Pesticide drift and the potential toxicity to beneficial carabids

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Summary

"Non-target" beneficial invertebrates are exposed to pesticides in arable fields and in surrounding boundary habitats, into which sprayed pesticides may drift. The aim of this work was to quantify spray drift outside sprayed areas and to investigate its potential effects on beneficial insects in a series of laboratory bioassays.

Three insecticides, deltamethrin, dimethoate and pirimicarb were evaluated against four carabids *Agonum dorsale*, *Demetrias atricapillus*, *Bembidion lampros* and *B. obtusum*. The predators were exposed to residual deposits at dilutions ranging from 0.15 % to 100 % of field rate. A new bioassay method was developed. The bioassays showed that dimethoate had more severe effects on the carabids than did deltamethrin or pirimicarb. Pirimicarb was the least toxic compound overall. The results are discussed in relation to the interpretation of the likely effects of drift on beneficial insects in the field.

Introduction

Pesticides may drift into field boundaries, including hedgerows or into unsprayed adjacent fields during conventional pesticide spray applications and may expose non-target arthropods to both direct and residual deposits (Cuthbertson & Jepson, 1993). Many beneficial invertebrates, which may contribute to pest control, overwinter in field boundaries (Sotherton, 1984, 1985; Thomas, Wratten & Sotherton, 1991, 1992; Wratten & Powell, 1991).

Although pesticide drift is a well-documented phenomenon (Yates, Akesson & Bayer. 1976; Byass & Lake, 1977; Lloyd & Bell, 1982; Elliot & Wilson, 1983; Cuthbertson & Jepson. 1993) its impact on non-target beneficial arthropods has yet to be investigated in detail. In general, the toxicity of drift on invertebrates has been studied less than that on plants. This may be partly due to the fact that the mobility and small size of many invertebrates and their rapid population fluctuations make them difficult subjects for drift hazard analysis. Although studies have been carried out on butterflies (Sinha, Lakhani & Davis, 1990; Davis, Lakhani, Yates & Frost, 1991; Davis, Lakhani & Yates, 1991; Çilgi & Jepson, 1993) and honeybees (Davis & Williams, 1990) there is no published evidence of the effects of drift of the compounds studied here on beneficial predatory arthropods.

Several long-term projects in the UK are examining the environmental and/or economic effects of reduced pesticide inputs, such as the U.K. Ministry of Agriculture, Fisheries & Food "SCARAB", "TALISMAN" (Cooper, 1990) and "LINK" (Holland, this volume) projects. These are based on experimental designs involving "split-field" treatments so pesticides, particularly insecticides, may be applied to only part of a field. Interpretation of the results of such projects requires information on the extent and biological significance of any insecticide that drifts from sprayed to unsprayed areas of fields.

In the present study the extent of pesticide drift into field boundaries and unsprayed adjacent fields was measured using a fluorescent spray tracer mixed in the spray tank. In the laboratory, three of the most commonly used insecticides in U.K. cereals (Wratten & Mann, 1988; Davis, Garthwaite & Thomas, 1991) were evaluated against four species of Carabidae, all highly-ranked as aphid predators (Sunderland & Vickerman, 1980). The pesticide residue levels to which the invertebrates were exposed in this work ranged from the low doses associated with the drift results from this study to higher rates recorded in other studies (Cuthbertson and Jepson, 1993). By this approach laboratory toxicological data can be related to possible levels of field exposure to provide a basis for drift hazard analysis (Çilgi & Jepson, 1993).

Materials and Methods

Measurement of pesticide drift in field boundaries

A water-soluble fluorescent dye (Acid yellow 73, Aldrich) was mixed in the spray tank with the pesticide (techniques fully described in Çilgi & Jepson, 1992). The dye was used to trace deposition of the spray formulation, assuming that the presence of the dye does not affect this. Three spray experiments were carried out to measure pesticide drift in a winter wheat field (cv. Galahad) at South Allenford Farm, Damerham, Hampshire. The spray applications took place on 26 June, 3 and 6 July 1989 at milky ripe (G.S. 70-79; Zadoks, Chang & Konzak, 1974) using a tractor-mounted hydraulic sprayer. The spray boom was 24m and fitted with 72 Albuz flat-fan nozzles (F110/0.94/1.8). The spray application rate of 200 l ha^{-1} was achieved with a 10 km h^{-1} tractor speed and at 1.8 bar spray pressure. At the time of spray application the wind speed (in m s^{-1}) and its direction (at the height of the spray boom) were recorded using an anemometer. Meteorological and spray application details are given in Table 1.

Plastic drinking straws, 6 cm in length and 0.37 cm in diameter, were used to recover the fluorescent tracer deposits (Cuthbertson & Jepson, 1993). Groups of straws were placed facing the crop at heights of 0, 0.5, 1, 1.5 and 2m on 3m-high bamboo canes. Within each group four vertical straws were spaced 0.5cm apart. Ten bamboo canes were used in the first experiment and twenty in the second and third spray experiments. The canes were pushed into the hedge bank alongside a mature hedge and they were spaced 1m apart and 2m from the crop.

Immediately after spraying, a group of four straws from the same height were placed in individually-labelled vials (2.5 x 7.5 cm) containing 10 ml of phosphate buffer

solution (pH 6.8, 0.1 M Na_2HPO_4 + $NaH_2PO_4H_2O$), shaken, and then stored in a dark room at 4° C prior to analysis with a spectrofluorimeter. In addition, twenty plastic straw targets, which had been unexposed to the spray, were taken as controls and four were placed in each of five vials. These were treated in the same way to provide blanks for spectrofluorimeter analysis. The sample collection was completed within one hour after each spray application to avoid any possibility of photodegradation of the fluorescent tracer. Immediately after the spray application, a sample of spray formulation (50-100 ml) was run from the spray tank into a light-proof plastic bottle for use in calibration of the volumetric analysis.

For each sample, three ml of solution were taken and the volume of tracer dye released into the buffer from the target was determined by analysis in a Perkin-Elmer LS3-R spectrofluorimeter operating at 490 nm excitation and 515 nm emission wavelengths. The control samples were used to zero the spectrofluorimeter. A standard calibration curve was obtained from measured amounts of the original spray formulation, which were added by microapplicator to a standard volume (10 ml) of buffer solution. All fluorescence readings were converted to the volume of spray formulation in microlitres per unit area, using the calibration curve.

Measurement of within-field pesticide drift outside sprayed areas

Five experiments were carried out to measure pesticide drift into the unsprayed parts of fields from a sprayed area. The situation of no physical barrier between sprayed and unsprayed areas is representative of the SCARAB, TALISMAN and LINK projects and occurs on farmland where adjacent crops are grown contiguously or are separated only by post-and-wire fences which are unlikely to hinder the passage of insecticide sprays. The experiments were performed in a variety of arable crops at three different M.A.F.F. Experimental Husbandry Farms (E.H.F.s) in England. The spray applications took place during conventional summer, autumn and winter insecticide applications in 1991 and 1992. The details of each spray experiment are given in Çilgi & Frampton (1992). The layout and results of only one spray experiment are given in this paper.

In the autumn of 1991, an assessment of insecticide spray drift was carried out at Drayton E.H.F., Stratford-upon-Avon, Warwickshire. Deltamethrin was applied for control of Barley Yellow Dwarf Virus to one half of the winter wheat crop (G.S. 12-13 (Zadocks *et al.*, 1974)) on 29 November 1991 using a tractor-mounted sprayer fitted with a 12m spray boom and 24 Lurmark flat-fan (F110/2.98/2.6) nozzles. The operating pressure was 2.6 bar and the application rate was 200 l ha^{-1}. At the time of spray application the wind speed was *c.* 2.7 m s^{-1} and its direction, at the height of the spray boom, was south-westerly (the sprayed half of the field was located to the west of the unsprayed half).

The techniques for the measurement of pesticide drift in this study were the same as for the quantification of pesticide drift in field boundaries described above. The same fluorescent dye (0.02% w v^{-1}) was mixed in the spray tank with deltamethrin (5 g a.i. ha^{-1}). The layout of the experiment is described below.

The drift sampling used eight rows of horizontal filter paper "targets" (Whatman no.1, 5.5 cm-diameter) each supported on a wooden cocktail stick to collect spray droplets, Each filter paper disc was *c*. 3 cm above the soil surface and located 5-10 cm away from the base of a crop plant. Approximately 3 cm of the supporting stick was exposed above each disc. Each row had 20 targets placed at 1m-intervals, the first at 75 m away from the hedgerow. Rows of targets were parallel to the boundary between the sprayed and unsprayed areas; six of the rows were in the unsprayed half of the field at distances of 2,4,6,12 and 48 m from the boundary between the two field areas in order to measure any drift of spray into the unsprayed area. Two more rows were sited in the sprayed area to measure the spray deposition under the spray boom. These were 2 and 4m from the border between the sprayed and unsprayed field halves.

After spraying, collection of filter paper targets started from the row which was the furthest distance from the sprayed area (48m) and progressed, row by row, towards the sprayed area. Each filter paper disc was placed in a labelled vial containing 10 ml of buffer. The vials were then gently shaken for 10 seconds. In addition, five filter paper discs unexposed to the spray were placed individually in vials as controls. The samples were analysed using the same procedure as described before, using a spectrofluorimeter.

Laboratory screening of beneficial insects

Test organisms

Species chosen for the laboratory bioassays were the carabids *Agonum dorsale* (Pont.), *Demetrias atricapillus* (L.), *Bembidion lampros* (Herbst) and *B. obtusum* Serville. The first three species were the top three carabids when polyphagous predators were ranked according to their importance as aphid predators in cereals (Sunderland & Vickerman, 1980). The last species, *Bembidion obtusum*, is ecologically important as it has been a key indicator species in the MAFF "Boxworth" (Burn, 1992; Vickerman, 1992) and "SCARAB" (Frampton, Çilgi & Wratten, this volume) projects; these experimental field programmes, investigating the long-term consequences of intensive pesticide use for "non-target" fauna have shown large and persistent declines in the populations of *B. obtusum* following pesticide use.

Test species were collected in cereal field margins and hedge banks in October 1992 at the Leckford Estate, Stockbridge, Hampshire, by hand-held air aspirator and surface searching.

Test compounds

The insecticides used in the bioassays were deltamethrin (Decis, 2.5% E.C. w v^{-1}), dimethoate (Croptex Dimethoate, 40% E.C. w v^{-1}) and pirimicarb (Aphox, 50% W.G. w w^{-1}). They were chosen because they were used during some of the drift assessments carried out in the experimental fields (Çilgi & Frampton, 1992), and are also among the most commonly used insecticides in cereals in the U.K. (Wratten & Mann, 1988; Davies *et al.*, 1991).

The test compounds were applied in the laboratory bioassays at a range of doses up to their highest recommended rates for use in cereals in the U.K.; these are 5 and 6.25 g a.i. ha^{-1} of deltamethrin for autumn and summer applications, respectively, 340 g a.i. ha^{-1} for dimethoate and 140 g a.i. ha^{-1} for pirimicarb.

Pre-treatment conditions

After collection from the field the beetles were sorted into species and stored in polystyrene boxes (10x15x27 cm) containing a layer of moist soil and pellets of cat food ("Delicat") in a cold room at 4° C. Seventy-two h prior to pesticide exposure the beetles were counted into groups of one hundred and stored in polystyrene boxes containing fresh cat food and damp filter papers (to maintain humidity). The boxes were kept in a controlled environmental room in an insectary (temp. range 18-20° C, relative humidity 60-70 % and photoperiod 16:8 L:D).

Residual spray application

A Potter laboratory spray tower (Burkard Manufacturing Co. Ltd., Rickmansworth, U.K.) was used to apply the compounds onto 7.5 cm-square glass plates and, in some experiments, also onto glass Petri dishes 5.5 cm-diameter x 1 cm deep (see below). The tower was calibrated to deliver a volume of liquid equivalent to the conventional field rate of 200 l ha^{-1}.

Field rate and fractions of field rate were applied for each test compound. The autumn field dose rate (5 g a.i. l^{-1}) of deltamethrin was used with *A. dorsale*, *B. lampros* and *B. obtusum*. The summer field dose rate was used with *D. atricapilus*. Controls treated with distilled water. The treatments were applied in the following order: control, 1/640, 1/320, 1/160, 1/80, 1/40, 1/20, 1/10, 1/5, 1/2 of field rate and lastly the field rate. This gave eleven treatments for each compound for each carabid species and the wide range of doses covered possible drift depositions in the field.

Exposure conditions

The sprayed glass plates and Petri dishes were left for approximately 1 h to dry after each spray application and then the test species were exposed to the residual deposits. In the first bioassay, unsprayed plastic cylinders 5.5 cm in diameter and 3 cm in height were clipped onto the sprayed 7.5 cm square glass plates. The interior of the plastic chambers had previously been painted with an aqueous suspension of "Fluon" (polytetrafluoroethylene) to prevent beetles from escaping. Groups of five *A. dorsale* were placed inside each chamber using a fine sable-hair brush. Twenty beetles (five on each of 4 treated glass plates) were used for each treatment giving a total of 220 beetles for each compound.

In the second bioassay, the test apparatus was modified to form a sealed chamber to prevent the beetles escaping. This was specifically done to prevent escape of the climbing species *D. atricapillus*, but was used also for the *Bembidion* spp. to allow comparisons to be made between species under similar test conditions. A test unit comprised a 7.5 cm square glass plate and a glass Petri dish (5.5 cm diameter and 1 cm in height) which were separated by a 1-mm-thick gasket of cork to provide an

escape-proof seal. The lid and base of the chamber were held in place with a metal clip after the insects were introduced.

A ventilating humidified airflow was provided to each test unit via a pair of syringe needles inserted through the cork gasket. One was connected to an aquarium pump (Elite 800, 1500 cc output min^{-1}) via tubing and the other on the opposite side served as an outlet for the airflow. This also served to extract the pesticide vapour from the test unit to ensure that any mortality which occurred was due only to the residual effects of the chemicals.

Five *B. lampros* and five *B. obtusum* were placed together in each test chamber using an aspirator. Forty beetles (i.e. four chambers) were used for each treatment, giving a total of 440 beetles for each compound.

In the third bioassay using the same test chambers as with the *Bembidion* spp., five *D. atricapillus* were placed in each chamber. Twenty beetles (i.e. four chambers) were used for each treatment, giving a total of 220 beetles for each compound. In this experiment the beetles were kept in a cold room at 4° C for 3 h prior to exposure and placed in the test chambers in this room to reduce the activity; *D. atricapillus* could climb out of the Petri dishes at laboratory temperatures before the glass plate was in place.

The test chambers were randomly placed on benches in a controlled environment room maintained at 20° C ± 2° C and with 16 h photoperiod of low-intensity, diffuse light. Humidity inside the test chambers was *c*. 80% ± 5% (measured with a Lovibond Comparator using cobalt thiocynate indicator paper).

Post-treatment observations

Assessments of the effects of the treatments (dose rates) were made at 24, 48 and 72 h after insects' initial exposure and individuals were classified as live (normally active and responsive), knocked down (inactive but still moving in response to a mechanical stimulus) and dead (not moving in response to a mechanical stimulus).

Results

Drift deposition in field boundaries

The deposition rates of spray drift at the different heights are shown in Fig. 1. On all spraying occasions fewer pesticide deposits were recovered at ground level than at any other heights in the hedgerow. The highest level of deposit was 1 m above the hedgerow bottom. The highest amount of drift was recorded on the 03-07-1989 when the wind speed was highest (Table 1) and the hedgerow was directly downwind of the sprayed area.

The frequency distribution of pesticide drift deposits at the hedgerow bottom is shown in Fig. 2. Although up to 3% of sprayed formulation was recovered at ground level in one sample, overall analyses of all ground samples (50 samples) revealed that 86% of individual samples received less than 0.31% of the sprayed formulation during

Figure 1. Deposition of drifted pesticide at different heights
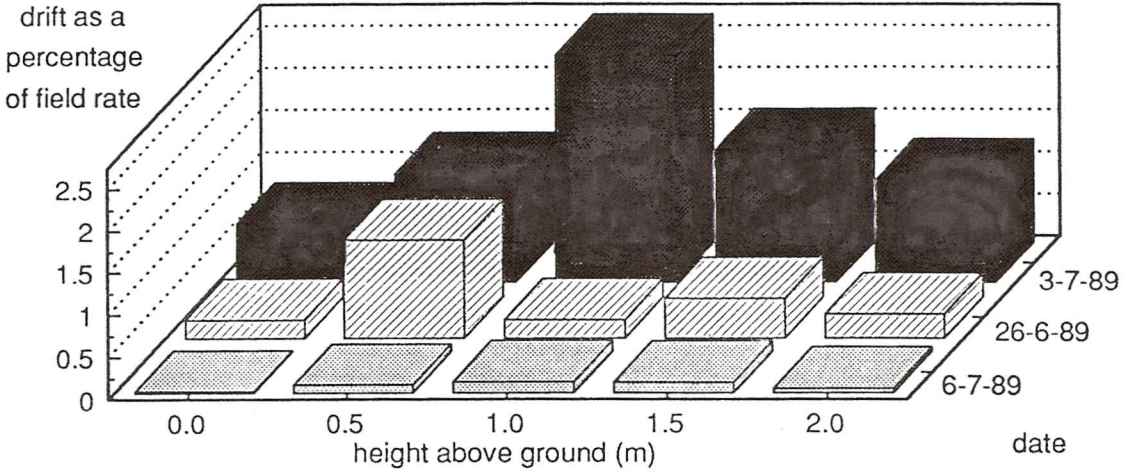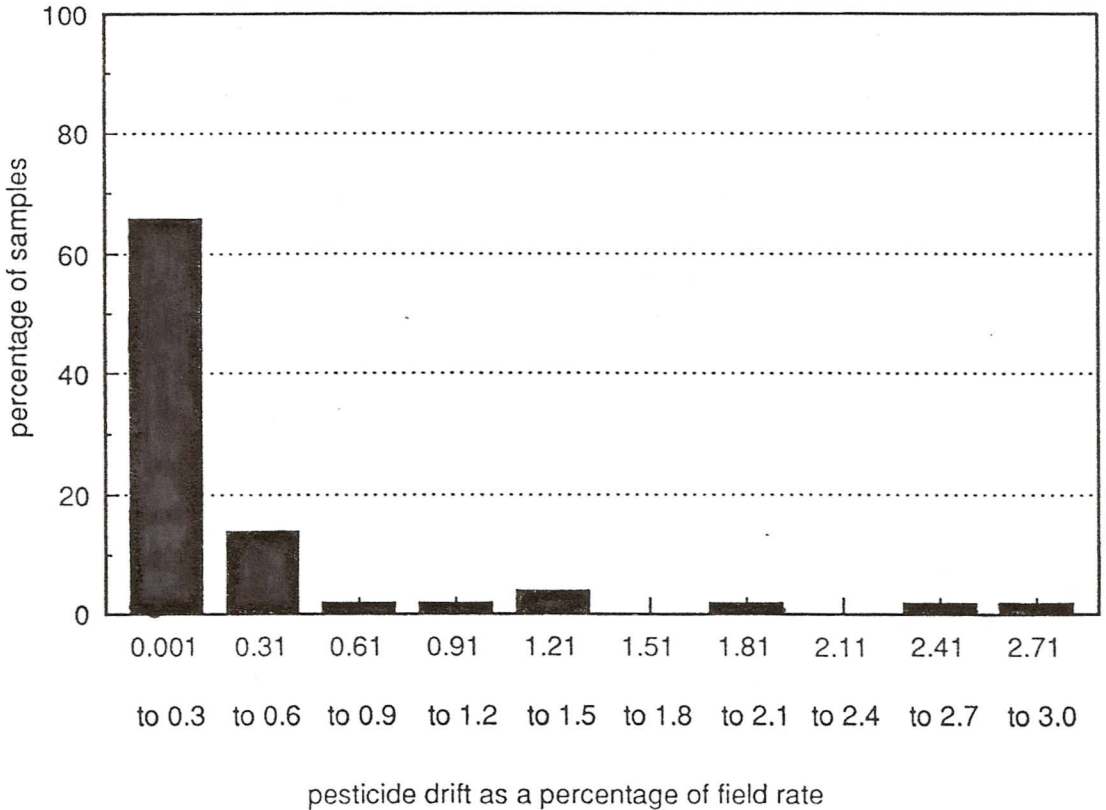above ground in a hedgerow on three application dates.

Figure 2. Frequency of occurrence of different levels of pesticide drift
at ground level in a hedgerow (based on 50 samples).

three summer spray experiments.

Drift deposition in unsprayed areas of fields

Fig. 3 shows deposition rates of the formulation in the sprayed half of the field and at the different distances into the unsprayed half of the field following the deltamethrin application. Drift deposits were detected from all targets, including those furthest (48m) from the edge of the sprayed area. Between c. 1% and 0.06% of the sprayed area's application rate was recovered at 2m to 48m into the unsprayed area respectively.

Residual toxicity of insecticides to Carabidae in laboratory bioassays

The percentage of each species which died after 24 hours or was knockdown at 24 hours and either remained knockdown or had died at 72 hours was calculated. The results are shown in Figs. 4-7.

Dimethoate and deltamethrin were highly toxic to *A. dorsale* and caused 100% mortality and knockdown at 5 and 20% of field rate (Fig. 4). Dimethoate was the most toxic to *D. atricapillus* and caused 100% mortality and knockdown at 0.62% of field rate (Fig. 5). Pirimicarb and deltamethrin caused 85% mortality and knockdown at field rate and 50% of field rate respectively. The toxicity of pirimicarb declined steeply with decreasing concentration, unlike deltamethrin which showed a more graduated response. The mortality and knockdown response of the *Bembidion* spp. to dimethoate, deltamethrin and pirimicarb was very distinct (Figs. 6 and 7). Dimethoate and deltamethrin caused 100% mortality and knockdown of *B. obtusum* at 0.62% and 10% of field rate respectively (Fig. 6). Pirimicarb, however only caused 90% mortality and knockdown at 100% of field rate. Dimethoate was more toxic to *B. lampros* than *B. obtusum* and caused 100% mortality and knockdown at 0.312% of field rate (Figs. 6 and 7). In contrast, deltamethrin and pirimicarb were less toxic to *B. lampros* than *B. obtusum*. Deltamethrin caused c. 100% mortality and knockdown at 10% and 100% field rate to *B. obtusum* and *B. lampros* respectively. At field rate primicarb caused c. 95 and 60% mortality and knockdown of *B. obtusum* and *B. lampros* respectively.

The maximum level of drift recorded in the hedgerow at ground level was 0.5% of field rate (Fig. 1). This concentration of dimethoate caused c. 90% mortality and knockdown of *D. atricapillus* and the two *Bembidion* spp. in the laboratory bioassays. The other insecticides tested here only caused <20% mortality and knockdown at the above rate. The level of drift deposition in the unsprayed field was <0.2% of field rate at >4m from the sprayer (Fig. 3). With dimethoate this concentration caused c. 30, 35 and 60% mortality and knockdown of *D. atricapillus*, *B. obtusum* and *B. lampros* respectively, in the laboratory bioassays.

Table 1 Meteorological conditions at the time of spraying

Spray date	Mean wind speed	Wind direction	Location of hedge	Temp.
26-06-1989	1.7 m/s	S-W	S-W	22° C
03-07-1989	3.3 m/s	N-E	S-W	24° C
06-07-1989	1.0 m/s	N	S-W	22° C

Figure 3. Deposition of deltamethrin at ground level at six distances into an unsprayed area at Drayton E.H.F., expressed as percentages of the deposition under the spray boom.

distance into unsprayed area
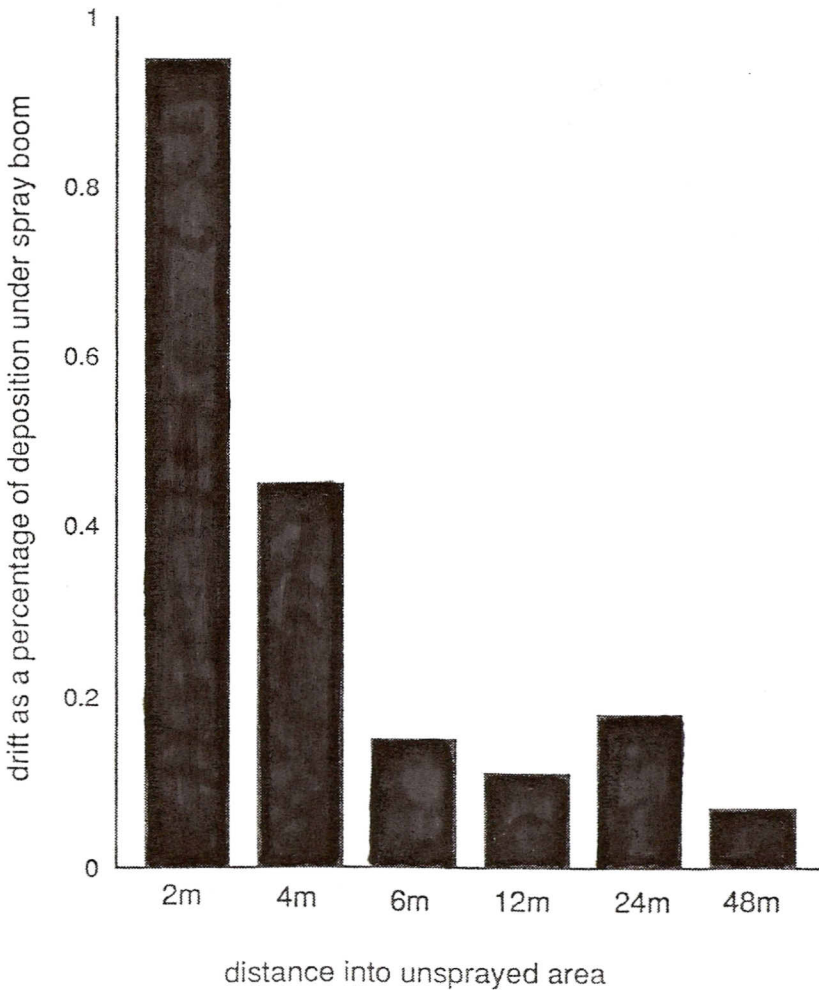
Discussion

Drift deposition in field boundaries

On all three spraying occasions, the volumetric deposition data showed that fewer pesticide deposits were recovered at ground level than at any other height in the hedgerow. The crop canopy (winter wheat, *c*. 1 m high and at G.S. 70-79 (Zadoks *et al.*, 1974)) and hedgerow flora would minimise the number of spray droplets reaching the ground. Drift penetrates to a greater extent to the hedgerow bottom from autumn pesticide applications because of the absence of a dense crop canopy and the presence of a senescing hedgerow flora (Cuthbertson & Jepson, 1993).

The wind speed and direction at the time of spraying during the first (26-06-1989) and third (06-07-1989) experiments were not conducive to the production of substantial drift. In the second experiment (03-07-1989) when the wind direction was towards the field boundaries and wind velocity was higher, the level of drift was more substantial, as predicted from work by Nordby & Skuterud (1975) and Davis & Williams (1990).

Drift deposition in unsprayed adjacent fields

The results of this experiment demonstrated that pesticide drift may occur up to 48 m from the sprayed area where there is no physical barrier between the sprayer and the adjacent field (as is the case in the SCARAB "split-field" experimental design; Cooper,1990). The level of drift beyond 4m from the boundary is unlikely to cause any noticeable mortality, except when spraying dimethoate.

During autumn or winter insecticide applications, in the absence of a dense crop canopy, non-target organisms would be more exposed to insecticide deposition because the crop would provide less shelter. Furthermore, synthetic pyrethroids such as deltamethrin and broad-spectrum insecticides, for example chlorpyrifos, which are usually applied in autumn and winter respectively, have a far higher toxicity to beneficial insects than at least one of the insecticides used in summer applications (pirimicarb). Of the test species used in our bioassays, only *B. obtusum* would be present in the field during autumn (Burn, 1992). This species was, however, highly susceptible to deltamethrin in this study and that of Vickerman *et al.* (1987). The other three species would be present in the field boundary during autumn (Sotherton, 1984) and would be less exposed to insecticide drift.

Toxicity of insecticide residues on beneficial insects

The findings indicate the possibility of significant harm (over 50% mortality) to the four carabid species exposed to 24 h residual deposition of dimethoate at a wide range of the doses (*c*. 1% to 100% of field rate) tested under laboratory conditions. However, the relatively lower toxicity of deltamethrin and pirimicarb could lead to significant harm to the four Carabidae only at higher doses (*c*. 5% to 100% and 50% to 100%, respectively). With regard to deltamethrin and pirimicarb, the quantities of pesticide drift detected at ground level in this study are unlikely to have adverse

Figure 4. The corrected percentage mortality and
knockdown of A. dorsale after 24 hours' exposure
to three insecticides in laboratory bioassays

% mortality and knockdown

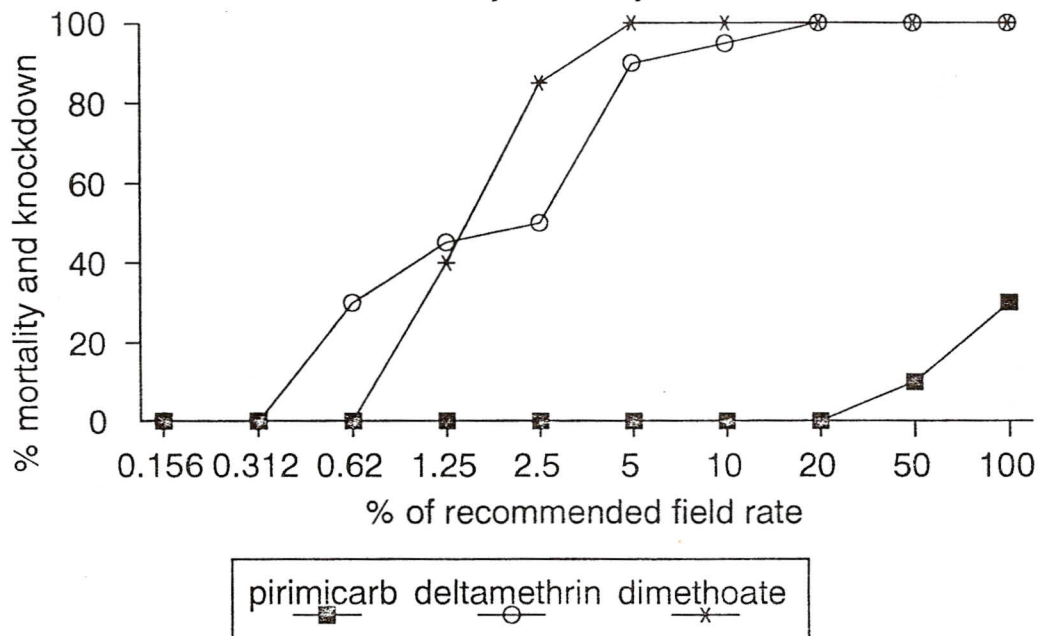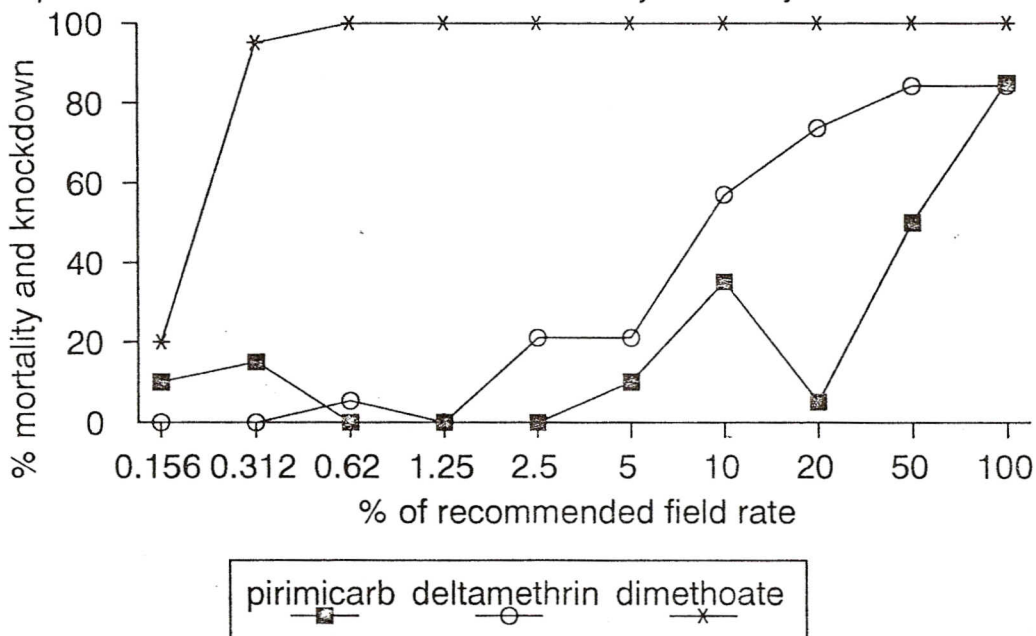% of recommended field rate

pirimicarb deltamethrin dimethoate

Figure 5. The corrected percentage mortality and
knockdown of D. atricapillus after 24 hours'
exposure to three insecticides in laboratory bioassays

% mortality and knockdown

% of recommended field rate

pirimicarb deltamethrin dimethoate

effects on the Carabidae tested here.

Given the potential effects of dimethoate on Carabidae in crops (Vickerman & Sunderland, 1977; Vickerman *et al.*, 1987), it is clear that the level of drift produced by this insecticide could affect invertebrate populations in unsprayed areas. Drift into field margins could affect the populations and fitness of potential post-spray colonising species, given that predators can colonise fields from the field boundary itself (Coombes & Sotherton, 1986) as well as through the boundary from adjacent fields (Mauremootoo & Wratten, this volume; Frampton, Çilgi, Fry & Wratten, 1993). In the case of the SCARAB, TALISMAN and LINK projects there is evidently a risk that the biological effects of dimethoate drift could obscure the effects of pesticides on the carabid faunas of contiguous sprayed and unsprayed areas. In view of this risk, routine monitoring of SCARAB fields has been undertaken to quantify the extent to which drift of insecticides has occurred from sprayed into unsprayed areas (Cilgi & Frampton, 1992).

In the present study, drift recorded above ground level could also lead to mortality of, or sub-lethal effects on, other field boundary-inhabiting invertebrates. For example, most, if not all, of the butterfly species colonising field margins may be at risk as a result of exposure to drift (Çilgi & Jepson, 1993). This is because the phenologies of most species coincide with one or more spray applications in the arable crop growing season between March and November (Davis *et al.*, 1991) and also because Lepidoptera have relatively long lifecycles and may be exposed to a number of these applications during their life-times (Cuthbertson & Jepson, 1988). Other invertebrates colonising hedgerow host plants or beneficial species such as hoverflies (Syrphidae) or honeybees (Apidae) which feed on nectar sources in these areas (Hickman & Wratten, this volume) may also be adversely affected (Davis & Williams, 1990).

In this paper, attempts were made to correlate the levels of pesticide drift in the field with laboratory-collected toxicological data. However, it is important to bear some variables in mind when extrapolating the results of laboratory bioassays to the field. Laboratory bioassays may over-estimate mortality by exposing test organisms to doses higher than those with which they would come into contact in the field (due to for example, the repellency effects of some compounds). This is because test insects are often continually exposed to insecticide residues in the test arena and also because pesticides are not subjected to adsorption or rapid breakdown on glass compared with soil. On the other hand, laboratory bioassays may also under-estimate mortality as they often take into account only one route of exposure. For example, *D. atricapillus* was less susceptible to deltamethrin residues than the other carabids tested in this study. This beetle has been shown to be relatively tolerant to this compound in laboratory bioassays (Wiles & Jepson, 1993). However, this carabid beetle is diurnal and climbs the vegetation in the field (Vickerman & Sunderland, 1975). On the ears and upper leaves it would, therefore, be more exposed to both direct and residual deposits of pesticides. Diurnal predators (e.g. *D. atricapillus*) inhabiting the upper levels of the crop are more likely to be at risk than are nocturnal, ground dwelling polyphagous species (e.g. *A. dorsale*), as the latter are afforded some degree of protection by the plant canopy (Çilgi, Jepson & Unal, 1988; Çilgi & Jepson, 1992). The level of exposure to pesticides in the field may also be increased if beetles ingest pesticide-contaminated prey (reviewed by Croft, 1990).

Figure 6. The corrected percentage mortality and
knockdown of B. obtusum after 24 hours' exposure
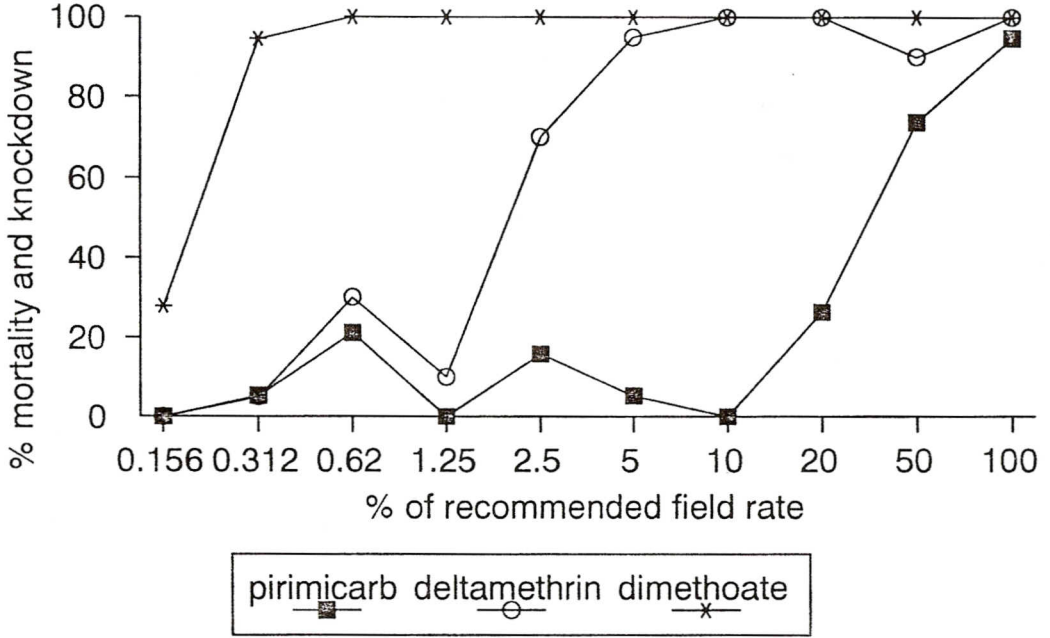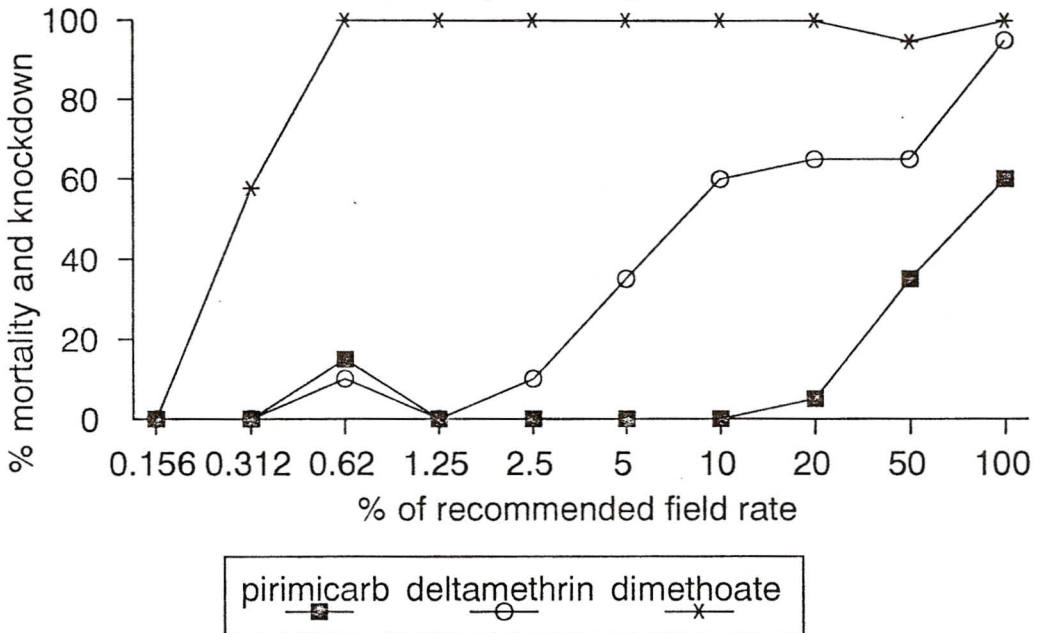to three insecticides in laboratory bioassays

pirimicarb   deltamethrin   dimethoate

Figure 7. The corrected percentage mortality and
knockdown of B. lampros after 24 hours' exposure
to three insecticides in laboratory bioassays

pirimicarb   deltamethrin   dimethoate

The ecotoxicology of invertebrate predators is complex as other studies have demonstrated that deltamethrin and dimethoate showed similar levels of foliar toxicity to *B. lampros* but deltamethrin was less toxic than dimethoate on the soil surface (Unal & Jepson, 1991). In another study, deltametrin was found to be less toxic to *Coccinella septempunctata* on soil than on a cereal crop (Wiles & Jepson, 1992) but similar levels of toxicity were found between cereal plants and glass plates (Wiles, 1992).

Despite the fact that the insects were tested in artificial conditions, the ranking of the toxicity of the three insecticides (at recommended field rates) to the carabid beetles tested here is still similar to the findings of field trials (Vickerman & Sunderland, 1977: Powell *et al.*, 1985; Vickerman *et al.*, 1987; Unal & Jepson, 1991). However, bioassays are needed to determine mortality from drift under field conditions.

Acknowledgements

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