

ERRATA

Page 20 line 13: for 'fenifrothion' read 'fenitrothion'.

Page 21 line 6 : for 'vailable' read 'available'.

Page 25 last paragraph, line 4: for '300 μm ' read '330 μm '.

Page 36 line 6 : for 'targest' read 'targets'.

Page 49 line 9 : for 'inconsistence' read 'inconsistent'.

Page 52 line 20: for 'fit' read 'fits'.

Page 64 table 6: for '1.0499' read '2.0499'.

BIOLOGICAL EFFICIENCY OF SMALL PESTICIDE DROPLETS

by

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ABSTRACT

The efficiency of ultra-low volume pesticide sprays was studied by examining the influence of droplet size and spray concentration on mortality of Tetranychus urticae (Koch). Various stages were sprayed with monosized droplets (18 to 150 μm in diameter) of oil-based formulations of 0.05 and 4% dicofol, plus a fluorescent tracer to aid location of individual droplets. Droplet size was determined using magnesium oxide coated slides. In each experiment 20 discs of bean leaf (Phaseolus vulgaris) each 1 cm^2 , were sprayed with a constant droplet size and concentration but varying droplet numbers. Mortality was recorded and the median lethal dose per disc was calculated using probit analysis.

Less than 10% of mite eggs were hit directly with spray, so egg mortality was largely dependent on dicofol spreading from the droplets across the disc.

The relationship between LD_{50} and droplet diameter for mite eggs was positive and curvilinear: at any one concentration LD_{50} was directly proportional to the square root of active ingredient (a.i.) per droplet. Thus the smaller the droplet, the more efficient the spray. However, there was an optimum dicofol concentration of about 1%, the efficiency decreasing with higher or lower concentrations. These relationships could be expressed by the following equation:

$$\text{LD}_{50} = b \left(\sqrt{\text{a.i.}} - z \right)$$

where 'b' is a slope dependent on concentration efficiency and

'z' is a constant.

Relationships between droplet diameter and LD_{50} showed that 20, 60 and 100 μm droplets required 1.6, 5 and 10 times more pesticide respectively than the theoretical optimum; while if 50 μm droplets of 0.5, 1 and 4% dicofol were sprayed against eggs, 5, 4 and 19 times more chemical would be required.

Similar 'square root' a.i. against LD_{50} relationships were also found with larvae. With protonymphs LD_{50} was directly proportional to $(\text{a.i.})^{1.12}$. 20 μm droplets of 1% dicofol were most efficient for larval control with an LD_{50} of 5 ng/cm^2 . However, droplets of this size and concentration gave an LD_{50} of 6 ng/cm^2 for protonymphs and 13 ng/cm^2 for eggs indicating that larvae are the most susceptible.

On pepper (Capsicum annuum) discs (using only 1% dicofol against eggs), it was found that about 2 times more chemical was required than on beans.

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INTRODUCTION

Pesticides are generally applied inefficiently (Graham-Bryce, 1977) but few studies have attempted to reduce wastage of these very active biocides. Most are applied as sprays with water as the diluent. Development of spraying methods dates to the end of the last century when equipment was made to apply Bordeaux mixtures to grapevines (Lodeman, 1896). Pesticides were diluted in very large volumes of water and sprayed so as to completely cover the foliage, inevitably much of the spray liquid could not be retained on the leaf and other plant surfaces. Such spraying to "run-off" was labour intensive so, as labour costs increased, new techniques were introduced to apply smaller volumes of spray. Weight considerations, particularly for aerial spraying, meant that operational costs of high volume spraying were very high and so increased the need to change to low volume application. In terms of amount of active ingredient (a.i.), this meant increasing the concentration of the spraying liquid in order to maintain the same mass application rates.

Logically, efficient use of a new pesticide would be studied to determine not only the appropriate dosage, but also the concentration of spray and volume needed for particular crop and spray situations. In practice, once the typical hydraulic sprayer had been established, it was assumed that all new pesticides would have to be applied by the same equipment. Thus screening of new insecticides and field trials data are based on high volume spraying.

Now, new application techniques are available to apply considerably less spray volume and these provide greater control of droplet

size. There is, therefore, greater incentive to study the interactions between droplet size, spray concentration and droplet density on targets. With new pesticide formulations, the biological effect is the important factor in determining its optimum use. This study, therefore, aims to determine the effect of size and pesticide concentration of small droplets on their biological efficiency.

The glasshouse red spider mite Tetranychus urticae (Koch) was chosen as the test organism and in each experiment eggs, larvae or protonymphs were sprayed with monosized droplets of oil based formulations of dicofol on French bean or pepper leaf surfaces.

LITERATURE REVIEW

Spraying techniques are often classified according to the volumes used in application. Maas (1971) classified them into High Volume (HV), Low Volume (LV) and Ultra-Low-Volume (ULV) (i.e. HV = >400 l/ha; LV = 5-400 l/ha and ULV = <5 l/ha). Matthews (1979) reclassified spraying techniques, differentiating between volume used for field and tree crops; and Fryer, Makepeace and Fearon (1977) suggested a classification for herbicide spraying which was essentially similar to that for field crops (Table 1).

Table 1: Classification of spraying techniques

Spraying technique	Volume application rate (l/ha)		
	Insecticides, Acaricides, Fungicides		Herbicides
	(Field crops)	(Tree crops)	(Weeds)
High volume (HV)	> 600	$>1,000$	> 700
Medium volume (MV)	200-600	500-1,000	200-700
Low volume (LV)	50-200	200-500	50-200
Very low volume (VLV)	5-50	50-200	10-50
Ultra-low-volume (ULV)	<5	<50	1-10

The high volume technique is still widely used although it is extremely labour intensive and inefficient. In Europe, however, medium volume sprays are more common. In HV and MV spraying, the crop is usually treated to "run off". Such a spray contains large droplets which can contain over a million times more chemical than the smallest. Rapid sedimentation of these large droplets results in their impingement, mostly on the upper exposed horizontal

surfaces or penetration down to the soil beneath. The 'lives' of water droplets are short in hot dry weather, thus Amsden (1962) showed that a 100 μm droplet may exist for only 50 seconds at 20°C, 80% RH and 14 seconds at 30°C, 50% RH. So, with pesticide sprays, the residue of concentrated pesticide is an aerosol particle of less than 10 μm which is liable to drift and pollute areas at great distances from the treated site. This is especially noticeable with certain hormone-type herbicides when susceptible crops are damaged, but is also important where pesticides kill bees and other beneficial insects. Despite large volumes of sprays, pests which are often on the undersides of leaves or in concealed habitats do not come into contact with the pesticide and so survive.

In recent years, more expensive labour has encouraged ULV application. The ULV technique originated in the control of the desert locust Schistocerca gregaria (Forsk) in East Africa shortly after the Second World War (Sayer, 1959). Rapid treatment of vast areas can be achieved so the technique is especially suited for regions where water is scarce and transportation of large volumes of spray liquid is a problem. Adequate crop coverage is possible with extremely small volumes, provided droplets are small and present in sufficient numbers to cover the target plants without being too small to minimise drift (Smith and Burt, 1970). Special formulations with higher pesticide concentrations were necessary to ensure effective pest control at such low volume rates. The formulations were usually oil based although sometimes pure pesticides were used (Barlow and Hadaway, 1974).

After its successful use against the desert locust in East Africa, the ULV technique has been used against a variety of pests, including glasshouse pests like the whitefly, Trialeurodes vaporariorum (Westwood) (Leyen, 1973; Fuller-Lewis and Sylvester,

1974; Mboob, 1975) and leaf miners on outdoor vegetables such as celery and lettuce. In America, ULV chlorobenzilate or hexachlorophene sprays were more effective against spider mites on citrus trees than conventional high volume sprays (Wright, 1978). In the UK, a number of apple pests such as Rhopalosiphum insertum (the apple grass aphid) and the apple scab disease, Venturia inaequalis, were controlled using the ULV method, but effective control of the apple mildew, Podosphaera leucotricha, has so far been achieved only on seedlings in the laboratory and not on trees. (Morgan, 1975, 1981; Cooke, Herrington, Jones and Morgan, 1976). The spruce budworm, Choristoneura fumiferana (Clem), on softwood forests in Canada is being successfully controlled by ULV sprays of fenitrothion and aminocarb (or Bacillus thuringiensis sprays in areas where environmental pollution is a sensitive issue) (Armstrong, 1981). In Nigeria the technique was as effective, and preferable to, conventional low volume sprays against cowpea pests (Raheja, 1976) and against tomato leaf diseases (Quinn, Johnstone and Huntingdon, 1975). Public health pests such as mosquitoes (Lofgren, Ford, Tonn and Jatanesen, 1970) and tsetse flies (Lee, Pope and Bowles, 1975) have also been successfully controlled using the ULV technique.

Different types of equipment have been used to apply ULV sprays from aircraft and ground machines. Aircraft were fitted with spinning cages (Micronair units), particularly for locust control. Subsequently simple hand-carried, battery operated spinning disc sprayers (Matthews, 1981), some fitted with fans (Fuller-Lewis et al., 1974, 1978; Boize, Matthews and Kuntha, 1975), or adapted knapsack mist blowers (Clayphon, 1974; Thornhill, 1974; Arnold and Thornhill, 1979), have been used by individual farmers, especially in tropical countries and in glasshouses in

Europe. ULV sprayers such as the Turbair Tot, the Micro-Gen and the Micron ulva, produce a narrower range of droplet sizes (Mboob, 1975; Fuller-Lewis et al., 1978), the mean size for spinning discs being inversely related to the speed of rotation (Bals, 1975; Boize et al., 1975). Tractor mounted ULV sprayers such as the KWH Bora are also available.

A cost comparison of the MV and the ULV techniques for the control of cotton pests in Malawi (Huntington and Johnstone, 1973) showed that ULV was more expensive when up to 3 l/ha of special low volatility formulations was needed. Wettable powders sprayed by ULV sprayers were equally effective, cheaper and used smaller quantities of water (— 15 l/ha) than conventional MV (200 l/ha) spraying. Thus Mowlam, Nyirenda and Tunstall (1975) recommended the use of water-ultra-low-volume (WULV) spraying in Malawi. Similar assessments resulted in its introduction in the Gambia (King, 1975). Promising results with the WULV method were also obtained when the fungicides carbendazim and chlorothalonil were applied against Cercospora spp. on groundnuts (Mercer, 1976). This system has considerable potential for peasant, small farmers in the tropics (Matthews, 1981) provided efficient servicing of the machines and supplies of batteries and spare parts (especially motors) is ensured. At voltages less than 6V, atomisation of the aqueous suspension becomes inefficient, reducing effective coverage. Thus, when applying aqueous suspensions it is essential to ensure sound batteries to prevent misuse and poor pest control.

The pest's nervous system is the ultimate target in insect or mite control with most insecticides. Unless spray droplets are deposited directly onto the arthropod, it is usually necessary to contaminate the habitat and/or food supply to achieve pest control (Ebeling, 1963; Bals, 1973). A totally efficient application

technique would theoretically put an exact dose on each individual (Graham-Bryce, 1977). In practice, however, up to 99.9% a.i. may be wasted. Rainey and Sayer (1953) found that a spray of 220 μm mmd dinitro-ortho-cresol droplets used against the desert locust was only 0.1 to 1% as efficient as a theoretical, ideal spray of 100 μm mmd droplets applied such that the individual locusts were dosed at 60 μg per locust. In practice, the kill resulted from an average dose of 1,000 μg per locust (> 16X overdose). Eighty percent of the measured mortality was due to droplets smaller than 100 μm in diameter and yet these formed less than 30% of the total spray volume. Joyce (1962) found that, even with efficient application, when locust swarms were directly sprayed, only 5% of the applied a.i. could be recovered. Such inefficiencies are inevitable when crops are sprayed to "run off" or when the operator's objective is to achieve total uniform coverage of the crop with a sprayer that can, at best, cover only exposed surfaces.

Improvement of pesticide application efficiency requires a fresh examination of the subject to determine where new technology or a new understanding of the processes of pesticide transfer can lead to better utilisation of the chemicals. Studies of physical and chemical properties of pesticide formulations which affect atomisation (David, 1946; Maas, 1970; Maas and de Lange, 1970) and of the influence of environmental conditions on droplets during their travel and deposition (La Mer and Hetchberg, 1949; Maas, 1971, 1972; Johnstone, Wische and Smith, 1949; Yeo and Thompson, 1954) have already been made. Techniques developed for sampling and measuring droplets (Cooke et al., 1976; Dunn and Walls, 1978; Himel, 1969; King and Johnstone, 1973; Lofgren, Anthony and Mount, 1973; Matthews, 1975, 1975a; Pieper, 1972; Roberts, Lyon, Page and Miskus, 1971; Russell and Mullins, 1969; Stafford, Byass and

Akesson, 1970; Yates and Akesson, 1963) enabled analysis of droplet deposition on target surfaces. Having studied production, travel and deposition of droplets, an evaluation of their effects against target pests should have followed logically, thus relating pesticide application directly to mortality. Attempts to investigate the biological efficiency of droplets were often unsuccessful because the available atomisers produced droplets of a wide size range. This made it impossible to relate size or number to mortality; sizes being measured and described in only average terms (vmd, nmd, mmd, or as vmd/nmd ratios)*. Sometimes droplet size was calculated from applied volumes and application rates (Hall and Reichard, 1978), or estimated from deposit photographs (Fisher and Morgan, 1968). For lack of more suitable alternatives, the amount of active ingredient causing a particular level of mortality was sometimes determined using extracts from artificial targets placed in the sprayed area (Hall et al., 1978). Another method analysed the amount of pesticide deposited from solvent soaked cotton-wool mops wiped over sprayed targets (Chiba and Herne, 1975) or by GLC analysis of extracts from sprayed targets (Armstrong, 1981). Sometimes a dye incorporated in the spraying liquid enabled colorimetric determination of a.i. on sampled targets to estimate the amount causing mortality (Johnstone, 1977, 1977a). Thus, estimates of dosages causing particular mortalities (i.e. evaluation of the

* FOOTNOTE: Mean droplet diameter can be measured in terms of volume as the volume median diameter (vmd), or numbers as number median diameter (nmd), or mass as mass median diameter (mmd).

pesticide's effectiveness) were imprecise.

Increasing costs of pesticides and the need to reduce environmental pollution are encouraging the adoption of a more logical approach to application technology (Matthews, 1977). Sayer's (1967) suggestion that biological targets for ULV sprays should be precisely defined and that optimum droplet sizes and formulation requirements for specific targets should be predetermined through both laboratory and field trials has been repeated by other scientists (e.g. Matthews, 1977, 1977a, 1979, 1979a; Joyce, 1979; Bals, 1973; Graham-Bryce, 1977). Instead of basing application rates on ground area of the crop, indices such as "leaf-area index" are now considered more appropriate and, rather than regarding the whole crop as the target, a precise definition of the pest target within the crop is required. Definition of the "spraying target" might involve identifying the most vulnerable developmental stage of the pest, its habits and habitat as well as the response characteristics in terms of lethal dose for a specific pesticide. In the past, small droplets ($< 50 \mu\text{m}$ diameter) were difficult to detect, so their role in pest control was not fully understood (Himel, 1969a). However, droplets collected on the undersides of leaves and in the concealed habitats of bollweevils and bollworms were less than $40 \mu\text{m}$ diameter (Himel, 1969a). Droplets on dead bollweevils were estimated to be $21 \mu\text{m}$ in diameter so Himel concluded that the optimum size for insecticide droplets was about $20 \mu\text{m}$ diameter. Sprays with a vmd under $20 \mu\text{m}$ were more efficient than the high volume technique previously used to control the glasshouse whitefly (Lindquist, 1974). Mboob (1975) also showed that $20 \mu\text{m}$ vmd droplets of resmethrin were more effective against whitefly than those $78 \mu\text{m}$ in diameter. Owen and Bennett (1978, 1978a) measured the sizes of droplets deposited on whitefly larvae

on undersides of leaves and concluded that the optimum droplet size for whitefly control was in the range 15-25 μm mmd. Himel and Uk (1975) suggested that for each pesticide/pest situation, the 'Biological Optimum Spray droplet size' (BOSS) should be identified. They defined this as "that size droplet which delivers sufficient insecticide mass to the actual biological target in its natural environment to satisfy pest control requirements". A survey of available data showed that this optimum size was usually between 15 and 80 μm in diameter.

Theoretically, the most efficient spray would result from spraying homogeneous droplets of the optimum droplet size. Entomologists are already theoretically advocating the development of target specific pesticide application methods based on pre-determined target doses (Joyce, 1979). Thus Controlled Droplet Application (CDA) defined as the use of a predetermined appropriate droplet size and density to achieve economic pest control (Matthews, 1979) is being strongly urged. However, in practice, commercial sprays have wide droplet spectra (15-300 μm diameter or even a D-max value of 950 μm). In such sprays, droplets of the optimum size form less than 2% of the spray volume (Himel, 1969). Thus, production of the BOSS would lead to a great improvement in application efficiency.

Centrifugal energy nozzles (spinning discs) can produce droplets within narrow size spectra and the sizes can be adjusted by varying the rotational speeds of discs. Bals (1975) developed a spinning disc CDA sprayer (the 'Herbi') that produces 300 μm diameter droplets at 1500 revs/min and 250 μm droplets at 2000 revs/min and is used in weed control. Pre-emergence sprays of herbicides, formulated in water, applied as 250 μm diameter

droplets at very low volume rates (20-40 l/ha) with a CDA sprayer were as effective as conventional medium volume (640 l/ha) applications against the weeds; Polygonum lapathifolium, Chenopodium album and Matricaria matricariodes (May and Ayres, 1978). Thus, in CDA, wettable powders and emulsifiable concentrates may be used and volume requirements need not necessarily be at ULV rates. CDA emphasizes the use of the correct droplet size and the importance of these being uniform to optimise the use of the minimum volume and dose so as to achieve effective control. Only when control is achieved by a chemical sprayed at ULV rates, as droplets of a narrow size range, are ULV and CDA synonymous (Matthews, 1981). The development of an electrostatic sprayer, which can generate small electrically charged droplets of remarkably uniform size and achieve a high recovery index on natural targets (Coffee, 1979), should enable real progress to be made in improving the efficiency of pesticide application with small droplets and thus further advance the utilisation of controlled droplet application.

Studies on the relationships between various spray parameters such as droplet size, concentration, density and pest responses (e.g. mortality) would improve our understanding of the mechanisms governing the efficiency of sprays and so improve methods of application. Frick (1970), using 100, 175 and 400 μm diameter droplets of dinocap, at five concentrations, from 0.002 to 0.05% a.i., showed that 175 μm droplets were most effective (i.e. 175 μm > 100 μm > 400 μm) against apple powdery mildew. At a constant droplet size, the more dilute solutions were most efficient. However, the lower the concentration, the less important droplet size became. Hilsop and Baines (1979) using 180 and 330 μm

diameter copper oxychloride droplets against the fungus Botrytis fabae on bean leaves, arranged spray and pest parameters in order of importance as follows:

Droplet Density > Droplet Size > Pest Size

In the control of the cotton leafworm Spodoptera littoralis (Boisd) using ULV sprays Reay and Ford (1977), Ford and Reay (1977) found that effectiveness of permethrin was inversely related to droplet diameter if droplet density and mass application rates were kept constant. The effect of droplet density on contact toxicity was too low to be of practical importance although the choice of density was important if the insecticide was applied as a protectant. Mortality increased with time of exposure such that a low droplet density/low mass application rate combination increased the response. Mortality also increased at larger mass application rates. Such fundamental studies are vital in determining methods of increasing a pesticide's effectiveness. Since, for most crop pests, the biologically optimum droplet size is said to be in the range 15-80 μm (Himel et al., 1975), spray parameter/pest response studies in the present work were done with small droplets.

Tetranychus urticae and its control

The red spider mite, Tetranychus urticae (Koch) (Acarina: Tetranychidae), is the principal pest of glasshouse cucumbers in Great Britain and is a serious pest throughout the world, on other glasshouse crops (Hussey, Read and Hesling, 1969). It also attacks many outdoor crops in the subtropics causing speckling of foliage and stunted plant growth. T. urticae produces silk webbing which may cover the growing point of the plants, interfering with growth and, in ornamental plants, making flowers unsaleable. The pest

multiplies rapidly; each female laying up to 100 eggs over 3 weeks. These hatch into six-legged larvae and then develop into 2 eight-legged immature stages: the protonymph and deutonymph. Each immature stage has an active and a resting phase. The developmental period varies between 9 days at 32°C to 38 days at 10°C (14 days at 23°C, the experimental temperature used). There is a succession of generations from March to September before "short day length" hibernation occurs (12½ hours being the critical day length) (Hussey et al., 1969).

Although biological control is widely used in glasshouses, many species of Tetranychid mites need to be controlled chemically especially on citrus and cotton.

Properties of dicofol against *T. urticae*

The acaricidal properties of dicofol (Kelthane) have already been thoroughly studied. Baker and Maughan (1956) and Garmus and Unger (1956), working extensively both in the laboratory and in the field, found that dicofol, having a rapid contact action, was extremely toxic both to *T. urticae* and a wide range of other mite species. Dicofol was more toxic to eggs and mobile stages of *T. urticae* than other acaricides such as dicrotophos, methidathion and methyl parathion when applied at comparable concentrations (Chamkrachang and Brook, 1970). Residues persisted for 9-12 weeks and no phytotoxicity was reported on a wide range of plants including beans, apples, peaches and tomatoes (Baker et al., 1956). Dicofol is not insecticidal and, at recommended dosages, was safer to warm blooded animals such as rats than DDT (Garmus et al., 1956).

More detailed laboratory studies assessing the effect of droplet size, number of droplets and spray concentration have been

reported. When large droplets ranging from 575-1560 μm in diameter were used with very dilute formulations (0.023 to 0.092% a.i.), the smaller droplets proved more effective (Fisher and Morgan, 1968; Fisher and Menzies, 1973; Fisher, Menzies, Herne and Chida, 1974). With uniform 575 μm diameter droplets, increasing spray concentration from 0.023 to 0.092% a.i. did not increase T. urticae mortality if 6 or 50 droplets per cm^2 were applied but increased the response if 25 droplets per cm^2 were used, suggesting that droplet density was an important parameter in determining the effect of dicofol against T. urticae and that spray concentration was comparatively less important.

The present study investigated the relationships between droplet size, density and chemical concentration in relation to the biological effectiveness of dicofol applied as small droplets (< 150 μm in diameter) against T. urticae. The aim was to provide some understanding of the efficacy of small droplets which could possibly lead to an improvement of existing application equipment or the development of new and more efficient application systems.

MATERIALS AND METHODS

Culturing mites

The glasshouse red spider mite T. urticae was cultured on four to five week old Phaseolus vulgaris cv. Prince, (French bean) plants, in a glasshouse at 22°C. Day length was supplemented with fluorescent light to give 16 hours to prevent diapause in the mites (Hussey et al., 1969).

Leaf discs (each one cm²) without main veins, were cut from uninfested bean or pepper (Capsicum annuum) leaves using a No. 6 cork borer, and placed inverted on wet cotton wool in petri dishes. Fifteen to twenty adult female mites were transferred individually onto each disc with a fine sable hair brush. All such cultures were maintained in a dark incubator at 23°C ($\pm$ 2°C) and 75% RH (70-85% RH). Temperature and humidity were recorded with a Cassella thermohydrograph. The period during which females were allowed to remain on the discs for egg laying depended on subsequent experiments, i.e. 18 to 20 hours for egg experiments and 5 to 6 hours for those with larvae and nymphs. Treatment of eggs was made immediately after removal of the females while that of larvae or nymphs was done after 5 or 7 days of egg incubation, respectively.

Spraying solutions

Oil based formulations were used in all experiments. Each spraying solution contained three main components: a carrier, a fluorescent tracer and the active ingredient.

A mixture of methylene chloride (75%) and risella oil (25%), known as VK1^(R) was the solvent in which fluorescent tracer, calcofluor white^(RW) powder, and the acaricide, dicofol, were dissolved.

The tracer (1 g) was first dissolved in 5 ml acetone and diluted to 20 ml with VK1, producing a 5% stock solution (i.e. 0.05 g/ml).

A 46.6% solution was prepared by dissolving 54.8 g technical dicofol (85% a.i.) in 100 ml VK1. 21.5 ml of this solution was diluted to 100 ml with VK1 producing a stock solution containing 0.1 g/ml (a 10% solution).

The 10% stock solution was further diluted to give 4%, 2%, 1% and 0.5% a.i. spraying solutions. Lower concentrations (i.e. 0.25% and 0.05% a.i.) were made by diluting the 0.5% solution (Table 2).

Table 2. Volumes of component solutions used to produce spraying solutions

Spraying solution concentration % ai	Dicofol stock solution (10% ai) ml	Calcofluor-white stock solution ml	VK1 ml	Total volume of spraying solution ml
4	4	3	3	10
2	2	3	5	10
1	2	6	12	20
0.5	2	12	26	40
0.25	5*	2	3	10
0.05	2*	5	13	20

* To make these solutions, 5 and 2 ml of 0.5% dicofol solution was used in place of the stock solution.

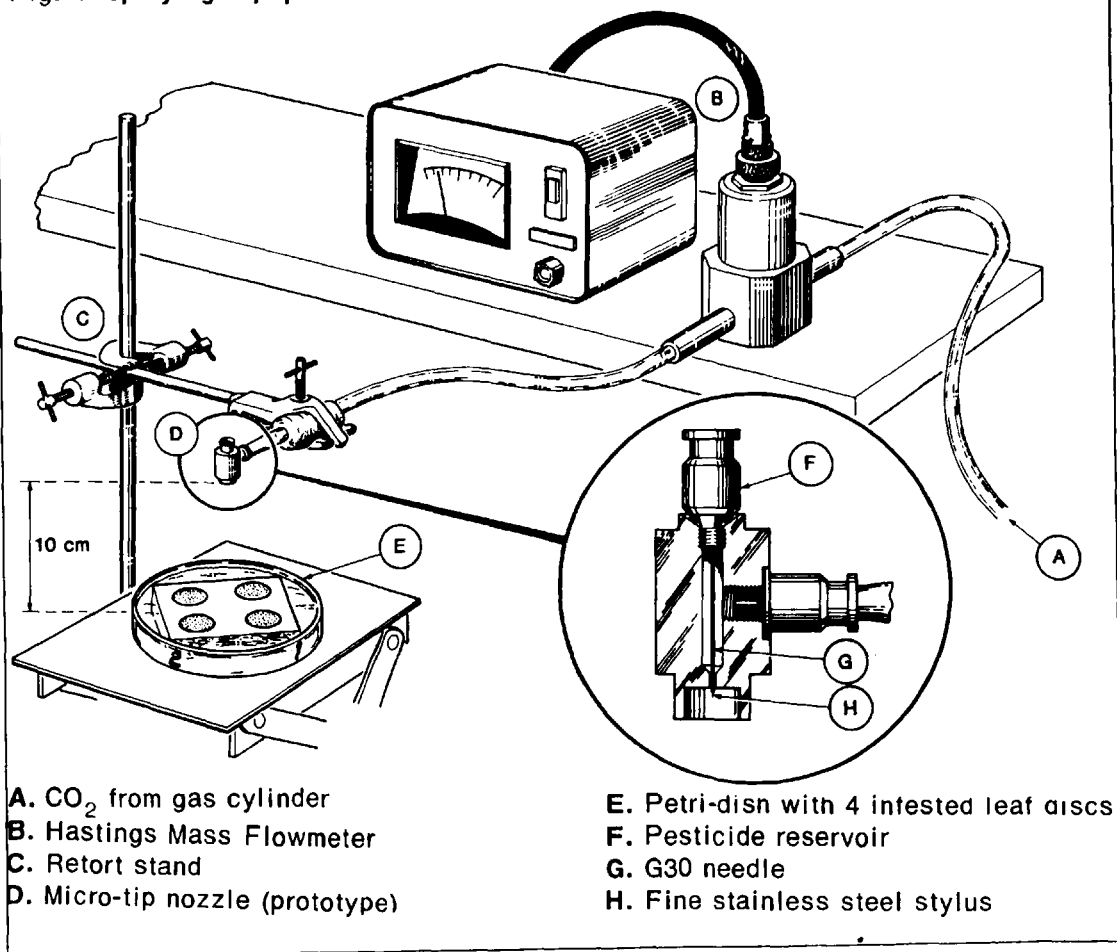
When not in use, all solutions were kept in sealed, graduated glass test tubes in a refrigerator at 1°C. New solutions were prepared every 2 weeks to prevent any deterioration.

Spraying equipment

A prototype of the twin fluid Micro-Tip nozzle (D in Fig. 1) (Uk, 1978) was used to produce as near monosized droplets as possible by using a rapid flow of carbon dioxide to shear a slow moving column of spray liquid from the tip of a fine stylus (H). The liquid was fed by gravity from a small reservoir (F) through a G30 needle (G) onto a fine central stylus (H) in the orifice of the chamber.

Monosized droplets could be produced within the range 20-150 μm in diameter by adjusting the flow of CO_2 (A) from 200 to 400 cm^3/min with a needle valve. The flow of gas was measured with a Hastings Mass Flowmeter (B). Smaller droplets were produced at higher gas flow but the range of droplet size could be modified also by raising or lowering the stylus within the orifice, thus raising the stylus tending to produce smaller droplets.

Fig.1. Spraying Equipment



A narrow range of droplet size was not produced if flow rates were less than $200 \text{ cm}^3/\text{min}$ or greater than $400 \text{ cm}^3/\text{min}$.

Regular cleaning of the delicate equipment, in acetone, was necessary and when the nozzle was not in use, it was kept submerged in acetone in a sealed jar.

Bioassay technique

Dosing procedure. Twenty labelled discs with known numbers of uniformly aged mites, as eggs, larvae or nymphs, were sprayed with monosized droplets of dicofol, in each experiment. Twelve similar discs were left untreated (as controls). Each disc was sprayed individually with the nozzle placed 10 cm above (Fig. 1). The period of spraying was varied to provide different droplet densities.

Samples of droplets were collected on magnesium oxide coated slides (May, 1950), both immediately before treating the first disc and after each spraying. Droplet sizes on both slides were measured using an eye piece graticule in a high power binocular microscope (Cooke microscope at 200 or 800X magnification). Two hundred droplets were measured from each of 10 experiments and showed that variation of droplet diameters was minimal ($\pm 2 \mu\text{m}$).

Droplets on each disc were counted with a stereo dissecting microscope illuminated by UV light (Wild microscope at 24X magnification), immediately after spraying. The number of mite eggs, larvae or protonymphs, directly hit by the spray was also counted.

Assessment of effect of dicofol on T. urticae

Eggs. Egg mortality was determined six days after spraying when those which remained unhatched were considered 'dead'.

Larvae and Protonymphs. Larval and nymphal mortality was assessed 48 hours after spraying. Mites that had already developed into the next instar (i.e. protonymph or deutonymph, respectively) were considered to be alive. Each of the mites remaining in the treated instar was observed under a dissecting microscope while being probed with a single hair from a fine sable brush. Mites that walked or moved their limbs were also classed as alive while those that showed no response were regarded as 'dead'.

RESULTS AND DISCUSSION

Dosage measurements used to evaluate the efficiency of dicofol droplets

Dosage parameters used to evaluate efficiency of droplets included:

LD_{50} : The median lethal dose in ng per cm^2 and estimated by probit analysis.

LN_{50} : The LD_{50} expressed as number of droplets per cm^2 .

Biocidal area: Assuming an LD_{50} value represents 50% effective coverage by the amount of active ingredient applied, the biocidal area per droplet is equal to half the treated area divided by the LN_{50} value (i.e. $0.5 \text{ cm}^2 \div LN_{50}$).

Eggs

Relationship between mortality of *T. urticae* and droplet density at constant droplet diameter and chemical concentration.

The proportion of mite eggs directly hit by droplets during spraying was invariably less than 8% even when high droplet densities (up to 151 per cm²) were used (Fig. 2, Table 3). Corresponding mortalities on treated leaf discs, however, were much greater than could be accounted for by 'direct hits'. Thus the contribution of 'direct hits' to mortality of these small, stationary target was negligible. Obviously death of those eggs that had been missed by droplets resulted from contact with dicofol spreading from the initial deposition sites on the leaf surface. Mortality, therefore, depended mainly on spread of the active ingredient. Thus sprays which spread more efficiently over the leaf surface are likely to be more effective. If eggs were the most vulnerable developmental stage (i.e. the biological 'spraying' target), use of an appropriate formulation would clearly improve the effectiveness of a pesticide which is essentially a contact poison.

Since monosized droplets were used in each experiment, plotting egg mortality against droplet density per disc was equivalent to plotting mortality against the amount of active ingredient per disc (i.e. equivalent to a dosage/mortality plot). Mite eggs showed a typical quantal response (Finney, 1952) (Figures 2 and 3). This response was observed in all experiments and the probit lines for four examples (two with 0.25% and two with 2.0% dicofol) are shown in Figures 4A and B. The probit lines at each concentration had similar slopes (Appendix Tables 1, 2, 3, 4, 5 and 6). In some experiments, however, mortalities in the twenty treated discs were in a narrow range, for example, when large

Fig.2. Relationship between mortality of *T. urticae* eggs and droplet density with 54 μm diameter droplets of 1% dicofol.

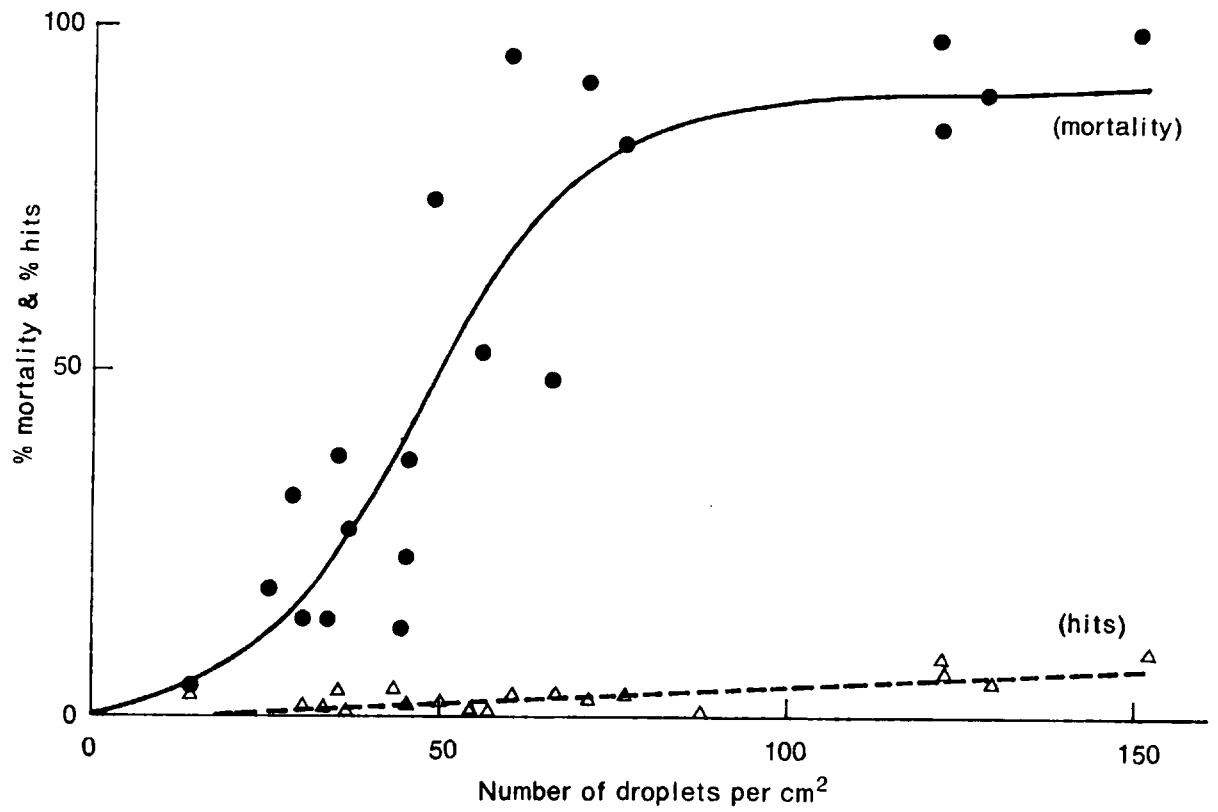


Fig.3. Egg mortality on probit scale against $\log_{10}$ number of droplets per cm^2

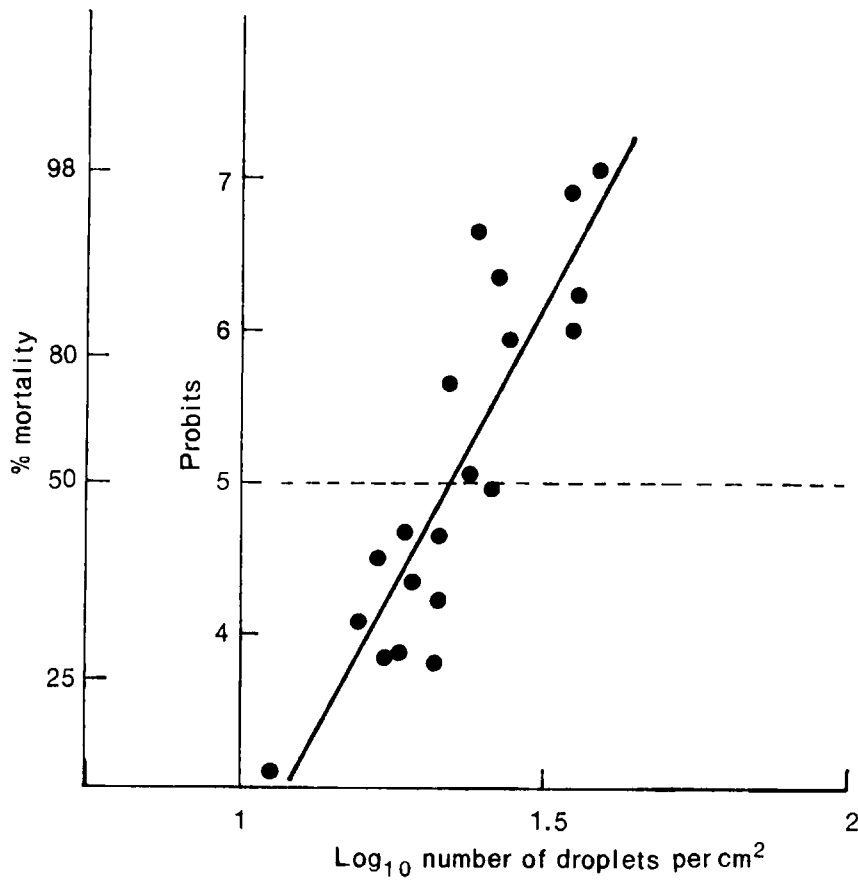


Table 3. Example data sheet showing measured and calculated values in each experiment

TARGET:		T. urticae eggs		DATA SHEET:		57	
SUBSTANCE:		Dicofol: 1.0% (a.i.)		DATE:		5.7.79	
DROPLET SIZE:		54 $\mu\text{m} \pm 2 \mu\text{m}$		GRAPH NO:		2 & 3	

	Disc no.	No.of targets	No. of drop-lets per disc	No. of targets hit	No. of targets dead	Total mortality (%)	% targets hit	% of spray hitting targets
E X P E R I M E N T	1	106	122	5	105	99	5	4
	2	148	151	12	148	100	8	8
	3	81	60	2	79	98	2	3
	4	96	49	1	73	76	1	2
	5	75	129	3	68	91	4	2
	6	83	71	1	78	94	1	1
	7	110	6	2	92	84	2	3
	8	108	122	6	93	86	6	5
	9	91	56	0	49	54	0	0
	10	83	36	0	23	28	0	0
	11	111	66	2	56	50	2	3
	12	92	45	1	35	38	1	2
	13	98	35	3	38	39	3	9
	14	80	13	2	4	5	3	15
	15	87	28	0	29	33	0	0
	16	54	25	0	11	20	0	0
	17	79	44	2	11	14	3	6
	18	82	45	1	20	24	1	2
	19	147	33	2	22	15	1	6
	20	130	30	1	19	15	1	3
C O N T R O L	1	51			0	0	LD ₅₀ = 41.15 ng FDL= 33.1-48.7 ng	
	2	129			2	2		
	3	48			0	0		
	4	88			2	2	Slope = 4.228 $\pm$ 0.216 r = 0.88	
	5	119			4	3		
	6	88			3	3		
	7	69			2	3	Where: FDL= Fiducial limits r= correlation coefficient	
	8	113			6	5		
	9	110			4	4		
	10	112			2	2		
	11	102			1	1		
	12	95			2	2		

droplets (108 μ m in diameter) of 2% dicofol were used, few discs had less than 50% mortality as indicated by the probit line in Figure 4B. LD_{50} was chosen because it provided a more sensitive comparison between different droplet sizes and concentrations.

Relating LD₅₀ to droplet size and concentration

Theoretically, when estimating an LD₅₀ value it is assumed that each individual pest comes into contact with the dose, but that the survivors are resistant at that dosage level. When such dosing is possible (such as with spraying to 'run off' or in experimental topical application) it would be logical to expect LD₅₀ for a particular pest (or at least a developmental stage of the pest) to be constant. With ULV sprays concentrated droplets are deposited as discrete deposits and so dosing of stationary targets like eggs depends on spread of a.i. from the initial deposits. Different sized deposits and/or deposits with different a.i. contents may have different spreading properties. It is, therefore, logical, with ULV sprays, to expect a relationship between LD₅₀, droplet size and concentration.

Increasing droplet size increased the LD₅₀ value (Figs. 4A and B, Appendix Tables 1-6), implying a reduction in efficiency of the spray. Plotting LD₅₀ against droplet diameter at each spraying concentration showed that there was a positive relationship which was linear (Fig. 5A, B, C, D, E, F and Fig. 6).

Fitted regression lines gave good fits but indicated negative intercepts for all except two concentrations. A negative intercept is illogical so direct comparison of these lines would not be valid. Thus it was necessary to find a more appropriate relationship between droplet size, concentration and mortality.

Fig.4. Results of individual tests showing the influence of droplet size on mortality of *T. urticae* eggs with different concentrations of dicofol

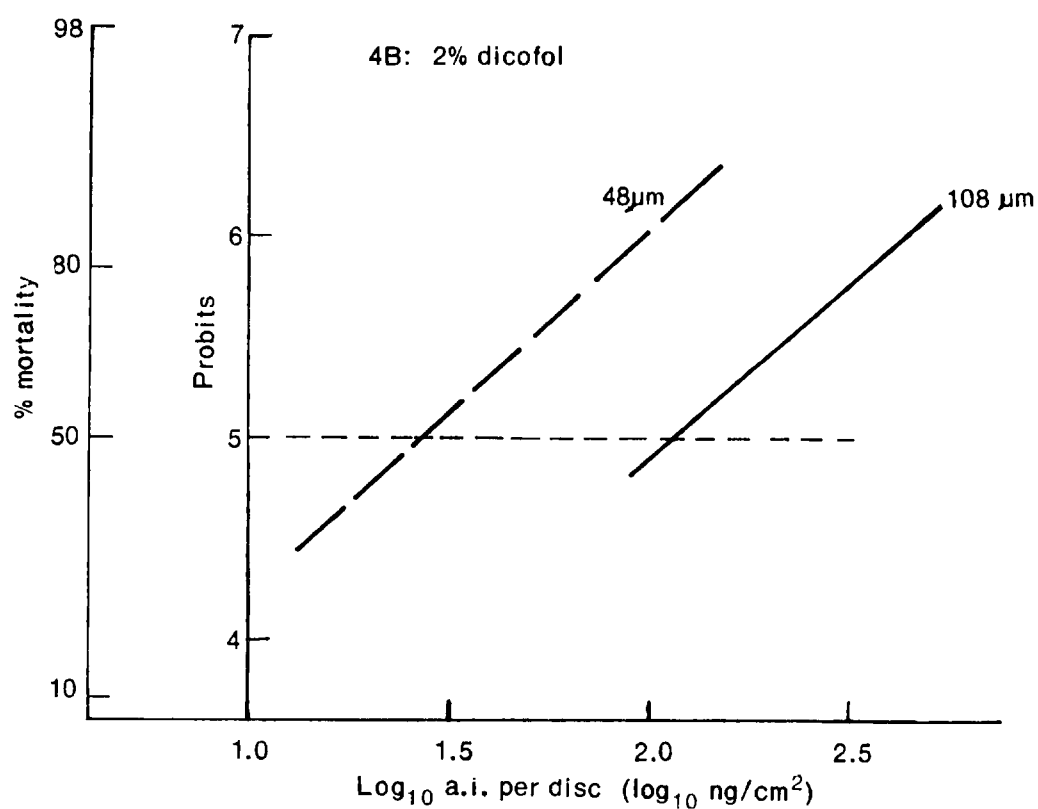
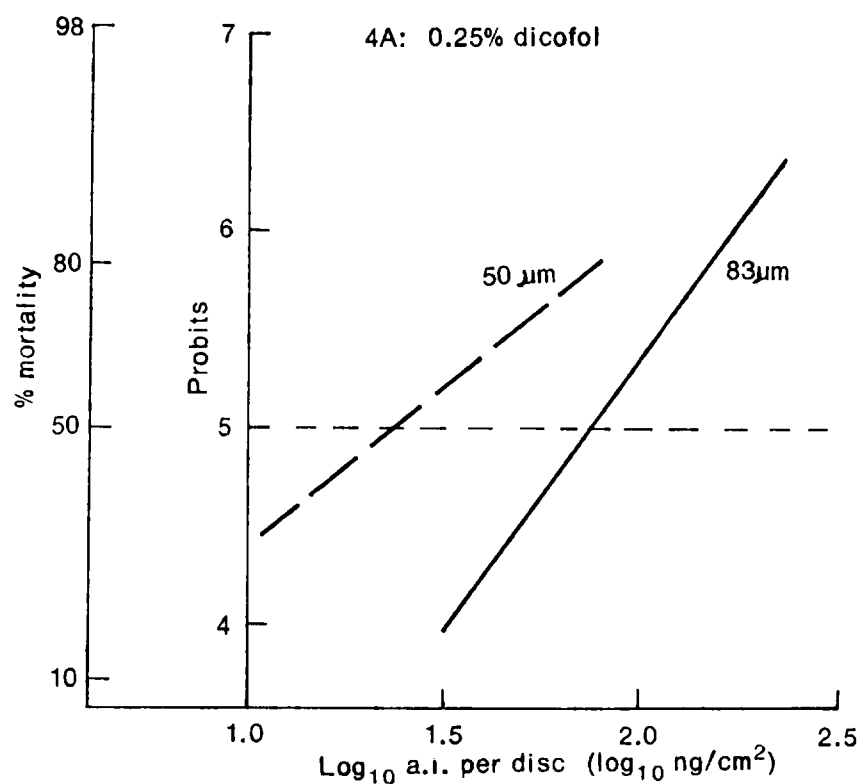


Fig.5. Combined results of all tests to show relationships between droplet size and mortality of *T. urticae* eggs with different spray concentrations.

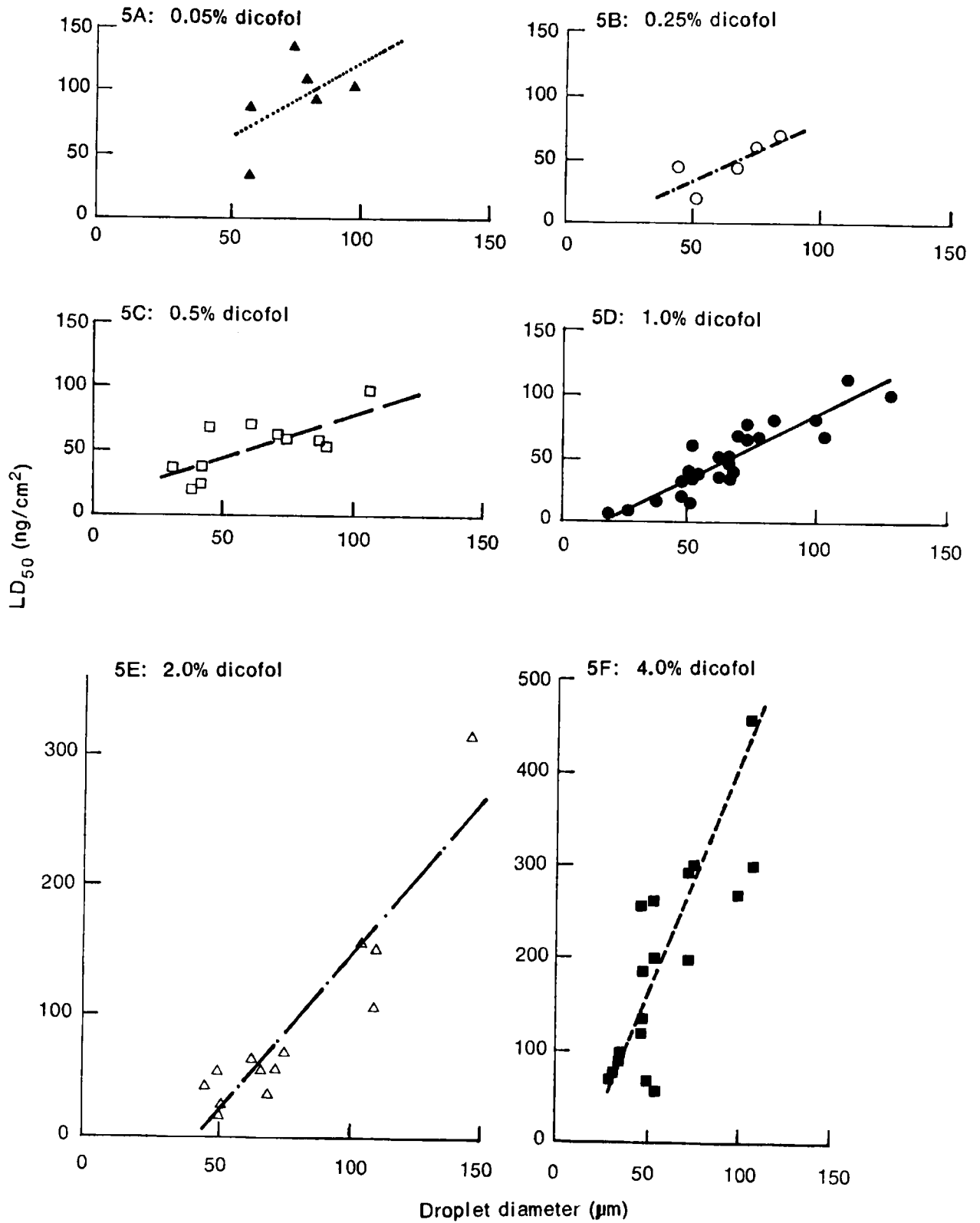
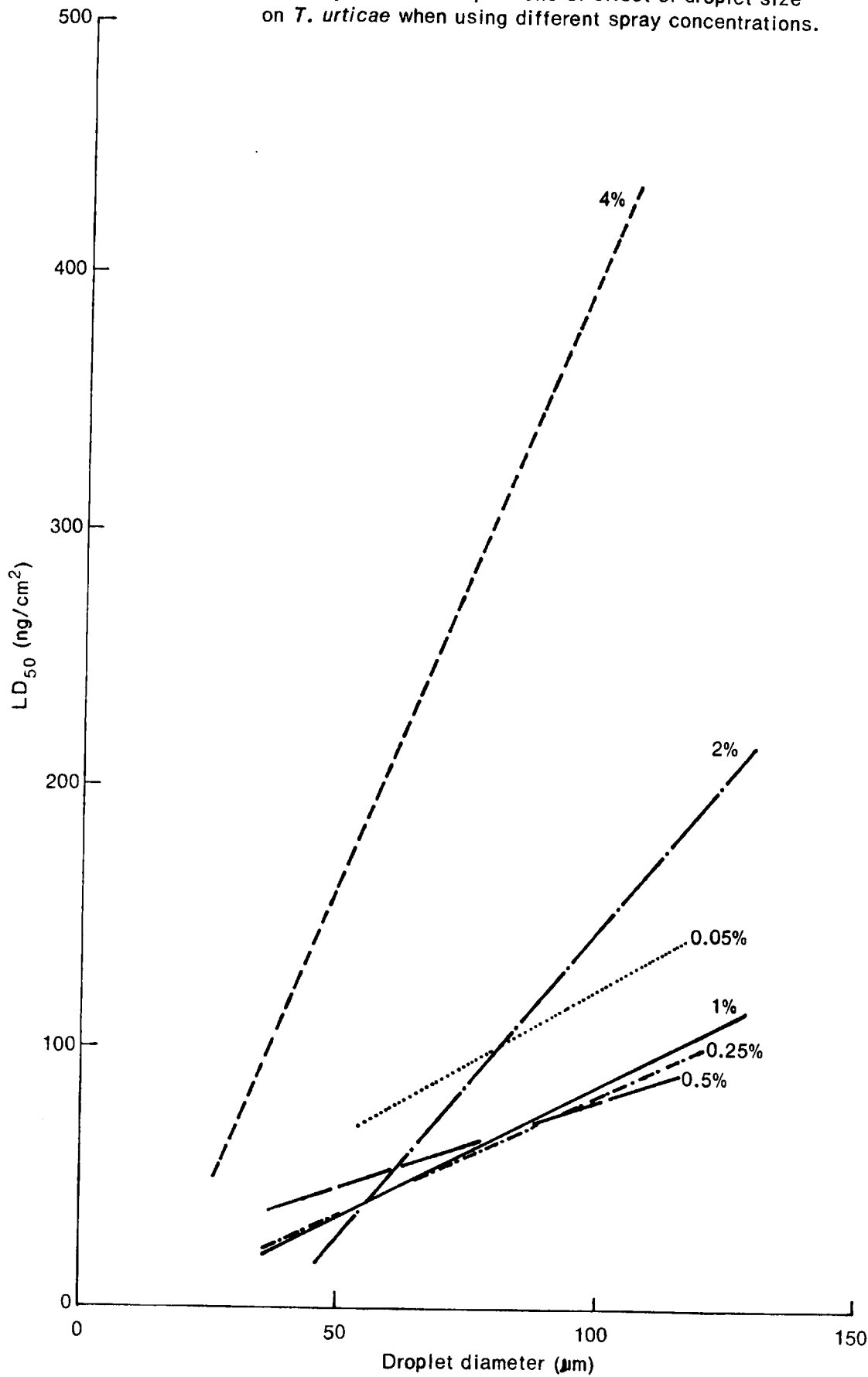


Fig 6. Summary to show comparisons of effect of droplet size on *T. urticae* when using different spray concentrations.



Development of a model relating spray droplet parameters to mite egg mortality

Criteria for choosing a model. In seeking a mathematical relationship to fit the droplet data, several criteria must be considered and, if possible, complied with. First, the relationship should be as logical as possible. Initially it was not known whether effectiveness was best expressed as LD_{50} values (i.e. for the whole spray effect) or as biocidal area (i.e. considering the area affected by single droplets). Similarly, the basic droplet parameter determining its effectiveness at any one concentration might be related to its diameter ($2r$), perimeter ($2\pi r$), volume ($\frac{4}{3}\pi r^3$), cross sectional area (πr^2) or surface area ($4\pi r^2$). The relationship could involve any combination of these. The droplet could spread over a particular area or perhaps a certain distance from the point of deposition. Since doses often act logarithmically it is as logical to expect $\log LD_{50}$ or $\log$ active ingredient to be involved as it is to expect LD_{50} or a.i.

Secondly, the model should preferably not produce any incongruities, even when extrapolated. Thus, any equation which indicates a negative biocidal area or LD_{50} value for a positive droplet size is clearly inadmissible. However, an infinitesimal biocidal area could result from an infinitesimal droplet, so a regression of biocidal area against droplet size could (or perhaps should) pass through the origin. On the other hand, an infinitesimal LD_{50} value is inconceivable since a 50% kill can hardly be expected unless there is a measurable dose. A response line involving LD_{50} should, therefore, pass above the origin.

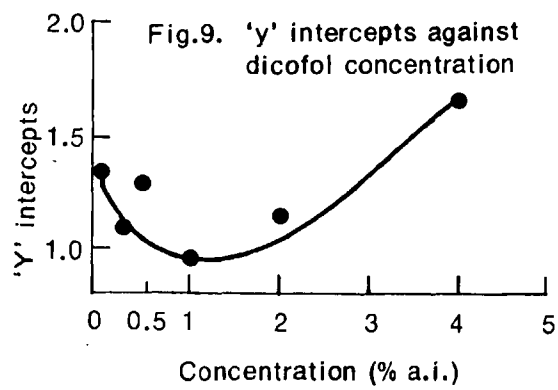
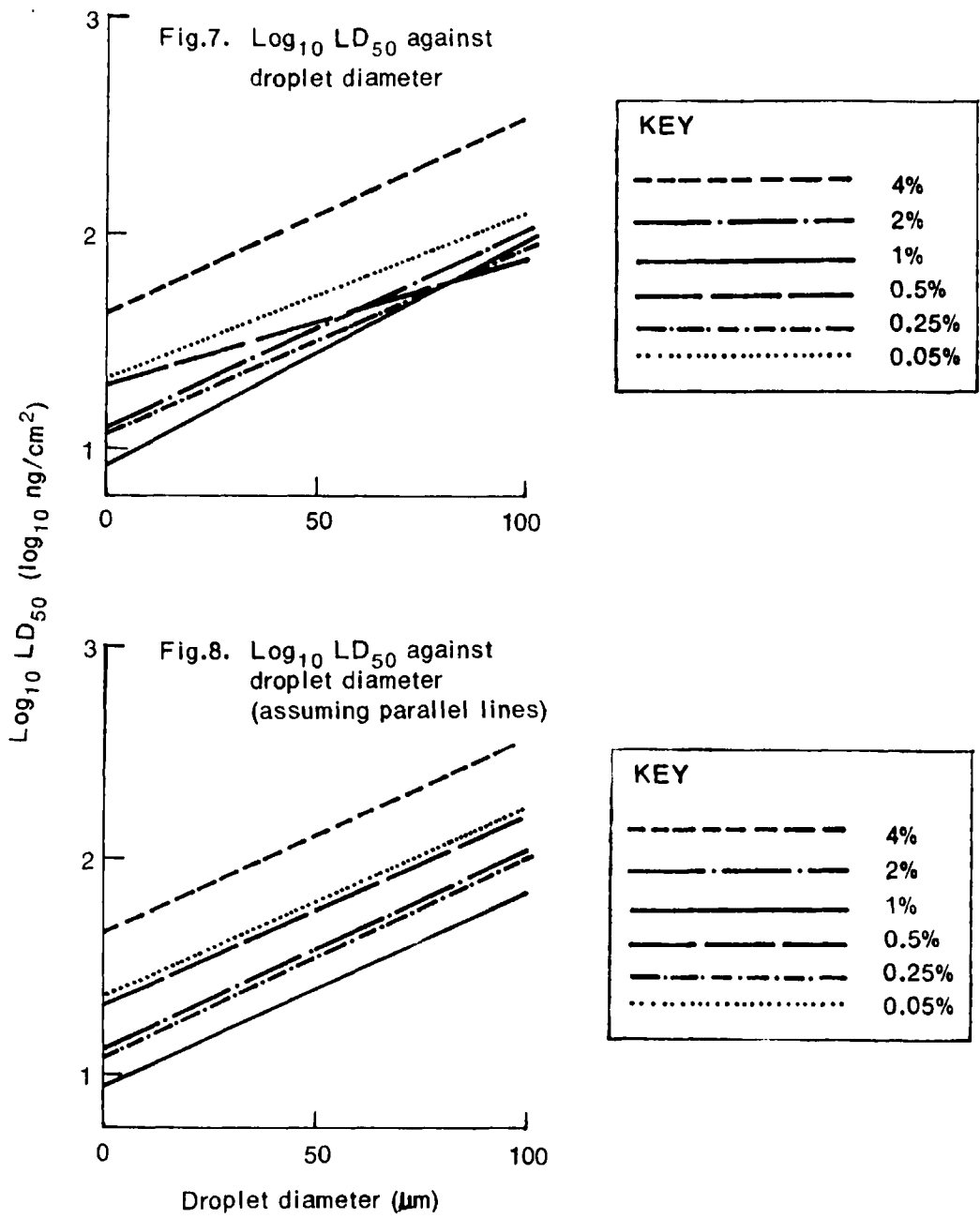
Thirdly, response curves fitted to the six concentrations should result in a logical "family" of curves, showing progressive

trends. Further, when expressed as straight lines, the relationship should be obvious: the lines preferably being parallel, convergent, divergent (perhaps from the origin) or even coincident.

Fourthly, the model should fit the data for all the concentrations as accurately as possible (measured by correlation coefficient) making due allowance for the variability which has been encountered. Not only should the model fit the parameters for which it is designed, but it should also give good predictions for other transformations without involving serious incongruities. Thus a model relating LD_{50} to droplet diameter should give good indications of the relationship between biocidal area and active ingredient per droplet.

Model 1: Relating $\log_{10} LD_{50}$ to droplet diameter

If $\log LD_{50}$ is fitted against functions of droplet dimensions, a negative value for LD_{50} cannot result since the Log of a negative number is unreal. It might be expected that $\log LD_{50}$ would be related to droplet volume and, therefore, to the cube of the diameter. This, however, gives a poor fit and inconsistent slopes. Of the regressions which have been attempted the best is between $\log_{10} LD_{50}$ and droplet diameter. The plotted regression lines (Fig. 7) were roughly parallel. On the assumption that they were parallel, a weighted mean slope was determined and new lines were calculated (Fig. 8). Their intercepts followed a well marked trend, being highest at 4% concentration, falling to a minimum at 1% and rising to 0.05% (Fig. 9). The only inconsistency was that 0.25% and 0.5% values were interchanged. A cubic equation was found by computer analysis which adequately fitted this trend and thus an equation was derived to describe the entire relationship between LD_{50} and



droplet diameter (D) at all concentrations (C):

$$\text{Log}_{10} \text{LD}_{50} = -1.705 - 0.525C + 0.2933C^2 - 0.03415C^3 + 0.009038D$$

..... (Model 1).

This model gave good fits to all LD_{50} data, and when transformed to other units such as the equivalent lethal number (LN_{50}) and biocidal area per droplet (BA), gave reasonably good predictions.

Model 2: Relating biocidal area per droplet to active ingredient per droplet

Alternatively, effectiveness of a spray might be related to the area covered by an individual droplet plus the area over which the pesticide spreads: that is, to relate the biocidal area (BA) (i.e. the area around the deposited droplet in which at least 50% of the organisms are killed), to the amount of active ingredient (a.i.) within the droplet. Various attempts were made to fit functions of BA to a.i. The plotted regression lines (Fig. 10) diverged regularly from near the origin; except for two concentrations with negative a.i. intercepts. When there is no active ingredient, no biocidal area would be expected, so it was concluded that the lines should pass through the origin. When lines were drawn from the origin to the means of points for each concentration (Fig. 11) and new slopes were calculated, the slopes increased from 0.05% to 2% and then fell to 4% tracing a smooth curve with no irregularity at 0.25% and 0.5% as before (Fig. 12). Smoothed values for the slopes were again obtained by fitting a cubic curve and an equation was derived as before:

Fig. 10. Biocidal area per droplet v $\sqrt{\text{a.i.}}$ per droplet

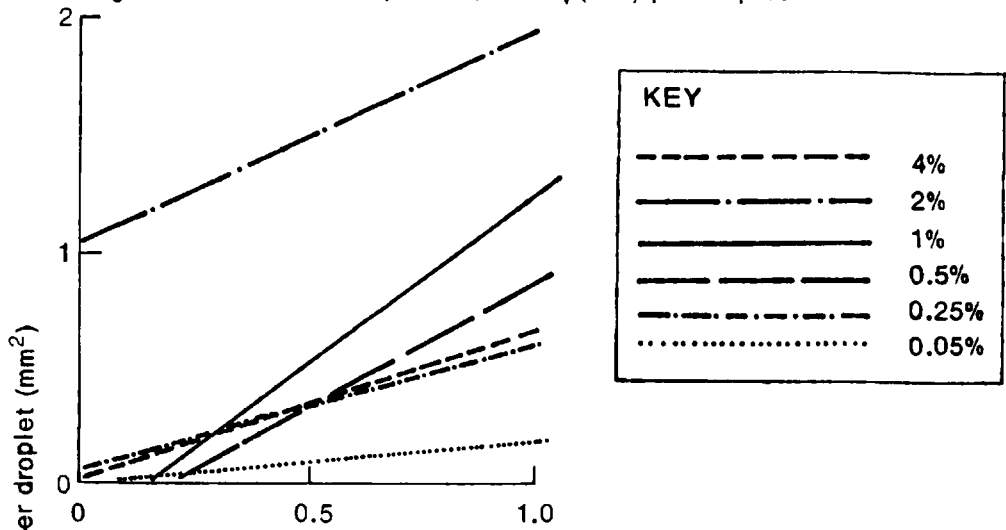


Fig.11. Biocidal area per droplet v $\sqrt{\text{a.i.}}$ per droplet (assuming divergence from the origin to averages of the points).

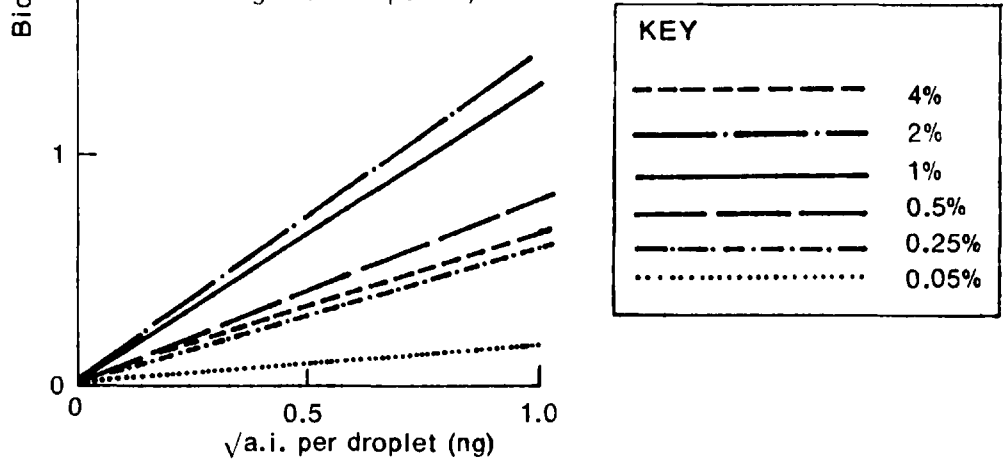
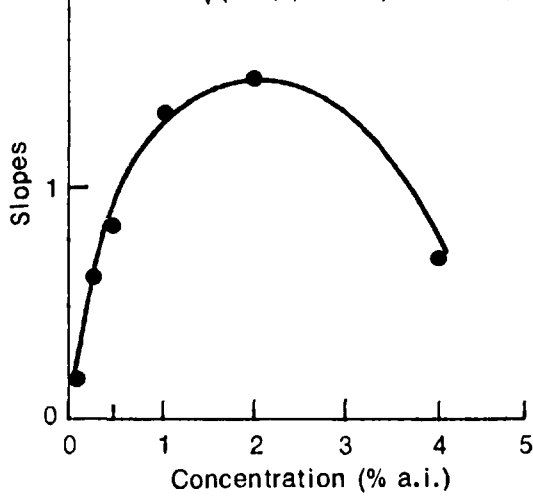


Fig. 12. Slopes v concentration (for the biocidal area v $\sqrt{\text{a.i.}}$ per droplet lines).



$$BA = \sqrt{(a.i.)} (0.3357 + 6.229C - 2.723C^2 + 0.317C^3) \\ \dots\dots\dots (\text{Model 2}).$$

This model similarly gave good fits to all the data, even when transformed. A disadvantage of this equation is that it predicts a zero LD₅₀ for infinitesimally small droplets, which is illogical. It is also difficult to understand why an area should be related to the square root of the amount of chemical. The relationship could also be expressed in terms of actual amount of chemical, but this would involve a fourth dimension! Other more logical associations (such as distance of spread with a.i.) gave inconsistency models.

Model 3: Relating biocidal area per droplet to droplet dimensions

On the thesis that a droplet might spread to an area related to its size, various attempts were made to relate these parameters. A fitted power curve indicated that the square root of the biocidal area was proportional to the droplet diameter. In other words the radius of spread was related to the radius of the droplet: a logical conclusion. Fitted regression lines were all of closely similar slopes with the exception of 0.05 and 0.25% concentrations, the data for which is based on fewer replicates. When parallel lines were fitted their intercepts were found to follow a smooth curve lowest at 0.05% rising to a maximum at 2% and falling to 4%. A cubic curve represented this and the equation was:

$$\sqrt{BA} = -7.112 + 17.05C - 6.616C^2 + 0.6386C^3 + 0.1273D \\ \dots\dots\dots (\text{Model 3}).$$

However, despite its apparently logical basis this model gives

completely nonsensical fittings for the concentrations of 0.05 and 0.25%. This was because the intercepts for these concentrations were negative and, therefore, predict a negative radius of spread. Except for the 2% line, the regression lines relating $\sqrt{BA}$ to droplet diameter diverged from near the origin. Another model based on this concept was suggested and an equation of the form:

$\sqrt{BA} = bD$ was derived as before, with 'b' representing a cubic function. This model gives a very good fit to most of the data though the fit is poor for 4% and very poor for 2%. The model gives a straight line relationship between LD_{50} and droplet diameter with all lines passing through the origin. No indication of the curvature, apparent in many of the scatter diagrams (i.e. Figs. 5A-F) is given and a zero LD_{50} is inconceivable.

Model 4: Relating $\log_{10} LD_{50}$ to $\log_{10}$ a.i. per droplet

Plotting power curves, achieved by regressing $\log LD_{50}$ against $\log$ a.i. per droplet (in other words, $\log$ dose against $\log$ dose) is quite reasonable since doses are usually expressed as Logs in bioassay studies. If the regression lines of $\log_{10} LD_{50}$ against $\log_{10}$ a.i. per droplet are plotted (Fig. 13) most are generally parallel except 0.25 and 0.5% having anomalous slopes. If parallel lines are fitted (Fig. 14) their intercepts are highest at 0.05% decreasing progressively to 2% and then rising to 4% (Fig. 15). The relationship can also be expressed in a different way. When $\log LD_{50}$ was plotted against $\log D$ the intercepts were similarly arranged. A cubic equation describing the relationships between LD_{50} , concentration and droplet diameter is:

Fig.13. $\log_{10} LD_{50}$ v $\log_{10}(a.i.)$ per droplet

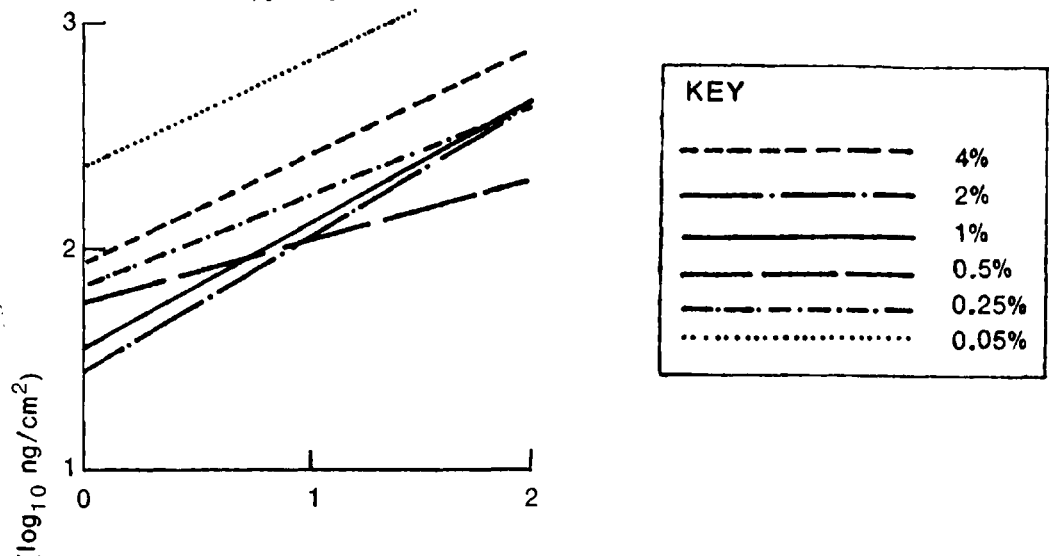


Fig.14. $\log_{10} LD_{50}$ v $\log_{10} (a.i.)$ per droplet
(assuming parallel lines)

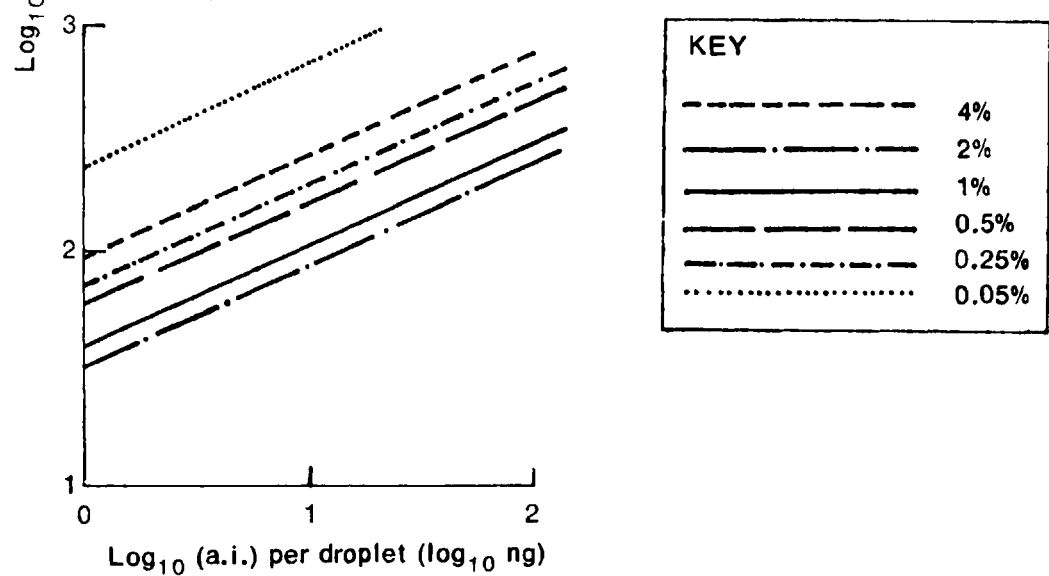
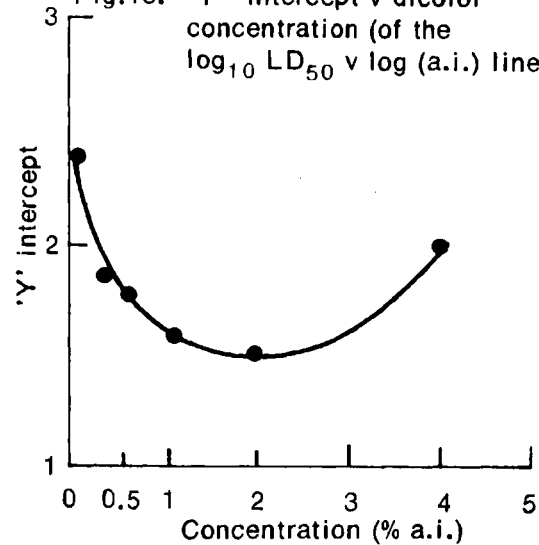


Fig.15. 'Y'- intercept v dicofol concentration (of the $\log_{10} LD_{50}$ v $\log (a.i.)$ lines).



$$\text{Log}_{10} \text{LD}_{50} = 3.686 - 0.3494C + 0.1902C^2 - 0.01833C^3 + 1.47 \text{Log}_{10} D$$

..... (Model 4).

Model 4 gives good fits to most of the data even when transformed to biocidal areas, although lines for 0.5% and 0.25% did not fit well. An illogical outcome of this model is that the LD_{50} lines pass through the origin.

Model 5: Relating LD_{50} to active ingredient per droplet

Finally LD_{50} might be related to the amount of pesticide in each droplet. Fitting a power curve between these two parameters gives a mean weighted power of 0.47 or very close to a square root. Thus the LD_{50} might be expected to be proportional to the square root of the amount of active ingredient. Fitted regression lines (Figs. 16A, B, C, D, E and F) have different slopes (Fig. 17) and all but one (2%) pass just above the origin with a mean weighted intercept of 10.7 ng. The corrected slopes, assuming divergence from the mean intercept to the means of the points, are highest at 0.05% falling progressively to 1% and rising again to 4% (Figs. 18 and 19). This could readily be represented by a cubic curve with an equation of the form:

$$\text{LD}_{50} = 10.7 + b\sqrt{\text{a.i.}}$$

(where 'b' varies with concentration)

.....(Model 5).

This model gives very good fit at all concentrations both for LD_{50} and biocidal area estimates. In all cases the LD_{50} line passes above the origin, implying the same minimum LD_{50} value for

Fig.16. Relationship between amount of (a.i.) per droplet and mortality of *T. urticae* eggs with different spray concentrations.

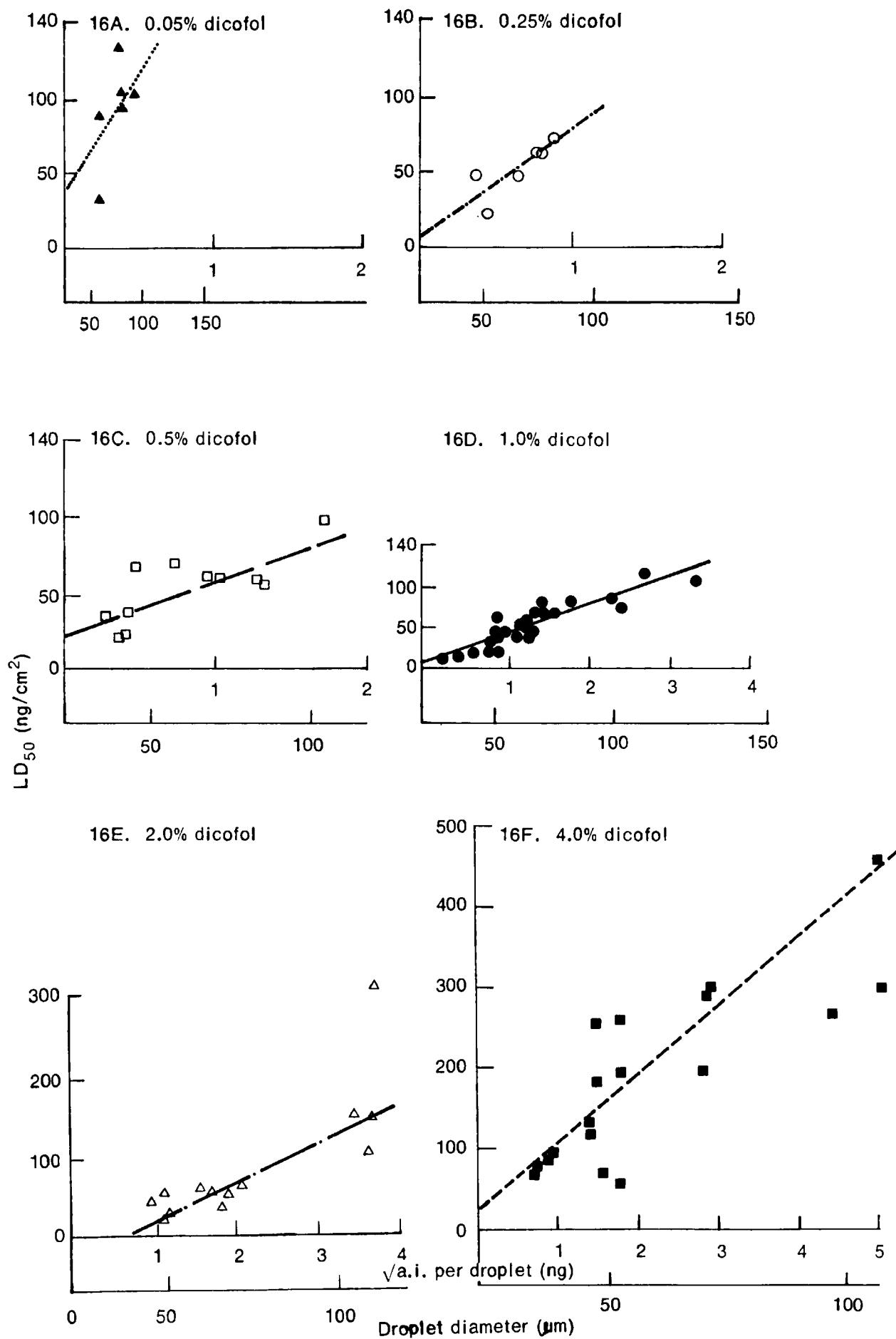
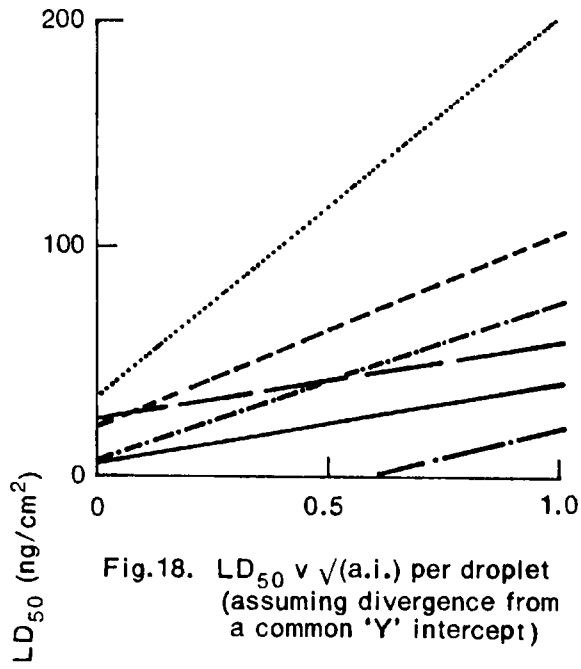
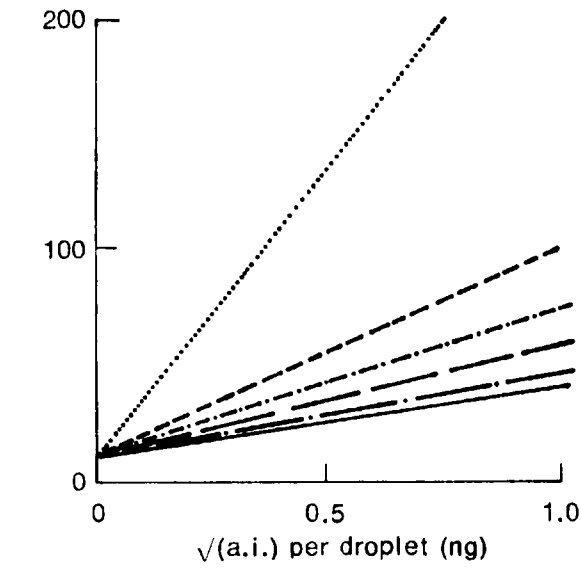


Fig.17. $LD_{50} \propto \sqrt{(a.i.)}$ per droplet



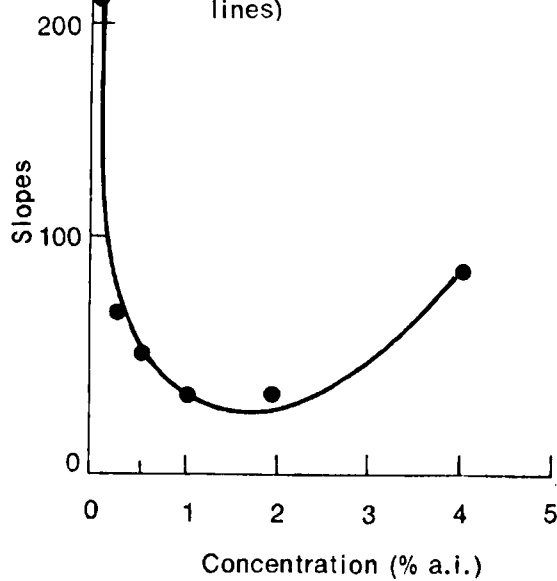
KEY	
-----	4%
- . - . - .	2%
—————	1%
——— ———	0.5%
- . . - . .	0.25%
.....	0.05%

Fig.18. $LD_{50} \propto \sqrt{(a.i.)}$ per droplet (assuming divergence from a common 'Y' intercept)



KEY	
-----	4%
- . - . - .	2%
—————	1%
——— ———	0.5%
- . . - . .	0.25%
.....	0.05%

Fig.19. Slopes $\propto$ concentration (for the $LD_{50} \propto \sqrt{(a.i.)}$ lines)



all concentrations. Biocidal area curves, however, pass through the origin indicating, as would be expected, that an infinitesimal droplet has an infinitesimal effect. Despite the advantages of this model it is still difficult to understand why LD_{50} should be related to the square root of a.i. or since a.i. is a function of "droplet diameter cubed", that: LD_{50}^2 is directly proportional to D^3 or $LD_{50} \propto D^{3/2}$, all of which seem to have no logical basis.

However, if we return to the fitting of power curves by regressing $\log LD_{50}$ against $\log a.i.$ it is interesting to note that the power is close to the square root. It may just be coincidental that LD_{50} is directly proportional to the square root of a.i. while a $\log LD_{50}$ against $\log a.i.$ relationship has a slope nearly equal to the square root.

Comparison of models

The relative merits of the five models is difficult to evaluate, but a close link exists between at least three of them.

By definition:

$$BA = \left(\frac{0.5}{LN_{50}} \right)$$

and since

$$LN_{50} = \left(\frac{LD_{50}}{(a.i.)/\text{droplet}} \right)$$

then

$$BA = \left(\frac{0.5(a.i.)}{LD_{50}} \right)$$

If we accept Model 5 but ignore the small intercept then:

$$LD_{50} = \left(b \sqrt{(a.i.)} \right),$$

and it follows that:

$$BA = \left(\frac{0.5(a.i.)}{b\sqrt{(a.i.)}} \right) = \left(\frac{0.5}{b} \sqrt{(a.i.)} \right)$$

In other words, BA is directly proportional to $\sqrt{(a.i.)}$ as is expressed in Model 2. Thus both Model 2 and Model 5 express the same relationship and both LD_{50} and BA are directly proportional to $\sqrt{(a.i.)}$. This, however, is paradoxical since an increase in LD_{50} should be accompanied by a decrease in biocidal area and, therefore, LD_{50} and BA would be expected to be inversely related.

It has already been suggested that Model 5 can be derived from Model 4. The latter states that:

$$\log_{10} LD_{50} = K + 1.47 \log_{10} D$$

or approximately:

$$\log_{10} LD_{50} = K + 1.5 \log_{10} D.$$

But since a.i. is a function of D^3 it can be concluded that:

$$\log_{10} LD_{50} = d + 0.5 \log_{10} (a.i.).$$

As said above the slope of 0.47 was also obtained when $\log LD_{50}$ was plotted against $\log (a.i.)$.

Thus $LD_{50} = b\sqrt{(a.i.)}$, which is Model 5 without its small intercept.

The remaining two Models raise serious objections: Model 3 become nonsensical since it suggests a straight line relationship of LD_{50} to D and, therefore, a very poor fit to the higher concentrations where a curvature is evident. Further, the Models may be compared using error mean squares (EMS) between observed values and the values predicted by each Model for LD_{50} and BA (Tables 4 and 5).

$$EMS = \left(\frac{(\text{Observed} - \text{Expected})^2}{n - 2} \right)$$

Table 4. Example comparing observed (obs.) LD_{50} , LN_{50} and biocidal area per droplet values with those predicted (pred.) by the $\sqrt{(a.i.)}$ per droplet v. LD_{50} relationship (Model 5) for 1% dicofol sprayed against *T. urticae* eggs

Data sheet	Droplet			Obs. LD ₅₀	Pred. LD ₅₀	Obs. LN ₅₀	Pred. LN ₅₀	Obs. BA	Pred. BA
	dia- meter μm	a.i. ng	√a.i. ng						
	ng/cm ²		No./cm ²		mm ²				
26	18	.03	.18	6	12	187	371	.27	.14
58	27	.10	.32	10	16	98	161	.51	.31
56	37	.27	.52	17	23	62	84	.80	.60
55	47	.54	.74	20	30	37	55	1.35	.91
68	49	.61	.78	33	31	55	52	.92	.97
67	50	.64	.80	35	32	55	50	.92	1.00
77	50	.67	.82	18	32	27	49	1.86	1.03
210	50	.67	.82	41	33	61	47	.82	1.06
24	51	.71	.84	61	35	86	43	.58	1.16
57	54	.82	.91	41	41	50	35	1.00	1.44
75	61	1.18	1.09	37	42	31	34	1.60	1.47
76	62	1.23	1.11	52	45	42	31	1.18	1.61
35	65	1.45	1.20	52	45	36	31	1.40	1.61
36	65	1.45	1.20	49	46	34	30	1.48	1.65
33	66	1.51	1.23	39	46	29	30	1.74	1.65
34	66	1.51	1.23	40	51	27	26	1.89	1.92
201	70	1.76	1.33	67	51	38	26	1.32	1.92
73	72	1.97	1.40	66	56	34	23	1.49	2.15
74	72	1.97	1.40	79	79	40	15	1.25	3.23
32	77	2.43	1.56	68	83	28	15	1.79	3.42
213	84	3.05	1.75	81	93	27	13	1.88	3.89
79	99	5.10	2.26	83	114	16	10	3.07	4.90
80	103	5.66	2.38	70	49	12	28	4.03	1.80
78	111	7.22	2.69	114	62	16	20	3.17	2.44
81	129	11.16	3.34	104	33	9	49	5.38	1.03

Table 5. Error mean squares (EMS) between observed LD₅₀ and BA[†] values and those predicted by each Model for the six dicofol concentrations

Effect- ness parameter	Model	Error mean squares at various dicofol concentrations						Average error mean squares	Total '*'
		.05%	.25%	.5%	1%	2%	4%		
LD ₅₀	1	.0407	.0346*	.0307**	.0289	.0153*****	.0343**	.0256*	9
	2	.0402*	.0293**	.0501	.0135*****	.0203**	.0370*	.0242***	10
	3	.0400**	.0233*****	.0227*****	.0136***	.184	.0374	.0440	13
	4	.0389***	.0370	.0355*	.0141**	.0215***	.0331*****	.0224*****	13
	5	.0388*****	.0233***	.0260***	.0246*	.0266*	.0338***	.0246**	15
Biocidal area per droplet	1	.0412	.0352*	.0299**	.0285	.0151*****	.0345**	.0254*	9
	2	.0407*	.0284**	.0508	.0134*****	.0204***	.0371*	.0243***	11
	3	.0401**	.0236***	.0225*****	.0256*	.0356	.0377	.0270	10
	4	.0396***	.0366	.0360*	.0143***	.0220**	.0334*****	.0227*****	13
	5	.0394*****	.0226*****	.0262***	.0241**	.0271*	.0340***	.0245**	17
n - 2		4	4	9	23	11	17		

NOTE: '*' was used to compare the Models at each concentration. The Model with the least EMS was given 4 *s (i.e. *****), the rating decreasing with increase in EMS so that the Model with the largest EMS had no '*'. The sums of *s at different concentrations with each Model gave a further indication of how good the Model was; and so did the mean EMS.

[†] BA = Biocidal area

Models 1 and 3 are particularly poor while 4 and 5 are the best.

When all these factors are considered, the most logical relationships giving the best fit to the data are the inter-related Models 4 and 5. Model 4 has the advantage of relating Log dose to Log dose (or can be modified to do so), while Model 5, although involving the somewhat illogical square root incorporates a positive intercept for the LD_{50} . A further model is required which incorporates both these advantages. Since a Log v Log relationship produces a power curve of the form:

$$LD_{50} = a(a.i.)^b$$

the form actually required is:

$$LD_{50} = J + a(a.i.)^b.$$

Attempts to fit this equation to the data using a non-linear regression programme on the H.P. computer were unsatisfactory as a wide range of parameter combinations was obviously possible without appreciable change in fit. There was, however, a strong indication that a 'b' value of 0.5 was approximately correct, giving support to the form of equation in Model 5 relating LD_{50} to the square root of a.i. As this was the most promising line of investigation, Model 5 was studied in more detail.

Improving Model 5

In the first consideration of Model 5, lines were fitted from 10.7 ng to the arithmetic mean of the co-ordinates to obtain slopes for each concentration. Later calculations showed that the mean intercept was probably lower so a value of 10 was chosen. Slopes were recalculated and a cubic equation calculated to describe the

sequence of slopes. Thus the equation 5A was obtained:

$$LD_{50} = 10 + (0.0012 - .000132C + .00471C^2 - .00490C^3) \sqrt{(a.i.)}$$

(where $C = \log_{10}$ concentration (%))

..... (Model 5A).

Since there was great variability in the results obtained for larger droplets the slopes were calculated using the geometric mean of the points. Equation 5B was derived in this way:

$$LD_{50} = 10 + (0.00096 - .000412C + .00476C^2 + .000851C^3) \sqrt{(a.i.)}$$

..... (Model 5B).

but on the basis of error mean square comparisons this gave an inferior fit.

Re-examination and extrapolation of the original regression lines (LD_{50} versus $\sqrt{(a.i.)}$) revealed that four of the six lines converged to a point on the 'x' axis, and not on the 'y' axis as was previously supposed. This point whether calculated on the four lines or on all six, had a mean weighted position of about -0.16. This concept introduces a slightly different interpretation. Whereas it had been assumed that infinitesimal droplets had the same effectiveness regardless of concentration, it must now be concluded that the limiting effectiveness varies with concentration in the same way at all droplet sizes. This supposition has an equally logical basis. Fitting lines from -0.16 to the arithmetic mean for each concentration gives a regular family of lines, the slopes of which can be fitted to a cubic curve. The new Model can be expressed as equation 5C:

$$LD_{50} = 0.00106 - .000215C + .00406C^2 + .000118C^3 \sqrt{(a.i.)} - 0.16$$

..... (Model 5C).

On the basis of error mean squares this gives a slightly better fit to the data than equation 5A.

Using Model 5C further improvements could be obtained by calculating the lines through the geometric means of the co-ordinates (Fig. 20). A better fit could be obtained when the six slopes were described more precisely, so various transformations were attempted. The most satisfactory fit was a cubic equation obtained by relating $\log_{10}$ of slopes of lines passing through geometric means of co-ordinates to concentration (Fig. 21 and Fig. 22A). The resulting Model is of the form:

$$LD_{50} = b \left(\sqrt{(a.i.)} - z \right)$$

$$\text{where } b = -2.306 - 1.167C + 0.5514C^2 - 0.06929C^3$$

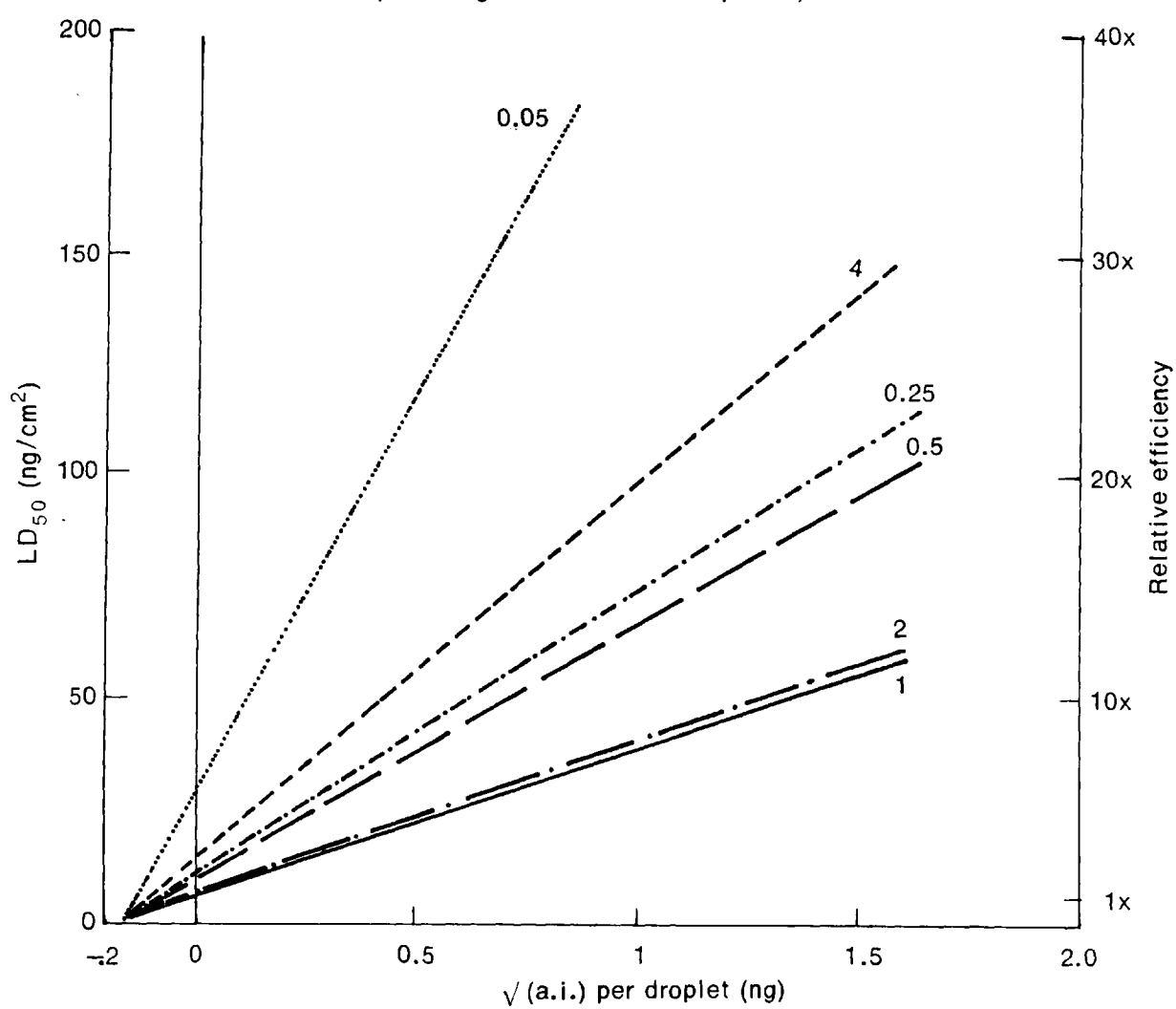
c = the concentration of (a.i.)%

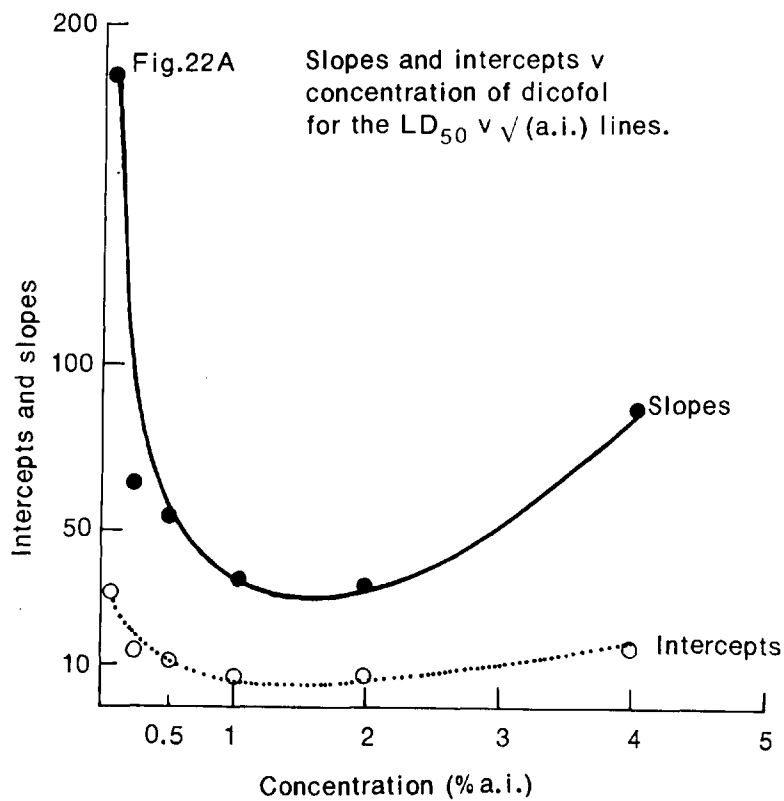
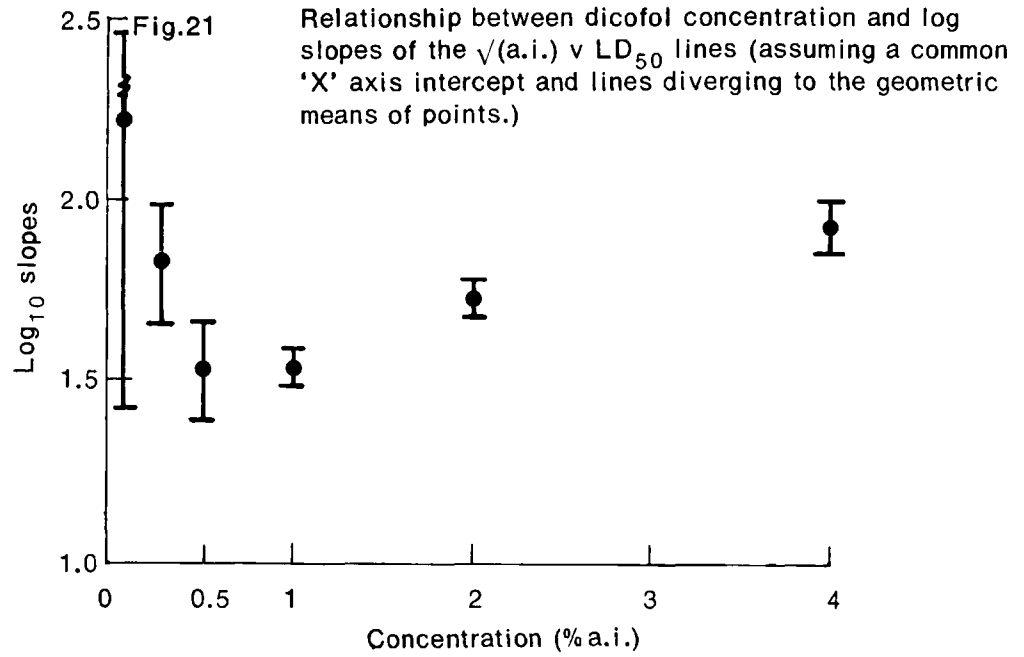
z = a constant (the 'x' axis intercept: -0.16)

..... (Model 5D).

The cubic equation has no intrinsic meaning but is merely a means of expressing the slopes in terms of concentration.

Fig.20. Relationship between LD_{50} and $\sqrt{(a.i.)}$ per droplet and relative efficiencies of different concentrations (assuming divergence from a common 'X' axis intercept to respective geometric means of points).





Comparing slopes

Differences between the slopes obtained by analysing the data using Model 5D were tested by calculating 'd' (Bailey, 1959):

$$d = \left(\frac{b_1 - b_2}{\sqrt{Sb_1^2 + Sb_2^2}} \right)$$

where b_1 = Slope₁
 b_2 = Slope₂
 Sb_1 = Standard error of slope₁
 Sb_2 = Standard error of slope₂

There was significant difference between 0.05% and 1%; 0.25 and 1% and 1% and 4% slopes (Table 6).

Table 6. 'd' values and confidence levels of significance of differences between various slopes

Slopes being compared	d	Significant at % confidence level	
Reference values	(	3.291	99.999%
	(		
	(	3.090	99.8%
	(		
	(	2.576	99.0%
	(	2.326	98.0%
	(	1.960	95.0%
	(	1.645	90.0%
.05% versus 1%		1.0499	95%
.25% versus 1%		2.0675	95%
1.0% versus 4%		2.0629	95%

This suggests that the slopes are arranged in a U with an optimum concentration of 1% dicofol. Thus with constant $\sqrt{(a.i.)}$ or a.i. values, the relationship between LD_{50} or LN_{50} and concentration is optimal at 1% to 2% dicofol (Figs. 22B and C). Similarly with droplets of constant size, LD_{50} values were minimal when 1% dicofol was sprayed rising at higher or lower concentrations (Fig. 22D).

The relationship between LD_{50} and amount of active ingredient per droplet

Plotting LD_{50} against $\sqrt{(a.i.)}$ per droplet relates a function of dose per droplet to dose required to achieve 50% kill using droplets of a specific size and concentration. In other words, this relationship ties together the effects of droplet size, concentration and droplet density on pest mortality. At any concentration, increasing $\sqrt{(a.i.)}$ per droplet (= increasing a.i. per droplet) resulted from use of larger droplets. When effectiveness of different sprays are compared, larger LD_{50} values imply lower efficiency. Thus relative efficiency decreased in the order: 1% > 2% > 0.5% > 0.25% > 4% > 0.05% dicofol. For the six concentrations tested, the lowest LD_{50} value would theoretically be expected from infinitesimal droplets of the 1% solution and was about 8 ng/cm². If this value is given an efficiency rating of one, the LD_{50} scale of the LD_{50} versus $\sqrt{(a.i.)}$ graph can then be converted into an 'efficiency scale' by dividing it into several units each equal to the optimum dose (Fig. 20). Any point on the LD_{50} against $\sqrt{(a.i.)}$ lines for the different concentrations can then be compared directly with the 'unit efficiency level' of 1%'s infinitesimal droplets. Predictions of relative changes in efficiency

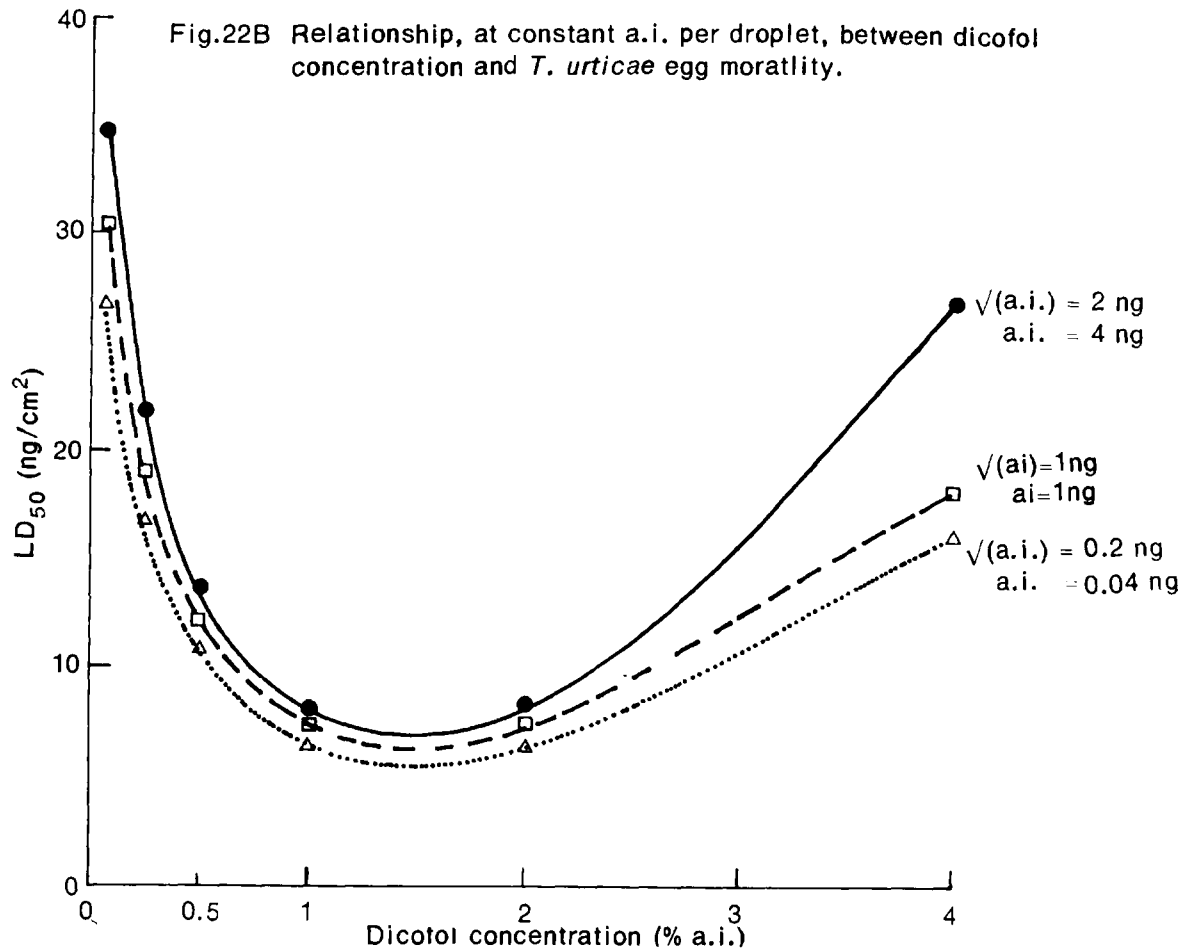
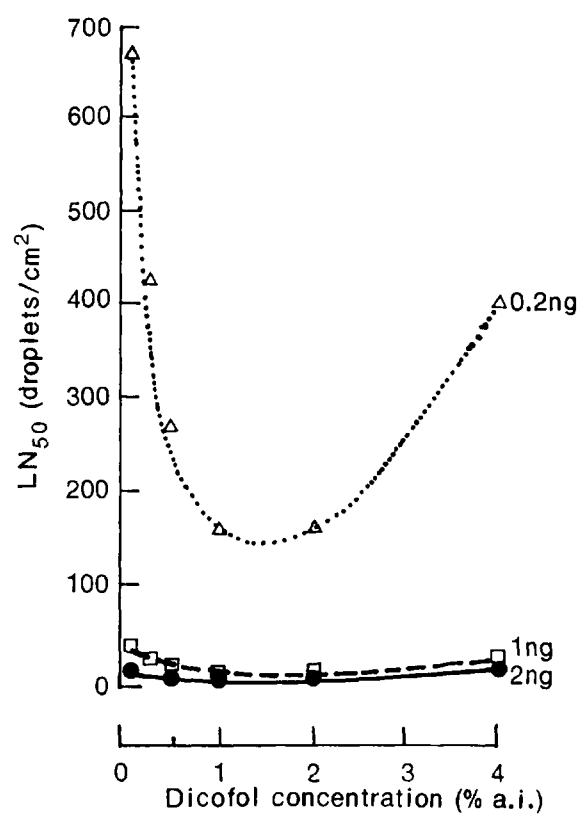
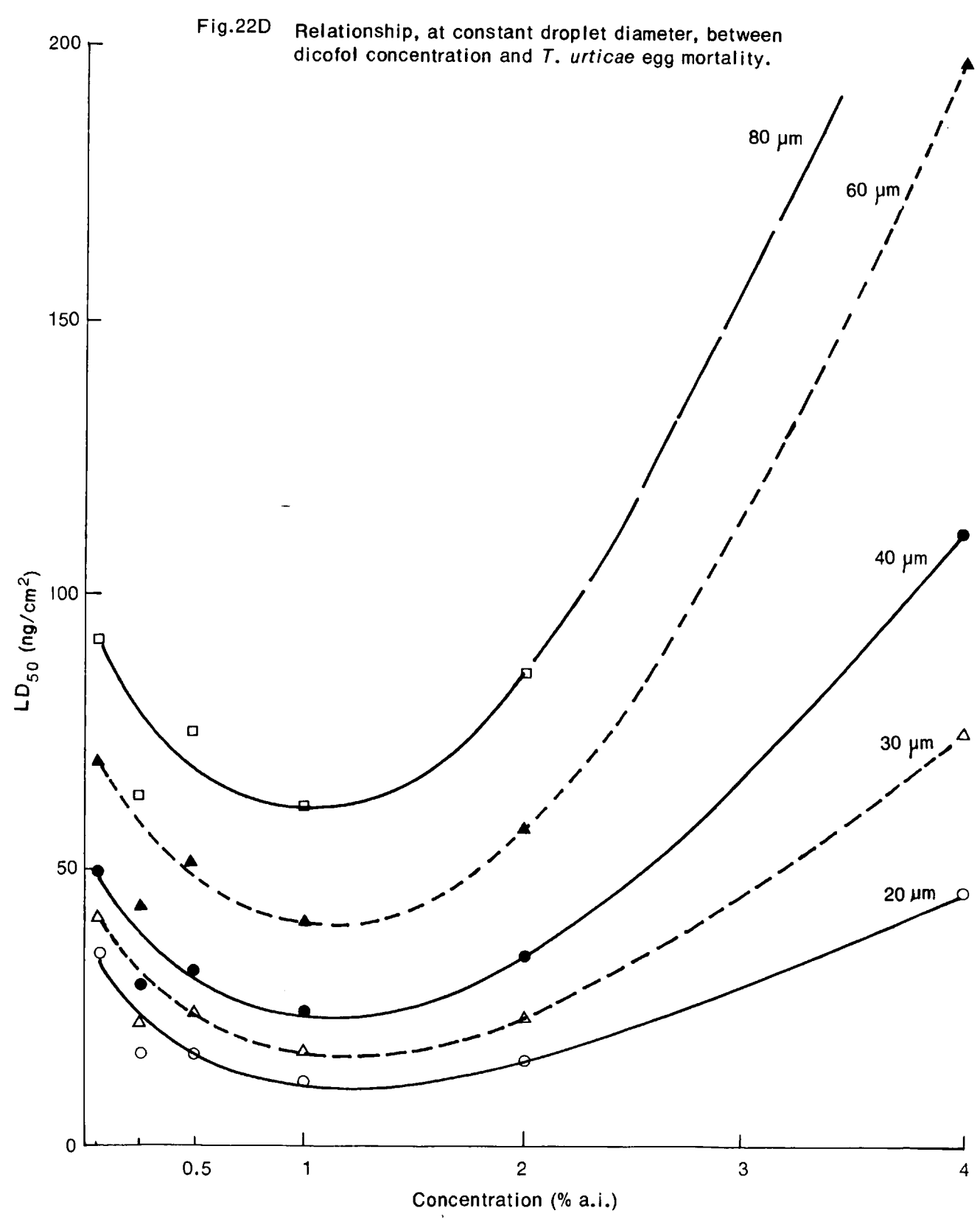


Fig.22C Relationship at constant a.i. per droplet between dicofol concentration and numbers of droplets required to achieve 50% mortality of *T. urticae* eggs.





resulting from changing droplet size, concentration or both, are therefore possible (Table 7).

Table 7. Relative efficiencies of sprays of different a.i. per droplet values depending on their sizes and concentrations

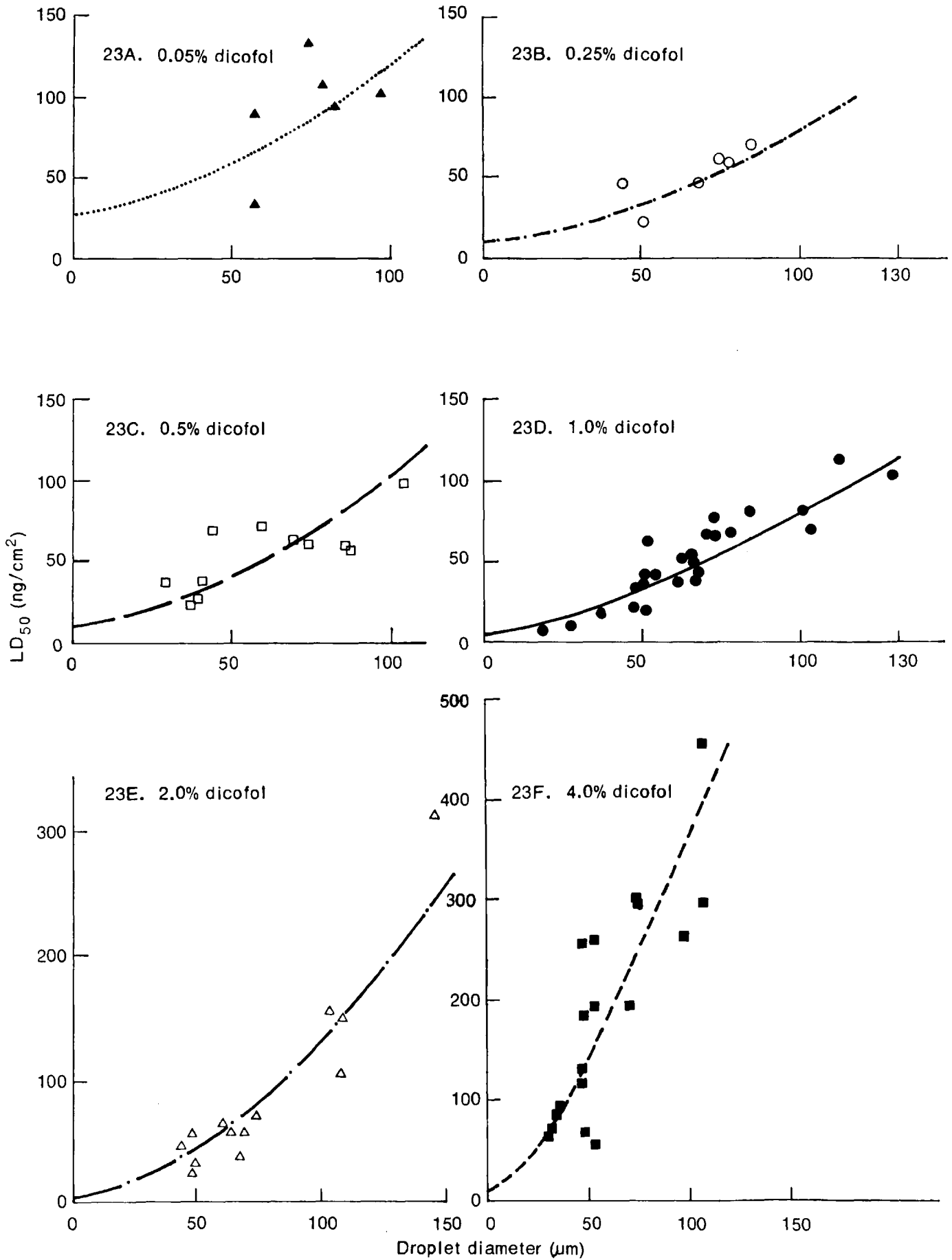
$\sqrt{\text{a.i.}}$ per droplet	a.i. per droplet ng	Efficiency level (X lower than 1)		
		Spraying solution concentration		
		.05%	1%	4%
0 [†]	0	5	1	3.6
0.4	0.16	17.5	3.3	8.5
0.8	0.64	29.8	5.6	14.5

† = infinitesimal droplet

The new relationship between LD_{50} and droplet diameter (assuming $LD_{50} \propto \sqrt{\text{a.i.}}$ per droplet)

The LD_{50} against $\sqrt{\text{a.i.}}$ per droplet relationships fitted by Model 5D can be used to derive new LD_{50} versus droplet diameter curves at each concentration. The new curves showing how LD_{50} is related to droplet diameter (Figs. 23A, B, C, D, E and F) fitted the scatter points better than the linear regression lines used previously. They also had positive intercepts. When the derived LD_{50} against droplet diameter lines are drawn together (Fig. 24) their relative positions suggest that for most droplet sizes (i.e. above 30 μm in diameter) the efficiencies of the different concentrations are in the order: 1% > 0.25% > 0.5% > 2% > 0.05% > 4%: a different order from that predicted by the LD_{50} against $\sqrt{\text{a.i.}}$

Fig.23. Relationship between droplet diameter and mortality of *T. urticae* eggs with different spray concentrations (assuming that LD_{50} is directly proportional to $\sqrt{(\text{a.i.})}$ per droplet.)



relationship. However, there is no discrepancy since inherent in the derived LD_{50} versus droplet diameter lines are the different slopes with the higher concentrations giving well pronounced curves and so fitting respective data points more closely.

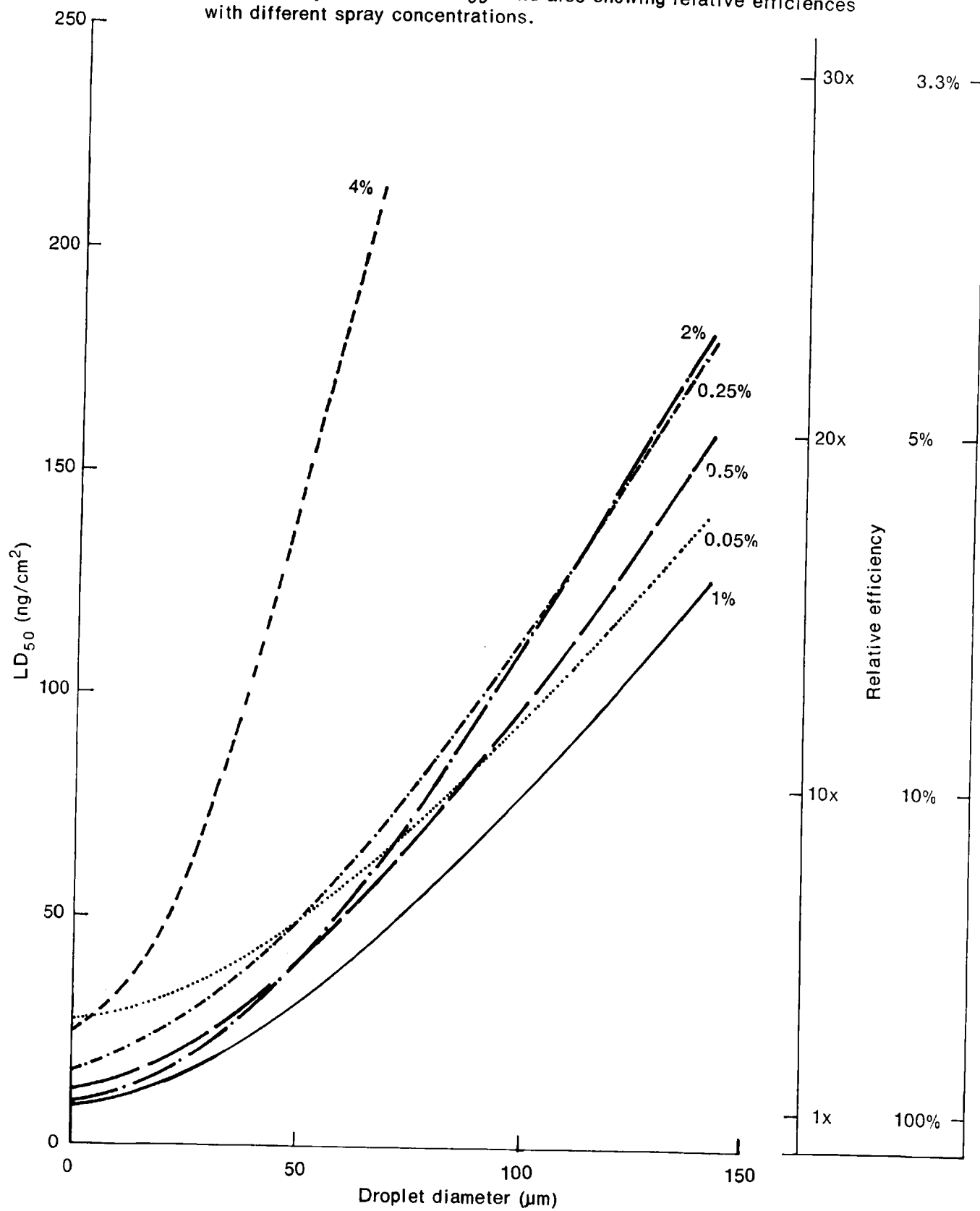
It is general practice to describe droplets by their diameters, so efficiencies of various sprays need to be discussed in terms of droplet diameters in order to be appreciated by those concerned with practical application. As before, an efficiency scale can be used to evaluate the derived LD_{50} versus droplet diameter lines; and similarly relative efficiencies can be predicted for sprays of different droplet sizes and concentrations (Fig. 24 and Table 8).

Table 8. Relative efficiencies of sprays of different droplet diameters and concentrations

Droplet diameter (μm)	Efficiency level (X lower than 1)		
	Spraying solution concentration		
	.05%	1%	4%
20	4	1.6	6.4
60	7.4	5	23.7
100	12.1	10	30

Another way of showing the relative efficiencies of these sprays is by making the theoretical optimum spray equal 100% efficiency and so describing each spray relative to this. In this case 20 μm diameter droplets of 0.05, 1 and 4% dicofol would be 25, 62.5 and 15.6% efficient, respectively, while if 1% dicofol droplets of different sizes were used 20, 60 and 100 μm droplets would be 62.5, 20 and 10% as efficient.

Fig.24. Summary of results showing relationship between droplet diameter and mortality of *T. urticae* eggs and also showing relative efficiencies with different spray concentrations.



The relationship between the median lethal dose expressed as numbers of droplets (i.e. LN_{50} s) and $\sqrt{(a.i.)}$ per droplet

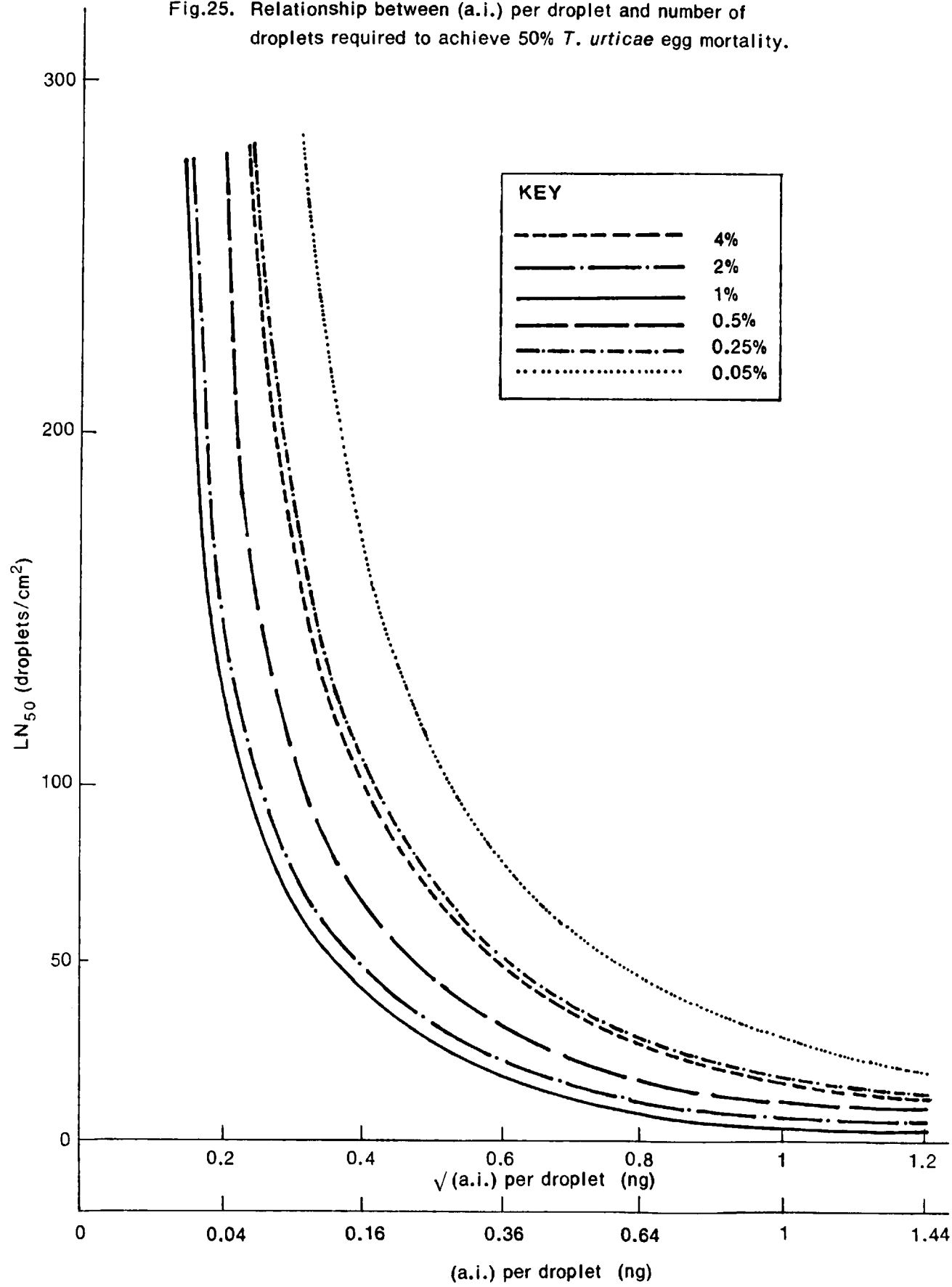
The basic relationship between LD_{50} and $\sqrt{(a.i.)}$ per droplet can be expressed in droplet density terms by plotting corresponding LN_{50} values against $\sqrt{(a.i.)}$ per droplet (Fig. 25). If efficiency of a pesticide spray was measured in LN_{50} terms; the fewer the droplets used to achieve 50% mortality the more efficient the spray. At constant $\sqrt{(a.i.)}$ value, LN_{50} values were lowest when 1% solutions were sprayed (Fig. 22C). Efficiency decreased in the order: 1% > 2% > 0.5% > 4% > 0.25% > 0.05% (Fig. 25). The LN_{50} against $\sqrt{(a.i.)}$ per droplet curve for 4% dicofol is close to that for the 0.25% solution and yet the former solution is 16X stronger. If LN_{50} values at a constant $\sqrt{(a.i.)}$ per droplet value (of 0.5 ng/droplet for example) were compared, both concentrations would require about 88 droplets to achieve 50% egg mortality. Thus droplets of the more concentrated solution would be 16X less efficient. The 0.25% solution is, in turn, 2.7X less efficient than the 1% solution at this $\sqrt{(a.i.)}$ value. The ideal combination of low LD_{50} and LN_{50} values achieved by the 1% dicofol solution strongly suggest that this is the optimum concentration at which dicofol should be formulated for use with small droplets.

Efficiency of sprays considered in terms of LD_{50} and LN_{50}

At any concentration, doubling droplet diameter means an 8 times increase in droplet volume and consequently a corresponding 8 times increase in the amount of active ingredient per droplet. Thus a 30 μ m droplet contains 1/8th the amount in a 60 μ m diameter droplet.

It seems logical to expect the dosage that achieves a specific pest mortality (such as the LD_{50}) to be constant for a specific pest target, regardless of the concentration of the spraying solution or

Fig.25. Relationship between (a.i.) per droplet and number of droplets required to achieve 50% *T. urticae* egg mortality.



the sizes of the droplets used provided droplet densities are properly adjusted to accommodate the changes in concentration and/or droplet size. Indeed, such an assumption was probably made by some scientists who had previously attempted to study relationships between these parameters.

If a 1% dicofol solution is sprayed as 30 μm diameter droplets, the LD_{50} value against mite eggs is 18.2 ng/cm^2 (Table 9).

Table 9. Relationships between LD_{50} , LN_{50} , biocidal area, droplet diameter, $\sqrt{(\text{a.i.})}$ /droplet and (a.i.) per droplet with a 1% dicofol solution

Droplet diameter	a.i. per droplet	$\sqrt{(\text{a.i.})}$ per droplet	LD_{50}	LN_{50}	Biocidal area per droplet
20	.419	.21	12.7	303.6	.165
30	.141	.38	18.2	129	.387
40	.335	.58	24.8	74	.680
60	1.131	1.06	40.4	36	1.40
80	2.680	1.64	58.9	22	2.27
100	5.236	2.29	79.9	15	3.28
140	14.367	3.79	128.3	9	5.59

In terms of droplet density, this represents 129 droplets per cm^2 . About 16 droplets (i.e. $\frac{129}{8}$), each 60 μm in diameter would contain this dose. Thus 16 droplets/ cm^2 of the 60 μm droplets would be expected to achieve 50% egg mortality. However, the LD_{50} value obtained experimentally with 60 μm droplets was 40.4 ng/cm^2 (2.2 times larger than the value for 30 μm droplets) which means that 36 instead of 16 droplets were actually required (2.25 times more). Thus when droplet diameter is doubled more than twice the amount of pesticide is needed to achieve 50% mite egg mortality.

The system using larger droplets is inefficient both in terms of amount of active ingredient and droplet density requirements.

At one droplet size (e.g. 30 μm diameter) a droplet from a 4% spraying solution contains 4 times as much dicofol as one from a 1% solution. In this case, assuming a constant LD_{50} value of 18.2 ng/cm^2 , it would be logical to expect 4 times fewer droplets of the more concentrated solution (i.e. 32.2 droplets/ cm^2) to achieve the 50% kill. The LD_{50} value obtained with the 4% solution, however, was 77 ng/cm^2 equivalent to 136 droplets/ cm^2 (Fig. 24, Table 10).

Table 10. LD_{50} and LN_{50} values at two droplet diameters with 1% and 4% dicofol solutions

Droplet diameter (μm)	1% dicofol		4% dicofol	
	LD_{50} (ng/cm^2)	LN_{50} (droplets/ cm^2)	LD_{50} (ng/cm^2)	LN_{50} (droplets/ cm^2)
30	18.2	129	77.0	136
60	40.4	36	189.5	42

Instead of decreasing from 129 to 32 droplets per cm^2 the density of droplets required increased to 136 droplets per cm^2 when the more concentrated solution was sprayed. The 30 μm droplets of 4% dicofol, therefore, were about 4 times less efficient than those of the 1% solution. On the other hand, 30 μm diameter droplets of the 4% solution were almost 2.5 times more efficient than 60 μm ones of the same concentration. Thus a spray of 30 μm droplets of 1% dicofol

was 10.4 times as efficient as that of 60 μm diameter droplets of 4% concentration:

$$\left(\text{i.e. } \frac{189.5 \text{ ng/cm}^2}{18.2 \text{ ng/cm}^2} \right)$$

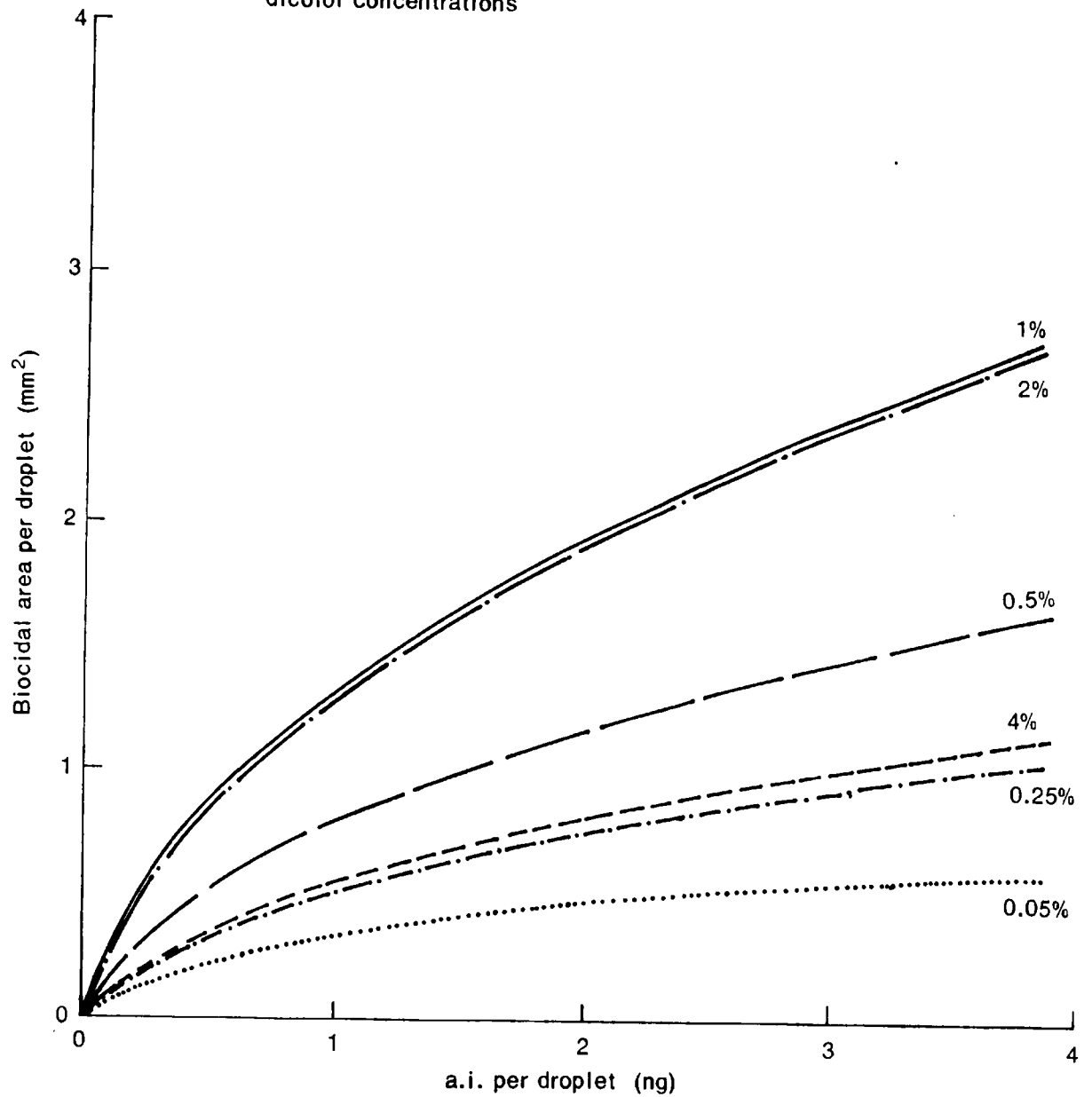
Relationship between biocidal area and amount of active ingredient (a.i.) per droplet (assuming $\text{LD}_{50} \propto \sqrt{\text{a.i.}}$ per droplet).

If biocidal area is used to measure efficiency, it is logical to expect the most efficient droplet to have the largest biocidal area.

Model 5D can be used to estimate biocidal area per droplet for various droplet sizes. Relating biocidal area per droplet to amount of active ingredient (a.i.) per droplet might seem logical, but the fitted lines show a positive curvilinear relationship, with the lines passing through the origin (Fig. 26). Although the concentrations are arranged in the expected order (with 1% as the most efficient) within each concentration, the higher the a.i. value the larger the biocidal area per droplet. Thus contrary to the predictions based on LD_{50} and LN_{50} measurements, this relationship suggests that the greater the a.i. per droplet (i.e. the larger the droplet size) the more efficient the spray.

Since direct hits of the sessile eggs were few, effectiveness of the spray depended mainly on the efficiency of spread of a.i. from initial deposits on the leaf surface. The biocidal area, therefore, measured the extent of effective spread of the a.i. from the different droplets. Determination of differences in effective spread is only possible if "spread per unit a.i." for the different concentrations are compared since it is the a.i. in the droplet deposit that spreads to a particular effective area. Thus the

Fig.26. Relationship between (a.i.) per droplet and biocidal area per droplet against *T. urticae* eggs sprayed with different dicofol concentrations



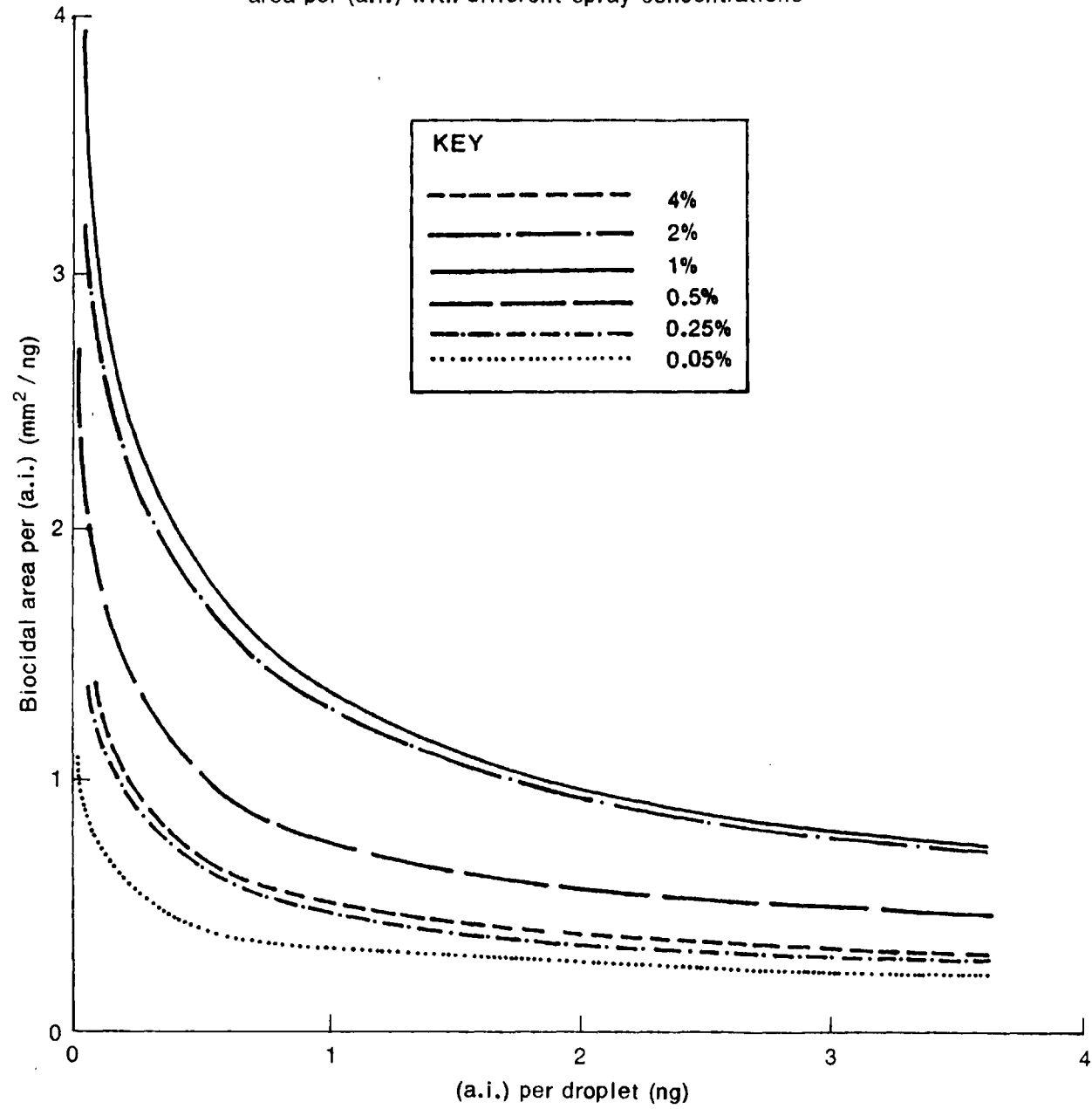
relationship to be sought was between $\sqrt{\text{a.i.}}$ per droplet (or better still between a.i. per droplet) and biocidal area per unit a.i. rather than $\sqrt{\text{a.i.}}$ per droplet against biocidal area per droplet.

When biocidal area per a.i. is plotted against a.i. per droplet a curvilinear relationship is apparent (Fig. 27). As expected, biocidal area decreases with increase in a.i. per droplet. Thus an initial droplet deposit containing 0.2 ng effectively spreads to 0.58, 2.44 or 1.00 mm² depending on whether it is of an 0.05, 1 or 4% dicofol concentration. The 1% dicofol spray, therefore, is 4 times more efficient than the 0.05% and 2.4 times than the 4% solution. With the 1% solution, an initial deposit of 0.2 ng dicofol effectively spreads to 2.44 mm² while a deposit with 10 times more a.i. (2 ng) only spreads to 0.98 mm² (2.5 times less area) (Table 11).

Table 11. Relationship between a.i. per deposit, concentration and biocidal area per a.i. using 0.05, 1 and 4% dicofol concentrations

Initial a.i. per deposit (ng)	Biocidal area per a.i. at concentration (mm ²)		
	0.05%	1%	4%
0.2	0.58	2.44	1.00
0.4	0.46	1.92	0.77
1.0	0.35	1.30	0.51
2.0	0.26	0.98	0.39

Fig.27. Relationship between (a.i.) per droplet and biocidal area per (a.i.) with different spray concentrations



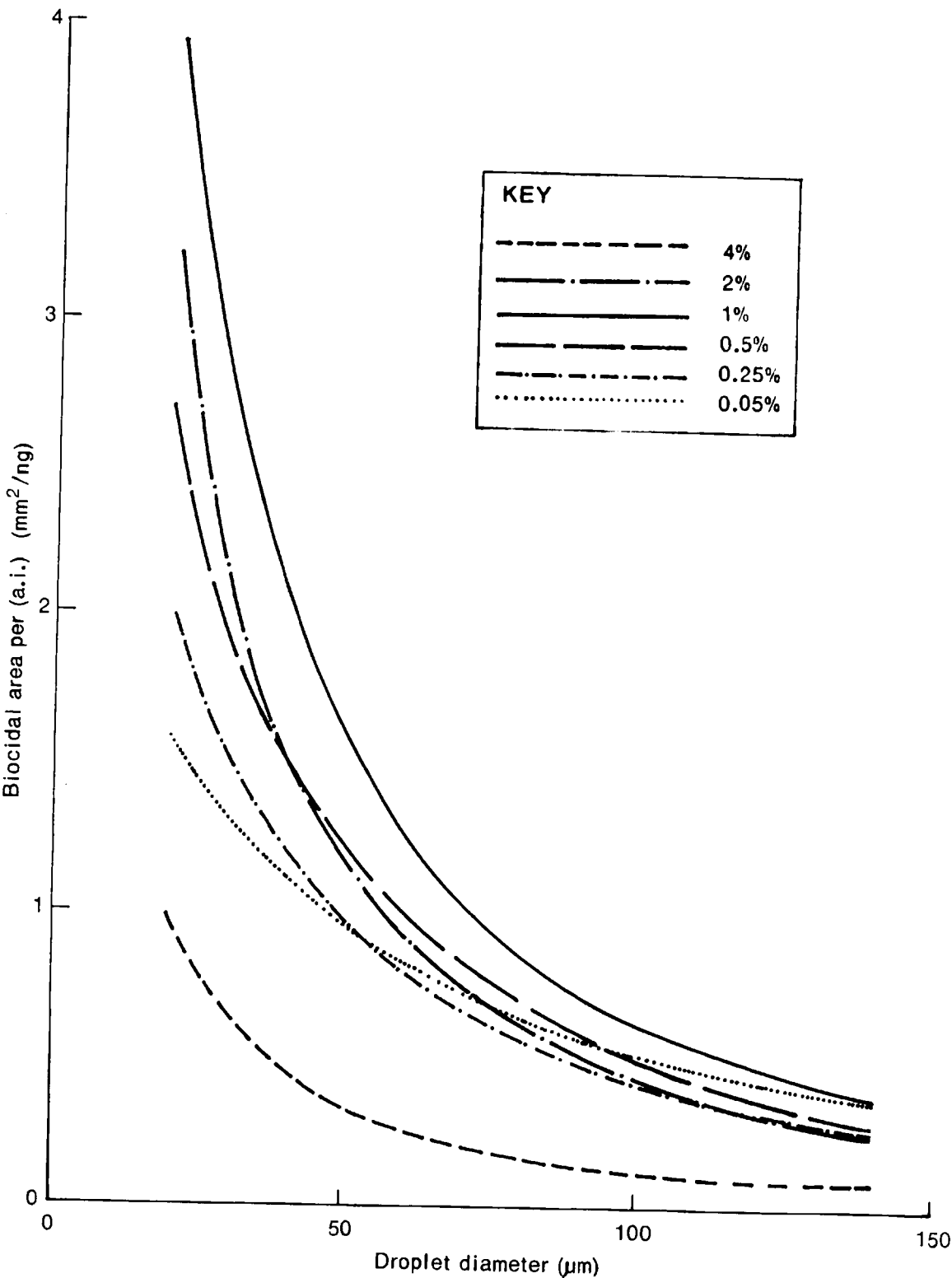
The relationship between biocidal area and droplet diameter can also be determined from Model 5D (Fig. 28). The derived lines show that single 30 μm diameter droplets of 0.05, 1 or 4% dicofol have biocidal areas of 1.30, 2.74 or 0.65 mm^2 respectively. The 1% dicofol droplet therefore spreads effectively to more than twice the area of an 0.05 and four times that of a 4% dicofol droplet of the same size. Similarly a 60 μm droplet effectively spreads to 0.83, 1.24 and 0.26 mm^2 depending on whether 0.05, 1 or 4% solutions were used (Table 12).

Table 12. Relationship between droplet diameter, concentration and biocidal area per a.i.

Droplet diameter (μm)	Biocidal area at dicofol concentration (mm^2)		
	0.05% dicofol	1% dicofol	4% dicofol
30	1.30	2.74	0.65
60	0.83	1.24	0.24

Thus with 1% dicofol, doubling droplet diameter resulted in halving the effective area from 2.74 to 1.24 mm^2 . If concentration is increased to 4%, use of the larger droplets means that biocidal area is reduced by 10.5 times (from 2.74 to 0.26 mm^2). In other words, a 30 μm , 1% dicofol droplet is 10.5 times more efficient than a 60 μm , 4% dicofol droplet.

Fig.28. Relationship between droplet diameter and biocidal area per (a.i.) with different spray concentrations



Efficiency of 1% dicofol droplets in controlling *T. urticae* eggs on pepper leaf discs

The slope of the regression line relating $\log LD_{50}$ to $\log a.i.$ (i.e. the 'power'), for data from experiments done on pepper leaf discs (Appendix Table 7), was 0.248. The regression line between LD_{50} and $(a.i.)^{(.248)}$ was a good fit to the data and, as expected, predicted a positive LD_{50} value for infinitesimal $(a.i.)^{(.248)}$ values (Fig. 29). This relationship is described by the equation:

$$LD_{50} = 2.73 + 79.3709 (a.i.)^{(.248)}$$

..... (Model 6)

To compare the relationships on bean with those on pepper leaf discs, LD_{50} needs to be plotted against $a.i.$ per droplet (Fig. 30). Control of mite eggs is more efficient on bean than on pepper discs. Thus on bean discs, with droplets containing 0.2 ng each, a dose of only 20 ng/cm² achieves 50% egg mortality while on pepper leaves a 2.75 times larger dose (55 ng/cm²) is required. With droplets containing 2.0 ng each, 51 and 96 ng/cm² are required on bean and pepper leaves respectively. Thus on bean leaves droplets containing 10 times more dicofol (i.e. 0.2 to 2.0 ng/droplet) were 2.55 times less efficient and if the more concentrated droplets were used against eggs on pepper leaves they were 4.8 times less efficient than '0.2 ng' droplets on bean discs.

Derived LD_{50} against droplet diameter lines (Fig. 31) indicate that the efficiency on both leaf surfaces increases as droplet size is reduced. At a constant droplet size, efficiency on bean is greater than on pepper. For example, 20 μ m, 60 μ m and 100 μ m diameter droplets are about 2.9 times (i.e. $\frac{38}{13}$), 2.1 times ($\frac{84}{40}$)

Fig.29. Relationship between (a.i.) per droplet and mortality of *T. urticae* eggs sprayed with 1% dicofol on pepper leaf discs.

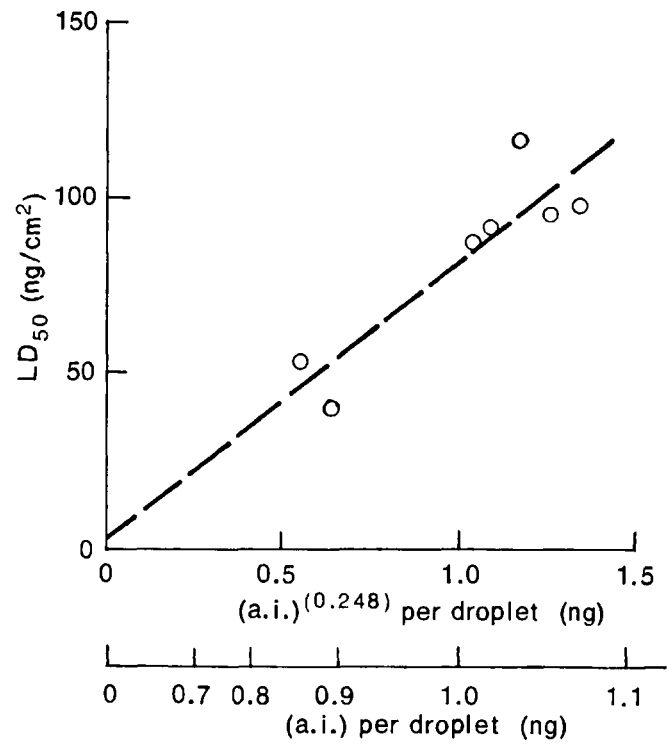


Fig.30. Relationship between (a.i.) per droplet and mortality of *T. urticae* eggs sprayed with 1% dicofol on bean and pepper leaf discs.

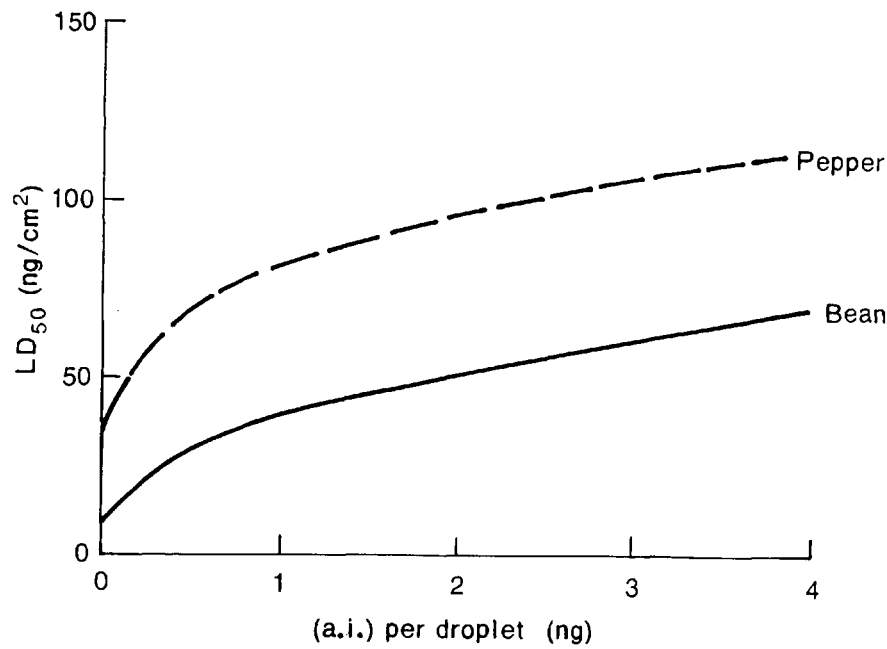


Fig.31. Relationship between droplet diameter and mortality of *T. urticae* eggs with 1% dicofol sprayed on bean and pepper leaf discs.

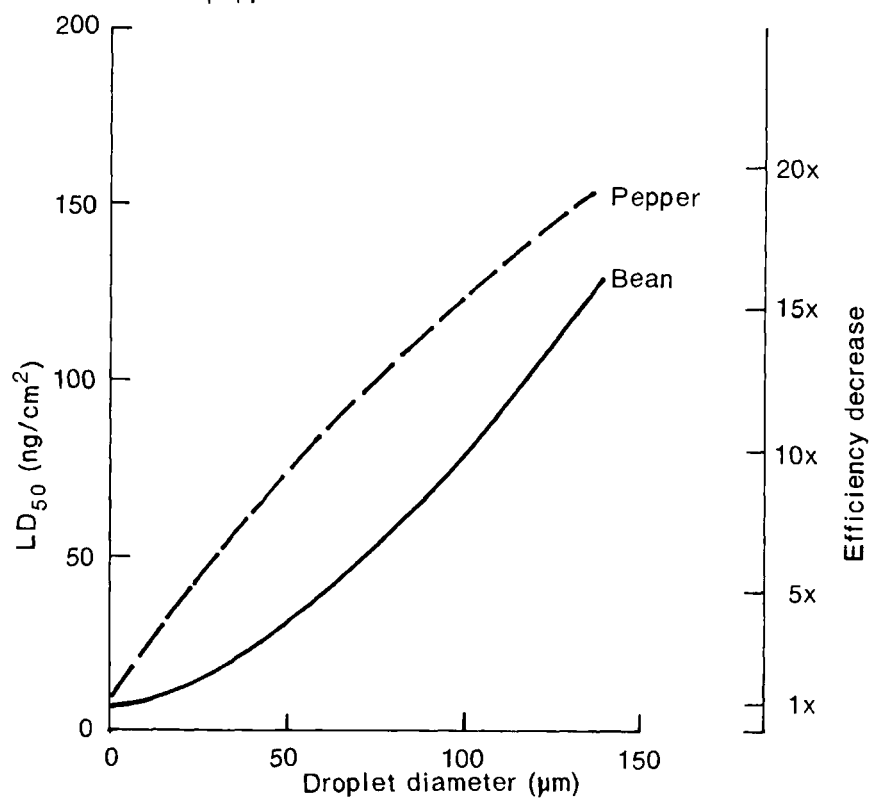
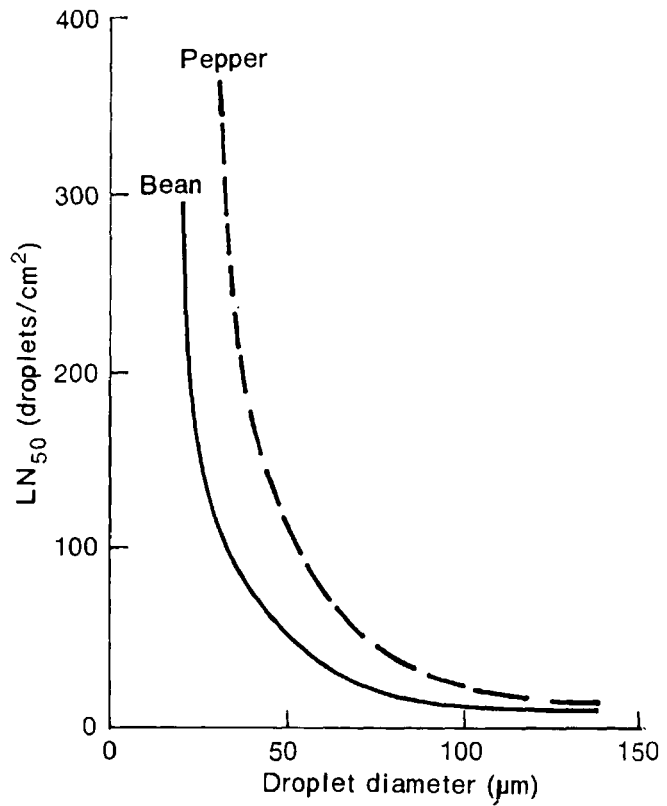


Fig.32. Relationship between droplet diameter and LN₅₀ values with 1% dicofol sprayed against *T. urticae* eggs on bean and pepper leaf discs



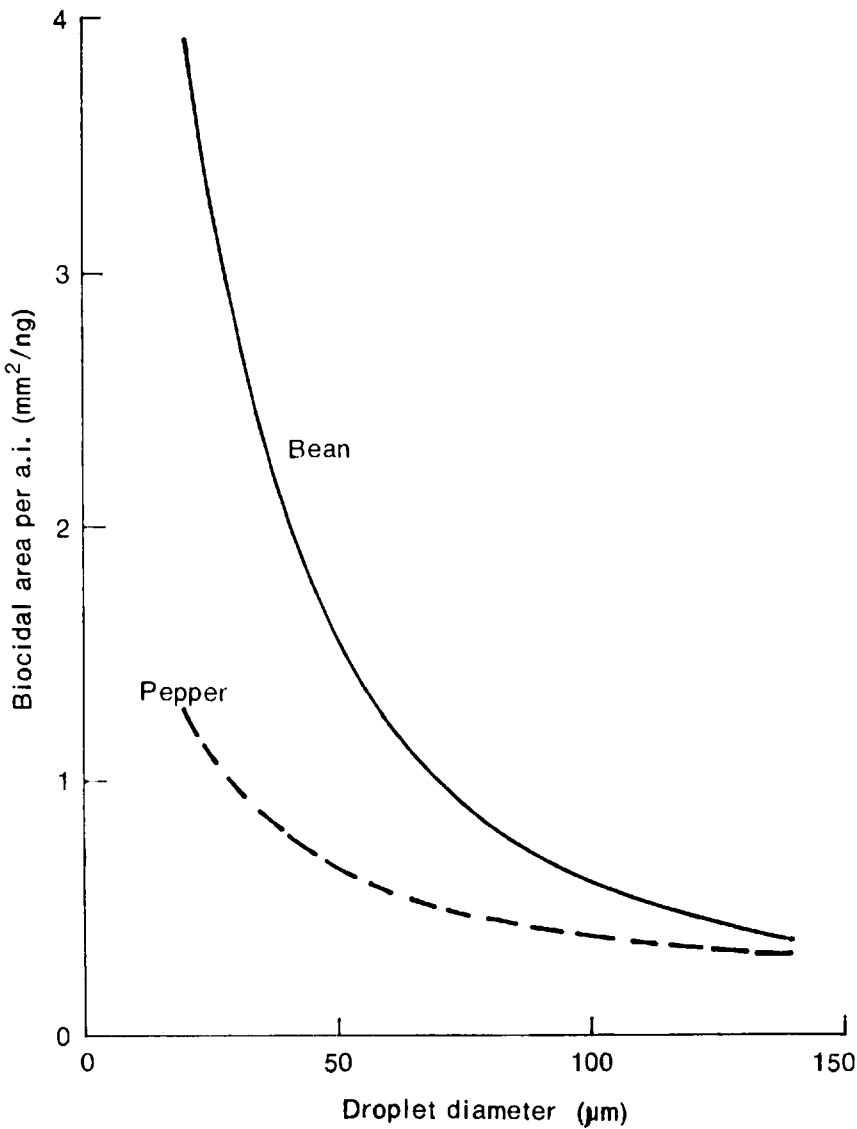
and 1.5 times ($\frac{122}{79}$) more efficient on bean than on pepper leaves.

As before, relative efficiency of a spray of droplets of a particular size on either bean or pepper leaf surfaces can be estimated by using the 'efficiency scale' (Fig. 31).

Relative efficiencies on pepper and bean leaf surfaces are also indicated by the LN_{50} and biocidal area methods. Thus with 30 μm diameter droplets, 4.9 times more droplets ($\frac{366}{74}$) were required to achieve 50% egg mortality on pepper than on bean leaves (Fig. 32). On bean, a.i. from each of these droplets spread to an effective area of 2.74 mm^2 while on pepper the a.i. from a 30 μm droplet effectively spread to only 0.98 mm^2 (Fig. 33).

Since effectiveness of a pesticide (e.g. dicofol) varies according to the type of leaf surface, its efficiency needs to be evaluated for each pest and host plant, and separate recommendations need to be made in each case. In this way, the pesticide will be applied with the greatest efficiency and economy.

Fig.33. Relationship between droplet diameter and biocidal area per (a.i.) with 1% dicofol sprayed against *T. urticae* eggs on bean and pepper leaf discs.



Direct hits of larvae by droplets during spraying

A mite larva is larger than an egg and, as expected, a higher proportion of larvae were hit by the spray.

Overall droplet densities applied need to be adjusted such that more droplets of the dilute solutions are applied to achieve effective control with different concentrations (Tables 13, 14 and 15). With a constant (or nearly constant) mite density, the more the droplets applied the greater the chance of hitting a larva. Thus the largest number of larvae were hit in experiments with 0.05% dicofol where the largest droplet densities were applied. The largest number of larvae were hit in experiments with 65 and 87 μm diameter droplets of 0.05% dicofol where 12 out of 19 and 12 out of 22 larvae per disc (i.e. 63 and 54% of larvae) were hit respectively. Thus in the experiment with 65 μm droplets, from a total of 430 applied droplets only 12 (i.e. only 2.8% of the spray) hit larvae directly. In all experiments, except two with 0.05% dicofol, there were some discs where all larvae were missed by droplets.

Corresponding larval mortality. No obvious relationship between mortality and hits was observed. Although in some experiments mortality on discs where the maximum number were hit directly was slightly higher than on those where larvae were missed completely, in others more larvae were killed on discs where no hits had occurred than on those with maximum hits per experiment (Tables 13, 14 and 15).

Redistribution of fluorescent tracer was often observed on the leaf surface within an hour of spraying. The limbs and mouthparts of most of the larvae on treated discs were often covered with

Table 13. Data showing droplet diameter (dia.), number of droplets per disc, hits per disc and mortality of T. urticae larvae with 0.05% dicofol

Data sheet	Droplets		Larvae/disc with maximum direct hits					No. drop-lets/disc	Larvae/disc with minimum direct hits		
	Dia. (µm)	No./disc	No./disc	No. hit	% hit	No. dead	% dead ⁺		No./disc	No. hit	% dead ⁺
53A	44	87	12	2	17	7	58	134	8	0	62
93	56	437	27	9	33	9	90	53	23	0	42
77	56	142	6	3	50	5	93	75	11	0	41
78	56	245	6	4	66	5	99	108	15	6	40
53B	63	41	16	4	25	8	61	48	20	0	42
84	63	441	16	6	38	14	90	32	18	6	0
83	65	430	19	12	63	18	94	60	12	0	36
86	87	421	22	12	54	19	86	84	30	0	74
90	139	31	12	5	42	11	90	21	5	0	44
89	156	102	16	9	56	14	96	15	13	0	66

⁺ Corrected percent mortality

Table 14. Data showing droplet diameter (dia.), number of droplets per disc, hits per disc and mortality of T. urticae larvae with 1% dicofol

Data sheet	Droplets		Larvae/disc with maximum direct hits					No. drop-lets/disc	Larvae/disc with minimum direct hits		
	Dia. (µm)	No./disc	No./disc	No. hit	% hit	No. dead	% dead ⁺		No./disc	No. hit	% dead ⁺
19	30	128	22	8	18	17	75	178	31	0	98
20	35	144	29	3	21	28	97	74	35	0	72
23	43	44	24	2	17	15	59	39	20	0	45
8	48	109	31	3	10	13	41	34	27	0	88
4	52	65	28	8	29	26	92	47	17	0	72
10	74	64	47	7	15	37	76	14	33	0	72
9	78	57	35	8	23	33	93	15	25	0	88

⁺ Corrected percent mortality

Table 15. Data showing droplet diameter (dia.), number of droplets per disc, hits per disc and mortality of T. urticae larvae with 4% dicofol

Data sheet	Droplets		Larvae/disc with maximum direct hits					No. drop-lets/disc	Larvae/disc with minimum direct hits		
	Dia. (µm)	No./disc	No./disc	No. hit	% hit	No. dead	% dead ⁺		No./disc	No. hit	% dead ⁺
105	35	26	24	4	17	9	37	22	17	0	59
106	39	12	10	1	8	3	22	15	25	0	63
104	42	17	11	2	18	7	60	19	12	0	81
101	48	70	12	3	25	12	92	59	11	0	80
102	48	51	10	2	20	6	58	44	17	0	93
95	52	37	10	2	20	8	75	32	14	0	93
98	56	36	6	3	50	5	83	80	9	0	98
96	61	47	16	5	31	11	80	34	14	0	80
100	64	18	17	2	12	14	93	76	19	0	97
103	65	7	3	1	33	0	0	26	10	0	88
97	87	10	10	2	20	6	65	41	11	0	95

⁺ Corrected percent mortality

fluorescent tracer within a short time, regardless of whether they had been directly hit. No deliberate avoidance of droplet deposits by larvae was observed. Thus although few were hit directly, pesticide was picked up on their limbs as they moved about and more contact was probably achieved through the mouthparts as the larvae pierced contaminated leaf tissue with their stylets during feeding.

Efficiency of dicofol droplets in controlling *T. urticae* larvae and protonymphs

Larvae. With larval data, plotting $\log LD_{50}$ against $\log a.i.$ per droplet gave similar slopes, the average weighted slope for the six concentrations being 0.495 (i.e. very close to the square root of $a.i.$). Of the evaluated relationships, the LD_{50} versus $\sqrt{(a.i.)}$ per droplet one gave the best fits to the data. It would be reasonable, therefore, to expect Model 5 (which relates LD_{50} to $\sqrt{(a.i.)}$ for mite egg control) to similarly estimate relationships for larval control. However, when applied, Model 5 gave poor predictions of LD_{50} , LN_{50} or Biocidal area per droplet values for various $\sqrt{(a.i.)}$ values (Table 16). Tests of differences between slopes of regression lines for the six concentrations showed that, apart from 0.5% dicofol, no significant differences existed between concentrations. In other words, most of these slopes are similar and not arranged in a U (unlike those in experiments with eggs). The equation relating LD_{50} to $\sqrt{(a.i.)}$ for larval control is, therefore, probably of the form:

$$LD_{50} = a + b \sqrt{(a.i.)}$$

..... (Model 7)

When plotted together, data from experiments with different concentrations (Appendix Tables 8, 9, 10, 11, 12 and 13) gave similar scatter diagram distributions (Fig. 34). A regression line calculated for the combined data gives a good fit and the equation describing this relationship is:

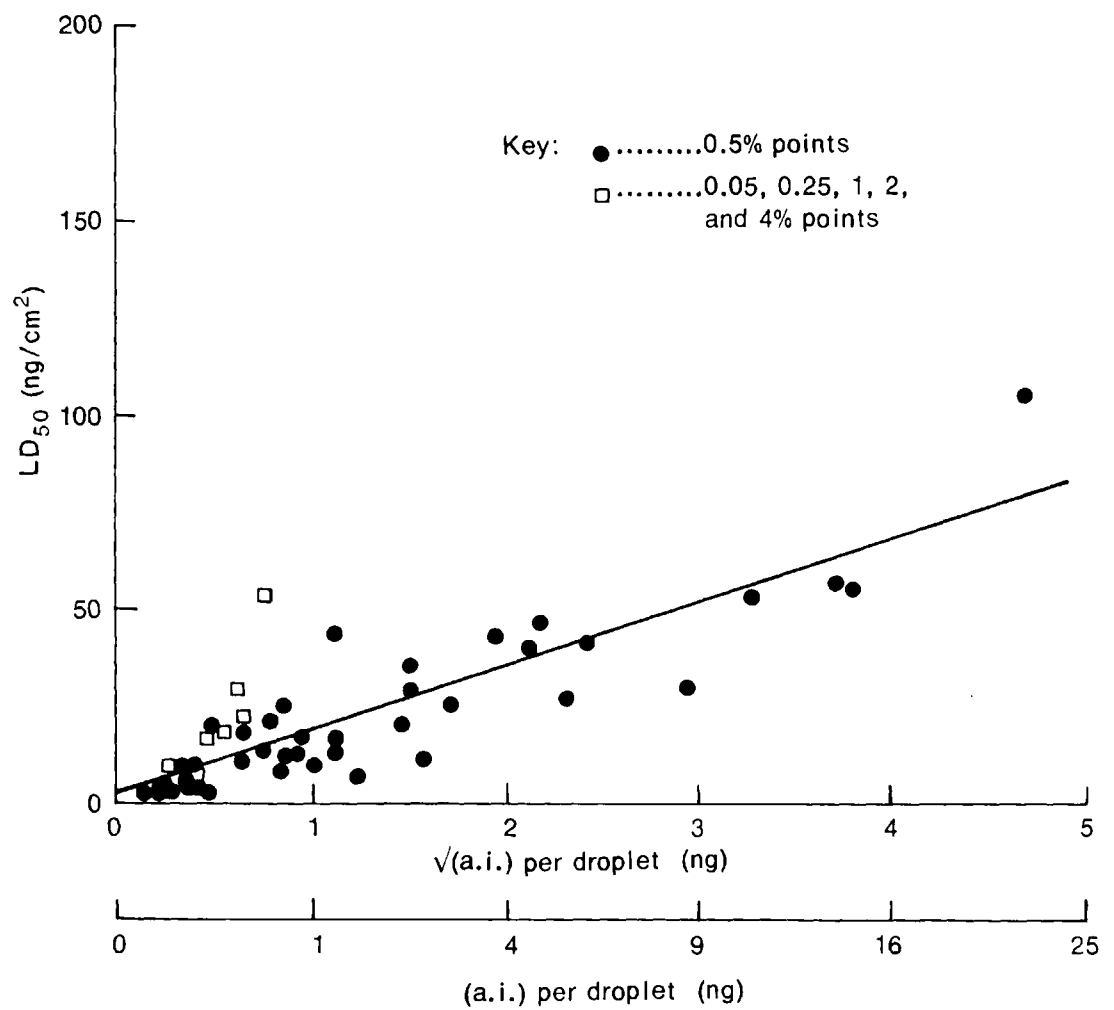
$$LD_{50} = 2.7 + 16.4555 \sqrt{(a.i.)}$$

..... (Model 8).

Table 16. Example comparing observed (Obs.) LD_{50} , LN_{50} and Biocidal area per droplet values at various droplet diameters and $\sqrt{a.i.}$ per droplet values with those values predicted (Pred.) by Model 5 and by Model 7 (which assumes that concentration does not affect mortality of *T. urticae* larvae) using 1% dicofol data

Data sheet	Droplet parameters			LD_{50} values (ng/cm ²)			LN_{50} values (droplets/cm ²)			Biocidal area/ droplet values (mm ²)		
	Dia. (μ m)	a.i. (ng)	$\sqrt{a.i.}$ (ng)	Obs.	Pred. by Model		Obs.	Pred. by Model		Obs.	Pred. by Model	
					5	7		5	7		5	7
19	30	.15	.38	5.2	18.5	6.8	35	126	46	1.43	.40	1.09
20	35	.22	.47	2.9	21.2	7.5	13	97	34	3.85	.52	1.47
23	43	.40	.64	12.0	26.6	8.9	30	66	22	1.79	.76	2.27
8	48	.57	.76	13.4	30.5	9.9	23	53	17	2.08	.94	2.94
4	52	.74	.86	12.4	33.9	10.8	17	46	15	2.94	1.09	3.33
10	74	2.11	1.45	20.4	52.9	15.9	10	25	8	5.00	1.99	6.25
9	78	2.50	1.58	10.9	57.2	16.9	4	23	7	12.50	2.19	7.14

Fig.34. Relationship between (a.i.) per droplet and mortality of *T. urticae* larvae sprayed with different dicofol concentrations and showing the scatter of points of 0.5% dicofol relative to the other five concentrations.



Redistribution and pick up of pesticides by the immatures as they move about and feed probably accounts for the reduction in the importance of concentration in larval control.

Protonymphs. Protonymphs are larger than larvae and so were even larger targets. However, as in experiments with larvae, high protonymph mortalities occurred equally on treated discs where all protonymphs had been missed as on those where maximum numbers of protonymphs had been hit directly (Table 17).

Protonymphs were treated only with 1% dicofol. Plotting Log LD_{50} against Log a.i. indicates a power of 1.12 and the LD_{50} versus $(\text{a.i.})^{(1.12)}$ regression line is a good fit to the data (Fig. 35 and Appendix Table 14). The equation describing this relationship is:

$$\text{LD}_{50} = 5.4 + 20.418 (\text{a.i.})^{(1.12)}$$

..... (Model 9).

The role of direct hits on effectiveness of dicofol droplets against *T. urticae* eggs, larvae and protonymphs

In this analysis, the role of hits was not fully evaluated because it was impossible to check whether individual mites that had been hit directly during spraying had died or not. So, the contribution of direct hits could not be measured precisely. Comparisons of mortalities on discs on which maximum hits occurred with those where mites had been missed completely gave a general indication of the role of hits. Direct hits of eggs, for example, were so few that their contribution was assumed to be negligible. However, it is possible that there is a measurable relationship between hits and mortality. Hits might be related to a factor of

Table 17. Data showing droplet diameter (dia.), number of droplets per disc, hits per disc and mortality of T. urticae protonymphs with 1% dicofol

Data sheet	Droplets		Protonymphs/disc with maximum direct hits					No. drop-lets/disc	Protonymphs/disc with minimum direct hits		
	Dia. (um)	No./disc	No./disc	No. hit	% hit	No. dead	% dead ⁺		No./disc	No. hit	% dead ⁺
1	39	49	16	3	19	11	69	23	31	0	84
4-5	59	57	14	5	36	7	50	139	16	0	94
2-3	65	74	15	5	33	10	67	63	27	0	56
10-11	74	33	20	6	30	17	85	75	9	0	89
8-9	104	50	23	8	35	21	91	23	13	0	85
6-7	118	39	24	6	25	16	67	29	26	0	62

⁺ Corrected percent mortality

Fig.35. Relationship between (a.i.) per droplet and mortality of *T. urticae* protonymphs sprayed with 1% dicofol on bean leaf discs.

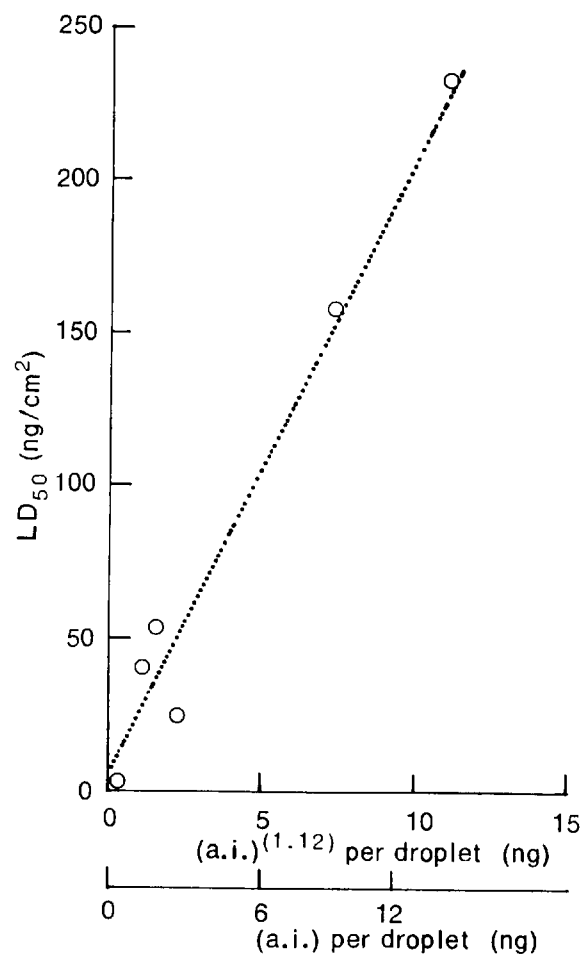
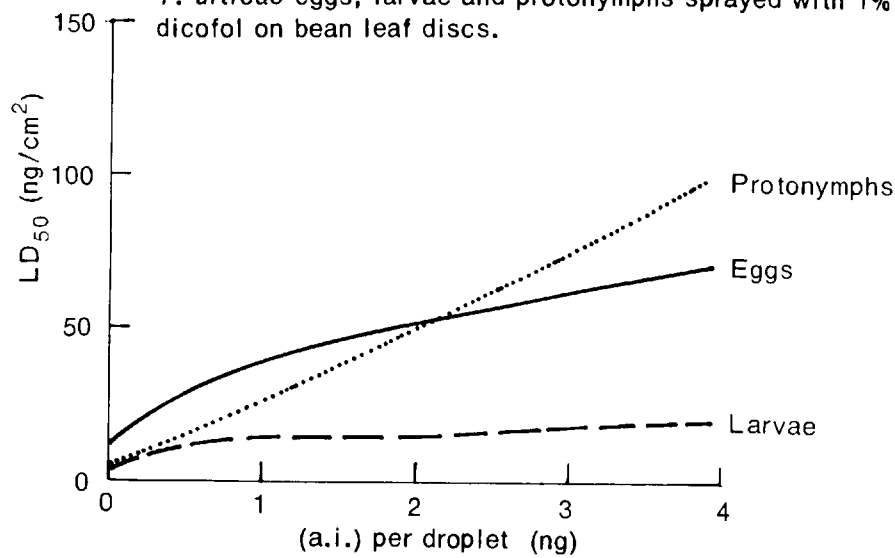


Fig.36. Relationship between (a.i.) per droplet and mortality of *T. urticae* eggs, larvae and protonymphs sprayed with 1% dicofol on bean leaf discs.



the limiting dose at various concentrations (i.e. the theoretical, optimum lethal dose achieved by infinitesimal droplets) for example. It might have been preferable to analyse this data taking the probability of hits into account. Theoretical probabilities could be determined taking into consideration the size and density of both droplets and mites.

However, the whole question of probabilities of hits needs careful evaluation. Do droplets of the same size, but different concentrations, have the same chance of hitting an egg, for example, or do their differences in viscosity, chemical composition or surface tension result in differences in chances of hitting an egg? When impacting on a leaf surface close to an egg, a droplet of low surface tension could be expected to flatten more than one of the same size but higher surface tension. Thus the former would be expected to have more chances of contacting the egg on impaction than the latter.

Thus, considerably more research is required on these topics before a model can be built taking the chances of hits into account.

Efficiency of dicofol droplets in controlling *T. urticae* eggs, larvae and protonymphs

Since with the three evaluated developmental stages of *T. urticae*, LD_{50} is directly proportional to different 'powers' of a.i. (i.e. 0.47 for eggs, 0.495 for larvae and 1.12 for protonymphs), direct comparisons of the straight line relationships is not possible. However, derived LD_{50} versus a.i. per droplet (Fig. 36) or LD_{50} versus droplet diameter (Fig. 37) relationships for these stages can be compared. Thus, with 1% dicofol and monosized droplets containing 1 ng each, 12.5 ng/cm^2 achieves 50% larval mortality while twice this amount (25 ng/cm^2) is required to kill 50% protonymphs and more than 3 times (38 ng/cm^2) is necessary against eggs. If droplets containing 4 times as much a.i. (i.e. 4 ng/droplet) are used, 19, 72 and 101.5 ng/cm^2 are required to kill 50% larvae, eggs and protonymphs, respectively. Larvae require the least dose and so are the most vulnerable stage. The LD_{50} versus a.i. per droplet relationship indicates that if droplets containing less than 2.16 ng each are used protonymphs require less chemical than eggs but if those with amounts beyond 2.16 ng each are applied, less pesticide is required to kill 50% eggs than protonymphs.

Derived LD_{50} versus droplet diameter relationships also show that with droplets of different sizes, larvae require the least amounts and so are the most susceptible stage, and that protonymphs are controlled with less amounts than eggs if droplets smaller than $75 \mu\text{m}$ in diameter are used but the amount is greater than for eggs if bigger droplets are sprayed. Protonymph dosage requirements with droplets below $30 \mu\text{m}$ in diameter are low and similar to those for larvae. The protonymphs probably detect larger droplets and so avoid them, thus increasing the dosage.

Fig.37. Relationship between droplet diameter and mortality of *T. urticae* eggs, larvae and protonymphs sprayed with 1% dicofol on bean leaf discs.

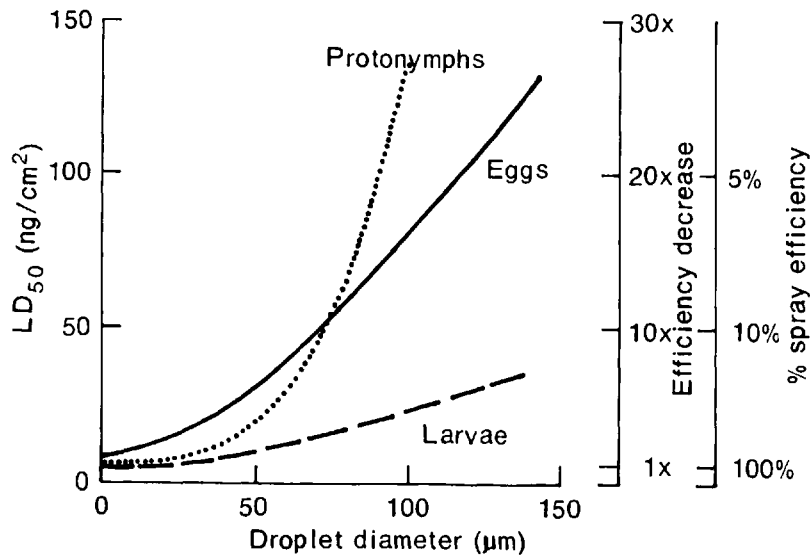
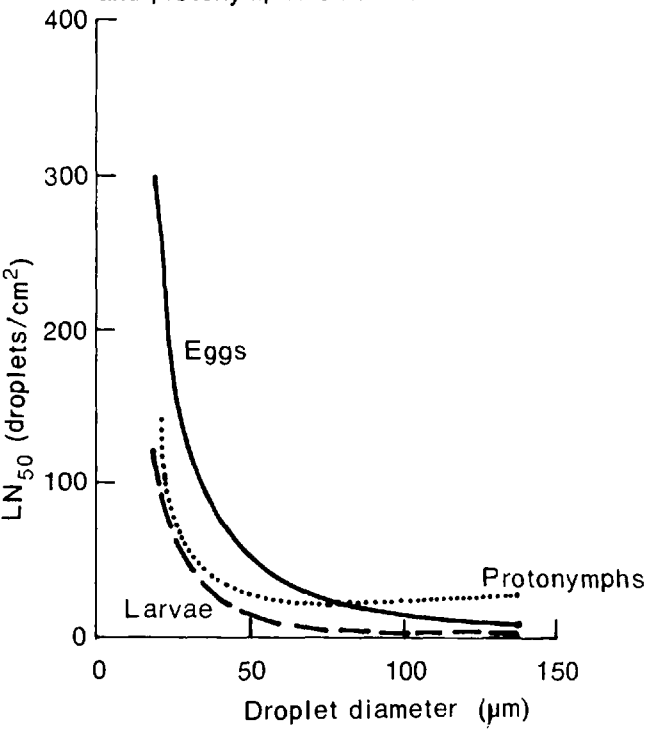


Fig.38. Relationship between droplet diameter and LN₅₀ values with 1% dicofol sprayed against *T. urticae* eggs, larvae and protonymphs on bean leaf discs.



requirements. The theoretical limiting dosage for larvae is about 5 ng/cm^2 and that for protonymphs is just slightly more than 5 ng while that for eggs is about 8 ng/cm^2 .

If $20 \mu\text{m}$ diameter droplets are used, about 5 ng/cm^2 is necessary to kill 50% larvae, 6 ng/cm^2 to kill 50% protonymphs and 13 ng/cm^2 to kill 50% eggs. As before, the LD_{50} scale can be converted to an efficiency scale and so used to estimate relative efficiencies with which droplets of different sizes control different T. urticae developmental stages (Fig. 37). For example, droplets with sizes below $20 \mu\text{m}$ in diameter have the same (1X) efficiency as the theoretical optimum (i.e. are 100% as efficient) in controlling larvae. However, $20 \mu\text{m}$ diameter droplets are 1.2 times less efficient than the "larval optimum" if applied against the protonymphs (i.e. 83% as efficient), and 2.6 times less efficient if applied against eggs (i.e. 38% as efficient). Similarly, if the size of droplets sprayed is doubled (to $40 \mu\text{m}$ in diameter), efficiency against larvae, protonymphs and eggs is reduced by 1.8, 2.2 and 3.8 times, respectively. In other words, the resulting sprays are 55.5, 45.5 and 26.3% as efficient as the optimum spray against larvae. Doubling droplet diameter reduced efficiency of controlling larvae from 100 to 55.5%; protonymphs from 83 to 45.5% and eggs from 38 to 26.3%.

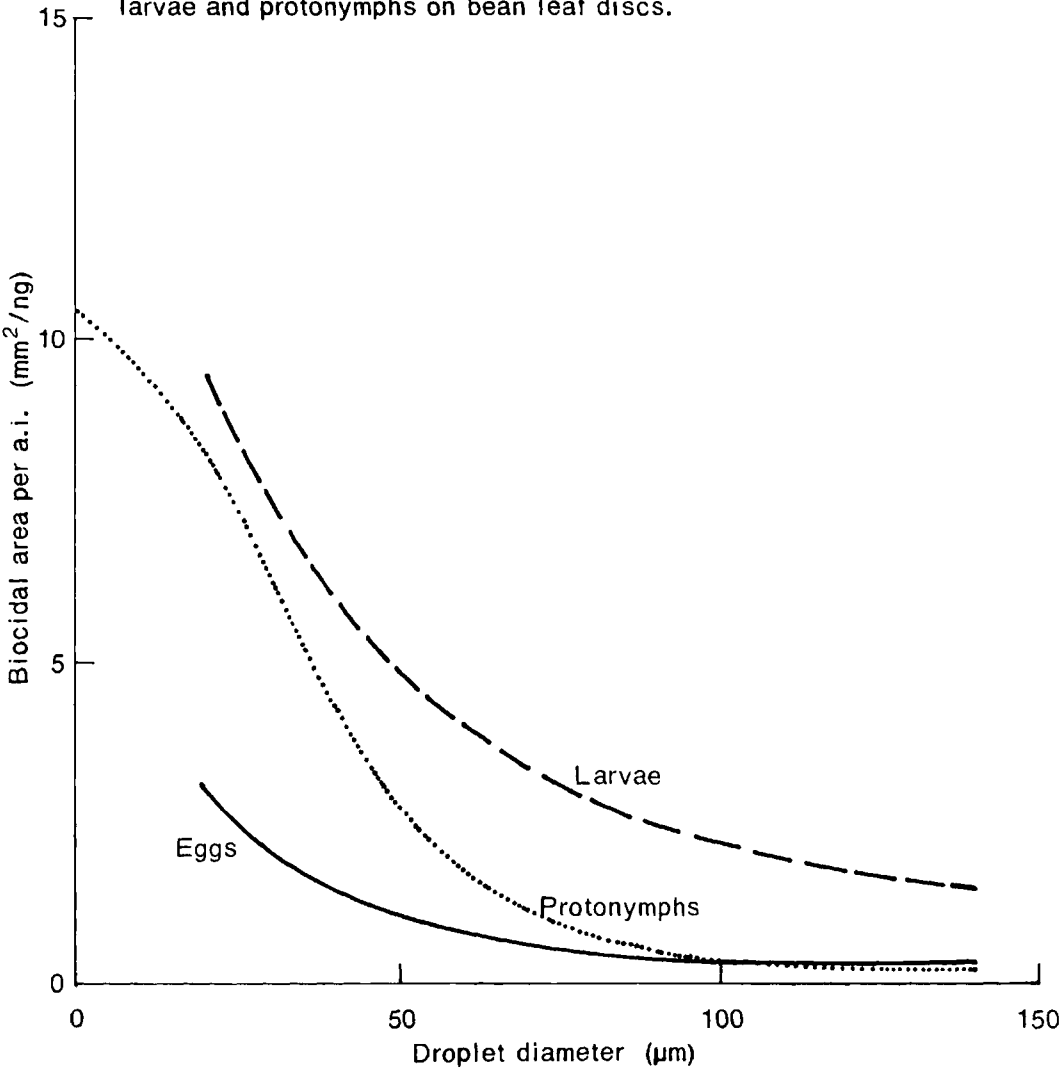
Median lethal numbers (LN_{50}) values plotted against droplet diameter (Fig. 38) show a similar arrangement of efficiencies as indicated by the LD_{50} versus droplet diameter relationship. Larvae require the least number of droplets at any droplet size. Density requirements against protonymphs and eggs for droplets larger or smaller than $75 \mu\text{m}$ in diameter indicate the same effects as in the LD_{50} against droplet diameter relationship.

Biocidal area per a.i. plotted against droplet diameter (Fig. 39) also showed the same effect with larvae being controlled most efficiently (i.e. with largest areas) relative susceptibilities interchanged when either larger or smaller droplets than $75\text{ }\mu\text{m}$ were used. The fitted biocidal area per a.i. against droplet diameter line for protonymphs when extrapolated indicated a limiting biocidal area of 10.5 mm^2 .

The method used to analyse the data involved calculating χ^2 and estimating heterogeneity by computer using a normal probit analysis programme and these indicated that probit analysis was less appropriate for eggs compared with larvae and protonymphs (Appendix Tables 1B-14B). However, correlation coefficients indicated that the probit lines were good fits to the egg data. It might be that normally accepted tests of goodness of fit such as χ^2 and the heterogeneity factor are inappropriate to use when assessing responses of small stationary 'targets' like eggs to a ULV spray of discrete, small droplets. Thus, while these tests may be appropriate for data from high volume application where total coverage is achieved and so even stationary targets come into contact with at least the lethal dose, they may not be suitable for data from ULV sprays where some of the eggs probably never even contact a.i. since contact depends on diffusion from the discrete deposits. Re-distribution of a.i. by mobile larvae or protonymphs, however, changes the characteristics of the ULV spray so that these immatures are dosed as in high volume application and so tests designed for 'efficient dosing' of individual pests are valid thus giving sensible χ^2 and heterogeneity factor values.

Further analysis of this type of data should consider the importance of the perimeter around a spray droplet after impaction and spread in relation to the overall biocidal area.

Fig.39. Relationship between droplet diameter and biocidal area per (a.i.) with 1% dicofol sprayed against *T. urticae* eggs, larvae and protonymphs on bean leaf discs.



CONCLUSIONS

1. The Micro-Tip proved a successful technique for testing the variations in effectiveness due to changes in droplet size and concentration.

Tests were conducted with droplets, the sizes of which ranged in diameter from 18 to 150 μm . The concentrations of spray liquids used were between 0.05 and 4% dicofol.

2. The most appropriate measure of effectiveness for comparing efficiencies of various sprays was the median lethal dosage (LD_{50}).
3. The main conclusion from this research was that droplet size has an over-riding influence in controlling all tested stages of Tetranychus urticae. The smaller the droplet size the more efficient the spray. Thus 20 μm droplets of 1% dicofol were 8X more effective than 120 μm droplets against eggs.
4. In tests with the egg stage, concentration was also important with an optimum of approximately 1%. Thus with 50 μm droplets, 1% was 5 times more effective than 4% and almost twice as effective as 0.05%.
5. Concentration of dicofol was less important in tests against larvae as they were active and contacted more droplets; consequently, this stage was the most susceptible and should be the 'target stage' since 20 μm droplets achieved the lowest recorded LD_{50} of only 5 ng/cm^2 .

6. Protonymphs were tested only at 1% and the results with droplets of various sizes were similar to those obtained with eggs and larvae (i.e. smaller droplets being more effective).
7. Dicofol was more effective against eggs on bean than on the more waxy pepper leaf surface.
8. The data was fitted to various mathematical models and LD_{50} appeared to be directly proportional to a power of the amount of active ingredient per droplet. This power was close to $\frac{1}{2}$ (that is the square root) for eggs and larvae on bean, about 1 for protonymphs on bean and $\frac{1}{4}$ for eggs on pepper.
9. It is concluded that the effectiveness of a droplet, especially against a sessile target such as an egg, is determined by the effective spread of the chemical from each droplet (i.e. the biocidal area).
10. Thus the physical properties of spray droplets are of paramount importance in determining the effectiveness of a spray technique. These properties are, therefore, worthy of intensive research both in the formulation of spray liquids and the design of sprayers in order to achieve the greatest efficiency of control and economy of materials. This is particularly so in the control of T. urticae where the optimum droplet size against the target stage is small (20 μ m).

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Appendix Table 1A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae eggs when 0.05% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter					LD ₅₀ / disc (ng/ cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ / disc (drop- lets/ cm ²)	Bio- cidal area/ drop- let (mm ²)
		dia. (µm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
240	66	57	1.75	.047	-1.33	.217	88	1.94	3,105	.016
250	61	57	1.75	.047	-1.31	.217	32	1.50	678	.074
244	47	74	1.87	.106	- .98	.325	135	2.13	1,277	.039
224	37	78	1.89	.126	- .90	.355	108	2.03	859	.058
247	35	82	1.91	.143	- .85	.375	94	1.97	658	.076
253	39	97	1.99	.242	- .62	.492	102	2.00	510	.098

Av. = Average

a.i. = Active ingredient

Appendix 1B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when .05% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
240	57	88	39 - > 300	1.06	.266	.67	18.0	18	1.0
250	57	32	19 - 144	1.81	.326	.72	39.5	18	2.2
244	74	135	52 - > 300	1.31	.462	.60	18.1	18	1.0
224	78	108	47 - > 300	.85	.197	.60	26.6	18	1.5
247	82	94	39 - > 300	1.25	.283	.52	46.7	18	2.6
353	97	102	45 - > 300	1.76	.422	.50	38.0	18	2.5

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 2A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae eggs when 0.25% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter					LD ₅₀ / disc (ng/ cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ / disc (drop- lets/ cm ²)	Bio- cidal area/ drop- let (mm ²)
		dia. (μm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
241	56	44	1.64	.108	-.97	.328	46	1.66	427	.117
237	39	50	1.70	.168	-.78	.409	21	1.32	125	.399
225	45	67	1.83	.392	-.41	.626	46	1.66	117	.426
248	69	74	1.87	.528	-.28	.727	61	1.79	116	.433
251	68	77	1.88	.586	-.23	.766	60	1.78	102	.488
245	45	84	1.92	.762	-.12	.872	72	1.86	95	.529

Av. = Average

a.i. = Active ingredient

Appendix 2B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when .25% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia.	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
	(µm)	(ng/cm ²)							
241	44	46	34 - 92	1.70	.261	.73	34.5	18	1.9
237	50	21	15 - 25	1.91	.294	.71	34.0	18	1.9
225	67	46	38 - 59	1.86	.221	.78	47.0	18	2.6
248	74	61	44 - 89	1.68	.171	.53	152.5	18	8.5
251	77	60	43 - 74	2.02	.179	.73	115.4	18	6.4
245	84	72	60 - 83	3.04	.271	.82	58.8	18	3.3

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 3A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae eggs when 0.5% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter					LD ₅₀ / disc (ng/ cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ / disc (drop- lets/ cm ²)	Bio- cidal area/ drop- let (mm ²)
		dia. (µm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
179/ 180	101	30	1.47	.067	-1.17	.259	36	1.56	536	.093
242	55	37	1.57	.137	- .86	.370	22	1.34	161	.311
208	103	39	1.59	.157	- .81	.396	23	1.36	147	.340
204	84	41	1.61	.179	- .75	.423	38	1.58	212	.236
177/ 178	125	44	1.64	.216	- .67	.464	69	1.84	320	.156
230	51	59	1.77	.540	- .27	.735	71	1.85	131	.380
200	104	70	1.84	.879	- .06	.938	62	1.79	71	.709
226	45	74	1.87	1.060	.02	1.230	60	1.78	57	.880
216	81	85	1.93	1.630	.22	1.280	58	1.76	36	1.400
220	77	87	1.94	1.720	.24	1.310	56	1.75	33	1.534
212	56	104	2.02	2.970	.47	1.720	98	1.99	33	1.515

Av. = Average

a.i. = Active ingredient

Appendix 3B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 0.5% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (μm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
179/180	30	36	27 - 62	2.46	.419	.70	58.0	50	1.2
242	37	22	19 - 25	4.09	.322	.75	120	18	6.7
208	39	23	19 - 31	1.69	.119	.79	97.0	18	5.4
204	41	38	25 - 102	1.68	.233	.78	47.9	18	2.7
177/178	44	69	54 - 110	1.96	.211	.75	157	62	2.5
230	59	71	60 - 85	2.12	.184	.88	50.1	18	2.8
200	70	62	54 - 75	2.59	.186	.88	79.8	18	4.4
226	74	60	46 - 71	2.66	.279	.77	61.8	18	3.4
216	85	58	53 - 63	3.06	.174	.95	38.3	18	2.1
220	87	56	31 - 60	3.87	.220	.89	81.2	18	4.5
212	104	98	85 - 113	2.58	.247	.87	45.1	18	2.5

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 4A. Data to indicate effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 1% dicofol was sprayed on bean leaf discs

Data sheet	Av. no. eggs/disc	Droplet parameter					LD ₅₀ /disc (ng/cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ /disc (drop-lets/cm ²)	Bio-cidal area/drop-let (mm ²)
		dia. (µm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
26	76	18	1.26	.032	-1.50	.179	6	.78	187	.267
58	91	27	1.43	.102	-.99	.319	10	1.00	98	.509
56	68	37	1.57	.274	-.56	.523	17	1.23	62	.805
55	52	47	1.67	.540	-.27	.735	20	1.30	37	1.36
68	97	49	1.69	.605	-.22	.778	33	1.52	54	.916
67	93	50	1.70	.639	-.19	.799	35	1.54	54	.916
77	30	50	1.70	.670	-.17	.819	18	1.26	26	1.86
210	69	50	1.70	.670	-.17	.819	41	1.61	61	.817
24	74	51	1.71	.707	-.15	.841	61	1.79	86	.579
57	96	54	1.73	.820	-.09	.905	41	1.61	50	1.00
75	34	61	1.79	1.18	-.07	1.81	37	1.57	31	1.60
76	31	62	1.79	1.23	0.09	1.11	52	1.72	42	1.18
35	89	65	1.81	1.45	.16	1.21	52	1.72	35	1.40
36	78	65	1.81	1.45	.16	1.21	49	1.69	33	1.48
33	70	66	1.82	1.51	.18	1.23	39	1.59	28	1.74
34	67	66	1.82	1.51	.18	1.23	40	1.60	26	1.89
201	80	70	1.84	1.76	.25	1.33	67	1.83	37	1.32
73	60	72	1.86	1.97	.30	1.40	66	1.82	33	1.49
74	64	72	1.86	1.97	.30	1.40	79	1.90	40	1.25
32	72	77	1.89	2.43	.39	1.56	68	1.83	28	1.88
213	53	84	1.92	3.05	.48	1.75	81	1.91	26	1.88
79	44	99	1.99	5.10	.71	2.26	83	1.92	16	3.07
80	43	103	2.01	5.66	.75	2.38	70	1.85	24	4.03
78	49	111	2.05	7.22	.86	2.69	114	2.06	15	3.16
81	47	129	2.11	11.2	1.05	3.34	104	2.02	9	5.38

Av. = Average; a.i. = Active ingredient

Appendix 4B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of T. urticae eggs when 1% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
26	18	6	5 - 7	5.42	.895	.81	190	18	10.6
58	27	10	8 - 11	2.89	.212	.96	61.5	18	3.4
56	37	17	11 - 22	2.78	.251	.82	74.0	18	4.1
55	47	20	6 - 31	1.40	.182	.70	101	18	5.6
68	49	33	29-36	4.21	.884	.71	155	18	8.6
67	50	35	21 - 46	2.79	.242	.80	144	18	8.0
77	50	18	13 - 22	3.13	.338	.77	67.4	18	3.7
210	50	41	34 - 56	2.37	.231	.71	78.2	18	4.3
24	51	61	48 - 95	2.01	.291	.83	39.8	18	2.2
57	54	41	33 - 49	4.23	.216	.88	233	18	12.9
75	61	37	28 - 46	3.87	.411	.82	100	18	5.6
76	62	52	41 - 61	5.42	.702	.89	58.4	18	3.2
35	65	52	16 - 88	1.81	.189	.63	212	18	11.8
36	65	49	32 - 61	2.15	.144	.83	146	18	8.1
33	66	39	30 - 49	2.28	.209	.76	115	18	6.4
34	66	40	24 - 54	2.76	.212	.85	143	18	7.9
201	70	67	55 - 77	2.50	.231	.81	97.9	18	5.4
73	72	66	55 - 78	2.20	.151	.91	43	18	2.4
74	72	79	52 - 82	2.99	.310	.72	132	18	7.3
32	77	68	46 - 91	1.83	.165	.81	113	18	6.2
213	84	81	62 - 99	2.39	.212	.71	104	18	5.8
79	99	83	66 - 112	2.17	.206	.83	111	18	6.2
80	103	70	56 - 85	2.24	.215	.88	45.7	18	2.5
78	111	114	72 - 146	2.68	.287	.89	61.2	18	3.4
81	129	104	76 - 129	2.42	.218	.85	59.0	18	3.3

DF = Degrees of freedom; FD LTS = Fiducial limits; HET F = Het. factor

Appendix Table 5A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae eggs when 2% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter					LD ₅₀ / disc (ng/ cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ / disc (drop- lets/ cm ²)	Bio- cidal area/ drop- let (mm ²)
		dia. (μm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
243	70	44	1.64	.862	-.06	.928	44	1.64	51	.980
60	75	48	1.68	1.14	.06	1.07	55	1.74	48	1.04
239	35	48	1.68	1.14	.06	1.07	23	1.36	20	2.49
14	43	50	1.70	1.28	.11	1.13	30	1.48	23	2.13
231	55	61	1.79	2.36	.37	1.54	63	1.80	27	1.88
22	38	64	1.81	2.78	.44	1.67	56	1.75	20	2.49
227	41	67	1.83	3.14	.50	1.77	37	1.57	12	4.24
249	73	70	1.84	3.53	.55	1.88	57	1.76	16	3.11
252	62	74	1.87	4.23	.63	2.06	68	1.83	16	3.11
255	41	104	2.02	11.90	1.08	3.45	153	2.19	13	3.88
235	77	108	2.03	13.10	1.12	3.62	103	2.01	8	6.33
91	76	109	2.04	13.4	1.13	3.67	149	2.17	11	4.50
246	36	146	2.16	32.6	1.51	5.71	311	2.49	10	5.26

Av. = Average

a.i. = Active ingredient

Appendix 5B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 2% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (μm)	LD ₅₀ disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
243	44	44	34 - 51	2.70	.218	.75	99.5	18	5.5
60	48	55	37 - 70	2.49	.166	.87	126	18	7.0
239	48	23	14 - 30	2.12	.219	.79	71.5	18	3.9
14	50	30	13 - 46	2.33	.300	.69	120	18	6.6
231	61	63	54 - 72	2.70	.228	.89	39.3	18	2.2
22	64	56	34 - 78	2.18	.232	.71	93.5	18	5.8
227	67	37	19 - 52	2.10	.227	.82	56.9	18	3.2
249	70	57	44 - 66	3.44	.261	.81	92.6	18	5.1
252	74	68	59 - 71	2.36	.171	.91	51.0	18	2.8
255	103	153	130 - 173	3.45	.264	.70	54.9	18	3.1
235	108	103	56 - 136	2.22	.256	.73	64.8	18	3.6
91	109	149	59 - 183	4.09	.745	.85	69.4	18	3.8
246	146	311	252 - 372	2.72	.235	.74	82.7	18	4.6

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 6A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae eggs when 4% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter					LD ₅₀ / disc (ng/ cm ²)	Log ₁₀ LD ₅₀	LN ₅₀ / disc (drop- lets/ cm ²)	Bio- cidal area/ drop- let (mm ²)
		dia. (µm)	Log ₁₀ dia.	a.i. (ng)	Log ₁₀ a.i.	√a.i. (ng)				
141	91	29	1.46	.495	-.31	.704	69	1.84	139	.359
142	88	29	1.46	.495	-.31	.704	73	1.86	147	.339
114	82	33	1.52	.753	-.12	.868	88	1.94	117	.428
113	115	34	1.53	.816	-.09	.903	94	1.97	115	.434
135	122	45	1.66	1.93	.29	1.39	118	2.07	61	.820
136	146	45	1.66	1.93	.29	1.39	133	2.12	69	.727
125	129	46	1.66	2.05	.31	1.43	183	2.26	89	.560
123	101	46	1.66	2.05	.31	1.43	255	2.41	124	.402
206	87	48	1.68	2.29	.36	1.51	67	1.83	29	1.71
211	71	52	1.72	2.96	.47	1.72	54	1.73	18	2.75
120	102	52	1.72	2.98	.47	1.73	195	2.29	66	.763
115	123	52	1.72	2.98	.47	1.73	258	2.41	87	.577
132	185	71	1.85	7.59	.88	1.76	195	2.29	26	1.95
133	119	73	1.86	8.15	.91	2.85	293	2.47	36	1.39
134	117	73	1.86	8.15	.91	2.85	298	2.47	37	1.37
215	68	97	1.99	19.3	1.29	4.39	263	2.42	14	3.68
130	182	105	2.02	24.4	1.39	4.94	456	2.66	19	2.67
108	99	106	2.03	25.0	1.40	5.00	296	2.47	12	4.24
128	163	109	2.04	26.9	1.43	5.19	672	2.83	25	2.01

Av. = Average

a.i. = Active ingredient

Appendix 6B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 4% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
141	29	69	42 - 93	2.40	.245	.20	187	18	10
142	29	73	48 - 92	2.92	.217	.87	150	18	8.3
114	33	88	1 - 125	2.68	.403	.77	178	18	9.9
113	34	94	69 - 168	1.49	.147	.76	113	18	6.2
135	45	118	78 - 143	2.89	.266	.82	77.4	18	4.3
136	45	133	102 - 159	2.65	.119	.86	229	18	13
125	46	183	146 - 219	2.78	.215	.84	106	18	5.9
123	46	255	193 - 350	1.74	.163	.87	90	18	5.0
206	48	67	49 - 83	2.32	.144	.86	144	18	8.0
211	52	54	38 - 66	2.50	.176	.77	145	18	8.0
120	52	195	153 - 347	2.27	.286	.75	92	18	5.1
115	52	258	161 - 500	1.40	.186	.64	102	18	5.6
132	71	195	120 - 250	2.46	.216	.84	233	18	13
133	73	293	14 - 432	1.92	.329	.79	136	18	7.5
134	73	298	222 - 528	1.49	.165	.78	81.3	18	4.5
215	97	263	208 - 310	3.19	.209	.89	117	18	6.5
130	105	456	316 - 560	2.99	.236	.91	135	18	7.5
108	106	296	221 - 458	1.78	.161	.79	94.1	18	5.2
128	109	672	393 - 907	1.81	.160	.85	143	18	7.9

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 7A. Data comparing observed (obs.) LD₅₀, LN₅₀ and biocidal area per droplet values at various droplet diameters and (a.i.)^(.248) values with those values predicted (pred.) by Model 6 when 1% dicofol was sprayed against *T. urticae* eggs on pepper leaf discs

Data sheet	Av. no. eggs/ disc	Droplet parameter			LD ₅₀ values (ng/cm ²)		LN ₅₀ values (droplets/ cm ²)		Biocidal area/droplet values (mm ²)	
		dia. (µm)	a.i. (ng)	(a.i.) ^(.248) (ng)	Obs.	Pred. by Model 6	Obs.	Pred. by Model 6	Obs.	Pred. by Model 6
168	74	26	.092	.553	53	47	576	511	.087	.098
167	58	31	.160	.635	41	53	256	331	.195	.151
170	51	61	1.78	1.04	87	85	49	48	1.020	1.042
175/ 176	59	65	1.45	1.10	91	90	63	62	.794	.806
169	51	71	1.90	1.17	117	96	62	51	.806	.980
173	71	78	2.50	1.26	95	102	38	41	1.316	1.219
171	54	85	3.24	1.34	99	109	30	34	1.667	1.479

Av. = Average

a.i. = active ingredient

Appendix Table 7B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 1% dicofol was sprayed on pepper leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
168	26	53	-	1.26	.363	.40	44.1	18	2.4
167	31	41	26 - 130	1.27	.215	.84	42.5	18	2.3
170	61	87	71 - 125	2.95	.405	.65	36.2	18	2.0
175/ 176	65	91	68 - 158	1.69	.207	.55	94.1	38	2.5
169	71	117	86 - 258	2.16	.360	.65	54.0	18	3.0
173	78	95	71 - 163	1.93	.188	.74	83.4	18	4.6
171	85	99	74 - 148	1.73	.151	.81	94.1	18	5.2

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 8A. Data to indicate effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when .05% dicofol was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (µm)	a.i. (ng)	$\sqrt{a.i.}$ (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drops/cm ²)	Bio-cidal area/drop-let (mm ²)
53A	12	44	.023	.151	1.5	67	.745
93	25	56	.045	.212	2.4	53	.936
77	11	57	.047	.218	2.9	60	.829
78	11	57	.047	.218	3.3	68	.739
53B	20	63	.064	.254	2.4	37	1.37
84	21	63	.064	.254	3.9	60	.833
83	18	65	.073	.269	4.6	63	.798
86	22	87	.172	.415	4.4	25	1.97
90	14	139	.705	.839	8.9	13	3.96
89	18	157	1.00	1.00	9.3	9	5.38

Av. = Average

a.i. = active ingredient

Appendix Table 8B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when .05% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ disc	FD LTS	Slope	SE (slope)	r (probit line)	χ ²	DF	HET F
		(ng/cm ²)							
53A	44	1.5	-	1.44	-	.41	10.5	18	.58
93	56	2.4	1.6 - 3.1	2.39	.298	.70	53.3	18	2.9
77	56	2.9	1.7 - 3.7	2.69	.509	.76	40.0	18	2.2
78	57	3.3	-	2.59	-	.58	28.2	18	1.6
53B	63	2.4	2.0 - 3.0	2.34	.327	.82	21.9	18	1.2
84	63	3.9	3.1 - 4.7	2.54	.291	.78	32.7	18	1.8
83	65	4.6	3.7 - 5.4	2.44	.292	.92	19.2	18	1.1
86	87	4.4	2.8 - 5.7	1.71	.258	.74	20.9	18	1.2
90	139	8.9	6.4 - 10.7	3.39	.573	.84	18.6	18	1.0
89	157	9.3	3.1 - 13.7	2.20	.356	.57	53.7	18	3.0

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 9A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae larvae when .25% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (µm)	a.i. (ng)	$\sqrt{a.i.}$ (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drops/cm ²)	Bio-cidal area/drop-let (mm ²)
54A	14	47	.135	.367	6.7	50	1.007
66	19	48	.143	.378	8.3	58	.866
79	13	48	.143	.378	8.7	60	.827
56	19	56	.226	.478	19.7	87	.574
62	19	70	.441	.664	18.7	42	1.178
60	18	77	.607	.779	21.4	35	1.416
69	17	87	.861	.928	12.9	15	3.338

Av. = Average

a.i. = active ingredient

Appendix Table 9B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when .25% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
54A	47	6.7	-	1.80	-	.66	19.8	18	1.1
66	48	8.3	6.1 - 30	2.59	.498	.59	63.2	18	3.5
79	48	8.7	3.6 - 12.2	2.77	.524	.80	35.7	18	2.0
56	56	19.7	13.7 - 47.6	1.73	.331	.83	27.6	18	1.5
62	70	18.7	10.0 - 25.6	1.95	.336	.64	55.4	18	3.1
60	77	21.4	18.5 - 24.9	4.27	.774	.76	22.25	18	1.2
69	87	12.9	7.1 - 18.3	1.79	.317	.50	66.3	18	3.7

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 10A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae larvae when .5% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (µm)	a.i. (ng)	√a.i. (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drops/cm ²)	Bio-cidal area/drop-let (mm ²)
41/42	30	30	.068	.261	9.3	14	.365
27	27	32	.087	.394	9.5	109	.460
31	25	40	.168	.410	6.2	37	1.366
36, 37 38	32	44	.216	.465	16.6	77	.650
29	26	52	.370	.535	18.4	50	1.004
43	25	54	.410	.608	29.5	72	.694
32	28	60	.566	.640	22.8	40	1.241
47/48	27	78	1.252	.750	53.9	43	1.163

Av. = Average

a.i. = active ingredient

Appendix Table 10B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of T. urticae larvae when .5% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
41/42	30	9.3	8.4 – 10.4	2.61	.206	.84	101.6	50	2.0
27	32	9.5	7.1 – 12.7	1.93	.245	.94	37.9	18	2.1
31	40	6.2	4.7 – 7.9	1.78	.289	.74	40.3	18	2.2
36, 37 38	44	16.6	14.7 – 18.8	2.26	.119	.84	257.2	70	3.7
29	52	18.4	13.9 – 29.7	1.77	.252	.84	32.7	18	1.8
43	54	26.5	25.6 – 35.4	2.82	.338	.84	24.3	18	1.4
32	60	22.8	18.8 – 30.5	2.19	.287	.85	30.4	18	1.7
47/48	78	53.9	46.9 – 64.7	1.98	.165	.89	59.7	50	1.2

DF = Degrees of freedom
 FD LTS = Fiducial limits
 HET F = Heterogeneity factor

Appendix Table 11A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae larvae when 1% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (μm)	a.i. (ng)	$\sqrt{\text{a.i.}}$ (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drop-lets/cm ²)	Bio-cidal area/drop-let (mm ²)
19	23	30	.147	.383	5.2	37	1.359
20	26	35	.219	.468	2.9	25	1.988
23	22	43	.405	.636	11.5	42	1.962
8	29	48	.572	.756	13.6	40	1.240
4	33	52	.741	.861	12.4	22	2.237
10	35	74	2.113	1.454	20.4	12	4.115
9	38	78	2.504	1.582	10.9	7	7.225

Av. = Average

a.i. = active ingredient

Appendix Table 11B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* eggs when 1% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
19	30	5.2	2.9 – 6.8	2.76	.345	.59	68.0	18	3.8
20	35	2.9	0 – 7.6	.97	.225	.54	75.8	18	4.2
23	43	11.5	8.7 – 15.3	2.01	.345	.66	41.6	18	2.3
8	48	13.6	6.8 – 22.3	1.14	.164	.65	57.2	18	3.2
4	52	12.4	2.1 – 20.8	1.31	.224	.67	81.0	18	4.5
10	74	20.4	8.0 – 28.6	2.99	.352	.62	139.4	18	7.7
9	78	10.9	4.1 – 17.2	1.67	.231	.60	38.3	18	2.1

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 12A. Data to indicate effect of droplet diameter (dia.)
on mortality of T. urticae larvae when 2% dicofol
was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (µm)	a.i. (ng)	√a.i. (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drop-lets/cm ²)	Bio-cidal area/drop-let (mm ²)
58	22	41	.722	.850	25.3	35	1.427
87	21	50	1.275	1.129	16.3	13	3.915
61	25	50	1.275	1.129	43.0	34	1.481
64	25	76	4.534	2.129	38.7	9	5.855
67	14	94	8.672	2.945	29.7	3	14.577
91	13	101	10.748	3.278	52.6	5	10.212
88	18	111	14.438	3.800	55.6	4	12.990
85	22	129	21.961	4.686	111.0	5	9.893

Av. = Average

a.i. = active ingredient

Appendix Table 12B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when 2% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (μm)	LD ₅₀ / disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
58	41	25.3	22.4 - 29.0	5.85	.509	.68	28.6	18	2.7
87	50	16.3	10.4 - 20.4	3.32	.643	.50	11.9	18	.7
61	50	43.0	37.2 - 50.4	4.33	.544	.76	53.1	18	2.9
64	76	38.7	30.0 - 47.2	1.75	.183	.91	10.9	18	.6
67	94	29.7	17.6 - 38.6	2.63	.474	.79	30.1	18	1.7
91	101	52.6	1.7 - 88.1	1.84	.449	.55	48.6	18	2.7
88	111	55.6	26.2 - 78.1	2.30	.352	.64	47.6	18	2.6
85	129	111.0	86.3 - 131.3	2.95	.367	.73	27.7	18	1.5

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor

Appendix Table 13A. Data to indicate effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when 4% dicofol was sprayed on bean leaf discs

Data sheet	Av. no. larvae/disc	Droplet parameter			Observed lethal dosage		
		dia. (μm)	a.i. (ng)	$\sqrt{\text{a.i.}}$ (ng)	LD ₅₀ /disc (ng/cm ²)	LN ₅₀ /disc (drops/cm ²)	Bio-cidal area/drop-let (mm ²)
105	13	35	.881	.939	17.1	19	2.575
106	17	39	1.255	1.119	17.3	14	3.620
104	10	42	1.533	1.238	6.7	4	11.521
101	15	48	2.292	1.514	35.3	15	3.245
102	12	48	2.292	1.514	28.6	13	4.030
95	12	52	2.974	1.725	25.4	9	5.848
98	11	56	3.782	1.945	42.9	11	4.409
96	11	61	4.724	2.173	46.3	10	5.107
100	14	64	5.358	2.315	27.4	5	9.766
103	7	65	5.810	2.410	41.4	7	7.013
97	10	87	13.773	3.711	56.7	4	12.136

Av. = Average

a.i. = active ingredient

Appendix Table 13B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* larvae when 4% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (µm)	LD ₅₀ /disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
105	35	17.1	13.1- 33.5	1.92	.492	.84	20.2	18	1.1
106	39	17.3	14.3- 21.2	3.34	.439	.82	47.2	18	2.6
104	42	6.7	2.3 - 10.1	1.30	.388	.67	19.2	18	1.1
101	48	35.3	27.7- 41.0	3.11	.534	.74	20.6	18	1.1
102	48	28.6	15.6- 39.1	2.09	.362	.66	38.9	18	2.2
95	52	25.4	16.3- 32.7	2.99	.450	.74	43.3	18	2.4
98	56	42.9	32.1- 51.1	3.33	.559	.85	19.9	18	1.1
96	61	46.3	21.9- 68.6	2.87	.514	.71	59.7	18	3.2
100	64	27.4	19.1- 33.7	3.14	.476	.79	25.9	18	1.4
103	65	41.4	33.8- 50.9	2.94	.521	.75	16.1	18	.9
97	89	46.7	25 - 76.9	3.01	.768	.77	13.9	18	.8

DF = Degrees of freedom
FD LTS = Fiducial limits
HET F = Heterogeneity factor

Appendix Table 14A. Data comparing observed (obs.) LD₅₀, LN₅₀ and biocidal area per droplet values at various droplet diameters and (a.i.)^(1.12) values with those values predicted (pred.) by Model 9 when 1% dicofol was sprayed against *T. urticae* protonymphs on bean leaf discs

Data sheet	Av. no. proto- nymphs/disc	Droplet parameter			LD ₅₀ values (ng/cm ²)		LN ₅₀ values (droplets/ cm ²)		Biocidal area/droplet values(mm ²)	
		dia. (um)	a.i. (ng)	(a.i.) ^(1.12) (ng)						
					Obs.	Pred. by Model 9	Obs.	Pred. by Model 9	Obs.	Pred. by Model 9
1	21	39	.310	.269	4.2	10.9	14	35	3.571	1.428
4/5	18	59	1.081	1.091	40.8	27.7	38	26	1.316	1.923
2/3	23	65	1.451	1.517	54.5	36.4	38	25	1.316	2.000
10/ 11	11	74	2.113	2.311	25.1	52.6	12	25	4.166	2.000
8/9	30	104	5.941	7.357	158.1	155.6	27	26	1.852	1.923
6/7	20	118	8.603	11.138	233.3	232.8	27	27	1.852	1.852

Av. = Average

a.i. = active ingredient

dia. = diameter

Appendix Table 14B. Statistical calculations on data indicating the effect of droplet diameter (dia.) on mortality of *T. urticae* protonymphs when 1% dicofol was sprayed on bean leaf discs

Data sheet	Drop-let dia. (μm)	LD ₅₀ disc	FD LTS	Slope	SE (slope)	r (probit line)	X ²	DF	HET F
		(ng/cm ²)							
1	39	4.2	1.3 - 6.5	1.30	.232	.61	53.9	18	3.0
4/5	59	40.8	33 - 49.3	2.05	.189	.85	108.4	46	2.4
2/3	65	54.5	46.8 - 63.6	1.86	.157	.76	109.9	50	2.2
10/11	74	25.1	7.6 - 38.6	1.04	.199	.50	104.3	49	2.1
8/9	104	158.1	138 - 182	2.21	.144	.66	140.9	50	2.8
6/7	118	233.3	199 - 285	1.68	.191	.74	86.5	50	1.7

DF = Degrees of freedom

FD LTS = Fiducial limits

HET F = Heterogeneity factor