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EFFECT OF CHANGING DROPLET TRAJECTORY ON COLLECTION EFFICIENCY

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ABSTRACT

Uneven distribution of spray on the target results from a number of factors many of which cannot be controlled, for example, meteorological, target orientation and surface structure. Tests have shown that it is possible to improve uniformity of distribution in a static situation by ensuring correct boom height and operating pressure by using selected nozzles under prescribed conditions. Also nozzles with fan angles of 110° are preferred to 80° nozzles as they give less variability at boom heights less than 40 cm. At pressures of 100 kPa it has been shown that very variable lateral spray distribution occurs. However, variability of distribution in the field, even with an optimum nozzle arrangement, is still much larger than that in the static situation. It was thought that some of the variability due to boom instability may be reduced by redirecting the spray sheet either into or away from the direction of travel. Tests to determine whether spray sheet direction at varying angles (45-90°) from the vertical in each direction influenced uniformity of distribution showed that whilst changes in spray sheet direction generally increase variability of deposit they lead to increased spray capture particularly by vertically growing plants. Retention on the weed Wimmera ryegrass (*Lolium rigidum*) was consistently 3 to 10 times greater than wheat and that cultivars of wheat and to a lesser extent barley, show differential retention. The relevance of the results to practical spray operations and future research are discussed.

INTRODUCTION

Over the past three years, application research for crop spraying in Victoria has been aimed at reducing water volumes to 25 to 30 ℓ/ha and herbicide dose rates by 12.5 to 15% without an increase in either operator or environmental hazard (Combellack 1984). To achieve these aims three areas were considered, sprayer design, nozzle performance and collection efficiency.

With respect to sprayer design, changes to the sprayer have been suggested to ensure better boom stability. These include pivoting axles on the chassis (Combellack *et al.* 1982) and improved boom suspension systems (Nation 1980). To reduce operator contamination during filling, the use of herbicide transfer systems have been encouraged. During spraying the use of enclosed cabs and solenoid switches, to eliminate live spray lines into the cab, have been recommended (Combellack *et al.* 1982). Dye or foam marking systems have been suggested to reduce inaccurate spray placement.

Efficiency of boom spraying can also be increased by selecting suitable nozzles and their operating parameters. Nozzles with flow rates ranging from 0.35 to 0.60 ℓ/min at 300 kPa, are necessary to achieve the lower volumes required. To achieve these aims they must have optimum droplet spectra, even lateral distribution and low wear rates (Combellack 1984). Whilst Rice (1980); Fabre *et al.* (1979) and Porskamp (1980) have shown that the correct operating height and pressure are necessary to produce even distribution, they only examined high flow rate (>1.0 ℓ/min) nozzles. There was therefore a need for similar data on low flow rate nozzles.

It has been postulated that the problem of boom instability and collection efficiency can partly be overcome by changing the orientation of the spray sheet. If it is projected horizontally then the effect of vertical, and to some extent horizontal boom movement would be reduced. Furthermore as droplet trajectory (Lake 1977) and velocity at impact (Taylor & Shaw 1983) have been shown to influence collection efficiency and as both of these parameters are affected by sheet orientation, its effect on spray capture was examined. Also, as changing collection efficiency can influence crop tolerance, the retention of spray solution on wheat and barley varieties was measured.

EXPERIMENTAL

Effect of pressure and operating height on nozzle performance

To test any given nozzle size from a manufacturer four randomly selected nozzles were set up on a boom 50 cm apart, with the spray sheet vertical to the ground but offset 10° to the spray boom. Lateral distribution of water from the nozzles was measured using a patternator with 30 mm channels. A description of the patternator and its performance in relation to the International Standard ISO 5682/1 and use have been reported elsewhere (Richardson *et al.* 1984). Lateral distribution of the liquid was calculated as coefficient of variation (C.V.). To assess the optimum operating parameters for nozzles, the C.V. at heights varying from 30 to 70 cm were determined at an operating pressure of 300 kPa. Though the lowest C.V. was usually found between these heights there were exceptions (Table 1(a)). It was noted that individual nozzles that produced a trapezoidal distribution pattern generally gave lower C.V.'s and optimized their C.V. at lower heights than nozzles that produced a triangular pattern. The effect of varying pressure, from 100 to 500 kPa on C.V. was then assessed by operating the nozzles at their optimum boom height. The results, (Table 1(b)) show that at the lowest pressure (100 kPa) all nozzles gave their worst distribution. Also with the A80° nozzles, increasing pressure lowered the C.V. whilst with the B80° nozzles it was raised with pressures over 400 kPa. These results clearly show the variability between nozzles from two manufacturers and how it is affected by both pressure and boom height.

TABLE 1(a)

Effect of pressure and nozzle height on the co-efficient of distribution of flat fan nozzles from two manufacturers with two spray angles.

C.V.% at 300 kPa pressure

Height (cm)	A80	B80	A110	B110
30	44.8	35.0	20.6	15.6
40	21.7	10.8	12.6	16.1
50	10.6	10.3	11.3	11.6
60	15.9	9.0	8.4	13.1
70	26.8	8.0	8.0	14.8

TABLE 1(b)

Effect of pressure and nozzle height on the co-efficient of distribution of flat fan nozzles from two manufacturers with two spray angles.

C.V.% at varying pressure

Pressure kPa	A80	B80	A110	B110
	Nozzle height cm (based on lowest C.V. Table 1(a))			
	50	70	70	50
100	50.0	22.0	29.2	26.4
200	15.1	5.6	8.9	14.0
300	10.6	8.0	8.0	11.6
400	9.4	14.2	7.1	11.0
500	8.4	14.0	9.6	11.1

Nozzles used

A80 = Lurmark 80-015 Acetal Plastic: A110 = Lurmark 110-02 Acetal Plastic.
B80 = Spraying Systems 80015 Brass: B110 = Spraying Systems 110015 Brass.

Effect of spray sheet orientation on spray collection

Wheat (cv. Olympic), Wimmera ryegrass (*Lolium rigidum*) and radish (*Raphanus sativus* cv. fireball) were grown individually in a commercial peatmoss and nutrient mixture (Jiffy-7). After emergence the plants were moved from the glasshouse to a shade house. When the wheat, ryegrass and radish had reached the 3-4, 2-3 and 4 leaf stages respectively, four plants of each were arranged in a 34.5 x 28.0 cm tray for spraying. Collection of spray on plant surfaces was measured using a fluorescent tracer technique developed by C.R. Merritt, W.R.O. (Richardson 1984). The plants were sprayed with a 0.01% fluoresceine and 2.0% Ulvapron (an emulsifiable paraffinic petroleum oil) using a laboratory sprayer with two Spraying Systems 80015 brass nozzles operating at 0.574 ℓ/min per nozzle at 240 kPa. The trays were passed beneath the nozzles on a conveyor at a speed of 5.36 km/h giving an effective spray volume of 117 ℓ/ha. The nozzles were operated at a height of 45 cm for vertical down, 32 cm for forward and back 45° and 25 cm for forward and back 90°. The 32 cm spraying height gave the same degree of overlap where the spray intercepted the crop canopy as for vertical nozzles. After spraying, each plant was cut at ground level and washed with 30 ml of 0.005 M NaOH solution to remove the fluoresceine for determination by fluorimetry. Leaf area was measured using an electronic planimeter.

A summary of the results are presented in Table 2. It was found that directing the spray sheet forward, i.e. with the plants moving into the spray sheet, significantly (P=0.05) increased spray capture by the three species. The 45° forward treatment gave the highest differential deposit between wheat and ryegrass. The only significant increase in capture from the spray sheet back treatment was for the 90° on wheat (P=0.05). It will be noted that the collection on wheat was approximately 10 times less than that on ryegrass while radish collected approximately 5 times less spray solution than ryegrass.

TABLE 2

Effect of nozzle orientation (angled to the normal vertical down arrangement) on spray collection on wheat, Wimmera ryegrass and radish. Each result is the mean of eight replicates

Treatment Nozzle Directions	Mean Deposit μℓ/cm²		
	Wheat	Ryegrass	Radish
Vertical down	0.423	1.649	1.197
Back 90°	0.647	1.793	1.082
Forward 90°	0.875	3.323	1.835
Forward 45°	0.679	4.719	1.454
Back 45°	0.461	1.519	0.924
LSD (P=0.05)	0.163	1.748	0.334

Spray collection by wheat and barley varieties

Wheat and barley were grown and sprayed as described above when they were at the three leaf growth stage. The experiment was repeated at time 2. These show (Table 3) that whilst there is no significant (P=0.05) difference in the collection between the barley varieties at time 1 there are at time 2. However with wheat there are significant differences at both times, in particular the variety Cook captured 97% and 93% more at times 1 and 2 respectively than did the variety Durati. Also wheat captured approximately twice as much spray per unit leaf area than barley at both times of spraying, and the spray capture at both times of application was similar for most varieties of both wheat and barley.

TABLE 3

Spray collected on varieties of barley

Variety	Mean Deposit μℓ/cm²	
	28.3.83	9.5.83
Corvette	0.270	0.275
Grimmet	0.372	0.307
Shannon	0.367	0.331
Galleon	0.323	0.372
Clipper	0.332	0.389
Stirling	0.335	0.305
Bandulla	0.323	0.382
Cutter	0.347	0.382
Beecher	0.370	0.329
Parwan	0.319	0.358
Mean	0.699	0.640
LSD P=0.05	0.1615	0.0600

(continued)

TABLE 3 (continued)

Spray collected on varieties of wheat

Variety	Mean Deposit μℓ/cm²	
	28.3.83	9.5.83
Olympic	0.677	0.726
Cook	0.946	0.963
Egret	0.681	0.563
Shortim	0.713	0.657
Harrier	0.762	0.604
Durati	0.478	0.500
M2386	0.693	0.584
DK2139	0.826	0.650
Sunkota	0.581	0.538
Sun 41A	0.629	0.616
Mean	0.699	0.640
LSD P=0.05	0.1615	0.0600

DISCUSSION

The results of the nozzle tests reported here and elsewhere (Combellack *et al.* 1982; Combellack & Andrew 1984; Combellack 1984) clearly confirm the importance of boom height on spray distribution in a static situation. They also show that it is not possible to generalize on the optimum operating height for any given nozzle as this appears to vary from manufacturer to manufacturer and between nozzle angles. These results, and others (Combellack 1984) show that 110° nozzles give less variability at boom heights less than 40 cm than do 80° nozzles and they are thus recommended for unstable booms. Also, at a pressure of 100 kPa the C.V. is much higher when compared with other pressures tested in the range 100-500 kPa. Whilst this is in agreement with the data of Wills and Combellack (1984) it is in conflict with the data presented by Faber *et al.* (1979) who found that the C.V. did not vary greatly over the pressure range used (100-320 kPa). The flow rates for the latter nozzles was 1.17 whilst for those reported here and by Wills & Combellack (1984) it ranged from 0.59 to 0.72 ℓ/min at 300 kPa which indicates that high flow rate nozzles may be less susceptible to pressure change. In the Australian context the higher C.V. at pressures under 200 kPa with low flow rate nozzles is of concern as many of the ground driven metered sprayers operate at such pressures (Wills and Combellack 1984).

The variation in collection efficiency between wheat and barley may explain in part the reasons for the differences in crop tolerance to certain herbicides (Lemerle *et al.* 1984, in press). Further, the large increase in capture by some varieties of wheat may also predispose them to increased phytotoxicity. It should also be pointed out that other work (Richardson, personal communication) has shown that by increasing the small droplet component (<100 μm) from 8.1 to 28.3% increased the spray capture by wheat by 238%. From this data it can be postulated that crop tolerance may be more related to spray capture than to inherent genetic resistance. If this is the case then assessment of tolerance of new varieties to herbicides can be more easily and quickly assessed during capture assessments. Work is underway at present in Australia to evaluate this hypothesis.

The potential advantage of changing sheet orientation and thus resultant velocity and trajectory of droplets at the instant of impaction, is shown by the results presented. It is realized that because the boom was stationary, and the plants moved, that these results cannot be directly related to the field situation. However they do show that considerable increases in spray capture are possible. Indeed, other work in the field has shown that directing the sheet parallel to the ground and away from the direction of travel leads to a 0-112% increase spray capture but at the expense of uniformity of distribution (Richardson, personal communication). In some of his experiments increases of up to 300% in capture have been measured where air turbulence has been accidentally created. It is thus obvious that this avenue of research offers considerable potential advantage.

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THE EFFECT OF NOZZLE TYPE AND 2,4-D CONCENTRATION ON SPRAY COLLECTION BY WHEAT AND WEEDS

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ABSTRACT

There is a trend in Australia to reduce the volume of herbicide spray application in wheat from 100 ℓ/ha to 25-30 ℓ/ha. The consequences of increasing the concentration of the spray on spray collection by both crop and weeds are not known. This paper describes experiments which were designed to determine the effect that change of concentration of 2,4-D amine and ester, may have on their performance and safety to the crop. The concentrations tested equated to changes in volume rates from 100 to 10 ℓ/ha. In particular, the influence of increasing herbicide concentration on lateral spray distribution, and its collection on plants and droplet spectra of three nozzles types were measured.

The results show that 2,4-D ester increased the variability of spray across the swath more than 2,4-D amine. As the concentration of both the amine or ester increased, the volume of droplets with diameters >300 µm generally decreased. Measurements of spray collection on plants, wheat (*Triticum aestivum* cv. Olympic), Wimmera ryegrass (*Lolium rigidum*) and radish (*Raphanus sativus* cv. fireball) were made using a fluorescent tracer technique. The addition of 2,4-D to the spray solution did not consistently alter collection of spray on radish, however with wheat and ryegrass more spray was collected. Increasing concentration of 2,4-D amine consistently increased spray collection by wheat. Concentration of 2,4-D ester consistently increased the capture of spray by wheat with one of the three nozzles used. Capture of spray by radish and ryegrass was not consistently affected by concentration.

These results indicate that reducing spray volumes to 10 ℓ/ha when using 2,4-D amine may predispose the crop to increased risk of herbicidal damage.

INTRODUCTION

With broad acre spraying of pesticides, as with all farm operations, there is a need to make the operation more efficient. One means of achieving this objective is to reduce the volume of spray applied for a given area, minimizing the time spent filling and ferrying the spray unit. As smaller machines may be used, soil compaction would be reduced.

The volume of spray applied to a given area can be reduced by one or more of the following: travelling at a faster speed, by changing the nozzle size, by reducing the pressure and by increasing nozzle spacing and height. Reducing volume rates necessitates an increase in herbicide concentration. This may alter the amount of spray captured by plants, or influence the distribution of the spray across the swath. The experiments described here were conducted to examine the effects of increasing concentration of the herbicides 2,4-D amine and 2,4-D ester, on the spraying operation. Ester and amine forms of 2,4-dichlorophenoxyacetic acid (2,4-D) were selected because they are the most commonly used herbicides for broad acre spraying in Australia. The effect of concentration on the efficiency of plants to collect spray from three different nozzle sizes, also its effect on distribution across the swath, and on droplet spectra were measured.

At lower volume spraying (50 ℓ/ha) there is an increase in small droplet component (<100 μm) of the spray increasing the likelihood of spray drift (Combellack 1984). The selection of nozzles, and their droplet spectra will be of major importance in efficient spraying in the field.

MATERIALS AND METHODS

The trials were carried out using 2,4-D iso-octyl ester (400 g/ℓ)(1) and 2,4-D dimethylamine salt (500 g/ℓ)(2). The range of concentrations used was from 0.6% wt/vol a.i. to 6.0% wt/vol which is equivalent to volume rates of 100 ℓ/ha to 10 ℓ/ha, however application volume rates were kept the same in these experiments to eliminate volume effects. All the spray solutions had 0.01% wt/vol fluoresciene added as a water soluble tracer. The surface tension of each solution was measured with a Torsion balance(3).

The nozzles used were brass flat fan Spraying Systems 8001LP, 8001 and 800067. They were selected on the basis that they were either in common use, or were likely to be in common use, for broad acre low volume spraying. Pairs of nozzles were spaced 50 cm apart on a boom and matched to give a static measurement of lateral distribution of the spray solution (water) with a coefficient of variation (C.V.) of <10% at an optimum operating height. The optimum operating height was determined by measuring the C.V. at 45, 50 and 59 cm above the patternator. For 800067 and 8001LP the optimum height setting was 45 cm and for 8001 was 59 cm. The nozzles were used in all subsequent experiments at their optimum height and same relative position. Fan angles of each nozzle were measured from photographs of the operating nozzle.

The variability of lateral spray distribution across the swath for various concentrations of herbicides and nozzle types were evaluated on a patternator with channels 5 cm wide and deep, using previously determined optimum height settings.

Droplet spectra of the nozzles was measured using a laser diffraction technique (Combellack & Matthews 1981). The laser beam was passed through the long axis of the spray sheet 15 cm from the nozzle. The data collected from the laser was fitted to a Rosin Rambler distribution model (Felton 1978). The weight of spray in the diameter ranges <100 μm, 100-300 μm, and >300 μm were calculated. Pressure was adjusted so that the flow rates through each nozzle were the same (0.37 ℓ/min).

The plants wheat (*Triticum aestivum* cv. Olympic), Wimmera ryegrass (*Lolium rigidum*), and radish (*Raphanus sativus* cv. fireball) were chosen to simulate a wheat-weed complex. The seeds were planted in a commercial

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(1)'DLV 400 Special Low Volatile Herbicide', Farmco, C.I.K., Kiwana, W.A..

(2)'Amacide 50', Nufarm Chemicals, Pty. Ltd., Melbourne, Victoria.

(3)White Electrical Instrument Co. Ltd., Worcestershire, England.

peatmoss and nutrient mixture (Jiffy-7(1)) germinated in a glasshouse and then moved to a shadehouse. When wheat, ryegrass and radish reached the 2-5, 1-4 and 4 leaf stage respectively, four plants of each species were arranged at random in a tray 34.5 x 28.0 cm to form one replicate for spraying.

Six experiments each with six replicates were conducted. Each experiment consisted of a control and a range of herbicide concentrations, with either the nozzle orifice size or the herbicide used being changed.

The plants were placed on a conveyor belt which carried them at 5.2 m/s, under two nozzles spaced 50 cm apart, with the spray sheet directed vertically down. The spray volume rate was 100 ℓ/ha. The height between the nozzles and plants was measured from the top of the plant canopy, and adjusted to the optimum height for each nozzle pair used.

A fluorescent tracer technique developed by C.R. Merritt, at the Weed Research Organization, Oxford was used to assess the amount of spray collected on the plant surface (Richardson 1984). After spraying, the plants were harvested to ground level and placed in separate plastic bags and shaken for 30 seconds with 30 ml of 0.005 M NaOH solution. Fluoresceine concentration was measured in a Pye Unicam SP8-100 Spectrophotometer fitted with a fluorescence accessory. The leaf area for each replicate was then determined using a planimeter. The results from amount of spray collected was calculated as μℓ/cm^2 of plant surface.

RESULTS

Variability of spray distribution across the swath was measured as C.V. and was dramatically increased when 2,4-D ester solution was sprayed through 8001LP and 800067 nozzles (Table 1). The spray pattern from 8001 nozzles,

TABLE 1

Measurement of spray distribution variability (C.V.) across the swath, static surface tension of the spray solutions and spray fan angles. All treatments have 0.01% wt/vol fluoresciene added

Solution	Surface tension	C.V.			Spray fan angle		
		Nozzle			Nozzle		
	mN/m	800067	8001	8001LP	800067	8001	8001LP
Water	73.0	3.6	10.9	10.7	85°	78°	83°
2,4-D ester							
0.6% wt/vol a.i.	33.0	20.0	9.1	16.3	94°	90°	94°
1.2% wt/vol a.i.	32.3	21.3	8.2	15.7			
2.4% wt/vol a.i.	32.5	20.4	10.2	17.3			
6.0% wt/vol a.i.	32.6	19.4	11.5	17.8	94°	85°	89°
2,4-D amine							
0.6% wt/vol a.i.	43.0	5.9	10.7	10.5			
1.2% wt/vol a.i.	43.8	6.7	10.0	10.8			
2.4% wt/vol a.i.	44.4	7.3	8.9	11.8			
6.0% wt/vol a.i.	43.9	8.2	10.5	11.5	93°	82°	94°

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(1) Jiffy-7 - Registered trademark - Jiffy Research and Service, Oslo, Norway.

however, when compared with water was not affected. Variability of spray distribution of 2,4-D amine increased through 8001LP nozzles although not to the same degree as with 2,4-D ester emulsions. C.V.'s for 8001 and 800067 nozzles were not affected by the 2,4-D amine spray solution when compared with the control and this is in agreement with the findings of Dransfield (1965).

It was noticed that the spray distribution of 2,4-D ester for 8001LP and 800067 nozzles was characterized by deposition of spray between the nozzles which indicates an excess of liquid or horning at the edge of the spray fan. This effect did not occur with 2,4-D amines from 8001LP nozzles. Concentration of herbicide did not appear to be a factor in affecting the C.V. or the spray distribution pattern.

The static surface tension measurements (Table 1) show that the spray solutions are saturated. Though small changes in fan spray angles were observed with different solutions (Table 1) these were not thought sufficient to cause the variability in distribution of spray noted for the 2,4-D ester.

With all nozzles the initial addition of 0.6% wt/vol of either 2,4-D amine or ester caused an increase in the percentage weight of large droplets, and a decrease in percentage of small droplets when compared with water plus fluoresciene. This effect confirms the findings of Combellack (1979). With all nozzles the percentage weight of small droplets (<100 μm) increased increased with higher concentrations of herbicide while the large droplet component (>300 μm) decreased (Table 2).

TABLE 2

Percent weight of droplets in size classes (μm) indicated. All treatments have fluoresciene at 0.01% wt/vol added

	NOZZLE								
	8001LP			8001			800067		
	<100	100-300	>300	<100	100-300	>300	<100	100-300	>300
Water	6.9	53.8	39.3	22.2	69.8	8.0	43.4	56.2	0.4
2,4-D ester									
0.6% wt/vol a.i.	5.3	49.2	45.5	12.8	77.1	10.1	30.8	68.1	1.1
1.2% wt/vol a.i.	6.6	52.8	40.7	13.3	76.9	9.9	39.8	59.7	0.5
2.4% wt/vol a.i.	6.1	52.8	41.2	18.2	76.5	5.4	39.1	60.5	0.4
6.0% wt/vol a.i.	7.2	55.1	37.8	22.7	74.8	2.4	53.6	46.4	0.0
2,4-D amine									
0.6% wt/vol a.i.	4.0	51.7	44.3	18.0	73.9	8.9	40.4	59.4	0.2
1.2% wt/vol a.i.	5.2	52.4	42.5	23.2	69.9	6.9	41.4	57.8	0.8
2.4% wt/vol a.i.	7.0	60.7	32.3	20.5	73.1	6.4	45.4	54.4	0.3
6.0% wt/vol a.i.	7.4	61.4	31.2	30.7	65.9	3.4	48.5	51.4	0.1

The results of the collection of spray by wheat, ryegrass and radish are presented in Table 3. The no herbicide treatment is expressed in μℓ/cm² of plant surface, while the other treatments have been expressed as percentages of this figure.

Collection of spray by the grasses was generally lower when 8001LP nozzles were used. Collection of spray by wheat was significantly (P=0.05) increased when either 2,4-D amine or ester were used. An increasing concentration of 2,4-D ester resulted in an increase in retention by wheat with the 8001LP nozzles, while the other two nozzle types gave variable results. As the concentration of 2,4-D amine increased collection consistently increased though the highest rate with the 8001LP nozzles was an exception to this trend.

TABLE 3

Retention of spray, μℓ/cm² of plant surface for the control plants. The treatments and LSD's have been expressed as a percentage of the control. All treatments have 0.01% wt/vol fluoresciene added

	Wheat			Ryegrass			Radish		
	Nozzle			Nozzle			Nozzle		
	8001LP	8001	800067	8001LP	8001	800067	8001LP	8001	800067
Water	0.124	0.126	0.231	0.615	0.711	0.657	0.641	0.588	0.635
2,4-D ester									
0.6% wt/vol a.i.	+212.9	+410.6	+161.9	+30.7	+41.9	+ 7.8	-12.9	+59.6	- 7.7
1.2% wt/vol a.i.	+256.5	+338.1	+212.5	+24.6	+ 0.1	+ 6.1	- 8.1	+22.1	-14.5
2.4% wt/vol a.i.	+316.9	+498.4	+286.1	+31.9	+18.7	+66.9	-18.7	+16.3	+ 4.9
6.0% wt/vol a.i.	+340.3	+482.5	+199.1	+23.7	+ 7.7	+21.6	-25.6	+21.7	-19.8
LSD P=0.05	46.8	73.8	65.8	15.7	29.4	14.2	12.9	14.6	13.8
Water	0.137	0.133	0.179	0.531	0.681	0.748	0.549	0.606	0.675
2,4-D amine									
0.6% wt/vol a.i.	+ 62.0	+130.1	+ 44.7	+17.2	+14.4	-17.5	+21.9	+ 6.6	- 3.1
1.2% wt/vol a.i.	+104.4	+201.1	+155.9	+ 8.7	+11.0	+ 6.3	+ 3.3	+ 4.3	+10.5
2.4% wt/vol a.i.	+224.5	+299.2	+302.8	+22.6	+21.0	+ 3.6	+ 5.6	- 7.6	-13.5
6.0% wt/vol a.i.	+204.4	+542.2	+307.3	+ 3.4	+32.3	- 0.4	- 9.6	- 2.8	- 1.0
LSD P=0.05	48.2	75.9	84.7	NS	NS	NS	13.8	NS	16.0

While a small increase in collection by ryegrass was found with 2,4-D ester or amine, it was not influenced by concentration. For radish, collection of spray was not consistently altered by the addition of either 2,4-D amine or ester at any concentration, even though significant variations were found.

DISCUSSION

The increased variation in lateral spray distribution when 2,4-D ester was used, means that higher dose rates may be necessary to ensure adequate control of the weeds across the swath. This also indicates that measurements on patternators should be made using the spray solution to be used.

It is suggested that the changes occurred as a result of changes in hydrodynamic flow within the nozzle orifice. The changes in droplet spectra do not appear to be related to static surface tension. This confirms previous work by Combellack (1979), and may reflect changes in dynamic surface tension. The results show that the consequences of decreasing the volume of application will be to increase the small droplet component and thus increase the risk of drift.

Spray collection efficiency by wheat increased when compared with weeds when the concentration of herbicides increased to 6.0% a.i. wt/vol (equivalent 10 ℓ/ha) with 2,4-D amine. This suggests that crop may be predisposed to an increased risk of phytotoxicity, however the results show that there should be no alteration to the control of the ryegrass or radish. Changing the application volume of the ester should not affect spray performance unless features such as percent cover of spray on leaf surface are important.

Collection by wheat and ryegrass plants apparently increased as the proportion of the >300 μm droplet component decreased when either the amine or ester were used. This shows the importance of maximizing the volume of the droplet spectra below >300 μm. Further work is necessary to examine the effect of faster travel speed of the boom and resultant droplet velocity at the time of impaction on the plant.

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THE INFLUENCE OF CEREAL CANOPY AND APPLICATION METHOD ON SPRAY DEPOSITION AND BIOLOGICAL ACTIVITY OF A HERBICIDE FOR BROAD-LEAVED WEED CONTROL

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ABSTRACT

In a single field experiment the influence of crop canopy and application method on the deposition and activity of a mixture of ioxynil, bromoxynil and mecoprop ester, applied to broad-leaved weeds in spring barley was examined. The herbicide mixture was applied at spray volume rates of 30 and 60 l/ha using rotary atomizers and at 60 and 120 l/ha using hydraulic nozzles. Rotary atomizers were used to produce a drop size of 250 µm at 30 l/ha and both 150 and 250 µm drop sizes at 60 l/ha. The herbicide mixture was applied at dose rates of 0.33, 0.66 and 1.31 kg a.i./ha when the crop had reached the first node detectable stage. Herbicide depositions on artifical targets, weed and crop and levels of weed control were compared. Evidence from the artifical targets suggested that more herbicide reached the ground from the hydaulic nozzle treatments. The crop canopy reduced the amount of herbicide deposited on the weed. Rotary atomizer treatments tended to give higher deposit levels on the weed and these deposits were greatest at the lowest volume rate. Although considerable variation in spray deposit levels was measured subsequent biological activity was uniform. Weed control was not affected either by application method, volume rate or drop size.

INTRODUCTION

While the reduction of spray volume rates can increase work rates, effective weed control must be maintained. Although rotary atomizers enable sprays to be applied at low volumes, herbicides that are poorly translocated can lose activity when applied in this way (Ayres 1976, Ayres & Merritt 1978). In addition, weed control may also be less effective with increasing crop growth stage (Ayres 1976, 1978). The reason for this is not entirely clear but may be because, in contrast to hydraulic nozzle sprayers, the slower sedimenting drops from the rotary atomizer are more effectively intercepted by the crop so less herbicide is deposited on the weed.

This experiment was designed to measure the effect of a barley crop canopy on deposition from sprays produced by different techniques and to relate these measurements to broad-leaved weed control. Hydraulic nozzle or rotary atomizer equipment was used to apply three spray liquid volumes and three doses of an emulsifiable concentrate containing ioxynil, bromoxynil and mecoprop esters ('Brittox'*). This mixture was chosen because bromoxynil can be easily analysed chemically and because contact herbicides such as ioxynil and bromoxynil are generally less effective when applied by

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* Registered name of May and Baker.

rotary atomizers at low spray liquid volumes (Ayres & Merritt 1978). The limitations of a single field experiment are appreciated, however the work requirements for this experiment were so high that it was not possible to carry out a second experiment.

MATERIALS AND METHODS

Experiment design and site detail

The site at Woodstock, Oxon, was sown with spring barley (cv. Jupiter) on 5 March 1980 at a seed rate of 157 kg/ha. The experiment was designed in two parts and comprised separate investigations on the biological activity and the depostion of the herbicide. Both studies took place on the same experimental area but a different design was used for each. The biological experiment was of split plot randomised block design containing five replicates. Each replicate measured 60 x 10 m and contained 17 main plots each measuring 3 x 10 m. Within the main plots there were four sub-plots of 1 x 1 m where all assessments were made. The replicates were separated by 2 m wide pathways. Deposition studies, including those on paper, were conducted on the five treatments applied at the highest dose rate only. To accomodate these treatments three extra plots were included on each replicate but these were not completely randomised within the experiment. Thus, the three additional plots on each replicate received the same treatment with different treatments applied on each replicate. The entire experimental area measured 60 x 58 m.

Pre-treatment assessments and application details

Seedlings of broad-leaved weeds were counted on 13 May 1980 in 60 x 0.1 m^2 quadrats thrown at random on each replicate. The predominant species present the mean number/m^2 and their growth stage at time of application are given in Table 1.

TABLE 1

Mean population and growth stage of predominant weed species present before treatment.

Species	Numbers/m^2	Growth stage
Polygonum aviculare	24.9	2-3 branches
Stellaria media	21.3	2-3 "
Bilderdykia convolvulus	3.1	4-6 true leaves
Others	9.1	
Total	58.4	

Prior to herbicide treatment the crop was cut at ground level and removed from two sub-plots on each main plot. Crop details at time of application were as follows; growth stage, first node detectable (GS 31 Zadoks *et al* 1974); height, 23-30 cm; row width, 15 cm; plants/m^2, 140;

tillers/plant, 3.8; dry weight plants/m^2, 134.4 g. A photograph of the crop canopy at time of application appears in Fig. 1. Care was taken not to damage or to remove the broad-leaved weed plants present and to minimise disturbance of the remaining crop. Following application the crop was similarly removed from the two remaining assessment areas. Treatments were applied on 22 May 1980, between the hours of 07.45 and 12.45 and a full list appears in Table 3.

Fig. 1. Photograph of spring barley crop canopy immediately prior to application.

Rotary atomizer applications were made using the Richmond Gibson CDA machine (Hind 1978). Feed to the discs was controlled by fitting Spraying Systems Orifice Plates Number 4916-18 into the spray lines immediately before the spray heads. At a pressure of 105 kPa the flow rate was 119 ml/min to each head. To achieve theoretical drop sizes of 250 and 150 µm disc speeds were set to 1750 and 2600 rev/min respectively. The desired volume rates were obtained by varying walking speeds from 0.6 m/s for 30 l/ha to 0.4 and 0.3 m/s for 60 l/ha. The hydraulic nozzle treatments were applied using a hand held 3 m boom fitted with six Spraying Systems 'Teejet' 6501 nozzles spaced at 50 cm intervals and spraying at a pressure of 210 kPa. The vmd of this nozzle type, as measured using a Particle Measuring System drop analyser, was 305 um when spraying water under laboratory conditions at 15°C (source, National Institute of Agricultural Engineering). The boom was carried at either 1.8 or 0.9 m/s to achieve spray volume rates of 60 and 120 l/ha.

Assessments

Spray deposition on paper

To determine the amount of herbicide reaching the target zone, 4 cm wide strips of chromatography paper were laid across the sub-plots receiving the highest dose. They were placed either below and between the transverse crop rows or on top of flattened crop. Immediately after spraying, the paper was removed for chemical analysis. The herbicide deposits were extracted from the filter paper with 250 mls methanol. An aliquot of the methanol extract was evaporated to dryness with a gentle stream of dry air and re-dissolved in hexane. The concentration of herbicide was determined by gas-liquid chromatographic estimation of the bromoxynil octanoate content of the extracts as described below. Recovery of a known amount of spray deposit using this method was in excess of 95% from paper treated in the laboratory.

Plant extraction

Thirty plants of P. aviculare were sampled at random from sub-plots both with and without crop plants. Ten samples of the crop (six plants/sample) were taken from within plots for each treatment. Both crop and weed samples were stored at $4^{o}C$ prior to analysis. All samples were macerated and then refluxed with alkaline methanol (Bache & Lisk 1966) to hydrolyse any conjugated herbicide. After conversion to the ethanoate by an ion-pair technique using ethyl iodide and tetrabutyl ammonium hydrogen sulphate (Cotterill 1982), the bromoxynil concentration was determined by gas chromatography. Recovery of spray deposits from plant material treated in the laboratory was 96.4% with a standard deviation of 4.9 for thirty determinations.

Chromatography

A Pye 104 gas chromatograph fitted with a ^{63}Ni electron capture detector was used for all determinations. The chromatographic conditions were; Column, 1.5 m x 4 mm i.d. glass packed with 5% E301 on Chromosorb$_2$ W.H.P; temperatures; column $210^{o}C$, injector $240^{o}C$; attenuation, 10×10^{2}; detector mode, pulsed at 150 µs. Standards within the range of 0.01 - 0.2 ng of bromoxynil ethanoate per injection gave a linear response. Concentrations of unknowns were calculated using a Perkin Elmer Sigma 10 Chromatography Data Station.

Broad-leaved weeds

Four weeks after spraying the surviving plants were assessed on each of the four designated areas of each main plot. All broad-leaved weeds within 0.8 x 0.8 m area were removed at ground level and separated into predominant species and others. The plants were weighed, dried for 24 h at $100^{o}C$ and then re-weighed.

RESULTS

Spray deposition

The design of the spray deposition study was such that the plots were not completely randomised and therefore the data is not susceptible to statistical analysis. Although, data are presented these should be treated with caution. Comparisons between deposit levels in the presence or absence of the crop for each treatment were valid and these have been subjected to a T-test ($p = 0.05$).

TABLE 2

Spray deposits recovered from a) filter paper, b) *P. aviculare* and c) spring barley

	Application method						
	Rotary atomizer				Hydraulic nozzle		
Volume rate (l/ha)	30	60	60	Mean	60	120	Mean
Drop size (μm)	250	150	250				
a) Filter paper (kg a.i./ha)							
Crop presence	0.71	0.66	0.71	0.69	0.80	0.99	0.90
absence	0.87	0.89	1.09	0.95	0.83	0.95	0.90
S.E.D	± 0.077	± 0.122	± 0.184	± 0.076	± 0.025	± 0.199	± 0.083
b) *P. aviculare* (μg bromoxynil/g dry wt. weed)							
Crop presence	27.1	18.0	21.5	22.2	15.0	11.7	13.3
absence	46.9	28.5	34.8	36.7	32.1	22.3	27.2
S.E.D	± 11.18	± 4.43	± 3.76	± 4.72	± 9.91	± 3.22	± 5.21
c) Spring barley (μg bromoxynil/g dry wt.)							
	11.4	14.0	16.7	14.0	18.4	11.8	15.1

The filter paper deposits (Table 2a) indicate that the target dose of 1.31 kg a.i./ha was not achieved with any treatment in the weed zone devoid of crop. Deposit levels measured on the filter paper positioned under the crop canopy from the hydraulic nozzle treatments did not differ from those measured in the absence of a crop canopy. The mean value for the three rotary atomizer treatments however does show a reduction in deposit in the presence of the crop. Weed plants sheltered below the canopy received spray deposits almost halved, compared to those plants which were fully exposed for both the application method means and for two treaments, 60 l/ha 250 μm rotary atomizer and 120 l/ha hydraulic nozzle (Table 2b). In the presence of a canopy the means suggest higher deposit levels on the *P. aviculare* from the rotary atomizer treatments than from the hydraulic nozzle treatments, and that deposits may increase as volume rate is reduced. Deposits on the crop appeared to be more influenced by volume rate than application method with the highest values recorded at 60 l/ha (Table 2c).

Response of broad-leaved weeds to herbicide

In the presence of a crop canopy there was no difference in numbers of surviving *P. aviculare* and *S. media* between the treated plots and unsprayed controls (Table 3). Where the crop was removed the main effect of dose shows a reduction in weed numbers at the highest rate. Differences between volume rates, drop size or application method were not significant for either species in the absence of crop canopy. Some treatment differences did occur where the canopy was present but these were few and inconsistent.

TABLE 3

Influence of application method and presence or absence of crop canopy on the effect of a mixture of ioxynil, bromoxynil and mecoprop on the numbers of surviving *P. aviculare* and *S. media* plants/m^2.

Volume rate (l/ha)	Drop or nozzle size	Dose rate (kg a.i./ha)	*P. aviculare* canopy		*S.media* canopy	
			−	+	−	+
30	250 µm	0.33	21.4	22.8	12.7(3.46)	23.1(4.56)
		0.66	27.0	26.6	11.3(3.21)	27.5(5.02)
		1.31	15.4	18.1	4.9(2.15)	12.7(3.31)
60	150 µm	0.33	33.4	31.7	16.6(4.05)	11.9(3.31)
		0.66	20.9	24.4	7.0(2.55)	14.5(3.75)
		1.31	12.0	16.7	5.9(2.18)	12.7(3.45)
60	250 µm	0.33	16.6	25.3	16.9(3.97)	16.7(3.78)
		0.66	27.0	33.8	12.3(3.28)	10.0(3.08)
		1.31	9.1	13.8	9.1(2.79)	18.8(3.93)
60	6501 Teejet	0.33	28.8	51.3	11.9(3.32)	12.7(3.41)
		0.66	15.2	13.6	19.2(4.17)	15.0(3.74)
		1.31	11.7	16.6	3.3(1.15)	14.7(3.43)
120	6501 Teejet	0.33	28.1	36.6	8.8(2.84)	11.4(3.28)
		0.66	13.9	25.3	13.1(3.57)	22.7(4.71)
		1.31	16.1	16.9	4.1(1.89)	11.1(3.12)
Mean			19.8	24.9	10.3(2.97)	15.7(3.73)
S.E. (between canopy means)			1.71		(0.142)	
S.E. (between treatment means)			6.63		(0.549)	
Unsprayed control			33.2	29.5	22.8(4.33)	19.1(4.05)

Transformed data in parenthesis $\sqrt{x}$

TABLE 4

Influence of application method and presence or absence of crop canopy on the effect of a mixture of ioxynil, bromoxynil and mecoprop on the dry weight (g) of surviving P. aviculare, S. media and total weeds/m^2.

Volume rate (1/ha)	Drop or nozzle size	Dose rate (kg a.i./ha)	P. aviculare		S. media		Total weeds	
			- canopy	+	- canopy	+	- canopy	+
30	250 µm	0.33	4.1(2.49)	4.9(2.50)	2.3(2.23)	5.4(2.41)	7.5(1.82)	11.8(1.97)
		0.66	4.0(2.35)	4.0(2.46)	1.2(1.92)	4.7(2.53)	6.0(1.66)	10.2(1.90)
		1.31	1.6(2.17)	2.5(2.33)	0.4(1.37)	2.2(2.17)	2.7(1.44)	6.0(1.69)
60	150 µm	0.33	5.3(2.50)	7.2(2.70)	2.1(2.27)	1.4(2.12)	8.3(1.87)	10.0(1.94)
		0.66	3.2(2.34)	4.7(2.49)	0.7(1.72)	1.8(2.22)	4.4(1.54)	7.5(1.83)
		1.31	1.0(1.91)	2.1(2.30)	0.5(1.19)	1.5(2.03)	2.0(1.27)	4.6(1.63)
60	250 µm	0.33	2.3(2.23)	5.9(2.55)	3.1(2.37)	2.5(2.11)	6.2(1.77)	11.1(1.97)
		0.66	4.4(2.50)	7.8(2.76)	1.5(1.75)	1.9(2.17)	6.3(1.75)	11.2(2.00)
		1.31	1.0(1.89)	1.9(2.18)	1.1(1.69)	4.6(2.18)	2.5(1.31)	7.6(1.72)
60	6501 Teejet	0.33	5.3(2.68)	10.0(2.96)	1.7(2.19)	2.2(2.16)	8.0(1.87)	13.4(2.09)
		0.66	2.5(2.16)	2.3(2.22)	3.0(2.29)	2.4(2.19)	6.0(1.68)	5.6(1.66)
		1.31	1.4(2.06)	2.6(2.37)	0.6(0.79)	3.3(2.17)	1.5(1.21)	6.5(1.72)
120	6501 Teejet	0.33	4.9(2.48)	7.5(2.79)	1.0(1.88)	2.3(2.12)	7.8(1.77)	11.1(2.02)
		0.66	2.3(2.17)	4.3(2.55)	0.9(1.94)	2.4(2.34)	3.8(1.47)	7.8(1.86)
		1.31	1.7(2.09)	2.6(2.40)	0.4(1.20)	2.0(2.15)	2.4(1.32)	5.2(1.69)
Mean			3.0(2.27)	4.7(2.50)	1.3(1.79)	2.7(2.21)	5.0(1.58)	8.6(1.85)
S.E. (between canopy means)			(0.043)		(0.056)		(0.032)	
S.E. (between treatment means)			(0.165)		(0.218)		(0.124)	
Unsprayed control			12.0(2.99)	10.4(2.98)	5.8(2.46)	4.1(2.30)	22.0(2.28)	18.0(2.23)

Transformed data in parenthesis - P. aviculare and S. media Log_{10} (n x 100), total weeds Log_{10} (n x 10)

The data for the dry weight assessment on both P. aviculare and S. media (Table 4) and the total surviving plants indicates an effect due to dose rate but no interaction with either volume rate or application method. Differences due to application method were not significant for either the individual species or the total. The main effect of a crop canopy was seen as a marked reduction in dry weight of weeds where the canopy was removed.

DISCUSSION

Whilst few firm conclusions should be drawn from the deposition data presented in this paper the results indicate some trends that are noteworthy. The filter paper deposits indicate that only 71% of the spray was reaching the soil surface where there was no crop canopy compared to 59% where the canopy was present. The apparent increase in deposit level on the paper targets under the crop canopy from the hydaulic nozzle treatments when compared to the rotary atomizer treatments suggests that faster drops are better able to penetrate through the canopy to the soil surface. Evidence from the bromoxynil deposits on P. aviculare however, indicates that the rotary atomizer treatments produced sprays that were more effectively retained on the target weed than from the hydraulic nozzle treatments. In the absence of a crop, application method did not influence deposition although the removal of the crop may have made the weed less erect.

Volume rate also appears to have influenced retention as there was a suggestion of an increase in spray deposit on the weed with lower volumes. A fourfold difference between the highest and lowest spray volume rate with a corresponding increase in herbicide concentration in the spray solution may have influenced the amount of deposit. However any increase in the amount retained appears not to be associated with any improvement in the level of weed control. Single drop studies conducted by Merritt (1982a, 1982b) concluded that whilst herbicide deposit at each drop location increased with concentration, activity could vary considerably depending on the herbicide applied. Results from this field experiment appear to support this indication that concentration can be a major factor in determining the effect of changing the volume rate for a given herbicide.

Measurements of bromoxynil on both crop and weed indicate higher deposits from the hydraulic nozzle treatment at 60 than at 120 l/ha. This would seem to support conclusions drawn by Merritt & Taylor (1978) which suggest that poorer retention of large drops may become more pronounced as volume rate is increased. A similar pattern from the rotary atomizer treatments is less evident and the reason for this is not clear.

The effect of canopy was most marked in its influence on herbicide activity, an effect not due to crop competition because the crop was removed on all plots after treatment. The absence of any significant effect of application other than dose on biological activity is of interest as there were substantial differences between treatments in drop formation, velocity and/or drop size and number. Any increase in the amount of spray retained using lower volumes appears to be balanced by a poorer effect when this herbicide is used at a higher concentration and this may have masked any small differences that could be associated with drop size range or velocity. However, differences were not evident at the lower doses and hence lower concentrations used for the biological assessment. Although it would be unwise to assume correlation between retention and effect, other application work with this herbicide mixture (Ayres 1982) has concluded that differences between drop or nozzle size and volume rate are few and inconsistant. The evidence suggests therefore, that within the variables investigated in these experiments, this particular herbicide may not be sensitive to changes in application factors.

The evidence from this single experiment should be treated with caution. Nevertheless the data indicates that sprays from rotary atomizers are able to penetrate the upper part of the crop canopy. However, the limited spray deposit data suggests considerable variability of the final quantity of spray retained and this, allied to the inherent variability in field experiments with naturally occurring broad-leaved weeds appears to have reduced the sensitivity of comparisons. The source of this variability could be reduced in subsequent experimentation by increasing assessment areas or sample numbers but this is both time consuming and labour intensive. Some attempt has also been made to improve the sensitivity by using Brassica spp as 'target' broad-leaved weeds in collaborative experiments between the NIAE and WRO. If the interaction between crop canopy and application method is important for effective weed control, as previously suggested (Ayres 1976, 1978), then alternative assessment techniques and the use of other criteria to describe herbicide deposition may be necessary to quantify such effects.

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STUDIES OF THE RELATIONSHIPS BETWEEN THE PROPERTIES OF CARRIER SOLVENTS AND THE BIOLOGICAL EFFICACY OF ULV APPLIED DROPS OF THE INSECTICIDE CYPERMETHRIN

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ABSTRACT

The properties of carrier oils which lead to persistence on leaf surfaces and efficient transfer to walking larvae have been studied by investigating the effect of wax cover, carrier solvent and concentration of active ingredient on the efficacy of ULV applied cypermethrin for the control of Spodoptera littoralis. The persistence of ULV drops can be increased by using viscous, involative carrier oils which reduce the rate of spread and penetration of droplets into the leaf waxes yet maintain a high adhesion to larval cuticle. These carrier properties result in an increased biological efficacy of ULV applied cypermethrin on leaves of cabbage (Brassica oleraceae) of varying wax cover.

INTRODUCTION

Although carrier properties of ULV deposits will undoubtedly influence the biological effect of insecticide treatments, very little information is available to suggest which factors are of importance. Hadaway and Barlow (1974) have concluded, however, that the correct choice of carrier solvent can be critical in the development of ULV treatments. Both the deposit persistence and the probability of transfer to a target organism will depend on the nature of the carrier properties. Efficient transfer, for example, may be related to the proportion of the deposit that remains in liquid state above the leaf waxes (Salt and Ford, 1984). Transfer will also depend on the properties of the plant and insect surfaces. This paper describes the effect of varying the nature of the carrier on the efficacy of ULV applied drops of the insecticide cypermethrin. These laboratory studies have identified some of the carrier properties which may be manipulated in order to increase the probability of transfer of an insecticide from the leaf surface to the target insect.

MATERIALS AND METHODS

Wax cover on leaf surfaces

To determine the density of cover of wax on cabbage leaf surfaces, individual leaves of known leaf area were washed in 100ml petroleum ether (BP 60°-80°) for five minutes. The solvent was then decanted into beakers of known weight, and allowed to evaporate. The beakers were reweighed, and the wax residue calculated by difference. In other experiments, leaf discs of 1cm diameter were extracted in 1ml hexane, and the wax extracted was determined by gas-liquid-chromatography. Calibration was based upon serial dilution of a standard solution of extracted plant wax.

Application of carrier solvents to leaf surfaces

Drops of various sizes were applied to leaf surfaces by one of three methods. (i) Large drops ($0.25 \mu \ell$) were topically applied from a microburette held in a Burkhard applicator; (ii) monosized drops of Sirius oil of (80 µm) diameter were sprayed onto leaf surfaces from a height of 40cm using a laboratory microsprayer (Coggins and Baker, 1983); (iii) drops of Sirius oil with randomly distributed diameters (mean of 80 µm) were applied using a modified Potter Tower, as previously described (Ford and Reay, 1977).

Persistence of oil drops

The proportion of ULV drops which remained proud of the leaf surface was determined by counting the number of drops which reflected the light through the objectives of a low power binocular microscope. The spread of large 0.25 µl drops over leaf surfaces was followed by determining the contact angle at various time intervals. The apparatus consisted of an adjustable stage on which treated leaf samples were held, and which could be adjusted to bring an oil drop into the view of a horizontally held microscope, positioned to view drops at low power across the leaf surface. A protractor mounted on the microscope eye piece rotates as a graticule is aligned. The contact angle is calculated from the difference between the angles corresponding to the graticule aligned with the leaf surface and a tangent to the drop surface at a point where it meets the leaf. It was important to view the drop exactly along the plane of the leaf surface, a condition which could be reliably achieved only for large drops with diameters above the ULV range.

Transfer of oil drops to larvae

Oil Red O was dissolved in each of the Sirius oils to give a standard concentration and hence absorbance at 515nm. Ten drops of oil (0.25 µℓ) were deposited on cabbage leaves of low wax cover and anaesthetised larvae of *S. littoralis* weighing 200mg were held on forceps so that their rear claspers made contact with an oil drop for two seconds. The mass of oil transferred from plant to insect surface was determined by washing each larva and leaf disc with hexane and analysing the extracts spectophotometrically.

Bioassay

Solutions of cypermethrin in Sirius oil were topically applied to larvae of *S. littoralis* from a microburette held in a Burkhardt applicator. Cypermethrin solutions in Sirius oil were sprayed at ULV onto cabbage leaf discs held in 9cm petridishes at the base of a Potter Tower fitted with a ULV spray head. Larvae of *S. littoralis* were placed by hand after the deposits had aged for 18 hours. Counts of knockdown and mortality were made at appropriate times after larval placement.

EXAMINATION OF THE EXPERIMENTAL DATA

A series of experiments were undertaken to investigate the factors which determine the efficacy of cypermethrin deposits. Cabbage (*B. oleracea*) was selected as a suitable experimental plant for initial studies of the behaviour of small drops impacted on leaf surfaces. Cabbage leaves provide a relatively smooth surface topography with a wide range of surface wax cover (Figure 1). By the choice of leaf number, leaves with a range of wax cover can be selected for experimental studies to determine the role of wax cover on droplet stability.

Behaviour of carrier solvent on leaf surface

The efficacy of insecticide drops will depend on their transfer from the plant to the insect surface and will be related to the physicochemical properties of these surfaces and the deposit itself. The behaviour of a low viscosity white oil, Sirius oil M40, applied to leaf surfaces of known waxiness was investigated for drops of 80 μm diameter. The drops spread on impaction until the oil had completely penetrated the surface wax: while oil remained above the surface the drops glistened, (an effect due to reflected light), but once penetration was complete they appeared as damp matt patches on the leaf surface. Counts of the proportion of drops remaining two minutes after application suggested that the persistence of drops with distinct profiles above the surface was dependent on the extent of wax cover (Figure 2). A critical level of waxiness (about 30 μg/cm^2) was observed above which a high proportion of drops spread and penetrated the surface within minutes of impaction.

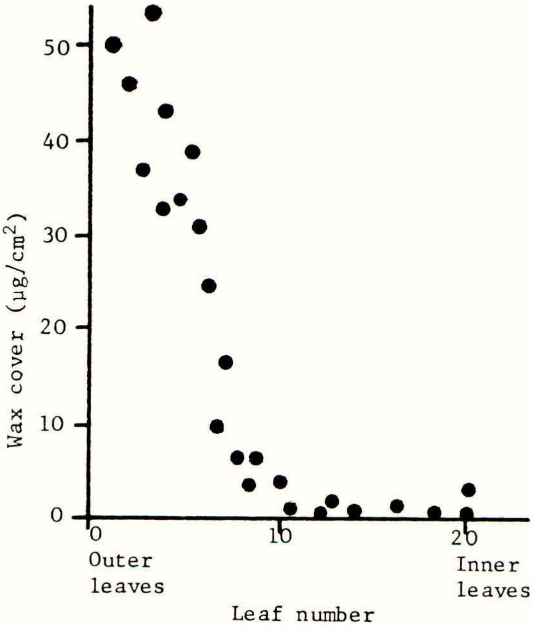

Fig. 1. The relationship between the surface wax cover of leaves of B. oleraceae and leaf position in the cabbage head.

It would be desirable for a carrier to have appropriate properties to enable drops to retain a distinct profile on leaves of plants which have higher wax concentrations than 30 μg cm^{-2}. Strawberry and rape for example can have mean wax deposits of 40 and 50 μg cm^{-2}, respectively (Baker et al 1983). The wax cover of most plants results in a hydrophobic surface for which mineral oil shows high affinity. The surface of S. littoralis also has hydrophobic properties and the high proportion transfer of Sirius oil drops to these larvae, predicted and observed by Salt and Ford (1984), must in part be attributed to this property. The effect of the hydrophobicity of the carrier solvent on the stability of large drops (0.25 μl) suggested that polar drops (e.g. hexane-1-ol, pentane-1,5-diol and hexane2,5-dione) remained stable and proud of the leaf surface over

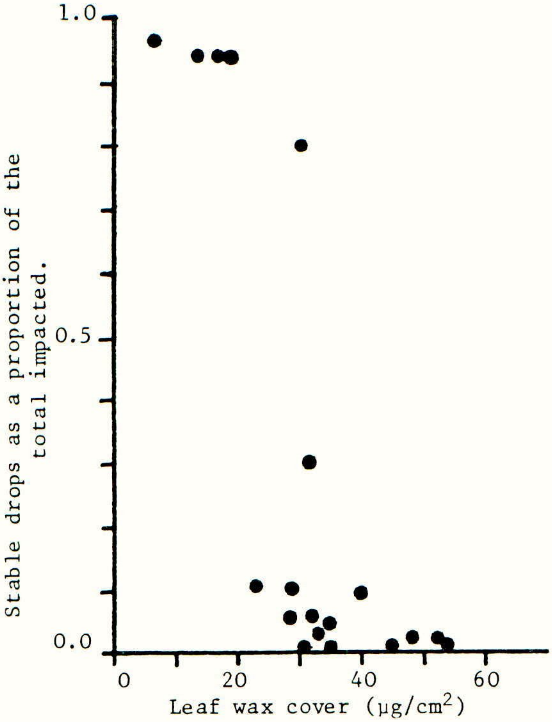

Fig. 2. The relationship between the drop persistence 2m after spraying and the surface wax cover of leaves of cabbage (B. oleraceae).

long periods of time. Tests of the affinity of these solvents on isolated cuticle of S. littoralis demonstrated the poor affinity of these polar materials for the larval cuticle, since they showed no tendency to spread over the hydrophobic insect. Pick-up of polar drops by larvae is therefore likely to be poor. Moreover, polar drops showed low resistance to rain washing and were completely removed by two water drops made to roll across the deposit. Mixtures of these compounds with Sirius oil did not significantly improve these characteristics. Thus, at this stage, there seems little prospect of increasing the transfer efficiency of ULV drops on surfaces of high wax content by adjusting carrier hydrophobicity.

TABLE 1

The proportion of carrier oil remaining on the surface of leaves of cabbage (B. oleraceae) following a two second contact by larvae of S. littoralis.

Carrier oil	Mean proportion remaining
Sirius M40	0.52
Sirius M100	0.62
Sirius M350	0.50

These results suggest that a combination of carrier properties which increase the persistence of drops above waxy leaf surfaces by reducing their rate of spread, yet retain high affinity for hydrophobic surfaces, is necessary for good drop transfer characteristics. We decided that high viscosity oils might confer the best compromise between persistence and transfer, since they should retain high affinity for the insect cuticle, but spread across the leaf surface at substantially reduced rates. A range of Sirius oils (M40, M100 and M350), with viscosity of 40.5, 100 and 355 Saybolt universal seconds (S.U.S. units) respectively, were examined for their suitability as carriers. Initial studies confirmed the similar affinities of these oils for the larval cuticle (Table 1).

Although this experiment is only a simulation of the transfer process, these provisional results indicate that adhesion between a viscous oil and the larval cuticle is sufficient to overcome the leaf-oil and oil-oil forces of adhesion and cohesion. The use of viscous oils in ULV formulations should therefore result in increased efficacy, provided their deposits exhibit stable profiles on waxy leaf surfaces. We have already shown that low viscosity oils, such as M40, lose their integrity by flowing rapidly over the leaf surface until they form a thin film with a sufficiently large contact area to result in their complete penetration into the wax layer beneath. This process can be described measuring the change in the contact angle of a placed drop with time.

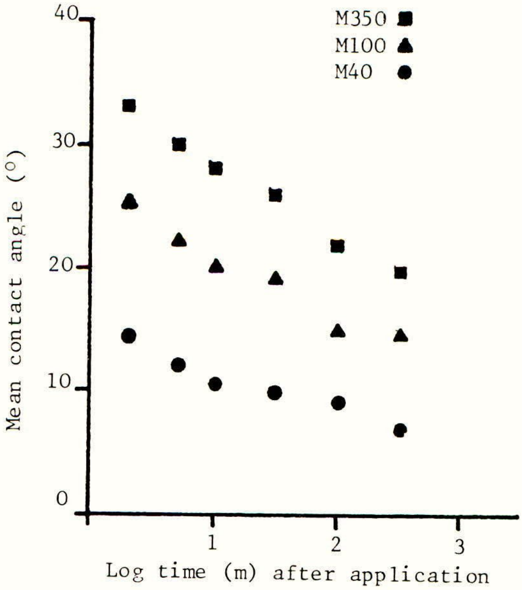

Fig. 3. The rate of change of mean contact angles for drops (0.25 μl) of Sirius oils of different viscosities topically applied to leaves of cabbage (<u>B. oleraceae</u>).

Drops (0.25 μl) of M40, M100 and M350 were applied to cabbage leaf surfaces of varying wax content and their contact angles measured at regular intervals after drop placement. The rates of change of the mean contact angles for five replicate drops per oil are presented in fig. 3. Following topical application onto the leaf surface, the low viscosity oils spread rapidly and acquire a mean contact angle of between 13 to 14°. As the viscosity of the oil increased, the rate of this rapid, initial spread was reduced and, for Sirius M350, the mean contact angle after two minutes was between 33 and 34°. Although, thereafter, the rates of spread of the oils are similar, by approximately five hours the M40 oil drops had spread to give an average contact angle of 7° and hence were in more intimate contact with the leaf surface than the M350 oil, which remained proud of the surface with a mean contact angle of approximately 19°. These results suggest that the rate of spread of oil drops in leaf surfaces is viscosity controlled.

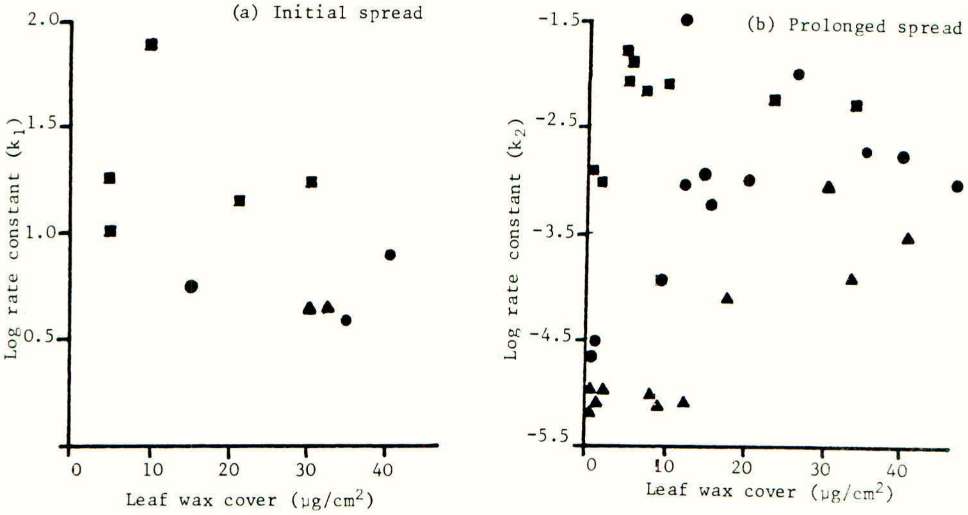

Fig. 4. Scatter plots to show the relationships between the spread of Sirius oil droplets and the density of leaf cover by the surface waxes of B. oleraceae. (M350 ▲, M100 ●, M40 ■).

This conclusion was examined in a second experiment. Cabbage leaf discs of known wax cover were sprayed with Sirius M40, M100 and M350 oils to give mean drop diameters of 80 µm. The treated discs were viewed under a binocular microscope at a magnification which ensured that approximately 40 drops of oil were contained in the field of view. Counts, based on the number of oil drops which reflected light, were made of the drops persisting at increasing intervals of time after spraying. Simple empirical equations of either a single or double exponential form can be used to describe the loss of persistence with time (t) viz. —

$$\text{number of drops} = A \exp(-kt) \qquad (1)$$
$$\text{number of drops} = B \exp(-k_1 t) + C \exp(-k_2 t) \qquad (2)$$

where k, k_1 and k_2 are rate constants and A, B and C are constants such that A and B+C equal the number of drops on the leaf at $t = 0$. There was an association between the single exponential loss and leaf discs with a low wax cover. The rate constants (k) describing this loss were generally small. An association was also observed between the double exponential decay and leaves of high wax cover. In this case a rapid initial loss of a proportion of the impacted drops characterised by a large value for k_1, is followed by a very much slower rate of loss characterised by small values of k_2 of similar size to k, the rate constant for the single exponential decay. These rate constants are further modified by the viscosity of the oil (Fig. 4a and b), suggesting that substantial increases in the persistence of drops retained with profiles above the leaf surface can be obtained by increasing the carrier viscosity. The drop halflife of M350 oil at wax levels below 20 μg/cm^2, for example, is of the order of weeks. However, oil drops of any viscosity landing on areas of heavy bloom spread instantly to disappear into the wax layer below. The importance of bloom in reducing persistence is underlined by the survival of drops landing on leaf areas where the bloom has been removed. This observation was confirmed by a simple experiment where the heavy bloom on half of a leaf was flattened by rubbing with a smooth metallic edge. GLC analysis confirmed that both halves retained a wax cover of 42 μg/cm^2. However, 80 μm diameter drops of M350 oil landing on the bloomed half disappeared instantly, whereas those landing on the rubbed segment of the leaf persisted with a half-life of approximately two days.

The influence of carrier properties on biological response

Multiple linear regression analysis was employed to test whether the increased persistence of ULV drops of cypermethrin dissolved in a viscous carrier was associated with an increased biological efficacy. ULV treatments of cypermethrin, based on two different viscosity carriers (M40 and M350) and three concentrations of a.i. (1, 8, 64 mg/ml), were sprayed from a modified Potter Tower to give deposits on cabbage leaf surfaces characterised by different wax covers (leaf numbers 1 to 10 (Fig. 1)). The resulting deposits, were characterised by drops of inflight diameter of 80 μm and a drop density of 5 per cm^2. The treated leaves were allowed to age for 18 hours. Larvae of mean mass 108.3 ± 15mg($\bar{x} \pm s$) were then placed on the treated surfaces (two larvae per leaf) and the time taken to knockdown individuals was recorded. The results are summarised by the following equation, where the standard errors of the regression coefficients are in parentheses:

$$\begin{aligned}\text{log time to knockdown (m)} = 1.89 &- 0.44 \times 10^{-2} \text{ conc a.i. (mg/ml)}\\ &\quad (0.56 \times 10^{-3})\\ &+ 0.64 \times 10^{-2} \text{ wax cover } (\mu g/cm^2)\\ &\quad (0.88 \times 10^{-3})\\ &- 0.76 \times 10^{-3} \text{ viscosity (S.U.S. units)}\\ &\quad (0.11 \times 10^{-3})\end{aligned}$$

where $n = 75$, $R = 0.78$ and $s = 0.14$.

All three factors, viscosity, wax cover and concentration were significant ($p < 0.01$). These provisional results associate short knockdown times with high viscosity oils, high concentrations of a.i. and leaves of low wax cover.

Topical application of cypermethrin dissolved in M40 and M350 oils to S. littoralis larvae result in very similar knockdown times suggesting that the influence of viscosity of the carrier oil is to increase the persistence on the leaf surface rather than to enhance the toxicity of the transferred deposit. This increased persistence is likely to result in the transfer of a larger proportion of oil to the larva as described earlier by Salt and Ford (1984).

Conclusion

The results reported here demonstrate the importance of the properties of the carrier solvent in determining the transfer properties of ULV deposits from the leaf to insect surface. These properties must ensure adequate retention by the plant surface to resist weathering but the deposits should remain above the leaf wax layer and be available for efficient transfer on contact by a walking larva. Maximum adhesion to larval cuticle should be obtained by involatile, hydrophobic carriers maintained in a liquid state (e.g. mineral oils).

ACKNOWLEDGEMENTS

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LOCALIZED ACTIVITY OF ULV PESTICIDE DROPLETS AGAINST SEDENTARY PESTS

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ABSTRACT

Studies of monosized, oil-based droplets of pesticides and of their activity against sedentary stages of glasshouse pests have revealed unexpected relationships with droplet size, concentration and formulation. Testing dicofol against eggs of Tetranychus urticae, it was shown that the smaller the droplet the greater was the efficiency of pesticide use. There was also an optimum concentration range (about 0.5 to 1.5%) above and below which efficiency declined markedly. By studying the mortality of whitefly scales, Trialeurodes vaporariorum, around isolated permethrin droplets, it was similarly shown that small droplets and low concentrations were more effective. Also formulation and plant species were shown to have considerable effects. Scanning electron microscope studies have shown that the perimeter of the droplet on the leaf is of primary importance in determining the amount of toxicant diffusing across the leaf surface and therefore in determining the biological effectiveness.

INTRODUCTION

With the recent rapid development of ultra-low-volume, controlled droplet and electrodynamic spraying methods, and especially in view of the present controversy concerning impending legislation to control their use, it is surprising that so little has been done to investigate the relative merits of available methods from the point of view of their biological effectiveness. When high volume methods are used, the aim is normally to wet the entire target surface: to spray to run-off. The mortality of insect pests, achieved in this way, is dependent on the amount of active ingredient actually deposited on the insect or the amount it will subsequently pick up from the surface, from the atmosphere, or by feeding. With low volume techniques, these possibilities are limited, especially when contact insecticides are sprayed against sedentary pests. The chances of achieving direct hits on the pest are remote (Munthali & Scopes, 1982) yet in practice, good control can be obtained. This indicates that the toxicant is somehow transferred from the site of deposition of the droplet to the pest, in a sufficiently lethal amount. It is important, therefore, to understand how this transfer takes place and what characteristics of the droplet influence its efficiency of action. A series of studies has therefore been made on the effects of droplet size, spread on the leaf, formulation, concentration and content of active ingredient and plant species, using monosized oil-based droplets of two contact pesticides.

MATERIALS AND METHODS

In the first study, monosized droplets (Uk, 1978) of dicofol in VK1 (Shell) were sprayed on 1 cm^2 leaf discs of French bean which had previously been heavily infested with eggs of the glasshouse red spider mite, Tetranychus urticae. Varying densities of droplets were applied to determine the median lethal number required and, thereby the LD_{50}. Droplet sizes were varied from about 20 to 120 µm and a range of concentrations from 0.05 to 4% was investigated. Further details of the method are given by Munthali & Scopes (1982).

In the second study, a row of droplets was sprayed across the centre of a 2 cm leaf square infested with settled first instar larvae of the glasshouse whitefly, Trialeurodes vaporariorum. Mortality was determined at right angles to the row of droplets and was related to the distance from the nearest droplet. Permethrin was formulated in three carriers, JF8133, JF8130 (ICI) and VK1, at concentrations ranging from 0.5 to 20%, using droplets of usually about 108 µm but in one test at 59 µm. Three host plants were tried: tobacco, French bean and tomato. The technique is reported in further detail by Abdalla & Scopes (1983).

Thirdly, permethrin in VK1 was sprayed on leaf discs of tomato infested with whitefly larvae to interrelate the two previous studies (Palmer, Wyatt & Scopes, 1983). Finally, various examinations were made of 80 µm droplets of various formulations of 10% permethrin after deposition on tobacco, French bean and tomato leaves (Atkey et al. 1983).

RESULTS AND DISCUSSION

The purpose of this paper is to draw together the findings of the above studies. It is proposed therefore to present the results only in sufficient detail for this purpose, since they have been, or will be, published in full elsewhere (Munthali 1981, Munthali & Scopes 1982, Atkey et al. 1983, Abdalla & Scopes 1983, Palmer et al. 1983, Abdalla 1984 and Wyatt et al. 1984).

First study

The main finding of the first study was that, at any dicofol concentration from 0.25 to 4%, the LD_{50} was roughly proportional to the original diameter of the droplet. In other words, the smaller the droplet the more efficient was the spray in its use of toxicant. Thus, for instance, using a 1% concentration, 15 times as much toxicant was required (per cm^2) for 120 µm droplets as for 20 µm. There were also unexpected results when concentration was varied. At all droplet sizes there was a marked falling off of efficiency (increase in LD_{50}) at 4% dicofol (Fig. 1,——). Similarly, at the lowest concentrations there was a decrease in efficiency, particularly at the smaller droplet sizes. It appeared therefore that there was an optimum concentration, possibly varying according to the droplet size. As an example, the LD_{50} for 100 µm droplets of 4% dicofol was assessed to be over 4 times as high as for 1%. Therefore, increasing the concentration of a droplet four times can sometimes give no improvement in its effectiveness. By taking size and concentration into account, this can mean that if 20 µm droplets of 1% dicofol are used instead of 100 µm of 4%, only one fiftieth of the quantity of active ingredient need be used to obtain the same kill.

Second study

The object of the second study was to determine the extent of the spread of toxicant from individual permethrin droplets by observing the mortality of whitefly scales. Mortality followed a sigmoid form with distance, being 100% close to the droplet, falling rapidly within the first mm and then declining very slowly. These results could then be translated into arbitrary concentrations of toxicant by standardizing against dipping tests. This showed a rapid fall of concentration near the droplet but a very gradual decline further away. Computer studies at Portsmouth Polytechnic (M. Ford, D.W. Salt & A. Sharkey, private communciation) have shown that this pattern and rate of spread are consistent with diffusion through a semi-solid such as wax. Assuming that the diffusion from one droplet did not interfere with that from a neighbouring droplet (that is, assuming concentrations were additive) it has been possible to determine the spacing of droplets on a leaf which would produce a 50% kill (LS_{50}). From this the LD_{50} could be derived for comparison with the first study.

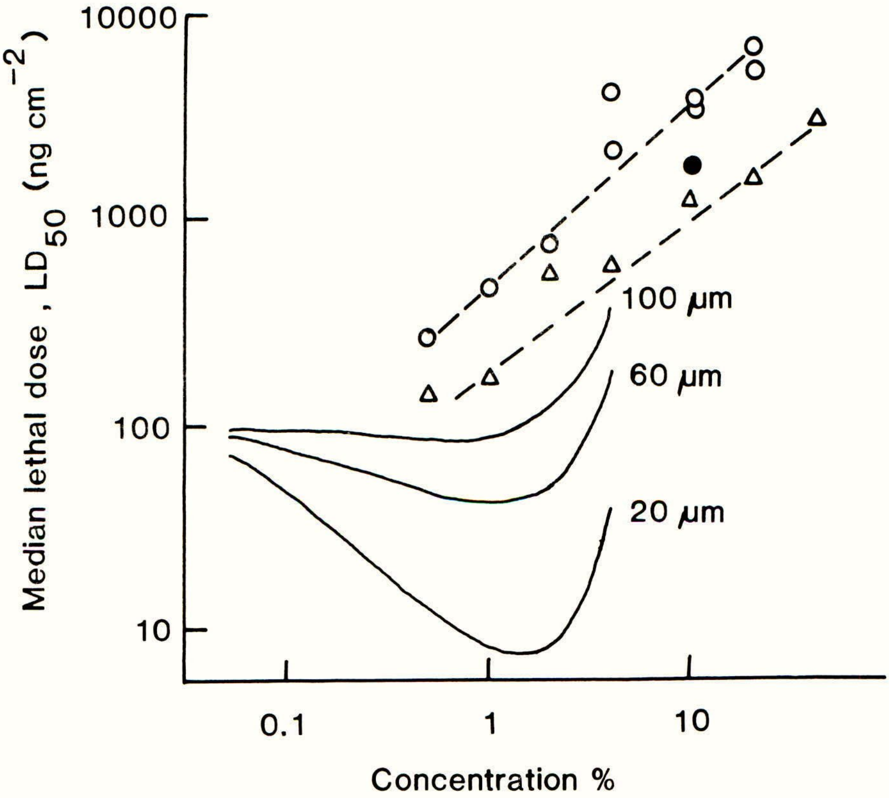

Fig. 1. Effect of pesticide concentration on the LD_{50} of small droplets of dicofol against spider mite eggs on French bean at 3 droplet sizes (———) and of 100 µm droplets of permethrin against whitefly scales in spray tests on tomato (Δ— —) and as deduced from single droplet studies on tobacco (O— — —) and tomato (●).

One experiment was carried out to compare droplet sizes of 59 and 114 μm with 10% permethrin. The LD_{50} of the latter was assessed to be 4.6 times that of the former. Thus great improvements were found by halving the size of the droplet, as was found with dicofol. Formulation was also found to produce a considerable effect, JF8130 being found to give an LD_{50} twice those of other mixtures. Similarly plant species influenced effectiveness: only 0.4 times the amount of permethrin was required on runner bean as on tobacco and half the amount on tomato.

Concentration changes again did not produce the expected responses. As concentration was increased from 0.5 to 20%, so the effectiveness of control diminished (Fig. 1,○ — —). Thus it was estimated that 23 times as much permethrin was required using a 20% spray as with a 0.5% spray. Looked at from another point of view, the area of leaf treated by a single droplet increased by only 1.75 times even though the concentration, and therefore the active ingredient, increased 40 times.

One would expect that, as concentration increased, the number of droplets needed would decrease proportionately. This would mean that, if LD_{50} (or log LD_{50}) were plotted against concentration the resulting line would be roughly horizontal. This was the case for 100 μm droplets of dicofol (Fig. 1, ——— 100 μm) except at the highest concentration. However, quite different conclusions were reached with smaller droplets (Fig. 1, ———— 20 μm, 60 μm), a distinct optimum concentration being apparent. The response from permethrin appeared to be entirely different showing a continuously increasing decline in effectiveness (increase of LD_{50}) as in Fig. 1 (○). It is, of course, possible that low enough concentrations were not investigated, but there is no indication even of a curvature over the existing range. The conclusion is that dicofol and permethrin (or possibly mite eggs and whitefly scales) respond in different ways to changing concentration.

Third study

It might be supposed that the LD_{50} values determined for permethrin were inaccurate due to the various assumptions made in their calculation. In this respect, the third study is useful to confirm the form of response of whitefly scales to changing concentrations of permethrin, but in this instance determined by spraying. The resulting observations (Fig. 1, △ — — —) again indicate a straight line closely parallel to that obtained in the second study. The downward displacement is due, at least in part, to the use of tomato as a host plant, since a lower LD_{50} was obtained with the one tomato experiment in the second study (Fig. 1, ●). An increase of concentration from 0.5 to 20% was estimated to have required 15 times as much permethrin for the same kill (c.f. 23 times in the second study).

Scanning electron microscope study

A limited study of the form of droplets after deposition on a leaf, using a scanning electron microscope, revealed that JF8130 produced compact, rounded droplets. Most tests were done with VK1 on tobacco, and flattened somewhat irregular drops resulted. On tomato, greater irregularity was found and, on French bean, the formulation tended to run out in fingers between the leaf cells (Fig. 2, a, b, c, d respectively). It was suspected that the conformation of the droplet might influence its effectiveness but examination of the area or overall dimensions of the droplet revealed no relationships. However, when perimeter of the droplet was compared with the median lethal spacing (LS_{50}) an apparently straight line relationship emerged. Although a significant correlation was found ($P < 0.01$), it will be necessary to continue this study to confirm the validity and general applicability of the findings. It appears, however, that the amount of toxicant diffusing across the leaf surface is, in some way, regulated by the length of the perimeter.

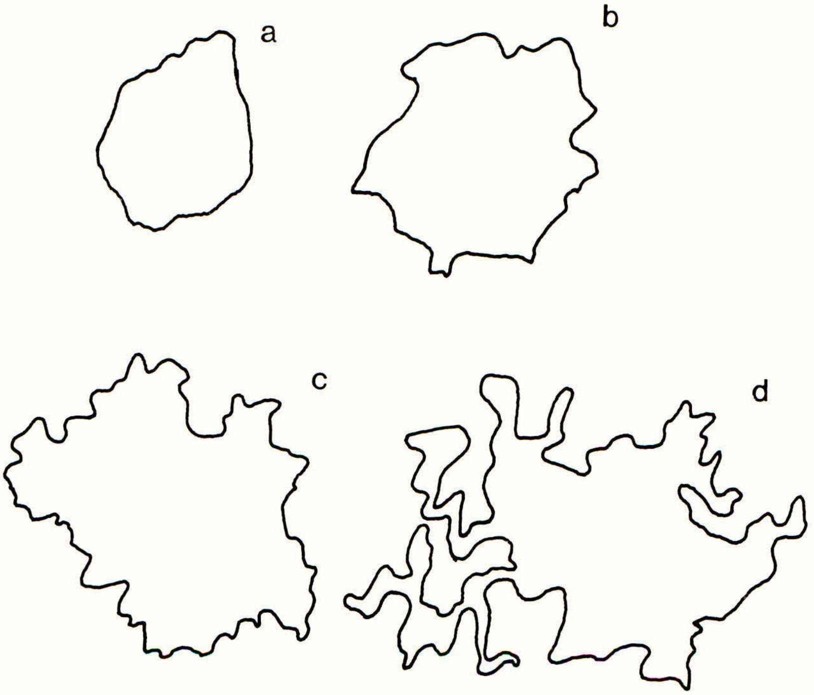

Fig. 2. Outlines of droplets (originally 100 µm of 10% permethrin) in JF8130 on a tobacco leaf (a) and in VK1 on tobacco (b), tomato (c) and French bean (d), all at the same magnification (approx. X150).

A further observation from the scanning electron micrographs was that some droplets appeared to contain solid inclusions or to have a scum of material floating on the surface. This has led to the supposition that, once the volatile components of the droplet have evaporated, the remaining oil has become saturated with the pesticide, with the resultant separation of the pesticide as crystals or liquid. In this case the oil in contact with the cuticular wax will be at a constant saturated concentration, and the amount of pesticide diffusing outward will depend on the length of the interface, namely the perimeter of the droplet. This may also help to explain the anomalous effects of concentration. Once saturation is attained, any increase in active ingredient within the droplet is unlikely to improve its effectiveness. Is this why dicofol suddenly ceases to benefit when the concentration rises above 2%? Or is permethrin partially separated over the whole concentration range investigated? These questions are perhaps best left to the physical chemist, but they would appear to merit further study.

CONCLUSIONS

These studies have led to several important conclusions concerning the biological activity of oil-based droplets of contact insecticides against sedentary pests. Smaller droplets make more efficient use of the active ingredient, but correspondingly larger numbers of droplets are required, which may result in difficulties of deposition. Concentration of active ingredient also affects the level of activity, although the pattern of response appears to depend on the pesticide concerned. In general, lower concentrations appear to use the chemical more economically, which may defeat the object of ULV application where transport or cost of carrier is a limitation. Formulation of carrier and species of host plant also have their effects, which suggest that, in future, it may be an advantage to devise formulations for specific needs of a pest or crop: account should be taken of the conflicting requirements of biological efficiency, economy in the use of the toxicant and the suitability for the particular mechanism of spray application.

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