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DEVELOPMENTS IN SPRAY APPLICATION AT ULTRA-LOW VOLUME RATES

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INTRODUCTION

In a recent paper (Joyce, 1969) the author defined ultra-low volume (ULV) rates as application of sprays at less than 5 l/ha. He drew attention to the need to avoid indentifying this procedure with concentrate spraying which was the form in which the technique was first introduced (Rose, 1961) and with which, moreover, it has unfortunately become confounded in definitions used by the United States Department of Agriculture. The rate of application determines the distribution of the target dose on the target surface, whilst the concentration determines the chemical dosage level. Both parameters are functions of the biology of the pest and both need to be determined experimentally. Because of the exacting nature of the task of distributing very small volumes of liquid over large surfaces ULV spraying demands an analytical approach to pest control problems by which the target and the target dose are rigorously defined so that a study can then be made to determine the most efficient means of achieving this dose in terms of deposit on the target per unit emission (DUE), a term introduced by Courshee (1959).

Such an analytical approach, first applied in the field of pest control by Gunn et al (1948), has been highly successful in the development of methods for controlling pests of primary economic importance, such as locusts, tsetse fly and mosquitoes, but has seldom been employed in regard to general crop pests. Indeed a search through literature reveals very few determinations of LD 50 levels of pesticides to particular insect species (i.e. doses which result in 50% mortality of test insects) and such data as are available usually refer to development of insecticidal resistance. The reasons for this are two-fold; firstly the number of crop pests (insects, fungi and weeds) are legion and relatively few can be maintained even in highly expensive laboratories; secondly crop protection techniques have been dominated by agronomists who are interested in only one measure of the value of a treatment, namely yield. The complex factors which intervene between the application of a treatment and the final measure are of interest to the agronomist only inasmuch as they enable him to increase the ultimate response.

The hazards inevitably generated by the interference with the complex biological relationships existing within a crop by the use of chemicals of increasingly complex biological activity emphasise the need to replace the empirical approach of the agronomist in crop protection by a more rational and thorough study.

If a crop pest is troublesome it is for the entomologist, pathologist or botanist to develop an efficient and economic way of removing this element from the environment in which the plant grows. It is for the plant physiologist to work out how the plant reacts to the new environment and for the agronomist to determine how the plant reaction is reflected in yield. All these facets are implicit in crop protection, but this paper is concerned with one only, namely, the most economic means of removing pests (particularly insect pests) from the plant environment.

It is evident that this approach relieves the entomologist from the constraints imposed by the agronomist's field plot techniques which have dominated the entomologist's experimental method for several decades, nor is this technique always suitable for entomological experimentation because its first requirement, namely the independence of the treatments, is seldom met. This effect was connoted "interplot effect" by Joyce (1956) and investigated experimentally by Joyce and Roberts (1959) in the Sudan Gezira where it was found that "interplot effect" became immeasurable only when plots reached 100 ha (10 acres) in area. Plots of this size are blunt instruments in randomised block techniques.

Interplot effect is exacerbated when sprays are applied at ULV rates, where choice of small droplets whose trajectory contains a large horizontal component is imposed by DUE. For example Bals and Joyce laid out an experiment at the Gezira Research Farm in 1967, in which each plot measured 2.5 ha and observations were confined to the upwind quarter. Sprays were applied to cotton by a battery operated spinning disc and by knapsack sprayers. Control of jassids, whitefly, thrips and fleabeetle was excellent in all treatments including the unsprayed control.

The object of this paper is to outline experimental methods which overcome difficulties implicit in convenional field-plot techniques, and which are at once more economic and more rewarding.

THE EVALUATION OF ULV FORMULATIONS

The analytical approach by definition does not permit "spraying" in general, but spraying directed against a particular target. When this is an insect, speedy evaluation of formulations may be made by determination of LD 50 values by topical application, using the type of micro-burette described by MacCuaig (1962). In fact the desert locust represents a notable example of this approach. Employing the concept "Toxicity Coefficient" defined by MacCuaig (1958) as half the number of LD 50 doses contained in 1 litre (or 1 gallon) of formulation (i.e. the number of locusts which could be killed) a direct means of comparison was available which could be expressed as the relative cost per toxic dose. Moreover, the efficiency of an operation could be described in terms of the proportion of toxic doses applied which could be accounted for by locust corpses (Rainey R.C. 1958). For recent work in Basle on the LD 50 level of ULV formulations a micro-drop applicator suitable for topical application has been devised and this can also be used for contaminating a surface with a pre-determined dose expressed as droplets per unit area (Sayer, unpublished). Using such a technique Singh (unpublished) was able to determine the contamination of rice leaves needed to obtain 50% mortality amongst recently hatched
1 larvae of <u>Chilo suppressalis</u> Walker (Lepidoptera : Pyralidae), a parameter upon which the subsequent development of an ULV spraying technique for control of rice stemborers was based.

The LD 50 measures the lethal dose, whilst a summation of lethal doses constitutes the "Target Dose" whose level is a function of the half-life of the pesticide on (or in) the plant, and the optimum duration of the interval between successive sprays (determined by factors such as plant growth and operational considerations).

For most field pest problems, however, a more direct approach to the determination of the level of the target dose is needed, and attention has been directed towards devising a simple field bio-assay technique, by which mortality of the pest concerned may be related to the insecticide dose to which it is exposed.

A model of such an experiment was executed by Meier et al (1968) in two trials in which various formulations were applied through a "Turbair-CIBA" spinning disc sprayer for the control of the Colorado Beetle on potatoes in Alsace.

In the first trial mortality was a function of the number of droplets applied (i.e. volume rate of application) rather than the amount of active ingredient applied. The best control (almost 100%) was achieved with "Dimecron 20" at 1200 ml/ha, giving an application rate of 240 g/ha of phosphamidon. The poorest result (erratic control) was from "Dimecron 100" at 650 g/ha of phosphamidon. The results may have been influenced by the rain which fell after spraying.

In the second trial 240 g of chlorfenvinphos was applied in 1200 ml/ha of "Sapecron 20". The control achieved (based on random sampling) was 94% and 100% after 24 and 72 hours respectively.

Samples of heavily infested plants were selected at random in the second trial and an estimate of the level of spray deposit was obtained by counting the droplets on encapsulated ink papers attached to labels or attached directly to the leaves. The mean deposit on papers attached to plant leaves was 2 $\mu g/cm^2$. It was possible to infer from these results that the LD 50 dose on papers attached to leaves was 1.2 $\mu g/cm^2$, a dosage amply exceeded by an application rate of 240 g of active ingredient in 1200 ml/ha.

Figure 1 shows the dosage mortality relation achieved by spraying a single drop, whilst Figure 2 provides a measure of the relationship between the spray deposit recorded on papers attached to labels in the vicinity of infested plants and on papers attached to infested leaves.

Bearing in mind the fact that whatever method of application is employed there will be a considerable variation in the amount of spray collected by different target surfaces, it is evident that a single swath produced in "Drift Spraying" (now termed, more correctly, Directional Aerial Dispersal) will contain all dosage levels necessary to establish LD 50 levels of deposits on plant surfaces. In fact the deposition of droplets on the target surface is likely to approximate to a Poisson random distribution, and be determined by two sets of probabilities, namely:

P_1 - that at least c droplets will be deposited on a unit area A when the mean number of droplets depositing is a_1

P_2 - that the droplets depositing have a certain diameter D and a_2 is the mean number of such droplets depositing on surface A.

On this basis Sayer (unpublished) has calculated the following probable deposits on plane horizontal surfaces from an application of 2 litres of spray per hectare using the "Turbair-CIBA" sprayer.

probability of at least 300 mm^3/m^2 (0.03 $\mu l/cm^2$)	P = 0.02
probability of at least 200 mm^3/m^2	P = 0.54
probability of at least 100 mm^3/m^2	P = 0.996

Variations in the field from these calculated values can be expected to derive from such factors as angle of approach of the droplets as functions of wind velocity, plant geometry, and attenuation of the spray cloud by deposition and collection.

It may be added at this stage that the approximately Poisson distribution expected from a single swath becomes approximately a normal distribution when surfaces are exposed to successive swaths due to incremental effects. Thus Sayer (unpublished) using the spinning disc for spraying cotton in the Sudan Gezira found that the DUE (1 ml/min) measured as phosphamidon per cm^2 of filter paper placed on plants across the swath was 0.83 $\mu g/cm^2$ $\pm$0.04 and a coefficient of variation of 13%.

Figure 1

Dose/mortality relationship for insecticide on Colorado Beetles

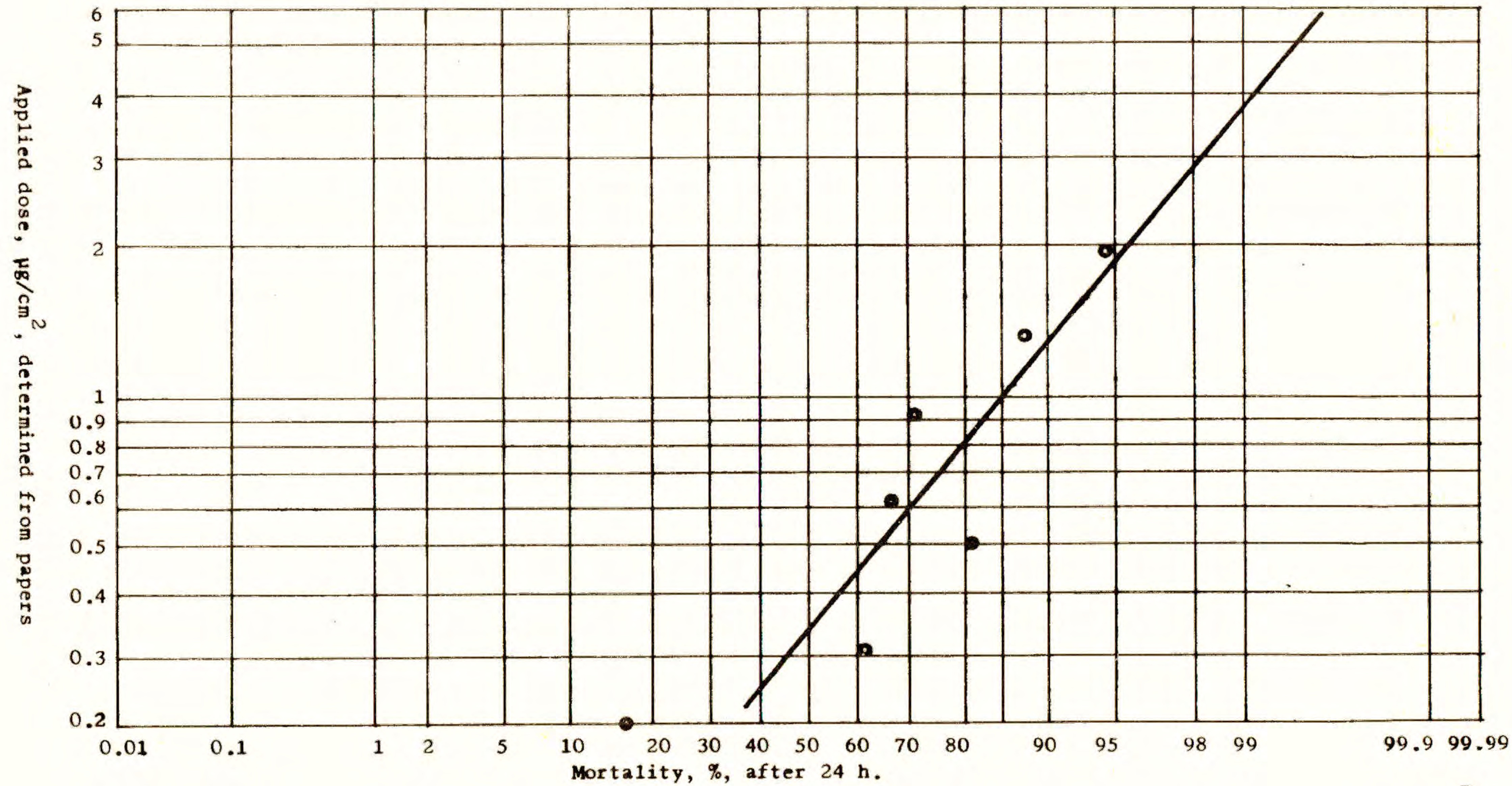
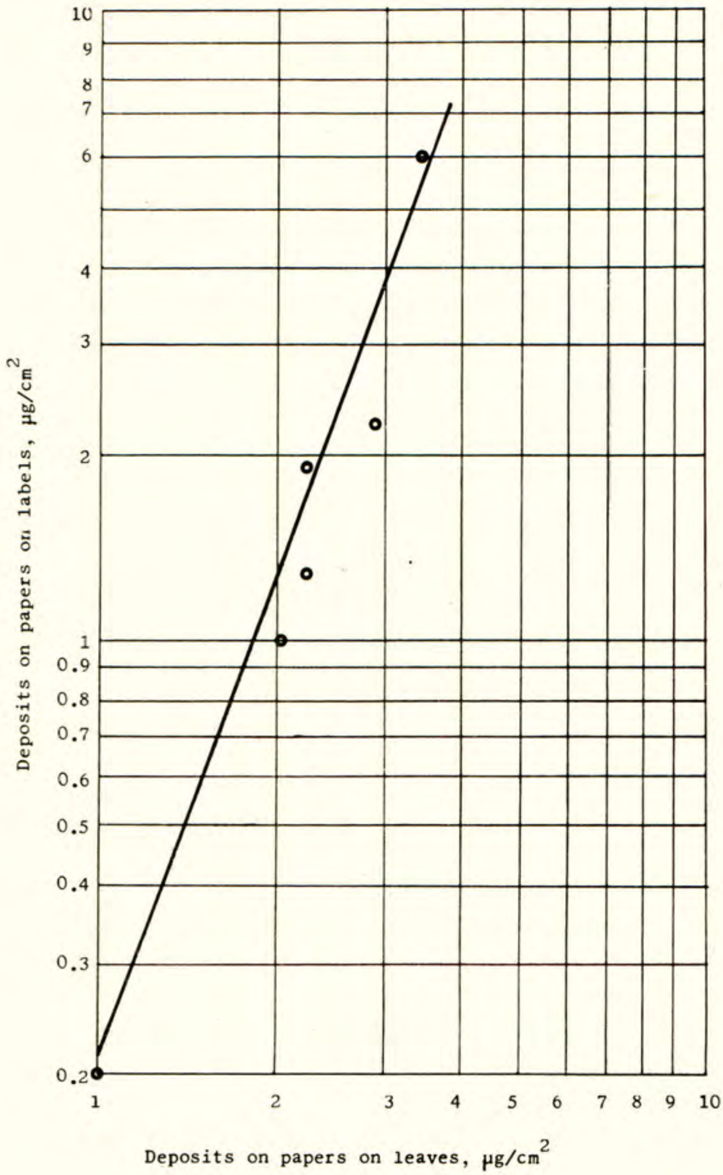


Figure 2

The relationship between deposits on papers attached to labels and papers on leaves of infested potato plants



The major problem in this technique is a practical field method of determining the level of contamination of the infested targets. The only completely satisfactory method for determining dosage levels achieved is by chemical analysis, and a suitable technique for organo-phosphorus compounds using blood cholinesterase inhibition was worked out by Voss and Sayer (unpublished). Chemical determination of dose, however, ignores distribution which can be best determined on target surfaces by using fluorescent dyes. Moreover, the use of fluorescent dyes has been shown by Himel (1969) to provide an elegant method of determining the size, distribution and number of droplets collected by target surfaces. Practical field bio-assay techniques are therefore becoming available, and these are, moreover, ones which are suitable for determining LD 50 levels for direct contact as well as residual deposits and systemic routes of entry.

In such field bio-assay experiments, designed primarily to determine LD 50 levels, additional information can be collected of value to the experimenter by recognition of the fact that the deposit on one surface influences the deposit on all other surfaces, due to attenuation of the spray cloud. This fact calls for multi-factorial analysis of the field data and a layout adopted accordingly. The requirements for such an analysis, as well as models, have been studied by Joyce (1962) and Davies (unpublished) in Eastern Africa and by Mullen (unpublished) at Basle. There is no reason why such layouts and techniques which involve a large number of small plots of 2 - 4 m^2 in size in a single plot should not be extended to include observations on plant growth and yield which are subsequently related to the primary treatment, namely, dose per unit area of target surface.

Such experiments do not need an experimental farm.

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APPLE PEST AND DISEASE CONTROL BY ULV SPRAYING

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Summary In preliminary trials, ultra-low volumes (0.2 - 2 gal/acre, 2.2 - 22 l./ha) of malathion, both undiluted (95% a.i.) and diluted with oil (5% a.i.) gave good control of apple aphids, Rhopalosiphum insertum, and apple sucker, Psylla mali, when applied to small Cox trees by a hand-held, fan-assisted disc sprayer and by an experimental tractor-mounted mist-blower. Similar applications to large heavily-infested Cheddar Cross trees were less effective, and insect control with 0.5% malathion in oil was poor.

In laboratory tests with apple seedlings, mildew, Podosphaera leucotricha, was controlled by ULV application of fungicides in oil, but in the field repeated applications of the same materials at 4 gal/acre (45 l./ha) failed to control the disease.

INTRODUCTION

Ultra-low volume (ULV) spraying can be defined as crop protection operations in which the total volume of liquid applied amounts to a few pints/acre (l./ha), in contrast to the use of large volumes, tens or hundreds of gal/acre (hundreds or thousands of l./ha) in conventional spraying. The chemical is usually either undiluted or formulated in oil and ULV applications have so far been made mainly in aircraft spraying where the small volumes and the less volatile liquids offer obvious operational advantages.

The recent inroduction of the hand-held spinning disc sprayer, employing a droplet generating and dispersing system similar to that used on some aircraft, has revived interest in the ULV technique for ground application, as also has the use of modified motorised knapsack sprayers.

In commercial fruit, particularly apple which requires 10 - 15 sprayings per season to control a large number of pests and diseases, the spraying technique, in addition to giving effective control must also be fast (at least 3 - 4 acre/h, 1 - 1.5 ha/h) and must therefore be applicable on a large scale by tractor-mounted equipment.

The present paper describes preliminary trials of ULV spraying of apple trees for control of apple aphids, apple sucker and apple mildew using a large, experimental tractor-mounted mist-blower and a small hand-directed spinning disc sprayer. Control of mildew with oil-based fungicides applied in ULV under laboratory conditions was also examined.

MATERIALS AND METHODS. TRIAL 1 MALATHION

A trial of ULV was carried out on apple in 1969 for the control of apple-grass aphid, Rhopalosiphum insertum, and apple sucker, Psylla mali, at the green cluster-pink bud stage. The materials were:

95 % technical malathion, undiluted)
5 % technical malathion, in oil) applied once by the ULV technique (2 methods)
0.5% technical malathion, in oil)
0.125% malathion emulsion in water - applied once by conventional large volume spraying. 250 gal/acre (2800 l./ha)

The two methods of ULV spraying were:

(a) the spinning disc sprayer, hand-directed at each quarter of each tree for 7.5 second (= 30 ml/tree or approximately 2 gal of oil-based malathion/acre)

(b) a hydraulically-driven mist-blower delivering 30,000 ft^3/min ($140m^3$/s), specially fitted for ULV spraying to apply up to 2 gal/acre at $2\frac{1}{2}$ mile/h (20 l./ha at 4 km/h) with the 38 in. (0.97 m) axial flow fan directed at 50^o to one side of each tree row at each pass.

The trees used for the trial were 17-year old Cox's Orange Pippin and Cheddar Cross planted at 15 ft x 9 ft (4.6 x 2.7 m). The Cox's were 3 m high, and the much denser Cheddar Cross 3 - 4.5 m high.

Four- and five-tree plots of each variety were used for the hand directed applications of each material. The mist-blower applications were done on 24-tree plots of Cheddar Cross and were repeated on 48-tree plots of Cox's Orange Pippin.

Shoots on which almost all the blossom was infested with aphid and sucker were labelled on each plot before spraying. Spraying dates were:

Spinning disc sprayer : 22 April (late green cluster)
Hydraulically driven mist-blower : 5 May (early pink bud)

The effects of the treatments on insect control were determined by recording the % number of flower trusses remaining infested a few days after spraying. Levels of malathion deposited on the targets by the different treatments were determined by gas chromatography.

RESULTS

Effects of the treatments on insect control are shown in Table 1.

Infestations by both aphid and sucker were heavier on Cheddar Cross than on Cox. On the latter variety, all the ULV treatments with 95% and 5% malathion gave virtually complete control, but both spinning disc sprayer and mist-blower applications of 0.5% malathion failed to do so, although some dead aphids were found with live ones on the blossom trusses, and the hand-held disc sprayer was better than the mist-blower. On the larger and more heavily infested Cheddar Cross the insect control was less complete than on Cox.

Levels of malathion deposits are expressed in Table 2 as μg/cm^2 of rosette leaves and as μg/blossom cluster.

As expected, more malathion was found on the trusses sprayed with 95% material than the 5%, although not in proportion to the concentration or to the dose/acre. The amounts of 5% malathion deposited by the two methods were of the same order but the hydraulic blower deposited more 95% malathion than did the disc sprayer.

Table 1

Insect control with ULV spraying

Malathion oz/acre (g/ha)	Method and Malathion concentration	gal/acre (l./ha)	Variety	% clusters remaining infested with Aphid	% clusters remaining infested with Sucker
	Unsprayed	-	Cox's Orange Pippin	22.0	21.0
			Cheddar Cross	56.0	41.6
60 (4200)	95% with mist-blower	0.4 (4.5)	Cox's Orange Pippin	0.2	0.6
			Cheddar Cross	6.6	17.5
30 (2100)	95% with disc sprayer	0.2 (2.2)	Cox's Orange Pippin	0.0	0.0
			Cheddar Cross	22.2	15.0
12 (840)	5% with mist-blower	1.5 (16.8)	Cox's Orange Pippin	1.2	0.4
			Cheddar Cross	11.0	22.6
16 (1120)	5% with disc sprayer	2.0 (22.5)	Cox's Orange Pippin	0.0	0.0
			Cheddar Cross	10.0	10.0
	Unsprayed	-	Cox's Orange Pippin	56.0	-
1.2 (84)	0.5% with mist-blower	1.5 (16.8)	Cox's Orange Pippin	42.5	-
1.6 (112)	0.5% with disc sprayer	2.0 (22.5)	Cox's Orange Pippin	9.5	-
50 (3500)	0.125% with high volume automatic sprayer	250 (2300)	Cox's Orange Pippin	1.1	-

Table 2

ULV malathion deposits on apple (Cox's)

Method and Malathion Concentration	Range of mean deposits	
	Rosette leaves µg/cm^2	Blossom clusters µg/cluster
95% with mist-blower	5 - 10	150 - 500
95% with disc sprayer	3 - 5	30 - 130
5% with mist-blower	0.5 - 0.8	8 - 33
5% with disc sprayer	0.6 - 1.0	9 - 17

DISCUSSION

Although insect control was poor on the larger, heavily infested trees the preliminary trial has demonstrated the feasability of the ULV technique on a practical scale. The tractor-mounted machine was spraying at the rate of 4 acre/h (1.5 ha/h) single-sided, while the rate with the disc sprayer, as used in the trial, was less than $\frac{1}{3}$ acre/h (0.1 ha/h).

The indications are that at the low rates of application the initial cover of the target was incomplete and that control depended on the mode of action of the spray deposit of the concentrated material. Although this effect was apparent when the malathion concentration was increased from 0.5 - 5% in oil, no better control was obtained when it was increased to 95%.

The lowest effective quantity of malathion used was 12 oz/acre (840 g/ha), 0.25 of the dose of active chemical and 0.006 of the volume applied by the conventional high volume method.

MATERIALS AND METHODS. TRIAL 2 FUNGICIDES

The same tractor-mounted and hand-operated sprayers were used in a trial of ULV application of two fungicides for control of apple mildew, Podosphaera leucotricha. The oil-formulated fungicides were dinocap (0.2% a.i.) and an experimental substituted dinitrophenol, W1263 (0.1% a.i.).

Each fungicide was applied by mist-blower to 14-tree blocks of heavily-infested Cheddar Cross and Cox's trees. Blocks of four trees were used for similar treatments with the disc sprayer. The trees were sprayed five times from petal fall at intervals of 7 - 15 days.

Each material was applied once by compressed air atomizing nozzle to potted apple seedlings of the variety Tremlett's Bitter in the laboratory. The seedlings were then dusted once in a spore dusting tower and the control of mildew assessed by counting the lesions. Six replicates were used for each ULV treatment and the results were compared with those obtained on seedlings dipped in the water-based materials.

Results obtained in the field and laboratory, expressed as % reduction of mildew from the level obtained on untreated plants, are given in Table 3.

Table 3

Mildew control with ULV spraying

Method	Material	a.i.	% reduction of mildew: Cheddar Cross	% reduction of mildew: Cox
Mist blower ULV	Dinocap	0.2 %	0	0
	W1263	0.1 %	9	0
Disc sprayer ULV	Dinocap	0.2 %	27	10
	W1263	0.1 %	28	0

Method	Material	a.i.	Tremlett's Bitter
Laboratory Sprayer ULV	Dinocap	0.2 %	92
		0.1 %	80
		0.05 %	79
	W1263	0.1 %	93
		0.05 %	82
		0.025 %	66
		0.0125%	66
	Oil only	-	34
Seedlings Dipped	Dinocap	160 ppm	95
		80 ppm	91
		40 ppm	92
		20 ppm	96
	W1263	80 ppm	98
		40 ppm	96
		20 ppm	97
		10 ppm	96

The ULV applications failed to control mildew in the field but in the laboratory ULV applications of the same materials gave nearly equal control to that on seedlings dipped in the dilute water-based fungicides, though lower concentrations of the oil-based materials were less effective. Amounts of the oil-based materials deposited on unit area of leaf surface in laboratory and field were similar.

DISCUSSION

The very marked difference between laboratory and field results may be attributed to the different conditions; better cover and distribution of the fungicides on a few unobstructed leaves, followed by a single dusting of spores under laboratory conditions compared with the rigorous field conditions of weathering of deposits and expanding foliage subjected to repeated spore loads.

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