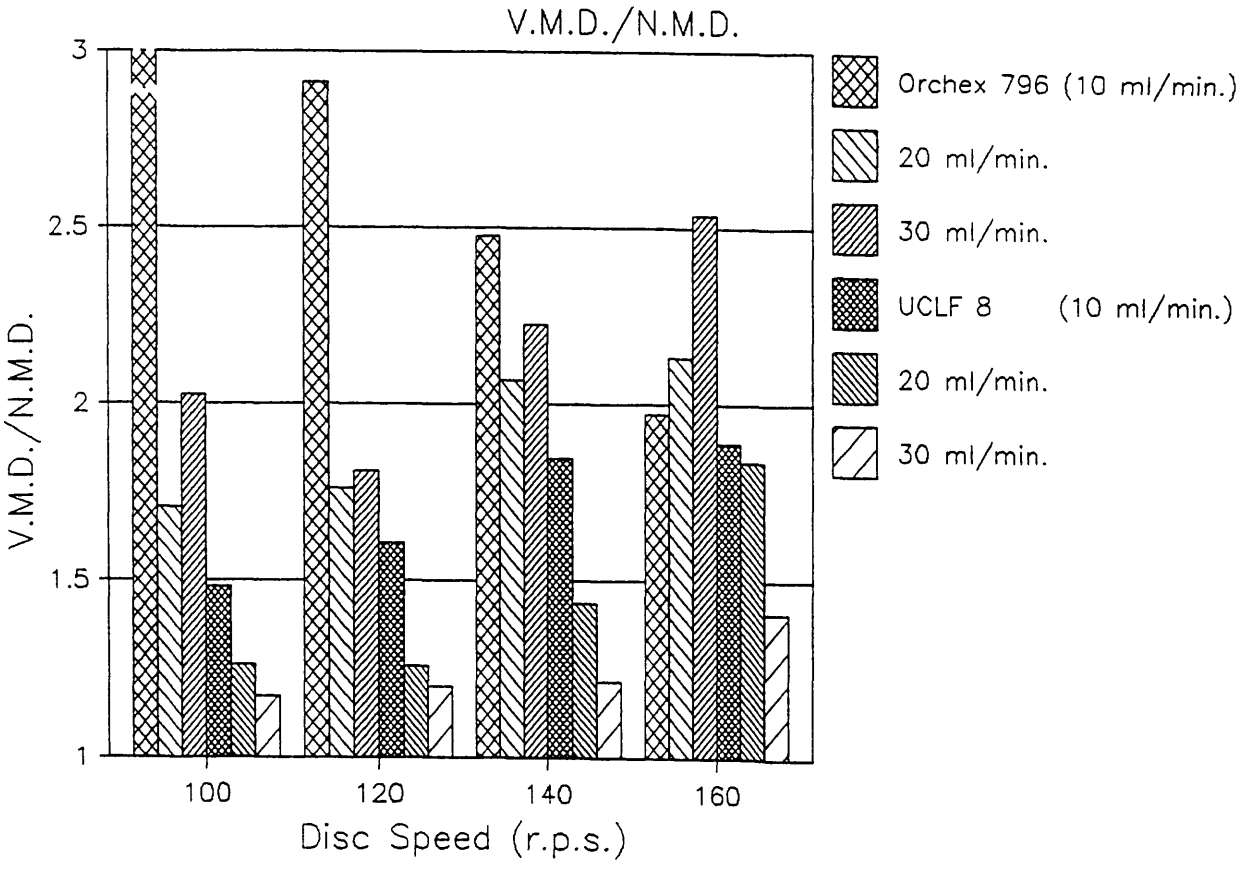
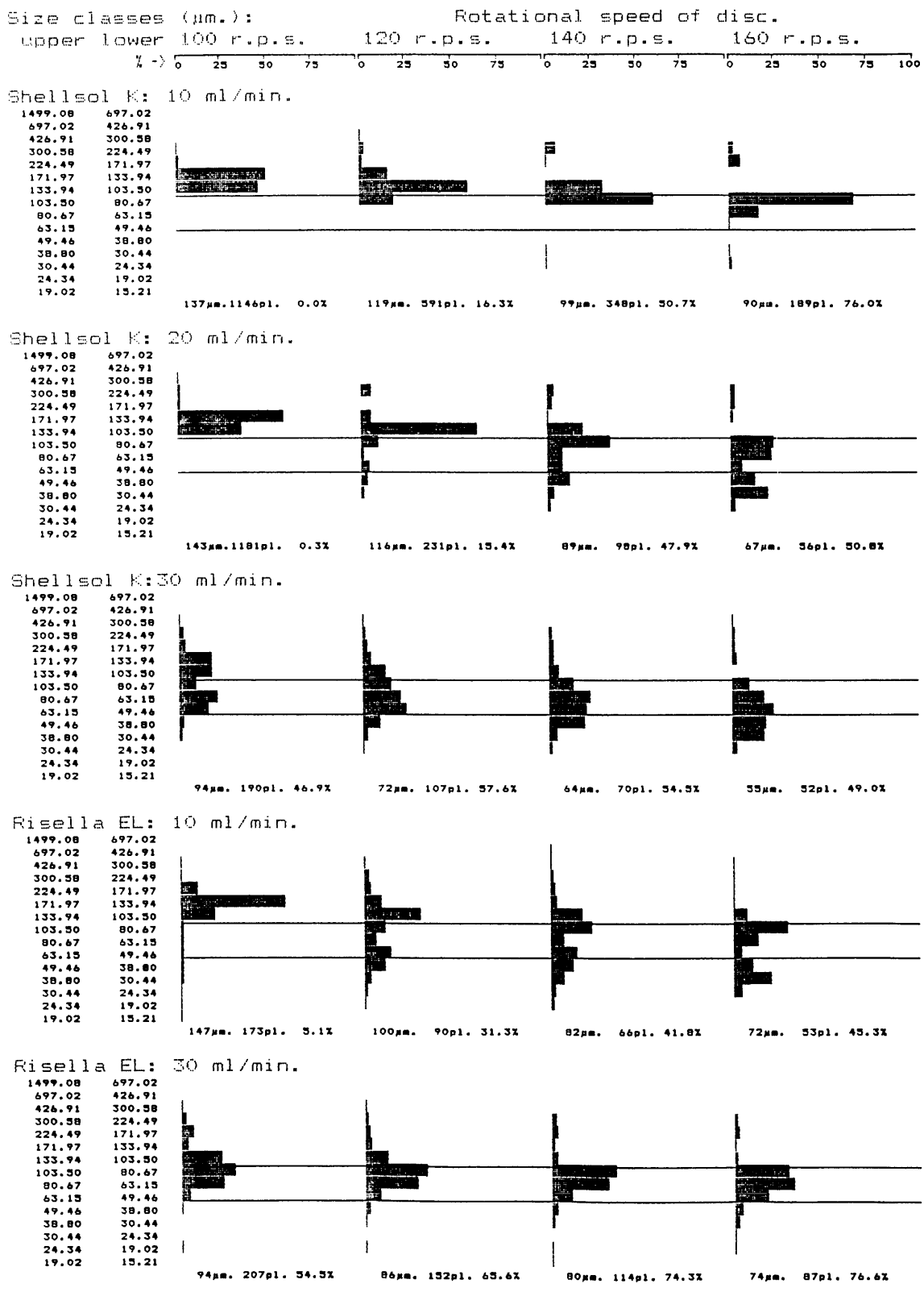


Fig. 3.4.2.7. Clear blank fluids: percent by volume.

Malvern ST1800 P.S.A.
Micro Ulva (standard)
Percentage distributions by VOLUME



Parameters are: VMD (µm.), ADV (pl.), and estimated % droplet volume between 50 - 100µm.

Fig. 3.4.2.8. Formulations, 10ml./min.: percent by volume.

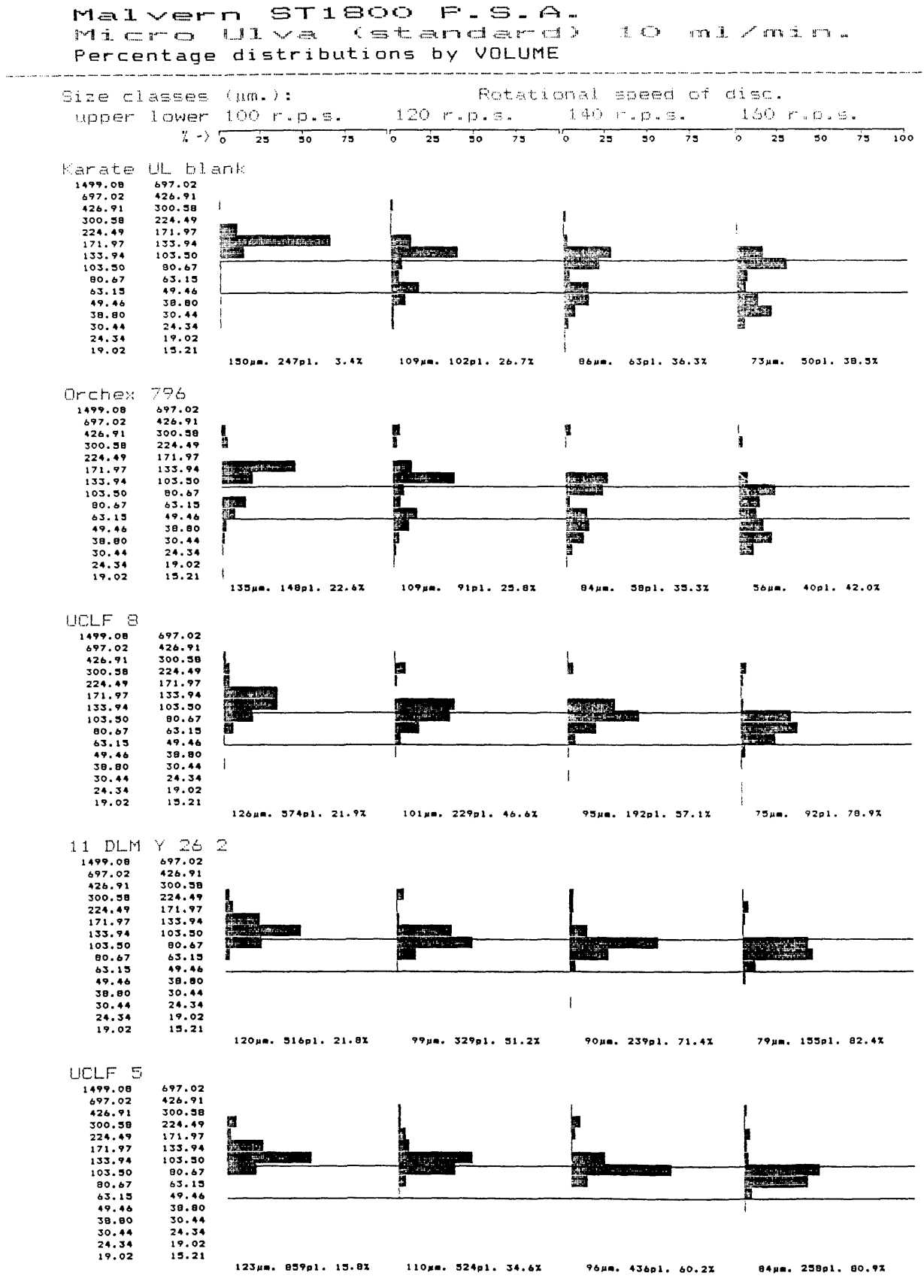
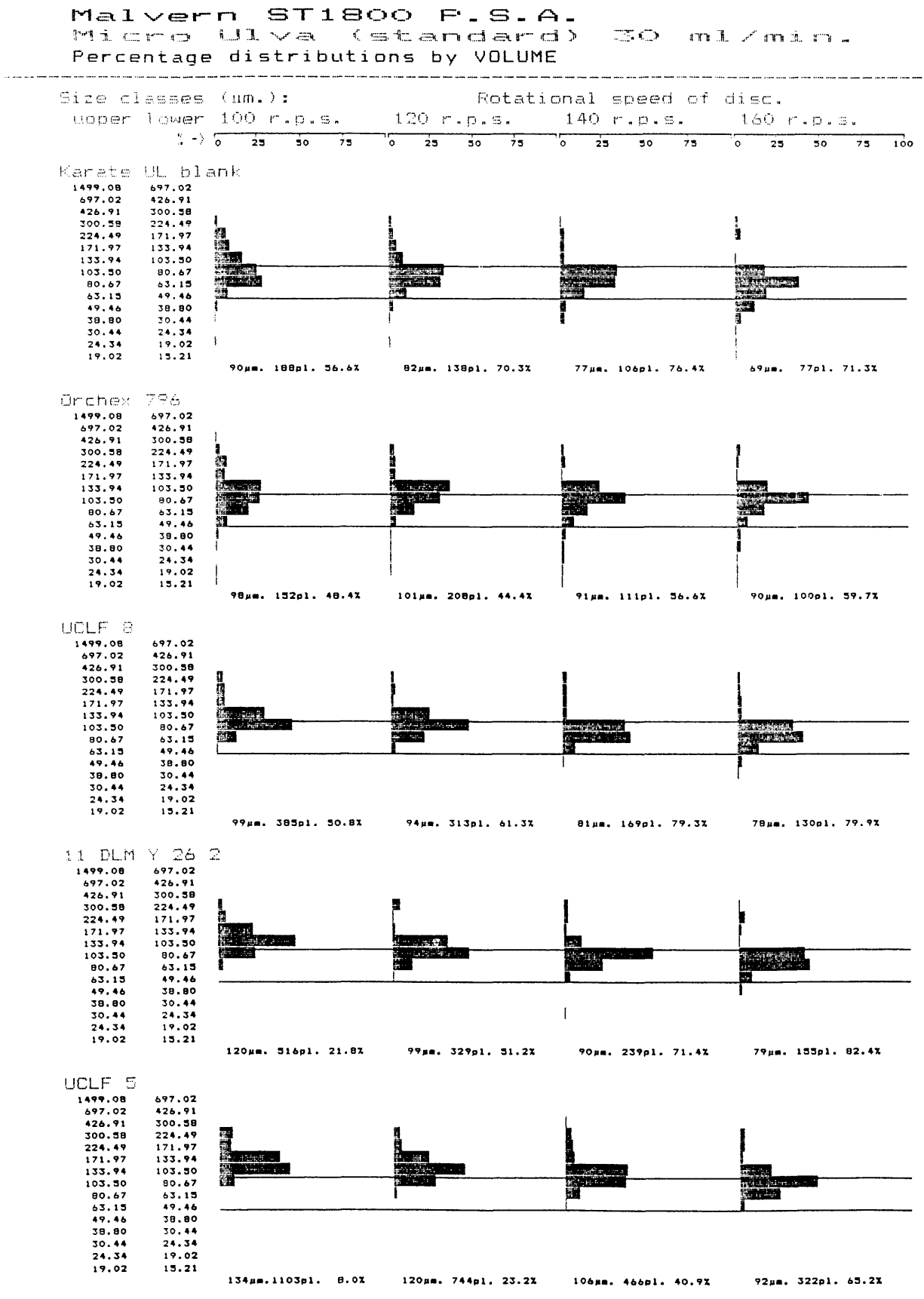


Fig. 3.4.2.9. Formulations, 30ml./min.: percent by volume.



3.5. ATOMISER DURABILITY

3.5.1. Durability Tests and Effects of Sprayer Head Motor Ageing

Disc speeds were monitored at least twice weekly and the "penultimate" reading in Table 3.5.1. indicates the last speed before a test was terminated. Further replication is required for some of these tests.

It was surprising to find that the Ulva and Mini-Ulva Mk.I failed much earlier than the Turbair XJ. The motors of both makes are essentially of the same type and they can be disassembled, examined and repaired if necessary. A deceleration of the Ulva disc is accompanied by a reduction in power consumption, and the cause of this particular problem seems to be an accumulation of black powder around the commutator. When carefully cleaned-out the motors perform practically as new, but this process may have to be repeated up to three times before reaching 500 hours. The farmer should however expect uninterrupted use from his sprayer. Fitting Turbair brushes to the Ulva motor, or adapting the sprayer so that it drove a single "Herbi" disc, appeared to improve longevity, but these modifications still did not extend service life beyond 500 hours.

Micro-Ulva sprayers are currently supplied with a handle that holds a maximum of six batteries. Operating them at high disc speeds dramatically reduces their longevity: motors driven at 7.5 v. last up to four times longer than at 10.5 v. They also slow down after relatively short time in the test rig, which corroborates findings illustrated in Fig. 3.2.1.. In the field this has been found to be due to water entering the motor housing, and forming rust deposits around the bearings. Accumulations of dust may also be found in worn motors, which cannot be repaired and must be replaced.

Table. 3.5.1 **Durability Test Results.**

Atomiser description (Voltage)	Hours to destruction (No. tested)	Disc speed (RPM): Initial	Penultimate	Current consumption (mA.)	Comments
Turbair XJ (10.5 v.)	2001 (1) 790 (1)	8000	7400 7600	640-680 650-720	First test terminated with atomiser working. Second: bearings failed.
Micro Ulva (10.5 v.)	143 (2)	10500	n./a.	390-450	Variable disc speeds after 10 h.
Micro Ulva (7.5 v.)	586 (4) s.e.m.= 196.1	8800 -9000	7000 -8200	170-250	Speed of one motor started to fluctuate at 220 h., 1 failed at 153 h.
Mini Ulva (12v) (10.5 v.)	253 (1)	9500	5800	400-425	Stalled and blew fuse at 251 hours
Mini Ulva (6v) (5.25 v.)	635 (2)	8800 -9600	7000 -7400	600-800	10-20 h. before failure, severe vibration at start of cycles.
Mini Ulva (experimental 3v. motor run at 3.0v.)	57 (1)	7000 -8000 (variable)	3000 -4800	480-520	Test terminated due to slow disc speed.
Standard Ulva (10.5 v.)	178 (3) s.e.m.= 28.5	7300	5200	600-640 (reduces to 450 before failure)	Working time may be increased over 500 hours by cleaning. (see text)
Ulva with Turbair motor brushes. (10.5 v.)	361 (1)	7200	6200	580	" "
Ulva with single "Herbi" disc (10.5 v.)	425 (1)	8000	6000	380-410	" "
Mini Ulva Mk.I (10.5 v.)	160 (1)	8200	7200	300	" "
Berthoud C8 (10.5 v.)	2024 (1)	6400	6400	400-470	Test terminated with atomiser still working.

N.B. Measurements of disc speed and current consumption are approximate limits: variations occur at different periods in each operation cycle, especially with smaller atomisers, during the later stages of tests.

3.5.3. A Note on Disc Deterioration

Damaged discs are commonly encountered in the field and this often results from contact with crops whilst rotating. Fig 3.5.2 illustrates the droplet spectra produced a Micro Ulva, with the teeth carefully removed from the disc to produce a smooth perimeter of 51 mm. diameter; these readings should be compared with those of a normal disc (Fig 3.5.1.). At lower disc speeds and flow rates, removal of teeth increases the likelihood of bimodal droplet distribution (Fig. 3.5.3.), which effectively reduces the average droplet size; changes in median diameter are less pronounced however.

Fig. 3.5.1. Droplet sizes of standard 'Micro Ulva'.

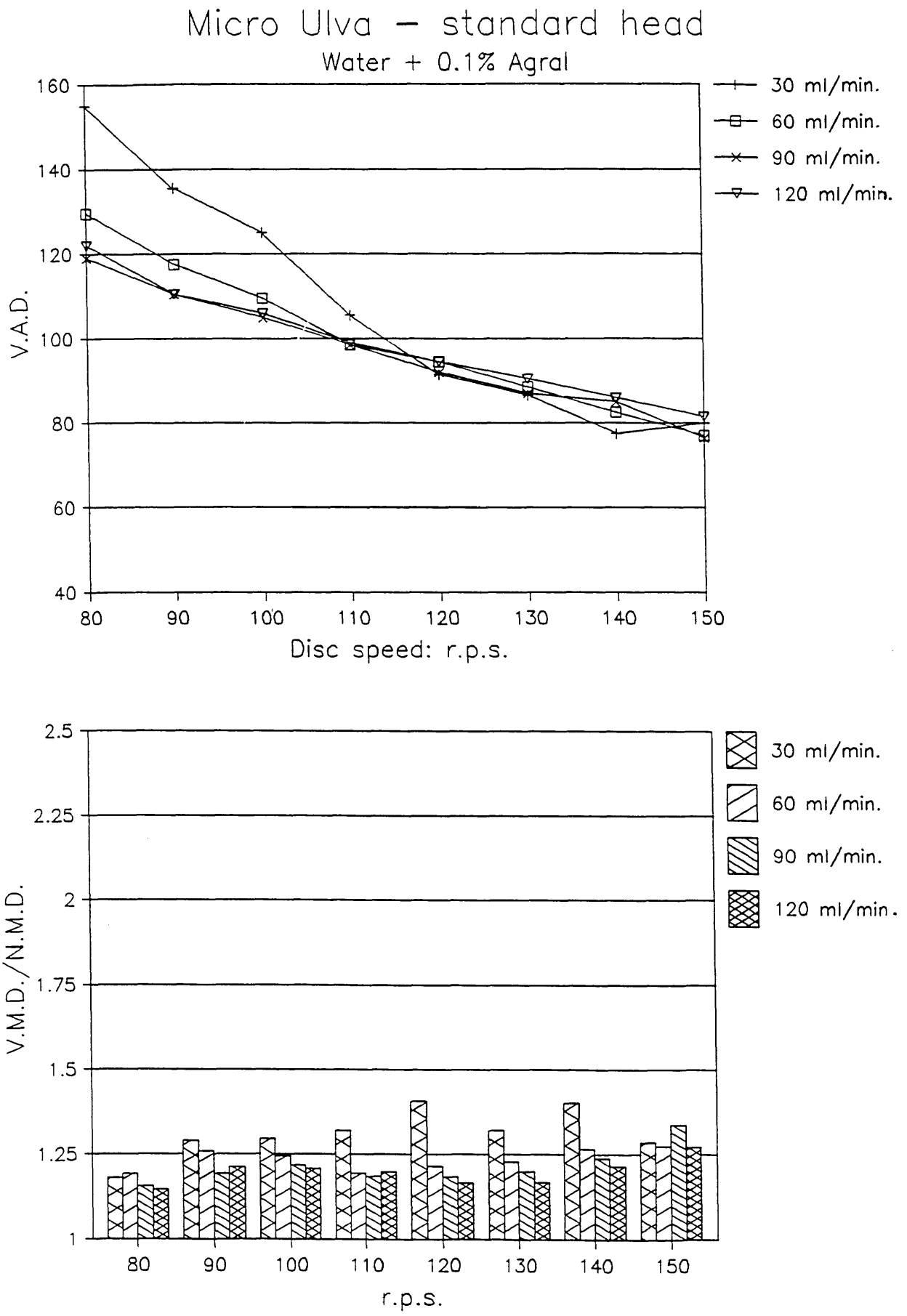
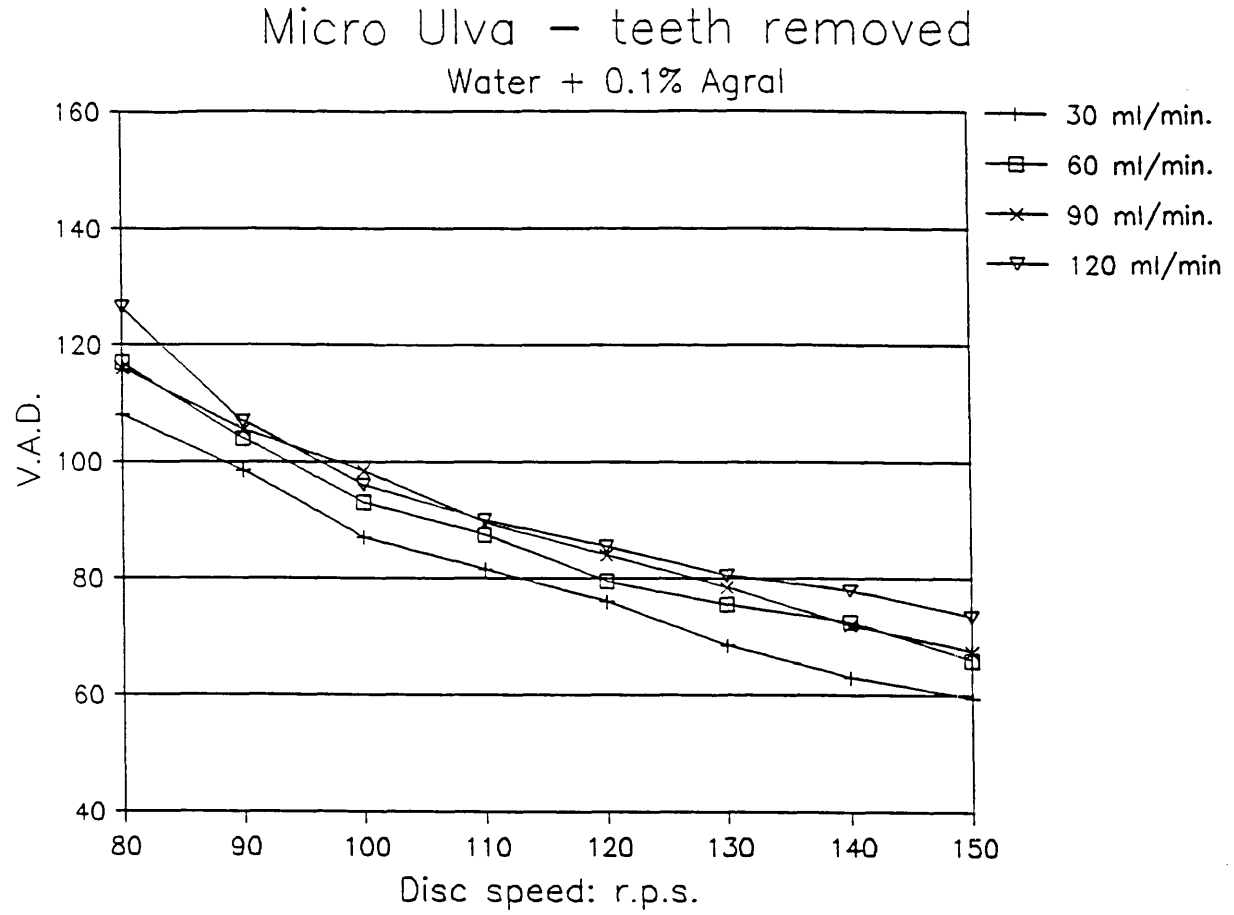


Fig. 3.5.2. 'Micro Ulva': Effects of disc tooth removal.



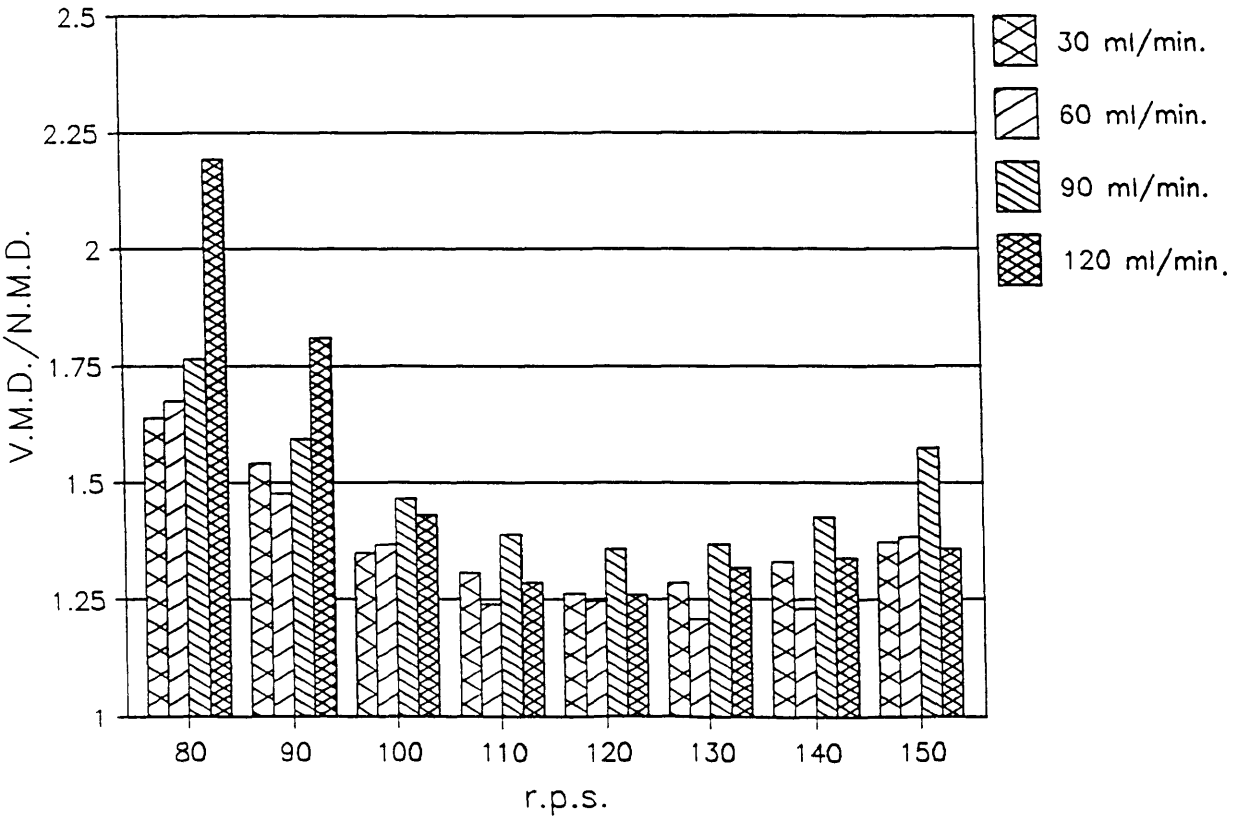
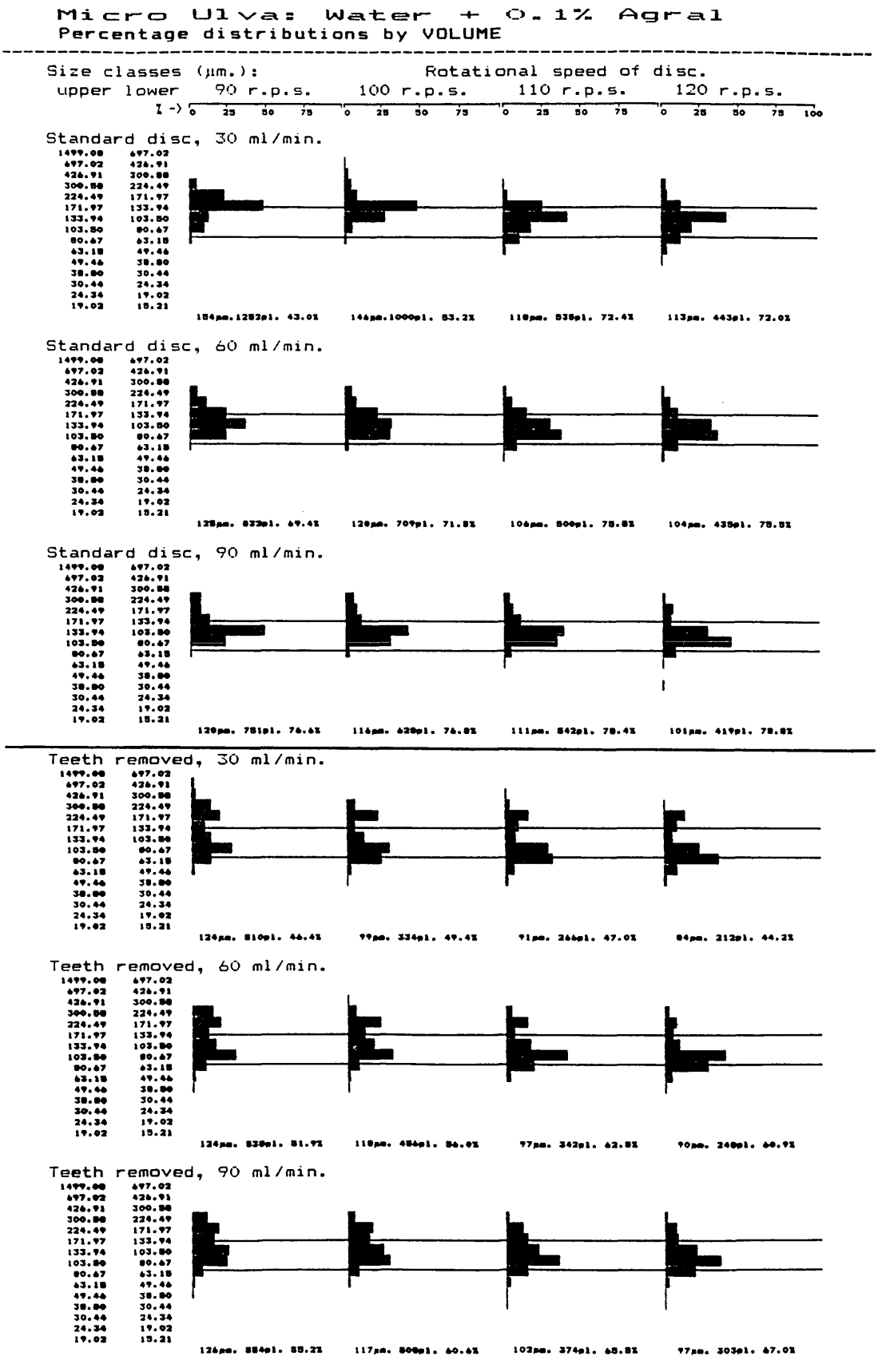


Fig. 3.5.3. Droplet Size Distributions by volume for Figs. 3.5.1-2.



CHAPTER 4

FIELD TRIALS

4.1 SWATH WIDTH TRACING STUDIES

During a pilot study in 1987, downwind recovery was assessed for three formulation types: aqueous SC, SC with 25% molasses, and oil-based formulations. The flow-rates were 30-40 ml/min., and swaths were retraced 3 times. Dry bulb temperatures were 29-31°C, and wet bulb readings were 20-22°C. Table 4.4.1. shows the calculated areas under curves (arbitrary units estimated during computer analyses, as illustrated in Figs. 4.4.1-3.) together with ADV readings (from the Malvern) and the ratios of estimated efficiency of volume recovery between small and large droplets.

Table 4.4.1. Droplet recovery and size data (1987 trials).

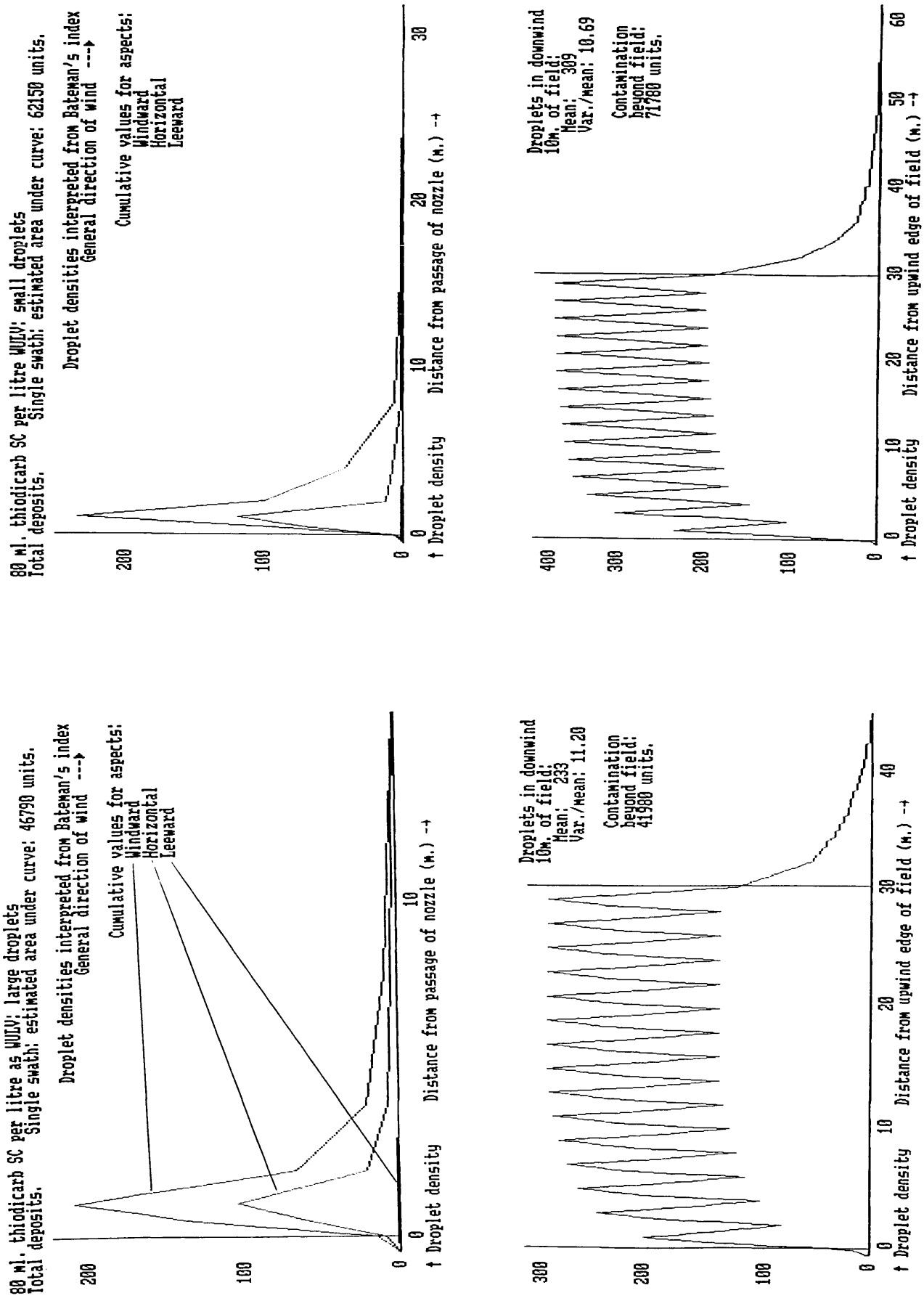
Formulation	Wind speed m./s.	Small Droplets curve area	VMD µm.	ADV pl.	Large Droplets curve area	VMD µm.	ADV pl.	Ratios (large/small) curve	ADV	(§1)
W.U.L.V.	0.0-2.0	**31850**	76	119	**30180**	114	408	1.1	3.6	**3.2**
M.U.L.V.	0.0-2.6	**96620**	76	122	**70880**	94	331	1.3	2.7	**2.0**
Mixing Oil	2.0-3.5	**189470**	79	97	**57140**	103	242	3.3	2.5	**0.8**
UCLF 8			78	132		98	381		2.9	

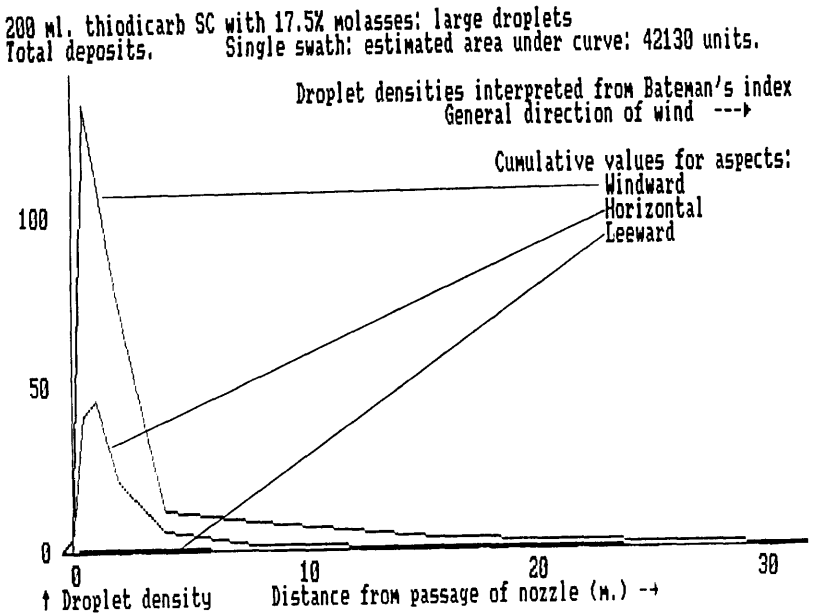
§1: Estimate of volume recovery ratio: $\frac{\text{Area under curve . ADV (large droplets)}}{\text{Area under curve . ADV (small droplets)}}$

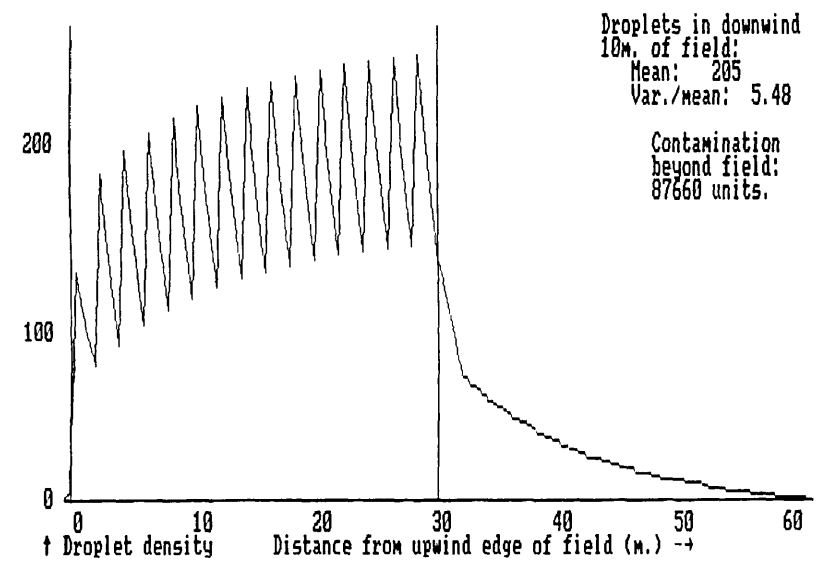
In 1988, the operating conditions were more carefully monitored, and the results obtained are shown in Table 4.4.2. Figs. 4.4.1. - 4.4.3. are examples of droplet number recoveries for the three application techniques. Computer simulations have been produced by the SWATH programme, described in Appendix III. Estimates for the area under a single swath curve are accumulated readings for the windward, horizontal and leeward samples. The programme also models deposit curves superimposed on one another at regular intervals to produce an "expected coverage" and an estimation of downwind contamination beyond the "field" (the illustrations are representations of 2m. swaths in 30m. plots).

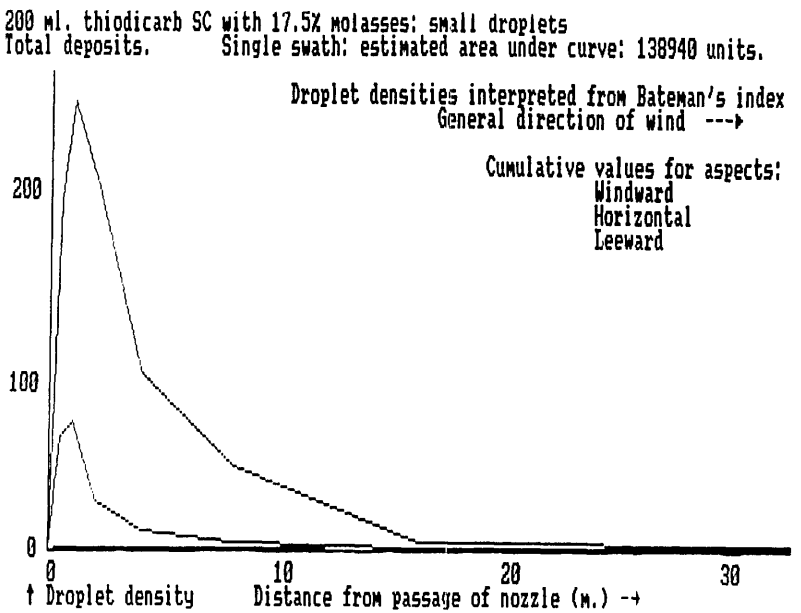
Fig. 4.4.1. Example Swath Curves for water-based CDA.

N.B. estimated areas under single swath curves (arbitrary units) are of accumulated total values for all aspects.









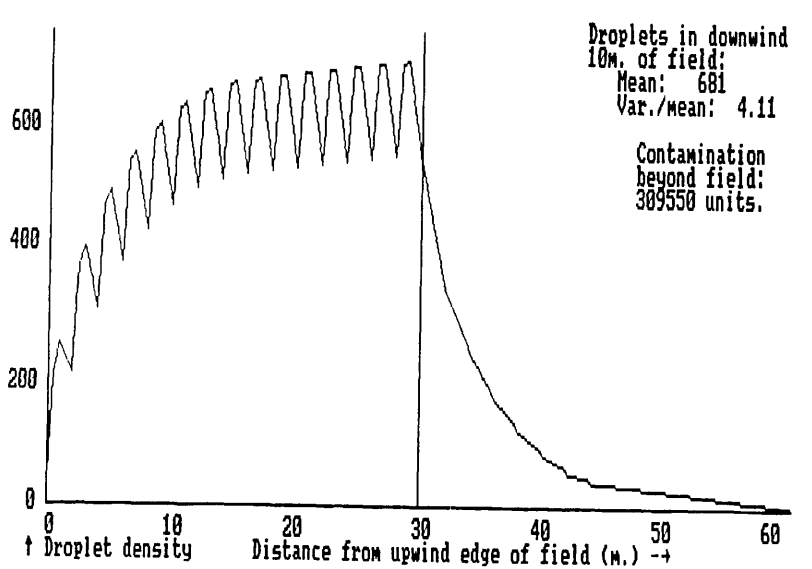
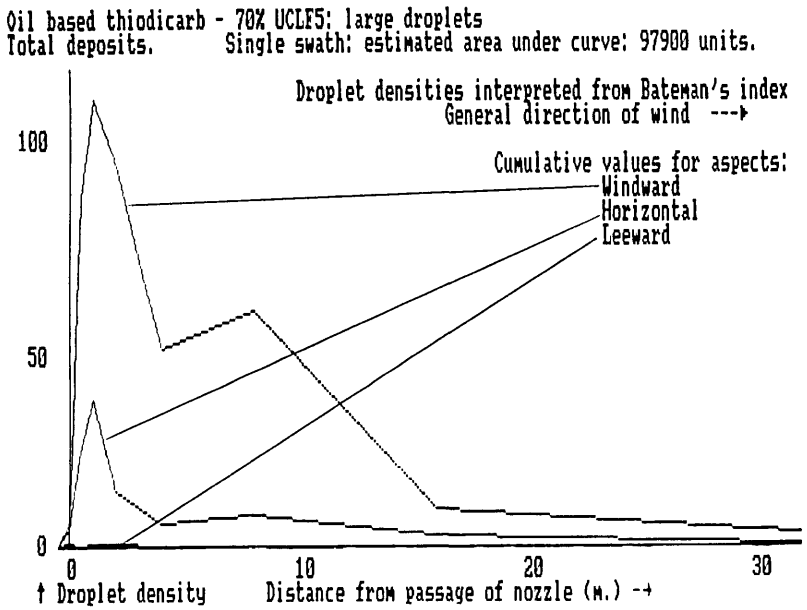
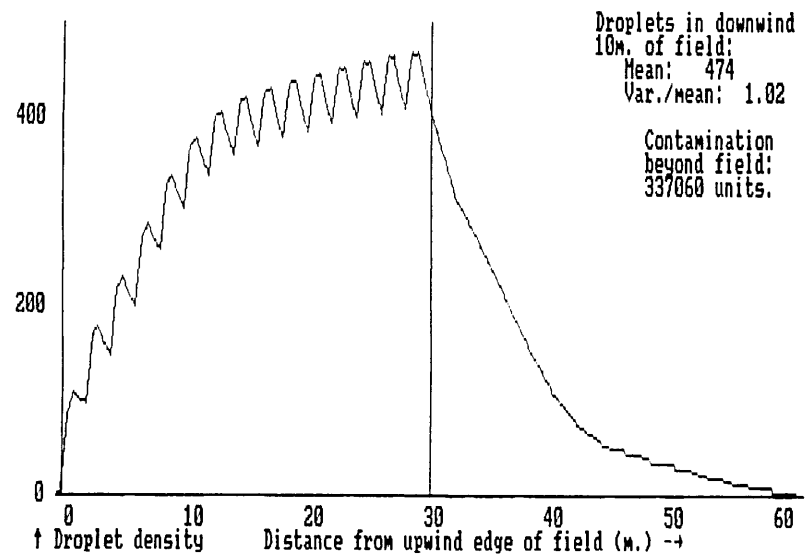
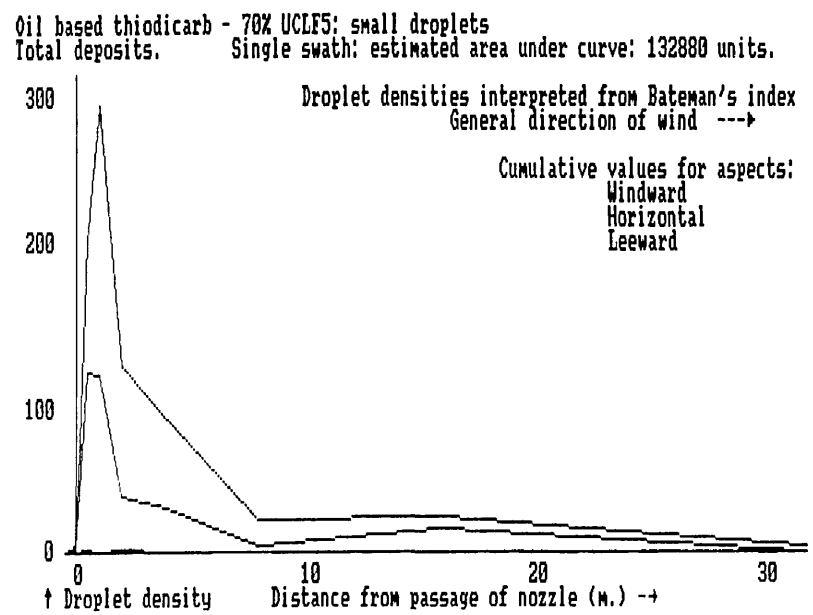


Fig. 4.4.2. Example Swath Curves for MULV.







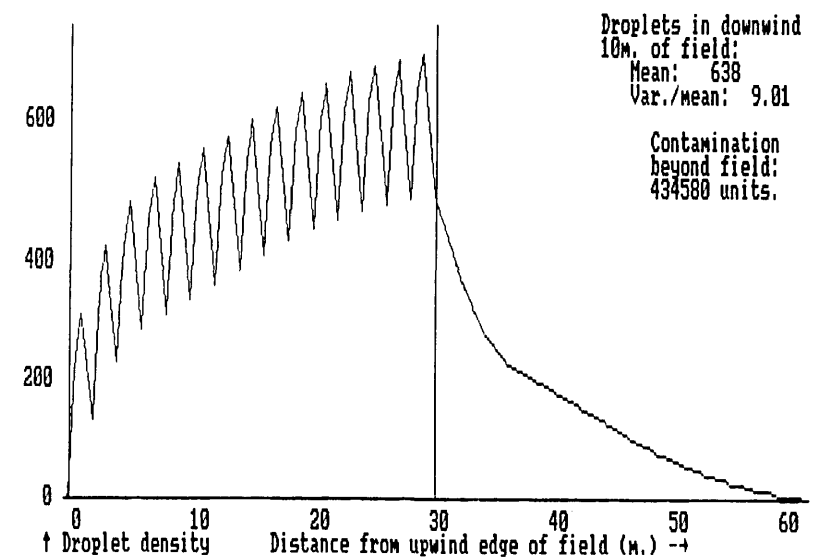


Fig. 4.4.3. Example Swath Curves for oil-based ULV.

Table 4.4.2. Droplet recovery of thiodicarb formulations (1988).

1. **Small droplets** (Micro Ulva at 160 rev.s^{-1})

Formulation	Temperature bulbs: Dry	wet	Wind speed m/s.	Deposit (curve area §A)	Estimated droplet: accumulation: mean	va./mean	VMD µm.	ADV pl.
"WULV":								
8% v/v. SC	27	22	1.6-2.2	**62150**	309	10.7	76	133
Anti-evaporants (§B):								
17.5% Molasses	23	18	2.3-4.0	**138940**	681	4.1	74	113
2.5% Derimin	29	23	1.1-3.1	**121290**	604	8.3	79	126
22.6 brix CMS.	27	20	1.1-2.2	**95920**	478	23.9	70	107
Oil-based:								
70% UCLF5	25	19	1.6-4.0	**132880**	638	9.0	75	134
UCLF8	26	21	0.0-2.5	**79570**	387	26.6	75	114

2. **Large droplets** (Micro Ulva at 110 rev.s^{-1})

Formulation	Temperature bulbs: Dry	wet	Wind speed m/s.	Deposit (curve area §A)	Estimated droplet: accumulation: mean	va./mean	VMD µm.	ADV pl.
"WULV":								
8% v/v. SC	27	22	1.4-2.6	**46790**	233	11.2	102	386
Anti-evaporants:								
17.5% Molasses	24	19	2.5-3.1	**42130**	205	5.5	92	294
2.5% Derimin	29	23	1.6-2.7	**81020**	404	13.5	122	528
22.6 brix CMS.	24	18	1.6-3.9	**72110**	352	7.4	88	275
Oil-based:								
70% UCLF5	24	17	2.1-4.0	**97900**	474	1.02	93	334
UCLF8	26	21	1.6-2.6	**62660**	310	25.6	94	328

§A: Area under accumulated single swath curves (arbitrary units: see Figs. 4.4.1-3)
§B: 21% v/v. SC with anti-evaporants (% by volume) and water.

3. Summary

Formulation	ESTIMATES for: Volume output (§1)	SMALL DROPLETS Number output (§2)	Recovery ratio (§3)	LARGE DROPLETS Number output (§2)	Recovery ratio (§3)	RATIOS ADV	Rec. (§4)
"WULV":							
8% v/v. SC	25.7	192982	**0.32**	66494	**0.70**	2.9	**2.2**
Anti-evaporants:							
17.5% Molasses	32.0	283186	**0.49**	108843	**0.39**	2.6	**0.8**
2.5% Derimin	25.0	198412	**0.61**	47348	**1.71**	4.2	**2.8**
22.6 brix CMS.	21.7	202492	**0.47**	78788	**0.91**	2.6	**1.9**
Oil-based:							
70% UCLF5	20.0	149254	**0.89**	59880	**1.63**	2.5	**1.8**
UCLF8	29.3	257310	**0.31**	89431	**0.70**	2.9	**2.3**

§1: Estimated volume output in micro-litres./10 milliseconds (i.e. per cm. of passage).
§2: Volume output / ADV.
§3: Area under swath curve / Estimated droplet number output.
§4: Ratios of large/small droplets for VAD and recovery ratios.

4.2. TRIALS IN ZIMBABWE

4.2.1. 1987 Trial (No. 1)

The 1987 season in Zimbabwe was dry, with practically no rain after mid-February. Bollworm incidence was generally low, with aphid and red spider mite populations higher than usual.

On the basis of Heliothis egg populations (Fig. 4.2.1.), three bollworm sprays were applied, of which probably only 1-2 were strictly necessary during an early peak at 75 days after cotton emergence (d.a.e.). A further bollworm spray was applied at 110 d.a.e. against Diparopsis, on the basis of the Zimbabwean recommendation to accumulate and project numbers of eggs. Another application might similarly have been justified at 130 d.a.e. As in most other trials, very few Earias larvae were found.

Plots were sprayed for Red Spider Mite control on three occasions: on the 11th March (96 d.a.e.) all were treated, but on the 17th March and 1st April, sprays were limited to treatments with high infestations. The most useful assessments are of results during the period of initial rapid increase (87-94 d.a.e.) between the second boll worm application and the first dimethoate spray at (96 d.a.e.), during which a third bollworm spray was applied at 89 d.a.e. (Appendix IVb.1.10-1.11). Because of the dissimilarities between the two later dimethoate applications, further analysis would be misleading.

Table 4.2.1. is a summary of both these results and the subsequent spraying that was necessary against red spider mites. Five out of 12 possible full dosage thiodicarb treatments/ treatment dates were sprayed whereas 8 out of 12 were required at half dosage. Differences in both the proportion of infested

plants and total scores were especially significant between the pyrethroid and water-based thiodicarb sprays. There were no significant differences between pyrethroids, oil-based thiodicarb ULV and controls. There was little sign that early bollworm sprays affected aphid populations (Appendix IVb.1.12, 1.13).

Table 4.2.1.

Trial 1: Red spider mites during the period of rapid increase

Formulation/ application method	Number of selected sprays (out of total possible)	% of plants infested	infestation indices (means)
Thiodicarb			
"WULV"	5 / 8	53	7.88
MULV	3 / 8	51	6.57
Oil-based	5 / 8	43	6.07
CLV tailboom	3 / 4	47	6.38
Fenvalerate (MULV)	3 / 8	35	4.76
Controls	4 / 8	43	5.38
l.s.d.$_{95\%}$		8.7	1.38

Apart from all insecticide sprays bringing about higher yields than controls, the only significant differences shown were between applications of fenvalerate and the standard thiodicarb (MULV) treatment. This was not reflected by any clear trends in bollworm larval control however (Table 4.2.2.).

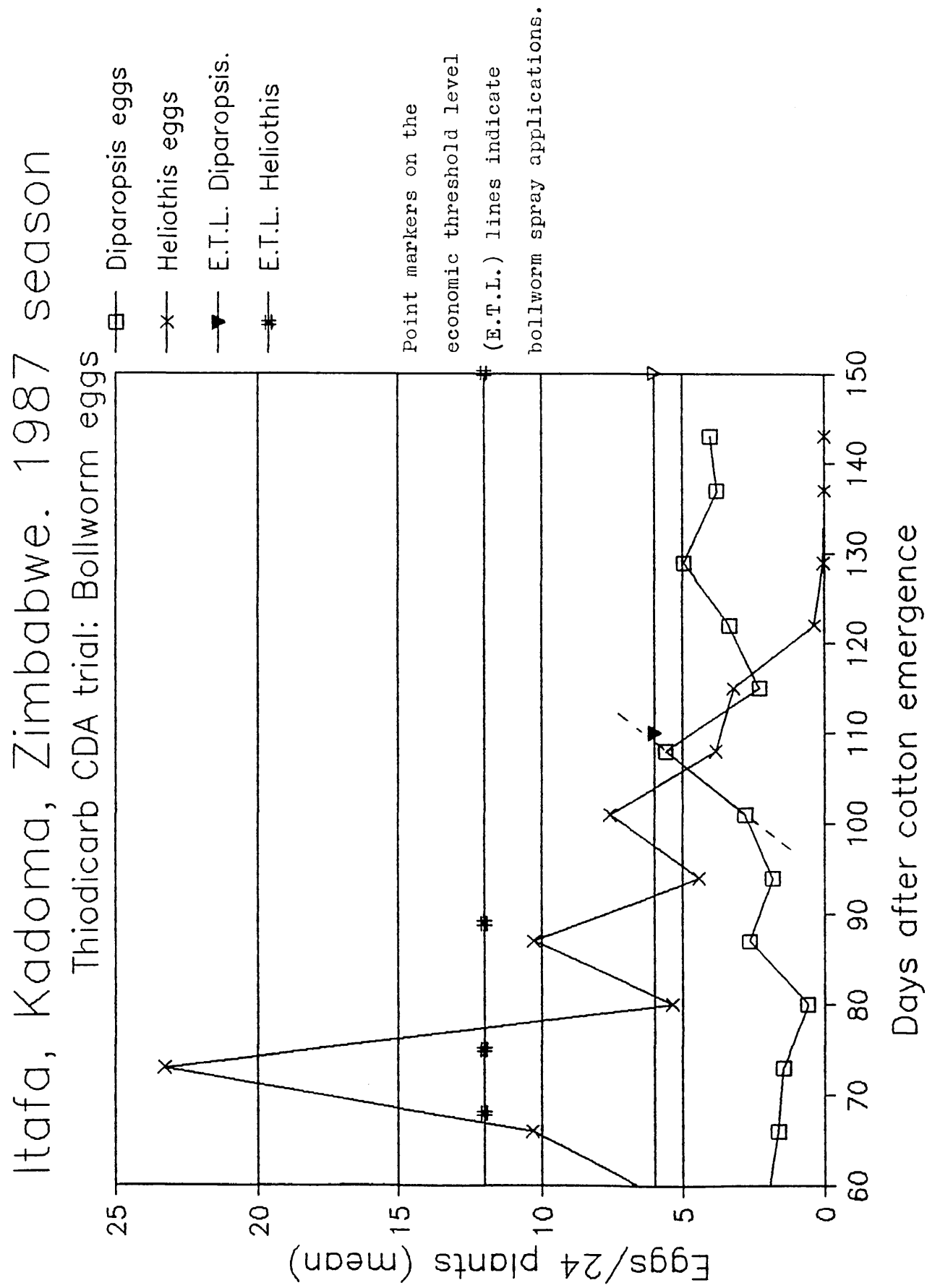
Table 4.2.2.

Trial 1: Bollworm larvae and seed cotton yields (g./plot).

Formulation/ application method	Heliothis (mean scores: 7 assessments)	Diparopsis	Yield: damaged	clean
Thiodicarb				
"WULV"	2.04	1.50	79	3126
MULV	2.54	1.63	97	2713
Oil-based	2.29	1.77	95	2967
CLV tailboom	2.14	1.57	59	2869
Fenvalerate (MULV)	2.09	1.50	47	3470
Controls	3.02	1.98	72	1902
l.s.d.$_{95\%}$	0.74	0.52	53	482

Fig. 4.2.1. Bollworm egg-laying in Zimbabwe: 1987 season.

The two horizontal lines indicate the economic thresholds for Diparopsis and Heliothis: 6 and 12 eggs/24 plants respectively. The dashed line illustrates the principal of thresholds based on projected egg scores.



4.2.2. **1987-8 Season Trials** (Nos. 4 and 5)

Two further trials took place in adjacent parts of the Cotton Training Institute, Kadoma:

Trial 4: thiodicarb only: 3 application strategies, 2 dosages (200 and 400 g.a.i./ha.) and 2 droplet sizes:

sprayers: Taurus Hi-Spins Mk. II ("Micro Ulva" heads).

Trial 5: 3 application strategies and 2 active ingredients: It was intended that thiodicarb be applied at 400 g.a.i./ha., and lambda-cyhalothrin at 10 g.a.i./ha.

sprayers: Taurus Hi-Spins Mk. I, fitted with 1.4 mm. restrictors and run from 12v. accumulators.

The 1987-88 season in the Zimbabwean Middleveldt was characterised by late rains continuing through to early March. During early March the presence of Heliothis started to build-up to unusually high levels, and apart from a sudden - but temporary - drop early in April, the mean scouting scores remained well above one egg per plant until boll split (Fig. 4.2.2.). There were no trends in bollworm egg-laying between treatments - plots even of this size (30 x 30 m.) would probably be too small to show significant repellence or attraction to adult moths.

Spraying took place in response to bollworm egg counts. The first sprays occurred on the 10th and 11th of February 1988, when the crop was 0.5m. tall, and eleven subsequent applications took place at weekly intervals until the 20th of April when boll splitting had commenced. The spray logs indicated that dosages on MULV treated plots were slightly higher than the others (Appendix IVb.4.2, and 5.2.), this was possibly due to variation in the composition of the molasses. Fine adjustments with the "Micro Ulva" are difficult because of a near-doubling progression in flow rates with each increasing restrictor size. The high standard errors for oil-based treatments also indicate a certain inexactitude in such applications - due in part to differences in

temperature affecting viscosity.

4.2.2.1. **Trial 4:**
Formulation strategies, dosage rates and droplet sizes

This trial was by far the largest, occupying 5.4 ha., and over this area, very marked variations occurred between blocks for pests, natural enemies and total yields (Appendix IVb.4); significant differences were found for scores of Heliothis, red spider mites, aphids and chrysopids. Both egg-laying and yields were highest in block 1. Heliothis oviposition exceeded the economic threshold five-fold in late March and mid April.

There were no important differences between surviving lepidopteran larval counts, apart from an allusion that oil-based sprays resulted in higher pooled defoliator larval scores (Table 4.2.3.). Populations of these pests were low, and the analysis is for scouting dates until the end of March, after which none were found. Early aphid infestations were replaced later in the season by red spider mites, with a period of rapid increase from mid March to early April. There were no significant differences between any of the treatments, for either pest.

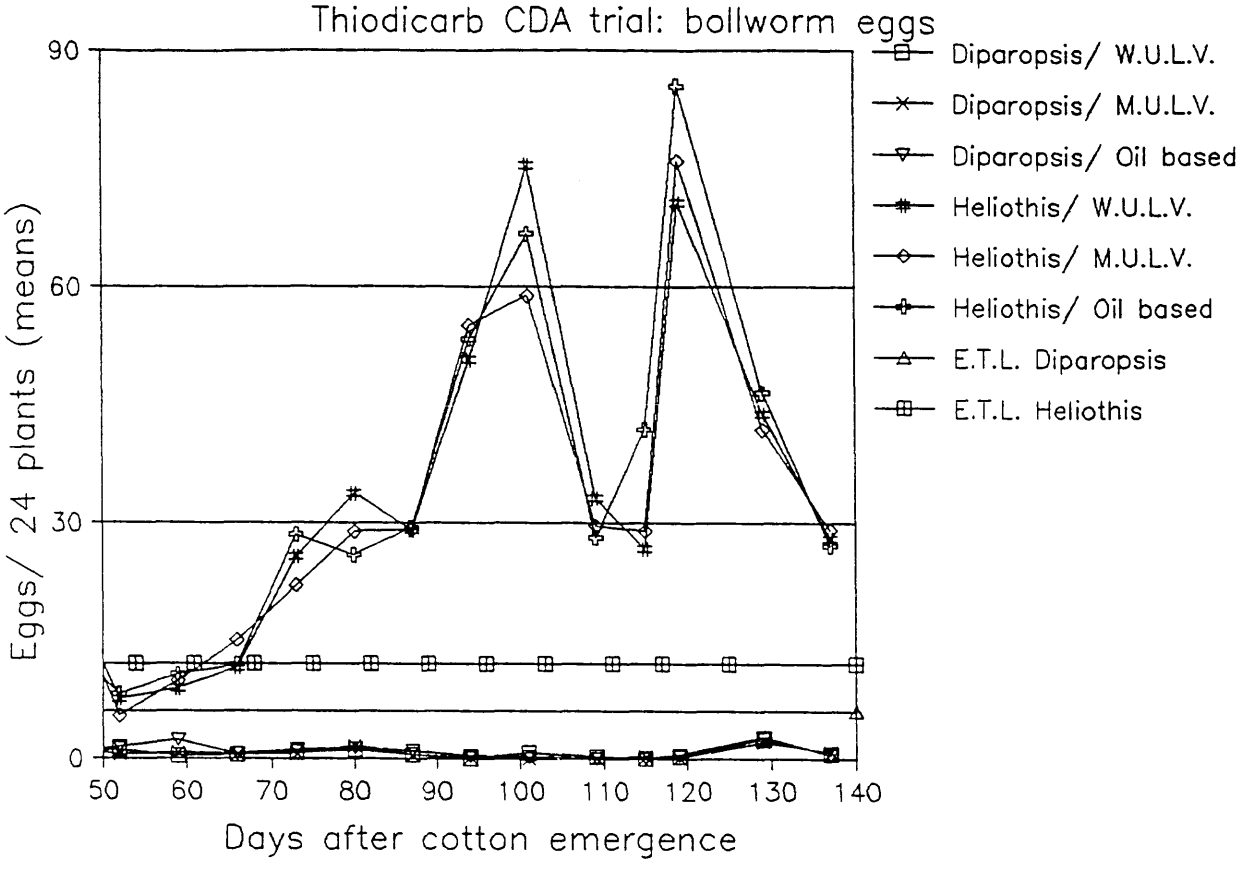
Table 4.2.3.

Trial 4: Surviving insect scores and seed cotton (all clean).

Treatments	Heliothis larvae	Dipar-opsis	RSM §1	Defoliator larvae	yields (g./plot)
"WULV": SC/EC	1.70	0.17	15.5	0.05	6853
MULV: SC/EC	1.68	0.15	15.1	0.08	6586
Oil-based SU/UL	1.62	0.21	15.2	0.17	6276
$l.s.d._{95\%}$: 2 DF	0.28	0.09	1.1	0.11	675
400 g.a.i./ha.	1.57	0.20	15.4	0.09	6494
200 g.a.i./ha.	1.76	0.16	15.1	0.11	6650
$l.s.d._{95\%}$: 1 DF	0.23	0.07	0.9	0.09	551
Small droplets	1.60	0.16	15.6	0.07	6543
Large Droplets	1.74	0.20	15.0	0.13	6600

§1: Red spider mites: infestation indices for March - mid April.

Fig. 4.2.2. Bollworm egg-laying in Zimbabwe: 1988 season.



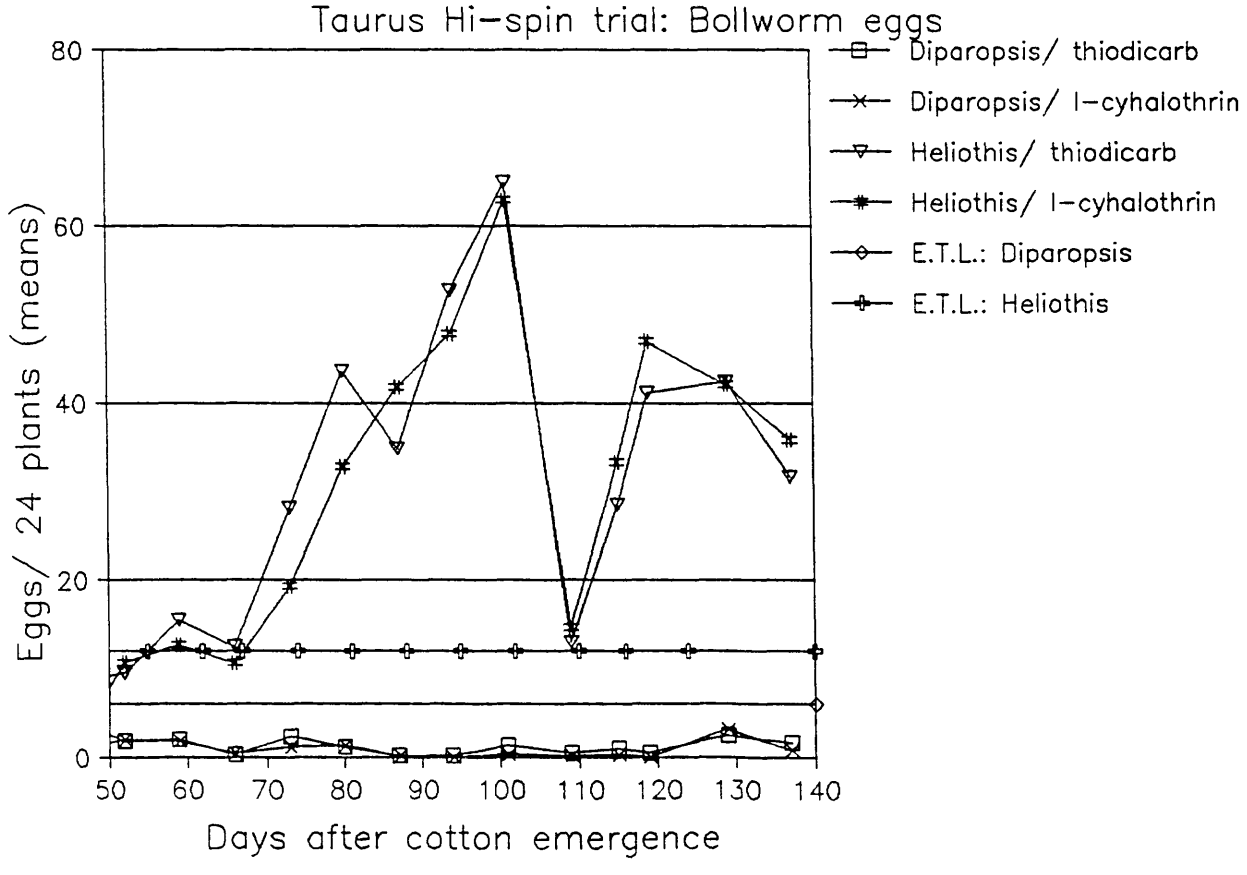
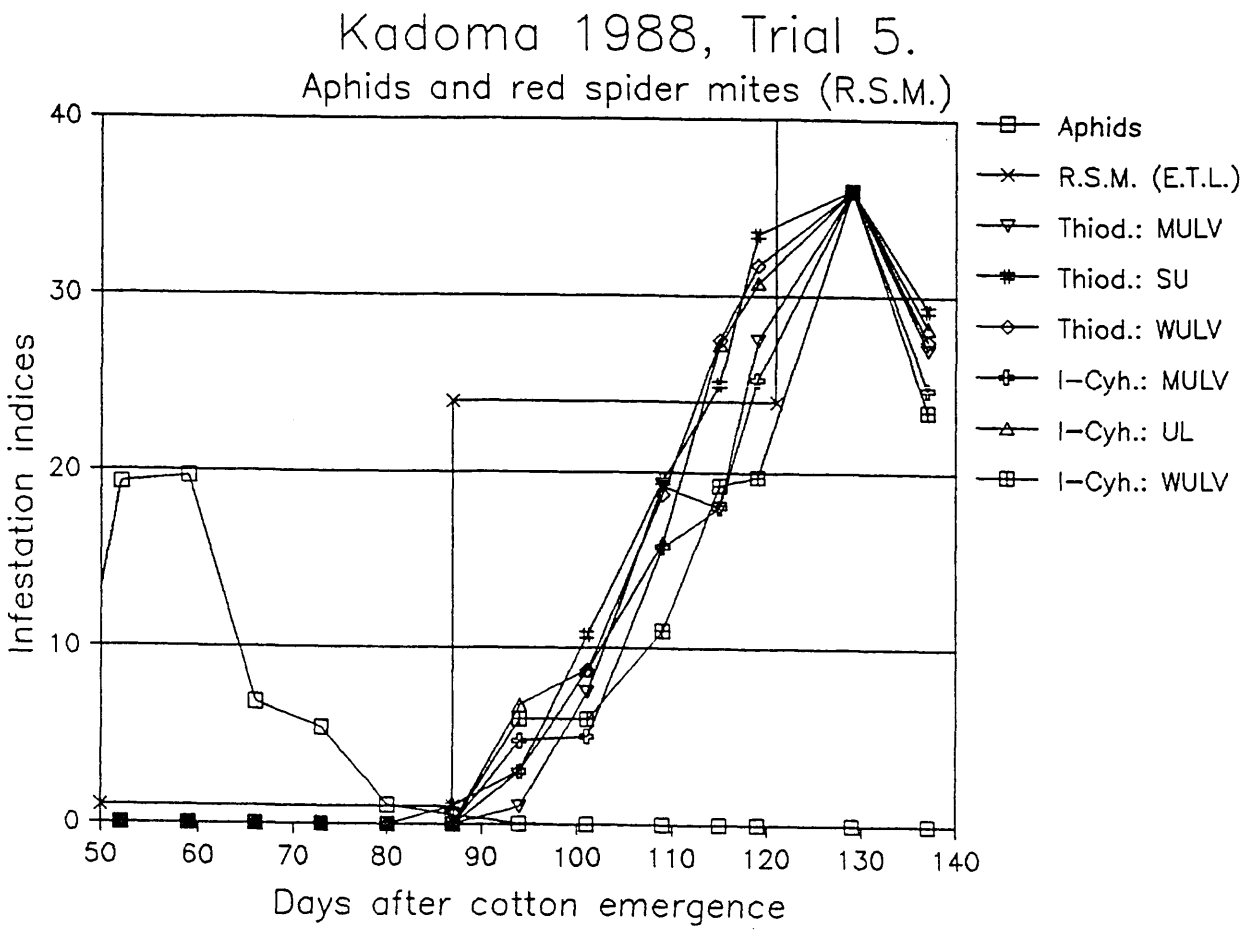
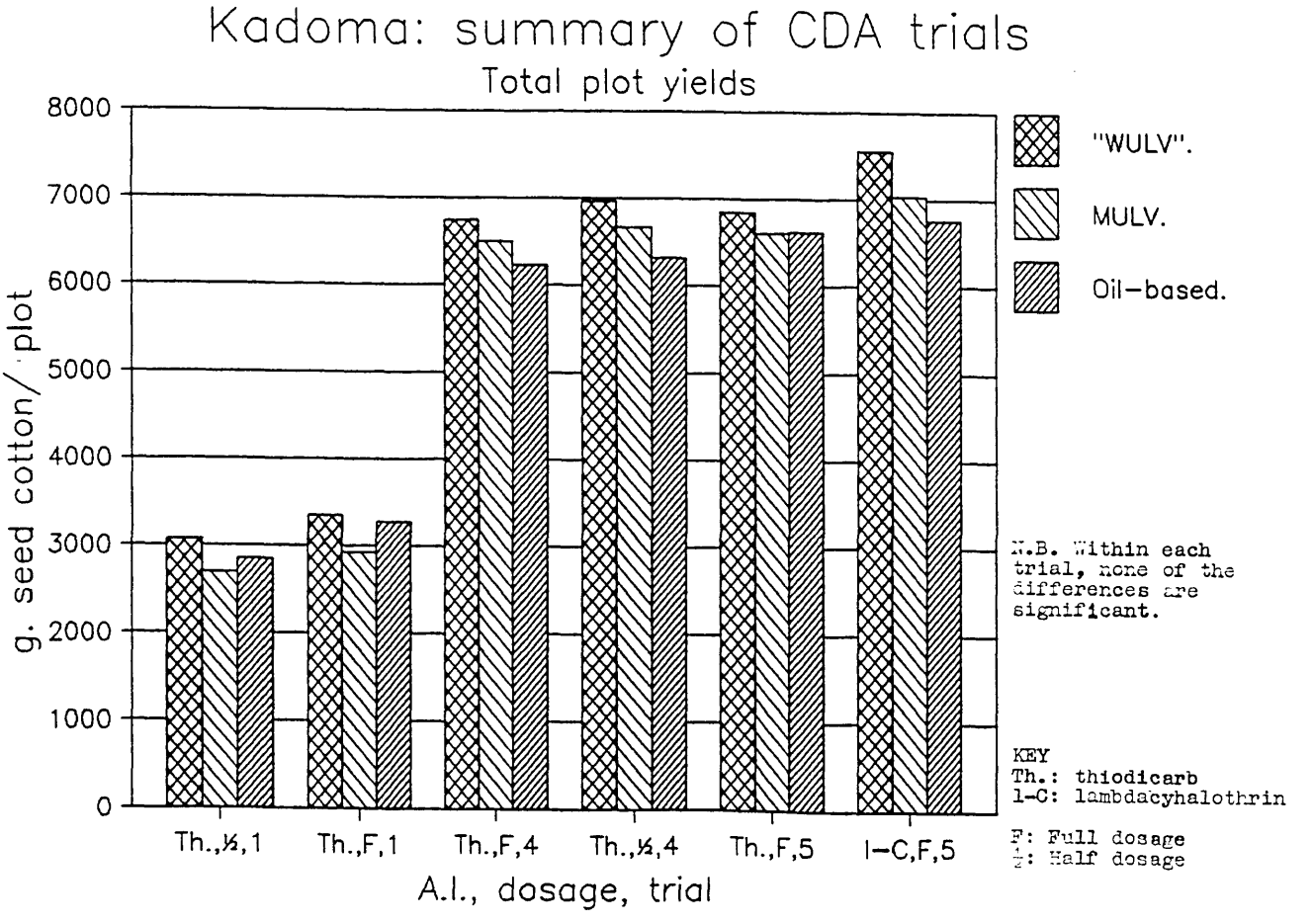


Fig. 4.2.3. A: Trial 5: Aphids and red spider mites.
B: Kadoma: yields with formulations and dosages.





4.2.2.2. **Trial 5:** Formulation strategies and Active Ingredients

As in trial 4, mean Heliothis egg-laying was very heavy from March to April, and there were no significant differences in numbers of bollworm larvae detected between treatments. Red spider mites were in evidence from mid March onwards, and on the basis of pooled infestation scores throughout the spraying period, there is evidence that their populations were lower in cyhalothrin treated plots than where thiodicarb was applied, and that they were higher where oil-based formulations were sprayed (Table 4.2.4, Fig. 4.2.3A.). Defoliator larvae were present at very low levels in this trial, and results were not analysed.

Table 4.2.4.

Trial 5: Surviving insect scores and seed cotton (all clean).

Treatments	Heliothis larvae	Dipar-opsis	RSM §1	Chrysopids: eggs	Chrysopids: larvae	yields (g./plot)
"WULV": SC/EC	1.32	0.07	17.2	1.86	0.02	7204
MULV: SC/EC	1.14	0.10	16.6	1.90	0.05	6824
Oil-based SU/UL	1.26	0.17	19.5	1.13	0.07	6692
$l.s.d._{95\%}$: 2 DF	0.37	0.10	1.5	0.53	0.07	730
Thiodicarb	1.28	0.13	18.7	1.69	0.03	6694
Lambda-cyhalothrin	1.20	0.10	16.9	1.57	0.07	7119
$l.s.d._{95\%}$: 1 DF	0.30	0.08	1.2	0.43	0.06	596

§1: Red spider mites: infestation indices.

Aphids were numerous until the beginning of March, but no differences between treatments were observed. Of the natural enemies, only spiders and chrysopid larvae were present in any numbers, but no significant differences were detected between treatments. Chrysopid eggs were found at considerably lower densities in plots treated with oil based formulations and it is possible that this was caused by a repellence to egg-laying, but this was not repeated in larval counts or other trials.

4.2.3. Summary of Cotton Yields in Zimbabwe

In 1987 there was only one cotton pick, and all the harvested lint was clean. In 1988, four picks took place between May and early July. The period of time between flowering and boll split is in the order of 50-70 days, depending primarily on night temperature (Munro, 1987). Since spraying stopped on the 20th April, yields from the fourth pick in July may bear little relation to insecticide sprays. There were no significant main factor differences in cotton yield due to dosage or droplet size in any of the trials (Table 4.2.5). An weak interaction between formulation, dosage and droplet size ($p = <0.05$) was recorded in trial 4, but the implications of this were unclear (Appendix IVb.4.3. and 3a.). Although analysis of individual trials showed no significant differences between the three CDA techniques, it is noteworthy that the "WULV" treatments repeatedly produced the highest yields (Fig. 4.2.3B.) and the probability of this occurring by chance is less than 1%.

The trials in 1988 did not contain untreated controls, and comparable yields occurred in an adjacent experiment at the Cotton Research Institute; cotton emerged on exactly the same day and yields in treated plots were approximately 2.6 times higher than with no insecticide sprays. In all eight trials there was evidence that spraying insecticides produced considerably higher yields than in control plots. There were no significant differences between thiodicarb sprayed by spinning disc machines or as CLV with a tailboom.

In 1987, fenvalerate applied at 40 g.a.i./ha. produced significantly higher yields than thiodicarb MULV. In 1988, no differences were detected between thiodicarb at 400 g.a.i./ha. and lambda-cyhalothrin at 10 g.a.i./ha.

Table 4.2.5.

SUMMARY OF SEED COTTON YIELDS: Kadoma
(all converted to equivalent total seed cotton weight in kg./ha.)

Trial	season	Oil. (§1)	WULV	MULV	Pyr. (§2)	CLV	control (§3)	Dosage	Droplet size.
1	1987	850	890	780	977	813	548	n.s.	n.s.
			n.s.		**		***		
4	1988	1743	1903	1830				n.s.	n.s.
			n.s.						
5	1988	1859	2001	1895	1978				
			n.s.		n.s.				
(§4) Check for 1988:					1881		772		

§1: Oil-based ULV sprays with SU thiodicarb formulations and pyrethroid UL in 1988.

§2: Pyrethroids: fenvalerate (1987), lambda-cyhalothrin (1988).

§3: Conventional Low Volume with knapsack and tailboom.

§4: 1988 trials did not contain untreated controls and data are taken from an adjacent experiment. The treatments for an IPM trial at Kadoma, which consisted of:
Cypermethrin for Bollworms,
Triazophos for Red Spider Mites, } 1881 kg. seed cotton/ha.
Dimethoate for Aphids.

Significance indicators

Analyses show differences between the thiodicarb CDA standard (MULV) and other treatments. In all experiments, controls (where present) were significantly different from all insecticide treatments. See Appendix IVa. for key.

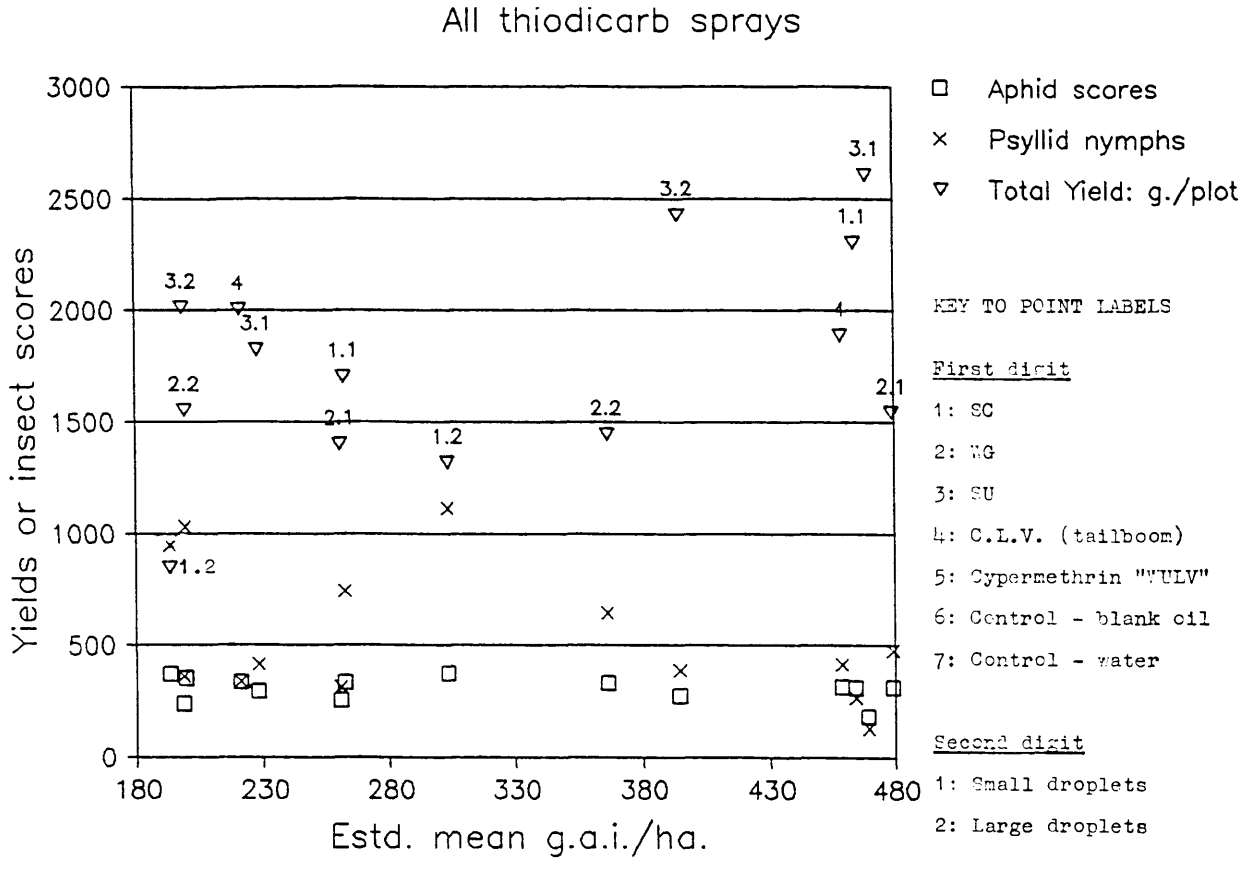
4.3. TRIALS IN MALAWI

4.3.1. 1987 Trials (Nos. 2 and 3)

Some of the largest and most significant differences between treatments occurred in trial 2 at Makoka. Unfortunately the spray logs (Appendix IVb.2.2) indicated large variations between the target (380 g.a.i./ha.) and actual rates of application for four full dosage sprays (preceded by one spray at double the normal swath width). Thiodicarb had been consequently applied in an almost continuous gradation of mass application rates (see Fig. 4.3.2.). Since differences in dosage rates applied in the Malawi trials clearly affect efficacy (see below), possible correlations between individual results were investigated, especially where there was an apparent similarity of ranking patterns for treatments between yield and certain pests in Appendix IVb.2.

Analysis of water-based sprays only showed a significant linear correlation between mass application rate and Heliothis control ($r = -0.81$, DF = 6, Fig. 4.3.3A.). CLV tailboom and oil-based sprays at 2 l./ha. (small droplets) appeared to give poor control, whereas fewer than 5 larvae per plot were found at both full and half dosage rates with high volume oil-based treatments (large droplets: 6 l./ha.). Similar comparisons between mass application rates with yield and two sucking pests were not significant (Fig. 4.3.2A.). There were very significant correlations between yields and Heliothis larval populations (Fig. 4.3.3B., $r = -0.69$, DF = 20), but correlation coefficients were higher with Paurocephala ($r = -0.78$, DF = 20) and aphids ($r = -0.82$, DF = 20 Fig. 4.3.4.).

Fig. 4.3.2. Trial 2 - Makoka, 1987:
a: Yields, aphids and psyllids with mass application rates. (correlations not significant)
b: Correlation of mortality between aphids and syrphids.



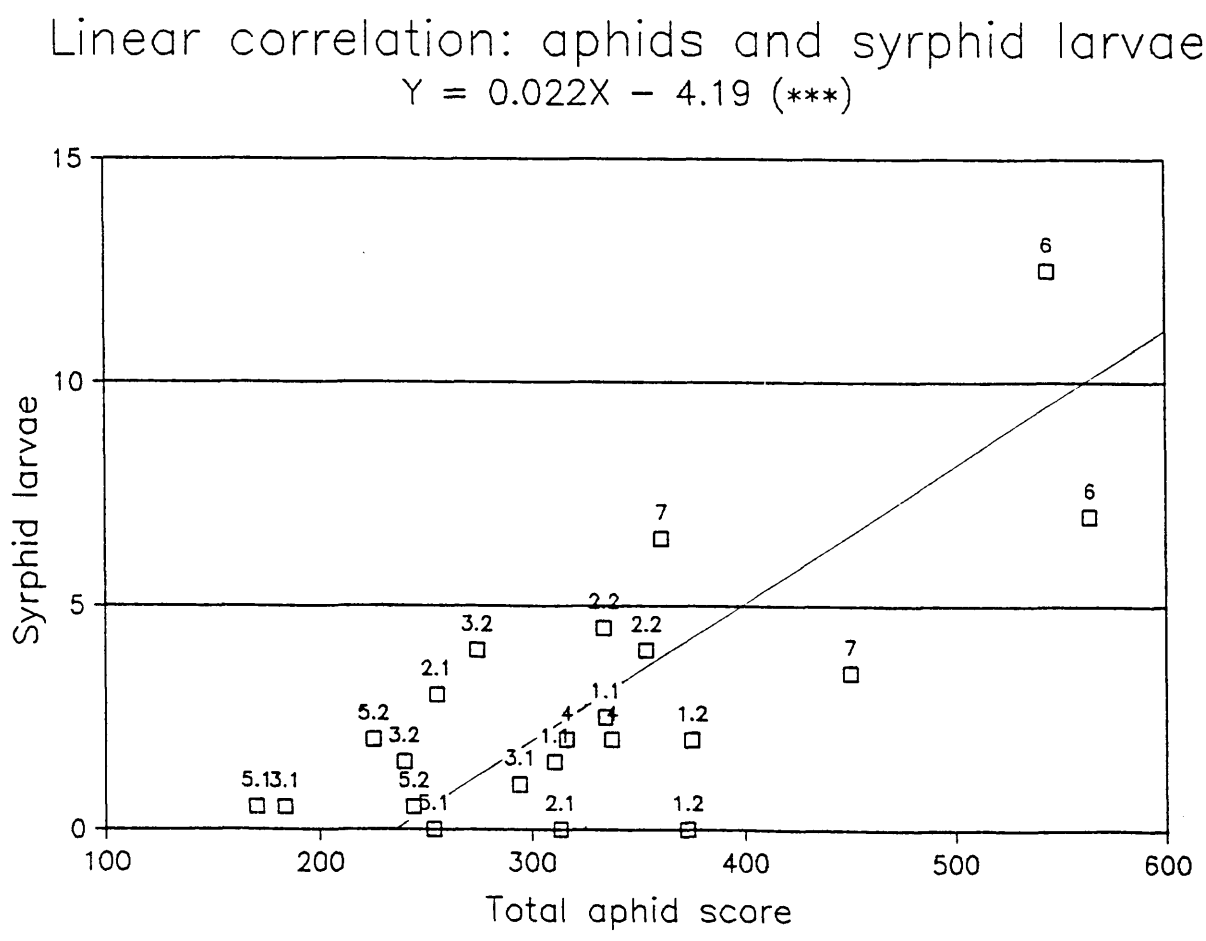
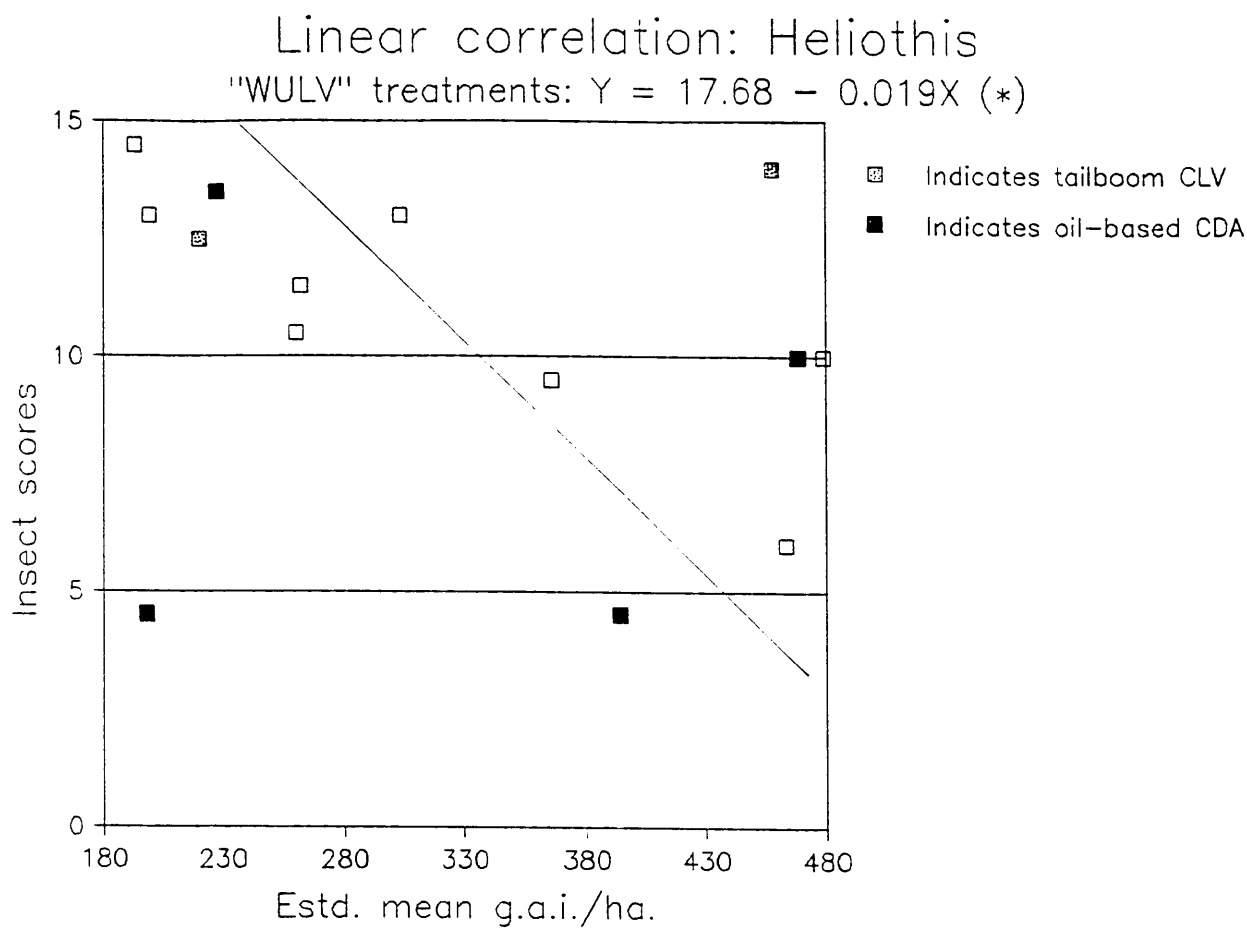


Fig. 4.3.3. Makoka 1987: Heliothis larvae.
(See Fig. 4.3.2a. for key to treatments)



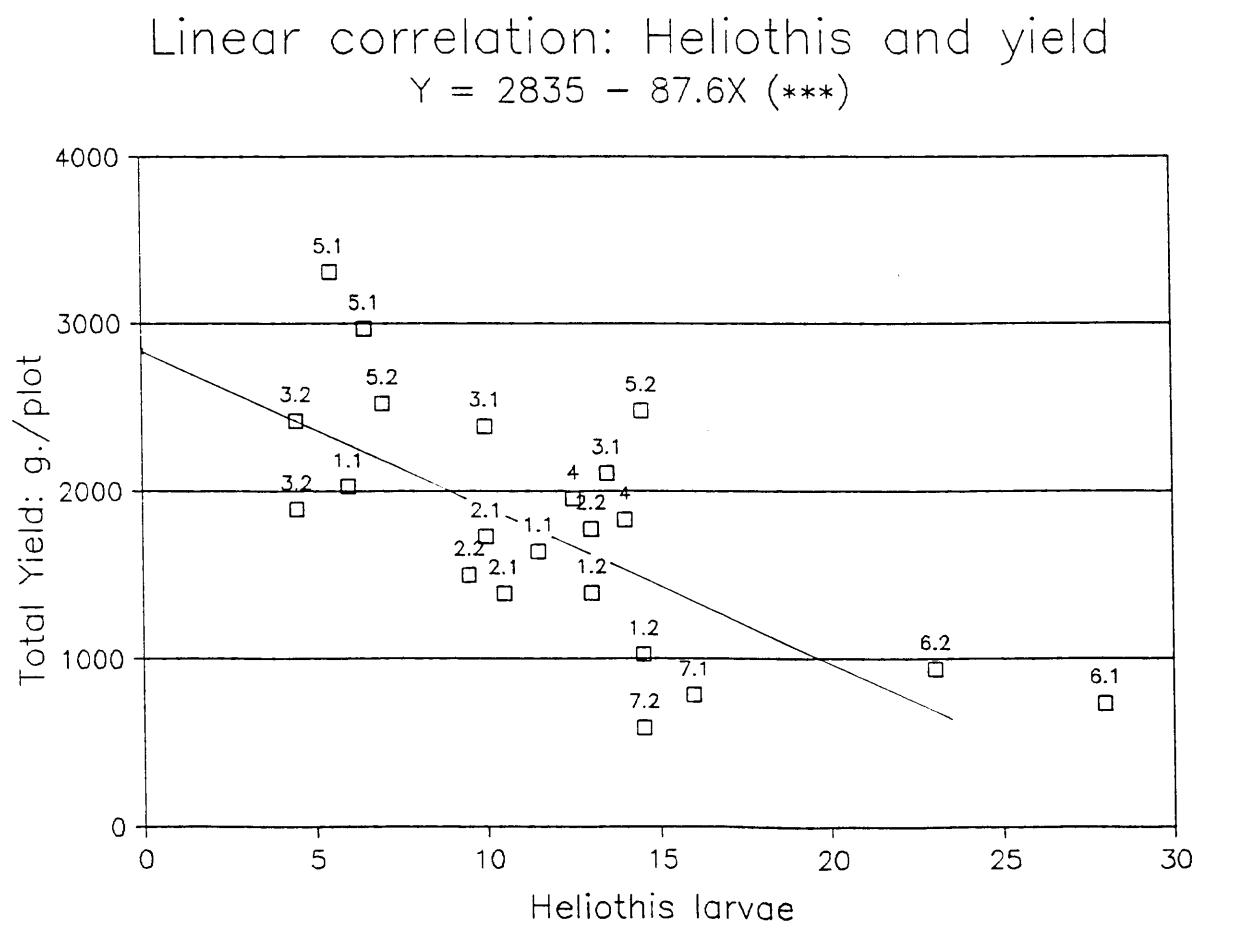
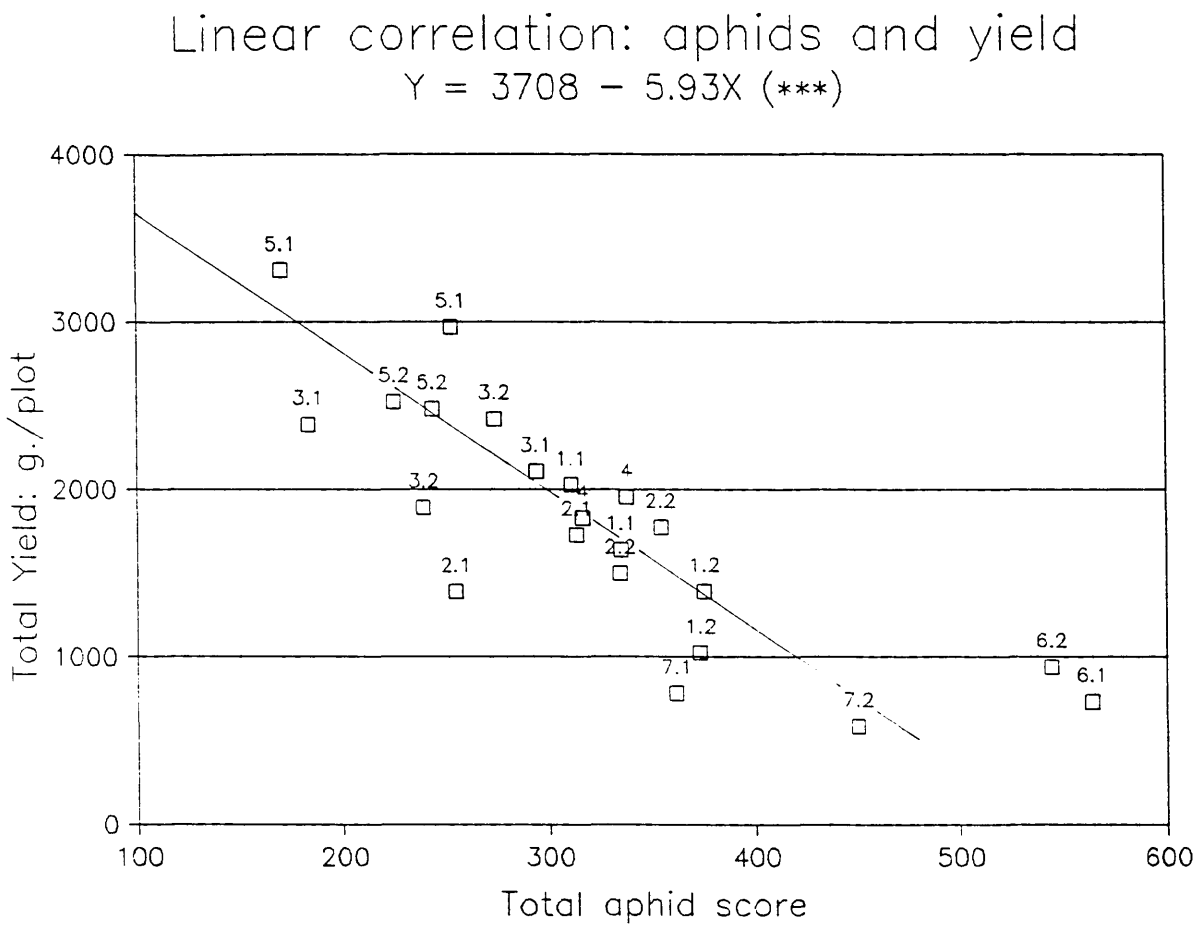
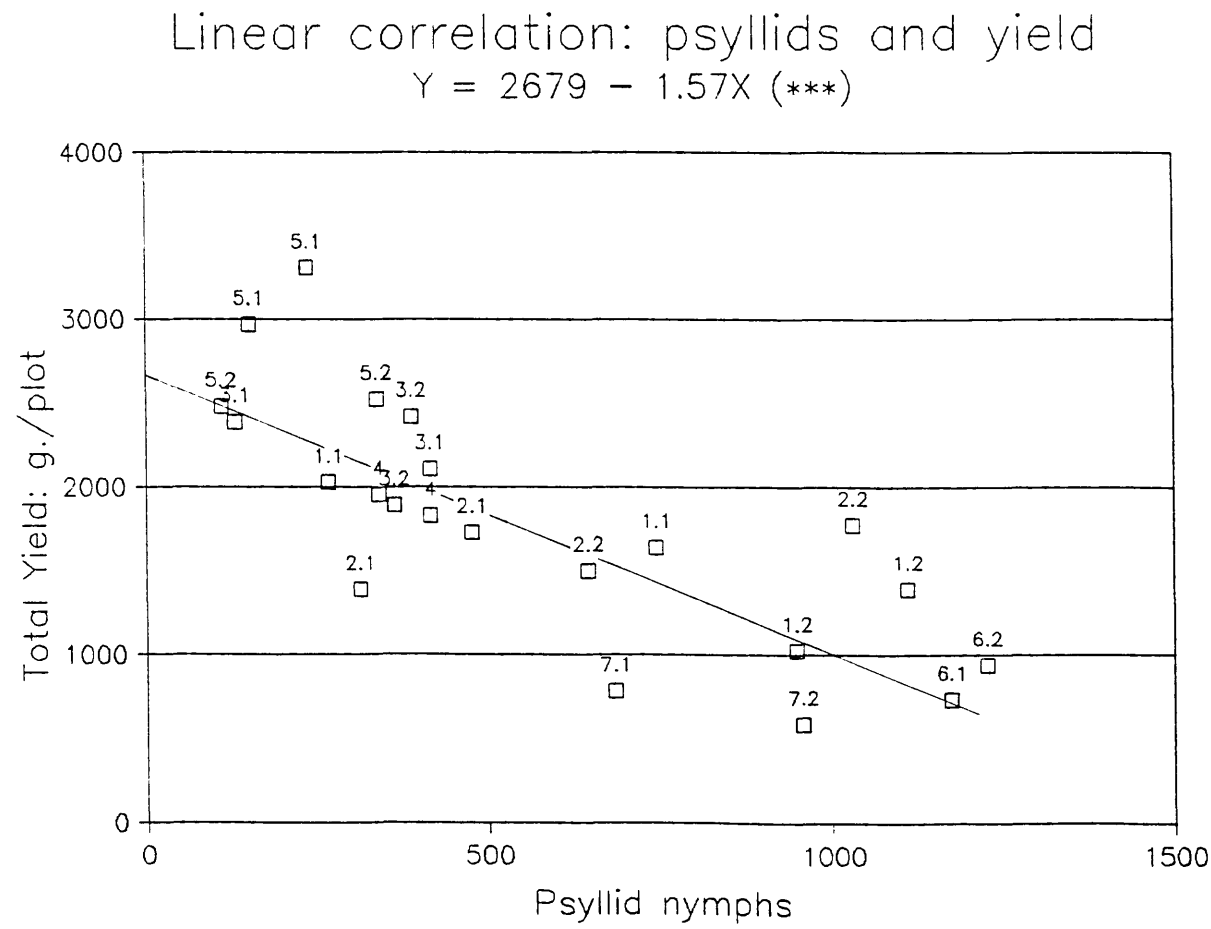


Fig. 4.3.4. Makoka 1987: sucking pests and yield.
(See Fig. 4.3.2a. for key to treatments)





Makoka 1987 was the only trial which showed any trends in natural enemy populations. Syrphid larval counts were higher than in many other trials, and the differences between control plots and different insecticide treatments were significant by varying degrees (Appendix IVb.2.14). Linear correlation between aphid scores and syrphid larvae was highly significant ($r = 0.73$, DF = 20, Fig. 4.3.2B.), indicating that there was no differential toxicity to pest or natural enemy between insecticide treatments. The pyrethroid was most toxic and controls produced the lowest mortalities. It appeared possible that aqueous blanks were reducing populations in comparison to blank oils, and this may have been due to contamination of the sprayer bottles.

At Toleza (trial 3), significant under-dosing occurred with knapsack and tailboom CLV treatments (Appendix IVb.3.2) after six full dosage sprays (preceded by one spray at double the normal swath width); this may have resulted in poorer control of Heliothis larvae (Table 4.3.1.). There were no other significant differences between treatments apart from poorer yields with a higher proportion of stained cotton in control plots.

Table 4.3.1.

Trial 3: Surviving insect scores and seed cotton yields.

Formulation/ application method	Heliothis larvae (accumulated scores: 7 assessments)	Psyllids (adults and nymphs)	Aphids §1	Yield (g./plot) damaged	Yield (g./plot) clean
Thiodicarb					
"WULV": SC	7.0	93.8	183	65.6	1670
"WULV": WG	7.0	140.9	190	55.6	1790
Oil-based SU	5.0	49.6	171	50.6	1976
CLV tailboom	13.5	105.0	199	57.5	1885
Cypermethrin ("WULV")	4.8	31.4	174	55.0	1893
Controls	12.1	101.4	289	113.1	1298
l.s.d.$_{95\%}$	5.3	153.9	42	24.0	441

§1: accumulated infestation indices (see Appendix IVa.).

4.3.2. **1988 Trials** (Nos. 6,7 and 8)

Two similar trials took place at Makoka and Chitala Research stations. They consisted of 3 way multi-factorial designs: Oil-based ULV with volume application rates ranging from 0.9 to 1.4 l./ha. (depending on dosage and row spacing), and "WULV" treatments with 2 water-miscible formulations, together with 2 dosages and 2 droplet sizes.

4.3.2.1. **Trial 6: Makoka**

The trial consisted of three replications and also contained three control plots, but as in 1987 it was not possible to arrange them into blocks because of the lie of the land. Following two sprays at double the normal swath width (starting on 9th March 1988), 13 full dosage applications took place at weekly intervals. With so many replicates, analysis of the spray logs indicated significant differences between treatments (Appendix IVb.6.1), but these were small and probably had little influence on results.

A split boll analysis was carried out on an average of ten plants per plot, and has been analysed according to guidelines described in Matthews (1989a). A summary of results is shown in Table 4.3.2. All indicators showed that thiodicarb sprays were significantly advantageous; untreated controls produced fewer bolls, lower percentages of clean cotton, and much lower yields of both clean and damaged cotton. Damage to bolls appeared to come principally from causes other than bollworms. The table also gives field data for *Heliothis*, whiteflies, and *Paurocephala*.

Table 4.3.2. **Makoka 1988, split boll analysis and trial results.**

Treatments	Average number of bolls per plant	Percentage of bolls: clean	damaged by: bollworms	other causes	Field trial scores: Heliothis larvae.
Formulations					
"WULV": SC	12.2	3	20	77	2.9
"WULV": WG	11.5	3	25	71	2.9
Oil-based SU	13.1	7	21	72	1.4 *
Dosage					
430 g.a.i./ha.	13.0	6	21	73	2.4
215 g.a.i./ha.	11.6	3	23	74	2.4
Droplet size					
Small	12.7	6	24	70	2.3
Large	11.9	3	20	76	2.6
CONTROLS	5.8	1	41	58	16.0

Treatments	Estimated potential yield (g./plant)	Percentage of potential yield: clean	damaged	lost	Field trial scores: Whitefly adults
"WULV": SC	51.34	18	19	64	195.3
"WULV": WG	48.68	17	14	69	203.2
Oil-based SU	54.97	27 *	19	53	135.5 ***
430 g.a.i./ha.	54.52	24	19	57	167.7
215 g.a.i./ha.	48.80	17	16	67	188.3
Small	53.37	23	17	60	178.2
Large	49.95	18	18	64	177.8
CONTROLS	24.57	7	11	82	483.7

Treatments	Field trial: Psyllids counts	damaged cotton	Estimated total yields: (kg./ha.) analysis	trial	% difference
"WULV": SC	18.0	578	775	989	78
"WULV": WG	36.2 *	511	671	908	74
Oil-based SU	21.3	578	1147 *	1145	100
430 g.a.i./ha.	16.3 ***	633 **	1018	1224 **	83
215 g.a.i./ha.	33.9	478	710	804	88
Small	21.7	556	967	1026	94
Large	28.6	567	761	1003	76
CONTROLS	170.0	156	174	179	97

Differences between yields estimated from split boll analysis and trial plots are due to deferent sampling methods. Significance marks show where a treatment differs from others in the factor.

Yields of both clean and damaged cotton were approximately 50% higher in plots treated at 430 g.a.i./ha., than with half dosage sprays. There was some indication that the better control of Heliothis and whitefly adults with oil-based sprays affected yields, but coefficients of variation were too high to reveal significant differences. Thus although populations were generally low, control of psyllids appears to give the best explanation of yield differences between dosage rates.

4.3.2.2. **Trial 7: Chitala**

There were four replications, with no control plots, and six narrow swath sprays were preceded by one on cotton less than 0.5m. tall. In contrast to the results at Makoka and Kasinthula, the oil-based formulation was less effective at Chitala, and had a higher proportion of damaged cotton (Table 4.3.3.). There was however an interaction between formulation and droplet size (Appendix IVb.7.3.), and this result may be wholly explained by loss in activity of enlarged oil-based ULV droplets (Fig.4.3.5.).

Significant differences between Heliothis egg counts (Appendix IVb.7.6.) were not reflected by any significant differences in bollworm larval counts. Higher control plot populations in an adjacent trial indicated that Diparopsis larvae may have influenced yields. Of all the assessments, only psyllid scores reflect the highly significant yield differences between the two mass application rates of thiodicarb. Although psyllose symptoms are commonly observed at this site, Paurocephala populations appeared to be low during this season, and were little different from controls. As at Makoka, differences between formulations appeared to have the most influence on whitefly mortality, although this may be purely due to chance since the ranking was different at Chitala, and the average scores were similar to controls in the adjacent trial.

Fig. 4.3.5. Chitala 1988: Effects of formulation and droplet size on total yield.

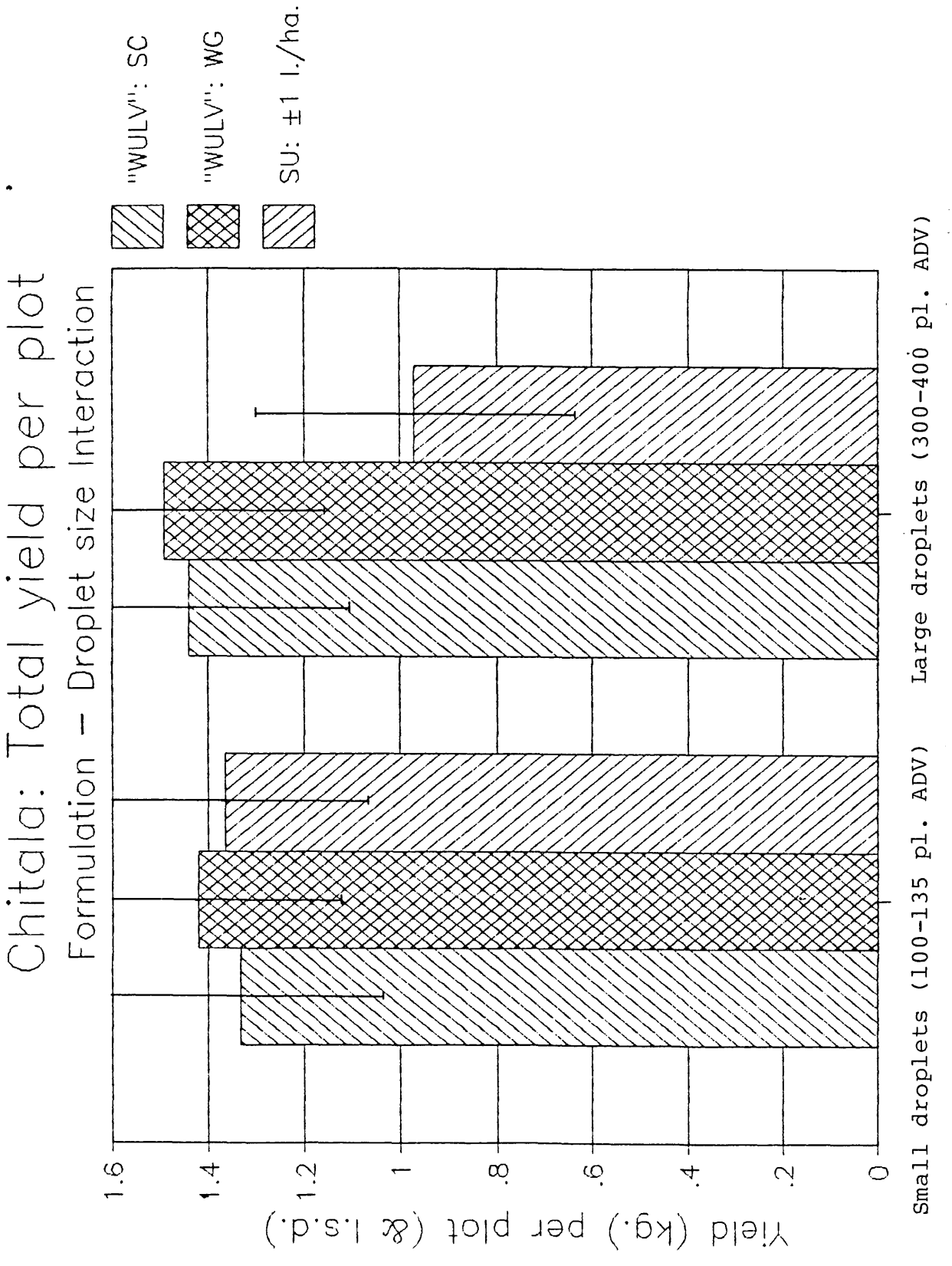


Table 4.3.3.

Trial 7: Surviving insect scores and seed cotton yields.

Treatments	Heliothis larvae	Diparopsis	Psyllid adults	Whitefly	yields (kg./plot) damaged	clean
"WULV": SC	8.9	2.1	15.2	75	0.20	1.19
"WULV": WG	9.3	3.2	11.1	91	0.20	1.26
Oil-based SU	8.4	2.6	14.3	83	0.30	0.87
$l.s.d._{95\%}$: 2 DF	3.3	1.5	7.6	12	0.10	0.22
430 g.a.i./ha.	8.0	2.6	9.7	85	0.24	1.31
215 g.a.i./ha.	9.7	2.6	17.3	82	0.23	0.90
$l.s.d._{95\%}$: 1 DF	2.6	1.2	6.2	10	0.08	0.18
Small	8.4	2.8	13.0	81	0.24	1.13
Large	9.4	2.5	14.1	85	0.22	1.08
CONTROLS (adjacent trial)	10.8	6.0	16.3	73	0.29	0.41

4.3.2.3. **Trial 8: Kasinthula**

At this trial site, the cotton was very uneven, with plots interspersed between patches of boggy ground and termite infested zones. Due to limited space this trial simply consisted of the three formulations, at recommended dosage rates, with untreated control plots; there were four replicates. Six sprays were applied at the standard swath width.

Table 4.3.4.

Trial 8: Surviving insect scores and seed cotton yields.

Treatments	Heliothis	Diparopsis	Earias	yields (kg./plot) damaged	clean
"WULV": SC	3.0	10.0	1.5	0.26	1.36
"WULV": WG	3.3	8.3	3.0	0.30	1.25
Oil-based SU	4.5	7.3	2.0	0.32	1.73
CONTROLS	4.8	9.0	5.3	0.33	0.58
$l.s.d._{95\%}$	4.5	5.1	2.4	0.16	0.60

Thiodicarb treatments all produced higher yields than the untreated controls, but there were no significant differences between formulations. Of all the recorded pests, yields appeared

to be most closely reflected in Earias larval mortality, although Heliothis appeared to be equally numerous, and there were more Diparopsis larvae in most plots (Table 4.3.4.).

4.3.3. Paired Comparisons and Farmers Assessments in N. Malaŵi

A series of paired comparisons took place in two Northern districts of Malaŵi, as a pilot project to investigate the suitability of the water dispersible granule formulation, in comparison with thiodicarb suspension concentrate. In Karonga, where pyrethroids are not recommended, this insecticide may become an important method of bollworm control since the Ministry of Agriculture is phasing-out the use of DDT (Nyirenda, pers. comm.). Farmers were issued with two formulations: suspension concentrate in standard 1 litre containers (where the cap is designed to measure-out sufficient formulation for one refilling of the sprayer bottle), and measured quantities of water-dispersible granules pre-packed in polythene sachets.

Farmers' fields of 0.5 - 1 ha. were divided into two halves, each of which was sprayed with a different formulation. The whole of the fields were treated, however no scouting and harvest measurement took place in 10m. areas next to the field boundaries and the central division between the two treatments. Scouting took place weekly with 24 readings in each plot. Decisions on bollworm spraying were based on egg counts: using the aggregated scores for egg densities in both plots. Further details are given in Appendix IVc. Both Heliothis and Diparopsis were recorded in all sites but one, with the American bollworm being generally more important. There was no significant difference between the activity of the two formulations.

The eleven farmers participating in these trials were asked

to complete survey forms at the end of the season. None of them had previous experience with liquid formulations in the form of pyrethroid ECs or thiodicarb SC. After being familiar with wettable powders, most farmers preferred thiodicarb SC, with only two liking the WG formulation more; however five out of the remaining eight would use water-dispersible granules if they were cheaper. The survey form probably did not distinguish clearly enough between WG and WPs and four farmer cited improved mixing for preferring liquid formulations, though technical staff found that WGs dispersed very easily. Two farmers commented that liquid formulations were less likely to cause blockages, and one said that pesticides in bottles were easier to protect from rain.

Half of the farmers surveyed (all in Mzuzu and one in Karonga) thought that the empty suspension concentrate bottles might be useful as paraffin containers. Four farmers in Karonga simply discarded pesticide containers or threw them into latrines. Three farmers (in Mzuzu) specifically mentioned burning or burial of packets as methods of disposal.

4.3.4. Summary of Cotton Yields in Malaŵi

Yields for the research station trials and paired comparisons are summarised in table 4.3.5. Mass application rates appear to be the most consistent single factor in determining yield in Malaŵi. All trials showed comparable yields, and few significant differences in biological efficacy, between the two water-miscible formulations. Oil-based SU sprays generally performed well, however yields were significantly lower at Chitala; at this site, volume application rates of oil-based treatments had been applied at 0.9-1.25 l./ha.. In Makoka (1987) yields were highly significantly better than water-based

thiodicarb sprays, where SU mixtures were applied at 2-6 l./ha. Cypermethrin applied at 40 g.a.i./ha. resulted in higher yields than all thiodicarb sprays. In Kasinthula, the higher yields of oil-based sprays were not significantly different and may be explained partially by higher stand counts and mass application rates (Appendix IVb.8.1.).

Table 4.3.5.

SUMMARY OF SEED COTTON YIELDS: Malaŵi.
(all converted to equivalent total seed cotton weight in kg./ha.)

Trial/season Malaŵi	Oil. (§1)	WULV: SC	WULV: WG	Pyr. (§2)	CLV control (§3)		Dosage (full l/2)		Droplet size.
Makoka '87	2448	1691	1775	3134	2103	846	2101	1879	(§5)
	***		n.s.	***	n.s.	***	*		
Toleza '87	2252	1928	2051	2164	2158	1567	2174	1841	n.s.
		n.s.		n.s.	n.s.	**	*		
Makoka '88	1233	956	911			179	1200	867	n.s.
	(*)	n.s.				***	*		
Chitala '88	1083	1287	1352			672	1426	1046	n.s.
	**		n.s.			(§4)	***		
Kasinthula '88	1144	900	856			511	-		-
		n.s.				**			
1988, paired comparisons:									
Mzuzu A.D.D.		1440	1210	n.s.					
Karonga A.D.D.		1570	1570	n.s.					

§1: Oil-based ULV sprays with SU thiodicarb formulations and pyrethroid UL in 1988.

§2: Pyrethroid (1987): cypermethrin.

§3: Conventional Low Volume with knapsack and tailboom.

§4: Trial did not contain untreated controls and data are taken from adjacent experiment.

§5: Significant difference, but see section 4.3.3.

Significance indicators
Analyses show differences between the thiodicarb CDA standard ("WULV") and other treatments. In all experiments, controls (where present) were significantly different from all insecticide treatments. See Appendix IVa. for key.

4.4. FIELD OBSERVATIONS ON FORMULATIONS

Bottles containing the 375 g./l. suspension concentrate, required regular agitation as a proportion of the suspended contents settled-out to form a "clay", which was difficult to re-suspend. These problems were exacerbated when the container had been partially used, since the formulation dried on the side and formed insoluble flakes in the spray mix. This is probably not a serious problem in conventional hydraulic spraying systems where the mixture passes through the nozzle under pressure and where there is an integral filter in the chemical tank. Blockages are more likely to occur when using hand-held spinning-disc sprayers, which invariably rely on gravity to feed the spray mixture through a relatively small orifice (typically a 1-1.6 mm. round hole). Not all these sprayers have a filter incorporated into the feed stem, so blockages may not always be noticed quickly, due to the fine nature of the spray.

Phytotoxicity was monitored with all formulations, but especially with the experimental ULV suspensions and their dilutions. Chemical burns were neither found on pre-trial test plants nor in trial plots after several applications at full dosage. The oil-based UCLF8 performed well de novo, although a small sediment was observed in bottles that had been left standing for more than a few days. This sediment was not difficult to re-suspend however, but samples which had been left standing for more than two months settled badly. Typical measured flow rates for undiluted UCLF8 were 44ml./min for the Micro-Ulva with a red restrictor and 29ml./min for the Turbair XJ with a 1.3 restrictor, and a stabilised formulation of this viscosity would be operationally practical.

CHAPTER 5

DISCUSSION

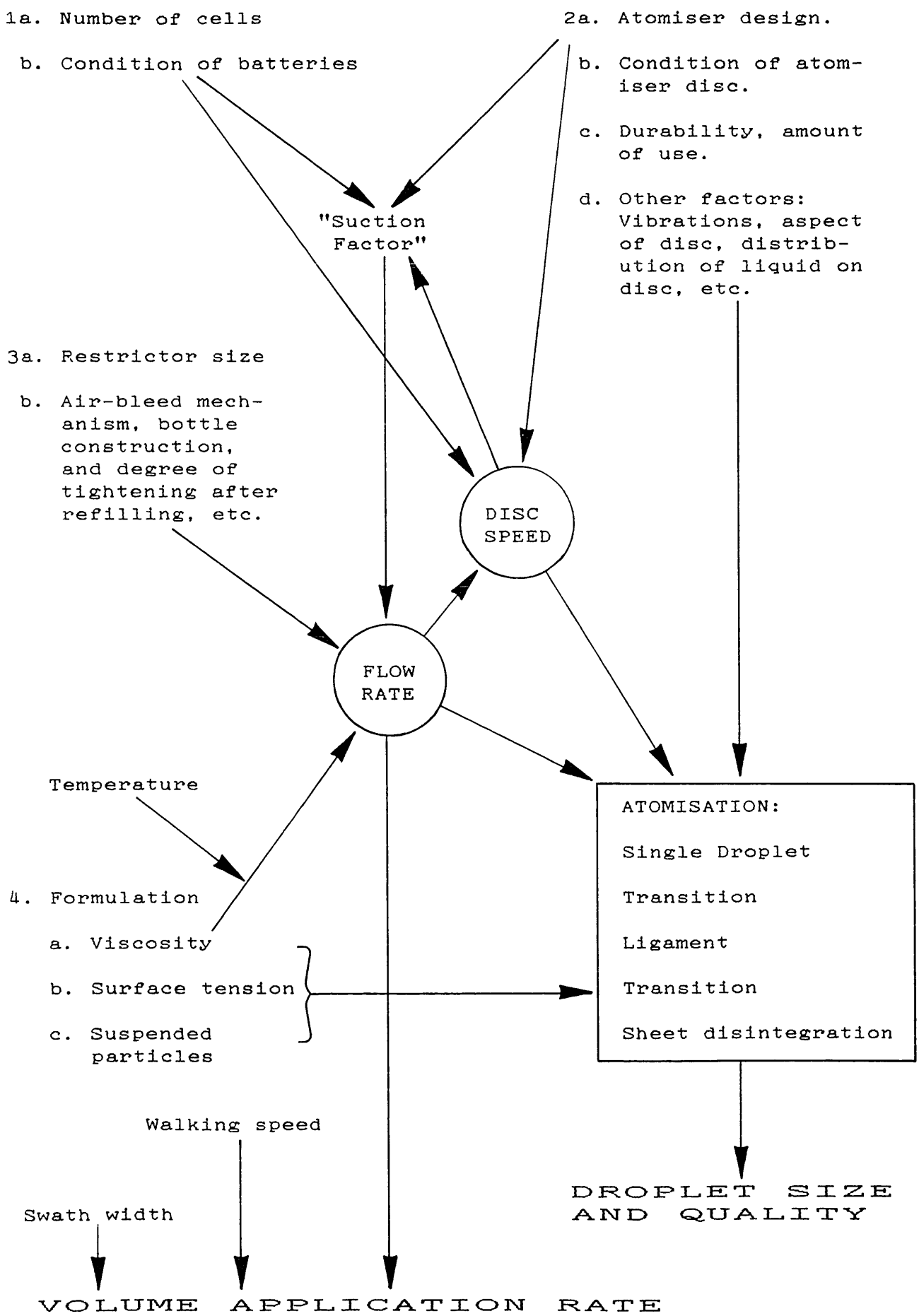
5.1. FORMULATION AND ATOMISATION

During the initial development of spinning disc sprayers, it was assumed that rotary atomisation provided a means of reliably producing sprays of determinable and uniform droplet size (Bals, 1970). Although highly superior to hydraulic atomisation in this respect, the output from a rotary nozzle is the product of many interacting factors, and may become rather unpredictable if operating conditions are such that more than one mode of atomisation takes place. Fig. 5.1. is a synthesis of the components that have been considered during laboratory studies.

5.1.1. Pesticide Flow in Spinning Disc Sprayers

The flow of a given formulation is dependent on the nature of the reservoir, restrictor and airbleed in combination, and an important initial consideration is the design of machinery. Atomisers with a double-disc or splash plate create a slight vacuum at the restrictor orifice, and the flow rate increases proportionally with rotational speed. Flow rate measurements with blank liquids indicated that whereas the Micro Ulva and Berthoud C8 increased less than 10%, the output of the Turbair XJ might increase by 26-35% and the Ulva by 21-27% over that with the disc stationary. Such sprayers therefore not only waste considerable energy by effectively pumping air, but also make flow rate calibration more difficult. This phenomenon has also been described by Cowell and Lavers (1988), who provide a useful guide on restrictor insertion into several atomiser heads, with Newtonian formulations of differing viscosity.

Fig. 5.1. Some Factors Affecting Droplet Size, Quality and Quantity in Rotary Atomisers.



Oil-based ULV insecticides are typically formulated in the 5 - 15 centistoke range, and often tested with newer designs of spinning disc sprayer (such as the Micro Ulva and Berthoud C8). The flow rates of more viscous fluids may become impractically low, intermittent or stop - where very viscous formulations completely inhibit air ingress. In order to dispense such formulations at practicable flow rates, it has been suggested that restrictors or other parts could be supplied with the formulation (E. Quattelbaum, pers. comm.). Nozzles in which the restrictor and air bleed are incorporated in one moulding could be modified, however sprayer designs with a hollow needle or narrow hole air inlet would require more profound alteration. One possibility might be to manufacture a secondary air-bleed that would be inserted between the bottle and the socket of the atomiser head. The restrictor/airbleed system on recent versions of the 'Ulva' is best suited for this purpose, but the durability of this sprayer is poor and power consumption is high (see below).

Viscosity measurement is discussed further in Appendix I. Relationships between viscosity and flow through rotary atomisers is especially complicated for pseudoplastic particulate suspensions where increase in shear rate results in a decrease in apparent viscosity. Certain authors (e.g. Sundaram and Retnakaran, 1987) have assessed viscosity of non-Newtonian fluids over a wide range of shear rates, but for practical purposes, flow rates must be determined empirically. The Ostwald viscometer and the standard cups intuitively give better representations of flow through these sprayers than measurement techniques based on rotors, since they also depend on the liquid being gravity fed through a restriction. Measurements made by the B4 cup are by far the most robust method for field use.

5.1.2. Droplet Description and Measurement

Computers coupled with the Malvern initially calculate droplet size distributions by volume, and number distributions are subsequently estimated from these. For "model independent" analyses from the ST1800 version, number distribution calculations are carried out by the secondary computer, having received volume data which has been rounded to two decimal places. Parameters calculated from number distributions, particularly where particles were detected in the lowest size class, should therefore be treated with caution.

5.1.2.1. **Droplet Size**

Although the parameters VMD and NMD are easier to visualise, VAD is perhaps the most useful single measure of droplet size for use in the field. VAD was originally favoured by Maas (1971), and it seems reasonable to use this parameter where only a **single measure** of spray droplet size at the nozzle may be required: for example when such studies are coupled with deposit assessments. The volume of liquid represented by this droplet size has here been called the average droplet volume (ADV), and should be helpful for correlating spray volume with droplet density. For convenience, ADV is expressed in terms of thousands of cubic microns (equivalent to pico-litres or 10^{-12} litres). Dividing one billion (Imperial: 10^{12}) by the ADV should therefore give an estimate of the number of spray droplets produced if 1 litre of liquid were atomised into droplets of reasonably uniform size.

Number distributions are required for calculation of VAD and the data presented shows how dramatically different average droplet volumes may be calculated from such estimates. Assuming that the smallest size class plays little part in the efficacy of sprays, its absence in ST1800 readings may actually improve the

applicability of VAD results. Under field conditions, droplets in the size ranges below 50 μm. may not impact onto nearby crops, (requiring an electrostatic charge, high windspeed, or calm conditions for sedimentation to take place); they also frequently account for only a tiny proportion of the total spray volume. When combining droplet size measurements with deposition studies, it might be helpful to modify VAD and ADV by calculating them with only the size classes above a lower size limit (say 25 μm.).

5.1.2.2. **Uniformity of Droplets**

VMD/NMD ratios may provide a helpful indication of spray quality, but there is always a danger of over-simplification in comparison with complete records of spray distribution by size class. They were proposed independently by Bals (1969) and Fisher and Dougan (1970); such ratios (r) have frequently been used in the evaluation of sprayers (e.g. Arnold, 1983). Johnstone (1978) and Matthews (1979) suggested that for CDA, r should not exceed 1.4 where droplets had been collected on magnesium oxide slides. Equivalent values from light diffraction droplet sizing techniques are likely to be larger.

Recent dissatisfaction over the validity of VMD/NMD ratios prompted Bals (1983) to propose the use of Malvern printout for determination of acceptable limits. It was suggested that if at least 80% of the droplets measured (correlating with relative span) were within a certain range then the spray could be classed as CDA; three size categories on the analysis were suggested, representing an approximate doubling between the lowest and highest size limit. The obvious disadvantage of this method is that it is only applicable to Malvern analyses.

Many field workers may wish to know the proportion of droplets within a size band suitable for their purposes. During

the course of this study, routines which provided a clear estimate of the percentage droplet volume between an upper and lower size limit were incorporated into analytical software. These limits have been rather arbitrarily selected, but were based on previous research; in all cases the upper size limit was double that of the lower limit, thus representing an eight-fold range of droplet volume (see Appendix IIa). Droplets with sizes outside the limits, can be considered non-optimal, but may have some efficacy; the term "waste", proposed by Bals may perhaps have been too strong. "Useful" size ranges would be of greater value, if agreement could be reached about the value of their limits. C.V. (or span) are of more theoretical value, but should be reliable being based solely on volume distributions.

5.1.2.3. **Droplet sizing with the Malvern P.S.A.**

Although small modifications have been made to the Malvern instrument itself, the most significant developments have been improved software and much faster micro-computer processing. In both these and other studies, the two later versions may record significant volumes of droplets in the band below the lowest size partition (i.e. 0 - 15.5µm.), which are not included in the ST1800. Serious inconsistencies may occur when attempting to derive number distributions from these data. Such apparently large numbers of very fine droplets could be the consequence of:

i. Water + Agral producing large numbers of satellite droplets,

ii. an artefact, perhaps similar to the effect described in 2.5.2.2., or

iii. very fine droplets re-circulated through the beam, since no suction was used in this experiment.

Although the third hypothesis may offer a partial explanation, it begs the question as to whether or not such droplets are really there. The LASER diffraction pattern is

independent of particle motion (Swithenbank et. al., 1975). Very small droplets (>20 μm.) that fail to impact on crops, may have little value for spraying and the primary practical consequence of their presence is as an inhalation hazard.

Only "Model Independent" analyses can satisfactorily describe the size distributions of multi-modal sprays. In practice however, the Rosin Rammler model generally produces very similar VMD readings on the ST1800. Malvern 2600 "model independent" data were significantly smaller by margins normally in the 2-5% range, and rarely exceeding 10%. Recent work with hydraulic nozzle measurement has suggested very little difference in the cumulative volume fraction curves produced by the two methods of Malvern analysis (Arnold, 1989). Rosin Rammler estimates of spray uniformity from rotary atomisers, may come closer to those of other instruments than "model independent" output from the ST1800. This is apparently caused by "tails" on either side of the principal spray size classes.

In practice, inconsistencies were common between droplet readings after endeavouring to repeat experimental conditions, especially when measurements were taken on different days. During work with formulations, attempts were made to minimise variability of nozzle positioning and orientation. On several occasions though, statistical analysis revealed significant differences between groups of readings (or "blocks": e.g. Figs 3.3.3 and 3.4.1.12). Because of such inconsistencies, uncertainties about the measurement technique, these results should be considered as comparisons rather than absolute values. Reference to high-speed photographs of droplet production at the disc periphery (e.g. Boize and Dombrowski: 1976) may help to resolve some of the problems.

5.1.2.4. **Comparison with other Measurement Techniques**

Droplet measurement using LASER diffraction techniques have become commonplace over the past decade. There has been some concern over the consistency of results, and there have been several attempts to assess these differences. Unadjusted PMS size results are practically always larger than those from the Malvern (Arnold, 1989). Young (1985) described experiments where samples of fine glass beads were simultaneously poured through the beams of a 2600 series Malvern and a PMS. Under these conditions he was able to show that "close agreement was possible" between these measuring methods, however in subsequent tests using hydraulic nozzles, unmodified readings from the PMS system always indicated larger droplet size distributions for such dynamic spray clouds (Young, 1988).

In this study the PMS produced VMD measurements that were 92-98% larger at 180 rev.s^{-1}, and 52-68% higher than Malvern readings at 120 rev.s^{-1}. There appears to be a trend towards closer agreement at droplet sizes typical of flat fan nozzles (i.e. with VMDs greater than 100 µm.). Smaller droplets lose momentum very rapidly, and it is possible that a portion of the spray slowed down to below a minimum sampling velocity that exists for this instrument (Parkin et. al., 1980). The Aerometrics readings were broadly consistent with those of the Malvern, and the spatially-reduced data was only slightly smaller than temporal calculations. It should be stressed that the P/DPA data are only a single set of measurements, and are taken from a restricted area of spray at the intersection of two LASER beams; all other instruments could be arranged so that light passed completely through the spray sheet. No large proportions of droplets were detected near the limit of resolution (7.8 µm.).

5.1.3. **Modelling and Control of Rotary Atomisation**

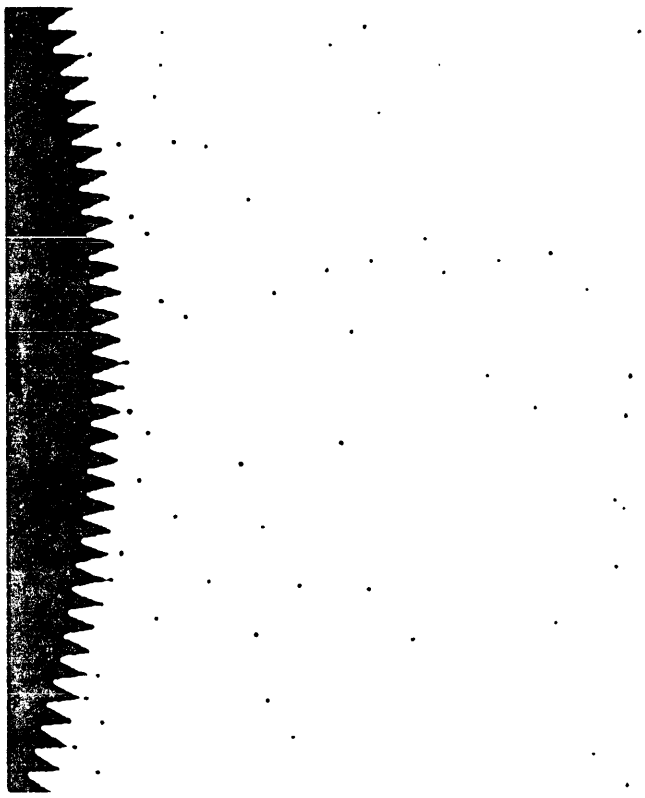
Of all the factors determining droplet size, rotational speed of the disc was consistently the most important, and this study is consistent with previous work. The relationship between disc speed and droplet size, for a given liquid and flow rate, showed a combined linear and quadratic element (Figs. 3.3.3, and 3.4.6.). At lower disc speeds, a further cubic trend (e.g. Fig. 3.3.3.) may have indicated transitions between single droplet formation and ligament break-up: to be subsequently termed mode transitions. This was corroborated by the grouped size distribution histograms such as Fig. 3.4.3. and may be confirmed with high speed photography (e.g. Fig. 5.2.).

Heijne (1981) found a poor relationship between predicted and measured VMD values, especially at lower rotational speeds of the tractor-mounted 'Battleship' spinning cup at flow rates of 400 ml/min. or more. He produced another model that conformed more closely with his observations by including flow rate as a factor. In Figs. 3.5.1. and 3.4.1., there were negligible differences between average sizes of water + Agral droplets, produced by the Micro Ulva and Turbair XJ **within their normal operating ranges.** Flow rate only significantly affected droplet size in hand-held spinning disc sprayers, when it was abnormally high, or so low that mode transitions took place.

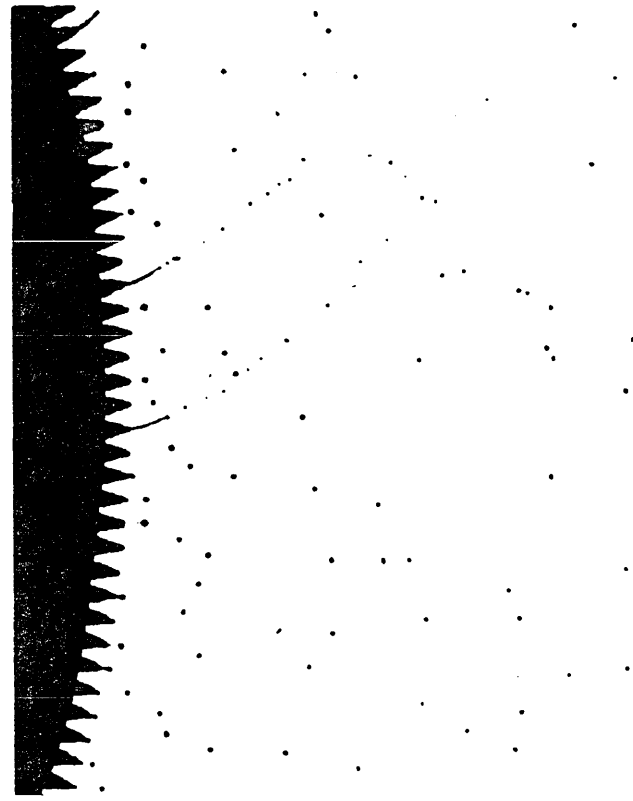
Fig. 5.3 illustrates data for two 88 mm. discs, taken from section 3.4.1.2., expressed in terms of VMD, and superimposed on three models described in section 1.2. Plain tap water has a high static surface tension (often quoted to be approximately 73 mN/m.), which is known to be reduced drastically by addition of most water miscible formulations.

Fig. 5.2. High speed photographs of droplet formation on the periphery of a 52 mm. Mini Ulva" disc (courtesy of Micron Sprayers Ltd.). Water + 0.1% Agral is shown atomised at 9000 R.P.M. (=150 rev.s^{-1}), at four feed rates:

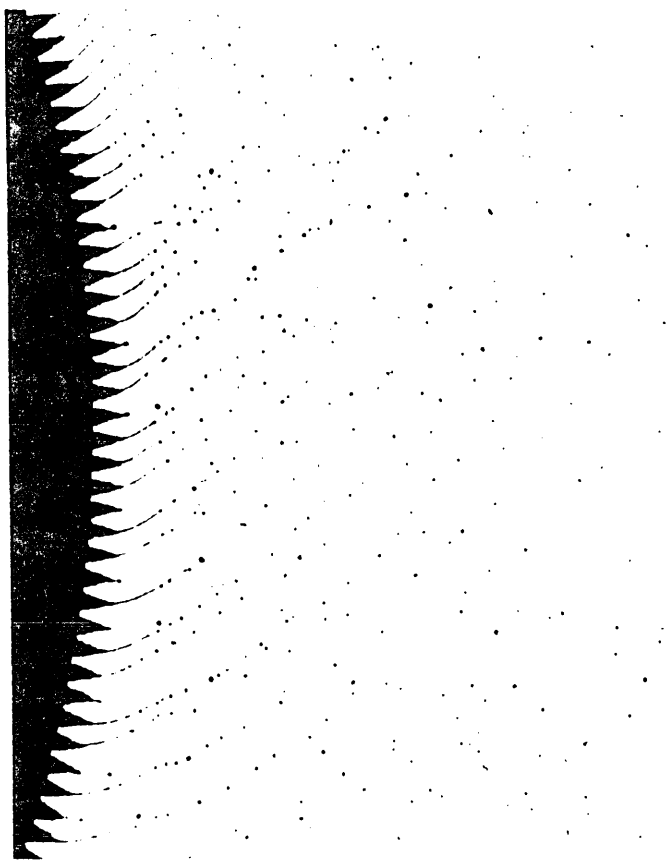
10 ml/min.
(single droplet formation)



20 ml/min.
(start of transition)



30 ml/min.
(single droplets produced on few teeth)



40 ml/min.
(ligaments on most teeth)

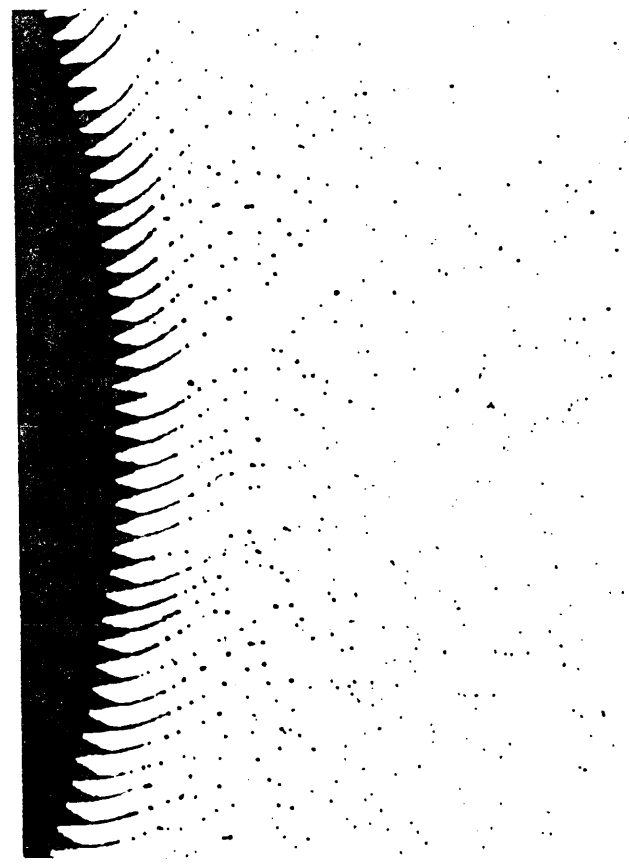
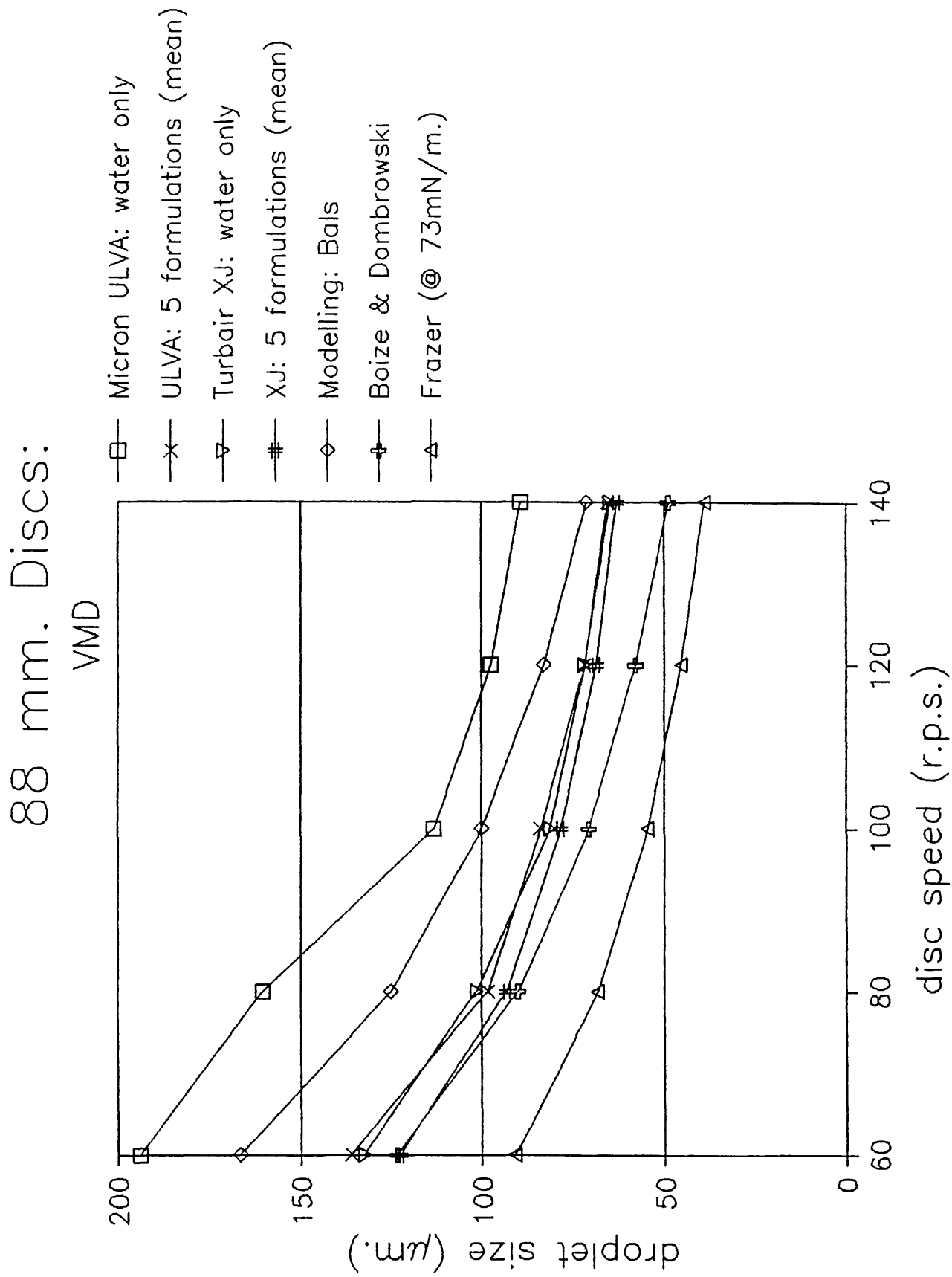


Fig. 5.3. Observed and modelled droplet sizes (VMD) with the Micron 'Ulva' and Turbair XJ. Average readings for five formulations are shown, and apart from 20% thiodicarb SC, example volume distributions were illustrated in Figs. 3.4.1.10-11. Flow rate: 60 ml/min.



Simple formulae, of the type quoted by Walton and Prewett (1949) and Frazer (1958: as illustrated) seem inadequate, especially since liquids with lower, more realistic surface tensions would have produced even smaller predicted VMD values. Bals' (1970) formula for 87-88 mm. discs (10,000/rev.s^{-1}) appeared to produce droplet size estimates that were higher than measurements with most water-based mixtures. The closest model was that of Boize and Dombrowski (1976) who also worked with an 'Ulva', however the slope of lines connecting observed droplet sizes becomes increasingly divergent from their prediction, as disc speed is increased. They did not include viscosity in their formula, yet there was apparently a relationship with average droplet diameters with oil-based fluids tested in this study (Fig. 3.4.2.3.); differences between formulations could not be explained merely by differences in spray quality. Viscosity measurements are usually obtained as "equilibrium" values at low shear rates. The dynamic viscosities of non-Newtonian fluids can cover a wide range at different shear rates, and it may be impossible to determine the precise conditions acting on a liquid: for example, at the edge of a toothed disc in an air current. Measurements of surface tension are also usually obtained at low flux, and may likewise alter dramatically under dynamic conditions (P. Wynn, pers.comm.).

Spillman (1988) has noted that "... the empirical formulae available tend only to fit well the experimental data from which they are derived." No further attempt was made to fit models to these experimental results, and attempting to predict mode transitions seemed equally futile, partly because it was difficult to delineate precisely where they occurred (see Figs. 3.4.9., 3.4.16., 3.5.3.). Bals (1969) stated that the

principal of a rotary atomiser was "... as simple as an ordinary water tap". Recent work has shown that as flow rate to a dripping tap is increased, near to the point where a ligament is formed, the periodicity of dripping changes from order to chaos, but may conform to a "strange attractor" paradigm (Crutchfield et. al., 1986). Developments in fractal mathematics may provide further insights into rotary atomisation.

5.1.4. Atomisation of Viscous Oil-based Formulations

Formulation chemists usually adjust viscosity in order to make their products suitable for existing machinery and available restrictors. Development work on thiodicarb SUs has highlighted the difficulty of producing stable formulations with viscosities below 100cP. In order to achieve good shelf-life and maintain suspensability, SCs and SUs are usually manufactured with viscosities over 200cP. ULV formulations should have a viscosity index which is as high as possible in order to minimise changes of viscosity with temperature. This should always be carefully evaluated over a reasonable working range - say 15 to 35°C. These values may be may be inadequate for ordinary UL formulations, but the reflectance of white SUs can maintain temperatures that are 5°C. cooler.

Practically monodisperse droplet spectra were produced by three SU formulations, and unlike ULs, they were little affected by changes of flow rate in the range of 10-60 ml/min. This was propitious since only low flow-rates were possible with the largest restrictors of many unmodified rotary atomisers (see above). Although tested on a well-finished, simple disc, this has favourable implications for double discs and less-well designed sprayers, where liquid may not be as evenly distributed

to all the teeth.

5.1.5. **Atomisation of Water-based Suspensions**

Within the normal ranges of flow rate and disc speed, differences between various operational water-based mixtures are often smaller than the variations between the two types of oil-based formulation (cf. Figs. 3.4.1.8. with 3.4.2.3. and 3.4.2.9.). At a given rotational speed, aqueous mixtures typically produce larger droplets than UL formulations (although SUs were fairly comparable); Johnstone and Huntington (1977) considered this to be due to the high surface tension of water. Gledhill and Brettell (1980) suspected that one possible advantage of molasses addition was that finer sprays were produced because this adjuvant lowered the surface tension. This work confirms that molasses addition may significantly reduce the droplet size. Certain adjuvants such as 'Derimin' may improve hydraulic nozzle spray recovery by increasing the droplet size. Under normal operating conditions, rotary atomisers may produce consistent droplet spectra with different adjuvants (see right hand side of Fig. 3.4.1.7.), however 'Derimin' mixtures produced sprays with high VMDs at low disc speeds and flow rates. At higher flow rates and disc speeds (normal operating conditions) all three adjuvants produced droplet spectra that were more comparable to other fluids. They may affect spraying by increasing the threshold at which mode transitions occur (Fig.3.4.1.15.).

Molasses is subject to availability in many areas and alternative anti-evaporants may be too expensive. Pesticide manufacturers might make their products more commercially attractive by preparing water-miscible formulations with appropriate additives already incorporated. Unfortunately

attempts to prepare a molasses-based thiodicarb formulation (similar to 'Sevimol': a product containing carbaryl) were unsuccessful due to rapid degradation of the active ingredient.

Flow rates of hydraulic spray nozzles can significantly increase after erosion by certain inert fillers in wettable powders, however Beeden and Matthews (1975) thought that abrasive foreign matter in water was more important. Since liquid is usually fed by gravity rather than pressure to rotary atomisers, erosion is unlikely to be a major factor. Enlarged restrictor orifices are commonplace in the field, however this is normally caused by operators using hard objects to remove blockages resulting from impure water or poor-quality wettable powders. The flow rate problems associated with SU atomisation do not accompany water-based techniques, and because Zimbabwe and Malaŵi practised water-based techniques, thiodicarb could be incorporated into cotton pest management programmes at an early stage in its development.

5.2. ACTIVITY OF THIODICARB IN FIELD TRIALS

5.2.1. The Rôle of Thiodicarb in Cotton Pest Management

'Larvin' SC remains expensive in comparison with many pyrethroids, and a clear vision of the role of this compound is essential, especially amongst smallholders who have expressed concern about its high price. Many commercial farmers consider it economically viable only if two species of bollworms required treatment, and the use of pyrethroids were restricted. Localised formulation might reduce costs and provide more appropriate products for local needs.

The relative specificity of thiodicarb in laboratory studies, was not reflected in the only field trial with natural enemy populations high enough to carry-out statistical analysis (see Fig. 4.3.2b.). The practical importance of preservation of natural enemies such as aphid predators may anyway be unconvincing to farmers, and the primary advantage of this compound may prove to be as part of Insecticide Resistance Management (IRM) strategies. Thiodicarb provides a versatile alternative to the pyrethroids for control of bollworms species that are susceptible to chemical sprays, but unfortunately trials in Zimbabwe provided further confirmation that thiodicarb may contribute to red spider mite resurgences (see section 5.2.3.).

Levels of Heliothis attack and control were generally most important in determining yields at the end of field trials. This work did not provide sufficient data to comment on Diparopsis control, which may be impaired if there is poor coverage on the lower parts of the plants. In Zimbabwe, further data would be required from the Lowveld where this species is often more abundant. Thiodicarb occasionally showed significant efficacy against Homopteran populations including: jassids, aphids

Paurocephala and whitefly. Although linear correlations are weak statistical tests, certain trials in Malaŵi (most notably trial 2) indicated that sucking pests may have an even greater effect on yield than Heliothis larvae (cf. Fig 4.3.3. and Fig. 4.3.4.).

5.2.2. Mass Application Rate of Thiodicarb

In Malaŵi, reduction of thiodicarb dosage significantly impaired pest control and cotton yields in all trials. In both Makoka and Toleza this appeared to be attributable to control of Paurocephala, and to a lesser extent, Heliothis larvae. The results from Zimbabwe show strikingly small differences between all treatments - in terms of both insect mortality and yield.

Comparison of infestations during the two seasons in Zimbabwe shows how a threshold-based system may **or may not** reduce the number of chemical applications in a season. In a calendar schedule, an order of five to ten insecticide sprays might be applied, depending on the country (e.g. Cauquil, 1985); during the 1986-7 season in Kadoma only three sprays were required in many blocks, however the high and persistent pest populations in the following year would have necessitated 11 bollworm and 3 sucking pest sprays.

Since halving the normal dosage of thiodicarb seems to cause little diminution of effectiveness in Zimbabwe, the recommended rate might be reviewed. Where Diparopsis populations are low, thiodicarb applications at 200 g.a.i./ha. - in response to Heliothis larval thresholds - appear to be effective in the Middleveld, and consistent with certain findings in the USA (see section 1.7.2.). During previous trials carried out by Dr. Brettell and others (described in C.R.I. annual reports), there has been a reduction of experimental dosage rates from 700

g.a.i./ha. in 1977 to 500 g.a.i./ha. in 1980, and in 1982 a comparison of dosages ranged from 375-450 g.a.i./ha. When thiodicarb was registered in 1975, 412 g.a.i./ha. - representing 1 litre of SC formulation - seemed to be a robust compromise, even though the 1982 trial had indicated no significant differences between lower rates. Serious consideration should be given to further reductions in this country, which would be a most effective way of reducing the treatment costs of this insecticide.

5.2.3. Comparisons with Controls and Other Standards

The merits and demerits of control (check) plots in pesticide trials remain controversial (Reed (1972). Three justifications for their inclusion are:

i. to provide a classic "check" on insect populations, and establish whether or not yields would have been seriously diminished if no spraying had taken place,

ii. to validate experiments by assessment of cross contamination of spray between plots,

iii. to provide a practical method of checking that correct volume application rates are applied during the execution of trials (blank formulations were sprayed before the insecticidal applications).

In all trials, yields of seed cotton were lower in control plots; the greatest difference between spraying blank and active materials occurred in trial 2, where there was 3.5-fold increase for the best chemical treatments - pyrethroid sprays. The number of control plots in 1987 retrospectively appear to have been excessive, however their absence in certain 1988 trials is also a matter of regret. Data for untreated cotton were obtained from

plots in adjacent trials, however they seemed inadequate in comparison with limited numbers of control plots situated within the trial, but analysed separately. Thiodicarb CDA techniques were also compared with two standards: knapsack and tailboom application at 200 l./ha. (see section 5.4.5.1.) and recommended pyrethroid treatments.

Red spider mites can be a particular problem in Zimbabwe, and trials during both seasons indicated that populations in plots sprayed by recommended pyrethroids were lower than those treated with thiodicarb. 1987 was a very dry year and populations became extremely high after 95 d.a.e. During the period of rapid mite increase, the controls were infested at intermediate levels, with significantly higher RSM scores in the thiodicarb "WULV" and MULV treatments; the lower scores in fenvalerate treated plots were not significantly different (Table 4.2.1.). Trial 5 indicated that lambda-cyhalothrin treated plots may have required one rather than two acaricide sprays (see Fig. 4.2.3a.). Although all these differences were significant, their importance seemed marginal.

5.2.4. CDA Strategies

5.2.4.1. **Principal Formulation Strategies**

In three Zimbabwean trials, methods of controlled droplet application were less important for determining yield than the selected active ingredients. The "WULV" technique consistently resulted in marginally higher yields, however the three approaches should be considered essentially equivalent in this country (in the absence of Diparopsis). Smallholder and communal farmers may especially benefit by adopting "WULV", which has many of the advantages of MULV, without the need to procure molasses.

"WULV" would probably become more acceptable if the volume application rates were to be reduced (see @@@ below).

These results from Zimbabwe are more or less consistent with those from recent trials in Francophone Africa, where considerable interest is being shown about water-based CDA. Research efforts carried-out in Chad (Deguine, 1989) and Cameroun (Oudinot, 1989) have included comparisons of "WULV" at 10 l/ha. and oil-based ULV at 3 l/ha. These authors believe that the higher volume application rate may achieve better droplet penetration, with significantly lower populations of aphids and whitefly being recorded in at least one trial. As in C.S. Africa, yields were essentially comparable with the two techniques, and the advantage of "WULV" lies essentially in its cost effectiveness and versatility.

Data on sucking pest control in Malaŵi sometimes appeared to run contrary to French findings. Populations of aphids and Paurocephala (in trial 2) and whiteflies (in trial 6) were significantly lower in oil-based ULV treated plots. Yields were generally greater with oil-based sprays than with water-based thiodicarb applications and significantly higher in both seasons at Makoka; lower yields at Chitala are discussed in section 5.3.3. Three obvious hypotheses for the greater efficacy of oil-based formulations at Makoka include:

i. they are more rain-fast,
ii. they have greater intrinsic efficacy against pests such as Paurocephala, that was especially important at this site,
iii. there was higher mass recovery rate of active ingredient in trial plots.

Efficacy against sucking pests was clearly a contributory

factor, but rainfastness could also provide satisfactory explanation. Matthews (1973) considered that the frequent daytime thunderstorms and heavy rain at this site may affect the persistence of spray deposits, and recommended that spraying should take place in the late afternoon if possible (it was not in this case), so that fresh pesticide deposits were made available to nocturnal moths and larvae.

Oil-based ULV spraying continues to be recommended in Malaŵi, although most farmers prefer to use hydraulic or "WULV" spraying techniques. If improved yields with thiodicarb SU were to prove consistent in this country, the increased return might enable farmers to pay for a more expensive oil-based formulation, however it is doubtful whether they would be willing to change techniques on the basis of just one active ingredient.

5.2.4.2 **Differences Between Thiodicarb SC and WG Formulations**

Suspension concentrates are sophisticated formulations that were originally developed in temperate climates. The stability of 'Larvin' SC is liable to be reduced if storage temperatures exceed 46°C, and problems were indeed encountered in the field (see section 4.4). Water dispersible granules were formulated for such circumstances, and would not entail logistic problems in Malaŵi, where farmers are well accustomed to powder formulations packed in sachets. Should such difficulties with SC become serious, there appears to be no technical reason why it could not be replaced with WGs, since practically no biological difference between the two formulations was detected in any trial.

5.2.4.3. **Volume Application Rate**

In 1987 a wide span of treatment volumes were applied, ranging between 4 and 200 l./ha. for water-based sprays (see

Table 2.7.2.). When volume application rates were reduced to less than 1.5 l/ha., plots treated with oil-based formulations appeared to produce slightly lower yields in Zimbabwe and less consistent results in Malawi than in 1987, when 2-6 l/ha. were applied. These may either have been consequences of poorer crop coverage, or an effect of fine spray drift away from small plots.

The analysis of total yield in Chitala was especially revealing, with a significant interaction between formulation and droplet size providing a satisfactory explanation for the only exception to generally high yields resulting from oil-based formulations. Thiodicarb SU essentially atomised into similar-sized sprays as water-based mixtures, yet there was a significant yield reduction with enlarged oil-based droplets. There was a small but insignificant increase in yield with both the water-based formulations applied at 14 l/ha. (Fig. 4.3.5.). A decrease in efficacy due to reduced coverage is indicated, also because the SU volume application rate (0.9-1.25 l/ha.) was especially low in this trial.

5.3. DROPLET SIZE AND THE PASSAGE OF SPRAY TO THE CROP CANOPY

Lowering the volume application rates in CDA techniques, necessitates detailed analysis of formulation, droplet size and recovery (Matthews, 1983). Assessment of deposit levels from single swaths is useful for estimating spray recovery and determining appropriate swath widths. Droplet recovery studies described here are based on few experiments; they have been included to illustrate the difference between "WULV" and other CDA techniques and further to develop a rapid, acceptably reliable, methodology that can be used with a minimum amount of equipment. Examples of such data sets already exist for cotton and include work carried out in C.S. Africa by Gledhill and Madende (1976) and Nyirenda (1986), and in Thailand by Johnstone et al. (1977b).

5.3.1. Droplet Recovery Assessment Techniques

It has been implicit that methods based on numbers can only be used where the droplet sizes are restricted to a fairly narrow band. The idea of using scoring systems rather than counting droplets is not new (e.g. Morton, 1977, Nyirenda, 1986), however the gauge described here was designed to improve accuracy over a wide range of densities. Courshee and Ireson (1961) compared subjective assessments of samples visually grouped into ten categories with careful chemical analyses. About 70% of all estimates lay within their correct category, and of the remaining inaccurate judgements, 80% deviated by 15% of the actual deposit, or less. A similar technique has been used in a study on spraying of irrigated cotton by Johnstone and Matthews (1965).

Methods for quantification of deposits have included Uk & Parkin's (1983) surface fluorimeter which allows large numbers of

samples marked with fluorescent tracers to be measured on natural surfaces, but is still qualitative rather than a quantitative measure (Pay 1984). Stonehouse (1986) described a photographic technique for recording fluorescent dye stains on leaves and observed that the droplet images are irregularly shaped due to inconsistencies in the leaf surface and are thus very difficult to size accurately. Last and Parkin (1987) developed a small microcomputer-based image analyser for making rapid measurements (20-25 seconds per reading, by one operator) of spray distribution and percent coverage. They also stressed the dangers of of correlating volume application rate, droplet density and biological efficacy. The only way to be sure of actual deposit levels is by absolute measurement - usually either by chromatographic assay of the pesticide itself or using alternative techniques for quantifying admixed tracers including dyes (e.g. Pickin in Heinrichs et al., 1981) and rare earth salts (Dobson, 1986), however these are time consuming and expensive. In a review of methods suitable for measurement of spray drift, Parkin and Merritt (1988) emphasised the need to establish agreed protocols, in order to build a comprehensive database. Within its limitations, a standardised scoring system for droplet density assessment would enfranchise the efforts of establishments with very low resources.

The ratios of measured average droplet volume, between sprays produced by discs spinning at 110 and 160 $rev.s^{-1}$, were less consistent than originally anticipated: droplets of "WULV" mixtures produced at the slower speed were 3.3 times larger on average, MULV was 2.7, and oil-based mixtures varied between 2.5 and 2.9 times. Estimates of pesticide deposit have been calculated using ADV measurements, but as discussed above, their

accuracy is also uncertain. There are further dangers of forming inappropriate conclusions from droplet counts:

i. A droplet may appear small either because of its size when it left the sprayer, or because of evaporation during flight.

ii. Impaction efficiencies differ with wind speed, droplet size and the nature of the target. Approximate collection efficiencies are tabulated in Appendix III. Impaction of droplets in the 60-100 μm. range may vary from less than 70% to more than 90%, however this would only partially explain an observed two-fold order of difference in spray volume recovery between the two sizes.

Unfortunately, there may also be very little relationship between droplet capture by artificial targets and natural surfaces. Leaves are more efficient than horizontal cards at capturing small droplets ($\leq$ 40 μm.), but conversely less efficient at collecting larger ($\geq$ 90 μm.) droplets, although such generalisations are complicated by factors such as leaf fluttering (Uk, 1977). In an attempt to compensate for differing collection efficiencies with diverse droplet sizes, Johnstone et. al. (1977a) used stepped targets of varying width. Total recovered deposit measurements may be less relevant than coverage if most deposited droplets contain a lethal dose.

It has been assumed that the ratios of estimated recovery, between sprays of differing average droplet sizes, are related to the efficacy of evaporation inhibitors in water-based mixtures. Monosized sprays with a droplet size of 100μm. have 70% of the surface area as those of 70μm (see Appendix IIa), and differences may have been more pronounced had sprays with a two-fold difference in VMD been compared. Although the meteorological conditions were as similar as possible, the technique could be

improved by the twin tracer method described by Johnstone (1977). The same precautions apply to droplet density estimations as to other techniques that require human assessment (e.g. bioassays). Double-blind procedures might be incorporated into the experimental design wherever possible, however the same person or group should carry out all evaluations and rest frequently during this work. A further improvement would be to increase the number of sampling stations within the first 4m. of the spray line.

5.3.2. Spray Deposition

Higher wind-speeds increase the total number of impacted droplets and carry them further, resulting in lower deposits on proximal targets and higher levels downwind. Estimates of total recovered droplets (the areas under single swath curves) were inconsistent, and appeared to depend more on wind speed than formulation type. There was generally a better mass recovery of pesticide with enlarged droplets, irrespective of formulation; estimated spray recovery was usually in the order of two times higher in 1988. The exception was for molasses, where the numbers of recovered large droplets were exceptionally low and small droplets exceptionally high, however this is not born-out by the 1987 data and may be atypical. Johnstone et. al. (1977b) similarly found a drastic reduction of spray recovery in a cotton crop, when the droplet size was decreased from 80 µm. VMD (109 pl. ADV) to 42 µm. (19 pl. ADV). Where spraying had taken place late in the morning, high convective turbulence caused half of the volume of the smaller spray to be lost as aerial drift, either beyond a distance of 15 m. or away from the crop altogether. Johnstone et. al. (1977a) also found that aerosol sprays could rapidly be drawn out of the crop, even when emitted below canopy level. Recoveries of small droplets of water-based

mixtures with no additives were always lower than those of other formulations, indicating a substantial lower mass recovery if droplets are too small. Droplets of spray containing an anti-evaporant, or oil-based mixture were generally recovered in much greater numbers as small droplets, provided that wind speeds were consistently high.

CDA has often been associated with drift spraying, however wind is a capricious force. Prevailing wind directions are rarely taken into consideration when planting crops; the rows are generally determined by the field's shape and the direction of any slopes present (e.g. Morton, 1973). If wide swath widths are chosen, the weather conditions during drift spraying may drastically affect the uniformity of accumulated deposits. Having shown that single row swaths were significantly more efficaceous than swaths of up to 5m., Matthews (1973) provisionally recommended 2 rows for fully grown cotton, since formulations with non-volatile diluents were costly. This compromise produced an effective volume application rate of 2.5 l./ha. (at 0.5 $ml.s^{-1}$) which has been adopted elsewhere; increasing the work rate by using wider swaths and higher flow rates has however often been recommended (e.g. in Tanzania).

Little attempt was made to select especially suitable spray days with good wind conditions in any of these trials; farmers treating their crops in response to pest monitoring, likewise have little leeway for timing sprays. It would be dangerous to make generalisations about heterogeneous data such as these, apart from recommending that swaths should be made as narrow as practicably possible with any type of CDA, in order to achieve a reliably even coverage.

Johnstone and Huntington (1977) compared droplet recovery over cotton for the three CDA techniques, with formulations of carbaryl. Unlike this study, their "WULV" and aquamol sprays were of wettable powders, and the oil-based application was a UL solution. Swaths with water-based sprays should not normally exceed two rows, and even the aquamol technique is thought to be a "placement spray which may benefit from wind-assistance" (Brettell, pers. comm.). Johnstone and Huntington considered that spray recovery was essentially similar to "WULV". In Zimbabwe, it is recommended that the early plant stage swath of 4m. be reduced to 2m. if there is little or no wind (Anon, 1985). The "Electrodyn" technique, is essentially a placement spraying. A reduction of the influence of wind and other variable factors was a basic goal during its development, in order to minimise decision making by the farmer.

5.3.3. The Significance of Droplet Size in Efficacy Trials

The high efficacy of small aerosol droplets under laboratory and glass-house conditions was introduced in section 1.5.1. Of all the main factors studied in the field trials, droplet size appeared to be the least significant. The only exception was in Makoka (1986-87), where inconsistencies in mass application rate provide an explanation for an apparently highly significant difference. The laboratory work carried-out by Omar (1987) and Munthali and Wyatt (1986) implied that at least a doubling of efficacy of contact pesticides might be expected with reduction of droplet size from 100µm. to 60µm. Contact activity with thiodicarb sprays would only be likely to occur when it acted as an ovicide, or if decomposition to methomyl had taken place. Munthali and Wyatt stressed that such effects might not be universal, and contrary results have been recorded elsewhere (see

section 1.5.1.). Two possible hypotheses might explain the apparent unimportance of droplet size in these trial results:

i. Stomach poisons such as thiodicarb and the lepidopteran pathogens assessed by Smith et. al. (1977), have a less intrinsically enhanced activity as small droplets than contact insecticides.

ii. Any enhanced activity of smaller droplets was counteracted by loss of active ingredient from the plot area during spraying.

Had the rate of recovery been an important factor, a interactions between droplet size and formulation might have been more commonly expected, however differences between oil-based sprays with different VMDs were detected at Chitala. Larger droplet size was probably only disadvantageous when it resulted in reduced crop coverage at extremely low volumes, however the first hypothesis, would have to be confirmed by extensive bioassay tests.

One of the most detailed studies of droplet size and recovery for the "WULV" technique, was carried-out by Pickin (1980) who found that the greatest spray recovery occurred with droplets of approximately 130 μm. VMD (100-120 μm. VAD). The air above paddy rice is usually very humid, and greater differences due to evaporation might be expected in a cotton crop, yet no dissimilarity in efficacy were detected between the two droplet sizes with "WULV" sprays. Like Picken, Nyirenda (1988) found that efficacy may be depressed if droplet size is very large. Yields, sucking pest control and sometimes Heliothis control were reduced when batteries were discarded at 3.5v. rather than 6v.; below 4.5v. even a new Turbair XJ would probably rotate at less than 50 $rev.s^{-1}$, producing droplets larger than 120 μm. VAD.

5.4. SELECTION OF CDA STRATEGY AND MACHINERY DEVELOPMENT

5.4.1. Introduction: The Alternatives to Spinning-disc Spraying

Timely applications in response to action thresholds are facilitated by the ease of use and high work rate for "classic" CDA. Three different strategies for using rotary atomisers have been described, but the small-holder essentially has two other options:

5.4.1.1. Hydraulic Knapsack Sprayers

The smaller the size of the crop to be treated, the less important work rate becomes, and taking a world-wide perspective, knapsack spraying remains a reliable and trusted means of applying pesticides to most crops. The high work rate for CDA was discussed in Chapter 1; the 1987 trials in Kadoma and Toleza exemplified how the large effort involved in applying 200 litres of liquid per hectare can result in significant under-dosing, even on research stations. At Toleza, this may have affected the control of Heliothis larvae, however yield were not significantly different in any of the trials.

This study provided no further evidence that applications of differing but acceptable spray quality show any significant differences in biological efficacy, at volume application rates greater than 5 l/ha.. The rationale for minimising the span of spray droplet sizes is based on the assumption that larger droplets (of 200 µm. for instance) are less efficaceous than the equivalent volume more finely atomised (e.g. eight 100 µm. droplets). The prospect of droplet size being relatively unimportant in practice (when most of the spray volume is within a reasonable range of perhaps 50-150 µm.) raises the prospect of using hydraulic nozzles for VLV application. The narrow orifices

in hollow cone nozzles designed for very low flow rates tend to clog easily, but this is less of a problem with spinning disc sprayers.

5.4.1.2. **Electrostatic Sprayers**

The only machine in this class that is presently commercially available is the 'Electrodyn' ('ED') sprayer. It was not possible to formulate a stable thiodicarb formulation within the range of viscosity required for the 'Bozzle' system. Any further work in this direction may depend on two factors:

i. The general success of the technique in important markets,

ii. The efficacy and cost-effectiveness of applying thiodicarb at ultra low volumes, with small droplets (see 5.3.3.).

Both the 'ED' and "WULV" have been unfavourably compared with the two drift spraying techniques - especially where large areas of a crop are to be treated. Although it has been suggested that the work rate for 'ED' is higher than for "WULV" (Matthews, 1989b) the two techniques are probably equivalent in this respect: usually achieving adequate control with 2 row swaths, but more reliable when the operator walks up every row of well-developed cotton. They are considerably less arduous than side-lever knapsack application, and appropriate for placement spraying small areas, without drift onto neighbours' land or adjacent crops.

5.4.2. Differences Between Oil- and Water-based Techniques

Problems of cleaning machinery between sprays would make it difficult to introduce an oil-based formulation where "WULV" or MULV are used, and vice versa. For this reason alone, it would have been a mistake to concentrate solely on one technique. High work rates, and in Malawi a generally improved efficacy, have been highlighted as advantages of oil-based ULV spraying. Lack of pesticide mixing and measuring should be considered a third advantage of this technique and small farmers cannot be expected to dilute viscous SU formulations.

Water-based CDA can be used to introduce the concept of ULV before UL and SU formulations become available, or to apply large quantities of active material in one operation. Water-based techniques have proved to be especially useful for simultaneous applications: where for example a boron deficiency and more than one pest problem occur at the same time, and a suitable mixture of two insecticides and a trace element fertiliser may be prepared and sprayed together. This flexibility presents one major disadvantage, in that it is equally possible to mix unwarranted "cocktails" or highly toxic materials. Such benefits and hazards do not occur where the farmer has only oil-based formulations available to him, however appropriately or inappropriately they have been pre-selected by pesticide companies or government agencies.

5.4.3. Evaluation of Hand-held Rotary Sprayers

5.4.3.1. **Development of a Protocol**

The need to equip farmers with **robust, serviceable tools** cannot be over-stressed. A farmer, farm manager, extension worker or technical project manager might consider the following factors, when selecting equipment for field use:

i. Initial cost,

ii. Running costs (usually related to power consumption),

iii. Robustness, availability of spare parts,

iv. Technical Qualities: ease of use, compatibility with formulations, atomisation characteristics, etc.

Cost and robustness of sprayer design are probably more important in practice than precise droplet spectra, however it is easier to evaluate the latter in the laboratory. This study has illustrated some of the complex interactions between applied voltage, power consumption, flow rate, disc speed and ultimately droplet spectrum, especially with the more complex double disc rotors. Because of the range of conditions under which rotary atomisers operate, there is a need to elaborate on Arnold's pioneering work (1983) and provide more comprehensive data for each nozzle.

5.4.3.2. **Durability**

Because of their high work rate, well-manufactured rotary atomisers should be able to treat greater areas of crop than knapsack sprayers before requiring repair, although this matter is rarely evaluated systematically in the field. Adaptation of CDA to water-based spraying has several implications that have not always been considered during atomiser development. Perhaps the most significant feature of this technique is greater wear and tear; as well as being a very convenient test liquid, water

may well be more "punishing" than oil.

It is important to define what is an acceptable durability: a minimum might be the equivalent service of a good side lever manual sprayer in terms of hectares treated. In the worst case, where tall crops are treated with water-based mixtures along every row, the work rate would be at most double that of manual spraying. Using the 500 hour criterion for side-lever knapsack sprayers, **at least 250 hours uninterrupted service** should be expected from rotary atomisers. As well as "passing", a further two categories are proposed: 500 hours for "good" and 1000 hours for "excellent" durability. In the final analysis the only accurate measure is the survival of machinery in the field - which may be very different from laboratory results - especially with oil-based sprays or mixtures containing wettable powders and other abrasive formulations. On the other hand, similar criticisms could be levelled at the durability test for side-lever knapsack sprayers, and this test might therefore still be appropriate for incorporation into the procedures for rotary atomiser assessment. These figures are nominal since equipment is often shared within a village, however they provide useful working standards.

Tests carried out on the 'Ulva' show how important it is to consider the machine as a whole during evaluation, and not make assumptions based on individual parts. The motor is of the same origin as the Turbair XJ, but virtually no parts are interchangeable since the armature, spindle and commutator arrangement is different. Coupled with the lighter, less complex design of disc, the service intervals for the Turbair XJ nozzle are apparently four times longer than for the 'Ulva'.

Mishandling of sprayers is commonplace in all farming environments; the obligatory long handles on rotary atomisers result in frequent impacts and contact with foliage during use, which cases wearing of disc teeth and affects the droplet spectrum of sprays. Johnstone and Johnstone (1976) carried-out investigations into "Mini-Ulva" discs with their teeth removed, and considered that this delayed the onset of ligament formation. Fig 3.4.2. indicates that bimodal droplet spectra do indeed occur more readily than otherwise, at lower flow rates, but provided that the damage is reasonably uniform round the circumference, this is possibly not too biologically deleterious at normal operating disc speeds. Protective flanges and disc design have an important mechanical function however, and the 'Ulva' atomiser is notoriously more prone to serious damage than the flatter, more flexible disc on the Turbair XJ. Disc covers that fitted securely and easily onto atomiser heads would be a useful innovation. Frequent reservoir refilling is another feature of water-based CDA, which is relieved by designs such as the Berthoud C8, where the sprayer can be placed upright on the ground, and refilled through a second opening. In this case the lid must be carefully designed and moulded, to maintain a good seal even after prolonged use.

5.4.3.3. **The choice of suitable blank test fluids.**

Cheap, non-toxic test fluids, with flow and atomisation characteristics similar to those of commercial pesticide formulations, are required to evaluate spray machinery. Water and 'Agral' has become a well established test liquid for hydraulic sprayers, and in the series of tests described in section 3.4.1., this mixture did not show any tendencies that were atypical of formulations used in 'WULV' spraying.

Although the SU preparations studied here showed markedly different droplet spectra than UL formulations, from a practical point of view, they tended to be more uniform than clear oils even at very low flow rates. If there are to be discrepancies, blank formulations should present a "worst case" perspective for such tests. UL formulations are available without the active ingredient and in this study the atomisation patterns of Cypermethrin UL and 'Karate' UL blank appeared to be similar to those of two moderately viscous clear fluids - Orchex and Risella. These can therefore be considered appropriate test materials for assessing sprayers, however the same can not be said for fluids such as Shellsol K, which has similar properties to deodorised kerosene (cf. Arnold, 1983).

5.4.4. Optimising Water-based VLV Spraying

5.4.4.1. Problems of Power Consumption and Atomiser Durability

Water-based CDA techniques have become established in at least three African countries and interest also appears to be spreading to the French speaking nations. Narrow swaths associated with water-based spraying result in longer battery usage, and in Malaŵi a problem of high power consumption is is exacerbated by high flow-rates.

No individual sprayer was found to be totally suitable for this technique, but several designs have useful features. The Turbair XJ and Berthoud C8 appear to have the most durable atomisers, although further confirmatory tests are required. The C8 is easy to use (see above), but must be powered by eight 'D' sized cells, and the versatility inherent in the Turbair design is an advantage, as is its strong uncomplicated metal handle. The XJ has a high power consumption, and farmers' perceptions of battery cost are important (see section 1.4.2.2.); in some areas the purchase of eight 'D' cells involves a heavy outlay. Although low powered sprayers in the 'Mini' and 'Micro Ulva' series are attractive in this respect, there appears to be a price to be paid in terms of durability, however more replication is required in these tests.

Low power consumption is important in areas where farmers have to pay for 'D' cells. If rural electrification has been installed and sprayers can be fitted with accumulators, power consumption is practically an irrelevance, durability and availability of spare parts may become of paramount importance. Solar panel technology also offers a possible solution to this problem, however procurement of eight nickel cadmium batteries may be considered a heavy initial outlay (Arnold, 1985b).

A system that relied on fewer batteries might be more acceptable, however one of the major obstacles to low voltage motors has been that they often consume more power for a given rotational speed - ultimately consuming more batteries for a given area of crop protection. The 6 v. 'Mini-Ulva' is apparently the most durable of the low powered atomisers, and although a new 'Micro Ulva' consumes 30% less power, this situation may change after use (see Table 5.5.1).

Table 5.4.1. **The implications of sprayer selection**

Figures given are nominal values for new atomisers, with aqueous fluid flowing at 60 ml/min (unless stated otherwise) at voltages equivalent to 7/8ths. of the standard battery pack output.

Sprayer	Rotational speed ($rev.s^{-1}$)	VMD µm.	Durability h.	Current mA.	Power W
Mini Ulva 6v.	150	75-80	630	560	2.8
New Micro Ulva:					
8 batteries	180-200	50-60	140	360	3.8
6 batteries	150	75-80	580	265	2.0
Old Micro Ulva (6 batteries)	80	130-150		460	3.4
Turbair XJ:					
60 ml/min. (Ø 1.1)	130	65-70	1000 ?	750	7.9
120 ml/min. (Ø 1.7)	120	70-75	n./a.	905	9.5
Old (60 ml/min.)	120	70-75		645	6.8
Ulva 8	120	70-75	180 §	600	6.5
Berthoud C8	105	± 75	1000 ?	400	4.2

§: Service life can be considerably increased with regular motor cleaning.

Other specifications different from those required by oil spraying may involve modifications to the feed stem and intended droplet size. Water-based CDA spraying would normally require only one size of restrictor, which should be screwed in place rather than being easily detachable as in the Micro Ulva. A more

elegant way of producing large numbers droplets in the 75-150µm. range, whilst maintaining a low power consumption, might use a single disc and a governed motor. This would be set to a faster speed than that where transition to single droplet formation occurs at 60 ml/min. and allow for a margin of error. For this purpose 52 mm. discs should be set to approximately 110 rev.s^{-1}, and 88mm. discs to 60 rev.s^{-1}.

5.4.4.2. **Application Strategy**

Flow rates between 60 and 120 ml/min. have little intrinsic effect on atomisation with most spinning disc sprayers. In Malaŵi, high flows have been used to deliberately reduce the disc speed, however this unnecessarily increases power consumption. Nyirenda (1988) found that 1.0 ml/s. (60 ml/min.) gave significantly better, although inconsistent, insect control than higher flow rates of 1.6 and 2.0 ml/s. (96-120 ml/min.). Since no evidence of loss in efficacy was found when volume application rates were reduced to 5 l/ha., there is probably little advantage in spraying with the "WULV" at more than 10 l/ha. Future research should establish if reliable pest management can be achieved at even lower volumes in order to reduce the very high power consumption presently incurred (see table 5.4.1.).

Following-on from experience with the Electrodyn, it might be useful to develop a "package" suitable for "WULV" spraying. Although prototype solar powered equipment has been developed, a complete and proven system has yet to made generally available. The 'Birky' constitutes another interesting development requiring only manual power, but it is presently too expensive for smallholders, prone to breakdown and primarily intended for herbicide application. In spite of technical imperfections in the atomiser, the Taurus Hi-Spin which comes with good

instructions (including comprehensive directions on recommended 'aquamol' pesticide mixtures); farmers also receive a measuring jug, a funnel, and excellent support from the Zimbabwean extension services. Approximately half of all insecticide production is applied to cotton (Matthews, 1989a), and CDA technology has often been likewise developed with this in mind; the "WULV" technique may be readily transferred to other crops and offers an even wider potential than at present.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONTROLLED DROPLET APPLICATION (GENERAL)

Controlled Droplet Application (CDA), using hand-held rotary atomisers, is the most important means of spraying in many African cotton growing areas. Three distinct strategies for applying insecticides with spinning disc sprayers have become established in different countries:

i. Conventional Ultra Low Volume (ULV) spraying with specific oil-based (UL) formulations. Typical volume application rates are 2-3 l/ha., although attempts have been made to reduce formulation costs by applying 1 l/ha. or less.

ii. Water-based CDA using higher volume application rates with aqueous mixtures containing conventional formulations; in a mature crop typical volume application rates are 10-16 l/ha.

iii. Modified water-based ULV using molasses or other evaporation retarding adjuvants (anti-evaporants), and water-miscible formulations, at volume application rates up to 5 l/ha.

In one form or another CDA techniques have encouraged smallholders to spray against pests that they would otherwise have been unable or unwilling to control. Pesticide and sprayer manufacturing companies should consider the diversity of available techniques as a useful means of breaking into new markets rather than as a threat to existing ones. In the light of recent developments with the 'Electrodyn' sprayer, the rôle of rotary atomisation perhaps needs re-examination.

Trials described here gave conflicting efficacy results, but all three techniques should be considered effective: each appropriate to the needs of farmers in different areas. In francophone West Africa the replacement of oil-based ULV

applications with the "WULV" technique is being considered: partly in the belief that greater crop coverage is achieved, resulting in better control of certain sucking pests. This has not been corroborated by this study however; "WULV" techniques produced only marginally better yields in Zimbabwe, and sometimes significantly poorer sucking pest control and yields in Malaŵi. More demonstrable advantages of using water miscible formulations include cost effectiveness and versatility; the latter has meant that a readily available method of spraying particulate suspensions with rotary atomisers has long been available to farmers in Central Southern Africa.

The implications of using water-based rather than oil-based low volume spraying include greater wear of the atomiser heads and higher battery consumption. There is a need for rigorous rotary atomiser testing and development (see 6.4.) and further investigation into lowering volume application rates; for example: there is little evidence that more than 10 l/ha. is necessary for the "WULV" technique. Other trials might include:

Water-based CDA at:	5,10, and 15 l/ha.
Modified WULV at:	2,4, and 6 l/ha.
Oil-based ULV at:	1,2, and 3 l/ha.

Modified water-based techniques have the advantages of lower power consumption and higher work rate over ordinary "WULV". Molasses is not always available in sufficient quantities to meet farmers' needs however, and further research is required on the use of other evaporation inhibiting adjuvants.

An extension manual giving details of all controlled application techniques is required, in order to disseminate the available alternatives. This could be augmented by extension booklets, based on "pictograms" and a minimal amount of text, that can easily be translated into required vernacular languages.

6.2. THIODICARB AND THE ROTARY ATOMISATION PROCESS

Thiodicarb is a carbamate insecticide which is virtually insoluble, and must be sprayed in the form of particulate suspensions. This is a property it shares with certain other selective insecticides useful for integrated pest management programmes. The flow and atomisation characteristics of all CDA sprays are the result of a complex interaction between sprayer head assembly, power source and formulation. The droplet spectra produced by rotary atomisers may be less determinate than many workers assume, and transitions between modes of atomisation may occur within normal operational conditions. Formulations and flow rates do not otherwise affect droplet size as much as disc speed, and issues of power supply and atomiser motor performance are therefore of more practical significance.

6.2.1. Oil-based Formulations

Bimodal spray distributions sometimes occurred when conventional UL formulations were atomised at low - but feasible - disc speeds and flow rates. Oil-based ULV suspensions (SUs) were more viscous than UL formulations, to reduce settling-out under prolonged storage, and only very low flow rates were possible with many commercial spinning disc sprayers. The rate of active ingredient flow of these viscous formulations may paradoxically be increased with dilution (see Fig. 3.2.5.), and the development of a stable formulation capable of suitable flow - without dilution - remains an outstanding problem. Altering the flow rate between 10 and 60 ml/min fortunately caused little difference in the commendable spray characteristics of thiodicarb SU formulations of varying viscosity.

6.2.2. Water-based Mixtures

Water-based CDA techniques obviate problems of low stability and high viscosity associated with SUs, and the atomisation of a wide range of operational and blank aqueous mixtures was evaluated. At typical flow rates (60-90 ml./min.), water-based mixtures generally produced satisfactory droplet spectra with rotary atomisers. Under conditions conducive to ligament formation, the addition of surfactants, suspended particles and molasses, all reduced droplet size spectra by small but measurable amounts. Mixtures containing thiodicarb suspensions, often produced narrower droplet spectra than molasses alone under these conditions. Transitions between modes of atomisation occur at higher disc speeds and flow rates with certain adjuvants including molasses, concentrated molasses solubles and 'Derimin', however within normal ranges atomisation is similar to other aqueous mixtures.

6.2.3. Recommendations

i. An SU formulation with a low viscosity, high viscosity index and an acceptable shelf life has yet to be developed. The material selected for the 1987 field trials (UCLF 8) may have been suitable if it had remained stable for two years rather than three months. Small-holder farmers can not be expected to dilute oil-based formulations.

ii. Water miscible formulations, with admixed evaporation inhibitors may prove a worthwhile option.

iii. Detailed investigations are required into atomisation in the zone of conditions conducive to transitions between single droplet and ligament formation. This may have important implications for producing enlarged droplets with water-based sprays.

6.3. FIELD STUDIES AND THEIR IMPLICATIONS

Two seasons of field trials on cotton were carried out in Zimbabwe and Malaŵi. Application techniques were compared under different combinations of formulation, dosage, droplet size and active ingredient in multi-factorial designs. Results differed markedly between the two countries, but in all experiments, insecticide sprays produced substantially higher yields than untreated controls (when present).

6.3.1. Zimbabwe Trials

In Zimbabwe there were few differences in insect mortality and crop yield between treatments. This was particularly remarkable in the case of Heliothis control during 1988, since egg-laying reached levels over five times the economic threshold. Recommended application rates of thiodicarb for controlling this pest might usefully be re-considered, since halving the dosage had no noticeable effect when applied in response to egg thresholds, however the effects on Diparopsis populations must also be assessed.

6.3.2. Malaŵi Trials

Unlike Zimbabwe reducing the field dosage may significantly impair the efficacy of thiodicarb in Malaŵi, since trial yields were most frequently and significantly affected by reducing the concentration of sprays. Differences in bollworm control partially account for variability, but in Makoka especially, yields appeared to be also related to levels of sucking pests including Paurocephala and aphids. Little significant biological difference was detected in the performance of two water-miscible formulations. Should storage problems be encountered with bottles of suspension concentrate, they might be replaced with water dispersible granules, pre-measured and packaged in sachets.

The highest yields were usually produced in plots treated with oil-based thiodicarb SU formulations, and this may have been a function of rainfastness, sucking pest control or a combination of both. Oil-based sprays may become less reliable if the volume application rate is reduced below 2 l./ha., and atomisation is poor, but increasing volume application rate of oil-based sprays above 1 l/ha. becomes progressively less economically viable.

6.3.3. Droplet Size and Crop Coverage

Good atomisation is therefore especially important when attempting to minimise ultra-low volume application rates with oil-based sprays, and efficacy of sprays may be impaired if they have average diameters significantly greater than Bals' original (1979) target droplet size of 70µm. However there is little evidence that smaller sizes are more effective in the field with uncharged or water-based droplets. The total mass recovery of all formulations is often improved with sprays enlarged to a VAD of 100µm, and uniformity of spray deposition may be reduced if swaths are not made as narrow as practically possible.

A gauge for the rapid estimation of monodisperse droplet densities on target surfaces was developed. Spray recovery depends on a complex interaction between air flows, the preservation of spray integrity, (i.e. lack of evaporation) and the nature of the target, which is exceedingly difficult to model. Numerous empirical studies on spray recovery are therefore appropriate, and would be of the greatest value if procedures were standardised. The gauge described in chapter 2 enables rapid droplet density assessment with minimal equipment, however the technique requires further validation by cross checking with residue analysis.

No differential toxicity was detected between thiodicarb and pyrethroid sprays between aphids and natural enemies, and in Zimbabwe populations of red spider mites were sometimes lower in plots sprayed by recommended pyrethroids. Although other studies have indicated that the specificity of thiodicarb would be useful for IPM, it may have a greater rôle as an alternative to pyrethroids in insecticide resistance management strategies.

Any new formulations will require a usual programme of efficacy trials before marketing takes place. A series of bioassay and other laboratory studies would however be helpful for interpretation of existing results, and might include:

i. The efficacy of different droplet sizes with particulate stomach poisons, to determine if they are subject to the same effects as contact insecticides and acaricides.

ii. Investigation into the effects of formulation and droplet size on rainfastness, interaction with leaf surfaces and insect mortality.

iii Scanning electron microscope studies on droplets deposited on leaf surface, before and after simulated rainfall.

6.4. SPRAYER EVALUATION AND DEVELOPMENT

6.4.1. Suggested Protocol for CDA Sprayer Evaluations

Rotary insecticide atomisers have usually been designed for spraying oil-based formulations. Water-based CDA techniques cause greater wear of rotary atomiser heads, so an apparatus was developed for assessing their durability under simulated

operating conditions. After only limited field use the atomisation by certain sprayers may bear little resemblance to their performance when new. A standard procedure for evaluating all spinning disc sprayers must be developed; information should be disseminated in a series of fact sheets for each model. Each assessment might consist of the following:

1. Photographs, general introduction.
2. Results of durability tests.
3. Power consumption and flow rate analysis over a range of operational voltages.
4. Additional assessments as necessary, depending on purpose of the machine, observations on airbleed assembly, etc. e.g.:

   a. Flow-rates as liquid reservoir empties,
   b. Swath widths of herbicide applicators.

5. Droplet sizing (model independent) over an appropriate operational range, using water + 0.1% 'Agral' and a standard oil such as Risella.
6. Other observations on how serviceable the sprayer is as a farmer's tool, including: sustainable trouble-free use, ease of refilling the liquid reservoir and cleaning, clarity of accompanying instructions and general presentation of the sprayer as a workable "package".

6.4.2. Droplet Sizing Techniques

This work has introduced the concept of Average Droplet Volume (ADV: the volume of liquid represented by the VAD) as a useful droplet size parameter for unifying laboratory and field studies. Unless sprays are practically monodisperse, uncertainty will surround their use until problems of reliable number distribution measurement can be resolved; VMDs may therefore be considered more suitable for laboratory use. Although VMD/NMD

ratios remain popular, parameters based on volume distributions - such as coefficient of variation and span - are probably more satisfactory for similar reasons.

LASER diffraction droplet sizing methods were compared, and there was an acceptable agreement between different versions of 'Malvern' instrument and the 'Aerometrics' phase Doppler analyser, but large discrepancies were found with the Knollenberg PMS. The principal problems that require further attention are:

i. Spray sampling and droplet measurement techniques,

ii. The apparent presence of droplets in the 0-15.5μm. range, with measurements by later versions of the Malvern,

iii. The data-base system developed here for comparing and storing particle size analyses needs refinement.

6.4.3. Machinery Development

The sprayer requirements for rotary atomisation of oil-based and water-based mixtures are rather different. If pesticide manufacturers are unwilling to market formulations with anti-evaporants, there could be a place for a specially designed spinning disc sprayer for water-based mixtures, however the ideal machine has yet to be developed. It should be durable and uncomplicated, possibly with a slower, governed durable motor and a pesticide reservoir system more capable of handling larger quantities of liquids.

The cost and availability of batteries remain perhaps the primary constraints with C.D.A. in many areas, and must constitute one of the more important lines of research. A relatively robust low power atomiser requiring 6v. was identified, which might be appropriate for the development of a solar powered system.

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APPENDIX I

A. SOME NOTES ON VISCOSITY AND ITS MEASUREMENT

Units

Viscosity can be defined as the internal friction, or the resistance to change of the arrangement of molecules within a liquid. It can be quantified in two ways:

i. Dynamic Viscosity (μ or η)

Unit: Poise - The tangential force in dynes required to move a plain surface of area 1 cm^2 over another plane surface at a rate of 1 cm/s when the surfaces are separated by a layer of liquid which is 1cm. thick; thus this is a measurement of the force needed to overcome internal friction.

N.B. centipoise (cp) = 0.01 poise = 1 $mNs.m^{-2}$
= 1 mPa.s (S.I. unit)

Pure water is typically 1.009 cp.

ii. Kinematic Viscosity ($\nu = \mu/\rho$)

Unit: Stokes - The ratio of the liquid's dynamic viscosity to it s density at a given temperature; in other words, this is the measurement of a force per unit density.

N.B. 1 centistoke (cS or cSt) = 0.01 Stokes = 1 $mm^2.s^{-1}$

Methods of Measurement

Four of the simpler methods of viscosity measurement are described here; Walters (1980) points out that **they practically never produce comparable data** since the nature and speed of liquid flow is different in each.

1. U-tube viscometers: includes designs such as the Ostwalde, the Cannon Fenske and the Ubbelohde or British Standard BS/IP/SL; the latter is preferred since no temperature correction test is required, once the tube has been calibrated. In order to measure opaque liquids (such as particulate pesticide

formulations) a reverse-flow version such as BS/IP/RF is required. Typical costs (1986) are in the region of £20 and a further £30 for an accompanying calibration certificate.

2. Rolling ball or Hoeppler viscometers probably constitute one of the cheapest methods at around £20. This is also a comparative method where the fall time of ball (of suitable known diameter, selected from a standard range) is measured through a liquid in a tube sloping at a fixed angle; the proportion of the terminal velocities through the test liquid and a known standard is equal to the proportion of their viscosities.

3. The Ford cup: conforms to British standard 1733 (1955) superseded by BS3900. The original B4 seems to be occasionally used for liquids which have viscosities outside its normal range which is 0.8-7.0 cSt., and the No. 6 cup is preferred for higher values in the region of 6-30 cSt. Measurements can simply be expressed as an emptying time at a given temperature. This probably makes the Ford cup the most reliable method of communicating viscosity data between the research laboratory and the field. Typical costs are about £40 for the standard cups with a further £35 for an accompanying stand and spirit level.

4. Rotary viscometers such as the 'Brookfield' device (costing £1000-1500) and the 'Haake' portable (at approximately £600) are the most expensive viscometers. The 'Brookfield' device is the only method described here with which any attempt may be made to characterise non-Newtonian fluids (see below).

H.A. Barnes in Walters (1980) has summarised the

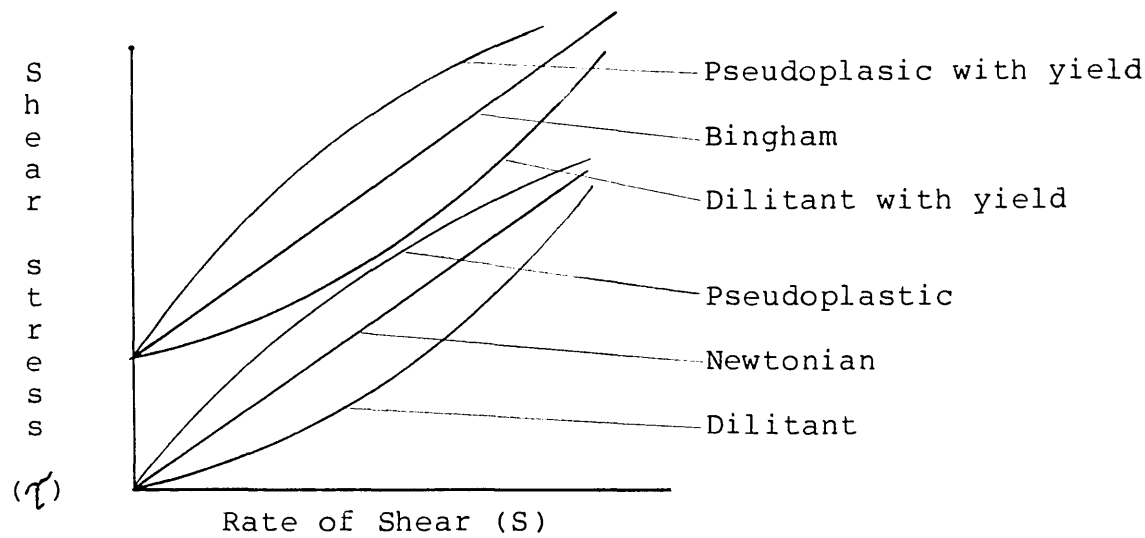
characteristics and advantages of these four methods as follows:

Type	Variables	Measurement	Convenience	Robustness
1	Capillary diameter	Flow time	*	*
2	Ball size	Velocity	**	**
3	Exit tube diameter	Efflux time	****	****
4	Bob speed & diameter	Couple	**	*

Non-Newtonian Fluid Flow

In newtonian liquid flow, the viscous dissipation of energy is due to collisions between fairly small molecules. Emulsions and particulate suspensions usually flow in a non-newtonian manner, and the viscosity of a liquid depends on the shear rate applied to it. Pseudoplastic behaviour is characterised by a logarithmic decrease in viscosity, as the shear rate is increased. Dilatancy is the opposite effect, and is occasionally encountered in suspensions of particulate solids (e.g. starch) but it is rare for emulsions to show this behaviour (Becher, 1957). Some particulate suspensions act as solids until a threshold of stress is reached, after which they may behave in a Newtonian (Bingham plastics) or non-Newtonian manner; familiar materials of this type include toothpaste and freshly made cement.

Fig. A1.1 **Consistency curves for time independent liquids.**



A useful term for describing non-newtonian flow is apparent viscosity (η_a). When quantifying viscosity with rotating instruments such as the Brookfield device, it is important to state the speed and the size of the rotor used; in pseudoplastic liquids the reading is lower at higher shear rates.

A further complication occurs with liquids exhibiting time dependent non-newtonian flow; Mewis (1979) reviews this branch of fluid mechanics and considers it to be "one of the most neglected areas of rheology". Many particulate suspensions exhibit thixotropy where viscosity decreases with the time that a shear force has been applied to the liquid. When these liquids are stirred or otherwise agitated, a substantial lowering of apparent viscosity occurs with time, and a sol is formed; the apparent viscosity is gradually raised on return to rest to form a gel. The opposite effect may also occur but is rare; it is referred-to as anti-thixotropy or negative thixotropy. In rheopectic liquids, the re-building of the gel structure is hastened by a gentle shearing action.

A third group of non-newtonian fluids are typically found in solutions or suspensions of long polymer molecules. These viscoelastic liquids are able to store energy and show some of the characteristics of elastic solids.

Viscosity Index (VI) is an empirical number, frequently used in the oil industry, which indicates the effect of temperature on the viscosity of a liquid. A high index signifies a relatively small change of viscosity with temperature, and is desirable for oil-based UL formulations. In order to obtain an idea of the upper extreme of the working temperature range, one litre bottles containing dark brown cottonseed oil and near-white UCLF8 were

left in the sun during a cloudless March day in Zimbabwe. Measured temperatures at the end of exposure periods were as follows:

Time	Measured temperature (°C.) Cottonseed oil	UCLF 8
0900-1100	37.6	32.4
1100-1300	40.2	35.6
1300-1420	42.2	37.7
1420-1530	44.5	38.7

Thus it is not unreasonable to assume that UL formulations might be used at 35° and even 40°C. It is conceivable that early morning applications might occur at 15°C, however most ULV insecticide spray operations probably take place between 20-30°C.

SURFACE TENSION

Surface tension can be considered as an imaginary elastic membrane that minimises the surface area of a fluid. It is however a complex and poorly understood phenomenon under dynamic conditions, with the age of a newly formed surface being a contributory factor in liquids containing surfactants.

Static surface tension (γ) is described in terms of $mN.m^{-1}$ (S.I.), or the equivalent $dyne.cm^{-1}$. Pure water has a surface tension of approximately 73 $mN.m^{-1}$, which is subject to temperature; this is considerably reduced on addition of surfactants (present in most water-miscible formulations), and measured values are in the order of half with oil formulations.

Measuring instruments include the 'de Nouy' tensiometer, which measures the force required to pull a solid probe out of the surface of the liquid under test.

B. DETAILS ON FORMULATIONS UNDER TEST

Formulations of thiodicarb were supplied by:

Rhône Poulenc Ag. Company,
(previously: Union Carbide Agricultural Products Co. Inc.)
2, T.W. Alexander Drive,
Research Triangle Park,
NC 27709, USA.

UCLF5 and UCLF8

A series of oil-based suspensions (SUs) was prepared for laboratory study and two of these were used in field trials: UCLF5 and UCLF8. These were experimental formulations, and proved to be rather variable in their physical characteristics; specifications have yet to be set for them.

Most laboratory tests with UCLF5 described here were carried out on batch numbers: 016-ED-67 (containing 38% a.i. w./v., measured density 1.02) and 8-DLM-Y-25. Settling was frequently encountered with samples and the contents of all containers had to be be vigorously shaken for at least one minute before use. A batch used for field trials in 1987-8 had an assay of 34.17%.

UCLF8 in its present form is an unacceptably unstable suspension, however at least one other 20% formulation sample (11-DLM-Y-26-2) showed more promise (see Fig. A1.2). A minimum acceptable flow rate (of at least 30 ml/min.) was achievable with the Berthoud C8 with a 2mm. green restrictor. Because of its fixed, narrow hole air-bleed construction this should be considered the critical machine (see section 5.1.1.).

Brookfield device measurements are in centipoise and were measured with a No.2 spindle at 20 R.P.M. At higher shear rates the viscosity of samples normally decreased, thus they were pseudoplastic, however some experimental UCLF5 formulations exhibited rheopectic behaviour (D.Miles, Pers. comm.). VC4 cup

measurements took place at 19-22°C and figures represent eflux time in seconds.

Fig. A1.2

Characteristics of some oil-based thiodicarb SU formulations

Code	Viscosity Brookfield cp.	Viscosity VC4 cup s.	Density g/ml.	Settling, oil layer %	§1	Flow rate Berthoud ml/min.
UCLF5 series (342-380 g.a.i./l.: variable, not optimised)						
Range between batches	500-700 cp.		1.01-1.04			
8-DLM-Y-25 (380 g.a.i./l.)		42 s.	1.01	5	**	0 §2
UCLF8 series (200 g.a.i./l.)						
	22°C	30°C				
11-DLM-Y-26-1	80	60	19.2	0.911	6 **	48.7
11-DLM-Y-26-2	125	80	22.5	0.916	4 ***	33.3
11-DLM-Y-26-4 §3	60	55	19.0	0.912	8 *	48.4
UCLF8	40	30	18.0	0.912	46 0	38.8

§1: Percent oil layer at top of column, and symbols representing a crude measure of degree of "claying" after 4 months, as follows:

***: No sedimentation noticed
**: Slight sedimentation, rectified by 30 s. of vigorous shaking.
*: Moderate sedimentation: rectified by stirring and shaking for 2 minutes.
0: Severe: sediment very difficult to re-suspend.

@2: reliable continuous flow not possible.
§3: original UCLF8 sample

Measured Particle Sizes of Formulations

Evaluation of the suspended particle size of thiodicarb and various other formulations took place using the Malvern ST1800 PSA, with a 100 mm. lens. All measurements gave NMD values of less than 1µm., however particle sizing techniques based on light scattering reach the limit of their resolution at about 2µm.

UCLF 5	VMD: <2µm.	Fenitrothion WP blank (Sumitomo)	15µm.
'Larvin' WP	3µm.	Malathion warehouse WP blank	5µm.
'Larvin' WG	2µm.	DDT WP (ADMARC, Malawi)	9µm.
'Larvin' SC	<2µm.		

4. Analysis of Mains Water Supply
(Courtesy of Thames water, Rickmansworth)

No.	Parameter	No. of tests		Maximum		Minimum		Mean	
		1987	1986	1987	1986	1987	1986	1987	1986
2.	Turbidity (JTU)	231	231	5.5	6.0	0.22	0.15	0.55	0.50
6.	pH Value	231	231	7.7	7.9	7.1	7.1	7.4	7.4
15.	Aluminium mg/l as Al	231	231	0.71	0.69	<0.01	<0.01	0.05	0.05
7.	Conductivity Microsiemens/cm	22	22	717	730	620	640	670	695
20.	Nitrates mg/l as N	22	22	9.9	10.5	6.2	4.8	8.5	7.1
21.	Nitrites mg/l as N	22	22	0.007	0.018	<0.001	<0.001	0.002	0.004
22.	Ammonia mg/l as N	22	22	0.04	0.09	<0.01	<0.01	0.02	0.03
1.	Colour (Hazen Units)	22	22	6	5	<1	2	3	3
8.	Chlorides mg/l as Cl	22	22	53	56	38	39	48	47
9.	Sulphates mg/l as SO_4	22	22	110.1	136.7	65.4	95.8	86.0	119.0
10.	Silica mg/l as SiO_2	22	22	13.9	14.1	<1	2.8	10.6	9.8
24.	Permanganate oxicizability mg/l as Oxygen	22	22	3.98	2.3	0.65	0.9	1.76	1.33
37.	Phosphorus mg/l as P	22	26	1.31	0.96	0.04	0.02	0.44	0.40
32.	THMs ug/l	22	30	107	74	30	24	54	44
	$CHCl_3$ ug/l	22	30	69	40	12	9.5	29	22
	Alkalinity mg/l as $CaCO_3$	4	5	220	200	190	185	206	190
11.	Calcium mg/l as Ca	4	5	125	116	112	108	119	111
12.	Magnesium mg/l as Mg	4	5	6.8	5.2	4.2	4.0	5.5	4.6
13.	Sodium mg/l as Na	4	5	41.2	56.8	29.2	31.2	34.4	42.1
14.	Potassium mg/l as K	4	5	6.7	7.4	4.9	4.9	5.9	6.1
16.	Total Haroness mg/l as $CaCO_3$	4	5	324	310	298	279	311	295
33.	Iron ug/l as Fe	7	12	30	100	<10	<10	16	25
34.	Manganese ug/l as Mn	4	5	5	<5	<5	<5	<5	<5
35.	Copper ug/l as Cu	4	5	20	40	<10	<10	10	22
36.	Zinc ug/l as Zn	4	5	30	30	<10	<10	13	19
51.	Lead ug/l as Pb	4	5	<10	<10	<10	<10	<10	<10
38.	Fluoride mg/l as F	4	5	0.17	0.17	0.10	<0.10	0.14	0.11

C. SUPPLIERS OF CHEMICALS AND EQUIPMENT

1. Formulations and Adjuvants (other than thiodicarb)

'Agral' 90,
Cypermethrin UL (ICI): Batch Ref. 2540, and
Lambda-cyhalothrin UL blank (equiv. 0.8% formulation): JF 9347.
ICI Agrochemicals PLC, Fernhurst, Haslemere, Surrey GU27 3JE.

Codacide oil: Microcide Ltd., Stanton, Suffolk, IP31 2BR.

Derimin: Hoechst AG.,
Postfach 80 03 20, D-6230, Frankfurt am Main 80, D.F.R.

Molasses:
Lab. work (UK): Equimix Feeds Ltd, Sandy Lane Trading Estate, Stourport on Severn, Worcestershire.
Field trials: Triangle Ltd., P.Bag 801, Triangle, Zimbabwe.

Orchex 796: Exxon Co., PO Box 2180, Houston, TX 77252-2180, USA.

Shellsol K, Risella EL oil: Shell chemicals (UK) Ltd.,
1, Northumberland Av., Trafalgar Square, London WC2N 5LA.

2. Equipment: General

Aerometrics Inc.: (P/DPA phase/doppler particle analyser)
P.O. Box 308, Mountain View, California 94042, USA.

Malvern Instruments Ltd. (Particle Size Analyser ST1800)
Spring Lane South, Malvern, Worcestershire WR14 1AQ.

Particle Measuring Systems Inc.: (Knollenberg)
1855 South 57th Court, Boulder, Colorado 80301, USA

Gap meter, needle valve, manostat: Platon Flowbits,
Platon Park, Viables, Basingstoke, Hants. RG22 4PS.

Electronic components: RS components Ltd.,
PO Box 99, Corby, Northants. NN17 9RS.

Top pan balance: Sartorius Instruments Ltd., Belmont, Surrey.

"Spartan" tank: The Cornelius Company,
Highway 10 West, Anoka, Minnesota 55303, USA.

3. Sprayers

Berthoud Pulverisation, ('C8')
B.P. 424, 69220 Belleville-sur-Saône, France.

Micron Sprayers Ltd., ('Ulva', 'Mini Ulva', 'Micro Ulva')
Three Mills, Bromyard, Herefordshire HR7 4HU.

Taurus Spraying Systems (Pvt.) Ltd., ('Hi-spin')
20 Harrow Rd., Msasa, P.O.Box AY18, Amby, Harare, Zimbabwe.

Turbair Ltd., ('XJ'; NB Battery pack is part No. B2936)
Britannica House, Waltham Cross, Herts. EN8 7DR.

D. **Example: SPINNING DISC SPRAYER DURABILITY TEST FORM**

Sheet		Atomiser I		Atomiser II	
NAME ->					
Initial rdg. on timer ->					
Date	Time	Disc Speed	Current mA.	Disc Speed	Current mA.

APPENDIX II

A. SOME FURTHER NOTES ON DROPLET SAMPLE SIZE AND DESCRIPTION

A practical way of determining how useful a spray is for its intended purpose is to estimate the proportion of droplets that occur within a pre-defined size band. Table A2.1 shows the size ranges that can be selected for estimation with the analysis programme (below); alternative sizes can be entered if required.

Table A2.1. Droplet Size Classes.

SIZE		PURPOSE
12-25 µm.	1-8 pl.	Fine aerosol for flying insects.
25-50 µm.	8-65 pl.	Aerosols with contact action against flying or sedentary insects.
50-100 µm.	65-524 pl.	Standard mist for ULV spraying.
75-150 µm.	221-1,767 pl.	Spray suitable for "WULV".
150-300 µm.	1,767-14,137 pl.	Spray suitable for herbicides.

The requirements for herbicide applicators are usually that a minimal proportions of spray droplets are subject to wind drift but not so large that they do not adhere to weed surfaces. These figures were arbitrarily fixed to maintain consistency in a doubling progression. Droplet sizes between 150-500 microns are all probably effective and not subject to excessive drift.

The practical requirements for insecticide sprays are much more complex. Attention has recently been focused on the heightened efficacy of droplets in the aerosol range (less than 50µm). Although this has been demonstrated for contact pesticides in the laboratory (e.g. Munthali and Wyatt 1986), very fine oil-based droplets are likely to be carried away by wind or convection currents if field spraying conditions are not optimal (which is the general rule), unless they have an electrostatic charge to assist impaction. Since insecticides include many of the more hazardous of pesticides, it is also desirable to

minimise the proportion of inhalable droplets. The proportion of droplets less than 10 μm that are present in hydraulic sprays was investigated by Merrett (1986). Few particles larger than 10μm. pass the larynx, but large numbers may be deposited there; maximum thoracic deposition probably occurs with particles in the 2-5μm. range (Swift and Proctor, 1982).

Droplet sizes in the region of 70 μm. are typically produced by the earlier design of CDA sprayers since they were empirically found to "produce a very good recovery... under varying conditions" Bals (1969); since few have questioned this size, an equally arbitrary 50-100 microns was selected as limits for a standard ULV spraying mist. In the humid air above a rice paddy, Pickin (1980) found that the greatest volume recovery rate of water-based mixtures occurred with droplets of 127 μm VMD, with acceptable recovery and increased droplet density at 86 μm; recovery of 54 μm droplets was however very poor. 75 to 150 μm therefore seemed to be appropriate limits for water-based insecticide sprays.

Categorisation of VMD/NMD ratios remains conjectural, but the Table A2.2 may be helpful for judging the quality of sprays produced by ULV nozzles.

Table A2.2. Some suggested inferences from VMD/NMD ratio ranges.

RATIO	QUALITY
1.000	Perfect monodisperse (theoretical)
1.0 - 1.4	Excellent
1.4 - 2.0	Good
2.0 - 5.0	Poor
5.0 - 20	Unacceptable for ULV but good hydraulic spectra
> 20	Commonly encountered hydraulic nozzle spectra

Table 3 has been prepared to illustrate the repercussions of

differing droplet sizes and volume application rates used during this study. "Coverage factors" are shown which represent the theoretical numbers of monosized droplets passing through on a horizontal plane of 1 cm^2. In the past VAD has primarily been used to estimate droplet sizes of spray recovered on targets or plant surfaces, having counted droplet densities produced by a known spray volume - for example, by the colorimetric method described by Pickin (1980), who estimated its value as follows:

$$VAD \cong \sqrt{VMD \times NMD}$$

It should be emphasised that this is only an approximation, but always produced values within 2% of those quoted in examples given by Johnstone (1978).

Table A2.3. Droplet Size, Number, Surface Area and Coverage

Droplet Characteristics				Theoretical Droplet Density per $Cm.^2$								
Diameter (μm.)	Volume (pl.)	Numbers per μl.	Surface area $mm^2\mu l^{-1}$	Volume application rate (l./ha.) 1.0	1.5	2	3	4	5	6	10	16
20	4	238732	300	2387	3581	4775	7162	9549				
25	8	122231	240	1222	1833	2445	3667	4889	6112	7334		
30	14	70736	200	707	1061	1415	2122	2829	3537	4244	7074	
35	22	44545	171	445	668	891	1336	1782	2227	2673	4454	7127
40	34	29842	150	298	448	597	895	1194	1492	1790	2984	4775
45	48	20959	133	210	314	419	629	838	1048	1258	2096	3353
50	65	15279	120	153	229	306	458	611	764	917	1528	2445
55	87	11479	109	115	172	230	344	459	574	689	1148	1837
60	113	8842	100	88	133	177	265	354	442	531	884	1415
70	180	5568	86	56	84	111	167	223	278	334	557	891
75	221	4527	80	45	68	91	136	181	226	272	453	724
80	268	3730	75	37	56	75	112	149	187	224	373	597
90	382	2620	67	26	39	52	79	105	131	157	262	419
100	524	1910	60	19	29	38	57	76	95	115	191	306
110	697	1435	55	14	22	29	43	57	72	86	143	230
120	905	1105	50	11	17	22	33	44	55	66	111	177
130	1150	869	46	9	13	17	26	35	43	52	87	139
140	1437	696	43	7	10	14	21	28	35	42	70	111
150	1767	566	40	6	8	11	17	23	28	34	57	91
160	2145	466	38	5	7	9	14	19	23	28	47	75
180	3054	327	33	3	5	7	10	13	16	20	33	52
200	4189	239	30	2	4	5	7	10	12	14	24	38
250	8181	122	24	1	2	2	4	5	6	7	12	20
300	14137	71	20	1	1	1	2	3	4	4	7	11
400	33510	30	15	0	0	1	1	1	1	2	3	5
500	65450	15	12	0	0	0	0	1	1	1	2	2

B. PRACTICAL DETAILS ON DROPLET ANALYSIS USING THE MALVERN ST1800 PARTICLE SIZE ANALYSER (P.S.A.)

Mechanism

The Malvern samples droplets by measuring the diffraction pattern created when liquid or solid particles, in suspension, pass through a collimated helium-neon laser beam (the 'Fraunhofer diffraction'). Light is scattered over a wider angle by smaller particles, and after the diffracted beam has been focused by a Fourier transformation lens, the radii of a series of concentric rings are registered on a linear array of photo-electric detectors. The array is electronically scanned, and the signals produced are processed into a number sequence, and droplet size distributions are estimated by iterative comparison of this sequence with a series of values calculated from either the Rosin-Rammler model, or a "model independent" distribution. For example, the PDP8 programmed with the Rosin Rammler model, sequentially adjusts PE and increases W until the Malvern error value (E) is minimised.

$$E = \sum (C-A)^2$$

In practice, each data set consists of a pre-set number of scans lasting 12 milliseconds; unless a very short scan time is selected, these are usually numbered in hundreds and each reading can therefore be considered statistically significant in itself. Where a series of similar, sequential readings has taken place, the analysis with the lowest Malvern error term is probably more appropriate than averaging out the calculated VMDs and NMDs . If the Malvern error value is much greater than 100,000, then the measurements should be repeated.

The range of droplet sizes capable of measurement depends on the focal length of the objective lens, and covers a 100-fold

increase from the smallest perceived particle diameter, to the largest; the smallest particles capable of measurement are approximately 2μm., when a 100mm. lens has been fitted. When evaluating agricultural spray nozzles, an 800mm. lens is usually attached as standard since droplets with diameters from 15-1500μm can be detected, thus easily covering all the useful size ranges described above. Further information on the general method may be found in Swithenbank et. al. (1975), and its use for the analysis of hydraulic spray nozzles in Arnold (1983a).

Table A2.4. Sample Malvern Output (Rosin Rammler).

(Micro Ulva test rig: 140 r.p.s. Water + 0.1% Agral @ 30 ml/min.)

PE= +81.0 W= +3.5 E= 00140342

D= *******	>	+697.03	P= +0.00%	R=+100.00%	N= +0.00%	C=0054	A=0024
D= +697.03	>	+426.89	P= +0.00%	R=+100.00%	N= +0.00%	C=0089	A=0049
D= +426.89	>	+300.58	P= +0.00%	R=+100.00%	N= +0.00%	C=0148	A=0147
D= +300.58	>	+224.48	P= +0.00%	R=+100.00%	N= +0.00%	C=0237	A=0295
D= +224.48	>	+171.98	P= +0.00%	R=+100.00%	N= +0.00%	C=0384	A=0468
D= +171.98	>	+133.93	P= +0.30%	R= +99.70%	N= +0.01%	C=0611	A=0739
D= +133.93	>	+103.49	P= +9.17%	R= +90.53%	N= +0.83%	C=0957	A=1085
D= +103.49	>	+80.66	P=+27.86%	R= +62.67%	N= +5.43%	C=1388	A=1479
D= +80.66	>	+63.16	P=+28.47%	R= +34.21%	N=+11.66%	C=1811	A=1849
D= +63.16	>	+49.46	P=+17.91%	R= +16.30%	N=+15.27%	C=2046	A=2047
D= +49.46	>	+38.81	P= +8.97%	R= +7.33%	N=+15.89%	C=1898	A=1997
D= +38.81	>	+30.44	P= +4.13%	R= +3.20%	N=+15.15%	C=1499	A=1800
D= +30.44	>	+24.35	P= +1.72%	R= +1.48%	N=+12.75%	C=1105	A=1257
D= +24.35	>	+19.02	P= +0.85%	R= +0.63%	N=+12.73%	C=0829	A=0567
D= +19.02	>	+15.22	P= +0.34%	R= +0.29%	N=+10.28%	C=0625	A=0443

Table A2.4 is an example of the standard Malvern printout produced for each reading; the actual (A) values for each droplet size range are to be found on the right-hand side are calculated from the number sequence mentioned above; the adjacent C values are the equivalents calculated from the model.

Model Independent output is similar to the above, but the percentages of droplets by number (N) are not given, and have to be calculated separately using the cumulative percentages by volume (R).

Model Fitting and Analysis

The Rosin-Rammler equation was originally developed for analysis of coal dust (Rosin and Rammler, 1934), but this has applied more generally in particle sizing, and was the original model used by the Malvern PSA. The family of curves have a left-skewed distribution and describe the volume fraction (R) of droplets larger than diameter size D where:

$$R = e^{-(D/PE)^{W}}$$

PE is the size category at which 63.2% of the total sample volume is made up of smaller droplets. W is inversely proportional to the spread of the size distribution, so that in a monodisperse spray, W would be infinite.

The Rosin Rammler model has proved to be a relatively quick and effective method for determining droplet spectra. It was thought to be inappropriate for this study, since it necessarily fits smooth curves to - what in the case of CDA may well be - multi-modal droplet size distributions. During the latter half of this study, the so-called "Model Independent" method of analysis was exclusively used. The term is a misnomer because sixteenth order polynomial models are iteratively compared to the instrument's number output eventually producing a best approximation to the actual spray distribution (Parkin, 1988).

Computer routines convert the PE and W values in the case of Rosin Rammler analysis, or the complete volume fraction output following the model independent method, into familiar descriptive parameters such as VMD and NMD. Coefficients of Variation are calculated from the ratio of the standard deviation (the difference between the 84 and 16 percentiles of the cumulative volume distribution) and the VMD. This parameter is

similar in nature to relative span where the 10 and 90 percentiles are used. The applicability of C.V. was proposed by Johnstone (1971) and assumes that the log-normal distribution provides a reasonable estimate of most spray distributions (further discussed by Mugele and Evans, 1951). VAD was calculated from accumulated size fractions in "Model Independent" analyses. Sample results from this study rarely showed deviations of more than 5% between the approximation given in section A and values calculated from volume distributions, provided Malvern error value (E) was low. The volume fraction (%V) above an upper limit (UL) and below a lower limit (LL) may be set for a range selected from table 2, and the two estimated volumes added together and subtracted from 100% are described as the "desired size band". Using Rosin Rammler analysis they are calculated as follows:

$$\%V_{LL} = 100-100.e^{(-(LL/PE)^W)} \quad \text{and} \quad \%V_{UL} = 100.e^{(-(UL/PE)^W)}$$

The programme below contains algorithms which convert the data from the Malvern into more comprehensible bar graphs, and to calculate various parameters describing the droplet distribution. A certain amount of caution should be exercised when reading this output; it is necessary to consider the error term (if E is greater than 500,000 the fit is certainly bad), the general credibility of the distribution, and high percentages at the smallest or more especially the largest size interval. In the latter case, although an upper limit is stated, this band actually indicates all droplets greater than the lower limit; for example: >697µm if an 800mm. lens has been used. VMD values are unlikely to be accurate when greater than the lower size limit of the largest size range.

Fig. A2.1. Malvern ST1800 P.S.A.: types of analysis and compensation for artefacts (1).

Micro Ulva: 160 r.p.s., tap water, 60 ml/min flow, no droplet suction.

NORMAL DETECTOR ARRAY

"MODEL INDEPENDENT"

Malvern model-fitting error = 692

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08 > +697.02	2.02	0.00
+697.02 > +426.91	0.25	0.00
+426.91 > +300.58	1.01	0.00
+300.58 > +224.49	3.53	0.04
+224.49 > +171.97	4.03	0.11
+171.97 > +133.94	6.05	0.35
+133.94 > +103.50	5.79	0.72
+103.50 > +80.67	23.93	6.40
+80.67 > +63.15	29.97	16.83
+63.15 > +49.46	17.13	20.04
+49.46 > +38.80	3.53	8.58
+38.80 > +30.44	1.51	7.60
+30.44 > +24.34	0.25	2.54
+24.34 > +19.02	0.25	5.12
+19.02 > +15.21	0.76	31.66

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 79 NMD = 43 VMD/NMD Ratio = 1.85 VAD = 59
VOLUME % DROPLETS: <50µm. = 6.98, >100µm. = 26.34; VADV = 109.4pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 66.69%

Re-analysed without uppermost size class

VMD = 78 NMD = 43 VMD/NMD Ratio = 1.82 VAD = 59
VOLUME % DROPLETS: <50µm. = 9.00, >100µm. = 24.32; VADV = 107.1pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 66.69%

ROSIN RAMMLER

Malvern model-fitting error = 17222

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00 > +697.03	0.00	0.00
+697.03 > +426.89	0.00	0.00
+426.89 > +300.58	0.00	0.00
+300.58 > +224.48	0.00	0.00
+224.48 > +171.98	0.00	0.00
+171.98 > +133.93	0.12	0.01
+133.93 > +103.49	10.05	1.37
+103.49 > +80.66	34.65	10.12
+80.66 > +63.16	30.21	18.52
+63.16 > +49.46	15.19	19.39
+49.46 > +38.81	6.13	16.25
+38.81 > +30.44	2.32	12.72
+30.44 > +24.35	0.81	8.95
+24.35 > +19.02	0.34	7.54
+19.02 > +15.22	0.11	5.13

Droplets accounted-for: 99.93%

VMD = 78 NMD = 47 VMD/NMD Ratio = 1.65 VAD = 61
VOLUME % DROPLETS: <50µm. = 10.21, >100µm. = 13.82; VADV = 117.1pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 75.97%

FIRST TWO DETECTOR READINGS NULLIFIED

Malvern model-fitting error = 6023

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08 > +697.02	0.00	0.00
+697.02 > +426.91	0.00	0.00
+426.91 > +300.58	0.00	0.00
+300.58 > +224.49	1.24	0.01
+224.49 > +171.97	4.46	0.12
+171.97 > +133.94	7.18	0.41
+133.94 > +103.50	6.19	0.76
+103.50 > +80.67	24.50	6.47
+80.67 > +63.15	32.18	17.85
+63.15 > +49.46	17.82	20.59
+49.46 > +38.80	3.47	8.33
+38.80 > +30.44	1.49	7.41
+30.44 > +24.34	0.25	2.51
+24.34 > +19.02	0.74	14.98
+19.02 > +15.21	0.50	20.57

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 77 NMD = 45 VMD/NMD Ratio = 1.73 VAD = 59
VOLUME % DROPLETS: <50µm. = 7.14, >100µm. = 22.82; VADV = 108.0pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 70.04%

Malvern model-fitting error = 18482

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00 > +697.03	0.00	0.00
+697.03 > +426.89	0.00	0.00
+426.89 > +300.58	0.00	0.00
+300.58 > +224.48	0.00	0.00
+224.48 > +171.98	0.00	0.00
+171.98 > +133.93	0.12	0.01
+133.93 > +103.49	10.05	1.37
+103.49 > +80.66	34.65	10.12
+80.66 > +63.16	30.21	18.52
+63.16 > +49.46	15.19	19.39
+49.46 > +38.81	6.13	16.25
+38.81 > +30.44	2.32	12.72
+30.44 > +24.35	0.81	8.95
+24.35 > +19.02	0.34	7.54
+19.02 > +15.22	0.11	5.13

Droplets accounted-for: 99.93%

VMD = 78 NMD = 47 VMD/NMD Ratio = 1.65 VAD = 61
VOLUME % DROPLETS: <50µm. = 10.21, >100µm. = 13.82; VADV = 117.1pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 75.97%

Fig. A2.2. Malvern ST1800 P.S.A.: types of analysis and compensation for artefacts (2).

Micro Ulva: 160 r.p.s., water + 20% acetone, 60 ml/min flow, suction of droplets through beam.

NORMAL DETECTOR ARRAY

"MODEL INDEPENDENT"

Malvern model-fitting error = 8275

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08 > +697.02	11.35	0.00
+697.02 > +426.91	4.28	0.00
+426.91 > +300.58	5.14	0.02
+300.58 > +224.49	0.86	0.01
+224.49 > +171.97	1.28	0.03
+171.97 > +133.94	1.93	0.09
+133.94 > +103.50	4.28	0.43
+103.50 > +80.67	4.93	1.07
+80.67 > +63.15	21.20	9.68
+63.15 > +49.46	22.91	21.80
+49.46 > +38.80	17.34	34.27
+38.80 > +30.44	2.78	11.38
+30.44 > +24.34	1.28	10.58
+24.34 > +19.02	0.21	3.50
+19.02 > +15.21	0.21	7.12

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 67 NMD = 44 VMD/NMD Ratio = 1.53 VAD = 55
VOLUME % DROPLETS: <50µm. = 22.74, >100µm. = 29.88; VADV = 88.9pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 47.38%

Re-analysed without uppermost size class

VMD = 60 NMD = 44 VMD/NMD Ratio = 1.35 VAD = 53
VOLUME % DROPLETS: <50µm. = 34.09, >100µm. = 18.53; VADV = 78.8pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 47.38%

ROSIN RAMMLER

Malvern model-fitting error = 30466

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00 > +697.03	0.00	0.00
+697.03 > +426.89	0.00	0.00
+426.89 > +300.58	0.00	0.00
+300.58 > +224.48	0.00	0.00
+224.48 > +171.98	0.00	0.00
+171.98 > +133.93	0.00	0.00
+133.93 > +103.49	0.10	0.01
+103.49 > +80.66	9.26	1.38
+80.66 > +63.16	34.35	10.77
+63.16 > +49.46	31.17	20.36
+49.46 > +38.81	15.43	20.93
+38.81 > +30.44	6.17	17.33
+30.44 > +24.35	2.16	12.24
+24.35 > +19.02	0.89	10.18
+19.02 > +15.22	0.29	6.79

Droplets accounted-for: 99.82%

VMD = 61 NMD = 38 VMD/NMD Ratio = 1.59 VAD = 48
VOLUME % DROPLETS: <50µm. = 26.14, >100µm. = 0.26; VADV = 58.2pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 73.60%

FIRST TWO DETECTOR READINGS NULLIFIED

Malvern model-fitting error = 5452

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08 > +697.02	0.00	0.00
+697.02 > +426.91	0.99	0.00
+426.91 > +300.58	1.24	0.00
+300.58 > +224.49	2.23	0.02
+224.49 > +171.97	2.23	0.04
+171.97 > +133.94	3.22	0.13
+133.94 > +103.50	4.95	0.43
+103.50 > +80.67	6.19	1.14
+80.67 > +63.15	24.75	9.61
+63.15 > +49.46	28.22	22.83
+49.46 > +38.80	20.54	34.51
+38.80 > +30.44	3.47	12.08
+30.44 > +24.34	1.24	8.71
+24.34 > +19.02	0.74	10.49
+19.02 > +15.21	0.00	0.00

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 61 NMD = 45 VMD/NMD Ratio = 1.37 VAD = 52
VOLUME % DROPLETS: <50µm. = 27.10, >100µm. = 15.80; VADV = 75.6pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 57.10%

Malvern model-fitting error = 19374

SIZE RANGE (µm.)	PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00 > +697.03	0.00	0.00
+697.03 > +426.89	0.00	0.00
+426.89 > +300.58	0.00	0.00
+300.58 > +224.48	0.00	0.00
+224.48 > +171.98	0.00	0.00
+171.98 > +133.93	0.00	0.00
+133.93 > +103.49	0.10	0.01
+103.49 > +80.66	9.26	1.38
+80.66 > +63.16	34.35	10.77
+63.16 > +49.46	31.17	20.36
+49.46 > +38.81	15.43	20.93
+38.81 > +30.44	6.17	17.33
+30.44 > +24.35	2.16	12.24
+24.35 > +19.02	0.89	10.18
+19.02 > +15.22	0.29	6.79

Droplets accounted-for: 99.82%

VMD = 61 NMD = 38 VMD/NMD Ratio = 1.59 VAD = 48
VOLUME % DROPLETS: <50µm. = 26.14, >100µm. = 0.26; VADV = 58.2pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 73.60%

Fig. A2.3. Malvern ST1800 P.S.A.: types of analysis and compensation for artefacts (3).

Micro Ulva: 200 r.p.s., water + 20% acetone, 60 ml/min flow, suction of droplets through beam. Replicate I.

NORMAL DETECTOR ARRAY

"MODEL INDEPENDENT"

Malvern model-fitting error = 8310

SIZE RANGE (µm.)		PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08	+697.02	48.93	0.01
+697.02	+426.91	5.50	0.01
+426.91	+300.58	0.00	0.00
+300.58	+224.49	0.31	0.00
+224.49	+171.97	0.00	0.00
+171.97	+133.94	0.31	0.02
+133.94	+103.50	1.83	0.24
+103.50	+80.67	1.22	0.35
+80.67	+63.15	7.03	4.22
+63.15	+49.46	17.43	21.80
+49.46	+38.80	7.34	19.07
+38.80	+30.44	10.09	54.23
+30.44	+24.34	0.00	0.00
+24.34	+19.02	0.00	0.00
+19.02	+15.21	0.00	0.00

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 644 NMD = 38 VMD/NMD Ratio = 16.90 VAD = 61
VOLUME % DROPLETS: <50µm. = 10.12, >100µm. = 57.07; VADV = 116.9pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 24.82%

Re-analysed without uppermost size class

VMD = 31 NMD = 38 VMD/NMD Ratio = 0.82 VAD = 48
VOLUME % DROPLETS: <50µm. = 67.05, >100µm. = 8.14; VADV = 59.7pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 24.82%

ROSIN RAMMLER

Malvern model-fitting error = 78626

SIZE RANGE (µm.)		PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00	+697.03	0.00	0.00
+697.03	+426.89	0.00	0.00
+426.89	+300.58	0.00	0.00
+300.58	+224.48	0.00	0.00
+224.48	+171.98	0.00	0.00
+171.98	+133.93	0.00	0.00
+133.93	+103.49	0.00	0.00
+103.49	+80.66	2.09	0.21
+80.66	+63.16	22.12	4.65
+63.16	+49.46	35.20	15.42
+49.46	+38.81	23.07	20.98
+38.81	+30.44	10.65	20.07
+30.44	+24.35	4.06	15.43
+24.35	+19.02	1.78	13.64
+19.02	+15.22	0.62	9.60

Droplets accounted-for: 99.59%

VMD = 53 NMD = 31 VMD/NMD Ratio = 1.71 VAD = 41
VOLUME % DROPLETS: <50µm. = 41.97, >100µm. = 0.01; VADV = 34.8pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 58.02%

FIRST TWO DETECTOR READINGS NULLIFIED

Malvern model-fitting error = 4318

SIZE RANGE (µm.)		PERCENT BY VOLUME	PERCENT BY NUMBER
+1499.08	+697.02	0.00	0.00
+697.02	+426.91	0.79	0.00
+426.91	+300.58	1.58	0.00
+300.58	+224.49	2.64	0.01
+224.49	+171.97	1.58	0.02
+171.97	+133.94	2.11	0.06
+133.94	+103.50	2.37	0.14
+103.50	+80.67	4.49	0.57
+80.67	+63.15	13.19	3.54
+63.15	+49.46	32.72	18.29
+49.46	+38.80	23.75	27.57
+38.80	+30.44	10.03	24.12
+30.44	+24.34	4.22	20.49
+24.34	+19.02	0.53	5.19
+19.02	+15.21	0.00	0.00

Any droplets less than 15.21µm. in diameter, have not been accounted-for.

VMD = 54 NMD = 39 VMD/NMD Ratio = 1.40 VAD = 46
VOLUME % DROPLETS: <50µm. = 39.81, >100µm. = 11.77; VADV = 52.2pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 48.42%

Malvern model-fitting error = 13134

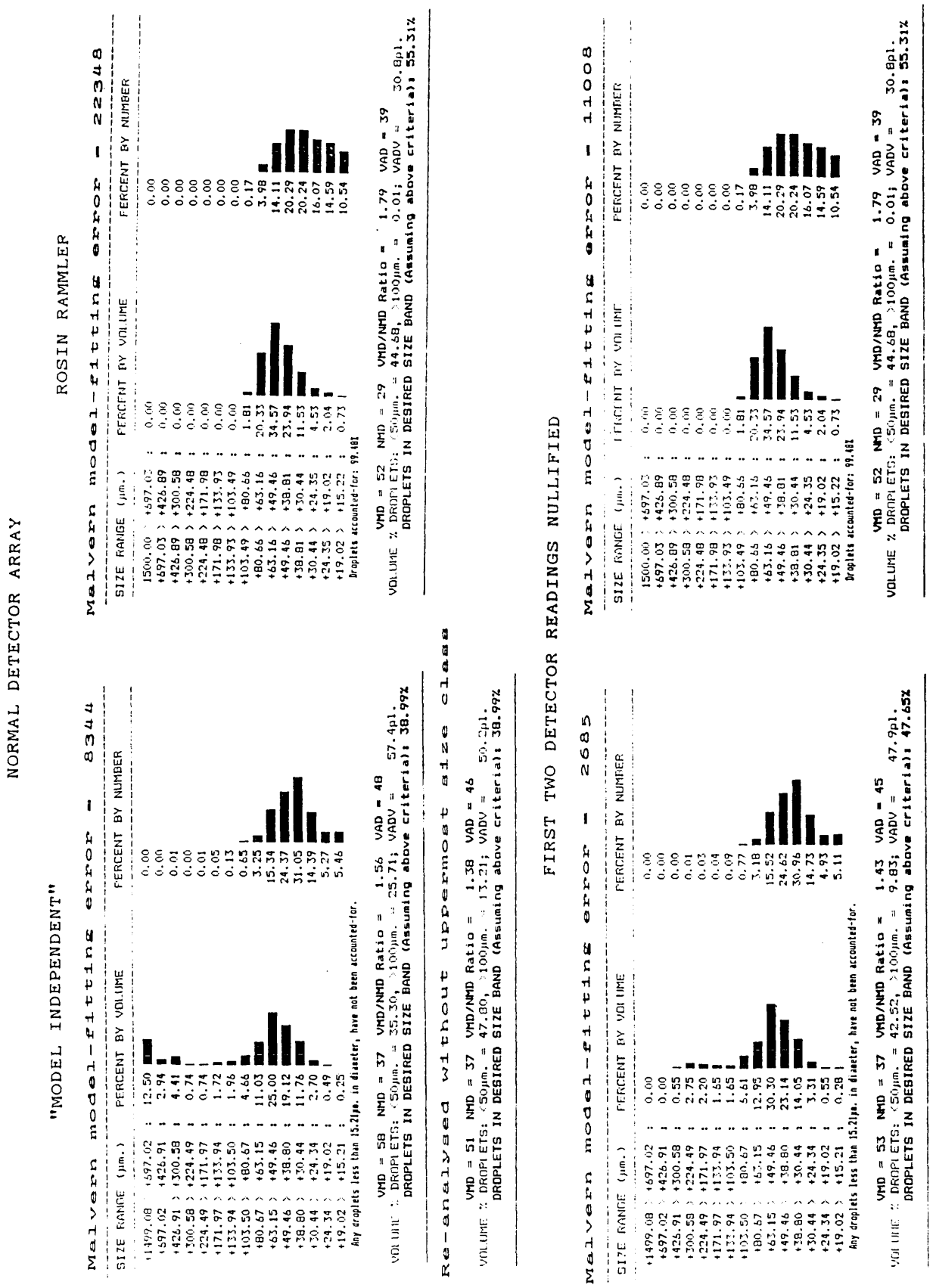
SIZE RANGE (µm.)		PERCENT BY VOLUME	PERCENT BY NUMBER
1500.00	+697.03	0.00	0.00
+697.03	+426.89	0.00	0.00
+426.89	+300.58	0.00	0.00
+300.58	+224.48	0.00	0.00
+224.48	+171.98	0.00	0.00
+171.98	+133.93	0.00	0.00
+133.93	+103.49	0.00	0.00
+103.49	+80.66	1.17	0.12
+80.66	+63.16	19.96	4.21
+63.16	+49.46	36.95	16.24
+49.46	+38.81	24.50	22.35
+38.81	+30.44	10.91	20.63
+30.44	+24.35	3.97	15.14
+24.35	+19.02	1.66	12.76
+19.02	+15.22	0.55	8.56

Droplets accounted-for: 99.67%

VMD = 52 NMD = 33 VMD/NMD Ratio = 1.59 VAD = 42
VOLUME % DROPLETS: <50µm. = 43.41, >100µm. = 0.00; VADV = 37.5pl.
DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): 56.59%

Fig. A2.4. Malvern ST1800 P.S.A.: types of analysis and compensation for artefacts (4).

Micro Ulva: 200 r.p.s., water + 20% acetone, 60 ml/min flow, suction of droplets through beam. Replicate II.



Compensation for Artefacts

Figs. A2.1. - A2.4. illustrate in detail four examples taken from Table 2.5.1., and show a gradation in severity of the effect described in section 2.5.2.2. from negligible to very severe; each page represents the same reading analysed in five different ways. Note how the Malvern model-fitting error term is usually improved with detector nullification, and that model independent analyses may be an order of magnitude better than those of Rosin Rammler for rotary atomisers.

D. EXPLANATORY NOTES FOR THE MALVERN AND SARTORIUS BALANCE CONTROLLER PROGRAMME (Versions 4.0 onwards)

MSC.PAS (Malvern and Sartorius Controller) is listed after these notes and has been written to assist in the analysis of droplet spectra and flow rate of agricultural sprayers. It will work on an Apricot Fle or, with minor modifications, on other MS-DOS computers. Its structured form should facilitate future changes as needs arise. This PASCAL programme has been modified from one originally written in BASIC; Pascal perfectionists will therefore appreciate that there are better ways of constructing many of the algorithms. Its functions are as follows:

1. To act as a "servo" for the original Malvern PDP8 computer and replace all the functions of the ageing teletext device.
2. Hasten and ease the LOading and DUmping of readings.
3. Automatically analyse data by the Rosin Rammler or model independent methods. The operator is obliged to label data before the analysis, which is stored on disc.
4. Store and load raw Malvern data to enable many consecutive readings to be included in large experimental designs.
5. Compensate for artefacts caused by minor fluctuation of the LASER beam by nullifying detector elements 1 and 2.

6. Calculate standard droplet parameters such as VMD etc., and prints-out droplet distributions as bar graphs.

7. Programme the PDP8 without the use of punched tape.

8. Provide interface routines for the Sartorius balance to quickly and accurately measures flow rates from sequential weighings. Results can be printed-out or stored on disc.

Communication with the devices is complicated by a plethora of protocols. The problem was resolved by installation of the "InfaPlug" system, which enables very rapid interchange between droplet sizing measurements on the Malvern and flow rate studies using the Sartorius balance. The settings are:

InfaPlug	9600 Baud, 8 Bits/Char., 1 Stop Bit, No Parity.
Malvern send/rcv.	2400 Baud, 7 Bits/Char., 2 Stop Bit, No Parity.
Program Malvern	2400 Baud, 8 Bits/Char., 1 Stop Bit, No Parity.
Sartorius balance	9600 Baud, 7 Bits/Char., 1 Stop Bit, Mark Parity.

Output can be written to a parallel printer or disc files:

<FILENAME>.BAL: Sartorius balance readings

<FILENAME>.DAT: Raw Malvern data

<FILENAME>.INT: Intermediate Malvern file of labels, PE, W and E

<FILENAME>.RES: Malvern results table

<FILENAME>.TAB: Tabular summary of Malvern droplet analysis

<FILENAME>.BAK: Backup original *.INT file before overwriting with Rosin Rammler analyses (menu option 3).

The author acknowledges the ideas and advice of Messrs. A. Arnold, C. Endacott and P. Muller, in the preparation of this facility.

Listing of: msc.pas

```
PROGRAM MSC;
{ Malvern and Sartorius controller programme version 4.41
  for Apricot F1 and compatibles }
{$C-,U-}
type
    byte = 0..255;
    interval = integer;
    TimeString = string[10];
    str128 = string[128];
    str80  = string[80];
    str20  = string[20];
    str12  = string[12];
    str8   = string[8];
    filetype = string[3];
    regpack = record
              ax,bx,cx,dx,bp,si,di,ds,es,flags: integer;
            end;
var
   person:                                  string[40];
   Dtl,weight:                              str20;
   FileNCore:                               str8;
   FileNstr:                                string[60];
   title:                                   array[0..64] of string[63];
   tstr:                                    string[160];
   mdt:                                     array[0..64] of str80;
   md:                                      array[0..90] of integer;
   mch:                                     array[1..1200] of char;
   labeled:                                 array[1..2] of integer;
   ch,mpg,ma,mb:                            char;  {ch: floating}
   wt:                                      array[1..2000] of real;
   dty,W,E,rnum,VNR,WL,WU,ADV:              real;  {rnum floating}
   flag,error,X,Y,Z:                        integer;  {floating}
   timelapse,timer,rdgs,NZ:                 integer;  {Sartorius}
   nu,fl,beg,stp,SN,en,malerno,PE,LL,UL:    integer;  {Malvern}
   VMD,NMD,VAD:                             integer;
   I:                                       byte;     {floating}
   print,quit,malverror:                    boolean;  {floating}
   dskbtfree:                               real;

Const
clf:            string[2] = #13#10 {CR & LF};
cdf:            string[3] = #13#10#10;
ctf:            string[4] = #13#10#10#10;
IOval:          integer = 0;
IOerr:          boolean = false;
Pathname:       string[2] = 'B:';
{$I IOERROR.PRC}
{$I COMPORT.PRC}
{$I TIMEDATE.PRC}
{-------------------------------------------------------------------------------
GENERAL}

Procedure CLS;  {ANSI codes}
begin  write(#27,'[1;3f',#27,'[2J',cdf); End;

Procedure  Waitkey;
var  wait: char;
begin
```

```
     writeln(clf);
     write(#9,#9,'Press ANY KEY to continue');
     Read(Kbd,wait); writeln;
End;

Function OK: boolean;
var      YN: char;
begin
     repeat read(kbd,YN); YN:= upcase(YN);
            until YN in ['Y','N']; write(YN,clf);
     if YN ='Y' then OK:= true else OK:= false;
end;

Procedure TS;
Begin
   write(#27,'[s',#27,'[1;1f');
   write('      *** SUPERMALVERN by Roy Bateman ***                    Time: ');
   writeln(time); write(#9,#27,'[7m'); {Reverse Video};
   case mpg of
        '$':     write(' No Communication with Malvern ');
        '#':     write('  Model Independent Analysis   ');
        '*':     write(' Rosin Rammler Model Analysis  ');
       end {case mpg};
   write(#27,'[0m'); {R.V. off}
   writeln('               Data Set: ',SN:2);
   write(#27,'[u'); {restore cursor position}
End;

PROCEDURE  Begen;
Begin
     quit:= false; repeat TS;
       write(clf,'What is the STARTING Data Set number?    '); Readln(Beg);
       write('At which Data Set do you wish to FINISH? '); Readln(En);
       if (Beg>0) and (En>=Beg) and (en<65) then quit:= true else
          writeln(clf,#7,'NONESENSE ! - Try again',cdf);
     until quit = true;
End;

Procedure pln(device,lenth: integer;  lineseg: char);
{Device - 1: screen, 2:printer, 3:both}
Begin
     For I:= 1 to lenth do
         begin
         if device <> 2 then write(lineseg);
         if device > 1 then write(lst,lineseg);
         end;
End;

Function exnum(object: str80;  start,length:  integer): real;
begin
     tstr:= copy(object,start,length);
     repeat
           val(tstr,rnum,error);
           delete(tstr,error,1);
           until error = 0;
     exnum:= rnum;
End;

{-------------------------------------------------------------------------
DISC FILE HANDLING: Directory and available bytes}
{$I DIRECTRY.PRC}
{$I FILESMSC.PRC}
```

```
Procedure Intdisc(RRFinal: boolean);
var
      FVInt:     Text;
      FNINT:     str12;
begin
     FNINT:= FileNCore+'.INT';
     Assign(FVInt,FNINT);  Rewrite(FVInt);
     if RRFinal = true then flag:= 3 else flag:= 1;
     str(flag,tstr);  write(FVInt,tstr,'  ');
     str(beg,tstr);  write(FVInt,tstr,'  ');
     str(en,tstr);  writeln(FVInt,tstr);
     For SN:= Beg to En do begin
         Writeln(FVInt,Title[SN]);
         if RRFinal = true then begin
            repeat  ch:= copy(mdt[SN],length(mdt[SN]),1);
                    if (ch in ['0'..'9']) = false then
                       delete(mdt[SN],length(mdt[SN]),1);
                    until (ch in ['0'..'9']);
            Writeln(FVInt,mdt[SN]); end;
         end;
     Close(FVInt);
End;

Procedure Intread(var err: boolean; final: boolean);
var
      FVI:           Text;
      FNINT,BFile:   str12;

function readint: integer;
var   num: integer;
begin repeat read(FVI,ch); write(ch);
            until ch in ['0'..'9'];
      tstr:= ch;  repeat read(FVI,ch); write(ch);
            tstr:= tstr + ch;
            until (ch in ['0'..'9']) = false;
      val(tstr,num,error); readint:= num;
end {subfunction};

begin
     {I-} repeat
           repeat filename('INT');
           FNINT:= FileNCore+'.INT';
           Assign(FVI,FNINT);
           until IOresult = 0;
     Reset(FVI)
     until IOresult=0; {I+}
     flag:= readint; beg:= readint;
     en:= readint; read(FVI,ch) {LF};
     If (((flag=3) and (final=false)) or ((flag<>3) and (final=true))) then begin
        Writeln(clf,#7,'Wrong sort of <INT> file: data already analysed');
        waitkey; close(FVI); err:= true; EXIT; end else err:= false;
     writeln(clf,'Labels are for data sets ',beg,' to ',en,clf);
     For SN:= Beg to En do begin
         Readln(FVI,Title[SN]); writeln(Title[SN]);
         if flag in [2,3] then begin
            readln(FVI,mdt[SN]); writeln(mdt[SN],clf); end;
         end {SN loop};
     Close(FVI);
     labeled[1]:= beg; labeled[2]:= en; BFile:= concat(FileNCore,'.BAK');
     if (flag=1) and (mpg='*') then rename(FVI,BFile);
End;
```

```
{-------------------------------------------------------------------------
LABELING & EXPLANATORY NOTES}

Procedure Labelset;
var
   segment:            array[0..4] of string[25]; {0 is floating}

const
   question:           array[1..4] of string[60] =
   ('Sprayer (22 characters: *<CR> : "(standard)") ',
    'Nozzle/Flow rate (12 characters: /<CR> : ml/min.)        ',
    'Pessure/Volts/Disc Speed (11 characters: -<CR> : r.p.s.) ',
    'Test Fluid (18 characters: +<CR> for water +Agral ');
     seglth:     array[1..4] of integer = (22,12,11,18);

procedure segmentedit(numb,posn,lenth:  integer);
label repl;
var   inlth:  integer;
begin
  segment[numb]:= copy(Title[0],posn,lenth);
  repl: writeln(segment[numb]);
  writeln('Limit of string segment:. . . . . . . . . . .......................v!');
  write('  REPLACEMENT STRING (CR to keep the same)');
  write(' ':(28-lenth));
  segment[0]:= ''; readln(segment[0]); inlth:= length(segment[0]);
  if inlth > lenth-1 then begin
     Writeln(#7,'Too long dummy!',clf,question[numb],'->'); Goto repl; end;
  If segment[0] <> '' then begin
     Case numb of
           1:   if (inlth < 12) and (pos('*',segment[0]) = inlth) then
                segment[0]:= copy(segment[0],1,inlth-1) + ' (standard)';
           2:   if (inlth < 5)  and (pos('/',segment[0]) = inlth) then
                segment[0]:= copy(segment[0],1,inlth-1) + ' ml/min.';
           3:   if (inlth < 5) and (pos('-',segment[0]) = inlth) then
                segment[0]:= copy(segment[0],1,inlth-1) + ' r.p.s.';
           4:   if segment[0] = '+' then
                segment[0]:= 'Water + 0.1% Agral';
           end {case};
     if inlth < lenth then for error:= length(segment[0])+1 to lenth do
             segment[0]:= segment[0] + ' ';
     segment[numb]:= segment[0];
     end {chars entered};
end {subproc};

procedure segmentcopy;
begin
     flag:= 1; For I:= 1 to 4 do begin
         Write(clf,question[I],'->'); segmentedit(I,flag,seglth[I]);
         flag:= flag + seglth[I]; end;
       Title[0]:= ''; for I:= 1 to 4 do  Title[0]:= Title[0] + segment[I];
end {subproc};

procedure labeledit;
begin
     Write(ctf,#7,Title[Y],clf,'Do you wish to CHANGE this? ');
           if OK then begin
                Title[0]:= Title[Y];
                writeln(clf);
                segmentcopy;
                Write(cdf,Title[0],clf,'Is this alright now?  ');
                     if OK then Title[Y]:= Title[0];
           end {editing};
```

```
end {subproc};

Begin {main procedure}
Title[0]:= ''; segment[0]:= '';
if beg = 0 then begin  beg:= 1; en:= 64; end;
CLS; TS; writeln(clf,clf);
Writeln('EASYLABEL - The routine to take some of the drudgery out of labeling data sets');
writeln;
Writeln('This produces labels that do not exceed 65 characters in length, and by ');
writeln('dividing them up into copyable segments, considerably speeds up the naming of');
writeln('Data Sets which differ only by one or two factors.  Ending entries with certain');

writeln('characters automatically inserts standard units (eg. r.p.s.).  Entering + only');
writeln('against test liqid writes "Water + 0.1% Agral".');
Writeln(cdf,'These factors have been divided-up as follows:',clf);
             for I:= 1 to 4 do Writeln(question[I]); writeln;
   write(' Same Data Set numbers (',beg,' to ',en,') as before (Y/N) ?');
   if OK = false then Begen else writeln;
labeled[1]:= Beg;  labeled[2]:= En;
   For Y:= Beg to En do
     begin CLS; TS;
     Writeln(ctf,'                    LABELING DATA SET *** ',Y,' ***');
     if Title[Y] = '' then begin
          segmentcopy; Title[Y]:= Title[0]; end {Title[Y] = ''}
     else labeledit;
   end {Y loop};
Quit:= false; Repeat; CLS; TS;
 Writeln(ctf,#9,'   THERE - DON'T YOU FEEL BETTER NOW?',clf);
 writeln('No. 123456789-123456789-123456789-123456789-123456789-123456789-12345.',clf);
 For Y:= Beg to En do begin
         if Y<10 then Write(' ');
         Writeln(Y,'  ',Title[Y]);
    end;
 Write(cdf,'IS THIS ALRIGHT? Y/N ');
       if OK=false then begin repeat
              write(cdf,'Which label number do you wish to edit? (99 to end)');
              readln(Y); if Y<65 then labeledit;
              until Y = 99;
          end {editing} else quit:= true;
 until quit = true;
Write(cdf,'Do you wish to save these labels on an <.INT> file? ');
  if OK then begin
     if FileNCore = '' then Filename('INT') else begin
        Write('Core Filename is: ',FileNCore,', do you want to change it? ');
        if OK then filename('INT'); end;
     Intdisc(false); end;
End {Proc};

Procedure ReadDoc(DFil: str80);

var       FVDoc:   text;

begin
     Assign(FVDoc,DFil); reset(FVDoc); CLS; TS; writeln(clf);
     While not Eof(FVDoc) do begin
           readln(FVDoc,tstr);
           If tstr = '******' then begin  Waitkey; CLS; TS; writeln; end
              else writeln(tstr); end;
end;

PROCEDURE NOTES;
```

```
begin
     FileNstr:= pathname + 'MSC.DOC';
     ReadDoc(FileNstr);
     waitkey; cls; ts;
Writeln(clf,#9,#9,'   SEQUENCE for AUTOMATIC MODE',cdf);
Writeln(' 1a. Label data sets, preparatory information on sequence and analysis type');
Writeln('  b. Save information on *FILE*.INT in case programme must be resumed later');
Writeln; if mpg in ['$','*'] then begin
Writeln(' 2a. Change focal length parameter to 1/10 of its actual size');
Writeln('  b. Analyse data sets using GO, place PE and W approximations in array');
Writeln('  c. Store approximations in *FILE*.INT - programme could be broken here');
Writeln('  d. Recalculate sets at full focal length using SE from above array');
     end {R.R.} else Writeln(' 2.  Analyse Data using GO');     {M.I. analysis}
Writeln(clf,' 3.  At each data set store droplet distribution table in *FILE*.RES');
Writeln(clf,' 4.  Analyse data for VMDs etc. by re-reading *FILE*.RES and placing');
writeln('     results in *FILE*.TAB. under menu option 5.');
Waitkey; Write(clf,'Would you like to label data sets now? Y/N ');
If OK then Labelset;
End;

Procedure Sizeband;

Begin
     FileNstr:= pathname + 'MSC2.DOC';
     ReadDoc(FileNstr);
   Write(cdf,'PLEASE PRESS THE NUMBER CORRESPONDING TO THE VALUES YOU REQUIRE ');
   Repeat Read(kbd,ch); until ch in ['1'..'6'];
   Write(ch,clf); Case ch of
          '1': begin LL:= 1; UL:= 25; end;     '2': begin LL:= 25; UL:= 50; end;
          '3': begin LL:= 50; UL:= 100; end;   '4': begin LL:= 75; UL:= 150; end;
          '5': begin LL:= 150; UL:= 300; end;
          '6': begin writeln;
                    write('Lower size limit '); Readln(LL);
                    write('Upper size limit '); Readln(UL); end {6};
   end {case};
End;

{-------------------------------------------------------------------------------}
PROCEDURE SARTORIUS;
var flow,avwtdif:      real;
    tl:                integer;

    procedure getweight; {obtain string and search for weight}
    begin
         Writeln(aux,#27,'P'); Readln(aux,weight);
         error:= 0; z:= z+1;
         repeat
               delete(weight,error,1); Val (weight,wt[z],error);
               until error=0;
         end;

Begin
  TS; writeln(clf,clf,title[0],clf);
  writeln('Density of fluid under test is understood to be: ',dty:1:3);
  writeln('The time interval between readings is set to ',timelapse:3,' seconds');
  write(clf,'Do you wish to change these criteria Y/N ?');
  if OK then begin
     Cls; Writeln(cdf,'What is the TITLE of this experiment (<CR> for no change)');
     Readln(tstr); if tstr<>'' then title[0]:= tstr;
     Writeln(clf,'Please state the required time-lapse between readings');
     Write('(up to 30 s. in whole seconds; calibrated for 1-5,10 & 30 s.): ');
     Readln(timelapse); If (timelapse in [1..30]) = false then timelapse:= 10;
```

```
      Write(clf,'Over how many readings are the flow-rates to be averaged (default 4): ');
      Readln(rdgs); if rdgs = 0 then rdgs:= 4;
      writeln(clf,'Press K to keep the density factor at ',dty:1:3,',');
      write('press A to alter it to a known value, or press M to measure it now.');
      Repeat read(kbd,ch); ch:= upcase(ch); until ch in ['K','A','M'];
      case ch of
      'A': begin
           write(cdf,'What is the density of the reservoir fluid? ');
           readln(dty); end;
      'M': begin  CLS;
           write(clf,'What is the volume of your measuring container (Metric in ml.)? ');
           readln(dty); writeln(aux,'C009'); writeln;
           write('Place the EMPTY container on the balance and press W when ready...');
           repeat read(kbd,ch); until ch in ['W','w'];
           getweight; writeln(clf,wt[z]:8:2,clf);
           write('Now fill the container to ',dty:2:2,' ml., and press W when ready.');
           repeat read(kbd,ch); until ch in ['W','w'];
           getweight; writeln(clf,wt[z]:8:2,clf);
           writeln(aux,#4,#4,#4);
           dty:= (wt[z]-wt[z-1])/dty;
           writeln(clf,'The DENSITY has been measured as ',dty:1:3,clf);
           end;
      end {case ch};
    end {case change parameters}
    else writeln;
    Waitkey;
    {tl:= round((timelapse-0.73)*1076.5);  Calibration}
    tl:= timelapse * 1030;
      Writeln(aux,'C009');                {Infaplug to balance}
      CLS;  write(clf,#9,#27,'[7m');      {Reverse Video}
      writeln('SARTORIUS: Press ANY KEY to end');
      write(#27,'[0m'); {R.V. off}
      writeln(clf,'          WEIGHT                          FLOW-RATE');
      write('                          ml/sec.         ml/min. <- accumulated (',rdgs,')');
      writeln(clf,#27,'[7;23r'); TS;   {Set screen scrolling region from lines 7 to 24}
      quit:=  false; z:= 0; avwtdif:= 0.0;   {reset weight records}
      Repeat
            getweight; TS;
            if z > 1 then flow:= (wt[z]-wt[z-1])/(timelapse*dty); {in ml/sec.}
            if z in [3..rdgs+2] then avwtdif:= avwtdif + (wt[z]-wt[z-1]);
            write(wt[z]:16:2,flow:16:4,flow*60:16:2);
            if z > rdgs+2 then begin
                  avwtdif:= avwtdif +wt[z] -wt[z-1] -wt[z-rdgs] +wt[z-rdgs-1];
                  write((avwtdif*60)/(timelapse*dty*rdgs):16:2); end;
            writeln; Delay(tl); quit:= keypressed;
      Until quit;
      NZ:= z;
      writeln(aux,#4,#4,#4);              {InfaPlug off}
    {Set screen scrolling region from lines 3 to 24}
    CLS; write(#27,'[2;23r'); TS;
End;

Procedure SARTDATA;  {display/store data on wt[z] array}
var
    FVS:      text;
    FNS:      str12;
    wtstr:    str80;
    flstr:    str20;
    dvce:     char;

begin TS;
      writeln(ctf,'Press 1 to display weights,');
```

```
     writeln('Press 2,to print them or');
     write('Press 3 to write them to disc: ');
     repeat read(kbd,dvce) until dvce in ['1'..'3']; Writeln(clf); TS;
     str(dty:6:4,wtstr); str(timelapse,flstr);
     tstr:= concat('Liquid density = ',wtstr,'; Timelapse = ',flstr,' seconds.',clf);
     case dvce of
     '1':  Write(Title[0],clf,tstr);
     '2':  begin
           Write(lst,#14,Title[0],clf,tstr); pln(2,42,'-');
           writeln(lst,clf,'  Minutes  WEIGHTS  FLOW RATES (ml/min.)'); pln(2,42,'-');
           writeln(lst); end;
     '3':  begin
           filename('BAL'); FNS:= Concat(FileNCore,'.BAL');
           writeln(clf,'Writing flow data on ',FNS,cdf);
           assign(FVS,FNS); Rewrite(FVS);
           writeln(FVS,person,clf,Dtl,clf,Title[0],clf,tstr);
           writeln(FVS,clf,'  Minutes  WEIGHTS  FLOW RATES (ml/min.)'); end;
        end {case};
     for y:= 1 to NZ do begin
         str(wt[y]:10:2,wtstr);
         if y > 1 then begin str(((wt[y]-wt[y-1])*60/timelapse/dty):14:2,flstr);
                   wtstr:= concat(wtstr,flstr); end;
         str((Y-1)*timelapse/60:8:2,flstr); wtstr:= concat(flstr,wtstr);
         case dvce of
              '1':    writeln(wtstr);
              '2':    writeln(lst,wtstr);
              '3':    begin  writeln(wtstr); writeln(FVS,wtstr); end;
             end;
         end{y loop};
     case dvce of
          '1':    Waitkey;
          '2':    Begin  pln(2,43,'-'); write(lst,clf,#12); end;
          '3':    Close(FVS);
         end;
End;

{-------------------------------------------------------------------------
MALVERN}

PROCEDURE Malvio(malvend: char;  saveon: boolean); {Receive characters from Malvern}
var      crlf:  integer;    {detect 2 CR & LFs when looking for '+' (= 4)}
begin
     if saveon = true then x:= 0;
     malverror:= false; crlf:= 0;
     TS;
     repeat
          read(aux,ch);
          if saveon = true then begin
                   x:= x+1; mch[x]:= ch; end
          else write(ch);
          case crlf of
          2:       if ch <> #13 then crlf:= 0;
          4:       EXIT;
              end {case crlf};
          case ch of
          #13:     crlf:= crlf + 1;
          #10:     if malvend = '+' then crlf:= crlf + 1;
          '?':     if malverror = true then malvend:= mpg else
                         malverror:= true;
              end {case ch};
          until ch = malvend;
     if saveon = true then for y:= 1 to x do
```

```
        write(mch[Y]);
end;

Procedure CtrlC(var reply: boolean);
begin
     comport(ch,error,1,3); TS; flag:= timer;
     repeat
           comport(ch,error,2,I); write(ch); tstr:= time;
           until (ch in ['#','*']) or (timer > flag+3);
     if ch in ['#','*'] then begin
        mpg:= ch; reply:= true; end   else reply:= false;
end;

PROCEDURE Malvwr(malvend: char); {re-format WR output to fill screen}
begin
     x:= 0; z:= 1;
     repeat
           x:= x+1; read(aux,mch[x]);
           if mch[x]=#13 then
              begin
                   if z=0 then begin
                      x:= x+1; read(aux,mch[x]);
                      write('    |    '); z:= 1;
                      end {z=0}
                   else begin
                      write(mch[x]); z:= 0;
                      end {z=1};
                   end {case <CR>}
            else write(mch[x]);
      until mch[x] = malvend;
      y:= x;
      writeln; writeln;
end;

PROCEDURE Malvin(fin: byte); {Input of complex commands to Malvern}
Begin
if ma = 'S' then write(aux,'SE',#10,#13) else writeln(aux,ma,mb);
malvio(':',false); read(aux,ch); write(ch);
  for I:=1 to fin do begin
    if I = fin then begin
           if ma = 'I' then writeln(aux,#3)
           else if (mpg = '*') and (ma = 'S') then
                   if W<10 then writeln(aux,W:3:1) else writeln(aux,W:4:1)
           else writeln(aux,md[I]);
           malvio(mpg,false); end
       else
           begin write(aux,md[I],' '); malvio(':',false);
           read(aux,ch); write(ch); end;
    end;
End;

PROCEDURE SetistDU;
      begin
           Case mpg of
           '*':  begin Writeln(aux,'EX'); Malvio(mpg,false);
                 For SN:= 1 to Beg-1 do begin
                     ma:= 'R'; mb:= 'E'; md[1]:= SN;
                     Malvin(1); Writeln(aux,'DU');
                     Malvio(mpg,false);
                     end {SN loop};
                 end {case *};
           '#':  begin
```

```
                ma:='S'; mb:= 'E'; md[1]:= Beg;
                Malvin(1);
                end {case #};
          end {case};
     End { setting initial dump slot no.};


PROCEDURE Malvindat; {Manual data input: prep.}
begin
writeln(ma,mb);  writeln;
     case ma of
          'N': begin
               write('What is the FOCAL LENGTH of the lens? ');
                 repeat readln(fl);
                 if (fl < 63) or (fl > 1000) then
                    write(#7,clf,'Enter number in range 63..1000: ');
                 until (fl > 62) and (fl < 1001);
               write('How many sweeps per reading? ');
                 repeat readln(nu);
                 if (nu < 1) or (nu > 4095) then
                    write(#7,clf,'Enter number in range 1..4095: ');
                 until (nu > 0) and (nu < 4096);
               md[0]:= 2; md[1]:= nu; md[2]:= fl; end {N};
          'R': begin    md[0]:= 1;
               write('Set number? '); readln(md[1]); end {R};
          'S': case mpg of
               '#': begin     md[0]:= 1;
                    write('Initial dump slot number? '); readln(md[1]);
                    end {#};
               '*': begin md[0]:= 2;
                    write('PE value? '); readln(md[1]);
                    write('W value? '); readln(W); end {*};
               end {S - case mpg};
          'I': begin
             X:= 0;  quit:= false;
             repeat
               write(clf,'Channel number? ');
               repeat
                     readln(md[X+1]);
                     until md[X+1] in [1..30];
               write('Background reading? '); readln(md[X+2]);
               write('Signal reading? '); readln(md[X+3]);
               X:= X+3; write(clf,'Press E to finish otherwise ANY OTHER KEY ');
               writeln('to input data to more channels');
               read(kbd,ch);  if ch in ['E','e'] then quit:= true;
               until quit or (X = 90);
               md[0]:= X+1; end {I};
          end {case ma};
end;

Procedure Malver(var malerno: integer); {Malvern error handling}
var    error:          string[5];

Begin
error:= '';  for y:= 1 to X do
             if mch[y] in ['0'..'9'] then error:= error + mch[y];
             Val(error,malerno,y);
case malerno of
506:      begin  writeln(cdf,#7,'Double precision adder overflow',clf);
                 ma:= 'S'; mb:= 'E'; md[1]:= 20; W:= 2; Malvin(2);
                 writeln(aux,'CO');
          end;
```

```
400,401,402,421,451,459,469,523,754,1147: begin
          {Common errors produced by wayward data}
          writeln(cdf,#7,'Bad data for analysis',clf);
          tstr:= 'Malvern ERROR = ' + error;
          end;
360:      Writeln('Incorrect Command (Bad connection?)');
else      begin  CLS;
          Writeln('Unfamiliar Malvern error encountered: ',error);
          Writeln('- please report it to Roy Bateman or Adrian Arnold.');
          writeln(clf,' Press any key to contiue'); quit:= false;
          repeat write(#7); delay(3000); quit:= keypressed;
          until quit;
          end;
     end {case malerno};
End;

PROCEDURE MALVERN; {Malvern terminal}
Begin
   Writeln(ctf,#10); Repeat
     Write('Please state the instruction (CC for Ctrl C, MM for menu): ');
     Read(kbd,ma); read(kbd,mb);
     ma:= upcase(ma); mb:= upcase(mb);
     if ((ma ='C') and (mb ='C')) or ((ma ='D') and (mb ='D'))then
        begin ma:= #0;  mb:= #3; end;
     Writeln(aux,'C011');
     Case mb of
          'E','N':      begin Malvindat; Malvin(md[0]); end;
          'R':          begin writeln(aux,'WR'); malvwr(mpg); end
        else begin           {all other commands}
             writeln(aux,ma,mb);
             malvio(mpg,false); end;
        end {case mb};
      write(#7); writeln(aux,#4,#4,#4);
   until (ma = 'M') and (mb = 'M');
End;

PROCEDURE MALVLOAD; {Rapid LOading and DUmping etc}
label out;
var   Seq: char;

Begin
quit:= false;
writeln(clf,'                          Rapid LOading and DUmping facility',clf);
writeln('Make sure that the remote switch is plugged in otherwise readings will take ')
writeln('place in very rapid sucession!',clf);
writeln('Press W if you wish to WRite raw data after each reading');
writeln('Press B for a BAckground count before readings');
write('Press ANY OTHER KEY for readings only ');
read(kbd,Seq); Seq:= upcase(Seq);
writeln(seq); writeln(aux,'C011');
repeat
      writeln(cdf);
      writeln(aux,'BA'); malvio(mpg,false);
      writeln(aux,'WR'); malvwr(mpg);
      write('Is the initial BAckground reading acceptable? Y/N ');
      until OK=true;
   repeat
     if Seq = 'B' then begin
        writeln(clf,'Press ANY KEY when ready for BAckground reading');
        read(kbd,ch); writeln(aux,'BA'); malvio(mpg,false); end;
     writeln('I simply await a press on the remote button.....');
     writeln('pressing any key beforehand will break the cycle');
```

```
      writeln(aux,'LO');
      malvio(mpg,false);
      if keypressed then begin
         quit:= true; goto out; end;
      if Seq in ['B','W'] then begin
         writeln(aux,'WR'); malvwr(mpg); end;
      writeln(aux,'DU');
      malvio(mpg,false);
   out:      write(#7);
   until quit;
writeln(aux,#4,#4,#4);
End;

Procedure Rosramval(calc:  boolean); {Calculate VMD,NMD if true}
Const
RMDconst: array[0..19,0..9] of real =  {VMD/NMD Data Matrix for Rosin Rammler}
((999,999,999,999,999,3.65E+08,1.89E+07,2.27E+06,4.62E+05,1.33E+05),
(4910,2160,1080,600,360,230,154,107,76.8,56.6),
(42.4,32.3,24.9,19.4,15.2,12.1,9.66,7.82,6.41,5.34),
(4.516,3.883,3.391,3.009,2.710,2.468,2.275,2.118,1.988,1.881),
(1.790,1.713,1.647,1.589,1.540,1.498,1.460,1.427,1.397,1.370),
(1.347,1.324,1.306,1.288,1.271,1.257,1.243,1.230,1.219,1.209),
(1.198,1.190,1.182,1.173,1.167,1.159,1.153,1.147,1.141,1.136),
(1.131,1.126,1.122,1.117,1.113,1.109,1.105,1.102,1.099,1.096),
(1.093,1.090,1.087,1.085,1.083,1.080,1.077,1.076,1.074,1.071),
(1.069,1.068,1.066,1.064,1.063,1.061,1.060,1.058,1.057,1.056),
(1.054,1.053,1.052,1.050,1.050,1.048,1.047,1.047,1.046,1.044),
(1.043,1.042,1.042,1.041,1.040,1.039,1.038,1.038,1.037,1.037),
(1.035,1.035,1.034,1.034,1.033,1.033,1.032,1.031,1.031,1.030),
(1.030,1.029,1.029,1.028,1.028,1.027,1.027,1.027,1.026,1.026),
(1.025,1.025,1.025,1.024,1.024,1.023,1.023,1.023,1.023,1.022),
(1.022,1.021,1.021,1.021,1.021,1.021,1.020,1.020,1.020,1.019),
(1.019,1.019,1.019,1.018,1.018,1.018,1.018,1.018,1.017,1.016),
(1.016,1.016,1.016,1.016,1.016,1.016,1.016,1.015,1.015,1.015),
(1.015,1.015,1.014,1.014,1.014,1.014,1.013,1.013,1.013,1.014),
(1.013,1.013,1.013,1.012,1.012,1.013,1.013,1.012,1.012,1.012));

Begin
     If pos('ERROR',mdt[SN]) <> 0 then begin
        Writeln(clf,'Data found to be bad on first run',clf);
        Malverror:= true; EXIT; End;
     PE:= round(Exnum(mdt[SN],5,7)); W:= Exnum(mdt[SN],16,7); E:= Exnum(mdt[SN],26,8);
     If calc = true then begin
          WU:= -exp(ln(UL/PE)*W); WL:= -exp(ln(LL/PE)*W);
          if WU<-38 then WU:= -38; if WL<-38 then WL:= -38;
          WU:= exp(WU) * 100; WL:= 100 - (exp(WL)*100);
          I:= trunc(W); Y:= round(frac(W)*10); VNR:= RMDConst[I,Y];
          rnum:= exp(ln(abs(ln(0.5)))*(1/W)) * PE;
          NMD:= round(rnum/VNR); VAD:= round(sqrt(rnum*rnum/VNR)); VMD:= round(rnum);
          ADV:= 4/3000*Pi*exp(ln(sqrt(rnum*rnum/VNR)/2)*3);
     end {if calculation};
End {rosramval};

PROCEDURE AUTOMALV; {Automatic anlysis of dumped Malvern readings}

label GOPos;
var
     FVRes,FVInt:         Text;
     FNRES,FNINT:         str12;
const
     intfilerror:         boolean = false;
```

```
    Procedure saveres(SetNo: integer);
         begin
              writeln(clf,'Saving Table ',SetNo,' on file: ',FNRES,clf);
              str(SetNo,tstr);
              tstr:= 'SET NUMBER = '+ tstr + CLF + Title[SetNo];
              Writeln(FVRes,CLF,tstr);
              if mpg = '*' then write(FVRes,mdt[SetNo],mch[1]);
              for Y:= 2 to X do
                  write(FVRes,mch[Y]);
         end {saveres};

    Procedure RecvPEWE(fin: char);
         begin
              mdt[SN]:= ''; repeat  read(aux,ch);
                     mdt[SN]:= mdt[SN] + ch; until ch = fin;
              writeln(clf,mdt[SN],'.. has been saved on array.',clf);
         end {PEWE};

Begin
    Repeat
          CLS; TS; Writeln(cdf);
          writeln('Press: I to input labels from an <.INT> file,');
          writeln('       L to prepare labels,');
          writeln('       M to return to the main menu,');
          writeln('       C to continue...',cdf);
          repeat read(kbd,ch); ch:= upcase(ch); until ch in ['I','M','C'];
          case ch of
               'I': begin  repeat
                           Intread(intfilerror, false);
                           until intfilerror = false; end;
               'L': begin writeln(clf); Labelset; end;
               'M': EXIT;
               end {case ch};
          until ch = 'C';
    write(cdf,'Data sets to be analysed are: ',beg,' to ',en,', is this alright? Y/N ');
       if OK=false then Begen;
    if (beg < labeled[1]) or (en > labeled[2]) then begin
       Write(#7); Labelset; end {if};
    filename('*  ');  FNRES:= FileNCore+'.RES'; FNINT:= FileNCore+'.INT';
  writeln; writeln(aux,'C011'); TS;
  Ctrl C(malverror); Ctrl C(malverror); {remove rubbish on line}
  ma:= 'N'; mb:='E'; malvindat;
  Case mpg of
  '#': Malvin(2);
  '*': begin
       md[2]:= round(fl/10); Malvin(2);
       assign(FVInt,FNINT);      rewrite(FVInt);
       For SN:= beg to en do
           begin
           Writeln(FVInt,Title[SN]);
           ma:= 'R'; mb:= 'E'; md[1]:= SN; malvin(1);
           TS; writeln('Please wait ...');
           writeln(aux,'GO');
  GOPos:   malvio('P',true);
           if malverror = true then begin       {Malvern error handling}
              malver(malerno); malverror:= false;
              if malerno = 506 then goto GOPos else
                 writeln(FVInt,tstr);
              end {malverror = true}
           else begin
              malvio('>',false);
              RecvPEWE(#10);
```

```
              writeln(clf,'Saving labels,PE, W and E on file: ',FNINT,clf);
              write(FVInt,mdt[SN]); write(mdt[SN]);
              malvio(mpg,true);
              end {malverror = false};
           end {SN loop};
       close(FVInt);
       ma:= 'N';mb:= 'E'; md[1]:= nu; md[2]:= fl; Malvin(2);
       end {case mpg of *: initial loop};
  end {case mpg};
  {*** Main Receiving/ Saving Loop ***}
  assign(FVRes,FNRES);  rewrite(FVRes);
  writeln(FVRes,mpg,clf,Person,clf,Dtl,clf);
  For SN:= beg to en do
      begin
      ma:= 'R'; mb:= 'E'; md[1]:= SN; malvin(1);
      TS; case mpg of
        '#': begin
             writeln(aux,'GO');
                  if SN>beg then begin
                     if SN>beg+1 then append(FVRes);
                     saveres(SN-1); close(FVRes); end;
             malvio('E',true);
             if malverror = true then begin       {Malvern error handling}
                  malver(malerno); malverror:= false;
                  writeln(FVRes,tstr);
                  end {malverror = true}
             else begin
                  malvio('+',false);
                  malvio(mpg,true);
                  end {error = false};
             end {case #};
        '*': begin
             write(mdt[SN]); rosramval(false);
             if malverror = false then begin
                ma:= 'S'; mb:= 'E'; md[1]:= (PE*10)-5; Malvin(2);
                writeln(aux,'CO');
                  if SN>beg then begin
                     if SN>beg+1 then append(FVRes);
                     saveres(SN-1); close(FVRes); end;
                malvio('>',false);
                RecvPEWE('>');
                malvio(mpg,true);
                end {malverror = false}
             else malverror:= false;
             end {case *};
        end {case mpg};
        end {receiving/saving loop};
    writeln(aux,#4,#4,#4);
    if en>beg then append(FVRes);
    saveres(SN); close(FVRes);
    if mpg = '*' then begin
    writeln(clf,'Saving labels,PE, W and E on file: ',FNINT,clf);
    intdisc(true); end {*};
End;

{-------------------------------------------------------------------------------}
PROCEDURE PRINTOUT;
Var
   FV:          Text;
   FN:          str12;
   NN:          real;
   all,rdat:    boolean;
```

```
   datype,Opt: char;
   M:          array[1..64,0..16,1..4] of real;
   sizedata:   array[1..15] of str20;

Const
{Codes for IPARC logo}
IPARC:          array[1..10] of string[21] =
(#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#1#1#0#0#0#0,
#0#0#1#7#7#15#15#7#7#1#0#0#0#24#126#126#255#255#126#126#24,
#7#7#14#30#63#63#30#14#6#6#6#14#127#255#255#255#254#254#254#127#15,
#7#7#135#230#254#254#254#254#230#135#3#3#3#6#6#14#110#110#15#7#7,
#255#255#0#0#255#255#0#0#103#103#103#7#15#252#224#129#23#119#23#129#224,
#252#255#255#0#0#103#99#97#8#28#255#131#1#56#124#124#124#56#125#255#255,
#192#192#224#237#237#224#192#192#128#128#128#131#207#255#255#255#255#207#131#192#192,
#224#252#254#254#255#255#254#254#252#224#192#192#192#224#240#248#248#240#224#192#192,
#48#252#252#254#254#252#252#48#0#0#0#0#192#192#224#224#192#192#0#0#0,
#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0#0);
{Lines are too long for compiler!}

Procedure readtab; {read tables from <.RES> files}
        procedure tabproc(i: byte); {extract data from tables}
        begin
          M[SN,i,4]:= exnum(mdt[0],11,10);
          case datype of
          '#': begin
               if SN = beg then sizedata[i]:= copy(mdt[0],1,19);
               M[SN,i,1]:= exnum(mdt[0],23,8); M[SN,i,3]:= exnum(mdt[0],37,8);
               end;{#}
          '*': begin
               if SN = beg then sizedata[i]:= copy(mdt[0],3,19);
               M[SN,i,1]:= exnum(mdt[0],25,8); M[SN,i,2]:= exnum(mdt[0],48,8);
               end;{*}
             end{case};
        end; {sub-subprocedure tabproc}
begin
     Filename('RES');    FN:= FileNCore+'.RES';
     Writeln(clf,clf,'Reading Malvern output on ',FN,'.  Please wait ...',clf);
     assign(FV,FN);   reset(FV);
     read(FV,ma); readln(FV);
     readln(FV,person); readln(FV,Dtl);
     If (ma <> '#') and (ma <> '*') then begin
        writeln(cdf,#7,'Malvern analysis type not flagged');
        writeln(#9,#9,'- Press I if model Independent or');
        write(#9,#9,'  press R if Rosin Rammler data is expected I/R');
        Repeat read(kbd,ch); ch:= upcase(ch); until ch in ['I','R'];
        end {Preparation for old RES files};
     If (ma = '#') or (ch = 'I') then datype:= '#' else datype:= '*';
     Beg:= 0; write(datype);
     Repeat
           repeat readln(FV,tstr);
                  until pos('SET NUMBER',tstr)>0;
           mdt[0]:= tstr;
           SN:= round(exnum(mdt[0],14,4)); write(SN:3,'   ');
           If beg = 0 then begin
              beg:= SN; labeled[1]:= SN; end;
           readln(FV,Title[SN]);
           readln(FV,mdt[SN]); writeln(mdt[SN]);
           repeat readln(FV,mdt[0]);
                  until length(mdt[0]) > 1;
           error:= pos('*******',mdt[0]);
           if error > 0 then begin
              delete(mdt[0],error,7); insert('1500.00',mdt[0],error); end;
```

```
            M[SN,0,3]:= 100; M[SN,0,4]:= exnum(mdt[0],1,10);
            tabproc(1);
            for I:= 2 to 15 do begin
                readln(FV,mdt[0]); tabproc(I);
                end {reading table SN};
            readln(FV); read(FV,ch); write(ch);
            until SeekEof(FV) = true;
     writeln(clf,'END OF FILE ENCOUNTERED');
     en:= SN; labeled[2]:= SN; rdat:= true;
     close(FV);
end {subprocedure readtab};

Procedure Mival; {Calculate VMDs etc.- M.I.}
var       P:      real;
   procedure param(A,B,limit: integer);
   begin
        I:= 0; repeat I:= I+1; until (M[SN,I,A] <= limit) or (I=16);
        rnum:= ((limit-M[SN,I,A])*(M[SN,I-1,B]-M[SN,I,B]))
                      /(M[SN,I-1,A]-M[SN,I,A]) + M[SN,I,B];
   end;

begin
     E:= exnum(mdt[SN],4,8);
     M[sn,16,3]:= 0.0; M[sn,16,4]:= 0.0;
     Param(4,3,LL); WL:= rnum;
     Param(4,3,UL); WU:= 100-rnum;
     Param(3,4,50); VMD:= round(rnum); VNR:= rnum;
     P:= 0; For I:= 1 to 15 do P:= P + M[SN,I,1]/exp(ln((M[SN,I-1,4]+M[SN,I,4])/2)*3);
     M[SN,16,2]:= 0; For I:= 15 downto 1 do {cumul. % by number}
        M[SN,I,2]:= M[SN,I+1,2] + (100*M[SN,I,1])/exp(ln((M[SN,I-1,4]+M[SN,I,4])/2)*3)/P;
     I:= 0; repeat I:= I+1; until M[SN,I,2] <= 50;
     rnum:= (50-M[SN,I,2])*(M[SN,I-2,4]-M[SN,I-1,4])/(M[SN,I-1,2]-M[SN,I,2]) +M[SN,I-1,4]
     NMD:= round(rnum); VNR:= VNR/rnum;
     rnum:= 0; M[SN,0,2]:= 0; For I:= 1 to 15 do M[SN,I,2]:= M[SN,I,2] - M[SN,I+1,2];
     For I:= 1 to 15 do
         rnum:= rnum + M[SN,I,2]*(exp(ln((M[SN,I-1,4]+M[SN,I,4])/2)*3))/100;
     rnum:= exp(ln(rnum)*(1/3)); VAD:= round(rnum);
     ADV:= exp(ln(rnum/2)*3)*4*pi/3000;
End;

Procedure showdata;

begin
     write(' ':10); pln(1,50,datype);
     writeln(clf,' ':12,'Upper size  Lower size        Volume    Number');
     If datype = '#' then Mival else Rosramval(true);
     write(' ':10); pln(1,50,'-'); writeln;
     for Y:= 1 to 15 do
         writeln(M[SN,Y-1,4]:20:2,M[SN,Y,4]:12:2,M[SN,Y,1]:15:2,M[SN,Y,2]:10:2);
     write(' ':10); pln(1,50,datype);
     write(clf,'VMD = ',VMD,'  NMD = ',NMD,'  VMD/NMD Ratio = ',VNR:7:3);
     writeln('  VAD = ',VAD,'  ADV =',ADV:8:0);
end;

Procedure printgraphs;

          Procedure printbar(N: real);  {8 dot graphic image selection}
           var  lenth: integer;
           begin
                 write(lst,N:7:2,' ');
                 lenth:= round(140*N/75);
                 {If lenth = 9 then lenth:= 10}
```

```
                write(lst,#27,'*',#5,chr(lenth),#0);
                For I:= 1 to lenth do
                          write(lst,chr($FF));
                Write(lst,#27,'J',#0,#27,'J',#0); {for Citizen printers}
          end {sub subprocedure printbar};

begin  STP:= STP + 1;
  If odd(stp) = true then begin
     writeln(lst,#27,#14,#27,'E',' MALVERN ST1800 P.S.A. DROPLET ANALYSIS',#27,'F');
     Writeln(lst,#27,'3',#24,#27,'1',#10); {1/9" line spacing, left margin: 10}
     For I:= 1 to 10 do begin
                          if odd(I) = true then write(lst,#27,'*',#5,#42,#0);
                          write(lst,IPARC[I]);
                          if odd(I) = false then writeln(lst,#27,'J',#0,#27,'J',#0);
                       end {IPARC logo};
     write(lst,#27,'j',#115,#27,#15,#27,'1',#75,#27,'S',#1,#27,'0');
     {reverse paper feed,condensed,LM75,subscript,1/8"line spacing}
     If datype = '#' then write(lst,'Model Independent ');
     write(lst,'LASER particle size analysis ');
     If datype = '*' then writeln(lst,'using Rosin Rammler model') else writeln(lst);
     writeln(lst,'Data file; ',FileNCore,'.  Date of analysis: ',Dtl);
     writeln(lst,'Measurements by ',person);
     writeln(lst,'Programmes; MSC & DROPDATA by Roy Bateman (1986)');
     writeln(lst,#27,'2',#27,'T',clf);     {1/6" line spacing, cancel sscrpt.}
  end {odd stp: heading};
 {Printout OF GRAPHS and analysis}
 showdata {includes calculations}; write(lst,#27,'1',#5);
 if length(Title[SN])<66 then write(lst,#14) else write(lst,#18);
 writeln(lst,Title[SN],clf,#9,#27,#15,'DATA: Set Number ',SN,',  ',mdt[SN],#18);
 pln(2,73,'-'); writeln(lst);
 writeln(lst,' SIZE RANGE (,m.)    PERCENT BY VOLUME          PERCENT BY NUMBER');
 pln(2,73,'-'); writeln(lst,#27,'M'); {elite}
 If datype = '#' then NN:= M[SN,15,4] else NN:= 0;
 write(lst,#27,'1',#6);
 For Y:= 1 to 15 do begin
         write(lst,sizedata[Y],' :');
         If datype = '*' then NN:= NN + M[SN,Y,1];
         Printbar(M[SN,Y,1]);   write(lst,#27,'1',#60);
         Printbar(M[SN,Y,2]);   writeln(lst,#27,'1',#6);
 end {Y loop};
 write(lst,#27,'1',#7,#27,'P',#27,#15);
 Case datype of
 '#':  begin write(lst,'  Any droplets less than ',NN:5:2);
       writeln(lst,',m. in diameter, have not been accounted-for.'); end;
 '*':  begin
          if NN>100 then NN:= 100; {rounding errors}
          writeln(lst,'  Droplets accounted-for:',NN:6:2,'%'); end {datype = *};
 end {case};
writeln(lst,#18,#27,'E',#27,'1',#5); {line,pica,emphasised}
writeln(lst,#9,'VMD = ',VMD,'  NMD = ',NMD,'  VMD/NMD Ratio = ',VNR:6:2,'  VAD = ',VAD);
write(lst,#27,'F','VOLUME % DROPLETS: <',LL,',m. = ',WL:5:2,', >',UL);
writeln(lst,',m. = ',WU:5:2,'; ADV = ',ADV:8:1,'pl.',#27,'E'); {ensure normalised}
write(lst,#9,'DROPLETS IN DESIRED SIZE BAND (Assuming above criteria): ');
writeln(lst,(100-WL-WU):5:2,'%',#27,'F'); pln(2,73,'_'); writeln(lst,clf,clf);
If odd(STP) = false then writeln(lst,#12) else write(lst,#27,#15);
write(lst,#27,'1',#0);
end {subprocedure printgraphs};

Procedure readwrite;
begin
   readln(FV,tstr);
   writeln('   ',tstr);
```

```
   if print = true then begin
      if ((pos('######',tstr)<>0) or (pos('******',tstr)<>0))
         then write(lst,#27,'E',#18,#13);
      writeln(lst,'     ',tstr); end;
end {subprocedure readwrite};

Procedure Fline(lineseg:char);
begin
     for I:= 1 to 74 do begin
         write(lineseg); if print = true then write(FV,lineseg); end;
     writeln; if print = true then writeln(FV);
end;

Procedure Printon;
begin
     Writeln(cdf,#7,'Make sure that the printer is turned on'); Waitkey;
     write(lst,#27,'R',#0); {Set US char. set for "#"}
     write(lst,#27,':',#0,#0,#0,#27,'&',#0,',,'); {Define Micron}
     write(lst,#11,#1,#6,#120,#4,#0,#0,#4,#120,#4,#0,#0);
     write(lst,#27,'%',#1,#0); {set micron char.}
end;

Begin {main procedure}
rdat:= false; Repeat
CLS; writeln(cdf);
writeln('  I L L U S T R A T I O N  O F  D R O P L E T  D I S T R I B U T I O N S');
writeln(#9,#9,'(Malvern output to this programme only)',cdf);
writeln('Two file types can be printed-out, or TAB files can be created from RES files:');
writeln('Results tables from MODEL INDEPENDENT analyses can also be "massaged" as ');
writeln('explained in the notes, but this is inferior to adjusting raw data.');
writeln(cdf,'  R:',#9,'Print full data - files ending in *.RES - with GRAPHICS');
writeln('  T:',#9,'Print summary tables - files ending in *.TAB');
writeln('  C:',#9,'Create a *.TAB file');
writeln('  D:',#9,'Data illustration (and massage)');
writeln('  M:',#9,'Return to MENU');
Write(clf,'Which do you require? R/T/C/D/M (Return to main Menu for new data file.)');
       Repeat read(kbd,Opt); Opt:= upcase(Opt);
              until Opt in ['R','T','C','D','M']; writeln(clf);
Case Opt of
 'M':     EXIT;
 'D':     begin
              If rdat = false then Readtab;
              write(ctf,' Press ANY KEY to continue ... and henceforeward to ');
              write('carry-on to next data set '); read(kbd,ch); CLS; UL:=9; LL:=1;
              For SN:= beg to en do begin
                  writeln(ctf,ctf,SN,'     ',Title[SN]); showdata; read(kbd,ch);
                  if datype='#' then begin
                     write(clf,#9,'DO YOU WISH TO MASSAGE THIS TABLE? Y/N  ');
                     if OK  then begin
                        rnum:= M[SN,1,1]; M[SN,1,1]:= 0;
                        for I:= 1 to 15 do
                            M[SN,I,3]:= M[SN,I,3] + rnum;
                     showdata; waitkey; end {if OK}; end {if #};
                  end;
          end {illustrating and massaging data};
 'C':     begin
              If rdat = false then begin
                write(cdf,'Is data to be taken from a final ROSIN RAMMLER *.INT file?');
                if OK then begin writeln(cdf); Intread(malverror,true);
                    if error=99 then EXIT; datype:= '*';
                    end else Readtab; end {rdat};
              Sizeband; FN:= FileNCore+'.TAB';
```

```
            write(clf,clf,'Summary table to be written to file: ',FN,', is this OK? ')
            if OK then print:= true else print:= false;
            if print = true then begin assign(FV,FN); rewrite(FV); end;
            tstr:= '   Data on files: ' + FileNCore + '.  Measurements by: ';
            tstr:= tstr + person + ' on ' + Dtl;
            Fline(datype); writeln(tstr); if print = true then writeln(FV,tstr);
            Fline('-'); If datype = '*' then
                 mdt[0]:= ' NO  P.E.  W    ERROR   ' else
                 mdt[0]:= ' SET NO. ERROR   CONF.  ';
            str(LL:3,tstr);
            mdt[0]:= mdt[0] + 'VMD   NMD  VMD/NMD    VAD   ADV   LL(' + tstr;
            str(UL:3,tstr);
            mdt[0]:= mdt[0] + ') UL(' + tstr + ')';
            writeln(mdt[0]); if print = true then writeln(FV,mdt[0]);
            Fline('-'); For SN:= beg to en do begin
               if print = true then writeln(FV,title[SN]);
               if datype = '*' then begin Rosramval(true);
                   str(SN:3,mdt[0]); str(PE:5,tstr); str(W:5:1,weight);
                   mdt[0]:= mdt[0] + tstr + weight; str(E:8:0,tstr) end
               else begin Mival;
                   str(SN:4,mdt[0]); str(E:10:0,tstr); mdt[0]:= mdt[0] + tstr;
                   error:= trunc(ln(E)/ln(10));
                   case error of
                         1:     tstr:= '  *****';
                         2:     tstr:= '   ****';
                         3:     tstr:= '    ***';
                         4:     tstr:= '     **';
                         5:     tstr:= '      *';
                         6..9:  tstr:= '   N.S.';
                         end {case error};
                   end {datype #};
               writeln(mdt[0],tstr,VMD:6,NMD:6,VNR:9:3,VAD:6,ADV:8:0,WL:8:2,WU:8:2);
               if print = true then
                writeln(FV,mdt[0],tstr,VMD:6,NMD:6,VNR:9:3,VAD:6,ADV:8:0,WL:8:2,WU:8:2

               end {FV}; Fline(datype);
            if print = true then close(FV); waitkey;
         end {creating TAB file};
'T':     begin
            Filename('TAB');  {Printout of summary table}
            FN:= FileNCore+'.TAB';
            assign(FV,FN);      reset(FV);
            CLS; write(clf,'Press P for a printout otherwise VDU display only');
            read(kbd,ch); If ch in ['P','p'] then begin
                          print:= true; Printon;
                          end else print:= false;
            repeat readwrite; until pos('----',tstr) <> 0;
            readwrite; mdt[0]:= tstr; readwrite;
            SN:= 1; Repeat
                   If print = true then begin
                     if odd(SN) = true then begin
                             if (SN=51) or (SN=101) then begin
                                write(lst,#12,#27,'E',clf,'     '); pln(2,74,'-');
                                write(lst,clf,'     ',mdt[0],clf,'     ');
                                pln(2,74,'-'); writeln(lst); end;
                             write(lst,#27,'F',#15,'      '); {condensed on} end
                        else write(lst,#27,'E',#18); {condensed off}
                     end {print prep.};
                   Readwrite; SN:= SN+1;
                   until EOF(FV) = true;
            If print = true then  write(lst,#27,'F');
            writeln(cdf,#9,#9,#7,'END OF FILE - To printout more reselect option');
```

```
                If print = true then writeln(cdf,'Form feed to the end of page? Y/N');
                If OK then write(lst,#12);
                Close(FV);
                end {case .TAB};
 'R':      begin
                If rdat = false then Readtab; Printon; Sizeband; CLS;
                stp:=0; writeln(cdf);
                write('Do you wish to make a printout of EVERY DATA SET on this file? ');
                If OK then all:= true else all:= false;
                write(ch,clf,clf); {Start of search/print loop}
                For SN:= beg to en do begin
                       if all = false then begin
                          writeln(clf,SN,'  ',Title[SN]);
                          write(#9,'DO YOU WISH TO PRINT THESE DATA? Y/N  ');
                          if OK then Printgraphs;
                          end {all = false}
                       else printgraphs;
                       end {printout loop};
                if odd(STP) = true then write(lst,#12);
                end {case RES};
 end {case Opt};
until Opt = 'M';
End {Printout procedure};

PROCEDURE RAWDAT;
{Automatic Loading/Saving of Raw Data}

label out;

var
     FVD:         Text;
     FNDAT:       str12;
     Begstr:      string[2];
     Enstr:       string[2];
     SL:          char;

     Procedure saveres; {save contents of mch array}
          begin
               writeln(clf,'Saving Table on file: ',FNDAT,clf);
               for Y:= 1 to X do
                   write(FVD,mch[Y]);
          end {subprocedure saveres};

     procedure readmd(endat: integer);
     {read data file array numbers in groups of 3}
     var   num: integer;
     begin
          for I:= 1 to endat do begin
              repeat read(FVD,ch); write(ch);
                 until ch in ['0'..'9'];
              tstr:= ch;  repeat read(FVD,ch); write(ch);
                       tstr:= tstr + ch;
                       until (ch in ['0'..'9']) = false;
              val(tstr,num,error); md[I]:= num;
              if (endat=90) and ((I+2) mod 3 = 0) and (md[I]<>(I+2)/3) then
                 begin      quit:= true; EXIT; end;
              end {reading md[I]};
          end {subprocedure readmd};
Begin
CLS; Writeln(clf,#9,#7,'SAVING AND LOADING OF RAW RESULTS IN *FILE*.DAT',cdf);
Writeln('WARNING This procedure is designed to facilitate multivariate droplet analysis')
writeln('etc..  Under normal cicumstances, you are stongly advised against creating a');
```

```
writeln('large backlog of raw data.',cdf);
writeln('Press S if you wish to Save-from  the Malvern');
writeln('      L if you wish to Load-to     "      " ');
  write('   or M to massage data already in "      "    (see notes)');
repeat read(kbd,SL); SL:= upcase(SL); until SL in ['S','L','M']; Writeln(SL,clf);
if SL in ['L','M'] then begin
   Write(#7,'You are about to OVERWRITE Data Sets on the MALVERN, Is this alright? ');
   read(kbd,ch); ch:= upcase(ch); Writeln(ch,clf);
   if ch <> 'Y' then EXIT;
   end {case SL = L,M};
writeln(aux,'C011');
if SL = 'M' then begin
           Begen; Writeln(clf); Set1stDU;
           md[1]:= 1; md[2]:= 0; md[3]:= 0; md[4]:= 2; md[5]:= 0; md[6]:= 0;
           ma:= 'I'; mb:= 'N';
           for SN:= beg to en do begin
               writeln(aux,'RE'); malvio(':',false);
               writeln(aux,SN); malvio(mpg,false);
               Malvin(7); writeln(aux,'DU'); Malvio(mpg,false); end;
           goto out; end {M};
filename('DAT'); FNDAT:= FileNCore + '.DAT';
assign(FVD,FNDAT);
case SL of
     'S':  begin {Saving using WR}
           {load labels from int file option}
           Begen; if (beg > labeled[1]) or (en < labeled[2]) then begin
              Write(#7); Labelset; end {if};
           rewrite(FVD);
           Str(Flag,tstr); Str(Beg,Begstr); Str(En,Enstr);
           Writeln(FVD,Dtl,clf,tstr,#9,Begstr,#9,Enstr);
           For SN:= BEG to EN do
               begin
               str(SN,tstr);
               Writeln(FVD,Title[SN]);
               writeln(aux,'RE'); malvio(':',false);
               writeln(aux,SN); malvio(mpg,false);
               writeln(aux,'WR');  Malvio(mpg,true);  Saveres;
               CLS; writeln; TS;
               end{SN loop};
           End {case S};
     'L':  begin {Loading result using IN}
           Writeln(clf,'Loading data sets into the malvern from selected file');
           reset(FVD);
           Repeat Readln(FVD,tstr);
                until Length(tstr)>2;
           Dtl:= tstr; Writeln('Date of data storage: ',Dtl,clf);
           Readmd(3); Flag:= md[1]; Beg:= md[2]; En:= md[3];
           Writeln(clf); Set1stDU;
          ma:= 'I'; mb:= 'N';
          Writeln(clf,'Reading data from disc and sending to Malvern',clf);
          For SN:= Beg to En do begin
               Repeat Readln(FVD,tstr);
                 until Length(tstr)>2;
               Title[SN]:= tstr; Writeln(cdf,'SET NUMBER = ',SN);
               Writeln('LABEL > ',Title[SN]);
               Readln(FVD,tstr);
                     if tstr<>'WR' then begin
                     Writeln(#7,'DATA POSITIONING ERROR'); Delay(3000); Goto out;
                     end {if data positioning error};
                     Quit:= false; Readmd(90); writeln(clf);
                     If quit = true then begin
                        Writeln(#7,'DATA FORMAT ERROR'); Delay(3000); Goto out; end;
```

```
            Malvin(91); writeln(aux,'DU'); Malvio(mpg,false);
            CLS; TS;
            end {SN loop};
          labeled[1]:= Beg; labeled[2]:= En;
          end {case L};
     end; {SL cases}
out: writeln(aux,#4,#4,#4); Close(FVD);
End {procedure Rawdat};

PROCEDURE MALVERNLOADER;
var
   FV:    file of char;

type
   FN  =  str8;

Function hextobt(A,B: Char): Integer;
         function N(C: char): Integer;
         begin
              if C in ['A'..'F'] then N:= ord(C)-ord('A')+10
              else N:= ord(C)-ord('0');
         end {function N};
   begin
   hextobt:= N(B)+(16*N(A));
End {function hextobt};

  Procedure Loader(ovl: FN; progtype: char);
  begin
       Comport(ch,flag,4,$A); Comport(ch,flag,6,7); Comport(ch,flag,8,3); {2400,2,7,None}
       Comport(ch,flag,5,$A); Comport(ch,flag,7,7); Comport(ch,flag,3,0); {<- initialise}
       CtrlC(malverror); Comport(ch,error,6,8); Comport(ch,error,8,1); {2400,1,8,None}
       Comport(ch,flag,3,0); assign(FV,ovl); reset(FV);
       Writeln(clf,'WHILE TONE SOUNDS, FLICK-UP BOOT SWITCH ON MALVERN then DOWN AGAIN');
       Waitkey; writeln(cdf,'Loading file into Malvern - Please tarry awhile ...');
       While not Eof(FV) do begin
             Read(FV,ma); Read(FV,mb);
             write(aux,chr(hextobt(ma,mb)));
             if hextobt(ma,mb)=128 then Write(#7);
             end {while not Eof};
       Close(FV);
       writeln(cdf,#7,'Switch the Malvern off then on again before continuing ...');
       writeln('... BUT RETAIN THE DIRECT LINK.');
       Comport(ch,flag,6,7); Comport(ch,flag,8,3); Comport(ch,flag,3,0); {2400,2,7,None}
       Waitkey; Write(aux,#3); delay(2000); Repeat
          comport(ch,error,2,I); write(ch);
          until error = - 1; CtrlC(malverror);
       if (malverror=false) or (progtype<>ch) then begin   mpg:= '$'; TS;
          write(#7,'Malvern programming unsucessful - please try again.');
       end  else begin   mpg:= ch; TS;
          write(clf,'Malvern contact sucessful ... now reconnect the Infa Plug if OK');
       end; waitkey;
       Comport(ch,flag,4,$E); Comport(ch,flag,6,8); Comport(ch,flag,8,1); {9600,1,8,None}
       Comport(ch,flag,5,$E); Comport(ch,flag,7,8); Comport(ch,flag,3,0);
    End {subproc};

begin
     CLS; Writeln(cdf);
     writeln('              M A L V E R N L O A D E R (Splendidsoft)',cdf);
writeln('The Apricot is presently connected to the Malvern via the InfaPlug circuit.');
writeln(cdf,'In order to reprogramme the Malvern you must:');
writeln(' - connect the two computers by a direct cable (in cupboard on left)');
writeln(' - make sure that the Malvern programme required has been copied onto B:');
```

```
 Writeln(cdf,'Press 1 for Rosin Rammler Programme');
     writeln('Press 2 for Model Independent Analysis');
       write('Press 3 to Return to Menu ');
             Repeat read(kbd,ch);
                    until ch in ['1','2','3'];
             Writeln(ch,cdf,'Check the set-up and ...'); waitkey;
     Case ch of '1':   Loader('B:RR.HEX','*');
                '2':   Loader('B:MI.HEX','#'); end {case};
END; {All Procs.}

{-------------------------------------------------------------------------------
PROGRAMME MENU
}
label 0001, 0005;

BEGIN
{Set Malvern constants}
   mpg:= '$'; beg:=0; en:=0; flag:= 0; SN:= 0;
   for Y:= 1to 64 do Title[Y]:= ''; FileNCore:= '';
{Set Sartorius constants}
   dty:=  1.0;  timelapse:= 10;  rdgs:= 4;  NZ:= 0;
   title[0]:= ' Title:  Flowrate';
{Set screen scrolling region from lines 3 to 24}
   CLS; write(#27,'[2;23r'); TS;

{Initial sequence establishing status of Malvern}
writeln(ctf,'The date is understood to be ',date);
write('Press TIME/DATE button if this needs correcting then any other key to continue');
read(kbd,ch); TS; write(cdf,'And who is the lucky worker today then ?');
readln(person); if person = '' then person:= 'Roy Bateman'; quit:= false;
   Repeat
         writeln(aux,'C011'); write(ctf,#9,'Please wait');
         CtrlC(quit); if quit=false then begin
              writeln(#7,cdf,#9,'CONTACT WITH MALVERN NOT ESTABLISHED ...');
              write('... press C to continue or ANY OTHER KEY to try again');
              read(kbd,ch); if ch in ['C','c'] then quit:= true;
              end;
         writeln(aux,#4,#4,#4);
         until quit = true;
{Start Menu loop}
0001: repeat
     Dtl:= date; CLS; TS; writeln(cdf);
     write('     MALVERN AND SARTORIUS CONTROLLER PROGRAMME Version 4.41 (Splendidsoft)');
     writeln(cdf,'                                    By Roy Bateman');
     writeln(cdf);
     if mpg = '$' then goto 0005;
       writeln('  1.    Malvern TERMINAL');
       writeln('  2.    Rapid LOading and DUmping of data into Malvern');
       writeln('  3.    Complete automatic analysis of dumped Malvern data');
       writeln('  4.    Load, Store or Massage Raw Data (automatic WR and IN)');
0005:  writeln('  5.    Calculations and Printout or Display of Analyses');
       writeln('  6.    Display Explanatory NOTES');
       writeln('  7.    Programme the Malvern');
       writeln('  8.    FLOW RATES using Sartorius balance');
       writeln('  9.    Handle stored Sartorius data');
       writeln('  0.    EXIT from programme');
     read(kbd,ch); CLS; TS;
     writeln(aux,#4,#4,#4);   {make sure InfaPlug is disconnected}
     case ch of
           '1':    malvern;
           '2':    malvload;
           '3':    automalv;
```

```
            '4':    rawdat;
            '5':    printout;
            '6':    notes;
            '7':    malvernloader;
            '8':    sartorius;
            '9':    sartdata;
           else write(#7);
       end {case menu options};
     until ch = '0';
   write(ctf,'Are you sure that you wish to LEAVE THE PROGRAMME? ');
   if OK then write(#27,'[0;23r') else goto 0001;
   ClrScr;
END.
```

Appendix III.

A SWATH PATTERN INTEGRATION PROGRAMME

SWATH has been written in BASIC, and although it is rather slow, taking several minutes to carry out an analysis, it has the advantages of flexibility and familiarity.

Data can be entered from within the programme, stored and retrieved from disc, or can be recovered from the text file output of a spreadsheet (enabling data to be received from all packages with an ASCII output). Since readings are often taken at irregular distances - usually the greater the distance from the spray line the further apart the sampling points - the programme firstly interpolates calculated deposit levels at 0.1m. intervals. These levels are also used to estimate the area under the deposit curve for recovery rate assessment methods such as those described by Pickin in Heinrichs et. al.. (1981).

The levels are copied from the single swath (ITT%) array onto elements of the totals (TOT%) array at regular starting points, corresponding to the swath width. The final calculations are of the mean and variance of estimated deposits in the "downwind" 10 m. of field, and an estimate of exodrift in arbitrary units represented by the area under the curve to the right of the "downwind" field margin. The variance/mean ratio is an indicator of the degree of homogeneity of population densities (Taylor, 1961); a value of 1 would imply random distribution, and larger values would indicate increasingly severe banding of deposit levels. Printed displays are either in the form of a screen-dump for dot-matrix printers, or in a rather crude dot form using the TAB command - the latter however precludes the use of graphics commands which are often machine dependent.

Where deposited droplet data have been obtained from artificial targets, and detailed infomation on droplet spectra and wind-speed are known, it might be useful to incorporate estimates of collection efficiencies into the calculations. Graphs have been given by several authors including Johnstone et. al (1977a), however the following table may usefully illustrate impaction with droplet sizes and 25 mm. (1 inch) vertical targets, similar to those used in this study. Percentages are taken from graphs in Egner and Campbell (1958).

Efficiencies (E_V) were calculated from the ratios of the mass collected on vertical collectors (M_V) and the area dose in the vertical plane (A_V): i.e. the mass of spray that would pass through an equivalent plane if unimpeded. $M_V = A_V \cdot E_V$.

		Ribbons					Cylinders				
Droplet size (μm.)		40	60	80	100	150	40	60	80	100	150
Wind speed: miles /hour	$m.s^{-1}$	E_V (%)									
2	0.9	21	56	72	80	90	9	28	43	55	74
4	1.8	51	**73**	**83**	**87**	94	23	45	60	71	86
6	2.7	62	**79**	**86**	**91**	95	34	55	69	78	88
8	3.6	68	**82**	**88**	**92**	96	40	61	74	81	90
12	5.3	73	84	90	93	97	48	70	80	85	91

Listing of: SWATH.BAS

```
1000 REM swath sample integration programme version 3.9 (GW Basic)
1010 CLEAR: SCREEN 0
1020 PTH$="SWATHDATA\"
1030 CR$=CHR$(13): LF$=CHR$(10): E$=CHR$(27): HT$=CHR$(9): CLF$=CR$+LF$
1040 DIM RDAT(12,12),R(12,4)      :REM Readings, spray line data
1050 DIM ITT%(900)                :REM Intermediate lines of swath (up to 90m.)
1060 DIM SPRDAT$(12)              :REM 3 CALCULATED sets of readings, 12 DATA
1070 DIM TOT%(10000)              :REM Total deposits up to 1000m.
1080 XMAX%=640: YMAX%=180         :REM some computers accept 720x348 (YMAX=335)
1090 UPWIND=0:                    :REM Distance "upwind" of swath
1100 SHOCAL=0:                    :REM Show calculated data
1110 TAILS=0:                     :REM Show 'tails' of deposit
1120 INDX%=0:                     :REM Bateman's index and display flag
1130 CLS: PRINT LF$;LF$;HT$;HT$;
1140 PRINT "SWATH DROPLET PATTERN INTEGRATION PROGRAMME"
1150 PRINT LF$;HT$;HT$;HT$;"    By Roy Bateman"
1160 PRINT LF$;LF$;LF$;HT$;"    Is data to be input manually or from Disc? M/D ";
1170 Y$=INPUT$(1)
1180 IF Y$="M" OR Y$="m" THEN GOSUB 1850 ELSE IF Y$="D" OR Y$="d" THEN GOSUB 2470 ELSE PRINT
 HT$;HT$;"Kindly press appropriate key!": BEEP: GOTO 1160
1190 PRINT CLF$;"Data loading, please wait a moment.": GOSUB 4200
1200 GOSUB 2610: GOSUB 2710                    :REM Connect points in single swath
1210 UPW%=UPWIND*10: LIMIT%=(R(SP,1)*10)+UPW%  :REM # units: upwind, total swath
1220 PRINT CR$;LF$;"Hard copy of graphs may be produced using screen dump if available."
1230 PRINT"Screen dump should be activated after tone sounds, provided that GRAPHICS have"
1240 PRINT"been installed.  An alternative dot sketch option will also be offered later."
1250 PRINT"Do you intend to print out graphs? ";
1260 PRN%=0: Y$=INPUT$(1): IF Y$="Y" OR Y$="y" THEN PRN%=1
1270 GOSUB 2940:                          :REM Illustration of single curve
1280 Y$="N": IF PRN%=1 THEN PRINT CLF$;"Skip to end of page? ";: Y$=INPUT$(1)
1290 PRINT CLF$: IF Y$="Y" OR Y$="y" THEN LPRINT CHR$(12);
1300 REM Start of swath superimposition routine
1310 PRINT "Lengths are to be entered in units of 0.1 - eg: 6.8 is OK, 3.75 is not"
1320 PRINT CLF$: INPUT"What is the swath width ";SW
1330 INPUT"What is the width of the field to be treated ";EN: PRINT CLF$
1340 REM PRINT"Press V if you wish to view calculated data; otherwise press ANY OTHER KEY";
1350 REM Y$=INPUT$(1):IF Y$="V" OR Y$="v" THEN SHOCAL=1
1360 PRINT LF$;LF$;"Please wait a minute, I'm now spraying ";
1370 SW%=SW*10: EN%=(EN*10)+UPW%: NSW%=EN\SW:   :REM EN% = posn. of end of field
1380 ENDROP%=EN%+ LIMIT%-SW%                    :REM End of all deposits
1390 PATH%=EN%-SW%:                             :REM X% = posn. on TOT% array
1400 WHILE PATH%>=UPW%                          :REM Start downwind end of field
1410    Z%=0
1420    FOR X%=PATH%-UPW% TO PATH%-UPW%+ LIMIT% :REM Present spray PATH
1430            Z%=Z%+1
1440            TOT%(X%)=TOT%(X%)+ITT%(Z%)
1450            NEXT X%
1460    PRINT".";
1470    PATH%=PATH%-SW%: WEND
1480 PRINT CR$;LF$
1490 REM End of "spraying" onto TOT% array.
1500 MAX%=0: CONTAMN=0: MEAN=0: VAR=0: REM Droplets: last 10m. & downwind of field
1510 IF SHOCAL=0 THEN PRINT"I'm now checking droplet levels ...";CR$;LF$
1520 FOR X%=1 TO ENDROP%
1530    IF X%>EN% THEN CONTAMN=CONTAMN+TOT%(X%)
1540    IF X%<=EN% AND X%>EN%-100 THEN MEAN=MEAN+(TOT%(X%)/10^DPL%)
1550    IF SHOCAL=1 THEN PRINT USING "##.#";X%/10;
1560    IF SHOCAL=1 THEN PRINT "      ";USING"###.##";TOT%(X%)/10^DPL%
1570    IF TOT%(X%)>MAX% THEN MAX%=TOT%(X%)
1580    NEXT X%
```

```
1590 CONTAMN=CONTAMN*10: MEAN=MEAN/100
1600 FOR X%=EN%-99 TO EN%
1610    VAR=VAR+((TOT%(X%)/10^DPL%)-MEAN)^2
1620    NEXT X%
1630 VAR=VAR/100
1640 PRINT LF$;LF$;"Output to:";HT$;"1  Screen (screendump output if available)
1650 PRINT HT$;HT$;"2  Printer";CR$;LF$;HT$;HT$;"3  Both";CR$;LF$;LF$
1660 OPT%=ASC(INPUT$(1))-48
1670 IF OPT%=1 THEN GOTO 1700
1680 PRINT"Show 'tails' of deposit up- and downwind of field? Y/N";
1690 Y$=INPUT$(1): IF Y$="Y" OR Y$="y" THEN TAILS=1
1700 ON OPT% GOSUB 3160,3750,1830:      :REM  Graphics
1710 Y$="N": IF PRN%=1 THEN PRINT CLF$;"Skip to end of page? ";: Y$=INPUT$(1)
1720 IF Y$="Y" OR Y$="y" THEN LPRINT CHR$(12);
1730 PRINT CR$;LF$;LF$;"Do you wish to Enter new data"
1740 PRINT "                Remodel swath superimposition"
1750 PRINT "                Quit (any other key) E/R/Q? ";: Y$=INPUT$(1)
1760 IF Y$="E" OR Y$="e" THEN GOTO 1010
1770 IF Y$<>"R" AND Y$<>"r" THEN GOTO 1810
1780 PRINT CLF$;LF$;"Please wait - I am cleaning the field ..."
1790 FOR X%=1 TO ENDROP%+1: TOT%(X%)=0: NEXT X%
1800 GOTO 1300
1810 END
1820 REM ------------------------------------------------------------------------
1830 REM multiple options
1840 GOSUB 3160:GOSUB 3750:RETURN
1850 REM Manual input of data
1860 CLS: PRINT LF$;"Give a title to this experiment (maximum of 60 characters):"
1870 INPUT TITLE$
1880 PRINT LF$;LF$:INPUT"How many sample points ";SP
1890 INPUT"How many sprayers/target lines to compare (Maximum of 12) ";SR
1900 IF SR >6 OR SR<1 THEN BEEP: PRINT "Kindly answer the question";CR$;LF$:GOTO 1890
1910 PRINT CR$;LF$;"All distances must be in METRES in units of 0.1m."
1920 PRINT"Now enter the positions of the sampling points downwind of the sprayer"
1930 PRINT:                                      :REM J at 0 indicates position
1940 FOR I=1 TO SP
1950 PRINT"Position of sample point no.";I;"is ";:INPUT RDAT(I,0)
1955 REM Set positive UPWIND flag to upwind distance
1960 IF RDAT(I,0)<0 AND RDAT(I,0)<-UPWIND THEN UPWIND=-RDAT(I,0)
1970 NEXT I
1980 PRINT "UP WIND = ";UPWIND
1990 IF SR<6 THEN GOTO 2050
2000 SPRDAT$(1)="#1 windward": SPRDAT$(2)="#1 horizontal": SPRDAT$(3)="#1 leeward"
2010 SPRDAT$(4)="#2 windward": SPRDAT$(5)="#2 horizontal": SPRDAT$(6)="#2 leeward"
2020 SPRDAT$(7)="#3 windward": SPRDAT$(8)="#3 horizontal": SPRDAT$(9)="#3 leeward"
2030 SPRDAT$(10)="#4 windward": SPRDAT$(11)="#4 horizontal": SPRDAT$(12)="#4 leeward"
2040 GOTO 2100
2050 PRINT CR$;LF$;"Now name the sprayers/target lines:"
2060 SPRAYER$(1)="Sample posn. (m.)"
2070 FOR J=1 TO SR
2080 PRINT"Number";J;:INPUT"is ";SPRDAT$(J)
2090 NEXT J
2100 PRINT CR$;LF$;LF$
2110 PRINT"Readings must be calculated as integers, press 0 if data is already in integer"
2120 PRINT"form; press 1 if data is calculated to one decimal place; press 2 for"
2130 PRINT"two decimal places...etc.  Enter 999 for Bateman's index."
2140 INPUT"Data format: ";DPL%
2150 PRINT CR$;LF$;LF$;"Enter data in YOUR format"
2160 FOR J=1 TO SR
2170    PRINT
2180    FOR I=1 TO SP
2190            PRINT SPRDAT$(J); TAB(30);"at";:
```

```
2200            PRINT USING"###.# ";RDAT(I,0);: PRINT"m.";TAB(50);
2210            INPUT"Reading: ";RDAT(I,J)
2220            NEXT I
2230    NEXT J
2240 PRINT CR$;LF$;LF$;"Is this data to be stored on disc? Y/N":
2250 Y$=INPUT$(1)
2260 IF Y$="Y" OR Y$="y" THEN GOSUB 2280
2270 RETURN
2280 REM Save data on disc
2290 FILES"*.dat": PRINT CLF$:INPUT"What is the name of the file ";NF$
2300 OPEN"O",#1,NF$
2310 PRINT #1,UPWIND,SR,SP,DPL%
2320 PRINT #1,TITLE$
2330 FOR J=0 TO SR
2340    PRINT #1,SPRDAT$(J)
2350    FOR I=1 TO SP-1
2360            PRINT #1,RDAT(I,J);"    ";
2370    NEXT I: PRINT #1,RDAT(SP,J)
2380 NEXT J
2390 CLOSE #1
2400 RETURN
2410 REM Format for input from Spreadsheets (place in *.DAT file):
2420 REM Upwind dist., # Sprayers, # Sampling Points, Decimal Place (0: Int%)
2430 REM Main title
2440 REM All the following data MUST be separated by commas or 2 spaces at least
2450 REM Sampling positions - preceded by title on different line
2460 REM Droplet data - preceded by spray type/sprayer on different line
2470 REM Load data from disc
2480 PRINT CLF$: NF$=PTH$+"*.dat"
2490 FILES NF$: PRINT CLF$: INPUT "Which file do you require ";NF$
2500 NF$=PTH$+NF$: OPEN"I",#1,NF$
2510 INPUT #1,UPWIND,SR,SP,DPL%
2520 INPUT #1,TITLE$
2530 FOR J=0 TO SR
2540    INPUT #1,SPRDAT$(J)
2550    FOR I=1 TO SP
2560            INPUT #1,RDAT(I,J)
2570            NEXT I
2580    NEXT J
2590 CLOSE #1
2600 RETURN
2610 REM select data group
2620 CLS: PRINT LF$;TITLE$
2630 PRINT LF$;"The sprayer data in store is as follows:";CR$;LF$;LF$;
2640 IF INDX%=3 THEN PRINT " 0",SPRAYER$(0);CLF$
2650 FOR J=2 TO 4
2660 PRINT J,SPRAYER$(J)
2670 NEXT J
2680 PRINT LF$;"Select number according to the data to be analysed"
2690 Y$=INPUT$(1): J%=VAL(Y$): IF J%=1 OR J%>4 THEN BEEP: CLS: GOTO 2630
2700 RETURN
2710 REM Connect up points in single swath at 0.1m. intervals
2720 MAXY%=0: CVAREA=0
2730 PRINT SPRAYER$(J%);CR$;LF$;LF$;"Please wait a few moments - I'm thinking"
2740 IVL%=0: NX%=0
2750 FOR I%=2 TO SP:                    :REM SP=total No of sampling points
2760 IVL%=IVL%+ NX%
2770 NX%=ABS(R(I%,1)-R(I%-1,1))*10      :REM Number of intermediate points
2780 R%=R(I%-1,J%)*10^DPL%              :REM DPL: Decimal place of readings
2790 D%=R%-(R(I%,J%)*10^DPL%)           :REM Difference
2800 FOR X%=IVL% TO IVL%+ NX%-1         :REM Filling in between ......
2810        ITT%(X%)=R%-(D%*((X%-IVL%)/NX%))
```

```
2820       CVAREA=CVAREA+ITT%(X%)
2830       IF ITT%(X%)>MAXY% THEN MAXY%=ITT%(X%)
2840 NEXT X%                              :REM .... sampling points
2845 REM PRINT I%,IVL%,NX%,R(I%,1),CVAREA
2850 NEXT I%
2860 ITT%(LIMIT%)=R(SP,J%)*10^DPL%: CVAREA=CVAREA*10
2870 REM Output ITT%(0-LIMIT%), LIMIT%
2880 RETURN
2890 REM Graphic display of data
2900 REM Set up graphics screen: use SCRNDUMP or GRAPHICS for IBM
2910 KEY OFF: SCREEN 2: CLS
2920 POSX2%=40: POSY2%=YMAX%
2930 RETURN
2940 REM Single curve
2950 IF PRN%=2 THEN WIDTH LPRINT 255 ELSE GOTO 2970
2960 LPRINT CHR$(27);"P";CHR$(15);CHR$(14);TITLE$;CHR$(27);"M";CLF$;LF$
2970 GOSUB 2900: XIVL=(XMAX%-40)/(R(SP,1)+UPWIND): YIVL=(YMAX%-30)/MAXY%
2980 LOCATE 1,1,0: PRINT TITLE$
2990 LOCATE 2,1,0: PRINT SPRAYER$(J%);".       Single swath: estimated area under curve:";CV
AREA;"units."
3000 IF INDX%>0 THEN LOCATE 4,30,0: PRINT"Droplet densities interpreted from Bateman's index
"
3010 SCALEX=R(SP,1)+UPWIND: SCALEY=MAXY%/10^DPL%: XAX$="passage of nozzle"
3020 ZEROLIN%=40+CINT(UPWIND*XIVL): GOSUB 3370
3030 LOCATE 5,45,0: PRINT"General direction of wind  ---";CHR$(16)
3040 LOCATE 7,50,0: PRINT"Cumulative values for aspects:";
3050 LOCATE 8,61,0: PRINT"Windward";
3060 LOCATE 9,61,0: PRINT"Horizontal";
3070 LOCATE 10,61,0: PRINT"Leeward";
3080 FOR I= 1 TO SP
3090    POSX1%=POSX2%: POSY1%=POSY2%
3100    POSX2%=40+CINT(R(I,1)*XIVL+UPWIND*XIVL)
3110    POSY2%=YMAX%-CINT(R(I,J%)*YIVL)
3120    LINE(POSX1%,POSY1%)-(POSX2%,POSY2%)
3130 NEXT I
3140 IF INDX%=3 THEN GOSUB 3570
3150 GOSUB 3540: RETURN
3160 REM Superimposed curves
3170 GOSUB 2900: XIVL=(XMAX%-40)/ENDROP%: YIVL=(YMAX%-30)/MAX%
3180 LOCATE 1,1,0: PRINT TITLE$;
3190 LOCATE 2,1,0: PRINT"Swath width:";SW;"m.;   Field length:";EN;"m.; ";NSW%;"swaths."
3200 SCALEX=ENDROP%/10: SCALEY=MAX%/10^DPL%: XAX$="upwind edge of field"
3210 ZEROLIN%=40+CINT(UPW%*XIVL)
3220 GOSUB 3370: Z%=CINT(EN%*XIVL)+40: LINE(Z%,YMAX%)-(Z%,20)
3230 LOCATE 3,60,0: PRINT "Droplets in downwind"
3240 LOCATE 4,60,0: PRINT "10m. of field:"
3250 LOCATE 5,63,0: PRINT "Mean:";: PRINT USING "#######";MEAN
3260 LOCATE 6,63,0: PRINT "Var./mean:";: PRINT USING "###.##";VAR/MEAN
3270 LOCATE 8,65,0: PRINT "Contamination"
3280 LOCATE 9,65,0: PRINT "beyond field:"
3290 LOCATE 10,64,0: PRINT CONTAMN;"units."
3300 FOR X%= 0 TO ENDROP%
3310    POSX1%=POSX2%: POSY1%=POSY2%
3320    POSX2%=40+CINT(X%*XIVL)
3330    POSY2%=YMAX%-CINT(TOT%(X%)*YIVL)
3340    LINE(POSX1%,POSY1%)-(POSX2%,POSY2%)
3350 NEXT X%
3360 GOSUB 3540: RETURN
3370 REM Procedure for X and Y axes and scaling
3380 IF UPWIND<>0 THEN SCALEX=SCALEX-UPWIND
3390 FOR X%=0 TO SCALEX STEP 10:       REM Simply mark every 10 m.
3400    Z%=CINT(73/SCALEX*(X%+UPWIND))+5:  REM 74 chars accross graph
```

```
3410    IF Z%<78 THEN LOCATE 24,Z%,0 ELSE LOCATE 24,77,0
3420    PRINT X%;
3430 NEXT X%
3440 LOCATE 25,4,0: PRINT CHR$(24);" Droplet density";
3450 PRINT"      Distance from ";XAX$;" (m.) -";CHR$(26);
3460 IF SCALEY<10 THEN IVL%=2 ELSE IF SCALEY<20 THEN IVL%=5 ELSE IF SCALEY<50 THEN IVL%=10 E
LSE IF SCALEY<100 THEN IVL%=20 ELSE IF SCALEY<200 THEN IVL%=50 ELSE IF SCALEY<500 THEN IVL%=
100 ELSE IF SCALEY<1000 THEN IVL%=200 ELSE IVL%=500
3470 FOR Y%=0 TO SCALEY STEP IVL%
3480   LOCATE (23-CINT(20/SCALEY*Y%)),1,0
3490   PRINT USING"####";Y%;
3500 NEXT Y%
3510 LINE(40,YMAX%)-(XMAX%,YMAX%)
3520 LINE(ZEROLIN%,YMAX%)-(ZEROLIN%,20)
3530 RETURN
3540 REM Finish output
3550 BEEP: Y$=INPUT$(1):                REM Screen dump here
3560 SCREEN 0: RETURN
3570 REM Superimpose lines for different aspects
3580 POSX2%=40: POSY2%=YMAX%
3590 REM horizontal + leeward
3600 FOR I= 1 TO SP
3610    POSX1%=POSX2%: POSY1%=POSY2%
3620    POSX2%=40+CINT(R(I,1)*XIVL+UPWIND*XIVL)
3630    POSY2%=YMAX%-CINT((R(I,4)+R(I,3))*YIVL)
3640    LINE(POSX1%,POSY1%)-(POSX2%,POSY2%)
3650 NEXT I
3660 POSX2%=40: POSY2%=YMAX%
3670 REM leeward only
3680 FOR I= 1 TO SP
3690    POSX1%=POSX2%: POSY1%=POSY2%
3700    POSX2%=40+CINT(R(I,1)*XIVL+UPWIND*XIVL)
3710    POSY2%=YMAX%-CINT(R(I,4)*YIVL)
3720    LINE(POSX1%,POSY1%)-(POSX2%,POSY2%)
3730 NEXT I
3740 RETURN
3750 REM printout of swath curves if screendump is not available
3760 DVD=MAX%/60:                       :REM Page width formatting max = 70
3770 LPRINT TITLE$:LPRINT:LPRINT CHR$(14);SPRAYER$(J%)
3780 LPRINT"Swath width: ";SW;"m.;  Field length: ";EN;"m.;";NSW%;" Swaths."
3790 LPRINT"Droplet Recovery Index (estimated area under a single curve)=";CVAREA
3800 LN$="*": ENDLINE%=72: GOSUB 4060: LPRINT
3810 LPRINT "Distance"; TAB(30);"Droplet density/squ.cm.-->"
3820 LPRINT "from leeward";CR$;LF$;"edge of field";CR$;LF$;" VV";
3830 IF MAX%/10^DPL%<10 THEN IVL%=1 ELSE IF MAX%/10^DPL%<50 THEN IVL%=5 ELSE IF MAX%/10^DPL%
<100 THEN IVL%=10 ELSE IF MAX%/10^DPL%<500 THEN IVL%=50 ELSE IVL%=100
3840 LPRINT TAB(10);"0";:FOR X%=IVL% TO MAX%/10^DPL% STEP IVL%
3850 LPRINT TAB(9+INT(X%*10^DPL%/DVD));X%;:NEXT X%:LPRINT
3860 LPRINT CHR$(27);"A";CHR$(1);CHR$(27);"2"  :REM Set line spacing @ 1/72"
3870 LN$="_"
3880 IF UPWIND >0 AND TAILS=1 THEN GOSUB 4060 ELSE GOTO 3930
3890 LPRINT CR$;LF$;LF$
3900 FOR Y%=1 TO UPW%
3910 GOSUB 4100
3920 NEXT Y%
3930 LPRINT"   ";: LN$="-": ENDLINE%=69: GOSUB 4060
3940 FOR Y%=UPW% TO EN%
3950 GOSUB 4100
3960 NEXT Y%
3970 LPRINT"   ";: GOSUB 4060
3980 IF TAILS=0 THEN GOTO 4030
3990 Y%=EN%+ 1
```

```
4000 WHILE V%>10
4010 GOSUB 4100
4020 Y%=Y%+ 1: WEND
4030 LPRINT E$;"A";CHR$(12)          :REM Reset line spacing
4040 IF TAILS=1 THEN LPRINT CHR$(12);  :REM End of page
4050 RETURN
4060 REM Print line of characters
4070 FOR L%=1 TO ENDLINE%
4080 LPRINT LN$;:NEXT L%
4090 RETURN
4100 REM Graph dot printing
4110 V%=10+INT(TOT%(0,Y%)/DVD)
4120 IF Y%<LIMIT% THEN U%=10+INT(ITT%(Y%)/DVD) ELSE U%=-10
4130 IF Y%<>0 AND (Y%-UPW%)\100=(Y%-UPW%)/100 OR Y%=EN% THEN LPRINT INT((Y%-UPW%)/10);
4140 LPRINT TAB(10);".";
4150 IF V%=U% THEN LPRINT E$;"G";            :REM Double stike
4160 IF U%>10 THEN LPRINT TAB(U%)".";
4170 IF V%=U% THEN LPRINT E$;"H": GOTO 4190 :REM Cancel double strike
4180 LPRINT TAB(V%);"."
4190 RETURN
4200 REM Load data into working array
4210 FOR I=1 TO SP
4220     R(I,1)=RDAT(I,0):              REM Sample positions
4230     NEXT I
4240 IF DPL%=999 THEN GOTO 4330
4250 REM Ordinary data
4260 FOR J=1 TO SR
4270    FOR I=1 TO SP
4280            R(I,J)=RDAT(I,J)
4290            NEXT I
4300    NEXT J
4310 INDX%=1
4320 RETURN
4330 REM interpretation of Bateman's index data
4340 INDX%=3: DPL%=0
4350 SPRAYER$(0)="Total deposits"
4360 SPRAYER$(1)="Sample posn. (m.)"
4370 SPRAYER$(2)="Windward"
4380 SPRAYER$(3)="Horizontal"
4390 SPRAYER$(4)="Leeward"
4400 NREPS=SR\3
4410 FOR J=2 TO 4:                      REM Orientation
4420    FOR I=1 TO SP:                  REM Sample points
4430            FOR REP=1 TO NREPS
4440                    JDAT=3*REP-4+J
4450                    R(I,J)=R(I,J)+(2^RDAT(I,JDAT)-1)/NREPS
4460                    NEXT REP
4470            R(I,0)=R(I,0)+R(I,J):   REM Total deposits
4480            NEXT I
4490 REM  PRINT SPRAYER$(J): FOR I=1 TO SP
4500 REM        PRINT R(I,1),R(I,J),R(I,0)
4510 REM        NEXT I
4520    NEXT J
4530 REM PRINT "REPS = ";NREPS: Y$=INPUT$(1)
4540 RETURN
```

APPENDIX IV

A. SCORING SYSTEM FOR APHIDS AND RED SPIDER MITES

In both Zimbabwe and Malaŵi, indices are used to assess the populations of these numerous pests. A description of the scoring method can be found in both the Zimbabwe and Malaŵi cotton handbooks as well as the standard Zimbabwean cotton pest management recording sheets. The principal of the index is the same for both pests in both countries.

NOTATION Malaŵi	NOTATION Zimbabwe	POPULATION ESTIMATE	Multiplier (Malaŵi)
A	-	Absent	0
B	I	1-10	1
C	II	11-30	2
D	III	More than 30	3

Scouting differs slightly between countries; in Malaŵi, 7 leaves from 12 plants are individually recorded as one of the four categories, and the final score for a plot or field is the sum of the product of the numbers in each category and the multiplier; in Zimbabwe, 24 samples are taken in farmers' fields (12 per plot for the purposes of the trial) and the highest score from any of the 4 sampling positions in the plant is recorded: the final score is simply the sum of sub-scores. For the purposes of these trials, two criteria have been assessed: percentage of plants infested, and a single score for infestation based on the index and multiplier.

B. ANCILLARY FIELD TRIAL DETAILS AND RESULTS

Data Analysis

All analyses are output from the author's PASCAL algorithm based statistics package, which relies heavily on information gleaned from Cooke et. al. (1985), Gomez and Gomez (1976), and Meddis (1975). It is hoped that the summary tables will be reasonably self explanatory; significance is denoted by a star rating as follows:

N.S. :	Not significant.		
* :	Probability is 95%	}	that at least one
** :	" " 99%	}	treatment is
*** :	" " 99.9%	}	significantly
**** :	" " 99.99%	}	different from
***** :	" " 99.999%	}	the others.

IV.B.1

THIODICARB CDA TRIAL

Project: Q30C/8616

Research Workers: P. Jowah and R.P. Bateman.

Location: Itafa Farm, Kadoma (Land 10).

Objective: To evaluate the effects of formulation, dosage rate and droplet size on the efficacy of thiodicarb suspensions, for the contol of two major bollworm species (appln. volume rate adjusted for droplet size).

Design: CDA: 5 x 2 x 2 factorial + 2 CLV (2 replicates).

Factors: a) Six insecticides/formulations -

(i) WULV mixture using "375" SC (FW)
(ii) "MOL" mixture incorporating SC and 25% molasses
(iii) Oil-based formulation (20% a.i.) (UCLF8)
(iv) Fenvalerate (Agrithrin 20% EC: a pyrethroid) as WULV
(v) Blank formulation as control
(vi) Conventional high volume knapsack treatment

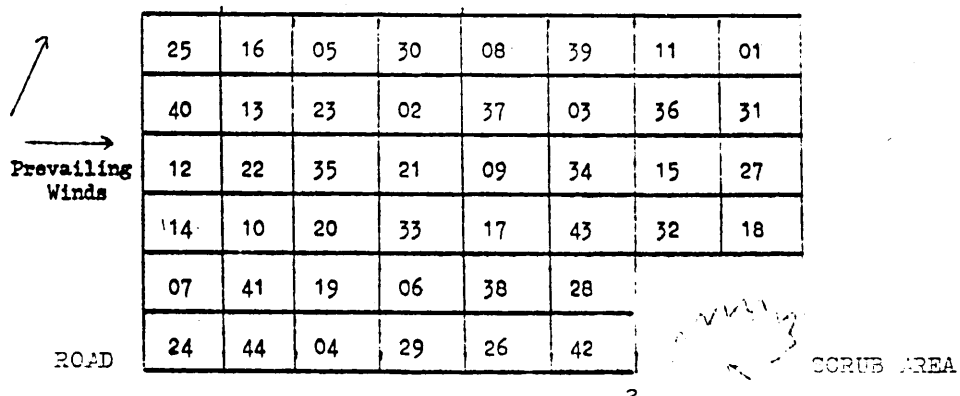
b) Two dosage rates -

(i) Standard rate
(ii) Half rate

c) Two droplet sizes -

(i) Approx. 70 um VMD
(ii) Approx. 100 um VMD

Field Plan:



Plot Size: 24 rows x 20 metres = 480m^2

Sampling Area: 6 rows x 6 metres (36m^2) in centre of plots.

Soil Insecticide: Aldrin w.p. at 1,0 kg per hectare on 27th November 1986

Fertilizer: Compound L at 300 kg per hectare on 18th October 1986

Soil Fungicide: Brassicol at 1,5 kg per hectare on 27th November 1986

Planted: 27th November 1986

Emerged: 6th December 1986

Thinned: 17th December 1986

Bollworm Treatments: (See Table 1)

Spray Timing: Insecticide applications are to take place according to the accepted standard threshold levels.

Records:

(a) Bollworm eggs and sucking pests scouting for each plot once a week before spraying.

(b) Bollworm and leaf-eating larvae and predator scouting for each plot once a week after spraying.

(c) At week 16 after emergence, three plants from each plot will be stripped and thoroughly examined for pests, boll attack and general anatomical measurement.

(d) Spray log for each treatment.

(e) Stand count and yield within the sampling area.

TREATMENT SCHEDULE

1. Sucking Pests and Red Spider Mites.

Plots are to be treated in pairs: according to the bollworm spray schedule: infested plots to be treated with Dimethoate MULV

2. Bollworm control with thiodicarb (Larvin).

Table 1.

TREATMENT SCHEDULE FOR BOLLWORM CONTROL WITH THIODICARB (LARVIN)

PLOTS	INSECTICIDE FORMULATION	MIXING INSTRUCTIONS	EXPECTED VOLUME OF MIXTURE FOR BOTH PLOTS			POWER SOURCE
			Restrictor	<50cm plant height 2m swaths	>50cm 1m swath	
01, 02	Larvin 375sc WULV	44ml	Red*	385	1152	Control Pack
03, 04	Larvin 375 Mol	44ml + 250ml molasses	"	385	1152	"
05, 06	UCLF 8 (oil)	1 Part UCLF 8: 3 parts oil	Red*	125	384	"
07, 08	Agrithrin EC Mol	8,3ml + 250ml Molasses	"	385	1152	"
09, 10	Control Water	Plain Water only	"	385	1152	"
11, 12	Larvin 375 SC Knapsack+Tailboom	21ml in 8 l water	See Plots 23-24			Manual
13, 14	Larvin 375SC WULV	89ml	Red*	385	1152	Control Pack
15, 16	Larvin 375 Mol	89ml + 250ml molasses	"	385	1152	"
17, 18	UCLF 8 (oil)	1 Part UCLF 8: 1 Part oil	Red*	125	384	"
19, 20	Agrithrin EC Mol	17cc + 250ml molasses	"	385	1152	"
21, 22	Control - Oil	Sunshine Oil only	Red*	125	384	"
			Number of nozzles			
			2	4	6	8
23, 24	Larvin 375 SC Knapsack+Tailboom	43ml in 8 l water	0,6 tanks	1,2 Tanks	1,8 Tanks	2,4 Tanks	Manual
			Normal Swaths:	Expected Volume(as above)		
			Restrictor	< 40cm	40-90cm	> 90cm
25, 26	Larvin 375SC WULV	133ml	Orange	125	256	385	Power Pack
27, 28	Larvin 375 Mol	133 + 250ml Molasses	"	125	256	385	"
29, 30	UCLF 8 (oil)	1 Part UCLF 8: 1 Part Oil	Red	64	128	192	"
31, 32	Agrithrin EC Mol	25 + 250ml Molasses	Orange	125	256	385	"
33, 34	Control - Water	Plain water only	"	"	"	"	"
35, 36	Larvin 375 SC WULV	267ml	"	"	"	"	"
37, 38	Larvin 375 Mol	257ml + 250ml Molasses	"	"	"	"	"
39, 40	UCLF 8 (oil)	Undiluted UCLF 8	Orange	64	128	192	"
41, 42	Agrithrin EC Mol	50ml +250ml molasses	"	125	256	385	"
43, 44	Control - Oil	Sunshine Oil Only	Red	64	128	192	"

* - Half normal swath width.

IV.B.1.2.

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 07/05/1987: Stand Counts

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	5868.23	10	586.82	0.937	N.S.
Dosages	105.09	1	105.09	0.168	N.S.
Dosage x Insecticides	7868.41	10	786.84	1.256	N.S.
Contrasts					
Controls vs Insecticides	311.88	(1)	311.88	0.498	N.S.
Large vs Small droplets	331.53	(1)	331.53	0.529	N.S.
Knapsack vs all ULV	92.25	(1)	92.25	0.147	N.S.
Knapsack vs Larvin UL	48.21	(1)	48.21	0.077	N.S.
Pyrethroid vs Larvin Mol	156.25	(1)	156.25	0.250	N.S.
MULV vs. other Larvin UL	243.00	(1)	243.00	0.388	N.S.
MULV " " " "	9.19	(1)	9.19	0.015	N.S.
UCLF8 " " " "	346.69	(1)	346.69	0.554	N.S.
Residual	13777.00	22	626.23		
Total	27618.73	43			

Coefficient of Variation = 14.8%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Plants (norm. ~133/plot)				0 200.00
3	OIL: UCLF8 - Large droplets	193.00	9.79	1.986	
4	Fenvalerate MULV - Large droplets	183.75	8.66	1.634	
8	MULV: SC + molasses - Small droplets	175.00	14.98	5.131	
5	CONTROL: blank - Large droplets	174.75	11.68	3.122	
7	WULV containing 375 SC - Small droplets	172.75	10.43	2.518	
10	Fenvalerate MULV - Small droplets	166.50	7.40	1.315	
6	Larvin SC with Knapsack/tailboom	166.00	10.14	2.478	
2	MULV: SC + molasses - Large droplets	162.75	21.68	11.557	
1	WULV containing 375 SC - Large droplets	157.75	5.25	0.699	
9	OIL: UCLF8 - Small droplets	157.25	22.05	12.368	
11	CONTROL: blank - Small droplets	152.50	5.52	0.798	
	Dosages				0 200.00
1	Half rate	167.73	5.90	4.562	
2	Standard	170.82	4.98	3.190	

1.3

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 1987 season: Bollworm sprays.

Cotton < 0.5m. Tall (11 & 18 Feb.)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	10788.09	10	1078.81	4.490	**
Dosages	3.55	1	3.55	0.015	N.S.
Dosage x Insecticides	1343.47	10	134.35	0.559	N.S.
Contrasts					
Controls vs Insecticides	96.53	(1)	96.53	0.402	N.S.
Large vs Small droplets	7293.30	(1)	7293.30	30.353	***
Knapsack vs all ULV	18.86	(1)	18.86	0.078	N.S.
Knapsack vs Larvin UL	0.68	(1)	0.68	0.003	N.S.
Pyrethroid vs Larvin Mol	743.93	(1)	743.93	3.096	N.S.
MULV vs. other Larvin UL	84.54	(1)	84.54	0.352	N.S.
MULV " " " "	462.52	(1)	462.52	1.925	N.S.
UCLF8 " " " "	151.59	(1)	151.59	0.631	N.S.
Residual	5286.25	22	240.28		
Total	17421.37	43			

Coefficient of Variation = 16.1%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: % of target rate.				0 100.00
3	OIL: UCLF8 - Large droplets	123.20	11.60	4.367	
1	MULV containing 375 SC - Large droplets	110.65	5.16	0.964	
5	CONTROL: blank - Large droplets	108.80	4.07	0.608	
4	Fenvalerate MULV - Large droplets	105.52	5.40	1.104	
2	MULV: SC + molasses - Large droplets	105.12	10.17	3.936	
10	Fenvalerate MULV - Small droplets	97.67	7.98	2.609	
6	Larvin SC with Knapsack/tailboom	93.72	10.42	4.638	
11	CONTROL: blank - Small droplets	90.42	5.14	1.169	
7	MULV containing 375 SC - Small droplets	83.00	2.83	0.386	
9	OIL: UCLF8 - Small droplets	72.25	3.73	0.772	
8	MULV: SC + molasses - Small droplets	70.80	4.67	1.230	
	Dosages				0 100.00
1	Half rate	96.75	4.23	4.062	
2	Standard	96.19	4.45	4.537	

1.4

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 1987 season: Bollworm sprays.

Cotton > 0.5m. Tall (4 & 25 March)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	13308.46	10	1330.85	7.755	***
Dosages	17.19	1	17.19	0.100	N.S.
Dosage x Insecticides	2471.01	10	247.10	1.440	N.S.
Contrasts					
Controls vs Insecticides	557.19	(1)	557.19	3.247	N.S.
Large vs Small droplets	2479.84	(1)	2479.84	14.449	***
Knapsack vs all ULV	3625.97	(1)	3625.97	21.128	***
Knapsack vs Larvin UL	2679.21	(1)	2679.21	15.611	***
Pyrethroid vs Larvin Mol	1410.00	(1)	1410.00	8.216	**
MULV vs. other Larvin UL	1585.85	(1)	1585.85	9.240	**
MULV " " " "	97.76	(1)	97.76	0.570	N.S.
UCLF8 " " " "	896.14	(1)	896.14	5.222	*
Residual	3775.68	22	171.62		
Total	19572.34	43			

Coefficient of Variation = 12.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: % of target rate.				0 100.00
10	Fenvalerate MULV - Small droplets	133.27	8.28	2.057	
11	CONTROL: blank - Small droplets	127.17	15.60	7.653	
7	MULV containing 375 SC - Small droplets	123.25	5.15	0.860	
8	MULV: SC + molasses - Small droplets	106.32	6.07	1.385	
1	MULV containing 375 SC - Large droplets	101.50	4.70	0.870	
4	Fenvalerate MULV - Large droplets	100.32	5.38	1.153	
5	CONTROL: blank - Large droplets	93.90	7.44	2.359	
3	OIL: UCLF8 - Large droplets	92.67	4.28	0.792	
9	OIL: UCLF8 - Small droplets	91.80	1.27	0.070	
2	MULV: SC + molasses - Large droplets	89.72	4.05	0.732	
6	Larvin SC with Knapsack/tailboom	72.92	2.02	0.225	
	Dosages				0 100.00
1	Half rate	103.61	4.01	3.421	
2	Standard	102.36	5.12	5.634	

1.5

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 04/05/1987: Pick No.1

Total Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	11286291.05	10	1128629.10	5.676	***
Dosages	274920.09	1	274920.09	1.383	N.S.
Dosage x Insecticides	1631933.41	10	163193.34	0.821	N.S.
Contrasts					
Controls vs Insecticides	8638600.03	(1)	8638600.03	43.442	***
Large vs Small droplets	9625.78	(1)	9625.78	0.048	N.S.
Knapsack vs all ULV	172333.42	(1)	172333.42	0.867	N.S.
Knapsack vs Larvin UL	32509.34	(1)	32509.34	0.163	N.S.
Pyrethroid vs Larvin Mol	2001517.56	(1)	2001517.56	10.065	**
MULV vs. other Larvin UL	387181.69	(1)	387181.69	1.947	N.S.
MULV " " " "	561168.75	(1)	561168.75	2.822	N.S.
UCLF8 " " " "	16096.69	(1)	16096.69	0.081	N.S.
Residual	4374829.00	22	198855.86		
Total	17567973.55	43			

Coefficient of Variation = 15.3%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight in grammes / plot				0 4000.00
10	Fenvalerate MULV - Small droplets	3569.75	266.02	79.297	
4	Fenvalerate MULV - Large droplets	3462.25	288.68	96.278	
1	MULV containing 375 SC - Large droplets	3296.75	221.86	59.723	
3	OIL: UCLF8 - Large droplets	3129.00	277.17	98.211	
7	MULV containing 375 SC - Small droplets	3112.25	189.22	46.018	
9	OIL: UCLF8 - Small droplets	2994.00	286.24	109.466	
8	MULV: SC + molasses - Small droplets	2984.00	170.57	39.001	
6	Larvin SC with Knapsack/tailboom	2927.50	141.96	27.534	
2	MULV: SC + molasses - Large droplets	2633.25	72.07	7.890	
5	CONTROL: blank - Large droplets	2012.25	113.74	25.715	
11	CONTROL: blank - Small droplets	1936.50	241.26	120.230	
	Dosages				0 4000.00
1	Half rate	2835.27	123.42	118.190	
2	Standard	2993.36	148.99	163.153	

1.6

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 04/05/1987: Pick No.1

Clean Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	11527938.73	10	1152793.87	5.779	***
Dosages	321822.02	1	321822.02	1.613	N.S.
Dosage x Insecticides	1768655.73	10	176865.57	0.887	N.S.
Contrasts					
Controls vs Insecticides	8570432.51	(1)	8570432.51	42.967	***
Large vs Small droplets	11628.12	(1)	11628.12	0.058	N.S.
Knapsack vs all ULV	142222.22	(1)	142222.22	0.713	N.S.
Knapsack vs Larvin UL	15124.02	(1)	15124.02	0.076	N.S.
Pyrethroid vs Larvin Mol	2290682.25	(1)	2290682.25	11.484	**
MULV vs. other Larvin UL	437008.33	(1)	437008.33	2.191	N.S.
MULV " " " "	593630.08	(1)	593630.08	2.976	N.S.
UCLF8 " " " "	11970.08	(1)	11970.08	0.060	N.S.
Residual	4388202.50	22	199463.75		
Total	18006618.98	43			

Coefficient of Variation = 15.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD95
	Units (untransformed) are: Weight in grammes / plot				0 4000.00
10	Fenvalerate MULV - Small droplets	3530.50	267.21	80.898	
4	Fenvalerate MULV - Large droplets	3408.50	290.76	99.212	
1	MULV containing 375 SC - Large droplets	3202.25	238.08	70.806	
3	OIL: UCLF8 - Large droplets	3056.75	290.91	110.743	
7	MULV containing 375 SC - Small droplets	3049.75	182.67	43.764	
8	MULV: SC + molasses - Small droplets	2894.25	156.48	33.843	
9	OIL: UCLF8 - Small droplets	2876.75	270.52	101.758	
6	Larvin SC with Knapsack/tailboom	2868.75	167.98	39.346	
2	MULV: SC + molasses - Large droplets	2531.25	81.89	10.597	
5	CONTROL: blank - Large droplets	1920.00	112.90	26.553	
11	CONTROL: blank - Small droplets	1884.50	252.84	135.690	
	Dosages				0 4000.00
1	Half rate	2752.95	123.73	122.332	
2	Standard	2924.00	151.56	172.831	

1.7

Thiodicarb ULV trial: Kadoma, Zimbabwe

Itafa 04/05/1987: Pick No.1

Stained Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	24352.64	10	2435.26	1.006	N.S.
Dosages	1846.02	1	1846.02	0.762	N.S.
Dosage x Insecticides	26186.73	10	2618.67	1.081	N.S.
Contrasts					
Controls vs Insecticides	135.01	(1)	135.01	0.056	N.S.
Large vs Small droplets	94.53	(1)	94.53	0.039	N.S.
Knapsack vs all ULV	1444.53	(1)	1444.53	0.596	N.S.
Knapsack vs Larvin UL	3286.01	(1)	3286.01	1.357	N.S.
Pyrethroid vs Larvin Mol	9751.56	(1)	9751.56	4.027	N.S.
MULV vs. other Larvin UL	1507.52	(1)	1507.52	0.622	N.S.
MULV " " " "	456.33	(1)	456.33	0.188	N.S.
UCLF8 " " " "	305.02	(1)	305.02	0.126	N.S.
Residual	53278.50	22	2421.75		
Total	105663.89	43			

Coefficient of Variation = 64.9%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight in grammes / plot				0 100.00
10	Fenvalerate MULV - Small droplets	39.25	15.69	25.093	
11	CONTROL: blank - Small droplets	52.00	18.85	27.346	
4	Fenvalerate MULV - Large droplets	53.75	17.67	23.223	
6	Larvin SC with Knapsack/tailboom	58.75	31.43	67.261	
7	MULV containing 375 SC - Small droplets	62.50	25.44	41.435	
3	OIL: UCLF8 - Large droplets	72.25	34.52	65.978	
8	MULV: SC + molasses - Small droplets	89.75	17.84	14.183	
5	CONTROL: blank - Large droplets	92.25	19.35	16.227	
1	MULV containing 375 SC - Large droplets	94.50	18.09	13.859	
2	MULV: SC + molasses - Large droplets	102.00	37.24	54.373	
9	OIL: UCLF8 - Small droplets	117.25	25.07	21.449	
	Dosages				0 100.00
1	Half rate	82.32	10.22	27.908	
2	Standard	69.36	10.97	38.152	

1.8

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Heliothis larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	47.59	10	4.76	1.215	N.S.
Dosages	1.57	1	1.57	0.401	N.S.
Assessments	695.67	6	115.94	29.611	*****
In. x Do.	22.36	10	2.24	0.571	N.S.
In. x As.	158.55	60	2.64	0.675	N.S.
Do. x As.	16.02	6	2.67	0.682	N.S.
In. x Do. x As.	179.05	60	2.98	0.762	N.S.
Contrasts					
Controls vs Insecticides	28.72	(1)	28.72	7.334	**
Controls vs Larvin Mol.	6.51	(1)	6.51	1.662	N.S.
Controls vs UCLF8	15.01	(1)	15.01	3.833	N.S.
Controls vs Pyrethroid	24.14	(1)	24.14	6.166	*
Large vs Small droplets	1.00	(1)	1.00	0.257	N.S.
CLV tailboom vs Larvin UL	0.49	(1)	0.49	0.125	N.S.
Pyrethroid vs Larvin Mol	5.58	(1)	5.58	1.425	N.S.
WULV vs other Larvin UL	5.25	(1)	5.25	1.341	N.S.
MULV " " " "	5.25	(1)	5.25	1.341	N.S.
UCLF8 " " " "	0.00	(1)	0.00	0.000	N.S.
Residual (Error)	603.00	154	3.916		
TOTAL	1723.81	307			

Coefficient of Variation = 83.5%

Units (untransformed) are: Surviving individuals

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD
	Insecticides	LSD =	1.05		0 6.00
1	WULV containing 375 SC - Large droplets	1.86	0.40	2.422	
10	Fenvalerate MULV - Small droplets	2.07	0.36	1.714	
4	Fenvalerate MULV - Large droplets	2.11	0.37	1.805	
6	Larvin SC with Knapsack/tailboom	2.14	0.47	2.894	
7	WULV containing 375 SC - Small droplets	2.21	0.44	2.487	
3	OIL: UCLF8 - Large droplets	2.21	0.32	1.283	
9	OIL: UCLF8 - Small droplets	2.36	0.47	2.615	
2	MULV: SC + molasses - Large droplets	2.50	0.38	1.644	
8	MULV: SC + molasses - Small droplets	2.57	0.41	1.827	
5	CONTROL: blank - Large droplets	2.64	0.61	3.930	
11	CONTROL: blank - Small droplets	3.39	0.61	3.042	
	Dosages	LSD =	0.45		0 6.00
1	Half rate: approx 200 g.a.i./ha.	2.44	0.20	2.495	
2	Standard rate: approx. 400 g.a.i./ha.	2.30	0.18	2.247	
	Assessments	LSD =	0.83		0 6.00
1	Itafa, 20/02/1987	2.86	0.32	1.569	
2	Itafa, 26/02/1987	5.30	0.46	1.762	
3	Itafa, 06/03/1987	3.30	0.26	0.897	
4	Itafa, 13/03/1987	0.89	0.15	1.166	
5	Itafa, 20/03/1987	2.30	0.27	1.430	
6	Itafa, 27/03/1987	1.16	0.18	1.202	
7	Itafa, 03/04/1987	0.80	0.18	1.788	

1.9

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Red Bollworm larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1.68	10	0.17	0.853	N.S.
Dosages	0.13	1	0.13	0.682	N.S.
Assessments	27.76	6	4.63	23.418	*****
In. x Do.	0.73	10	0.07	0.368	N.S.
In. x As.	11.14	60	0.19	0.940	N.S.
Do. x As.	1.56	6	0.26	1.314	N.S.
In. x Do. x As.	7.39	60	0.12	0.624	N.S.
Contrasts					
Controls vs Insecticides	0.53	(1)	0.53	2.694	N.S.
Controls vs Larvin Mol.	0.28	(1)	0.28	1.396	N.S.
Controls vs UCLF8	0.06	(1)	0.06	0.283	N.S.
Controls vs Pyrethroid	0.51	(1)	0.51	2.600	N.S.
Large vs Small droplets	0.07	(1)	0.07	0.365	N.S.
CLV tailboom vs Larvin UL	0.03	(1)	0.03	0.140	N.S.
Pyrethroid vs Larvin Mol	0.04	(1)	0.04	0.186	N.S.
WULV vs other Larvin UL	0.18	(1)	0.18	0.903	N.S.
MULV " " " "	0.00	(1)	0.00	0.008	N.S.
UCLF8 " " " "	0.21	(1)	0.21	1.076	N.S.
Residual (Error)	30.43	154	0.198		
TOTAL	80.83	307			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 32.2%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Surviving individuals				0 2.00
1	WULV containing 375 SC - Large droplets	1.25	0.21	0.985	
2	MULV: SC + molasses - Large droplets	1.39	0.24	1.188	
4	Fenvalerate MULV - Large droplets	1.46	0.27	1.441	
9	OIL: UCLF8 - Small droplets	1.54	0.25	1.133	
10	Fenvalerate MULV - Small droplets	1.54	0.25	1.133	
6	Larvin SC with Knapsack/tailboom	1.57	0.30	1.623	
7	WULV containing 375 SC - Small droplets	1.75	0.36	2.058	
8	MULV: SC + molasses - Small droplets	1.86	0.34	1.744	
5	CONTROL: blank - Large droplets	1.96	0.42	2.469	
11	CONTROL: blank - Small droplets	2.00	0.34	1.630	
3	OIL: UCLF8 - Large droplets	2.00	0.35	1.704	
	Dosages				0 2.00
1	Half rate: approx 200 g.a.i./ha.	1.74	0.14	1.614	
2	Standard rate: approx. 400 g.a.i./ha.	1.59	0.13	1.566	
	Assessments d.a.e.				0 2.00
1	Itafa, 20/02/1987 77	0.82	0.13	0.925	
2	Itafa, 26/02/1987 83	0.73	0.10	0.599	
3	Itafa, 06/03/1987 91	0.84	0.10	0.550	
4	Itafa, 13/03/1987 98	1.75	0.19	0.880	
5	Itafa, 20/03/1987 105	3.61	0.34	1.380	
6	Itafa, 27/03/1987 112	2.20	0.21	0.898	
7	Itafa, 03/04/1987 119	1.70	0.22	1.298	

N.B. Bars represent transformed data.

1.10

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Red Sider Mites (% of infested plants)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	4067.23	10	406.72	2.756	**
Dosages	19.73	1	19.73	0.134	N.S.
Assessments	55417.46	1	55417.46	375.535	*****
In. x Do.	1759.79	10	175.98	1.193	N.S.
In. x As.	1674.56	10	167.46	1.135	N.S.
Do. x As.	177.56	1	177.56	1.203	N.S.
In. x Do. x As.	1046.40	10	104.64	0.709	N.S.
Contrasts					
Controls vs Insecticides	118.55	(1)	118.55	0.803	N.S.
Controls vs Larvin Mol.	555.56	(1)	555.56	3.765	N.S.
Controls vs UCLF8	2.17	(1)	2.17	0.015	N.S.
Controls vs Pyrethroid	488.28	(1)	488.28	3.309	N.S.
Large vs Small droplets	17.36	(1)	17.36	0.118	N.S.
CLV tailboom vs Larvin UL	34.93	(1)	34.93	0.237	N.S.
Pyrethroid vs Larvin Mol	2085.50	(1)	2085.50	14.132	***
WULV vs other Larvin UL	382.67	(1)	382.67	2.593	N.S.
MULV " " " "	87.53	(1)	87.53	0.593	N.S.
UCLF8 " " " "	836.23	(1)	836.23	5.667	*
Residual (Error)	6493.06	44	147.569		
TOTAL	70655.78	87			

Coefficient of Variation = 26.9%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD 5%
	Units (untransformed) are: mean % of infested plants				0 60.00
4	Fenvalerate MULV - Large droplets	33.33	9.58	22.024	
10	Fenvalerate MULV - Small droplets	36.46	11.02	26.633	
9	OIL: UCLF8 - Small droplets	37.50	9.05	17.460	
5	CONTROL: blank - Large droplets	42.71	11.07	22.967	
11	CONTROL: blank - Small droplets	42.71	8.97	15.070	
6	Larvin SC with Knapsack/tailboom	46.87	8.90	13.519	
3	OIL: UCLF8 - Large droplets	48.96	12.44	25.304	
1	WULV containing 375 SC - Large droplets	51.04	11.51	20.773	
8	MULV: SC + molasses - Small droplets	51.04	8.97	12.609	
2	MULV: SC + molasses - Large droplets	51.04	12.93	26.215	
7	WULV containing 375 SC - Small droplets	55.21	8.76	11.119	
	Dosages				0 60.00
1	Half rate: approx 200 g.a.i./ha.	44.70	4.44	19.373	
2	Standard rate: approx. 400 g.a.i./ha.	45.64	4.20	17.018	
	Assessments				0 60.00
1	Itafa, 2/3/1987 (87 D.A.E.)	20.08	2.07	9.383	
2	Itafa, 9/3/1987 (94 D.A.E.)	70.27	1.94	2.363	

1.11

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Red Sider Mites (infestation indices)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	122.82	10	12.28	3.295	**
Dosages	4.55	1	4.55	1.220	N.S.
Assessments	1207.68	1	1207.68	324.012	*****
In. x Do.	36.95	10	3.70	0.991	N.S.
In. x As.	52.32	10	5.23	1.404	N.S.
Do. x As.	0.18	1	0.18	0.049	N.S.
In. x Do. x As.	47.82	10	4.78	1.283	N.S.
Contrasts					
Controls vs Insecticides	13.46	(1)	13.46	3.610	N.S.
Controls vs Larvin Mol.	18.00	(1)	18.00	4.829	*
Controls vs UCLF8	3.78	(1)	3.78	1.014	N.S.
Controls vs Pyrethroid	3.13	(1)	3.13	0.838	N.S.
Large vs Small droplets	0.39	(1)	0.39	0.105	N.S.
CLV tailboom vs Larvin UL	2.17	(1)	2.17	0.582	N.S.
Pyrethroid vs Larvin Mol	36.12	(1)	36.12	9.692	**
WULV vs other Larvin UL	21.09	(1)	21.09	5.659	*
MULV " " " "	0.09	(1)	0.09	0.025	N.S.
UCLF8 " " " "	18.37	(1)	18.37	4.930	*
Residual (Error)	164.00	44	3.727		
TOTAL	1636.32	87			

Coefficient of Variation = 31.1%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: mean infestation indices				0 11.00
4	Fenvalerate MULV - Large droplets	4.13	1.22	2.870	
9	OIL: UCLF8 - Small droplets	5.00	1.39	3.086	
5	CONTROL: blank - Large droplets	5.38	1.48	3.239	
11	CONTROL: blank - Small droplets	5.38	1.18	2.070	
10	Fenvalerate MULV - Small droplets	5.38	1.72	4.409	
6	Larvin SC with Knapsack/tailboom	6.38	1.41	2.507	
8	MULV: SC + molasses - Small droplets	6.75	1.46	2.529	
2	MULV: SC + molasses - Large droplets	7.00	1.87	4.000	
3	OIL: UCLF8 - Large droplets	7.13	2.05	4.709	
1	MULV containing 375 SC - Large droplets	7.63	1.61	2.733	
7	MULV containing 375 SC - Small droplets	8.13	1.63	2.618	
	Dosages				0 11.00
1	Half rate: approx 200 g.a.i./ha.	5.98	0.65	3.093	
2	Standard rate: approx. 400 g.a.i./ha.	6.43	0.67	3.026	
	Assessments				0 11.00
1	Itafa, 2/3/1987 (87 D.A.E.)	2.50	0.27	1.237	
2	Itafa, 9/3/1987 (94 D.A.E.)	9.91	0.40	0.694	

1.12

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Aphids (% of infested plants)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1042.72	10	104.27	0.385	N.S.
Dosages	118.37	1	118.37	0.437	N.S.
Assessments	1686.66	2	843.33	3.113	N.S.
In. x Do.	1299.45	10	129.95	0.480	N.S.
In. x As.	4945.29	20	247.26	0.913	N.S.
Do. x As.	287.25	2	143.62	0.530	N.S.
In. x Do. x As.	7867.95	20	193.39	0.714	N.S.
Contrasts					
Controls vs Insecticides	73.07	(1)	73.07	0.270	N.S.
Controls vs Larvin Mol.	144.68	(1)	144.68	0.534	N.S.
Controls vs UCLF8	52.08	(1)	52.08	0.192	N.S.
Large vs Small droplets	0.00	(1)	0.00	0.000	N.S.
Knapsack vs all UL	20.58	(1)	20.58	0.076	N.S.
Knapsack vs Larvin UL	49.74	(1)	49.74	0.184	N.S.
Pyrethroid vs Larvin Mol	175.06	(1)	175.06	0.646	N.S.
MULV vs other Larvin UL	1.93	(1)	1.93	0.007	N.S.
MULV " " " "	12.06	(1)	12.06	0.044	N.S.
UCLF8 " " " "	23.63	(1)	23.63	0.087	N.S.
Residual (Error)	17881.94	66	270.939		
TOTAL	31129.52	131			

Coefficient of Variation = 20.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: mean % of infested plants				0 100.00
11	CONTROL: blank - Small droplets	75.69	5.93	5.581	
10	Fenvalerate MULV - Small droplets	78.47	4.86	3.614	
6	Larvin SC with Knapsack/tailboom	81.25	5.34	4.215	
4	Fenvalerate MULV - Large droplets	81.94	4.08	2.440	
8	OIL: UCLF8 - Large droplets	81.94	4.69	3.210	
1	MULV containing 375 SC - Large droplets	81.94	4.45	2.902	
9	MULV: SC + molasses - Small droplets	83.33	4.23	2.576	
9	OIL: UCLF8 - Small droplets	83.33	3.97	2.273	
2	MULV: SC + molasses - Large droplets	84.72	4.68	3.105	
5	CONTROL: blank - Large droplets	85.42	3.72	1.940	
7	MULV containing 375 SC - Small droplets	85.42	3.57	1.792	
	Dosages				0 100.00
1	Half rate: approx 200 g.a.i./ha.	81.19	1.96	3.114	
2	Standard rate: approx. 400 g.a.i./ha.	83.08	1.84	2.700	
	Assessments				0 100.00
1	Itafa, 23/2/1987 (80 D.A.E.)	78.03	3.03	5.178	
2	Itafa, 2/3/1987 (87 D.A.E.)	81.63	1.91	1.962	
3	Itafa, 9/3/1987 (94 D.A.E.)	86.74	1.66	1.390	

1.13

Thiodicarb CDA: Kadoma, Zimbabwe (1987)

Aphids (infestation indices)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	115.80	10	11.58	0.829	N.S.
Dosages	25.48	1	25.48	1.824	N.S.
Assessments	118.68	2	59.34	4.248	*
In. x Do.	62.35	10	6.23	0.446	N.S.
In. x As.	263.65	20	13.18	0.944	N.S.
Do. x As.	6.47	2	3.23	0.232	N.S.
In. x Do. x As.	149.20	20	7.46	0.534	N.S.
Contrasts					
Controls vs Insecticides	9.09	(1)	9.09	0.651	N.S.
Controls vs Larvin Mol.	24.08	(1)	24.08	1.724	N.S.
Controls vs UCLF8	2.08	(1)	2.08	0.149	N.S.
Large vs Small droplets	38.76	(1)	38.76	2.775	N.S.
Knapsack vs all UL	0.01	(1)	0.01	0.001	N.S.
Knapsack vs Larvin UL	1.24	(1)	1.24	0.089	N.S.
Pyrethroid vs Larvin Mol	42.19	(1)	42.19	3.020	N.S.
MULV vs other Larvin UL	2.78	(1)	2.78	0.199	N.S.
MULV " " " "	4.69	(1)	4.69	0.336	N.S.
UCLF8 " " " "	14.69	(1)	14.69	1.052	N.S.
Residual (Error)	922.00	66	13.970		
TOTAL	1663.64	131			

Coefficient of Variation = 30.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: mean infestation indices				0 17.00
4	Fenvalerate MULV - Large droplets	10.92	0.69	0.524	
3	OIL: UCLF8 - Large droplets	11.25	0.79	0.665	
10	Fenvalerate MULV - Small droplets	11.42	0.96	0.979	
11	CONTROL: blank - Small droplets	11.50	1.09	1.241	
5	CONTROL: blank - Large droplets	11.75	0.70	0.497	
1	MULV containing 375 SC - Large droplets	11.83	1.11	1.242	
6	Larvin SC with Knapsack/tailboom	12.33	1.25	1.509	
2	MULV: SC + molasses - Large droplets	12.67	1.02	0.981	
9	OIL: UCLF8 - Small droplets	12.83	0.96	0.862	
8	MULV: SC + molasses - Small droplets	13.42	1.44	1.849	
7	MULV containing 375 SC - Small droplets	14.08	1.10	1.039	
	Dosages				0 17.00
1	Half rate: approx 200 g.a.i./ha.	11.74	0.45	1.143	
2	Standard rate: approx. 400 g.a.i./ha.	12.62	0.42	0.933	
	Assessments				0 17.00
1	Itafa, 23/2/1987 (80 D.A.E.)	10.93	0.55	1.214	
2	Itafa, 2/3/1987 (87 D.A.E.)	12.39	0.59	1.225	
3	Itafa, 9/3/1987 (94 D.A.E.)	13.23	0.41	0.566	

IV.B.2 and 3.

MK/CPR/ENT/143

OPTIMIZATION OF FORMULATION AND ATOMIZATION CHARACTERISTICS FOR CONTROLLED DROPLET APPLICATION ON SMALL SCALE COTTON FARMERS.

AIM : To investigate optimum strategies for WULV application conventional insecticide using hand-held equipment.

SITES : Makoka and Toleza.

PLOT SIZE : 20m x 20m for Toleza, 20m by 20 rows Makoka.

DESIGN : 5 x 2 x 2 + 2, 2 Replicates (5 formulations x 2 dosage rates x 2 droplet size + 2 knapsack high volume, 2 Replicates).

SPACING : 0.30m within and 0.75m between ridges for Makoka.

: 0.60m within and 0.75m between ridges for Toleza.

- Suitable droplet sizes can be achieved by using Turbair XJ machines at <12v. and 5.5v.

ASSESSMENT/EVALUATION REQUIRED.

Weekly red and american bollworm eggs on 12 plants per plot.

Weekly red american, Spiny bollworm larvae on the same plants as above.

Aphids, red spider mites, whiteflies, psyllid and jassid on the same plants as above.

General scouting for pests such as stainers and leaf eaters as well as beneficial insects.

At week 16 after emergence, three plants from each plot will be stripped and and thoroughly examined for pests, boll attack and general anatomical measurement.

Yield seed cotton, clean and damaged from a sampling area 3m by 4 ridges in the centre of each plot.

Split boll analysis 3m by 1 row selected randomly on either side adjacent to the sampling area.

Dimethoate should be applied to both replicates of the affected treatments only to control aphids and red spider mites.

At Makoka Solubor should be applied with the first 6 sprays to all treatments at 70g/litre or 70g/13.6 l if using T.B.

Ser. MK/CPR/ENT/143

DETAILED APPLICATION INSTRUCTIONS - MAKOKA (Plots 20m x 20 rows(15m)

Plot No.	Insecticide Formulation	Mixing Instructions *1	Restrictor	Crops less than 0.5m		Crops greater than 0.5m	
				Swath (rows)	Qtty*2	Swath (rows)	Qtty*2
	a)	12 V Battery pack					
1,2	Larvin 375 SC	WULV (96ml)	1.3	4	166	2	333
3,4	Larvin 80 DF	WULV(45g)	1.3	4	166	2	333
5,6	UCLF 8(UL)	SU :1 part UCLF 8: 1 part oil	1.3	4	60	2	120
7,8	Cypermethrin 20EC	WULV (18ml)	1.3	4	166	2	333
9,10	Control	Water only	1.3	4	166	2	333
11,12	Larvin 375 SC	36ml. per 13.6l tank High volume with tailboom					
13,14	Larvin 375 SC	WULV (192ml)	1.4	4	166	2	333
15,16	Larvin 80 DF	WULV (90g)	1.3	4	166	2	333
17,18	UCLF 8 (L)	SU Undiluted	1.3	4	60	2	120
19,20	Cypermethrin 20EC	WULV (36ml)	1.3	4	166	2	333
21,22	Control	Oil only	1.3	4	60	2	120
23,24	Larvin 375 SC	72ml per 13,6l tank High volume with tailboom					
	b)	6 V Battery pack					
25,26	Larvin 375SC	WULV (32ml)	1.3	2	500	1	1000
27,28	Larvin 80 DF	WULV (15g)	1.3	2	500	1	1000
29,30	UCLF 8 (L)	SU 1 pack UCLF 8: 5 parts oil	1.4	2	174	1	348
31,32	Cypermethrin 20EC	WULV (6 ml)	1.3	2	500	1	1000
33,34	Control	Water only	1.3	2	500	1	1000
35,36	Larvin 375 SC	WULV (64ml)	1.3	2	500	1	1000
37,38	Larvin 80 DF	WULV (30g)	1.3	2	500	1	1000
39,40	UCLF 8(UL)	SU 1 part UCLF 8: 2 parts oil	1.4	2	174	1	348
41,42	Cypermethrin 20 EC	WULV (12ml)	1.3	2	500	1	1000
43,44	Control	Oil only	1.4	2	174	1	348

* 1 - For WULV quantities given in brackets of formulated product to be made up to 1 litre with water.

Note: 'OIL' means special mixing oil of some viscosty as UCLF 8; made from 3 parts cooking oil: 1 part Shellsol K.

2 - Quantities of insecticide mixtures expected to be sprayed on both replicates.

IV.B.2.2

Thiodicarb ULV trial: Malawi

Makoka 1987: Bollworm spray logs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	14316.09	10	1431.61	4.661	***
Dosages	622.81	1	622.81	2.028	N.S.
Dosage x Insecticides	5179.88	10	517.99	1.687	N.S.
Contrasts					
Controls vs Insecticides	540.66	(1)	540.66	1.760	N.S.
Large vs Small droplets	11103.91	(1)	11103.91	36.153	***
Knapsack vs all ULV	95.91	(1)	95.91	0.312	N.S.
Knapsack vs Larvin UL	131.29	(1)	131.29	0.427	N.S.
Pyrethroid vs Larvin SC	282.62	(1)	282.62	0.920	N.S.
SC vs. other Larvin UL	235.32	(1)	235.32	0.766	N.S.
DF " " " "	124.30	(1)	124.30	0.405	N.S.
UCLF8 " " " "	17.57	(1)	17.57	0.057	N.S.
Residual	20270.80	66	307.13		
Total	40389.58	87			

Coefficient of Variation = 15.9%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Percent of target rate.				0 100.00
2	WULV containing 80% DF - Small droplets	125.19	4.26	1.157	
1	WULV containing 375 SC - Small droplets	123.69	6.99	3.157	
5	CONTROL: blank - Small droplets	123.62	10.48	7.108	
4	Cypermethrin WULV - Small droplets	123.50	6.43	2.682	
3	OIL: UCLF8 - Small droplets	115.62	9.52	6.275	
6	Larvin SC with Knapsack/tailboom	112.50	1.57	0.176	
11	CONTROL: blank - Large droplets	107.71	7.63	4.319	
9	OIL: UCLF8 - Large droplets	102.33	1.60	0.200	
10	Cypermethrin WULV - Large droplets	98.37	1.63	0.215	
8	WULV containing 80% DF - Large droplets	95.61	4.02	1.353	
7	WULV containing 375 SC - Large droplets	86.30	8.65	6.931	
	Dosages				0 100.00
1	Half rate	113.06	3.18	3.939	
2	Standard	107.74	3.30	4.450	

MEANS:

Large 98.0%

Small 122.3%

(say 24% difference)

WG (DF) 110.4%

SC 105.0%

SU 109.0%

Cypermethrin 110.9%

CLV tailboom 112.5%

2.3

Thiodicarb CDA: Makoka, Malawi (1987)

Total Seed Cotton (June/1987)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	20858183.64	10	2085818.36	31.253	*****
Dosages	436805.82	1	436805.82	6.545	*
In. x Do.	658108.18	10	65810.82	0.986	N.S.
Contrasts					
Controls vs Insecticides	10365006.08	(1)	10365006.08	155.303	*****
Controls vs SC WULV	4854310.56	(1)	4854310.56	72.734	*****
Controls vs WG WULV	1550025.00	(1)	1550025.00	23.225	****
Controls vs UCLF8	5583769.00	(1)	5583769.00	83.664	*****
Large vs Small droplets	811219.53	(1)	811219.53	12.155	**
Knapsack vs Larvin UL	47773.15	(1)	47773.15	0.716	N.S.
Pyrethroid vs Larvin SC	6750903.06	(1)	6750903.06	101.152	*****
SC vs. WG	23256.25	(1)	23256.25	0.348	N.S.
UCLF8 " thiodicarb WULV	2207634.08	(1)	2207634.08	33.078	*****
Residual (Error)	1468290.00	22	66740.455		
TOTAL	23421387.64	43			

Coefficient of Variation = 14.4%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Weight (g) in 3x3m. plot				0 3000.00
4	Cypermethrin WULV - Small droplets	3138.50	224.35	64.149	
10	Cypermethrin WULV - Large droplets	2503.00	139.79	31.227	
3	OIL: UCLF8 - Small droplets	2249.00	167.91	50.147	
9	OIL: UCLF8 - Large droplets	2157.25	160.26	47.622	
6	Larvin SC with Knapsack/tailboom	1892.25	47.99	4.868	
1	WULV containing 37.5% SC: Small droplets	1834.00	161.32	56.759	
8	WULV containing 80% WG - Large droplets	1637.00	122.37	36.589	
2	WULV containing 80% WG - Small droplets	1558.75	123.44	39.101	
7	WULV containing 37.5% SC: Large droplets	1209.25	131.68	57.358	
11	CONTROL: blank - Large droplets	764.00	110.26	63.645	
5	CONTROL: blank - Small droplets	759.00	42.60	9.563	
	Dosages				0 3000.00
1	Half rate	1691.45	155.31	313.730	
2	Standard rate	1890.73	160.09	298.215	

2.4

Thiodicarb ULV trial: Malawi

Makoka: June/1987

Clean Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	20844317.18	10	2084431.72	31.990	***
Dosages	438800.82	1	438800.82	6.734	*
Dosage x Insecticides	588237.18	10	58823.72	0.903	N.S.
Contrasts					
Controls vs Insecticides	9836309.56	(1)	9836309.56	150.961	***
Large vs Small droplets	650085.03	(1)	650085.03	9.977	**
Knapsack vs all ULV	113407.03	(1)	113407.03	1.740	N.S.
Knapsack vs Larvin UL	34171.52	(1)	34171.52	0.524	N.S.
Pyrethroid vs Larvin SC	7265720.25	(1)	7265720.25	111.509	***
SC vs. other Larvin UL	657306.02	(1)	657306.02	10.088	**
DF " " " "	399857.52	(1)	399857.52	6.137	*
UCLF8 " " " "	2082500.08	(1)	2082500.08	31.961	***
Residual	1433473.00	22	65157.86		
Total	23304828.18	43			

Coefficient of Variation = 15.6%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight in grammes/3m.^2				0 3000.00
4	Cypermethrin WULV - Small droplets	3002.25	222.44	65.922	
10	Cypermethrin WULV - Large droplets	2424.50	145.38	34.868	
3	OIL: UCLF8 - Small droplets	2049.50	145.41	41.267	
9	OIL: UCLF8 - Large droplets	1983.00	185.91	69.719	
6	Larvin SC with Knapsack/tailboom	1699.50	50.50	6.002	
1	WULV containing 375 SC - Small droplets	1654.75	168.88	68.945	
8	WULV containing 80% DF - Large droplets	1458.25	115.04	36.304	
2	WULV containing 80% DF - Small droplets	1376.00	104.76	31.901	
7	WULV containing 375 SC - Large droplets	1076.50	117.28	51.105	
5	CONTROL: blank - Small droplets	641.75	41.97	10.982	
11	CONTROL: blank - Large droplets	623.00	89.02	50.885	
	Dosages				0 3000.00
1	Half rate	1535.50	154.15	340.440	
2	Standard	1735.23	160.41	326.247	

2.5

Thiodicarb CDA: Makoka, Malawi (1987)

Damaged Seed Cotton (June/1987)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	102494.91	10	10249.49	2.666	*
Dosages	1807.36	1	1807.36	0.470	N.S.
In. x Do.	31658.64	10	3165.86	0.824	N.S.
Contrasts					
Controls vs Insecticides	8463.28	(1)	8463.28	2.202	N.S.
Controls vs SC WULV	17358.06	(1)	17358.06	4.515	*
Controls vs WG WULV	5662.56	(1)	5662.56	1.473	N.S.
Controls vs UCLF8	26569.00	(1)	26569.00	6.911	*
Large vs Small droplets	561.12	(1)	561.12	0.146	N.S.
Knapsack vs Larvin UL	676.01	(1)	676.01	0.176	N.S.
Pyrethroid vs Larvin SC	29670.06	(1)	29670.06	7.718	*
SC vs. WG	5550.25	(1)	5550.25	1.444	N.S.
UCLF8 " thiodicarb WULV	800.33	(1)	800.33	0.208	N.S.
Residual (Error)	84574.00	22	3844.273		
TOTAL	220534.91	43			

Coefficient of Variation = 41.5%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{75}
	Units (untransformed) are: Weight (g) in 3x3m. plot				0 200.00
4	Cypermethrin WULV - Small droplets	61.25	17.66	20.358	
10	Cypermethrin WULV - Large droplets	78.50	25.00	31.851	
5	CONTROL: blank - Small droplets	99.25	34.80	48.815	
7	WULV containing 37.5% SC: Large droplets	132.75	19.21	11.116	
11	CONTROL: blank - Large droplets	141.00	28.62	23.229	
9	OIL: UCLF8 - Large droplets	174.25	27.07	16.820	
1	WULV containing 37.5% SC: Small droplets	179.25	36.64	29.956	
2	WULV containing 80% WG - Small droplets	182.75	19.64	8.439	
6	Larvin SC with Knapsack/tailboom	192.75	11.64	2.810	
3	OIL: UCLF8 - Small droplets	199.50	31.84	20.326	
8	WULV containing 80% WG - Large droplets	203.75	53.77	56.757	
	Dosages				0 200.00
1	Half rate	155.95	14.92	31.396	
2	Standard rate	143.14	15.84	38.559	

2.6

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Heliothis larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1032.64	10	103.26	8.352	***
Dosages	0.09	1	0.09	0.007	N.S.
Dosage x Insecticides	332.91	10	33.29	2.693	*
Contrasts					
Controls vs Insecticides	700.79	(1)	700.79	56.681	***
Large vs Small droplets	6.13	(1)	6.13	0.495	N.S.
Knapsack vs all ULV	46.72	(1)	46.72	3.779	N.S.
Knapsack vs Larvin UL	35.29	(1)	35.29	2.854	N.S.
Pyrethroid vs Larvin SC	33.06	(1)	33.06	2.674	N.S.
SC vs. other Larvin UL	17.52	(1)	17.52	1.417	N.S.
DF " " " "	6.02	(1)	6.02	0.487	N.S.
UCLF8 " " " "	44.08	(1)	44.08	3.566	N.S.
Residual	272.00	22	12.36		
Total	1637.64	43			

Coefficient of Variation = 29.5%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 20.00
9	OIL: UCLF8 - Large droplets	4.50	0.65	0.370	
4	Cypermethrin WULV - Small droplets	6.00	1.47	1.444	
1	WULV containing 375 SC - Small droplets	8.75	2.10	2.010	
2	WULV containing 80% DF - Small droplets	10.25	0.48	0.089	
10	Cypermethrin WULV - Large droplets	10.75	2.53	2.380	
8	WULV containing 80% DF - Large droplets	11.25	1.44	0.733	
3	OIL: UCLF8 - Small droplets	11.75	1.11	0.418	
6	Larvin SC with Knapsack/tailboom	13.25	2.32	1.629	
7	WULV containing 375 SC - Large droplets	13.75	0.48	0.067	
11	CONTROL: blank - Large droplets	18.75	3.61	2.787	
5	CONTROL: blank - Small droplets	22.00	3.85	2.697	
	Dosages				0 20.00
1	Half rate	11.95	0.94	1.629	
2	Standard	11.86	1.63	4.931	

2.7

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Heliothis eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1884.91	10	188.49	1.528	N.S.
Dosages	99.00	1	99.00	0.803	N.S.
Dosage x Insecticides	984.00	10	98.40	0.798	N.S.
Contrasts					
Controls vs Insecticides	403.06	(1)	403.06	3.267	N.S.
Large vs Small droplets	569.53	(1)	569.53	4.617	*
Knapsack vs all ULV	56.00	(1)	56.00	0.454	N.S.
Knapsack vs Larvin UL	118.34	(1)	118.34	0.959	N.S.
Pyrethroid vs Larvin SC	189.06	(1)	189.06	1.533	N.S.
SC vs. other Larvin UL	6.75	(1)	6.75	0.055	N.S.
DF " " " "	157.69	(1)	157.69	1.278	N.S.
UCLF8 " " " "	99.19	(1)	99.19	0.804	N.S.
Residual	2714.00	22	123.36		
Total	5681.91	43			

Coefficient of Variation = 25.2%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 70.00
8	WULV containing 80% DF - Large droplets	33.50	5.72	3.910	
7	WULV containing 375 SC - Large droplets	36.00	6.94	5.352	
5	CONTROL: blank - Small droplets	37.50	5.12	2.800	
11	CONTROL: blank - Large droplets	37.75	3.97	1.667	
3	OIL: UCLF8 - Small droplets	45.25	2.46	0.536	
2	WULV containing 80% DF - Small droplets	45.50	3.52	1.092	
9	OIL: UCLF8 - Large droplets	46.75	4.73	1.916	
10	Cypermethrin WULV - Large droplets	47.00	2.86	0.695	
6	Larvin SC with Knapsack/tailboom	49.00	6.36	3.306	
1	WULV containing 375 SC - Small droplets	51.75	7.91	4.836	
4	Cypermethrin WULV - Small droplets	54.50	6.44	3.040	
	Dosages				0 70.00
1	Half rate	42.55	2.44	3.091	
2	Standard	45.55	2.47	2.950	

Earias larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	0.96	10	0.10	0.773	N.S.
Dosages	0.00	1	0.00	0.037	N.S.
Dosage x Insecticides	1.08	10	0.11	0.871	N.S.
Contrasts					
Controls vs Insecticides	0.51	(1)	0.51	4.103	N.S.
Large vs Small droplets	0.01	(1)	0.01	0.067	N.S.
Knapsack vs all ULV	0.10	(1)	0.10	0.804	N.S.
Knapsack vs Larvin UL	0.17	(1)	0.17	1.379	N.S.
Pyrethroid vs Larvin SC	0.12	(1)	0.12	0.972	N.S.
SC vs. other Larvin UL	0.03	(1)	0.03	0.239	N.S.
DF " " " "	0.01	(1)	0.01	0.118	N.S.
UCLF8 " " " "	0.00	(1)	0.00	0.021	N.S.
Residual	2.74	22	0.12		
Total	4.79	43			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 38.9%

2.8

Thiodicarb CDA: Makoka, Malawi (1987)

Psyllid Nymphs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	4575393.05	10	457539.30	5.499	***
Dosages	11618.75	1	11618.75	0.140	N.S.
In. x Do.	882137.50	10	88213.75	1.060	N.S.
Contrasts					
Controls vs Insecticides	1928144.05	(1)	1928144.05	23.172	****
Controls vs SC WULV	1296182.25	(1)	1296182.25	15.577	***
Controls vs DF WULV	355514.06	(1)	355514.06	4.272	N.S.
Controls vs UCLF8	829465.56	(1)	829465.56	9.968	**
Large vs Small droplets	605000.00	(1)	605000.00	7.271	*
Knapsack vs Larvin UL	124859.52	(1)	124859.52	1.501	N.S.
Pyrethroid vs Larvin SC	1247689.00	(1)	1247689.00	14.994	***
SC " other Larvin UL	470052.08	(1)	470052.08	5.649	*
DF " " " "	26555.02	(1)	26555.02	0.319	N.S.
UCLF8 " " " "	720055.02	(1)	720055.02	8.653	**
Residual (Error)	1830643.50	22	83211.068		
TOTAL	7299792.80	43			

Coefficient of Variation = 50.9%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 1500.00
4	Cypermethrin WULV - Small droplets	194.00	32.10	21.247	
10	Cypermethrin WULV - Large droplets	224.00	94.28	158.717	
3	OIL: UCLF8 - Small droplets	273.50	105.38	162.424	
9	OIL: UCLF8 - Large droplets	375.75	17.16	3.136	
6	Larvin SC with Knapsack/tailboom	378.75	99.73	105.044	
2	WULV containing 80% DF - Small droplets	395.50	93.73	70.902	
1	WULV containing 37.5% SC: Small droplets	504.75	204.24	330.581	
8	WULV containing 80% DF - Large droplets	837.75	202.86	196.485	
5	CONTROL: blank - Small droplets	929.00	259.64	290.267	
7	WULV containing 37.5% SC: Large droplets	1030.25	82.20	26.231	
11	CONTROL: blank - Large droplets	1093.00	178.10	116.085	
	Dosages				0 1500.00
1	Half rate	550.68	83.68	279.740	
2	Standard rate	583.18	93.66	330.958	

2.9

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Psyllid Adults

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	116734.05	10	11673.40	3.329	**
Dosages	327.27	1	327.27	0.093	N.S.
Dosage x Insecticides	20520.23	10	2052.02	0.585	N.S.
Contrasts					
Controls vs Insecticides	59193.70	(1)	59193.70	16.880	***
Large vs Small droplets	5050.12	(1)	5050.12	1.440	N.S.
Knapsack vs all ULV	2123.35	(1)	2123.35	0.606	N.S.
Knapsack vs Larvin UL	345.72	(1)	345.72	0.099	N.S.
Pyrethroid vs Larvin SC	28561.00	(1)	28561.00	8.145	**
SC vs. other Larvin UL	8694.08	(1)	8694.08	2.479	N.S.
DF " " " "	234.08	(1)	234.08	0.067	N.S.
UCLF8 " " " "	11781.33	(1)	11781.33	3.360	N.S.
Residual	77147.00	22	3506.68		
Total	214728.55	43			

Coefficient of Variation = 57.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Remaining Insect Counts				0 200.00
10	Cypermethrin WULV - Large droplets	39.25	10.37	10.962	
4	Cypermethrin WULV - Small droplets	42.00	3.89	1.444	
9	OIL: UCLF8 - Large droplets	55.00	9.96	7.212	
2	WULV containing 80% DF - Small droplets	68.75	15.42	13.832	
3	OIL: UCLF8 - Small droplets	78.75	25.10	32.012	
1	WULV containing 375 SC - Small droplets	95.50	27.76	32.269	
6	Larvin SC with Knapsack/tailboom	108.25	23.89	21.089	
8	WULV containing 80% DF - Large droplets	136.50	40.55	48.188	
7	WULV containing 375 SC - Large droplets	154.75	22.16	12.697	
5	CONTROL: blank - Small droplets	158.25	54.63	75.439	
11	CONTROL: blank - Large droplets	205.00	24.80	12.000	
	Dosages				0 200.00
1	Half rate	101.09	12.77	35.516	
2	Standard	106.55	17.35	62.126	

2.10

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Aphid scores

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	343285.50	10	34328.55	6.955	***
Dosages	1171.11	1	1171.11	0.237	N.S.
Dosage x Insecticides	74371.14	10	7437.11	1.507	N.S.
Contrasts					
Controls vs Insecticides	240245.50	(1)	240245.50	48.674	***
Large vs Small droplets	11514.03	(1)	11514.03	2.333	N.S.
Knapsack vs all ULV	6699.03	(1)	6699.03	1.357	N.S.
Knapsack vs Larvin UL	1880.02	(1)	1880.02	0.381	N.S.
Pyrethroid vs Larvin SC	62250.25	(1)	62250.25	12.612	**
SC vs. other Larvin UL	24075.52	(1)	24075.52	4.878	*
DF " " " "	1365.33	(1)	1365.33	0.277	N.S.
UCLF8 " " " "	36907.52	(1)	36907.52	7.477	*
Residual	108588.50	22	4935.84		
Total	527416.25	43			

Coefficient of Variation = 21.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Scores from 0..3 indeces				0 600.00
4	Cypermethrin WULV - Small droplets	212.25	29.32	16.202	
10	Cypermethrin WULV - Large droplets	235.00	18.84	6.040	
3	OIL: UCLF8 - Small droplets	239.00	45.13	34.095	
9	OIL: UCLF8 - Large droplets	257.25	26.08	10.580	
2	WULV containing 80% DF - Small droplets	284.50	17.01	4.069	
1	WULV containing 375 SC - Small droplets	322.75	25.74	8.214	
6	Larvin SC with Knapsack/tailboom	327.00	19.57	4.683	
8	WULV containing 80% DF - Large droplets	344.00	54.64	34.715	
7	WULV containing 375 SC - Large droplets	374.00	29.28	9.168	
5	CONTROL: blank - Small droplets	462.75	70.96	43.520	
11	CONTROL: blank - Large droplets	497.25	34.64	9.651	
	Dosages				0 600.00
1	Half rate	318.09	16.31	18.399	
2	Standard	328.41	29.55	58.484	

2.11

Thiodicarb CDA: Makoka, Malawi (1987)

Whitefly (nymphs and adults)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	6338.68	10	633.87	2.672	*
Dosages	192.36	1	192.36	0.811	N.S.
In. x Do.	3979.14	10	397.91	1.677	N.S.
Contrasts					
Controls vs Insecticides	1132.33	(1)	1132.33	4.773	*
Controls vs SC WULV	210.25	(1)	210.25	0.886	N.S.
Controls vs DF WULV	85.56	(1)	85.56	0.361	N.S.
Controls vs UCLF8	1105.56	(1)	1105.56	4.660	*
Large vs Small droplets	318.78	(1)	318.78	1.344	N.S.
Knapsack vs Larvin UL	16.10	(1)	16.10	0.068	N.S.
Pyrethroid vs Larvin SC	3481.00	(1)	3481.00	14.674	***
SC vs other Larvin UL	623.52	(1)	623.52	2.628	N.S.
DF " " " "	336.02	(1)	336.02	1.416	N.S.
UCLF8 " " " "	44.08	(1)	44.08	0.186	N.S.
Residual (Error)	5219.00	22	237.227		
TOTAL	15729.18	43			

Coefficient of Variation = 32.2%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 90.00
4	Cypermethrin WULV - Small droplets	27.25	2.78	1.135	
10	Cypermethrin WULV - Large droplets	29.50	3.93	2.090	
3	OIL: UCLF8 - Small droplets	39.75	4.61	2.136	
8	WULV containing 80% DF - Large droplets	44.25	5.66	2.898	
2	WULV containing 80% DF - Small droplets	46.50	8.67	6.459	
6	Larvin SC with Knapsack/tailboom	48.50	7.58	4.735	
5	CONTROL: blank - Small droplets	49.00	8.78	6.299	
1	WULV containing 37.5% SC: Small droplets	54.25	12.94	12.355	
9	OIL: UCLF8 - Large droplets	57.75	8.88	5.465	
7	WULV containing 37.5% SC: Large droplets	61.50	11.77	9.003	
11	CONTROL: blank - Large droplets	68.25	10.56	6.538	
	Dosages				0 90.00
1	Half rate	45.77	4.05	7.892	
2	Standard rate	49.95	4.15	7.579	

2.12

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Live Dysdercus

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	2.34	10	0.23	2.289	N.S.
Dosages	0.02	1	0.02	0.206	N.S.
Dosage x Insecticides	2.43	10	0.24	2.375	*
Contrasts					
Controls vs Insecticides	0.00	(1)	0.00	0.013	N.S.
Large vs Small droplets	1.55	(1)	1.55	15.171	***
Knapsack vs all ULV	0.23	(1)	0.23	2.218	N.S.
Knapsack vs Larvin UL	0.27	(1)	0.27	2.605	N.S.
Pyrethroid vs Larvin SC	0.07	(1)	0.07	0.685	N.S.
SC vs. other Larvin UL	0.01	(1)	0.01	0.089	N.S.
DF " " " "	0.02	(1)	0.02	0.196	N.S.
UCLF8 " " " "	0.06	(1)	0.06	0.550	N.S.
Residual	2.25	22	0.10		
Total	7.03	43			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 34.4%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 1.00
4	Cypermethrin WULV - Small droplets	0.00	0.00	0.000	
5	CONTROL: blank - Small droplets	0.00	0.00	0.000	
6	Larvin SC with Knapsack/tailboom	0.00	0.00	0.000	
1	WULV containing 375 SC - Small droplets	0.00	0.00	0.000	
3	OIL: UCLF8 - Small droplets	0.00	0.00	0.000	
2	WULV containing 80% DF - Small droplets	0.25	0.25	1.000	
10	Cypermethrin WULV - Large droplets	0.75	0.48	1.222	
9	OIL: UCLF8 - Large droplets	1.00	0.71	2.000	
11	CONTROL: blank - Large droplets	1.00	0.71	2.000	
8	WULV containing 80% DF - Large droplets	1.25	0.75	1.800	
7	WULV containing 375 SC - Large droplets	1.50	0.87	2.000	
	Dosages				0 1.00
1	Half rate	0.45	0.19	1.829	
2	Standard	0.59	0.24	2.201	

N.B. Bars represent transformed data.

2.13

Thiodicarb ULV trial: Malawi

Makoka: summary for 1987 season

Jassids

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	510.41	10	51.04	2.049	N.S.
Dosages	17.82	1	17.82	0.715	N.S.
Dosage x Insecticides	115.68	10	11.57	0.464	N.S.
Contrasts					
Controls vs Insecticides	252.28	(1)	252.28	10.128	**
Large vs Small droplets	47.53	(1)	47.53	1.908	N.S.
Knapsack vs all ULV	11.28	(1)	11.28	0.453	N.S.
Knapsack vs Larvin UL	6.88	(1)	6.88	0.276	N.S.
Pyrethroid vs Larvin SC	4.00	(1)	4.00	0.161	N.S.
SC vs. other Larvin UL	2.52	(1)	2.52	0.101	N.S.
DF " " " "	28.52	(1)	28.52	1.145	N.S.
UCLF8 " " " "	14.08	(1)	14.08	0.565	N.S.
Residual	548.00	22	24.91		
Total	1191.91	43			

Coefficient of Variation = 70.8%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 20.00
7	WULV containing 375 SC - Large droplets	3.75	1.49	2.378	
10	Cypermethrin WULV - Large droplets	4.50	1.32	1.556	
4	Cypermethrin WULV - Small droplets	4.75	1.75	2.579	
9	OIL: UCLF8 - Large droplets	4.75	1.70	2.439	
8	WULV containing 80% DF - Large droplets	5.00	1.73	2.400	
3	OIL: UCLF8 - Small droplets	5.25	2.56	5.000	
1	WULV containing 375 SC - Small droplets	7.50	0.65	0.222	
6	Larvin SC with Knapsack/tailboom	7.50	1.26	0.844	
5	CONTROL: blank - Small droplets	8.25	4.84	11.343	
2	WULV containing 80% DF - Small droplets	10.25	0.48	0.089	
11	CONTROL: blank - Large droplets	16.00	3.42	2.917	
	Dosages				0 20.00
1	Half rate	6.41	0.85	2.477	
2	Standard	7.68	1.35	5.212	

Red Spider Mite scores

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	79682.14	10	7968.21	0.742	N.S.
Dosages	17961.84	1	17961.84	1.673	N.S.
Dosage x Insecticides	142170.41	10	14217.04	1.324	N.S.
Contrasts					
Controls vs Insecticides	14280.01	(1)	14280.01	1.330	N.S.
Large vs Small droplets	22155.12	(1)	22155.12	2.063	N.S.
Knapsack vs all ULV	7080.50	(1)	7080.50	0.659	N.S.
Knapsack vs Larvin UL	4972.60	(1)	4972.60	0.463	N.S.
Pyrethroid vs Larvin SC	72.25	(1)	72.25	0.007	N.S.
SC vs. other Larvin UL	11102.08	(1)	11102.08	1.034	N.S.
DF " " " "	5655.02	(1)	5655.02	0.527	N.S.
UCLF8 " " " "	910.02	(1)	910.02	0.085	N.S.
Residual	236229.50	22	10737.70		
Total	476043.89	43			

Coefficient of Variation = 75.0%

2.14

Thiodicarb CDA: Makoka, Malawi (1987)

Syrphid larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	16.99	10	1.70	4.336	**
Dosages	0.35	1	0.35	0.905	N.S.
In. x Do.	4.56	10	0.46	1.163	N.S.
Contrasts					
Controls vs Insecticides	12.26	(1)	12.26	31.289	****
Controls vs SC WULV	5.39	(1)	5.39	13.764	**
Controls vs WG WULV	9.68	(1)	9.68	24.706	****
Controls vs UCLF8	5.22	(1)	5.22	13.310	**
Large vs Small droplets	0.69	(1)	0.69	1.771	N.S.
Knapsack vs Larvin UL	0.06	(1)	0.06	0.142	N.S.
Pyrethroid vs Larvin SC	0.36	(1)	0.36	0.914	N.S.
SC vs. WG	0.59	(1)	0.59	1.500	N.S.
UCLF8 " thiodicarb WULV	0.22	(1)	0.22	0.553	N.S.
Residual (Error)	8.62	22	0.392		
TOTAL	30.53	43			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 39.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Remaining Insect Counts				0 3.00
4	Cypermethrin WULV - Small droplets	0.25	0.25	1.000	
3	OIL: UCLF8 - Small droplets	0.75	0.48	1.222	
7	WULV containing 37.5% SC: Large droplets	1.00	1.00	4.000	
10	Cypermethrin WULV - Large droplets	1.25	0.95	2.867	
2	WULV containing 80% WG - Small droplets	1.50	0.96	2.444	
6	Larvin SC with Knapsack/tailboom	2.00	0.41	0.333	
1	WULV containing 37.5% SC: Small droplets	2.00	0.41	0.333	
9	OIL: UCLF8 - Large droplets	2.75	1.89	5.182	
8	WULV containing 80% WG - Large droplets	4.25	1.31	1.627	
5	CONTROL: blank - Small droplets	6.75	0.85	0.432	
11	CONTROL: blank - Large droplets	8.00	3.19	5.083	
	Dosages				0 3.00
1	Half rate	2.23	0.46	2.050	
2	Standard rate	3.32	0.91	5.493	

N.B. Bars represent transformed data.

2.15

Thiodicarb CDA: Makoka, Malawi (1987)

Chrysopid larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	3.73	10	0.37	2.373	*
Dosages	0.00	1	0.00	0.001	N.S.
In. x Do.	2.72	10	0.27	1.729	N.S.
Contrasts					
Controls vs Insecticides	0.32	(1)	0.32	2.012	N.S.
Controls vs SC WULV	0.21	(1)	0.21	1.358	N.S.
Controls vs WG WULV	0.01	(1)	0.01	0.075	N.S.
Controls vs UCLF8	0.36	(1)	0.36	2.268	N.S.
Large vs Small droplets	0.07	(1)	0.07	0.424	N.S.
Knapsack vs Larvin UL	0.44	(1)	0.44	2.788	N.S.
Pyrethroid vs Larvin SC	0.12	(1)	0.12	0.796	N.S.
SC vs. WG	0.49	(1)	0.49	3.132	N.S.
UCLF8 " thiodicarb WULV	0.17	(1)	0.17	1.078	N.S.
Residual (Error)	3.46	22	0.157		
TOTAL	9.90	43			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 35.1%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: Remaining Insect Counts				0 2.00
4	Cypermethrin WULV - Small droplets	0.25	0.25	1.000	
6	Larvin SC with Knapsack/tailboom	0.25	0.25	1.000	
7	WULV containing 37.5% SC: Large droplets	0.25	0.25	1.000	
3	OIL: UCLF8 - Small droplets	0.25	0.25	1.000	
10	Cypermethrin WULV - Large droplets	0.50	0.29	0.667	
11	CONTROL: blank - Large droplets	0.75	0.48	1.222	
8	WULV containing 80% WG - Large droplets	1.00	0.41	0.667	
9	OIL: UCLF8 - Large droplets	1.25	0.25	0.200	
1	WULV containing 37.5% SC: Small droplets	1.50	0.87	2.000	
5	CONTROL: blank - Small droplets	2.50	1.55	3.867	
2	WULV containing 80% WG - Small droplets	2.50	0.87	1.200	
	Dosages				0 2.00
1	Half rate	0.95	0.25	1.444	
2	Standard rate	1.05	0.35	2.594	

N.B. Bars represent transformed data.

2.16

Thiodicarb CDA: Makoka, Malawi (1987)

Coccinellid larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1.09	10	0.11	2.116	N.S.
Dosages	0.34	1	0.34	6.498	*
In. x Do.	1.28	10	0.13	2.486	*
Contrasts					
Controls vs Insecticides	0.00	(1)	0.00	0.005	N.S.
Controls vs SC WULV	0.00	(1)	0.00	0.000	N.S.
Controls vs WG WULV	0.12	(1)	0.12	2.422	N.S.
Controls vs UCLF8	0.01	(1)	0.01	0.154	N.S.
Large vs Small droplets	0.03	(1)	0.03	0.621	N.S.
Knapsack vs Larvin UL	0.14	(1)	0.14	2.743	N.S.
Pyrethroid vs Larvin SC	0.55	(1)	0.55	10.663	**
SC vs. WG	0.37	(1)	0.37	7.267	*
UCLF8 " thiodicarb WULV	0.01	(1)	0.01	0.199	N.S.
Residual (Error)	1.14	22	0.052		
TOTAL	3.85	43			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 27.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: Remaining Insect Counts				0 1.50
8	WULV containing 80% WG - Large droplets	0.00	0.00	0.000	
6	Larvin SC with Knapsack/tailboom	0.00	0.00	0.000	
10	Cypermethrin WULV - Large droplets	0.00	0.00	0.000	
9	OIL: UCLF8 - Large droplets	0.00	0.00	0.000	
4	Cypermethrin WULV - Small droplets	0.00	0.00	0.000	
2	WULV containing 80% WG - Small droplets	0.25	0.25	1.000	
11	CONTROL: blank - Large droplets	0.25	0.25	1.000	
5	CONTROL: blank - Small droplets	0.25	0.25	1.000	
1	WULV containing 37.5% SC: Small droplets	0.50	0.29	0.667	
3	OIL: UCLF8 - Small droplets	0.75	0.48	1.222	
7	WULV containing 37.5% SC: Large droplets	1.25	0.95	2.867	
	Dosages				0 1.50
1	Half rate	0.50	0.21	1.857	
2	Standard rate	0.09	0.06	0.952	

N.B. Bars represent transformed data.

Ser. MK/CPR/ENT/143.

DETAILED APPLICATION INSTRUCTIONS - TOLEZA

Plot No.	Insecticide Formulation	Mixing Instructions *1	Restrictor	Crops less than 0.75m. tall		Crops greater greater 0.75m.	
				Swath (rows)	Qtty*2	Swath (rows)	Qtty*2
	a)	12 V Battery Pack					
1,2	Larvin 375 SC	WULV (96ml)	1.3	4	225	2	450
3,4	Larvin 80 DF	WULV (45g)	1.3	4	225	2	450
5,6	ULLF 8 (UL)	SULV: 1 part UCLF8 1 part oil	1.3 1.3	4	80	2	160
7,8	Cypermethrin 20 EC	WULV (18ml)	1.3	4	225	2	450
9,10	Control	Water only	1.3	4	225	2	450
11,12	Larvin 375 SC	36ml. per 13.6l tank		High volume with tail-boom			
13,14	Larvin 375 SC	WULV (192ml)	1.4	4	225	2	450
15,16	Larvin 80 DF	WULV (90g)	1.3	4	225	2	450
17,18	UCLF 8(UL)	SULV Undiluted	1.3	4	80	2	160
19,20	Cypermethrin 20 EC	WULV (36 ml)	1.3	4	225	2	450
21,22	Control	Oil only	1.3	4	80	2	160
23,24	Larvin 375 SC	72ml per 13.6l tank		High volume with tailboom			
	b)	6V Battery pack					
25,26	Larvin 375 SC	WULV (32ml)	1.3	2	665	1	1,335
27,28	Larvin 80 DF	WULV (15g)	1.3	2	"	1	"
29,30	UCLF 8 (UL)	SULV 1 part UCLF 8 5 parts oil	1.4	2	240	1	480
31,32	Cypermethrin 20 EC	WULV (6 ml)	1.3	2	665	1	1,335
33,34	Control	Water only	1.3	2	"	1	"
35,36	Larvin 375 SC	WULV (64ml)	1.3	2	"	1	"
37,38	Larvin 80 DF	WULV (30g)	1.3	2	"	1	"
39,40	UCLF 8 (UL)	SULV 1 part UCLF 8: 2 parts oil	1.4	2	240	1	480
41,42	Cypermethrin 20 EC	WULV (12 ml)	1.3	2	665	1	1,335
43,44	Control	Oil only	1.4	2	240	1	480

* 1 - For WULV quantities given in brackets of fomulated product to be made up to 1 litre with water.

* 2 - Quantities of insecticide mixtures expected to be sprayed on both replicates.

IV.B.3.2

Thiodicarb ULV trial: Malawi

Toleza 1987: Bollworm spray logs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	8719.05	10	871.91	2.530	**
Dosages	205.29	1	205.29	0.596	N.S.
Dosage x Insecticides	3259.47	10	325.95	0.946	N.S.
Contrasts					
Controls vs Insecticides	53.35	(1)	53.35	0.155	N.S.
Large vs Small droplets	1242.93	(1)	1242.93	3.606	N.S.
Knapsack vs all ULV	3470.52	(1)	3470.52	10.069	**
Knapsack vs Larvin UL	2858.30	(1)	2858.30	8.293	**
Pyrethroid vs Larvin SC	905.43	(1)	905.43	2.627	N.S.
SC vs. other Larvin UL	372.19	(1)	372.19	1.080	N.S.
DF " " " "	6.46	(1)	6.46	0.019	N.S.
UCLF8 " " " "	280.58	(1)	280.58	0.814	N.S.
Residual	37913.32	110	344.67		
Total	50097.13	131			

Coefficient of Variation = 18.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD.05
	Units (untransformed) are: Percent of target rate.				0 100.00
3	OIL: UCLF8 - Small droplets	117.81	14.66	21.902	
4	Cypermethrin WULV - Small droplets	111.61	4.85	2.529	
5	CONTROL: blank - Small droplets	110.99	6.36	4.373	
10	Cypermethrin WULV - Large droplets	106.63	3.47	1.356	
2	WULV containing 80% DF - Small droplets	104.48	1.70	0.330	
8	WULV containing 80% DF - Large droplets	103.66	1.23	0.174	
1	WULV containing 375 SC - Small droplets	100.56	2.17	0.563	
7	WULV containing 375 SC - Large droplets	100.31	1.99	0.472	
11	CONTROL: blank - Large droplets	98.34	2.47	0.746	
9	OIL: UCLF8 - Large droplets	95.07	1.73	0.378	
6	Larvin SC with Knapsack/tailboom	86.98	0.52	0.037	
	Dosages				0 100.00
1	Half rate	104.56	3.23	6.594	
2	Standard	102.07	1.09	0.766	

3.3

Thiodicarb ULV trial: Malawi

Toleza: June/1987

Total Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	2233416.14	10	223341.61	1.333	N.S.
Dosages	987301.84	1	987301.84	5.891	*
Dosage x Insecticides	2320668.41	10	232066.84	1.385	N.S.
Contrasts					
Controls vs Insecticides	1534984.46	(1)	1534984.46	9.159	**
Large vs Small droplets	49928.00	(1)	49928.00	0.298	N.S.
Knapsack vs all ULV	10200.68	(1)	10200.68	0.061	N.S.
Knapsack vs Larvin UL	18333.48	(1)	18333.48	0.109	N.S.
Pyrethroid vs Larvin SC	179776.00	(1)	179776.00	1.073	N.S.
SC vs. other Larvin UL	214668.75	(1)	214668.75	1.281	N.S.
DF " " " "	6768.75	(1)	6768.75	0.040	N.S.
UCLF8 " " " "	297675.00	(1)	297675.00	1.776	N.S.
Residual	3686945.50	22	167588.43		
Total	9228331.89	43			

Coefficient of Variation = 22.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight in grammes/3m.^2				0 2000.00
9	OIL: UCLF8 - Large droplets	2118.75	135.81	34.819	
4	Cypermethrin WULV - Small droplets	2026.25	236.51	110.429	
6	Larvin SC with Knapsack/tailboom	1942.50	272.06	152.420	
3	OIL: UCLF8 - Small droplets	1935.00	344.86	245.848	
1	WULV containing 375 SC - Small droplets	1877.50	187.50	74.900	
2	WULV containing 80% DF - Small droplets	1875.00	179.71	68.898	
10	Cypermethrin WULV - Large droplets	1869.00	176.44	66.626	
8	WULV containing 80% DF - Large droplets	1816.25	160.64	56.833	
7	WULV containing 375 SC - Large droplets	1593.75	176.24	77.954	
11	CONTROL: blank - Large droplets	1461.25	303.78	252.608	
5	CONTROL: blank - Small droplets	1360.00	260.48	199.559	
	Dosages				0 2000.00
1	Half rate	1657.05	101.63	137.125	
2	Standard	1956.64	86.66	84.434	

3.4

Thiodicarb ULV trial: Malawi

Toleza: June/1987

Clean Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	2662223.41	10	266222.34	1.595	N.S.
Dosages	1005359.11	1	1005359.11	6.023	*
Dosage x Insecticides	2214266.14	10	221426.61	1.327	N.S.
Contrasts					
Controls vs Insecticides	1912780.41	(1)	1912780.41	11.459	**
Large vs Small droplets	55195.03	(1)	55195.03	0.331	N.S.
Knapsack vs all ULV	9905.28	(1)	9905.28	0.059	N.S.
Knapsack vs Larvin UL	18229.17	(1)	18229.17	0.109	N.S.
Pyrethroid vs Larvin SC	199247.56	(1)	199247.56	1.188	N.S.
SC vs. other Larvin UL	242252.08	(1)	242252.08	1.451	N.S.
DF " " " "	5852.08	(1)	5852.08	0.035	N.S.
UCLF8 " " " "	323408.33	(1)	323408.33	1.937	N.S.
Residual	3672310.50	22	166923.20		
Total	9554159.16	43			

Coefficient of Variation = 23.5%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight in grammes/3m.^2				0 2000.00
9	OIL: UCLF8 - Large droplets	2065.00	138.95	37.401	
4	Cypermethrin WULV - Small droplets	1970.00	238.36	115.364	
3	OIL: UCLF8 - Small droplets	1887.50	339.22	243.863	
6	Larvin SC with Knapsack/tailboom	1885.00	272.78	157.896	
2	WULV containing 80% DF - Small droplets	1825.00	182.32	72.858	
10	Cypermethrin WULV - Large droplets	1815.25	169.81	63.538	
1	WULV containing 375 SC - Small droplets	1812.50	168.29	62.506	
8	WULV containing 80% DF - Large droplets	1755.00	158.14	56.999	
7	WULV containing 375 SC - Large droplets	1527.50	186.83	91.408	
11	CONTROL: blank - Large droplets	1365.00	293.67	252.723	
5	CONTROL: blank - Small droplets	1230.00	268.64	234.688	
	Dosages				0 2000.00
1	Half rate	1588.64	102.74	146.183	
2	Standard	1890.95	89.15	92.469	

3.5

Thiodicarb ULV trial: Malawi

Toleza: June/1987

Damaged Seed Cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	24353.41	10	2435.34	4.915	***
Dosages	81.82	1	81.82	0.165	N.S.
Dosage * Insecticides	9280.68	10	928.07	1.873	N.S.
Contrasts					
Controls vs Insecticides	20761.40	(1)	20761.40	41.904	***
Large vs Small droplets	132.03	(1)	132.03	0.266	N.S.
Knapsack vs all ULV	2.17	(1)	2.17	0.004	N.S.
Knapsack vs Larvin UL	0.15	(1)	0.15	0.000	N.S.
Pyrethroid vs Larvin SC	451.56	(1)	451.56	0.911	N.S.
SC vs. other Larvin UL	833.33	(1)	833.33	1.682	N.S.
DF " " " "	33.33	(1)	33.33	0.067	N.S.
UCLF8 " " " "	533.33	(1)	533.33	1.076	N.S.
Residual	10900.00	22	495.45		
Total	44615.91	43			

Coefficient of Variation = 33.2%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Weight in grammes/3m.^2				0 100.00
3	OIL: UCLF8 - Small droplets	47.50	6.61	3.684	
2	WULV containing 80% DF - Small droplets	50.00	3.54	1.000	
9	OIL: UCLF8 - Large droplets	53.75	5.54	2.287	
10	Cypermethrin WULV - Large droplets	53.75	7.47	4.147	
4	Cypermethrin WULV - Small droplets	56.25	2.39	0.407	
6	Larvin SC with Knapsack/tailboom	57.50	11.64	9.420	
8	WULV containing 80% DF - Large droplets	61.25	10.08	6.633	
1	WULV containing 375 SC - Small droplets	65.00	25.33	39.487	
7	WULV containing 375 SC - Large droplets	66.25	11.25	7.642	
11	CONTROL: blank - Large droplets	96.25	14.77	9.069	
5	CONTROL: blank - Small droplets	130.00	17.80	9.744	
	Dosages				0 100.00
1	Half rate	68.41	5.98	11.499	
2	Standard	65.68	7.79	20.311	

3.6

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Heliothis larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	506.00	10	50.60	2.075	N.S.
Dosages	3.84	1	3.84	0.158	N.S.
Dosage x Insecticides	117.91	10	11.79	0.484	N.S.
Contrasts					
Controls vs Insecticides	187.15	(1)	187.15	7.674	*
Large vs Small droplets	2.00	(1)	2.00	0.082	N.S.
Knapsack vs all ULV	203.35	(1)	203.35	8.339	**
Knapsack vs Larvin UL	176.10	(1)	176.10	7.221	*
Pyrethroid vs Larvin SC	20.25	(1)	20.25	0.830	N.S.
SC vs. other Larvin UL	5.33	(1)	5.33	0.219	N.S.
DF " " " "	5.33	(1)	5.33	0.219	N.S.
UCLF8 " " " "	21.33	(1)	21.33	0.875	N.S.
Residual	536.50	22	24.39		
Total	1164.25	43			

Coefficient of Variation = 63.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Remaining Insect Counts				0 20.00
10	Cypermethrin WULV - Large droplets	2.50	0.87	1.200	
3	OIL: UCLF8 - Small droplets	3.75	1.38	2.022	
2	WULV containing 80% DF - Small droplets	5.50	2.20	7.455	
9	OIL: UCLF8 - Large droplets	6.25	2.06	2.707	
1	WULV containing 375 SC - Small droplets	6.50	1.04	0.667	
4	Cypermethrin WULV - Small droplets	7.00	2.48	3.524	
7	WULV containing 375 SC - Large droplets	7.50	1.71	1.556	
8	WULV containing 80% DF - Large droplets	8.50	1.50	1.059	
5	CONTROL: blank - Small droplets	11.25	4.17	6.185	
11	CONTROL: blank - Large droplets	13.00	1.35	0.564	
6	Larvin SC with Knapsack/tailboom	13.50	2.47	1.802	
	Dosages				0 20.00
1	Half rate	8.05	1.29	4.551	
2	Standard	7.45	0.92	2.501	

3.7

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Heliothis eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	801.05	10	80.10	1.013	N.S.
Dosages	581.82	1	581.82	7.361	*
Dosage x Insecticides	333.68	10	33.37	0.422	N.S.
Contrasts					
Controls vs Insecticides	388.92	(1)	388.92	4.920	*
Large vs Small droplets	30.03	(1)	30.03	0.380	N.S.
Knapsack vs all ULV	0.78	(1)	0.78	0.010	N.S.
Knapsack vs Larvin UL	0.86	(1)	0.86	0.011	N.S.
Pyrethroid vs Larvin SC	196.00	(1)	196.00	2.480	N.S.
SC vs. other Larvin UL	117.19	(1)	117.19	1.483	N.S.
DF " " " "	6.75	(1)	6.75	0.085	N.S.
UCLF8 " " " "	67.69	(1)	67.69	0.856	N.S.
Residual	1739.00	22	79.05		
Total	3455.55	43			

Coefficient of Variation = 23.0%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 50.00
8	WULV containing 80% DF - Large droplets	44.75	1.70	0.259	
1	WULV containing 375 SC - Small droplets	44.25	6.07	3.335	
7	WULV containing 375 SC - Large droplets	44.00	6.99	4.439	
6	Larvin SC with Knapsack/tailboom	40.50	3.62	1.292	
9	OIL: UCLF8 - Large droplets	39.50	2.40	0.582	
4	Cypermethrin WULV - Small droplets	38.50	5.84	3.541	
3	OIL: UCLF8 - Small droplets	37.75	3.47	1.278	
2	WULV containing 80% DF - Small droplets	35.75	3.50	1.368	
10	Cypermethrin WULV - Large droplets	35.75	4.09	1.872	
5	CONTROL: blank - Small droplets	33.50	4.66	2.597	
11	CONTROL: blank - Large droplets	31.25	4.11	2.163	
	Dosages				0 50.00
1	Half rate	35.05	1.74	1.890	
2	Standard	42.32	1.79	1.669	

3.8

Thiodicarb CDA: Toleza, Malawi (1987)

Aphids: 7 sampling positions, 12 plants, 7 days.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	87642.50	10	8764.25	5.690	***
Dosages	2994.75	1	2994.75	1.944	N.S.
In. x Do.	7987.50	10	798.75	0.519	N.S.
Contrasts					
Controls vs Insecticides	75934.37	(1)	75934.37	49.303	*****
Controls vs SC WULV	29070.25	(1)	29070.25	18.875	***
Controls vs DF WULV	48730.56	(1)	48730.56	31.640	****
Controls vs UCLF8	45796.00	(1)	45796.00	29.735	****
Large vs Small droplets	6699.03	(1)	6699.03	4.350	N.S.
Knapsack vs Larvin UL	1045.01	(1)	1045.01	0.679	N.S.
Pyrethroid vs Larvin SC	324.00	(1)	324.00	0.210	N.S.
SC vs other Larvin UL	46.02	(1)	46.02	0.030	N.S.
DF " " " "	808.52	(1)	808.52	0.525	N.S.
UCLF8 " " " "	1240.33	(1)	1240.33	0.805	N.S.
Residual (Error)	33883.50	22	1540.159		
TOTAL	132508.25	43			

Coefficient of Variation = 19.5%

Units (untransformed) are: Accumulated infestation indices

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Insecticides	**LSD =**	**57.54**		0 300.00
9	OIL: UCLF8 - Large droplets	155.50	15.59	6.249	
7	WULV containing 37.5% SC: Large droplets	157.00	7.22	1.329	
10	Cypermethrin WULV - Large droplets	169.75	20.70	10.095	
8	WULV containing 80% DF - Large droplets	178.00	20.16	9.135	
4	Cypermethrin WULV - Small droplets	178.75	7.92	1.404	
3	OIL: UCLF8 - Small droplets	186.75	9.04	1.751	
6	Larvin SC with Knapsack/tailboom	198.75	11.76	2.782	
2	WULV containing 80% DF - Small droplets	201.00	16.09	5.151	
1	WULV containing 37.5% SC: Small droplets	209.50	6.22	0.740	
5	CONTROL: blank - Small droplets	288.00	24.45	8.306	
11	CONTROL: blank - Large droplets	290.75	37.82	19.681	
	Dosages	**LSD =**	**24.54**		0 300.00
1	Half rate	209.50	11.63	14.207	
2	Standard rate	193.00	12.04	16.533	

3.9

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Psyllid Nymphs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	157619.64	10	15761.96	0.889	N.S.
Dosages	31538.27	1	31538.27	1.779	N.S.
Dosage x Insecticides	181219.73	10	18121.97	1.022	N.S.
Contrasts					
Controls vs Insecticides	1475.46	(1)	1475.46	0.083	N.S.
Large vs Small droplets	6612.50	(1)	6612.50	0.373	N.S.
Knapsack vs all ULV	2357.56	(1)	2357.56	0.133	N.S.
Knapsack vs Larvin UL	433.93	(1)	433.93	0.024	N.S.
Pyrethroid vs Larvin SC	12210.25	(1)	12210.25	0.689	N.S.
SC vs. other Larvin UL	90.75	(1)	90.75	0.005	N.S.
DF " " " "	22576.69	(1)	22576.69	1.274	N.S.
UCLF8 " " " "	19804.69	(1)	19804.69	1.117	N.S.
Residual	389958.00	22	17725.36		
Total	760335.64	43			

Coefficient of Variation = 177.3%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 300.00
4	Cypermethrin WULV - Small droplets	3.50	1.32	2.000	
7	WULV containing 375 SC - Large droplets	7.00	4.45	11.333	
3	OIL: UCLF8 - Small droplets	11.25	6.54	15.193	
5	CONTROL: blank - Small droplets	19.00	10.34	22.526	
10	Cypermethrin WULV - Large droplets	48.50	35.70	105.093	
9	OIL: UCLF8 - Large droplets	75.50	53.26	150.300	
8	WULV containing 80% DF - Large droplets	89.50	78.93	278.454	
6	Larvin SC with Knapsack/tailboom	95.25	78.29	257.388	
1	WULV containing 375 SC - Small droplets	155.50	80.71	167.556	
11	CONTROL: blank - Large droplets	155.75	113.78	332.492	
2	WULV containing 80% DF - Small droplets	165.25	118.85	341.888	
	Dosages				0 300.00
1	Half rate	101.86	29.84	192.266	
2	Standard	48.32	26.22	312.921	

3.10

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Psyllid Adults

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	1206.73	10	120.67	0.827	N.S.
Dosages	20.45	1	20.45	0.140	N.S.
Dosage x Insecticides	1297.55	10	129.75	0.889	N.S.
Contrasts					
Controls vs Insecticides	135.84	(1)	135.84	0.930	N.S.
Large vs Small droplets	81.28	(1)	81.28	0.557	N.S.
Knapsack vs all ULV	0.42	(1)	0.42	0.003	N.S.
Knapsack vs Larvin UL	3.43	(1)	3.43	0.023	N.S.
Pyrethroid vs Larvin SC	203.06	(1)	203.06	1.391	N.S.
SC vs. other Larvin UL	36.75	(1)	36.75	0.252	N.S.
DF " " " "	90.75	(1)	90.75	0.622	N.S.
UCLF8 " " " "	243.00	(1)	243.00	1.664	N.S.
Residual	3212.00	22	146.00		
Total	5736.73	43			

Coefficient of Variation = 117.6%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD.05
	Units (untransformed) are: Remaining Insect Counts				0 30.00
10	Cypermethrin WULV - Large droplets	4.00	3.08	9.500	
3	OIL: UCLF8 - Small droplets	5.50	2.53	4.667	
7	WULV containing 375 SC - Large droplets	6.00	1.08	0.778	
4	Cypermethrin WULV - Small droplets	6.75	4.52	12.086	
9	OIL: UCLF8 - Large droplets	7.00	3.49	6.952	
5	CONTROL: blank - Small droplets	8.00	3.14	4.917	
6	Larvin SC with Knapsack/tailboom	9.75	2.75	3.103	
2	WULV containing 80% DF - Small droplets	12.75	4.44	6.190	
8	WULV containing 80% DF - Large droplets	14.25	5.01	7.035	
1	WULV containing 375 SC - Small droplets	19.00	9.46	18.842	
11	CONTROL: blank - Large droplets	20.00	13.27	35.233	
	Dosages				0 30.00
1	Half rate	10.95	1.53	4.681	
2	Standard	9.59	3.17	23.034	

3.11

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Whiteflies

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	768.55	10	76.85	1.027	N.S.
Dosages	4.45	1	4.45	0.060	N.S.
Dosage x Insecticides	212.55	10	21.25	0.284	N.S.
Contrasts					
Controls vs Insecticides	214.32	(1)	214.32	2.863	N.S.
Large vs Small droplets	312.50	(1)	312.50	4.174	N.S.
Knapsack vs all ULV	34.72	(1)	34.72	0.464	N.S.
Knapsack vs Larvin UL	34.38	(1)	34.38	0.459	N.S.
Pyrethroid vs Larvin SC	16.00	(1)	16.00	0.214	N.S.
SC vs. other Larvin UL	56.33	(1)	56.33	0.752	N.S.
DF " " " "	20.02	(1)	20.02	0.267	N.S.
UCLF8 " " " "	143.52	(1)	143.52	1.917	N.S.
Residual	1647.00	22	74.86		
Total	2632.55	43			

Coefficient of Variation = 36.3%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 40.00
10	Cypermethrin WULV - Large droplets	18.00	2.45	1.333	
7	WULV containing 375 SC - Large droplets	18.25	2.63	1.511	
8	WULV containing 80% DF - Large droplets	19.00	2.92	1.789	
6	Larvin SC with Knapsack/tailboom	20.00	2.61	1.367	
1	WULV containing 375 SC - Small droplets	23.75	4.37	3.211	
2	WULV containing 80% DF - Small droplets	24.75	1.80	0.522	
9	OIL: UCLF8 - Large droplets	24.75	3.71	2.219	
11	CONTROL: blank - Large droplets	27.00	5.60	4.642	
4	Cypermethrin WULV - Small droplets	28.00	5.70	4.643	
3	OIL: UCLF8 - Small droplets	28.50	5.17	3.754	
5	CONTROL: blank - Small droplets	30.00	0.71	0.067	
	Dosages				0 40.00
1	Half rate	24.14	1.82	3.036	
2	Standard	23.50	1.54	2.208	

3.12

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Red Spider Mite scores

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	27.80	10	2.78	1.191	N.S.
Dosages	0.01	1	0.01	0.004	N.S.
Dosage x Insecticides	21.64	10	2.16	0.927	N.S.
Contrasts					
Controls vs Insecticides	0.96	(1)	0.96	0.410	N.S.
Large vs Small droplets	6.47	(1)	6.47	2.770	N.S.
Knapsack vs all ULV	2.50	(1)	2.50	1.069	N.S.
Knapsack vs Larvin UL	1.32	(1)	1.32	0.565	N.S.
Pyrethroid vs Larvin SC	5.16	(1)	5.16	2.209	N.S.
SC vs. other Larvin UL	0.84	(1)	0.84	0.362	N.S.
DF " " " "	0.47	(1)	0.47	0.203	N.S.
UCLF8 " " " "	2.58	(1)	2.58	1.107	N.S.
Residual	51.36	22	2.33		
Total	100.81	43			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 110.5%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Scores from 0..3 indeces				0 5.00
4	Cypermethrin WULV - Small droplets	0.00	0.00	0.000	
5	CONTROL: blank - Small droplets	0.00	0.00	0.000	
8	WULV containing 80% DF - Large droplets	0.00	0.00	0.000	
10	Cypermethrin WULV - Large droplets	0.00	0.00	0.000	
7	WULV containing 375 SC - Large droplets	0.50	0.50	2.000	
3	OIL: UCLF8 - Small droplets	0.50	0.50	2.000	
11	CONTROL: blank - Large droplets	2.25	1.65	4.852	
9	OIL: UCLF8 - Large droplets	2.25	2.25	9.000	
6	Larvin SC with Knapsack/tailboom	7.00	4.95	14.000	
2	WULV containing 80% DF - Small droplets	8.50	3.12	4.588	
1	WULV containing 375 SC - Small droplets	19.75	19.75	79.000	
	Dosages				0 5.00
1	Half rate	2.77	1.21	11.573	
2	Standard	4.64	3.59	61.246	

N.B. Bars represent transformed data.

3.13

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Jassids

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	362.64	10	36.26	2.751	*
Dosages	29.45	1	29.45	2.234	N.S.
Dosage x Insecticides	335.55	10	33.55	2.546	*
Contrasts					
Controls vs Insecticides	190.08	(1)	190.08	14.420	***
Large vs Small droplets	4.50	(1)	4.50	0.341	N.S.
Knapsack vs all ULV	1.68	(1)	1.68	0.127	N.S.
Knapsack vs Larvin UL	0.48	(1)	0.48	0.037	N.S.
Pyrethroid vs Larvin SC	9.00	(1)	9.00	0.683	N.S.
SC vs. other Larvin UL	0.75	(1)	0.75	0.057	N.S.
DF " " " "	9.19	(1)	9.19	0.697	N.S.
UCLF8 " " " "	4.69	(1)	4.69	0.356	N.S.
Residual	290.00	22	13.18		
Total	1017.64	43			

Coefficient of Variation = 59.6%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Remaining Insect Counts				0 10.00
10	Cypermethrin WULV - Large droplets	3.75	0.25	0.067	
9	OIL: UCLF8 - Large droplets	4.00	1.00	1.000	
6	Larvin SC with Knapsack/tailboom	4.50	1.55	2.148	
3	OIL: UCLF8 - Small droplets	4.50	2.63	6.148	
1	WULV containing 375 SC - Small droplets	4.50	1.55	2.148	
2	WULV containing 80% DF - Small droplets	4.75	1.25	1.316	
7	WULV containing 375 SC - Large droplets	4.75	1.75	2.579	
8	WULV containing 80% DF - Large droplets	6.75	1.84	2.012	
11	CONTROL: blank - Large droplets	7.00	3.72	7.905	
4	Cypermethrin WULV - Small droplets	8.50	2.72	3.490	
5	CONTROL: blank - Small droplets	14.00	3.54	3.571	
	Dosages				0 10.00
1	Half rate	5.27	1.04	4.537	
2	Standard	6.91	1.03	3.348	

3.14

Thiodicarb ULV trial: Malawi

Toleza: summary for 1987 season

Live Dysdercus

Source	Sum of Squares	DF	Mean Squares	F	Significance
Insecticides	0.81	10	0.08	0.623	N.S.
Dosages	0.54	1	0.54	4.100	N.S.
Dosage x Insecticides	1.21	10	0.12	0.928	N.S.
Contrasts					
Controls vs Insecticides	0.06	(1)	0.06	0.464	N.S.
Large vs Small droplets	0.01	(1)	0.01	0.100	N.S.
Knapsack vs all ULV	0.01	(1)	0.01	0.114	N.S.
Knapsack vs Larvin UL	0.04	(1)	0.04	0.305	N.S.
Pyrethroid vs Larvin SC	0.03	(1)	0.03	0.200	N.S.
SC vs. other Larvin UL	0.10	(1)	0.10	0.774	N.S.
DF " " " "	0.05	(1)	0.05	0.368	N.S.
UCLF8 " " " "	0.29	(1)	0.29	2.211	N.S.
Residual	2.87	22	0.13		
Total	5.44	43			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 39.7%

No.	Insecticides	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Remaining Insect Counts				0 1.00
7	WULV containing 375 SC - Large droplets	0.00	0.00	0.000	
4	Cypermethrin WULV - Small droplets	0.00	0.00	0.000	
6	Larvin SC with Knapsack/tailboom	0.25	0.25	1.000	
10	Cypermethrin WULV - Large droplets	0.25	0.25	1.000	
8	WULV containing 80% DF - Large droplets	0.25	0.25	1.000	
2	WULV containing 80% DF - Small droplets	0.50	0.50	2.000	
11	CONTROL: blank - Large droplets	0.50	0.50	2.000	
1	WULV containing 375 SC - Small droplets	0.75	0.75	3.000	
5	CONTROL: blank - Small droplets	0.75	0.48	1.222	
3	OIL: UCLF8 - Small droplets	0.75	0.48	1.222	
9	OIL: UCLF8 - Large droplets	1.00	0.58	1.333	
	Dosages				0 1.00
1	Half rate	0.73	0.22	1.464	
2	Standard	0.18	0.08	0.857	

N.B. Bars represent transformed data.

IV.B.4

THIODICARB CDA TRIAL

Project: Q30C/8716

Research workers: P Jowah and R P Bateman

Location: Itafa Farm, Kadoma (Land 9)

Objective: To evaluate the effects of formulation dosage rate and droplet size on the efficacy of suspended thiodicarb (Larvin) pesticide for control of the two major cotton bollworms.

Design: Randomised blocks: 3 x 2 x 2 factorial x 4 replicates

Factors: a) Three formulations:

(i) WULV using "375" SC (FW); 2 then 1 row swath width. Typically 11-13 l/ha on fully grown cotton

(ii) MULV incorporating SC and Molasses according to standard practice, however swath widths simplified to 4 and 2 rows. Typically 5 l/ha on fully grown cotton

(iii) Oil Based: UCLF diluted with Shellsol K; 4 then 2 row swath width. Typically 1,6 - 2 l/ha on fully grown cotton.

b) Two dosage rates:

(i) Full dose rate 400g a.i./ha

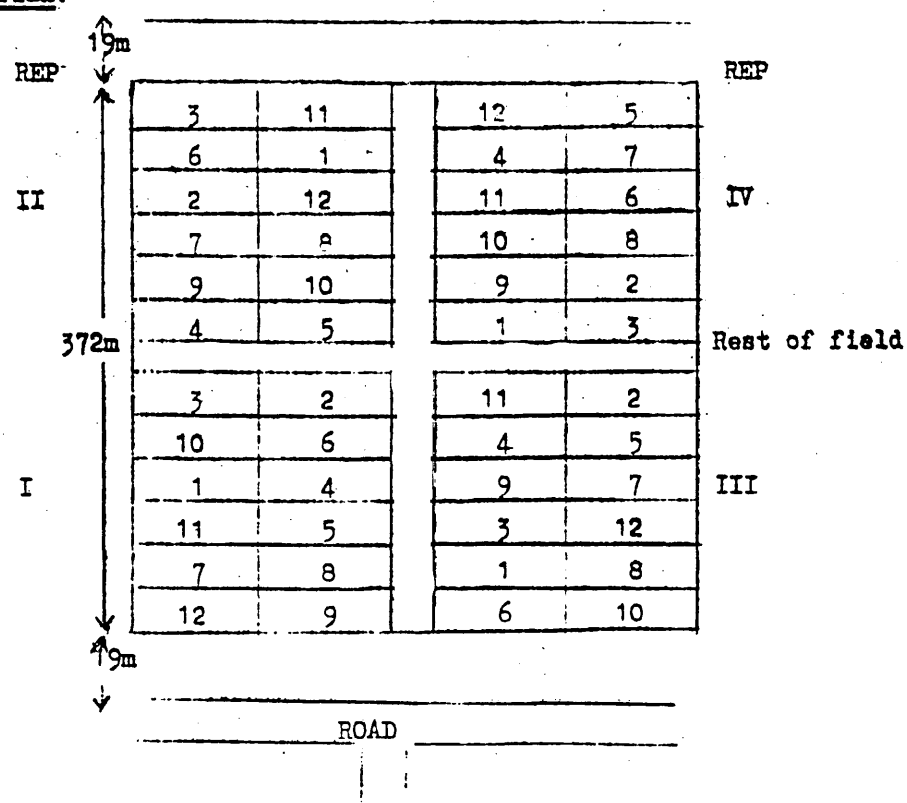
(ii) Half dose rate 200g a.i./ha

c) Two droplet sizes:

(i) 65-70 µm VAD

(ii) 90-100 µm VAD

Field Plan:



IV.B.4.1

Plot Size: 36 rows x 31m = 1116m^2

Sampling Area: 6 rows x 6m = 36m^2

Soil Insecticide: Aldrin w.p. at 1,0 kg per hectare on 5th November 1987

Fertiliser: Compound L (5%N; 18% P_2O_5; 10% K_2O; 8%S; 0.25%B) at 300 kg per hectare on 10th October 1987

Planted: 5th November 1987

Replanted: 8 December 1987

Emerged: 18 December 1987

Thinned: 23 December 1987

Bollworm Treatments:

The bollworm treatments shown in the Table below are to be applied through the Hi-Spin Mk II (Micro-Ulva) ULV spinning disc sprayer fitted with the indicated restrictor and battery pack.

	Strategy	Mixing instructions to make up 1 litre. All quantities in ml.*			Restrictor	Battery Pack	Expected quantity (ml) of mixture per plot row given swath width***	
T.No.		"375" SC		Water			2 rows	1 row
1	ULV	83		917	Red	Normal	714	1428
2						Control		
3		42		958	Red	Normal	714	1428
4						Control		
T.No.		"375" SC	to level**	% molasses		Battery Pack	4 rows	2 rows
5	MULV	200	825	17.5%	Red	Normal	298	595
6						Control		
7		97	800	20.0%	Red	Normal	307	614
8						Control		
T.No.		UCLF 5		Shellsol K		Battery Pack	4 rows	2 rows
9	OIL-BASED	700		300	Orange	Normal	91	182
10						Control		
11		275		725	Yellow	Normal	116	233
12						Control		

* Mixtures of Larvin must be shaken well before use.

** Add water to SC up to this level before adding molasses to make up 1 litre.

*** Row pattern to be changed when crop height reaches 60cm.

IV.B.4.2

Sucking Pest Sprays:

Aphid or spider mite attacks are to be treated with blankent C.D.A. sprays according to standard practice i.e. using the recommended aphicide or acaricide applied through the Hi-Spin Mk I ULV spinning disc sprayer.

Records:

(a) Bollworm eggs and sucking pests scouting for each plot once a week before spraying.

(b) Bollworm and leaf-eating larvae and predator scouting for plots once a week after spraying.

(c) Spray log for each treatment

(d) Stand count and yield within the sampling area

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Itafa: CDA spray logs

Narrow swaths: 10 sprays

Source	Sum of Squares	DF	Mean Squares	F	Significance
Spray dates	2274.26	9	252.70	8.139	*****
Formulations	3280.44	2	1640.22	52.830	*****
Rate of a.i.	1981.38	1	1981.38	63.818	*****
Fo. x Ra.	2850.27	2	1425.14	45.902	*****
Droplet size	12.34	1	12.34	0.397	N.S.
Fo. x Dr.	50.26	2	25.13	0.809	N.S.
Ra. x Dr.	13.67	1	13.67	0.440	N.S.
Fo. x Ra. x Dr.	18.47	2	9.24	0.297	N.S.
Total (all treatments)	8206.84	11	746.08	24.030	*****
Residual (Error)	3073.69	99	31.047		
TOTAL	13554.79	119			

Coefficient of Variation = 5.3%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD 5%
	Units (untransformed) are: Mean % of target volume				0 100.00
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	110.86	0.93	0.309	
2	Oil-based formulation: approx. 1.6 l/ha.	105.85	2.33	2.052	
1	Water-based CDA: approx. 12 l./ha.	98.15	0.55	0.122	
	Rate of a.i.				0 100.00
1	Approx. 400 g.a.i./ha.	109.02	1.44	1.142	
1	Approx. 200 g.a.i./ha.	100.89	1.09	0.710	
	Droplet size				0 100.00
1	65-70 microns V.A.D.	104.63	1.33	1.020	
1	90-100 microns V.A.D.	105.28	1.43	1.166	

4.3

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

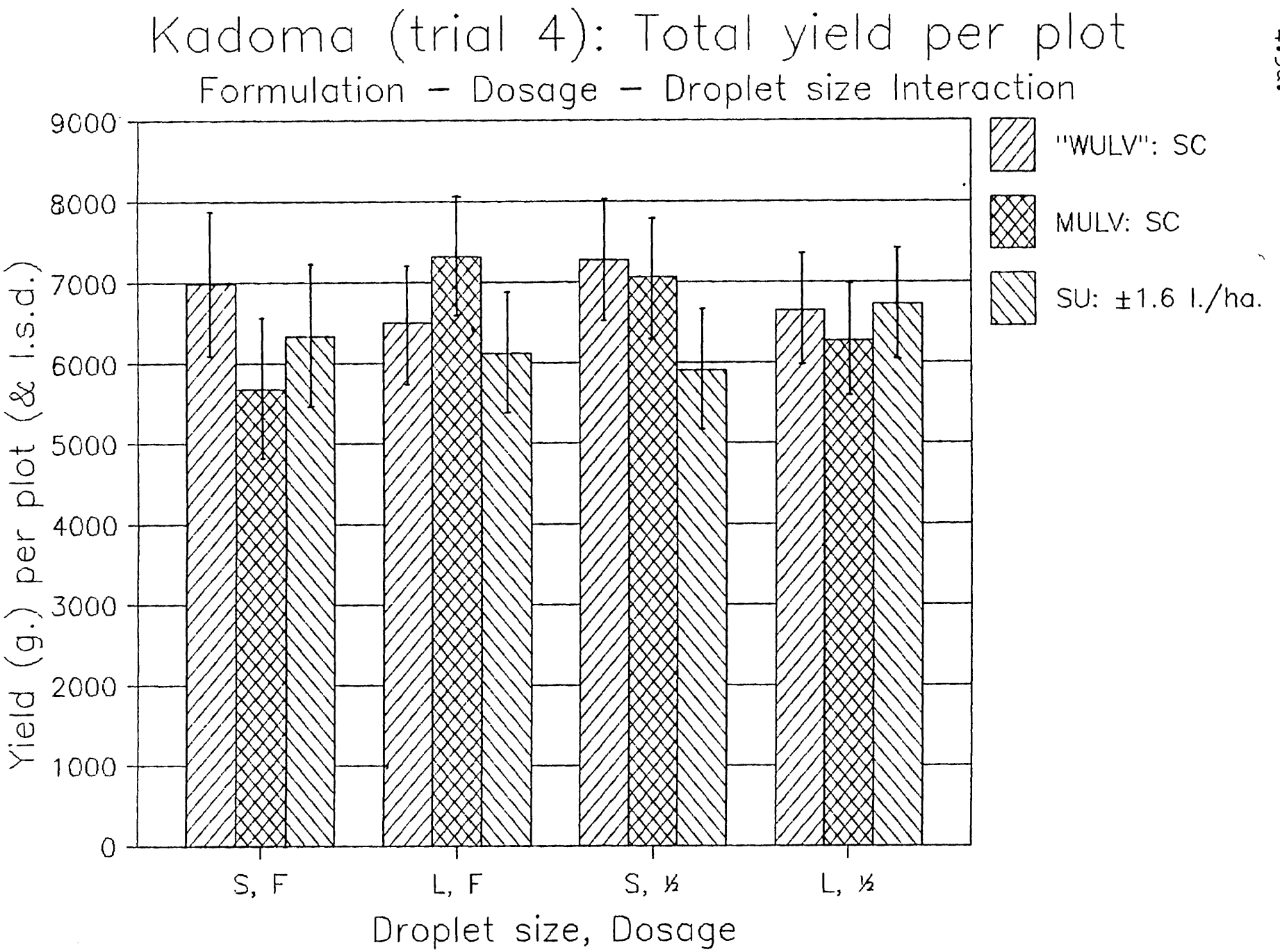
Itafa: seed cotton weight (all clean):

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	9644512.43	3	3214837.48	13.779	*****
Formulations	668696.34	2	334348.17	1.433	N.S.
Rate of a.i.	72735.25	1	72735.25	0.312	N.S.
Droplet size	9818.38	1	9818.38	0.042	N.S.
Assessments	91576719.52	3	30525573.17	130.833	*****
Fo. x Ra.	8731.76	2	4365.88	0.019	N.S.
Fo. x Dr.	569371.76	2	284685.88	1.220	N.S.
Fo. x As.	2111187.78	6	351864.63	1.508	N.S.
Ra. x Dr.	197440.88	1	197440.88	0.846	N.S.
Ra. x As.	659581.18	3	219860.39	0.942	N.S.
Dr. x As.	385458.06	3	128486.02	0.551	N.S.
Fo. x Ra. x Dr.	1541385.51	2	770692.75	3.303	*
Fo. x Ra. x As.	352639.86	6	58773.31	0.252	N.S.
Fo. x Dr. x As.	924012.36	6	154002.06	0.660	N.S.
Ra. x Dr. x As.	1021281.39	3	340427.13	1.459	N.S.
Fo. x Ra. x Dr. x As.	721552.78	6	120258.80	0.515	N.S.
Contrasts					
Water-based vs MULV	142778.32	(1)	142778.32	0.612	N.S.
Water-based vs oil-based	667445.70	(1)	667445.70	2.861	N.S.
Molasses-based vs others	1250.65	(1)	1250.65	0.005	N.S.
Oil-based vs others	525918.02	(1)	525918.02	2.254	N.S.
Total (all treatments)	100820612.83	47	2145119.42	9.194	*****
Residual (Error)	32897709.32	141	233317.087		
TOTAL	143362834.58	191			

Coefficient of Variation = 29.4%

Units (untransformed) are: Weight (g.) per plot

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**168.85**		0 2000.00
1	Water-based CDA: approx. 12 l./ha.	1713.36	116.05	503.021	
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	1646.56	108.16	454.751	
3	Oil-based formulation: approx. 1.6 l/ha.	1568.94	101.12	417.069	
	Rate of a.i.	**LSD =**	**137.86**		0 2000.00
1	Approx. 400 g.a.i./ha.	1623.49	91.54	495.511	
2	Approx. 200 g.a.i./ha.	1662.42	85.63	423.396	
	Droplet size	**LSD =**	**137.86**		0 2000.00
1	65-70 microns V.A.D.	1635.80	90.19	477.384	
2	90-100 microns V.A.D.	1650.10	87.09	441.228	
	Assessments	**LSD =**	**194.97**		0 2000.00
1	1st. pick: 12/5/1988	1323.79	55.13	110.204	
2	2nd. pick: 27/5/1988	2599.17	85.38	134.622	
3	3rd. pick: 13/6/1988	1911.25	77.51	150.891	
4	4th. pick: 07/7/1988	737.60	81.35	430.651	


Kadoma (trial 4): Total yield per plot
Formulation – Dosage – Droplet size Interaction
"WULV": SC
MULV: SC
SU: ±1.6 l./ha.
Yield (g.) per plot (& l.s.d.)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
S, F
L, F
S, ½
L, ½
Droplet size, Dosage

4.4

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Summary: all scores

Heliothis eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	202.02	3	67.34	20.602	*****
Formulations	11.86	2	5.93	1.814	N.S.
Rate of a.i.	0.01	1	0.01	0.004	N.S.
Fo. x Ra.	7.33	2	3.66	1.121	N.S.
Droplet size	0.39	1	0.39	0.120	N.S.
Fo. x Dr.	4.06	2	2.03	0.621	N.S.
Ra. x Dr.	9.04	1	9.04	2.766	N.S.
Fo. x Ra. x Dr.	6.37	2	3.18	0.974	N.S.
Total (all treatments)	39.07	11	3.55	1.087	N.S.
Residual (Error)	107.86	33	3.269		
TOTAL	348.95	47			

Coefficient of Variation = 11.2%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: Eggs/ 12 plants				0 20.00
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	15.51	0.77	0.609	
1	Water-based CDA: approx. 12 l./ha.	16.24	0.69	0.466	
3	Oil-based formulation: approx. 1.6 l/ha.	16.71	0.58	0.327	
	Rate of a.i.				0 20.00
1	Approx. 400 g.a.i./ha.	16.14	0.61	0.558	
2	Approx. 200 g.a.i./ha.	16.17	0.51	0.381	
	Droplet size				0 20.00
1	65-70 microns V.A.D.	16.06	0.64	0.615	
2	90-100 microns V.A.D.	16.24	0.47	0.325	

Diparopsis eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.08	3	0.03	1.986	N.S.
Formulations	0.08	2	0.04	3.164	N.S.
Rate of a.i.	0.00	1	0.00	0.129	N.S.
Fo. x Ra.	0.05	2	0.02	1.922	N.S.
Droplet size	0.01	1	0.01	1.032	N.S.
Fo. x Dr.	0.01	2	0.01	0.420	N.S.
Ra. x Dr.	0.00	1	0.00	0.010	N.S.
Fo. x Ra. x Dr.	0.00	2	0.00	0.060	N.S.
Total (all treatments)	0.16	11	0.01	1.118	N.S.
Residual (Error)	0.42	33	0.013		
TOTAL	0.65	47			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 12.5%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: Eggs/ 12 plants				0 1.00
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	0.26	0.05	0.169	
1	Water-based CDA: approx. 12 l./ha.	0.28	0.05	0.133	
3	Oil-based formulation: approx. 1.6 l/ha.	0.42	0.05	0.104	
	Rate of a.i.				0 1.00
1	Approx. 400 g.a.i./ha.	0.33	0.04	0.122	
2	Approx. 200 g.a.i./ha.	0.31	0.05	0.169	
	Droplet size				0 1.00
1	65-70 microns V.A.D.	0.28	0.04	0.112	
2	90-100 microns V.A.D.	0.35	0.05	0.165	

N.B. Bars represent transformed data.

4.5

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Heliothis larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	2.18	3	0.73	3.364	*
Formulations	0.07	2	0.04	0.173	N.S.
Rate of a.i.	0.46	1	0.46	2.152	N.S.
Droplet size	0.44	1	0.44	2.044	N.S.
Assessments	52.31	11	4.76	22.042	*****
Fo. x Ra.	0.19	2	0.09	0.431	N.S.
Fo. x Dr.	0.45	2	0.22	1.040	N.S.
Fo. x As.	2.22	22	0.10	0.467	N.S.
Ra. x Dr.	0.34	1	0.34	1.580	N.S.
Ra. x As.	1.76	11	0.16	0.743	N.S.
Dr. x As.	2.67	11	0.24	1.126	N.S.
Fo. x Ra. x Dr.	0.14	2	0.07	0.333	N.S.
Fo. x Ra. x As.	3.90	22	0.18	0.822	N.S.
Fo. x Dr. x As.	3.67	22	0.17	0.773	N.S.
Ra. x Dr. x As.	2.06	11	0.19	0.869	N.S.
Fo. x Ra. x Dr. x As.	3.65	22	0.17	0.770	N.S.
Contrasts					
Water-based vs MULV	0.00	(1)	0.00	0.004	N.S.
Water-based vs oil-based	0.05	(1)	0.05	0.227	N.S.
Molasses-based vs others	0.03	(1)	0.03	0.119	N.S.
Oil-based vs others	0.07	(1)	0.07	0.342	N.S.
Total (all treatments)	74.34	143	0.52	2.410	*****
Residual (Error)	92.56	429	0.216		
TOTAL	169.08	575			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 33.9%

Units (untransformed) are: Live insect counts.

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	LSD =	0.09		0 1.70
3	Oil-based formulation: approx. 1.6 l/ha.	1.62	0.12	0.216	
1	Water-based CDA: approx. 12 l./ha.	1.70	0.12	0.224	
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	1.68	0.11	0.207	
	Rate of a.i.	LSD =	0.08		0 1.70
1	Approx. 400 g.a.i./ha.	1.57	0.09	0.205	
2	Approx. 200 g.a.i./ha.	1.76	0.10	0.224	
	Droplet size	LSD =	0.08		0 1.70
1	65-70 microns V.A.D.	1.60	0.10	0.224	
2	90-100 microns V.A.D.	1.74	0.10	0.206	
	Assessments	LSD =	0.19		0 1.70
1	Itafa 12/02/1988	0.31	0.09	0.092	
2	Itafa 19/02/1988	0.52	0.11	0.116	
3	Itafa 26/02/1988	1.00	0.14	0.136	
4	Itafa 04/03/1988	2.29	0.25	0.193	
5	Itafa 11/03/1988	1.75	0.24	0.207	
6	Itafa 18/03/1988	3.10	0.31	0.207	
7	Itafa 25/03/1988	3.06	0.26	0.133	
8	Itafa 31/03/1988	1.71	0.19	0.155	
9	Itafa 08/04/1988	1.92	0.25	0.212	
10	Itafa 15/04/1988	0.92	0.15	0.159	
11	Itafa 28/04/1988	2.31	0.15	0.058	
12	Itafa 03/05/1988	1.10	0.13	0.105	

N.B. LSDs, Variance/Mean ratios and bars are transformed data.

4.6

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

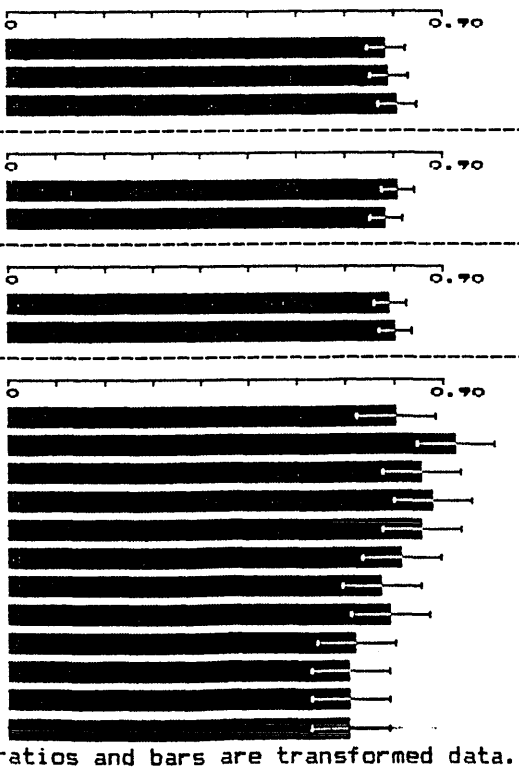
Red Bollworm larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.05	3	0.02	0.366	N.S.
Formulations	0.08	2	0.04	0.881	N.S.
Rate of a.i.	0.06	1	0.06	1.478	N.S.
Droplet size	0.02	1	0.02	0.524	N.S.
Assessments	2.89	11	0.26	6.061	*****
Fo. x Ra.	0.00	2	0.00	0.023	N.S.
Fo. x Dr.	0.01	2	0.01	0.154	N.S.
Fo. x As.	1.55	22	0.07	1.625	*
Ra. x Dr.	0.00	1	0.00	0.010	N.S.
Ra. x As.	0.77	11	0.07	1.612	N.S.
Dr. x As.	0.78	11	0.07	1.628	N.S.
Fo. x Ra. x Dr.	0.15	2	0.07	1.724	N.S.
Fo. x Ra. x As.	0.91	22	0.04	0.950	N.S.
Fo. x Dr. x As.	0.73	22	0.03	0.766	N.S.
Ra. x Dr. x As.	0.39	11	0.04	0.828	N.S.
Fo. x Ra. x Dr. x As.	1.06	22	0.05	1.116	N.S.
Contrasts					
Water-based vs MULV	0.01	(1)	0.01	0.149	N.S.
Water-based vs oil-based	0.04	(1)	0.04	0.821	N.S.
Molasses-based vs others	0.04	(1)	0.04	0.940	N.S.
Oil-based vs others	0.07	(1)	0.07	1.612	N.S.
Total (all treatments)	9.40	143	0.07	1.518	***
Residual (Error)	18.58	429	0.043		
TOTAL	28.03	575			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 26.2%

Units (untransformed) are: Live insect counts.

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	LSD =	0.04		
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	0.15	0.03	0.051	
1	Water-based CDA: approx. 12 l./ha.	0.17	0.04	0.061	
3	Oil-based formulation: approx. 1.6 l/ha.	0.21	0.04	0.073	
	Rate of a.i.	LSD =	0.03		
1	Approx. 400 g.a.i./ha.	0.20	0.03	0.068	
2	Approx. 200 g.a.i./ha.	0.16	0.03	0.055	
	Droplet size	LSD =	0.03		
1	65-70 microns V.A.D.	0.16	0.02	0.050	
2	90-100 microns V.A.D.	0.20	0.03	0.072	
	Assessments	LSD =	0.08		
1	Itafa 12/02/1988	0.21	0.08	0.080	
2	Itafa 19/02/1988	0.46	0.11	0.118	
3	Itafa 26/02/1988	0.29	0.08	0.080	
4	Itafa 04/03/1988	0.35	0.09	0.092	
5	Itafa 11/03/1988	0.31	0.10	0.104	
6	Itafa 18/03/1988	0.21	0.06	0.055	
7	Itafa 25/03/1988	0.13	0.05	0.039	
8	Itafa 31/03/1988	0.17	0.06	0.055	
9	Itafa 08/04/1988	0.02	0.02	0.008	
10	Itafa 15/04/1988	0.00	0.00	0.000	
11	Itafa 28/04/1988	0.00	0.00	0.000	
12	Itafa 03/05/1988	0.00	0.00	0.000	



N.B. LSDs, Variance/Mean ratios and bars are transformed data.

4.7

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Red Spider Mites (% of infested plants)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	3426.55	3	1142.18	7.394	****
Formulations	224.45	2	112.23	0.726	N.S.
Rate of a.i.	129.17	1	129.17	0.836	N.S.
Droplet size	59.73	1	59.73	0.387	N.S.
Assessments	518971.97	6	86495.33	559.909	*****
Fo. x Ra.	746.94	2	373.47	2.418	N.S.
Fo. x Dr.	69.86	2	34.93	0.226	N.S.
Fo. x As.	1963.05	12	163.59	1.059	N.S.
Ra. x Dr.	16.74	1	16.74	0.108	N.S.
Ra. x As.	595.65	6	99.28	0.643	N.S.
Dr. x As.	1093.34	6	182.22	1.180	N.S.
Fo. x Ra. x Dr.	271.58	2	135.79	0.879	N.S.
Fo. x Ra. x As.	937.09	12	78.09	0.506	N.S.
Fo. x Dr. x As.	630.37	12	52.53	0.340	N.S.
Ra. x Dr. x As.	789.10	6	131.52	0.851	N.S.
Fo. x Ra. x Dr. x As.	2008.52	12	167.38	1.083	N.S.
Contrasts					
Water-based vs MULV	209.57	(1)	209.57	1.357	N.S.
Water-based vs oil-based	15.19	(1)	15.19	0.098	N.S.
Molasses-based vs others	209.26	(1)	209.26	1.355	N.S.
Oil-based vs others	14.88	(1)	14.88	0.096	N.S.
Total (all treatments)	528507.56	83	6367.56	41.219	*****
Residual (Error)	38465.82	249	154.481		
TOTAL	570399.93	335			

Coefficient of Variation = 21.6%

Units (untransformed) are: mean % of infested plants

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	LSD =	3.27		0 ... 100.00
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	56.40	3.96	31.171	
3	Oil-based formulation: approx. 1.6 l/ha.	57.81	3.87	29.008	
1	Water-based CDA: approx. 12 l./ha.	58.33	3.90	29.172	
	Rate of a.i.	LSD =	2.67		0 ... 100.00
1	Approx. 400 g.a.i./ha.	58.13	3.19	29.498	
2	Approx. 200 g.a.i./ha.	56.89	3.18	29.878	
	Droplet size	LSD =	2.67		0 ... 100.00
1	65-70 microns V.A.D.	57.94	3.20	29.640	
2	90-100 microns V.A.D.	57.09	3.18	29.740	
	Assessments	LSD =	5.00		0 ... 100.00
1	Itafa 07/03/1988	0.87	0.45	11.028	
2	Itafa 14/03/1988	7.12	2.31	36.114	
3	Itafa 21/03/1988	39.58	2.85	9.817	
4	Itafa 28/03/1988	64.06	2.59	5.035	
5	Itafa 05/04/1988	93.23	1.33	0.908	
6	Itafa 11/04/1988	97.74	0.81	0.325	
7	Itafa 15/04/1988	100.00	0.00	0.000	

4.8

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Red Spider Mites (infestation indices)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	257.25	3	85.75	5.226	**
Formulations	9.60	2	4.80	0.292	N.S.
Rate of a.i.	9.67	1	9.67	0.589	N.S.
Droplet size	35.36	1	35.36	2.155	N.S.
Assessments	57624.71	6	9604.12	585.273	*****
Fo. x Ra.	38.79	2	19.39	1.182	N.S.
Fo. x Dr.	18.95	2	9.48	0.577	N.S.
Fo. x As.	138.36	12	11.53	0.703	N.S.
Ra. x Dr.	6.57	1	6.57	0.401	N.S.
Ra. x As.	47.10	6	7.85	0.478	N.S.
Dr. x As.	153.99	6	25.67	1.564	N.S.
Fo. x Ra. x Dr.	41.52	2	20.76	1.265	N.S.
Fo. x Ra. x As.	56.01	12	4.67	0.284	N.S.
Fo. x Dr. x As.	106.01	12	8.83	0.538	N.S.
Ra. x Dr. x As.	51.86	6	8.64	0.527	N.S.
Fo. x Ra. x Dr. x As.	102.60	12	8.55	0.521	N.S.
Contrasts					
Water-based vs MULV	7.88	(1)	7.88	0.480	N.S.
Water-based vs oil-based	6.45	(1)	6.45	0.393	N.S.
Molasses-based vs others	3.15	(1)	3.15	0.192	N.S.
Oil-based vs others	1.72	(1)	1.72	0.105	N.S.
Total (all treatments)	58441.10	83	704.11	42.908	*****
Residual (Error)	4086.00	249	16.410		
TOTAL	62784.35	335			

Coefficient of Variation = 26.5%

Units (untransformed) are: mean infestation indices

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**1.07**		0 30.00
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	15.13	1.30	12.488	
3	Oil-based formulation: approx. 1.6 l/ha.	15.17	1.30	12.479	
1	Water-based CDA: approx. 12 l./ha.	15.51	1.29	12.073	
	Rate of a.i.	**LSD =**	**0.87**		0 30.00
1	Approx. 400 g.a.i./ha.	15.44	1.06	12.242	
2	Approx. 200 g.a.i./ha.	15.10	1.05	12.375	
	Droplet size	**LSD =**	**0.87**		0 30.00
1	65-70 microns V.A.D.	15.60	1.06	12.203	
2	90-100 microns V.A.D.	14.95	1.05	12.406	
	Assessments	**LSD =**	**1.63**		0 30.00
1	Itafa 07/03/1988	0.13	0.07	1.915	
2	Itafa 14/03/1988	1.00	0.30	4.383	
3	Itafa 21/03/1988	6.10	0.55	2.358	
4	Itafa 28/03/1988	11.19	0.79	2.661	
5	Itafa 05/04/1988	23.56	0.85	1.468	
6	Itafa 11/04/1988	30.56	0.66	0.682	
7	Itafa 15/04/1988	34.35	0.34	0.162	

4.9

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Itafa 29/02/1988

Infestation score: Aphids

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	203.83	3	67.94	12.549	****
Formulations	2.17	2	1.08	0.200	N.S.
Rate of a.i.	4.08	1	4.08	0.754	N.S.
Fo. x Ra.	5.17	2	2.58	0.477	N.S.
Droplet size	14.08	1	14.08	2.601	N.S.
Fo. x Dr.	6.17	2	3.08	0.569	N.S.
Ra. x Dr.	0.00	1	0.00	0.000	N.S.
Fo. x Ra. x Dr.	6.50	2	3.25	0.600	N.S.
Total (all treatments)	38.17	11	3.47	0.641	N.S.
Residual (Error)	178.67	33	5.414		
TOTAL	420.67	47			

Coefficient of Variation = 32.5%

Itafa 07/03/1988

% of plants with Aphids

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	5494.56	3	1831.52	18.610	*****
Formulations	39.97	2	19.98	0.203	N.S.
Rate of a.i.	130.36	1	130.36	1.325	N.S.
Fo. x Ra.	318.86	2	159.43	1.620	N.S.
Droplet size	25.20	1	25.20	0.256	N.S.
Fo. x Dr.	297.79	2	148.90	1.513	N.S.
Ra. x Dr.	168.31	1	168.31	1.710	N.S.
Fo. x Ra. x Dr.	538.90	2	269.45	2.738	N.S.
Total (all treatments)	1519.40	11	138.13	1.404	N.S.
Residual (Error)	3247.66	33	98.414		
TOTAL	10261.63	47			

Data have undergone ARCSINE transformation.

Coefficient of Variation = 45.3%

4.10

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

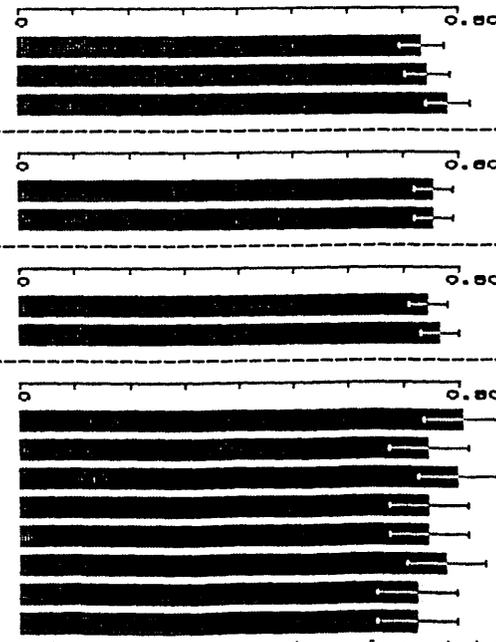
Defoliating Larvae (combined)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.14	3	0.05	1.457	N.S.
Formulations	0.15	2	0.08	2.327	N.S.
Rate of a.i.	0.00	1	0.00	0.012	N.S.
Droplet size	0.05	1	0.05	1.505	N.S.
Assessments	0.38	7	0.05	1.661	N.S.
Fo. x Ra.	0.21	2	0.11	3.291	*
Fo. x Dr.	0.01	2	0.01	0.215	N.S.
Fo. x As.	0.62	14	0.04	1.368	N.S.
Ra. x Dr.	0.00	1	0.00	0.056	N.S.
Ra. x As.	0.58	7	0.08	2.542	*
Dr. x As.	0.15	7	0.02	0.654	N.S.
Fo. x Ra. x Dr.	0.05	2	0.02	0.714	N.S.
Fo. x Ra. x As.	0.71	14	0.05	1.557	N.S.
Fo. x Dr. x As.	0.27	14	0.02	0.602	N.S.
Ra. x Dr. x As.	0.06	7	0.01	0.266	N.S.
Fo. x Ra. x Dr. x As.	0.44	14	0.03	0.975	N.S.
Contrasts					
Water-based vs MULV	0.01	(1)	0.01	0.233	N.S.
Water-based vs oil-based	0.14	(1)	0.14	4.252	N.S.
Molasses-based vs others	0.01	(1)	0.01	0.402	N.S.
Oil-based vs others	0.14	(1)	0.14	4.421	*
Total (all treatments)	3.69	95	0.04	1.195	N.S.
Residual (Error)	9.27	285	0.033		
TOTAL	13.11	383			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 23.9%

Units (untransformed) are: Remaining larvae

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	**LSD =**	**0.04**		
1	Water-based CDA: approx. 12 l./ha.	0.05	0.02	0.022	
2	Molasses-based aqu.ULV.: approx. 5 l/ha.	0.08	0.03	0.031	
3	Oil-based formulation: approx. 1.6 l/ha.	0.17	0.06	0.081	
	Rate of a.i.	**LSD =**	**0.04**		
1	Approx. 400 g.a.i./ha.	0.09	0.03	0.037	
2	Approx. 200 g.a.i./ha.	0.11	0.04	0.054	
	Droplet size	**LSD =**	**0.04**		
1	65-70 microns V.A.D.	0.07	0.02	0.030	
2	90-100 microns V.A.D.	0.13	0.04	0.060	
	Assessments	**LSD =**	**0.07**		
1	Itafa 12.02.1988	0.27	0.15	0.153	
2	Itafa 19.02.1988	0.06	0.04	0.022	
3	Itafa 26.02.1988	0.19	0.08	0.073	
4	Itafa 04.03.1988	0.06	0.04	0.022	
5	Itafa 11.03.1988	0.06	0.04	0.022	
6	Itafa 18.03.1988	0.13	0.05	0.039	
7	Itafa 25.03.1988	0.02	0.02	0.008	
8	Itafa 31.03.1988	0.02	0.02	0.008	



N.B. LSDs, Variance/Mean ratios and bars are transformed data.

4.11

Thiodicarb CDA: Kadoma, Zimbabwe (1988)

Summary: mean of scores from 12.02.1988 to 15.04.1988

Chrysopid eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	1.89	3	0.63	3.050	*
Formulations	0.76	2	0.38	1.824	N.S.
Rate of a.i.	0.00	1	0.00	0.004	N.S.
Fo. x Ra.	0.21	2	0.10	0.499	N.S.
Droplet size	0.14	1	0.14	0.680	N.S.
Fo. x Dr.	0.71	2	0.36	1.719	N.S.
Ra. x Dr.	0.19	1	0.19	0.906	N.S.
Fo. x Ra. x Dr.	0.29	2	0.14	0.688	N.S.
Total (all treatments)	2.29	11	0.21	1.005	N.S.
Residual (Error)	6.83	33	0.207		
TOTAL	11.01	47			

Coefficient of Variation = 35.3%

Summary: mean of scores from 12.02.1988 to 15.04.1988

Chrysopid larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.02	3	0.01	6.340	**
Formulations	0.00	2	0.00	0.539	N.S.
Rate of a.i.	0.00	1	0.00	0.730	N.S.
Fo. x Ra.	0.00	2	0.00	0.270	N.S.
Droplet size	0.00	1	0.00	1.863	N.S.
Fo. x Dr.	0.01	2	0.00	2.252	N.S.
Ra. x Dr.	0.00	1	0.00	0.586	N.S.
Fo. x Ra. x Dr.	0.00	2	0.00	0.231	N.S.
Total (all treatments)	0.01	11	0.00	0.887	N.S.
Residual (Error)	0.04	33	0.001		
TOTAL	0.08	47			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 4.8%

Summary: mean of scores from 12/02/1988 to 15/04/1988

Spiders

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.02	3	0.01	1.069	N.S.
Formulations	0.02	2	0.01	1.226	N.S.
Rate of a.i.	0.01	1	0.01	1.862	N.S.
Fo. x Ra.	0.03	2	0.02	2.169	N.S.
Droplet size	0.00	1	0.00	0.280	N.S.
Fo. x Dr.	0.02	2	0.01	1.540	N.S.
Ra. x Dr.	0.00	1	0.00	0.119	N.S.
Fo. x Ra. x Dr.	0.00	2	0.00	0.131	N.S.
Total (all treatments)	0.09	11	0.01	1.127	N.S.
Residual (Error)	0.23	33	0.007		
TOTAL	0.34	47			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 9.0%

IV.B.5

ALTERNATIVE BOLLWORM INSECTICIDE FIELD FORMULATIONS

Project: Q30C/8718

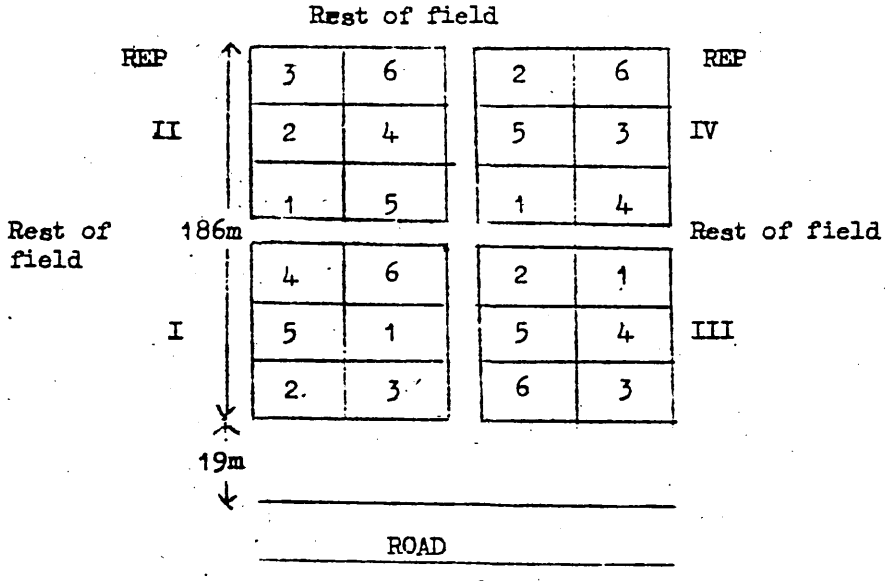
Research workers: P Jowah and R P Bateman

Location: Itafa Farm, Kadoma (Land 9)

Objective: To evaluate the efficacy of three field formulations of two insecticides against the two major cotton bollworms.

Design: Randomised blocks: 6 treatments x 4 replicates.

Field Plan:



Plot Size: 36 rows x 31m = 116m^2

Sampling Area: 6 rows x 6m = 36m^2

Soil Insecticide: Aldrin w.p. at 1,0 kg per hectare on 5th November 1987

Fertiliser: Compound L (5%N, 18% P_2O_5, 10%K_2O, 8%S, 0,25%B) at 300 kg per hectare on 10th October 1987

Soil Fungicide: Brassicol at 1,5 kg per hectare on 5th November 1987

Planted: 5th November 1987

Replanted: 8th December 1987

Emerged: 18th December 1987

Thinned: 23rd December 1987

Bollworm Treatments:

The bollworm treatments shown in the Table below are to be applied through the HiSpin MkI ULV spinning disc sprayer fitted with the standard 1,4mm diameter nozzle using a spray bottle with a notched tip and a 12 volt wet cell lead/acid battery as the power source.

T.No.	Spray strategy and mixing instructions	Flowrate (ml/min)	Expected quantity (ml) of mixture per plot for given swath width	
			4 rows	2 rows
1	LARVIN MULV: 210ml of "375" SC are made up to 825ml with water, then to 1 litre with 175ml molasses	60,0	279,0	558
2	LARVIN OIL-BASED: 700ml of UCLF 5 are mixed with 300ml of Shellsol K	19,5	91,0	182
			2 rows	1 row
3	LARVIN WULV: 94ml of "375" SC are made up to 1 litre with water	68.0	630,5	1261
			4 rows	2 rows
4	KARATE MULV: 40ml of Karate EC are made up to 650ml with water, then to 1 litre with 350ml molasses	60,0	279,0	558
5	KARATE UL: 120ml of Karate EC are blended with 780ml of crude cotton seed oil then to 1 litre with 100ml of Shellsol K	20.0	89,5	179
6	KARATE WULV: 17,7ml of Karate EC are made up to 1 litre with water	68,0	630,5	1261

* Mixture of Larvin must be shaken well before use

** Row pattern to be changed when crop height reaches 60cm

Sucking Pest Sprays:

Aphid or spider mite attacks are to be treated with blanket C.D.A. sprays according to standard practice i.e. using the recommended aphicide or acaricide applied through the Hi-Spin MKI ULV spinning disc sprayer.

Records:

(a) Bollworm eggs and sucking pests scouting for each plot once a week before spraying.

(b) Bollworm and leaf-eating and predator scouting for each plot once a week after spraying.

(c) Spray log for each treatment

(d) Stand count and yield within the sampling area.

IV.B.5.2

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Itafa: CDA spray logs

Narrow swaths: 10 sprays

Source	Sum of Squares	DF	Mean Squares	F	Significance
Spray dates	1946.97	9	216.33	3.505	**
Formulations	1308.15	2	654.07	10.597	***
A.Is.	112.26	1	112.26	1.819	N.S.
F. x A.	10.76	2	5.38	0.087	N.S.
Residual (Error)	2777.48	45	61.72		
Total	6155.62	59			

Coefficient of Variation = 6.9%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Mean % of target volume				0 100.00
2	Oil-based formulation: approx. 1.6 l/ha.	110.50	3.15	1.800	
3	Water-based CDA: approx. 11 l./ha.	111.09	0.80	0.114	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	120.69	1.48	0.361	
	A.Is.				0 100.00
1	Thiodicarb	112.73	1.54	0.631	
2	l.-Cyhalothrin	115.46	2.14	1.189	

5.3

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Itafa: seed cotton weight (all clean).

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	256166.67	3	85388.89	0.639	N.S.
Formulations	282002.08	2	141001.04	1.055	N.S.
A.Is.	270937.50	1	270937.50	2.027	N.S.
Assessments	85679433.33	3	28559811.11	213.660	*****
Fo. x A..	81943.75	2	40971.87	0.307	N.S.
Fo. x As.	1296872.92	6	216145.49	1.617	N.S.
A.. x As.	211045.83	3	70348.61	0.526	N.S.
Fo. x A.. x As.	1019547.92	6	169924.65	1.271	N.S.
Contrasts					
Water-based vs others	264775.52	(1)	264775.52	1.981	N.S.
Water-based vs oil-based	261376.56	(1)	261376.56	1.955	N.S.
Molasses-based vs others	20625.52	(1)	20625.52	0.154	N.S.
Oil-based vs others	137602.08	(1)	137602.08	1.029	N.S.
Total (all treatments)	88841783.33	23	3862686.23	28.897	*****
Residual (Error)	9223183.33	69	133669.324		
TOTAL	98321133.33	95			

Coefficient of Variation = 21.2%

Units (untransformed) are: Weight (g.) per plot

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**182.39**		0 3000.00
3	Water-based CDA: approx. 11 l./ha.	1800.94	195.09	676.262	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	1705.94	185.16	643.108	
2	Oil-based formulation: approx. 1.6 l/ha.	1673.12	162.74	506.564	
	A.Is.	**LSD =**	**148.92**		0 3000.00
1	Thiodicarb	1673.54	138.93	553.604	
2	l.-Cyhalothrin	1779.79	155.44	651.591	
	Assessments	**LSD =**	**210.60**		0 3000.00
1	1st. pick: 11/5/1988	1521.67	70.14	77.602	
2	2nd. pick: 26/5/1988	2939.17	83.05	56.325	
3	3rd. pick: 14/6/1988	2103.33	98.56	110.841	
4	4th. pick: 06/7/1988	342.50	37.01	95.976	

5.4

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

2nd. pick: 26/5/1988

Heat: seed cotton weight (all mean)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	816850.00	3	272283.33	3.021	N.S.
Formulations	1070533.33	2	535266.67	5.938	*
A.Is.	331350.00	1	331350.00	3.676	N.S.
Fo. x A..	236800.00	2	118400.00	1.314	N.S.
Contrasts					
Molasses-based vs others	9633.33	(1)	9633.33	0.107	N.S.
Oil-based vs others	885633.33	(1)	885633.33	9.825	**
Water-based vs others	710533.33	(1)	710533.33	7.883	*
Residual (Error)	1352050.00	15	90136.667		
TOTAL	3807583.33	23			

Coefficient of Variation = 10.2%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Weight (g.) per plot				0 3000.00
0	Water-based CDA: approx. 11 l./ha.	3182.50	141.04	50.003	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	2967.50	110.19	32.733	
2	Oil-based formulation: approx. 1.6 l/ha.	2667.50	129.78	50.510	
	A.Is.				0 3000.00
1	Thiodicarb	2921.67	94.66	38.107	
2	L-Cyhalothrin	3056.67	171.31	48.211	

Summary: all scores

Heliothis eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	998.17	3	332.72	0.656	N.S.
Formulations	2059.08	2	1029.54	2.029	N.S.
A.Is.	266.67	1	266.67	0.525	N.S.
F. x A.	1305.08	2	652.54	1.286	N.S.
Residual (Error)	7612.83	15	507.52		
Total	12241.83	23			

Coefficient of Variation = 13.0%

5.5

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Heliothis larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	2.43	3	0.81	0.484	N.S.
Formulations	1.75	2	0.88	0.524	N.S.
A.Is.	0.42	1	0.42	0.252	N.S.
Assessments	93.68	11	8.52	5.098	*****
Fo. x A..	0.03	2	0.01	0.008	N.S.
Fo. x As.	25.92	22	1.18	0.705	N.S.
A.. x As.	25.62	11	2.33	1.394	N.S.
Fo. x A.. x As.	20.81	22	0.95	0.566	N.S.
Contrasts					
Water-based vs others	1.00	(1)	1.00	0.599	N.S.
Water-based vs oil-based	0.19	(1)	0.19	0.112	N.S.
Molasses-based vs others	1.56	(1)	1.56	0.935	N.S.
Oil-based vs others	0.06	(1)	0.06	0.037	N.S.
Total (all treatments)	168.22	71	2.37	1.418	*
Residual (Error)	355.82	213	1.671		
TOTAL	526.47	287			

Coefficient of Variation = 104.3%

Units (untransformed) are: Live insect counts.

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	**LSD =**	**0.37**		0 2.00
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	1.14	0.12	1.291	
2	Oil-based formulation: approx. 1.6 l/ha.	1.26	0.14	1.474	
3	Water-based CDA: approx. 11 l./ha.	1.32	0.15	1.663	
	A.Is.	**LSD =**	**0.30**		0 2.00
1	Thiodicarb	1.28	0.11	1.384	
2	l.-Cyhalothrin	1.20	0.12	1.590	
	Assessments	**LSD =**	**0.74**		0 2.00
1	Itafa 12/02/1988	0.25	0.09	0.783	
2	Itafa 19/02/1988	0.42	0.12	0.817	
3	Itafa 26/02/1988	0.83	0.20	1.113	
4	Itafa 04/03/1988	1.63	0.24	0.846	
5	Itafa 11/03/1988	0.96	0.19	0.951	
6	Itafa 18/03/1988	2.42	0.46	2.084	
7	Itafa 25/03/1988	1.54	0.21	0.676	
8	Itafa 30/03/1988	1.21	0.20	0.790	
9	Itafa 08/04/1988	1.17	0.28	1.615	
10	Itafa 15/04/1988	1.83	0.41	2.166	
11	Itafa 28/04/1988	1.38	0.18	0.557	
12	Itafa 03/05/1988	1.25	0.24	1.130	

5.6

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Red Bollworm larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.00	3	0.00	0.031	N.S.
Formulations	0.10	2	0.05	1.740	N.S.
A.Is.	0.02	1	0.02	0.778	N.S.
Assessments	0.56	11	0.05	1.718	N.S.
Fo. x A..	0.06	2	0.03	0.965	N.S.
Fo. x As.	0.79	22	0.04	1.204	N.S.
A.. x As.	0.35	11	0.03	1.065	N.S.
Fo. x A.. x As.	0.56	22	0.03	0.845	N.S.
Contrasts					
Water-based vs others	0.05	(1)	0.05	1.800	N.S.
Water-based vs oil-based	0.10	(1)	0.10	3.277	N.S.
Molasses-based vs others	0.01	(1)	0.01	0.204	N.S.
Oil-based vs others	0.10	(1)	0.10	3.217	N.S.
Total (all treatments)	2.45	71	0.03	1.153	N.S.
Residual (Error)	6.37	213	0.030		
TOTAL	8.82	287			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 22.6%

Units (untransformed) are: Live insect counts.

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**0.05**		0 0.90
3	Water-based CDA: approx. 11 l./ha.	0.07	0.03	0.025	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	0.10	0.04	0.040	
2	Oil-based formulation: approx. 1.6 l/ha.	0.17	0.04	0.054	
	A.Is.	**LSD =**	**0.04**		0 0.90
1	Thiodicarb	0.13	0.03	0.044	
2	l.-Cyhalothrin	0.10	0.03	0.036	
	Assessments	**LSD =**	**0.10**		0 0.90
1	Itafa 12/02/1988	0.00	0.00	0.000	
2	Itafa 19/02/1988	0.21	0.10	0.071	
3	Itafa 26/02/1988	0.08	0.06	0.028	
4	Itafa 04/03/1988	0.29	0.11	0.082	
5	Itafa 11/03/1988	0.17	0.08	0.049	
6	Itafa 18/03/1988	0.13	0.07	0.040	
7	Itafa 25/03/1988	0.04	0.04	0.015	
8	Itafa 30/03/1988	0.08	0.06	0.028	
9	Itafa 08/04/1988	0.00	0.00	0.000	
10	Itafa 15/04/1988	0.04	0.04	0.015	
11	Itafa 28/04/1988	0.08	0.06	0.028	
12	Itafa 03/05/1988	0.25	0.12	0.092	

N.B. LSDs, Variance/Mean ratios and bars are transformed data.

5.7

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Red Spider Mites (% of infested plants)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	911.46	3	303.82	1.984	N.S.
Formulations	521.56	2	260.78	1.703	N.S.
A.Is.	175.06	1	175.06	1.143	N.S.
Assessments	245081.02	7	35011.57	228.669	*****
Fo. x A..	100.55	2	50.27	0.328	N.S.
Fo. x As.	2134.69	14	152.48	0.996	N.S.
A.. x As.	2672.16	7	381.74	2.493	*
Fo. x A.. x As.	680.70	14	48.62	0.318	N.S.
Contrasts					
Water-based vs others	399.49	(1)	399.49	2.609	N.S.
Water-based vs oil-based	122.07	(1)	122.07	0.797	N.S.
Molasses-based vs others	382.67	(1)	382.67	2.499	N.S.
Oil-based vs others	0.18	(1)	0.18	0.001	N.S.
Total (all treatments)	251365.74	47	5348.21	34.930	*****
Residual (Error)	21588.54	141	153.110		
TOTAL	273865.74	191			

Coefficient of Variation = 17.9%

Units (untransformed) are: mean % of infested plants

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD
	Formulations	LSD =	4.33		0 100.00
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	67.06	4.96	23.521	
3	Water-based CDA: approx. 11 l./ha.	69.14	4.67	20.205	
2	Oil-based formulation: approx. 1.6 l/ha.	71.09	4.62	19.194	
	A.Is.	LSD =	3.53		0 100.00
1	Thiodicarb	70.05	3.95	21.362	
2	l.-Cyhalothrin	68.14	3.80	20.318	
	Assessments	LSD =	7.06		0 100.00
1	Itafa 14/03/1988	0.69	0.48	7.971	
2	Itafa 21/03/1988	25.35	4.30	17.505	
3	Itafa 28/03/1988	55.21	3.91	6.652	
4	Itafa 05/04/1988	81.25	3.02	2.694	
5	Itafa 11/04/1988	92.71	2.37	1.453	
6	Itafa 15/04/1988	97.57	1.84	0.834	
7	Itafa 25/04/1988	100.00	0.00	0.000	
8	Itafa 03/05/1988	100.00	0.00	0.000	

5.7a

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Red Spider Mites (infestation indices)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	226.39	3	75.46	4.366	**
Formulations	297.17	2	148.58	8.595	***
A.Is.	152.30	1	152.30	8.810	**
Assessments	27332.62	7	3904.66	225.883	*****
Fo. x A..	115.63	2	57.81	3.344	*
Fo. x As.	335.33	14	23.95	1.386	N.S.
A.. x As.	353.66	7	50.52	2.923	**
Fo. x A.. x As.	163.04	14	11.65	0.674	N.S.
Contrasts					
Water-based vs others	32.67	(1)	32.67	1.890	N.S.
Water-based vs oil-based	171.12	(1)	171.12	9.899	**
Molasses-based vs others	126.04	(1)	126.04	7.291	**
Oil-based vs others	287.04	(1)	287.04	16.605	****
Total (all treatments)	28749.74	47	611.70	35.386	*****
Residual (Error)	2437.36	141	17.286		
TOTAL	31413.49	191			

Coefficient of Variation = 23.4%

Units (untransformed) are: mean infestation indices

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD
	Formulations	**LSD =**	**1.45**		0 30.00
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	16.61	1.58	9.571	
3	Water-based CDA: approx. 11 l./ha.	17.17	1.59	9.367	
2	Oil-based formulation: approx. 1.6 l/ha.	19.48	1.65	8.935	
	A.Is.	**LSD =**	**1.19**		0 30.00
1	Thiodicarb	18.65	1.35	9.354	
2	l.-Cyhalothrin	16.86	1.27	9.170	
	Assessments	**LSD =**	**2.37**		0 30.00
1	Itafa 14/03/1988	0.17	0.13	2.435	
2	Itafa 21/03/1988	4.08	0.91	4.832	
3	Itafa 28/03/1988	7.79	0.73	1.640	
4	Itafa 05/04/1988	16.71	1.25	2.240	
5	Itafa 11/04/1988	22.50	1.31	1.843	
6	Itafa 15/04/1988	28.08	1.50	1.926	
7	Itafa 25/04/1988	36.00	0.00	0.000	
8	Itafa 03/05/1988	26.71	0.69	0.431	

5.8

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Aphids (% of infested plants)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	1175.85	3	391.95	1.589	N.S.
Formulations	703.85	2	351.92	1.427	N.S.
A.Is.	226.06	1	226.06	0.916	N.S.
Assessments	241735.75	7	34533.68	140.005	*****
Fo. x A..	187.36	2	93.68	0.380	N.S.
Fo. x As.	2907.26	14	207.66	0.842	N.S.
A.. x As.	1640.26	7	234.32	0.950	N.S.
Fo. x A.. x As.	3736.26	14	266.88	1.082	N.S.
Contrasts					
Water-based vs others	695.17	(1)	695.17	2.818	N.S.
Water-based vs oil-based	590.82	(1)	590.82	2.395	N.S.
Molasses-based vs others	247.58	(1)	247.58	1.004	N.S.
Oil-based vs others	113.03	(1)	113.03	0.458	N.S.
Total (all treatments)	251136.79	47	5343.34	21.663	*****
Residual (Error)	34779.01	141	246.660		
TOTAL	287091.65	191			

Coefficient of Variation = 34.9%

Units (untransformed) are: mean % of infested plants

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**5.49**		0 — 100.00
3	Water-based CDA: approx. 11 l./ha.	42.32	4.67	32.993	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	46.09	4.81	32.187	
2	Oil-based formulation: approx. 1.6 l/ha.	46.61	5.10	35.741	
	A.Is.	**LSD =**	**4.48**		0 — 100.00
1	Thiodicarb	46.09	4.01	33.492	
2	l.-Cyhalothrin	43.92	3.92	33.600	
	Assessments	**LSD =**	**8.97**		0 — 100.00
1	Itafa 05/02/1988	75.69	3.92	4.860	
2	Itafa 08/02/1988	94.79	1.99	1.007	
3	Itafa 15/02/1988	86.46	3.71	3.828	
4	Itafa 22/02/1988	46.18	4.89	12.420	
5	Itafa 29/02/1988	43.06	4.51	11.314	
6	Itafa 07/03/1988	9.03	1.50	5.964	
7	Itafa 14/03/1988	4.51	1.58	13.350	
8	Itafa 21/03/1988	0.35	0.35	8.333	

5.8a.

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Aphids (infestation indices)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	104.77	3	34.92	2.024	N.S.
Formulations	111.20	2	55.60	3.222	*
A.Is.	0.63	1	0.63	0.037	N.S.
Assessments	10634.99	7	1519.28	88.048	*****
Fo. x A..	7.95	2	3.97	0.230	N.S.
Fo. x As.	308.55	14	22.04	1.277	N.S.
A.. x As.	42.24	7	6.03	0.350	N.S.
Fo. x A.. x As.	111.80	14	7.99	0.463	N.S.
Contrasts					
Water-based vs others	104.17	(1)	104.17	6.037	*
Water-based vs oil-based	56.45	(1)	56.45	3.271	N.S.
Molasses-based vs others	7.88	(1)	7.88	0.457	N.S.
Oil-based vs others	54.75	(1)	54.75	3.173	N.S.
Total (all treatments)	11217.37	47	238.67	13.832	*****
Residual (Error)	2432.98	141	17.255		
TOTAL	13755.12	191			

Coefficient of Variation = 52.6%

Units (untransformed) are: mean infestation indices

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	**LSD =**	**1.45**		0 20.00
3	Water-based CDA: approx. 11 l./ha.	6.86	0.87	6.992	
2	Oil-based formulation: approx. 1.6 l/ha.	8.19	1.12	9.767	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	8.66	1.18	10.240	
	A.Is.	**LSD =**	**1.19**		0 20.00
1	Thiodicarb	7.96	0.86	8.830	
2	l.-Cyhalothrin	7.84	0.88	9.500	
	Assessments	**LSD =**	**2.37**		0 20.00
1	Itafa 05/02/1988	10.25	0.64	0.961	
2	Itafa 08/02/1988	19.29	1.38	2.360	
3	Itafa 15/02/1988	19.67	1.45	2.550	
4	Itafa 22/02/1988	6.88	0.93	3.040	
5	Itafa 29/02/1988	5.46	0.56	1.386	
6	Itafa 07/03/1988	1.08	0.18	0.716	
7	Itafa 14/03/1988	0.54	0.19	1.602	
8	Itafa 21/03/1988	0.04	0.04	1.000	

5.9

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Chrysopid eggs

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.88	3	0.29	1.033	N.S.
Formulations	2.64	2	1.32	4.649	*
A.Is.	0.32	1	0.32	1.114	N.S.
Assessments	10.74	9	1.19	4.204	****
Fo. x A..	0.81	2	0.41	1.434	N.S.
Fo. x As.	9.39	18	0.52	1.837	*
A.. x As.	3.79	9	0.42	1.485	N.S.
Fo. x A.. x As.	5.56	18	0.31	1.087	N.S.
Contrasts					
Water-based vs others	0.76	(1)	0.76	2.663	N.S.
Water-based vs oil-based	2.07	(1)	2.07	7.296	**
Molasses-based vs others	0.57	(1)	0.57	2.002	N.S.
Oil-based vs others	2.63	(1)	2.63	9.282	**
Total (all treatments)	33.25	59	0.56	1.985	***
Residual (Error)	50.24	177	0.284		
TOTAL	84.37	239			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 40.0%

Units (untransformed) are: Eggs per 12 plants

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	LSD =	0.17		0 1.80
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	1.90	0.25	0.314	
2	Oil-based formulation: approx. 1.6 l/ha.	1.13	0.14	0.188	
3	Water-based CDA: approx. 11 l./ha.	1.86	0.23	0.263	
	A.Is.	LSD =	0.14		0 1.80
1	Thiodicarb	1.69	0.16	0.233	
2	l.-Cyhalothrin	1.57	0.19	0.299	
	Assessments	LSD =	0.30		0 1.80
1	Itafa 12.02.1988	1.00	0.20	0.133	
2	Itafa 19.02.1988	0.63	0.20	0.165	
3	Itafa 26.02.1988	1.33	0.33	0.229	
4	Itafa 04.03.1988	1.25	0.28	0.202	
5	Itafa 11.03.1988	1.21	0.23	0.149	
6	Itafa 18.03.1988	2.04	0.53	0.380	
7	Itafa 25.03.1988	2.29	0.51	0.303	
8	Itafa 30.03.1988	2.21	0.29	0.144	
9	Itafa 08.04.1988	1.21	0.27	0.194	
10	Itafa 15.04.1988	3.13	0.61	0.406	

N.B. LSDs, Variance/Mean ratios and bars are transformed data.

5.10

Taurus Hi-Spin: Kadoma, Zimbabwe (1988)

Chrysopid larvae

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	0.11	3	0.04	2.744	*
Formulations	0.03	2	0.01	1.029	N.S.
A.Is.	0.02	1	0.02	1.372	N.S.
Assessments	0.13	9	0.01	1.105	N.S.
Fo. x A..	0.06	2	0.03	2.401	N.S.
Fo. x As.	0.15	18	0.01	0.648	N.S.
A.. x As.	0.05	9	0.01	0.419	N.S.
Fo. x A.. x As.	0.21	18	0.01	0.877	N.S.
Contrasts					
Water-based vs others	0.02	(1)	0.02	1.544	N.S.
Water-based vs oil-based	0.03	(1)	0.03	2.058	N.S.
Molasses-based vs others	0.02	(1)	0.02	1.544	N.S.
Oil-based vs others	0.00	(1)	0.00	0.000	N.S.
Total (all treatments)	0.64	59	0.01	0.837	N.S.
Residual (Error)	2.30	177	0.013		
TOTAL	3.05	239			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 15.6%

Units (untransformed) are: Insects per 12 plants

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	**LSD =**	**0.04**		0 0.80
2	Oil-based formulation: approx. 1.6 l/ha.	0.07	0.03	0.025	
1	Molasses-based aqu.ULV.: approx. 5 l/ha.	0.05	0.02	0.018	
3	Water-based CDA: approx. 11 l./ha.	0.02	0.02	0.009	
	A.Is.	**LSD =**	**0.03**		0 0.80
1	Thiodicarb	0.03	0.02	0.012	
2	l.-Cyhalothrin	0.07	0.02	0.023	
	Assessments	**LSD =**	**0.07**		0 0.80
1	Itafa 12.02.1988	0.13	0.07	0.040	
2	Itafa 19.02.1988	0.08	0.06	0.028	
3	Itafa 26.02.1988	0.00	0.00	0.000	
4	Itafa 04.03.1988	0.04	0.04	0.015	
5	Itafa 11.03.1988	0.13	0.07	0.040	
6	Itafa 18.03.1988	0.04	0.04	0.015	
7	Itafa 25.03.1988	0.04	0.04	0.015	
8	Itafa 30.03.1988	0.00	0.00	0.000	
9	Itafa 08.04.1988	0.00	0.00	0.000	
10	Itafa 15.04.1988	0.04	0.04	0.015	

N.B. LSDs, Variance/Mean ratios and bars are transformed data.

Summary: all scores

Spiders

Source	Sum of Squares	DF	Mean Squares	F	Significance
Blocks	1.22	3	0.41	1.390	N.S.
Formulations	0.35	2	0.18	0.604	N.S.
A.Is.	0.14	1	0.14	0.479	N.S.
F. x A.	0.07	2	0.03	0.112	N.S.
Residual (Error)	4.38	15	0.29		
Total	6.16	23			

Data have undergone SQUARE ROOT transformation.

Coefficient of Variation = 30.8%

MAKOKA 1988

Cotton

Typically 0.8m. spacing between ridges; cotton on bunds.

Factors

a. Three formulations
   i. WULV using 37.5% SC (FW); 2 then 1 row swath;
   ii. WULV using 80% WG (DF): applied as with SC
   iii. Oil-based CDA using UCLF5 diluted with Shellsol K 4 then 2 row swath; ULV of 0.9 - 1.4 l/ha.
b. Two dosage rates: based on new Malawi recommendations:
   i. Full rate of 430 g.a.i./ha.
   ii. Half rate of 215 g.a.i./ha.
c. Two droplet sizes:
   i. 70-75 µm. VAD. (normal battery pack)
   ii. 90-100 µm. VAD. (controlled voltage battery pack)

Design

Three replicates: completely randomised plots of 24 ridges x 30m.

Treatment details

Trt No.	Mixing instructions to make up 1 litre all quantities in ml. or g.			Restrictor	Battery pack	Expected quantity of mixture for 3 * plots with swaths: l/ha.	2 rows	1 row
1	72	928		1.3	normal	15.9	1374	2748
2	72	928		1.3	control	15.9	1374	2748
3	36	964		1.3	normal	15.9	1374	2748
4	36	964		1.3	control	15.9	1374	2748
Trt No.	80% WG (DF)	Water				l/ha.	2 rows	1 row
5	33.75g.	to 1 litre		1.3	normal	15.9	1374	2748
6	33.75g.	"		1.3	control	15.9	1374	2748
7	16.875g.	"		1.3	normal	15.9	1374	2748
8	16.875g.	"		1.3	control	15.9	1374	2748
Trt No.	UCLF 5	Oil	Shellsol K **			l/ha.	4 rows	2 rows
9	880	0	120	1.5	normal	1.40	121	241
10	880	0	120	1.5	control	1.40	121	241
11	600	170	230	1.0	normal	1.02	88	177
12	600	170	230	1.0	control	1.02	88	177

13 Untreated CONTROL

*: Row pattern to be changed when crop height reaches 0.5m.
**: Usually pre-mixed before trial day; normally use "Kasinga" cottonseed oil: SHAKE WELL BEFORE USE.

CHECKLIST OF ITEMS REQUIRED

MALAWI: 13 TREATMENT CRITICAL TRIALS

Trial protocol
Spray logs sheets (12)
Plot layout plans
Pen
Windspeed meter
Whirling hygrometer

Water
Weighed out DF formulation in sachets (+ 1 extra sachet at each dose rate - in case of accidents!)
2 bottles pre-mixed oil based @ 88%
2 " " " @ 60%
2 full bottles of 37.5% SC
Stirring stick
Funnel
4 empty bottles
6 sprayers:
    4 feed-stems @ 1.3
    2 " @ 1.0
    2 " @ 1.5
3 control packs set for 60 r.p.s. (3600 r.p.m.) loaded
3 normal battery packs @ 12 v.
Alkaline cells for above
2 x 2l. measuring beakers
1 litre measuring cylinder
250 ml. measuring cylinder

Old toothbrushes for cleaning
Turbair XJ servicing tool
Bottle of Shellsol K for flushing sprayers after oil based treatments.

IMPORTANT Keep all oil based equipment SEPARATE from other sprayers and measuring cylinders.

==========

Thiodicarb to be sprayed against:

All bollworms
Leaf-eaters
Psyllids
Jassids
Stainers

Aphid and whitefly attacks to be treated with BLANKET spray of Dimethoate (including controls). Solubor may be mixed with these treatments, but neither dimethoate nor solubor should be mixed with the Thiodicarb formulations.

NO SCOUTING TO TAKE PLACE WITHIN 5 METRES OF PLOT BOUNDARIES

IV.B.6.1

Thiodicarb CDA: Makoka, Malawi (1988)

Analysis of SPRAY LOGS: plants over 0.5m. tall.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Spray Dates	4215.00	12	351.25	2.635	**
Formulations	907.04	2	453.52	3.403	*
Rate of a.i.	632.45	1	632.45	4.745	*
Droplet size	42.38	1	42.38	0.318	N.S.
Fo. x Ra.	1970.01	2	985.01	7.390	***
Fo. x Dr.	7.88	2	3.94	0.030	N.S.
Ra. x Dr.	414.23	1	414.23	3.108	N.S.
Fo. x Ra. x Dr.	231.57	2	115.79	0.869	N.S.
Contrasts					
Water-based vs Oil-based	891.32	(1)	891.32	6.687	*
SC vs WG	15.72	(1)	15.72	0.118	N.S.
Total (all treatments)	4205.57	11	382.32	2.869	**
Residual (Error)	17593.24	132	133.282		
TOTAL	26013.82	155			

Coefficient of Variation = 11.4%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
	Units (untransformed) are: % of target volume				0 110.00
3	Oil-based formulations: @ < 1.5 l/ha.	104.44	2.98	4.433	
2	Water-based CDA: WG formln. @ < 16 l/ha.	99.76	0.42	0.090	
1	Water-based CDA: SC formln. @ < 16 l/ha.	98.98	0.62	0.205	
	Rate of a.i.				0 110.00
1	Approx. 430 g.a.i./ha.	99.05	0.91	0.659	
2	Approx. 215 g.a.i./ha.	103.08	1.84	2.564	
	Droplet size				0 110.00
1	65-70 microns V.A.D.	100.54	1.62	2.041	
2	90-100 microns V.A.D.	101.58	1.30	1.300	

6.2

Thiodicarb CDA: Makoka, Malawi (1988)

Plant stand

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	30.72	2	15.36	1.177	N.S.
Rate of a.i.	10.03	1	10.03	0.768	N.S.
Droplet size	2.25	1	2.25	0.172	N.S.
Fo. x Ra.	32.72	2	16.36	1.253	N.S.
Fo. x Dr.	31.50	2	15.75	1.206	N.S.
Ra. x Dr.	17.36	1	17.36	1.330	N.S.
Fo. x Ra. x Dr.	97.06	2	48.53	3.717	*
Contrasts					
Water-based vs Oil-based	30.68	(1)	30.68	2.350	N.S.
SC vs WG	0.04	(1)	0.04	0.003	N.S.
Residual (Error)	313.33	24	13.056		
TOTAL	534.97	35			

Coefficient of Variation = 9.3%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: plants in plot area				0 40.00
3	Oil-based formulations: @ < 1.5 l/ha.	40.33	1.01	0.304	
1	Water-based CDA: SC formln. @ < 16 l/ha.	38.42	1.41	0.617	
2	Water-based CDA: WG formln. @ < 16 l/ha.	38.33	0.91	0.258	
	Rate of a.i.				0 40.00
1	*Approx.* 430 g.a.i./ha.	38.50	1.01	0.474	
2	Approx. 215 g.a.i./ha.	39.56	0.84	0.319	
	Droplet size				0 40.00
1	65-70 microns V.A.D.	39.28	1.04	0.500	
2	90-100 microns V.A.D.	38.78	0.81	0.302	

Untreated control plots 34.0 5.7

6.3

Thiodicarb CDA: Makoka, Malawi (1988)

Total seed cotton yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.28	2	0.14	1.307	N.S.
Rate of a.i.	1.29	1	1.29	11.871	**
Droplet size	0.00	1	0.00	0.036	N.S.
Fo. x Ra.	0.14	2	0.07	0.658	N.S.
Fo. x Dr.	0.08	2	0.04	0.385	N.S.
Ra. x Dr.	0.00	1	0.00	0.001	N.S.
Fo. x Ra. x Dr.	0.04	2	0.02	0.167	N.S.
Contrasts					
Water-based vs Oil-based	0.25	(1)	0.25	2.313	N.S.
SC vs WG	0.03	(1)	0.03	0.300	N.S.
Residual (Error)	2.60	24	0.108		
TOTAL	4.43	35			

Coefficient of Variation = 36.1%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD 5%
	Units (untransformed) are: kg. per 3x3m plot				0 1.30
3	Oil-based formulations: @ < 1.5 l/ha.	1.03	0.10	0.108	
1	Water-based CDA: SC formln. @ < 16 l/ha.	0.89	0.10	0.136	
2	Water-based CDA: WG formln. @ < 16 l/ha.	0.82	0.11	0.177	
	Rate of a.i.				0 1.30
1	Approx. 430 g.a.i./ha.	1.10	0.07	0.070	
2	Approx. 215 g.a.i./ha.	0.72	0.08	0.149	
	Droplet size				0 1.30
1	65-70 microns V.A.D.	0.92	0.09	0.153	
2	90-100 microns V.A.D.	0.90	0.08	0.132	

Untreated controls: 0.16 0.026

6.4

Thiodicarb CDA: Makoka, Malawi (1988)

Clean cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.16	2	0.08	1.110	N.S.
Rate of a.i.	0.51	1	0.51	7.048	*
Droplet size	0.01	1	0.01	0.125	N.S.
Fo. x Ra.	0.04	2	0.02	0.257	N.S.
Fo. x Dr.	0.11	2	0.05	0.733	N.S.
Ra. x Dr.	0.02	1	0.02	0.311	N.S.
Fo. x Ra. x Dr.	0.01	2	0.01	0.090	N.S.
Contrasts					
Water-based vs Oil-based	0.16	(1)	0.16	2.214	N.S.
SC vs WG	0.00	(1)	0.00	0.006	N.S.
Residual (Error)	1.74	24	0.072		
TOTAL	2.60	35			

Coefficient of Variation = 65.4%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected $LSD_{.05}$
	Units (untransformed) are: kg. per 3x3m plot				0 0.70
3	Oil-based formulations: @ < 1.5 l/ha.	0.51	0.08	0.153	
1	Water-based CDA: SC formln. @ < 16 l/ha.	0.37	0.08	0.207	
2	Water-based CDA: WG formln. @ < 16 l/ha.	0.36	0.08	0.188	
	Rate of a.i.				0 0.70
1	Approx. 430 g.a.i./ha.	0.53	0.06	0.115	
2	Approx. 215 g.a.i./ha.	0.29	0.06	0.211	
	Droplet size				0 0.70
1	65-70 microns V.A.D.	0.43	0.07	0.195	
2	90-100 microns V.A.D.	0.40	0.06	0.174	

Untreated controls: 0.026 0.0034

6.5

Thiodicarb CDA: Makoka, Malawi (1988)

Damaged cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.04	2	0.02	0.944	N.S.
Rate of a.i.	0.18	1	0.18	9.427	**
Droplet size	0.00	1	0.00	0.058	N.S.
Fo. x Ra.	0.07	2	0.03	1.854	N.S.
Fo. x Dr.	0.01	2	0.00	0.177	N.S.
Ra. x Dr.	0.02	1	0.02	1.013	N.S.
Fo. x Ra. x Dr.	0.03	2	0.02	0.936	N.S.
Contrasts					
Water-based vs Oil-based	0.01	(1)	0.01	0.538	N.S.
SC vs WG	0.03	(1)	0.03	1.351	N.S.
Residual (Error)	0.45	24	0.019		
TOTAL	0.79	35			

Coefficient of Variation = 27.3%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: kg. per 3x3m plot					0 0.60
2	Water-based CDA: WG formln. @ < 16 l/ha.	0.46	0.06	0.080	
1	Water-based CDA: SC formln. @ < 16 l/ha.	0.52	0.03	0.027	
3	Oil-based formulations: @ < 1.5 l/ha.	0.52	0.04	0.035	
	Rate of a.i.				0 0.60
1	Approx. 430 g.a.i./ha.	0.57	0.03	0.038	
2	Approx. 215 g.a.i./ha.	0.43	0.03	0.033	
	Droplet size				0 0.60
1	65-70 microns V.A.D.	0.50	0.03	0.037	
2	90-100 microns V.A.D.	0.51	0.04	0.056	

Untreated controls: 0.14 0.024

6.6

Thiodicarb CDA: Makoka, Malawi (1988)

Split boll analysis: Clean yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	820.88	2	410.44	2.738	N.S.
Rate of a.i.	475.54	1	475.54	3.172	N.S.
Droplet size	262.82	1	262.82	1.753	N.S.
Fo. x Ra.	74.69	2	37.34	0.249	N.S.
Fo. x Dr.	128.05	2	64.03	0.427	N.S.
Ra. x Dr.	121.99	1	121.99	0.814	N.S.
Fo. x Ra. x Dr.	222.73	2	111.36	0.743	N.S.
Contrasts					
Water-based vs Oil-based	817.35	(1)	817.35	5.452	*
SC vs WG	3.53	(1)	3.53	0.024	N.S.
Residual (Error)	3597.95	24	149.915		
TOTAL	5704.65	35			

Coefficient of Variation = 59.0%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD.05
	Units (untransformed) are: percentages				0 30.00
3	Oil-based formulations: @ < 1.5 l/ha.	27.49	3.98	6.920	
1	Water-based CDA: SC formln. @ < 16 l/ha.	17.76	3.60	8.748	
2	Water-based CDA: WG formln. @ < 16 l/ha.	17.00	2.86	5.786	
	Rate of a.i.				0 30.00
1	Approx. 430 g.a.i./ha.	24.38	2.72	5.444	
2	Approx. 215 g.a.i./ha.	17.12	3.12	10.215	
	Droplet size				0 30.00
1	65-70 microns V.A.D.	23.45	3.60	9.936	
2	90-100 microns V.A.D.	18.05	2.20	4.825	

Untreated controls: 6.63 2.64

6.6a.

Thiodicarb CDA: Makoka, Malawi (1988)

Makoka 1988: Split boll analysis: estimated yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	1501289.30	2	750644.65	3.318	N.S.
Rate of a.i.	851015.47	1	851015.47	3.762	N.S.
Droplet size	381588.87	1	381588.87	1.687	N.S.
Fo. x Ra.	132905.82	2	66452.91	0.294	N.S.
Fo. x Dr.	125054.73	2	62527.36	0.276	N.S.
Ra. x Dr.	33050.26	1	33050.26	0.146	N.S.
Fo. x Ra. x Dr.	546471.95	2	273235.98	1.208	N.S.
Contrasts					
Water-based vs Oil-based	1436029.33	(1)	1436029.33	6.347	*
SC vs WG	65259.97	(1)	65259.97	0.288	N.S.
Residual (Error)	5429723.21	24	226238.467		
TOTAL	9001099.61	35			

Coefficient of Variation = 55.0%

Units (untransformed) are: Estimated yield: kg./ha.

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Formulations	**LSD =**	**400.70**		0 1500.00
3	Oil-based formulations: @ < 1.5 l/ha.	1146.54	186.82	365.292	
1	Water-based CDA: SC formln. @ < 16 l/ha.	775.00	107.70	179.604	
2	Water-based CDA: WG formln. @ < 16 l/ha.	670.71	101.57	184.562	
	Rate of a.i.	**LSD =**	**327.17**		0 1500.00
1	Approx. 430 g.a.i./ha.	1017.83	109.55	212.248	
2	Approx. 215 g.a.i./ha.	710.33	120.96	370.789	
	Droplet size	**LSD =**	**327.17**		0 1500.00
1	65-70 microns V.A.D.	967.04	146.63	400.184	
2	90-100 microns V.A.D.	761.13	81.66	157.709	

Untreated controls: 173.6 50.8

6.7

Thiodicarb CDA: Makoka, Malawi (1988)

Split boll analysis: Damaged yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	185.58	2	92.79	2.403	N.S.
Rate of a.i.	94.76	1	94.76	2.454	N.S.
Droplet size	2.82	1	2.82	0.073	N.S.
Fo. x Ra.	60.48	2	30.24	0.783	N.S.
Fo. x Dr.	68.26	2	34.13	0.884	N.S.
Ra. x Dr.	36.31	1	36.31	0.940	N.S.
Fo. x Ra. x Dr.	33.37	2	16.69	0.432	N.S.
Contrasts					
Water-based vs Oil-based	64.28	(1)	64.28	1.665	N.S.
SC vs WG	121.31	(1)	121.31	3.141	N.S.
Residual (Error)	926.76	24	38.615		
TOTAL	1408.35	35			

Coefficient of Variation = 36.0%

Split boll analysis: Number of Bolls/plant.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	13.94	2	6.97	0.838	N.S.
Rate of a.i.	17.40	1	17.40	2.093	N.S.
Droplet size	5.85	1	5.85	0.703	N.S.
Fo. x Ra.	2.79	2	1.40	0.168	N.S.
Fo. x Dr.	6.80	2	3.40	0.409	N.S.
Ra. x Dr.	10.23	1	10.23	1.231	N.S.
Fo. x Ra. x Dr.	56.08	2	28.04	3.372	N.S.
Contrasts					
Water-based vs Oil-based	11.34	(1)	11.34	1.363	N.S.
SC vs WG	2.60	(1)	2.60	0.313	N.S.
Residual (Error)	199.59	24	8.316		
TOTAL	312.68	35			

Coefficient of Variation = 23.5%

Bolls damaged by bollworms

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	194.43	2	97.22	0.592	N.S.
Rate of a.i.	31.69	1	31.69	0.193	N.S.
Droplet size	109.68	1	109.68	0.668	N.S.
Fo. x Ra.	101.90	2	50.95	0.310	N.S.
Fo. x Dr.	17.41	2	8.71	0.053	N.S.
Ra. x Dr.	3.73	1	3.73	0.023	N.S.
Fo. x Ra. x Dr.	240.05	2	120.03	0.731	N.S.
Contrasts					
Water-based vs Oil-based	32.91	(1)	32.91	0.200	N.S.
SC vs WG	161.53	(1)	161.53	0.984	N.S.
Residual (Error)	3939.65	24	164.152		
TOTAL	4638.57	35			

Coefficient of Variation = 57.6%

6.8

Thiodicarb CDA: Makoka, Malawi (1988)

Heliothis larvae: 16 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	1.83	2	0.92	3.636	*
Rate of a.i.	0.01	1	0.01	0.035	N.S.
Droplet size	0.14	1	0.14	0.563	N.S.
Fo. x Ra.	0.70	2	0.35	1.385	N.S.
Fo. x Dr.	0.06	2	0.03	0.121	N.S.
Ra. x Dr.	0.60	1	0.60	2.398	N.S.
Fo. x Ra. x Dr.	1.25	2	0.63	2.486	N.S.
Contrasts					
Water-based vs Oil-based	1.80	(1)	1.80	7.135	*
SC vs WG	0.03	(1)	0.03	0.137	N.S.
Residual (Error)	6.05	24	0.252		
TOTAL	10.65	35			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 31.0%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: total surviving larvae				0 2.00
3	Oil-based formulations: @ < 1.5 l/ha.	1.42	0.36	1.086	
2	Water-based CDA: WG formln. @ < 16 l/ha.	2.92	0.40	0.652	
1	Water-based CDA: SC formln. @ < 16 l/ha.	2.92	0.68	1.899	
	Rate of a.i.				0 2.00
1	Approx. 430 g.a.i./ha.	2.39	0.39	1.140	
2	Approx. 215 g.a.i./ha.	2.44	0.48	1.695	
	Droplet size				0 2.00
1	65-70 microns V.A.D.	2.28	0.48	1.798	
2	90-100 microns V.A.D.	2.56	0.39	1.069	

N.B. Bars represent transformed data.

Untreated controls: 16.0 3.7

6.9

Thiodicarb CDA: Makoka, Malawi (1988)

Heliothis eggs: 16 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	977.72	2	488.86	2.321	N.S.
Rate of a.i.	10.03	1	10.03	0.048	N.S.
Droplet size	56.25	1	56.25	0.267	N.S.
Fo. x Ra.	140.39	2	70.19	0.333	N.S.
Fo. x Dr.	1458.17	2	729.08	3.461	*
Ra. x Dr.	30.25	1	30.25	0.144	N.S.
Fo. x Ra. x Dr.	339.50	2	169.75	0.806	N.S.
Contrasts					
Water-based vs Oil-based	690.68	(1)	690.68	3.279	N.S.
SC vs WG	287.04	(1)	287.04	1.363	N.S.
Residual (Error)	5056.00	24	210.667		
TOTAL	8068.31	35			

Coefficient of Variation = 23.5%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: total egg numbers				0 80.00
3	Oil-based formulations: @ < 1.5 l/ha.	55.67	3.74	3.016	
2	Water-based CDA: WG formln. @ < 16 l/ha.	61.50	5.02	4.918	
1	Water-based CDA: SC formln. @ < 16 l/ha.	68.42	3.81	2.547	
	Rate of a.i.				0 80.00
1	Approx. 430 g.a.i./ha.	62.39	3.15	2.870	
2	Approx. 215 g.a.i./ha.	61.33	4.05	4.809	
	Droplet size				0 80.00
1	65-70 microns V.A.D.	60.61	4.26	5.383	
2	90-100 microns V.A.D.	63.11	2.84	2.298	

Untreated controls: 46.3 7.0

5.10

Thiodicarb CDA: Makoka, Malawi (1988)

Psyllid Adults: 16 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	2.00	2	1.00	4.988	*
Rate of a.i.	3.96	1	3.96	19.785	***
Droplet size	0.28	1	0.28	1.379	N.S.
Fo. x Ra.	1.18	2	0.59	2.960	N.S.
Fo. x Dr.	0.41	2	0.20	1.014	N.S.
Ra. x Dr.	1.00	1	1.00	4.973	*
Fo. x Ra. x Dr.	1.11	2	0.55	2.765	N.S.
Contrasts					
Water-based vs Oil-based	0.48	(1)	0.48	2.402	N.S.
SC vs WG	1.52	(1)	1.52	7.573	*
Residual (Error)	4.80	24	0.200		
TOTAL	14.73	35			

Data have undergone LOGARITHMIC transformation.
Coefficient of Variation = 14.6%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: total insect numbers				0 3.00
1	Water-based CDA: SC formln. @ < 16 l/ha.	18.00	2.09	2.909	
3	Oil-based formulations: @ < 1.5 l/ha.	21.25	4.70	12.484	
2	Water-based CDA: WG formln. @ < 16 l/ha.	36.17	6.07	12.235	
	Rate of a.i.				0 3.00
1	Approx. 430 g.a.i./ha.	16.33	2.57	7.253	
2	Approx. 215 g.a.i./ha.	33.94	4.36	10.067	
	Droplet size				0 3.00
1	65-70 microns V.A.D.	21.67	3.29	8.976	
2	90-100 microns V.A.D.	28.61	4.74	14.133	

N.B. Bars represent transformed data.

Untreated controls: 170.0 5.7

6.11

Thiodicarb CDA: Makoka, Malawi (1988)

Whitefly Adults: 16 days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	32846.06	2	16423.03	9.629	***
Rate of a.i.	3823.36	1	3823.36	2.242	N.S.
Droplet size	1.36	1	1.36	0.001	N.S.
Fo. x Ra.	2890.39	2	1445.19	0.847	N.S.
Fo. x Dr.	1256.72	2	628.36	0.368	N.S.
Ra. x Dr.	8.03	1	8.03	0.005	N.S.
Fo. x Ra. x Dr.	97.72	2	48.86	0.029	N.S.
Contrasts					
Water-based vs Oil-based	32470.01	(1)	32470.01	19.038	***
SC vs WG	376.04	(1)	376.04	0.220	N.S.
Residual (Error)	40933.33	24	1705.556		
TOTAL	81856.97	35			

Coefficient of Variation = 23.2%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: total insect numbers				0 200.00
3	Oil-based formulations: @ < 1.5 l/ha.	135.50	7.58	5.089	
1	Water-based CDA: SC formln. @ < 16 l/ha.	195.25	13.49	11.190	
2	Water-based CDA: WG formln. @ < 16 l/ha.	203.17	11.48	7.783	
	Rate of a.i.				0 200.00
1	Approx. 430 g.a.i./ha.	167.67	11.82	15.000	
2	Approx. 215 g.a.i./ha.	198.28	10.74	11.022	
	Droplet size				0 200.00
1	65-70 microns V.A.D.	178.17	11.67	13.769	
2	90-100 microns V.A.D.	177.78	11.46	13.286	

Untreated controls: 483.7 23.4

6.12

Thiodicarb CDA: Makoka, Malawi (1988)

Jassids: 16 days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.61	2	0.31	1.477	N.S.
Rate of a.i.	0.35	1	0.35	1.699	N.S.
Droplet size	0.10	1	0.10	0.45[9]	N.S.
Fo. x Ra.	0.04	2	0.02	0.107	N.S.
Fo. x Dr.	0.60	2	0.30	1.448	N.S.
Ra. x Dr.	0.26	1	0.26	1.256	N.S.
Fo. x Ra. x Dr.	0.06	2	0.03	0.149	N.S.
Contrasts					
Water-based vs Oil-based	0.41	(1)	0.41	1.953	N.S.
SC vs WG	0.21	(1)	0.21	1.002	N.S.
Residual (Error)	4.98	24	0.208		
TOTAL	7.01	35			

Data have undergone LOGARITHMIC transformation.
Coefficient of Variation = 15.0%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: total insect numbers				0 3.00
3	Oil-based formulations: @ < 1.5 l/ha.	18.25	2.28	3.418	
1	Water-based CDA: SC formln. @ < 16 l/ha.	20.83	2.23	2.852	
2	Water-based CDA: WG formln. @ < 16 l/ha.	25.67	3.09	4.458	
	Rate of a.i.				0 3.00
1	Approx. 430 g.a.i./ha.	20.00	2.51	5.665	
2	Approx. 215 g.a.i./ha.	23.17	1.74	2.342	
	Droplet size				0 3.00
1	65-70 microns V.A.D.	22.83	2.19	3.788	
2	90-100 microns V.A.D.	20.33	2.15	4.085	

N.B. Bars represent transformed data.

Untreated controls: 125.3 14.8

CHITALA

Cotton

Typically 0.9m. spacing between ridges; cotton on bunds.

Factors

a. Three formulations
   i. WULV using 37.5% SC (FW); 2 then 1 row swath;
   ii. WULV using 80% DF: as with SC
   iii. Oil-based CDA using UCLF5 diluted with Shellsol K 4 then 2 row swath; ULV of 0.9 - 1.4 l/ha.
b. Two dosage rates: based on new Malawi recommendations:
   i. Full rate of 382 g.a.i./ha.
   ii. Half rate of 191 g.a.i./ha.
c. Two droplet sizes:
   i. 70-75 µm. VAD. (normal battery pack)
   ii. 90-100 µm. VAD. (controlled voltage battery pack)

Design

Four replicates completely randomised in plots of 38 ridges x 24m. Control data taken from an adjacent trial (MK/CTN/ENT/137).

Treatment details

Trt No.	Mixing instructions to make up 1 litre all quantities in ml. or g.			Restrictor	Battery pack	Expected quantity of mixture for 3 * plots with swaths: l/ha.	2 rows	1 row
1 - 4	37.5% SC 72	Water 928		1.3	normal	14.1	2320	4640
5 - 8	72	928		1.3	control	14.1	2320	4640
9 - 12	36	964		1.3	normal	14.1	2320	4640
13 - 16	36	964		1.3	control	14.1	2320	4640
Trt No.	80% WG (DF)	Water				l/ha.	2 rows	1 row
17 - 20	33.75g.	to 1 litre		1.3	normal	14.1	2320	4640
21 - 24	33.75g.	"		1.3	control	14.1	2320	4640
25 - 28	16.875g.	"		1.3	normal	14.1	2320	4640
29 - 32	16.875g.	"		1.3	control	14.1	2320	4640
Trt No.	UCLF 5	Oil	Shellsol K **			l/ha.	4 rows	2 rows
33 - 36	880	0	120	1.5	normal	1.24	204	407
37 - 40	880	0	120	1.5	control	1.24	204	407
41 - 44	600	170	230	1.0	normal	0.91	149	299
45 - 48	600	170	230	1.0	control	0.91	149	299

*: Row pattern to be changed when crop height reaches 0.5m.
**: Usually pre-mixed before trial day; normally use "Kasinga" cottonseed oil: SHAKE WELL BEFORE USE.

IV.B.7.1

Thiodicarb CDA: Chitala, Malawi (1988)

Analysis of SPRAY LOGS: plants over 0.5m. tall.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Spray Dates	1855.43	5	371.09	3.247	*
Formulations	74.95	2	37.47	0.328	N.S.
Rate of a.i.	78.88	1	78.88	0.690	N.S.
Droplet size	3.21	1	3.21	0.028	N.S.
Fo. x Ra.	59.46	2	29.73	0.260	N.S.
Fo. x Dr.	1.39	2	0.70	0.006	N.S.
Ra. x Dr.	0.24	1	0.24	0.002	N.S.
Fo. x Ra. x Dr.	38.55	2	19.27	0.169	N.S.
Contrasts					
Water-based vs Oil-based	68.09	(1)	68.09	0.596	N.S.
SC vs WG	6.86	(1)	6.86	0.060	N.S.
Total (all treatments)	256.68	11	23.33	0.204	N.S.
Residual (Error)	6284.93	55	114.271		
TOTAL	8397.03	71			

Coefficient of Variation = 10.6%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{75}
	Units (untransformed) are: % of target volume				0 110.00
3	Oil-based formulations: @ < 1.5 l/ha.	101.89	3.75	3.307	
2	Water-based CDA: WG formln. @ < 15 l/ha.	100.20	0.65	0.101	
1	Water-based CDA: SC formln. @ < 15 l/ha.	99.45	0.78	0.148	
	Rate of a.i.				0 110.00
1	Approx. 430 g.a.i./ha.	101.56	1.13	0.453	
2	Approx. 215 g.a.i./ha.	99.46	2.31	1.927	
	Droplet size				0 110.00
1	65-70 microns V.A.D.	100.72	1.79	1.144	
2	90-100 microns V.A.D.	100.30	1.86	1.242	

IV.B.7.2

Thiodicarb CDA: Chitala, Malawi (1988)

Plant stand

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	200.79	2	100.40	3.285	*
Rate of a.i.	67.69	1	67.69	2.215	N.S.
Droplet size	35.02	1	35.02	1.146	N.S.
Fo. x Ra.	130.87	2	65.44	2.141	N.S.
Fo. x Dr.	184.29	2	92.15	3.015	N.S.
Ra. x Dr.	2.52	1	2.52	0.082	N.S.
Fo. x Ra. x Dr.	17.04	2	8.52	0.279	N.S.
Contrasts					
Water-based vs Oil-based	195.51	(1)	195.51	6.397	*
SC vs WG	5.28	(1)	5.28	0.173	N.S.
Residual (Error)	1100.25	36	30.562		
TOTAL	1738.48	47			

Coefficient of Variation = 18.5%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: plants in sample area				0 30.00
3	Oil-based formulations: @ < 1.5 l/ha.	32.75	1.86	1.696	
1	Water-based CDA: SC formln. @ < 15 l/ha.	28.87	1.43	1.131	
2	Water-based CDA: WG formln. @ < 15 l/ha.	28.06	0.95	0.511	
	Rate of a.i.				0 30.00
1	Approx. 430 g.a.i./ha.	28.71	1.07	0.965	
2	Approx. 215 g.a.i./ha.	31.08	1.37	1.446	
	Droplet size				0 30.00
1	65-70 microns V.A.D.	29.04	1.15	1.097	
2	90-100 microns V.A.D.	30.75	1.33	1.372	

Adjacent trial: controls 36.3 0.9

7.3

Thiodicarb CDA: Chitala, Malawi (1988)

Total seed cotton yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.73	2	0.36	4.377	*
Rate of a.i.	2.05	1	2.05	24.669	****
Droplet size	0.06	1	0.06	0.742	N.S.
Fo. x Ra.	0.21	2	0.11	1.271	N.S.
Fo. x Dr.	0.63	2	0.31	3.775	*
Ra. x Dr.	0.01	1	0.01	0.068	N.S.
Fo. x Ra. x Dr.	0.15	2	0.07	0.890	N.S.
Contrasts					
Water-based vs Oil-based	0.69	(1)	0.69	8.295	**
SC vs WG	0.04	(1)	0.04	0.459	N.S.
Residual (Error)	2.99	36	0.083		
TOTAL	6.82	47			

Coefficient of Variation = 21.6%

Units (untransformed) are: Kg. per 3 x 3.6m plot

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Formulations	LSD =	0.21		0 1.70
2	Water-based CDA: WG formln. @ < 15 l/ha.	1.46	0.09	0.097	
1	Water-based CDA: SC formln. @ < 15 l/ha.	1.39	0.10	0.105	
3	Oil-based formulations: @ < 1.5 l/ha.	1.17	0.09	0.102	
	Rate of a.i.	LSD =	0.17		0 1.70
1	Approx. 430 g.a.i./ha.	1.54	0.07	0.080	
2	Approx. 215 g.a.i./ha.	1.13	0.06	0.074	
	Droplet size	LSD =	0.17		0 1.70
1	65-70 microns V.A.D.	1.37	0.07	0.098	
2	90-100 microns V.A.D.	1.30	0.08	0.123	

Adjacent trial: controls 0.73 0.18

7.4

Thiodicarb CDA: Chitala, Malawi (1988)

Clean cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	1.39	2	0.69	7.398	**
Rate of a.i.	1.96	1	1.96	20.938	****
Droplet size	0.02	1	0.02	0.267	N.S.
Fo. x Ra.	0.16	2	0.08	0.841	N.S.
Fo. x Dr.	0.54	2	0.27	2.887	N.S.
Ra. x Dr.	0.00	1	0.00	0.042	N.S.
Fo. x Ra. x Dr.	0.04	2	0.02	0.199	N.S.
Contrasts					
Water-based vs Oil-based	1.35	(1)	1.35	14.382	***
SC vs WG	0.04	(1)	0.04	0.415	N.S.
Residual (Error)	3.37	36	0.094		
TOTAL	7.49	47			

Coefficient of Variation = 27.7%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Kg. per 3 x 3.6m plot				0 1.50
2	Water-based CDA: WG formln. @ < 15 l/ha.	1.26	0.10	0.120	
1	Water-based CDA: SC formln. @ < 15 l/ha.	1.19	0.09	0.104	
3	Oil-based formulations: @ < 1.5 l/ha.	0.87	0.09	0.152	
	Rate of a.i.				0 1.50
1	Approx. 430 g.a.i./ha.	1.31	0.08	0.109	
2	Approx. 215 g.a.i./ha.	0.90	0.06	0.109	
	Droplet size				0 1.50
1	65-70 microns V.A.D.	1.13	0.08	0.122	
2	90-100 microns V.A.D.	1.08	0.09	0.172	

Adjacent trial: controls 0.413 0.120

7.5

Thiodicarb CDA: Chitala, Malawi (1988)

Damaged cotton

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.11	2	0.05	3.105	N.S.
Rate of a.i.	0.00	1	0.00	0.055	N.S.
Droplet size	0.01	1	0.01	0.462	N.S.
Fo. x Ra.	0.01	2	0.00	0.192	N.S.
Fo. x Dr.	0.02	2	0.01	0.490	N.S.
Ra. x Dr.	0.00	1	0.00	0.009	N.S.
Fo. x Ra. x Dr.	0.04	2	0.02	1.089	N.S.
Contrasts					
Water-based vs Oil-based	0.11	(1)	0.11	6.210	*
SC vs WG	0.00	(1)	0.00	0.000	N.S.
Residual (Error)	0.63	36	0.018		
TOTAL	0.81	47			

Coefficient of Variation = 57.3%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: Kg. per 3 x 3.6m plot				0 0.40
2	Water-based CDA: WG formln. @ < 15 l/ha.	0.20	0.02	0.048	
1	Water-based CDA: SC formln. @ < 15 l/ha.	0.20	0.03	0.076	
3	Oil-based formulations: @ < 1.5 l/ha.	0.30	0.04	0.075	
	Rate of a.i.				0 0.40
1	Approx. 430 g.a.i./ha.	0.24	0.03	0.106	
2	Approx. 215 g.a.i./ha.	0.23	0.02	0.045	
	Droplet size				0 0.40
1	65-70 microns V.A.D.	0.24	0.03	0.110	
2	90-100 microns V.A.D.	0.22	0.02	0.038	

Adjacent trial controls: 0.289 0.073

7.6

Thiodicarb CDA: Chitala, Malawi (1988)

Heliothis eggs: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	1121.37	2	560.69	3.486	*
Rate of a.i.	1564.08	1	1564.08	9.726	**
Droplet size	1121.33	1	1121.33	6.973	*
Fo. x Ra.	615.79	2	307.90	1.915	N.S.
Fo. x Dr.	396.29	2	198.15	1.232	N.S.
Ra. x Dr.	270.75	1	270.75	1.684	N.S.
Fo. x Ra. x Dr.	705.87	2	352.94	2.195	N.S.
Contrasts					
Water-based vs Oil-based	63.37	(1)	63.37	0.394	N.S.
SC vs WG	1058.00	(1)	1058.00	6.579	*
Residual (Error)	5789.50	36	160.819		
TOTAL	11585.00	47			

Coefficient of Variation = 12.5%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{.05}$
Units (untransformed) are: total egg numbers					0 110.00
1	Water-based CDA: SC formln. @ < 15 l/ha.	94.69	3.93	2.606	
2	Water-based CDA: WG formln. @ < 15 l/ha.	106.19	3.74	2.107	
3	Oil-based formulations: @ < 1.5 l/ha.	102.87	3.77	2.207	
	Rate of a.i.				0 110.00
1	Approx. 430 g.a.i./ha.	106.96	2.30	1.191	
2	Approx. 215 g.a.i./ha.	95.54	3.58	3.227	
	Droplet size				0 110.00
1	65-70 microns V.A.D.	106.08	2.84	1.830	
2	90-100 microns V.A.D.	96.42	3.30	2.706	

Adjacent trial: controls 48.3 4.4

Diparopsis eggs: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.06	2	0.03	0.164	N.S.
Rate of a.i.	0.01	1	0.01	0.072	N.S.
Droplet size	0.00	1	0.00	0.007	N.S.
Fo. x Ra.	0.36	2	0.18	1.048	N.S.
Fo. x Dr.	0.04	2	0.02	0.111	N.S.
Ra. x Dr.	0.33	1	0.33	1.955	N.S.
Fo. x Ra. x Dr.	1.15	2	0.57	3.385	*
Contrasts					
Water-based vs Oil-based	0.05	(1)	0.05	0.322	N.S.
SC vs WG	0.00	(1)	0.00	0.005	N.S.
Residual (Error)	6.11	36	0.170		
TOTAL	8.05	47			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 24.0%

	mean	standard error
This trial: all plots	2.60	0.21
Adjacent trial: controls	5.5	1.3

7.7

Thiodicarb CDA: Chitala, Malawi (1988)

Heliothis larvae: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	5.38	2	2.69	0.132	N.S.
Rate of a.i.	33.33	1	33.33	1.640	N.S.
Droplet size	12.00	1	12.00	0.591	N.S.
Fo. x Ra.	18.04	2	9.02	0.444	N.S.
Fo. x Dr.	30.37	2	15.19	0.747	N.S.
Ra. x Dr.	14.08	1	14.08	0.693	N.S.
Fo. x Ra. x Dr.	38.54	2	19.27	0.948	N.S.
Contrasts					
Water-based vs Oil-based	4.59	(1)	4.59	0.226	N.S.
SC vs WG	0.78	(1)	0.78	0.038	N.S.
Residual (Error)	731.50	36	20.319		
TOTAL	883.25	47			

Coefficient of Variation = 50.8%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD$_{95}$
	Units (untransformed) are: total surviving larvae				0 14.00
3	Oil-based formulations: @ < 1.5 l/ha.	8.44	0.74	1.042	
1	Water-based CDA: SC formln. @ < 15 l/ha.	8.94	1.28	2.916	
2	Water-based CDA: WG formln. @ < 15 l/ha.	9.25	1.22	2.559	
	Rate of a.i.				0 14.00
1	Approx. 430 g.a.i./ha.	8.04	0.65	1.249	
2	Approx. 215 g.a.i./ha.	9.71	1.06	2.772	
	Droplet size				0 14.00
1	65-70 microns V.A.D.	8.37	0.83	1.992	
2	90-100 microns V.A.D.	9.38	0.94	2.261	

Adjacent trial: controls 10.8 2.2

7.8

Thiodicarb CDA: Chitala, Malawi (1988)

Diparopsis larvae: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.84	2	0.42	1.157	N.S.
Rate of a.i.	0.03	1	0.03	0.089	N.S.
Droplet size	0.06	1	0.06	0.158	N.S.
Fo. x Ra.	0.63	2	0.32	0.869	N.S.
Fo. x Dr.	0.13	2	0.06	0.174	N.S.
Ra. x Dr.	0.02	1	0.02	0.062	N.S.
Fo. x Ra. x Dr.	0.07	2	0.03	0.090	N.S.
Contrasts					
Water-based vs Oil-based	0.01	(1)	0.01	0.020	N.S.
SC vs WG	0.83	(1)	0.83	2.295	N.S.
Residual (Error)	13.05	36	0.362		
TOTAL	14.82	47			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 36.0%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: total surviving larvae					0 2.00
1	Water-based CDA: SC formln. @ < 15 l/ha.	2.06	0.41	1.323	
3	Oil-based formulations: @ < 1.5 l/ha.	2.56	0.46	1.299	
2	Water-based CDA: WG formln. @ < 15 l/ha.	3.19	0.58	1.682	
	Rate of a.i.				0 2.00
1	Approx. 430 g.a.i./ha.	2.63	0.47	1.981	
2	Approx. 215 g.a.i./ha.	2.58	0.33	1.041	
	Droplet size				0 2.00
1	65-70 microns V.A.D.	2.75	0.44	1.715	
2	90-100 microns V.A.D.	2.46	0.36	1.273	

N.B. Bars represent transformed data

Adjacent trial: controls 6.0 1.7

7.9

Thiodicarb CDA: Chitala, Malawi (1988)

Whitefly adults: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	2032.54	2	1016.27	3.610	*
Rate of a.i.	105.02	1	105.02	0.373	N.S.
Droplet size	165.02	1	165.02	0.586	N.S.
Fo. x Ra.	970.54	2	485.27	1.724	N.S.
Fo. x Dr.	430.04	2	215.02	0.764	N.S.
Ra. x Dr.	1354.69	1	1354.69	4.812	*
Fo. x Ra. x Dr.	375.87	2	187.94	0.668	N.S.
Contrasts					
Water-based vs Oil-based	0.51	(1)	0.51	0.002	N.S.
SC vs WG	2032.03	(1)	2032.03	7.218	*
Residual (Error)	10134.75	36	281.521		
TOTAL	15568.48	47			

Coefficient of Variation = 20.2%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: total insect counts					0 100.00
1	Water-based CDA: SC formln. @ < 15 l/ha.	75.06	3.91	3.264	
3	Oil-based formulations: @ < 1.5 l/ha.	83.25	4.74	4.317	
2	Water-based CDA: WG formln. @ < 15 l/ha.	91.00	4.32	3.275	
	Rate of a.i.				0 100.00
1	Approx. 430 g.a.i./ha.	84.58	3.48	3.442	
2	Approx. 215 g.a.i./ha.	81.62	3.99	4.670	
	Droplet size				0 100.00
1	65-70 microns V.A.D.	81.25	3.96	4.624	
2	90-100 microns V.A.D.	84.96	3.50	3.461	

Adjacent trial: controls 73.0 7.6

7.10

Thiodicarb CDA: Chitala, Malawi (1988)

Psyllid Adults: 13 days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.41	2	0.21	0.835	N.S.
Rate of a.i.	2.42	1	2.42	9.771	**
Droplet size	0.33	1	0.33	1.349	N.S.
Fo. x Ra.	0.60	2	0.30	1.205	N.S.
Fo. x Dr.	0.67	2	0.33	1.344	N.S.
Ra. x Dr.	0.18	1	0.18	0.743	N.S.
Fo. x Ra. x Dr.	0.10	2	0.05	0.193	N.S.
Contrasts					
Water-based vs Oil-based	0.21	(1)	0.21	0.854	N.S.
SC vs WG	0.20	(1)	0.20	0.817	N.S.
Residual (Error)	8.92	36	0.248		
TOTAL	13.63	47			

Data have undergone LOGARITHMIC transformation.
Coefficient of Variation = 19.8%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected $LSD_{5\%}$
Units (untransformed) are: total insect counts					0 3.00
2	Water-based CDA: WG formln. @ < 15 l/ha.	11.06	1.46	3.103	
3	Oil-based formulations: @ < 1.5 l/ha.	14.31	2.17	5.252	
1	Water-based CDA: SC formln. @ < 15 l/ha.	15.19	4.02	17.051	
	Rate of a.i.				0 3.00
1	Approx. 430 g.a.i./ha.	9.71	0.90	1.993	
2	Approx. 215 g.a.i./ha.	17.33	2.87	11.376	
	Droplet size				0 3.00
1	65-70 microns V.A.D.	12.96	2.76	14.156	
2	90-100 microns V.A.D.	14.08	1.62	4.457	

N.B. Bars represent transformed data.

Adjacent trial: controls 16.3 3.8

7.11

Thiodicarb CDA: Chitala, Malawi (1988)

Jassids: 13 scouting days, 12 plants per plot.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Formulations	0.54	2	0.27	0.818	N.S.
Rate of a.i.	0.99	1	0.99	2.982	N.S.
Droplet size	1.06	1	1.06	3.200	N.S.
Fo. x Ra.	0.75	2	0.37	1.127	N.S.
Fo. x Dr.	0.86	2	0.43	1.300	N.S.
Ra. x Dr.	0.06	1	0.06	0.180	N.S.
Fo. x Ra. x Dr.	0.63	2	0.32	0.955	N.S.
Contrasts					
Water-based vs Oil-based	0.08	(1)	0.08	0.244	N.S.
SC vs WG	0.46	(1)	0.46	1.391	N.S.
Residual (Error)	11.93	36	0.331		
TOTAL	16.82	47			

Data have undergone LOGARITHMIC transformation.
Coefficient of Variation = 39.1%

No.	Formulations	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: total insect counts				0 2.00
2	Water-based CDA: WG formln. @ < 15 l/ha.	3.19	0.44	0.971	
3	Oil-based formulations: @ < 1.5 l/ha.	4.50	0.83	2.430	
1	Water-based CDA: SC formln. @ < 15 l/ha.	4.69	0.81	2.239	
	Rate of a.i.				0 2.00
1	Approx. 430 g.a.i./ha.	3.46	0.53	1.961	
2	Approx. 215 g.a.i./ha.	4.79	0.62	1.923	
	Droplet size				0 2.00
1	65-70 microns V.A.D.	4.92	0.67	2.209	
2	90-100 microns V.A.D.	3.33	0.45	1.426	

N.B. Bars represent transformed data.

Adjacent trial: controls 15.8 8.3

IV.B.8.

KASINTHULA

Cotton

Typically 0.9m. spacing between ridges; cotton on bunds.

Factor

Three formulations

i. WULV using 37.5% SC (FW); 2 then 1 row swath;
ii. WULV using 80% WG (DF): as with SC
iii. Oil-based CDA using UCLF5 diluted with Shellsol K 4 then 2 row swath; ULV of 1.0 - 1.4 l/ha.

Dosage rate

Normal Malawian practice: effectively 191 then 382 g.a.i./ha at this spacing.

Design

Four replicates, plots 36 ridges x 30m.
Trial was originally arranged in blocks, but data was analysed as completely randomised design, since cotton was very heterogeneous and plots were not always strictly adjacent to one another.

Treatment details

	Mixing instructions to make up 1 litre all quantities in ml. or g.		Restr-ictor	Batt-ery pack	Expected quantity of mixture for 4 * plots with swaths:		
Trt No.	37.5% SC	Water			l/ha.	2 rows	1 row
1	72	928	1.3	normal	14.1	2741	5482
Trt No.	80% WG (DF)	Water			l/ha.	2 rows	1 row
2	33.75g.	to 1 litre	1.3	normal	14.1	2741	5482
Trt No.	UCLF 5 **	Shellsol K			l/ha.	4 rows	2 rows
3	880	120	1.5	normal	1.24	241	482
4	Untreated control						

*: Row pattern to be changed when crop height reaches 0.5m.
**: Usually pre-mixed before trial day; SHAKE WELL BEFORE USE.

IV.B.8.1

Thiodicarb CDA: Kasinthula (1988)

Analysis of SPRAY LOGS: plants over 0.5m. tall.

Source	Sum of Squares	DF	Mean Squares	F	Significance
Spray Dates	945.26	5	189.05	2.259	N.S.
Treatments	358.85	2	179.42	2.144	N.S.
Contrasts					
Water-based vs Oil-based	228.39	(1)	228.39	2.729	N.S.
SC vs WG	130.45	(1)	130.45	1.559	N.S.
Residual (Error)	836.87	10	83.687		
TOTAL	2140.98	17			

Coefficient of Variation = 9.2%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: % of target volume					0 120.00
3	Oil-based formulation: @ < 1.5 l/ha.	104.25	5.11	1.502	
1	Water-based CDA: SC formln. @ < 16 l/ha.	99.99	2.60	0.405	
2	Water-based CDA: WG formln. @ < 16 l/ha.	93.40	5.15	1.706	

Plant stand

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	46.19	3	15.40	3.041	N.S.
Contrasts					
Water-based vs Oil-based	40.04	(1)	40.04	7.909	*
SC vs WG	0.13	(1)	0.13	0.025	N.S.
Insecticides vs Control	6.02	(1)	6.02	1.189	N.S.
Residual (Error)	60.75	12	5.063		
TOTAL	106.94	15			

Coefficient of Variation = 6.6%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: plants in sample area					0 40.00
3	Oil-based formulation: @ < 1.5 l/ha.	37.00	0.58	0.036	
2	Water-based CDA: WG formln. @ < 16 l/ha.	33.25	1.44	0.248	
1	Water-based CDA: SC formln. @ < 16 l/ha.	33.00	1.08	0.141	
4	Untreated CONTROL.	33.00	1.22	0.182	

8.2

Thiodicarb CDA: Kasinthula (1988)

Total seed cotton yield

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	2.63	3	0.88	4.933	*
Contrasts					
Water-based vs Oil-based	0.58	(1)	0.58	3.283	N.S.
SC vs WG	0.01	(1)	0.01	0.063	N.S.
Insecticides vs Control	2.03	(1)	2.03	11.454	**
Residual (Error)	2.13	12	0.178		
TOTAL	4.76	15			

Coefficient of Variation = 27.4%

Units (untransformed) are: kg. per 3x3m plot

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Treatments LSD =	0.65			0 2.00
3	Oil-based formulation: @ < 1.5 l/ha.	2.05	0.23	0.104	
1	Water-based CDA: SC formln. @ < 16 l/ha.	1.62	0.29	0.203	
2	Water-based CDA: WG formln. @ < 16 l/ha.	1.55	0.12	0.040	
4	Untreated CONTROL.	0.92	0.16	0.115	

8.3

Thiodicarb CDA: Kasinthula (1988)

Clean cotton (total pick)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	2.75	3	0.92	6.151	**
Contrasts					
Water-based vs Oil-based	0.49	(1)	0.49	3.304	N.S.
SC vs WG	0.02	(1)	0.02	0.162	N.S.
Insecticides vs Control	2.24	(1)	2.24	14.985	**
Residual (Error)	1.79	12	0.149		
TOTAL	4.54	15			

Coefficient of Variation = 31.3%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: kg. per 3x3m plot				0 2.00
3	Oil-based formulation: @ < 1.5 l/ha.	1.73	0.20	0.092	
1	Water-based CDA: SC formln. @ < 16 l/ha.	1.36	0.29	0.249	
2	Water-based CDA: WG formln. @ < 16 l/ha.	1.25	0.12	0.050	
4	Untreated CONTROL.	0.58	0.10	0.062	

Damaged cotton (total pick)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	0.01	3	0.00	0.320	N.S.
Contrasts					
Water-based vs Oil-based	0.00	(1)	0.00	0.328	N.S.
SC vs WG	0.00	(1)	0.00	0.214	N.S.
Insecticides vs Control	0.00	(1)	0.00	0.419	N.S.
Residual (Error)	0.14	12	0.011		
TOTAL	0.15	15			

Coefficient of Variation = 35.1%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: kg. per 3x3m plot				0 0.50
1	Water-based CDA: SC formln. @ < 16 l/ha.	0.26	0.03	0.017	
2	Water-based CDA: WG formln. @ < 16 l/ha.	0.30	0.05	0.038	
3	Oil-based formulation: @ < 1.5 l/ha.	0.32	0.05	0.031	
4	Untreated CONTROL.	0.33	0.07	0.059	

8.4

Thiodicarb CDA: Kasinthula (1988)

Earias larvae (accumulated from 7 scouting days)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	33.19	3	11.06	4.462	*
Contrasts					
Water-based vs Oil-based	0.17	(1)	0.17	0.067	N.S.
SC vs WG	4.50	(1)	4.50	1.815	N.S.
Insecticides vs Control	28.52	(1)	28.52	11.504	**
Residual (Error)	29.75	12	2.479		
TOTAL	62.94	15			

Coefficient of Variation = 53.6%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: Surviving lrv./12 plants					5 ... 7.00
1	Water-based CDA: SC formln. @ < 16 l/ha.	1.50	0.65	1.111	
3	Oil-based formulation: @ < 1.5 l/ha.	2.00	0.41	0.333	
2	Water-based CDA: WG formln. @ < 16 l/ha.	3.00	0.82	0.889	
4	Untreated CONTROL.	5.25	1.11	0.937	

Heliothis larvae (accumulated from 7 scouting days)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	9.25	3	3.08	0.368	N.S.
Contrasts					
Water-based vs Oil-based	5.04	(1)	5.04	0.602	N.S.
SC vs WG	0.13	(1)	0.13	0.015	N.S.
Insecticides vs Control	4.08	(1)	4.08	0.488	N.S.
Residual (Error)	100.50	12	8.375		
TOTAL	109.75	15			

Coefficient of Variation = 74.7%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
Units (untransformed) are: Surviving lrv./12 plants					5 ... 10.00
1	Water-based CDA: SC formln. @ < 16 l/ha.	3.00	1.47	2.889	
2	Water-based CDA: WG formln. @ < 16 l/ha.	3.25	0.63	0.487	
3	Oil-based formulation: @ < 1.5 l/ha.	4.50	1.26	1.407	
4	Untreated CONTROL.	4.75	2.06	3.581	

8.5

Thiodicarb CDA: Kasinthula (1988)

Diparopsis larvae (accumulated from 7 scouting days)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	0.46	3	0.15	0.550	N.S.
Contrasts					
Water-based vs Oil-based	0.25	(1)	0.25	0.889	N.S.
SC vs WG	0.20	(1)	0.20	0.703	N.S.
Insecticides vs Control	0.02	(1)	0.02	0.056	N.S.
Residual (Error)	3.37	12	0.281		
TOTAL	3.84	15			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 17.8%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Surviving lrv./12 plants				0 4.00
3	Oil-based formulation: @ < 1.5 l/ha.	7.25	1.11	0.678	
2	Water-based CDA: WG formln. @ < 16 l/ha.	8.25	1.97	1.889	
4	Untreated CONTROL.	9.00	2.04	1.952	
1	Water-based CDA: SC formln. @ < 16 l/ha.	10.00	1.35	0.733	

N.B. Bars represent transformed data.

Whitefly adults (accumulated from 7 scouting days)

Source	Sum of Squares	DF	Mean Squares	F	Significance
Treatments	2.12	3	0.71	2.179	N.S.
Contrasts					
Water-based vs Oil-based	0.02	(1)	0.02	0.063	N.S.
SC vs WG	0.59	(1)	0.59	1.815	N.S.
Insecticides vs Control	1.51	(1)	1.51	4.660	N.S.
Residual (Error)	3.89	12	0.324		
TOTAL	6.01	15			

Data have undergone SQUARE ROOT transformation.
Coefficient of Variation = 41.6%

No.	Treatments	Mean	Std.Error	Var./Mean	Mean & Fisher's protected LSD_{95}
	Units (untransformed) are: Insects/12 plants: 7 days				0 2.00
4	Untreated CONTROL.	0.25	0.25	1.000	
1	Water-based CDA: SC formln. @ < 16 l/ha.	1.50	1.19	3.778	
3	Oil-based formulation: @ < 1.5 l/ha.	2.50	1.26	2.533	
2	Water-based CDA: WG formln. @ < 16 l/ha.	2.75	0.48	0.333	

N.B. Bars represent transformed data

IV.C.1.

PAIRED COMPARISON FARMER TRIALS

INSTRUCTIONS

Aim

To compare the efficacy and acceptability of two thiodicarb (Larvin) formulations: the 37.5% SC (FW) and the 80% WG (DF).

Requirements

Each farmer to be provided with:
1 bottle of 37.5% SC
6 sachets of 80% DF weighed out with 40g. of formulation
Sufficient dimethoate if aphid problems arise.

Ensure he has a properly working Turbair X or XJ spinning disc sprayer.

Locations

A total of five farms in Karonga and six in Rumphi districts.

Plots

Two plots are to be demarcated: each one equivalent to one litre (up to top line of Turbair bottle) of pesticide mixture sprayed onto a maturing crop (>0.5m. tall). With a 0.9m. ridge spacing, and an application volume of, say, 12.5 l./ha. At this volume the caps of the SC containers (measured volume: 84 ml.) and the DF sachets should deliver an equivalent of 400 g.a.i./ha. The plot sizes would therefore be 30m. x 30m.

Scouting and Treatment

Scouting for all major pests to take place on 24 plants in the central 10 x 10m. area of each plot: preferably twice a week - before and after spraying. Should aphids become serious, a blanket spray of dimethoate would be required; otherwise one plot is to be treated with the SC formulation and the other with a full sachet of DF. Crop yields also to be taken from central 10m. x 10m. of plot.

IV.C.2.

QUESTIONNAIRE ASSOCIATED WITH THIODICARB FORMULATIONS PROJECT

- To be filled-in at the end of the trial season.

1. Farmers name:

Village, District:

How many square metres of cotton:

" " " " of other crops (which crops?):

2. Does he use his own sprayer?

If so: when did he buy it:

is it a Turbair X, Turbair XJ, Knapsack, other?

is it working well? (note down any problems:)

Has the farmer had experience of spraying crops before?

if so, how many years:

3. Which chemicals, and formulations of these chemicals, does the farmer use on his cotton and other crops? Indicate how many years they have been used, and how many applications, on average, are made per year:

4. At the end of the season, the farmer will have had experience of Larvin as a solid (DF = Dry Flowable in sachets) and as a liquid (SC = Suspension Concentrate in 1 l. bottle).
Which does he prefer to use and why?

If the DF were slightly cheaper than the SC, would this make any difference to the previous answer?

What did he do (or does he intend to do) with the empty SC bottle?

What does he do with old carbaryl/DDT/Larvin sachets?

IV.C.3

PAIRED COMPARISON FARMER TRIALS: NORTHERN MALAWI, 1988.

NAME OF FARMER	Number of applications	Bollworm Larvae: Dipar. SC	Dipar. WG	Helio. SC	Helio. WG	Yield (kg. in sampling area) Clean SC	Clean WG	Damaged SC	Damaged WG	Total SC	Total WG
MZUZU A.D.D. (Henda Kasitu Valley)											
Loyid Chipeta	7	1	6	15	22	7.4	9.3	.28	.41	7.7	9.7
Morton Singini	6	0	4	11	10	10.6	12.1	3.2	2.9	13.8	15.0
Aliki Nyirenda	5	8	7	12	9	18.7	13.0	.28	.29	19.0	13.3
Kettie Harawa	6	7	10	11	18	12.5	10.9	.25	.11	12.7	11.0
Mai Nyagwonde	11	25	16	14	45	19.0	11.7	0	0	19.0	11.7
Mean >		8.2	8.6	13	21	13.6	11.4	.80	.74	14.4	12.1
S.E. >		4.0	1.9	.73	5.8	2.04	0.56	.54	.49	1.9	.82
t >		0.08		0.58		0.53		0.39		0.55	

Critical value of t @ 5% (4df): 2.132

Applications	SC	WG	SC	WG	SC	WG	SC	WG	SC	WG
KARONGA A.D.D.										
L. Ndovi	6	1	0	8	8	22.5	24.2	.16	.28	22.7	24.5
S. Mwenelupembe	6	1	0	2	2	14.3	18.9	.15	.2	14.5	19.1
F. Mtalama	5	1	0	4	4	10.9	6.7	.50	.84	11.4	7.5
S. Kajumba	6	2	3	13	12	15.6	11.4	.16	.6	15.7	12.0
R. Sichali	5	0	0	0	0	7.4	11.0	.20	.16	7.6	11.1
E. Mwenechilanga	5	2	1	7	11	21.8	19.8	.26	.2	22.1	20.0
Mean >		1.2	0.7	5.7	6.2	15.4	15.3	.24	.38	15.7	15.7
S.E. >		0.3	.45	1.7	1.8	2.2	2.5	.05	.10	2.2	2.4
t >		0.56		0.30		0.02		0.626		0.02	

Critical value of t @ 5% (5df): 2.015

None of the differences between the two formulations are significant.

Mzuzu: all farmers surveyed borrowed sprayers to treat their cotton, and had an average of 3.5 years experience with pesticide usage (an average of 9 applications per season: mostly with carbaryl and DDT wettable powders).

Karonga: farmers had an average of 16 years experience with pesticides, with a mean total of 12 DDT, dimethoate and carbaryl applications per season (all WPs). The typical size of a cotton holding was about 9000m^2. Only one farmer did not possess a sprayer; of the rest, five had hydraulic knapsack equipment, and one had a Turbair X as well.