5 INSECTICIDE DRIFT FROM ORCHARD SPRAYERS

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5.1 INTRODUCTION

Drift from air-assisted sprayers in orchards is potentially much greater than from conventional hydraulic sprayers in ground crops. The spray is directed outwards and upwards from a series of nozzles on both sides of the spray tank while the sprayer traverses back and forth between rows of trees. Spray droplets that go above the trees are thus liable to be carried some distance by wind before falling to the ground, and evaporation during this time will further extend their potential for drift.

Although much work has been done to measure and improve the efficiency of spray coverage on fruit trees (see Lavers *et al.*, 1991), there have been relatively few studies of drift from orchard sprayers. Fig. 5.1 shows the results of three such studies (reproduced from Williams *et al.*, 1987). Cooke *et al.* (1976) found that nearly half of the total spray fell to the ground with deposits up to 40 m downwind; this was within the orchard with the wind blowing at right angles to the rows of trees. MacCollom *et al.* (1986) detected drift deposition 300 m beyond the downwind edge of an orchard in the absence of a perimeter shelterbelt.

Faull (1991) cites statistics showing an increase in the proportion of poisoning incidents and complaints between 1987 and 1989 which were investigated by HMI and were attributable to air-assisted spraying. Most of these were from orchards and hop gardens. Air-assisted spraying of pesticides other than herbicides accounted for only about 2.6% of the total area sprayed in England and Wales in 1989 yet gave rise to 29% of all incidents reported.

Most commercial orchards have tall hedges or shelterbelts around the perimeter, and often internal shelterbelts as well. ADAS has produced a booklet describing the use of living and artificial windbreaks in horticulture (MAFF, 1986). The primary purpose of these is to reduce wind within the orchard thus reducing mechanical damage, chill factor, water loss and soil erosion, and improving conditions for pollinating insects, all of which benefit yields.

Shelterbelts also allow spraying to take place when it would be impossible on more exposed sites, and at the same time they serve to reduce spray drift out of the orchard. The following studies on drift and the effects of shelter were carried out in four orchards in Cambridgeshire through personal contacts or with the initial help of ADAS at Cambridge.

Artificial windbreaks were not studied. These are generally made of polyethylene 1-2 m high with a porosity of 50%. They are especially useful for container-grown nursery stock or as a short-term measure (5 years) until living windbreaks become established. Data on percentage reduction in wind flow 2-20 m downwind are given in MAFF (1986).

5.1.1 Site descriptions

Dry Drayton (TL3861). About 30 ha, mainly apples, surrounded by arable land. A tall hedge or boundary plantation around most of the orchard with 3-3.6 m tall shelterbelts of alder down the middle

Fig. 5.1. Relationships between drift deposit concentration and distance downwind of trees sprayed with air-assisted sprayers.
From: Δ = MacCollom et al (1986), ■ = Nigg et al (1984), ⊙ = Cooke et al (1976). Comparable deposits from conventional hydraulic ground-crop sprayer (broken lines) from Grover et al 1978.

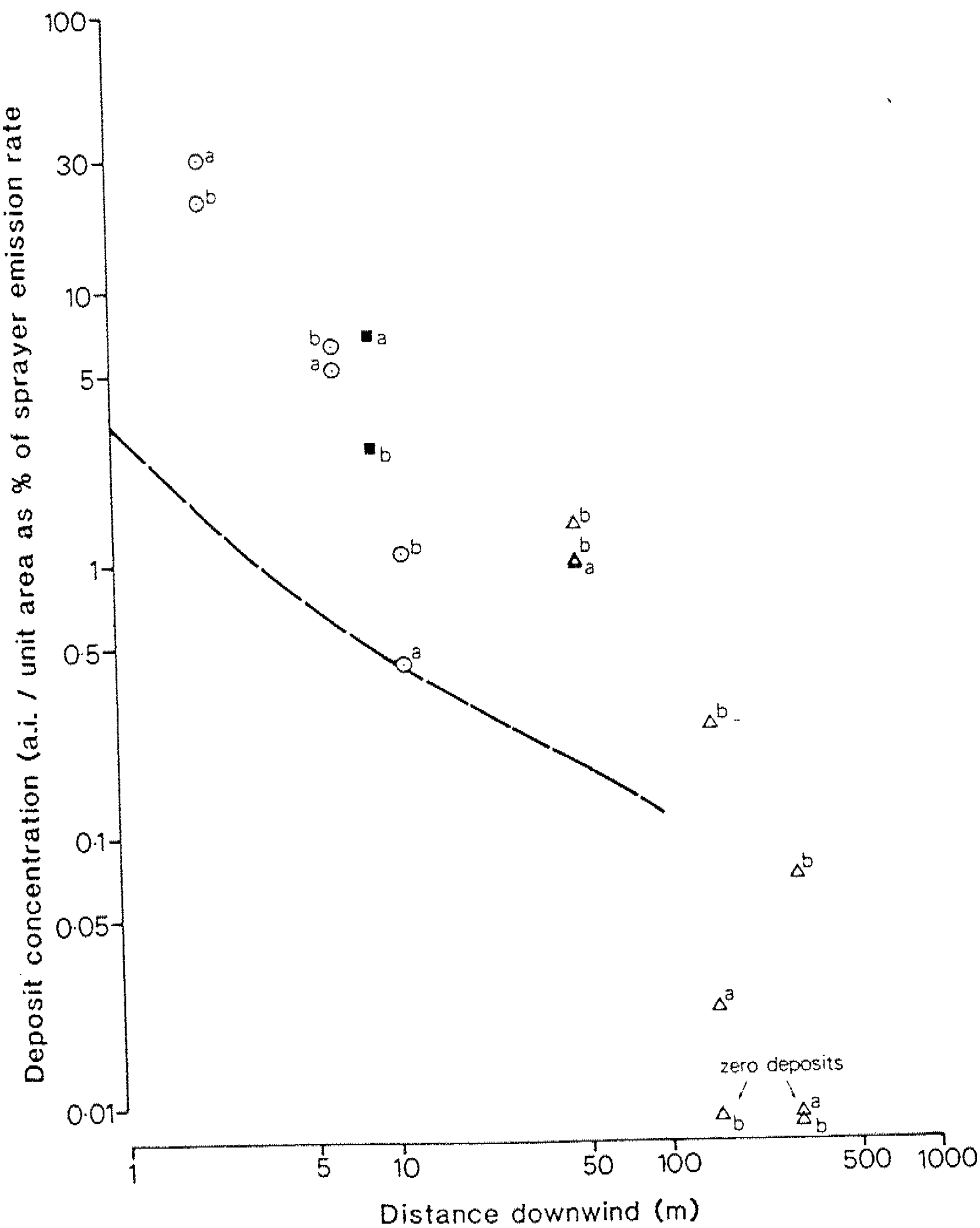
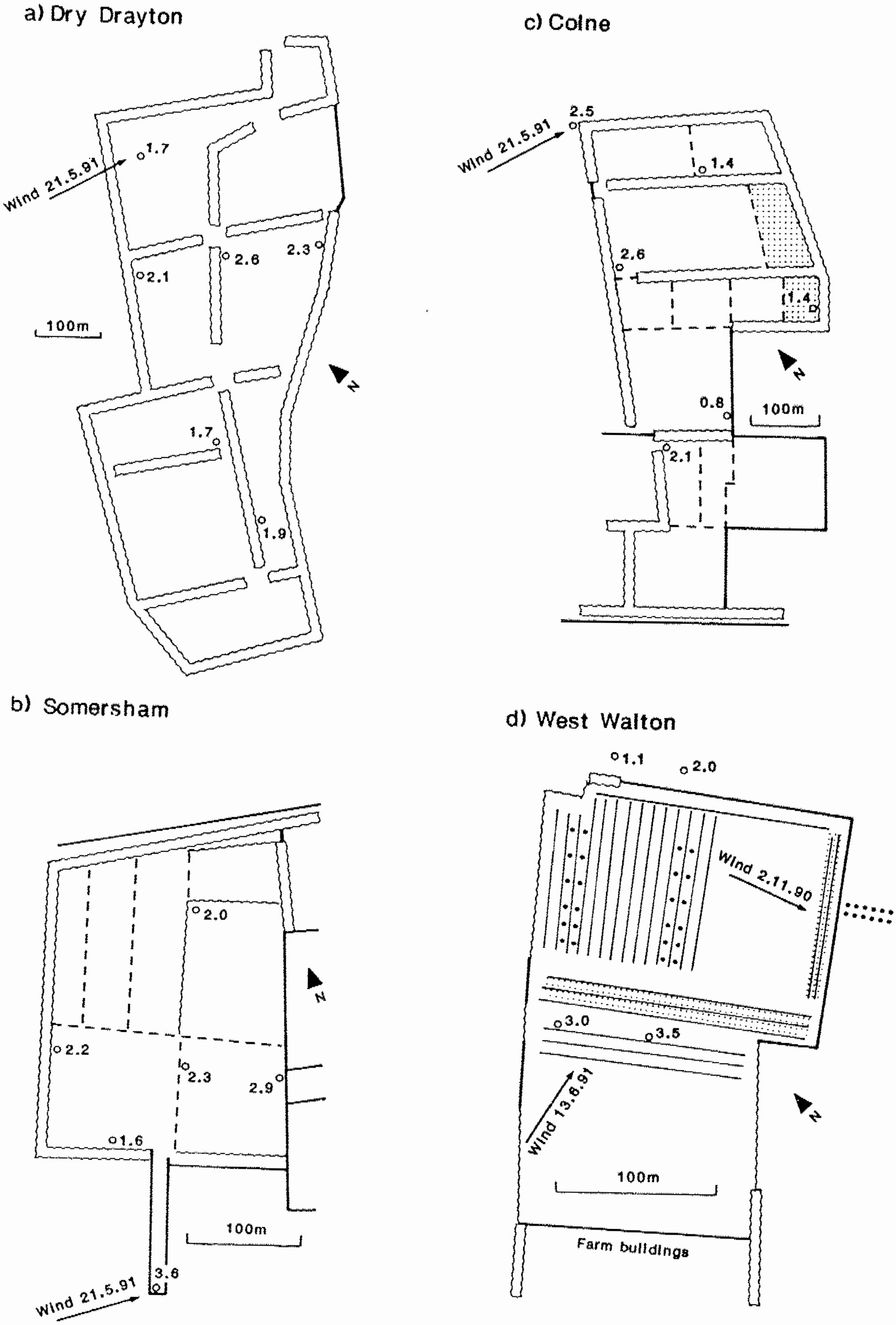


Fig. 5.2. Plans of four Cambridgeshire orchards showing thick shelterbelts (double wavy lines), thin shelterbelts (single wavy lines), unsheltered boundaries (heavy lines) and compartments (broken lines). Numbers show wind speeds at given dates in 1991. Stippled areas in Colne and West Walton orchards show sprayed areas, the latter with target positions as dots.



(along the crest of a hill) and a series of similar belts at right angles dividing up the compartments (Fig 5.2a).

Somersham (TL348747). About 5 ha, mainly apples with pears and plums. Bounded by tall poplar trees (ca. 10 m) along most of two sides bordering arable fields, with a tall hedge along the roadside and a neighbouring orchard of old plum trees to the east. Some recently planted alders along the southern boundary and near the centre to provide internal shelter (Fig. 5.2b).

Colne (TL376773). About 24 ha, mainly pears and plums. Tall poplars (ca. 10 m) around much of the north-west and north-east boundaries, and across the orchard dividing it into blocks. Parts of the south-eastern boundary were unsheltered (Fig. 5.2c).

West Walton (TF488137). About 7 ha, mainly apples. A thin broken line of poplars and willows (ca. 7 m) along the north and north-east, a thicker belt along the south-west, but open to arable fields over the south-eastern corner. No internal shelterbelts (Fig. 5.2d).

In all these orchards, the well-pruned apple and pear trees seldom exceeded 2 m in height but areas of old plum trees at Somersham and Colne produced considerably taller and denser foliage. All the orchards complied with ADAS recommendations for shelter to be provided primarily from prevailing winds in the south-west and west, and generally also for protection from the north-west and north-east (MAFF, 1986).

5.2 BIOASSAYS OF INSECTICIDE DRIFT IN ORCHARDS

Four bioassay studies of insecticide drift were undertaken but only two of these gave much useful data. These were from West Walton where arrangements were made with Dr I Newton to suit an experimental timetable. Although the owners or managers of the other three orchards had all agreed to inform us when they planned to use certain insecticides, in practice it was necessary to keep checking, and most spray operations were carried out at too short notice or were missed altogether. On one occasion, the wind speed was so low that no discernible drift occurred, and on the last occasion, on 23 July, all larvae suffered high mortality because of prolonged storage of the eggs. (Drift deposition from this latter occasion is described in section 5.4).

5.2.1 Methods

Standardized methods were used in all the bioassays with 20-30 2-day old *P. brassicae* larvae on leaves of horse-radish placed in pots on the ground at measured distances downwind of the sprayed areas. Mortality was assessed over three days.

Trial 1, West Walton, 2 November 1990; cypermethrin.
Cypermethrin 10EC was sprayed at about 130 ml ha^{-1} (13 g a.i. ha^{-1}) in 450 litre ha^{-1} of water. The wind was from the north, and drift was measured from a single pass upwind of a double row of apple trees which formed the boundary in the south-east of the orchard (see Fig. 5.2d). An initial pass was made with water-sensitive papers placed along two transects 12 m apart at intervals from 5 to

50 m downwind (measured from the trunks of the inner row of trees) into a bare arable field. After a visual inspection of drift deposition, larvae were put out at selected intervals along these transects up to 60 m. A second pass was then made with insecticide added. However, at this moment a fine rain started and the second batch of water-sensitive papers was spoiled.

Trial 2, West Walton, 13 June 1991; carbaryl.
Thinsec was applied as a fruit thinner to Bramley apples at 4.8 litre ha^{-1} (2160 g a.i. ha^{-1}) in 500 litre ha^{-1} of water. There was a west wind so drift was assessed from the sprayer running south-north in the centre of the orchard (Fig. 5.2d). Three passes were made covering three rows of trees and giving a total sprayed width of 20 m. Target insects were put out along four transects between rows of trees running at right angles to the sprayed rows. The transects were divided into two pairs 8 m apart. One pair was placed about 30 m from the northern boundary, and the other pair about 70 m further away, near the middle of the orchard. It was expected that the northerly pair would receive more wind and therefore more drift, but the anemometer readings showed slightly more wind opposite the southerly pair (Fig. 5.2d). The targets were spaced at intervals between 20 and 100 m downwind from the nearest sprayed line of trees. Water-sensitive papers were again spoiled by rain just before the insects were put out.

A standard series of tests was done in the laboratory to determine the topical LD_{50} dose for carbaryl to 2-day-old *P. brassicae* larvae for comparison with other insecticides (Sinha *et al.*, 1990; Davis *et al.*, 1991)

Trial 3, Colne, 3 July 1991; chlorpyrifos.
Dursban was applied to plums at 1 litre ha^{-1} (480 g a.i. ha^{-1}) in 1100 litre ha^{-1} of water. The mean wind speed over a half hour period was very low (0.20-0.26 m s^{-1}) and with scarcely discernible direction within the orchard. Targets were placed along two adjacent inter-rows, first to the north-west of a dense compartment of old plum trees that were sprayed, and then north-east of a very open block of young plum trees (Fig. 5.2b). Water-sensitive papers were not used because of the misty conditions.

5.2.2 Results

The larval mortalities for the pair of transects in Trial 1 and the two pairs in Trial 2 are given separately in Table 5.1. When mean values at each distance are taken for pairs of transects they show essentially similar profiles for cypermethrin and carbaryl (Fig. 5.3). Both compounds gave 50% mortality at about 20-25 m and 10% mortality at about 50 m; thereafter, mortality was similar to controls.

The wind speed was noticeably higher upwind of the sprayer in Trial 2 than in Trial 1, which would be expected to cause more drift. However, the fruit trees themselves reduced the wind speed through the orchard in Trial 2 (Fig. 5.2d) and would have filtered some of the drift unlike the open field in Trial 1.

There was considerable variation within pairs of transects, especially in Trial 2 where air turbulence through the apple trees

Table 5.1. Field bioassays from orchard spraying at West Walton: % mortality of 2-day old *P. brassicae* larvae from drift of cypermethrin and carbaryl at given distances downwind.

Date	2.11.90		13.6.91			
Product/rate (g ai ha^{-1})	cypermethrin/13		carbaryl/2160			
Wind speed (mode m s^{-1})	2		3.0		3.5	
Distance (m)	A	B	A	B	C	D
15	80.8	100	-	-	-	-
20	36.8	60	68.0	30.0	100.0	38.1
30	4.0	14.3	4.2	16.7	5.3	61.9
40	13.6	36.4	9.5	4.8	20.0	40.0
50	4.0	18.2	-	-	-	-
60	0	7.7	10.0	0	5.0	5.3
80	-	-	0	5.0	5.0	0
100	-	-	0	0	0	5.6
Control	6.3		0		5.0	
Mean larvae/station	23.5		20.6		20.2	

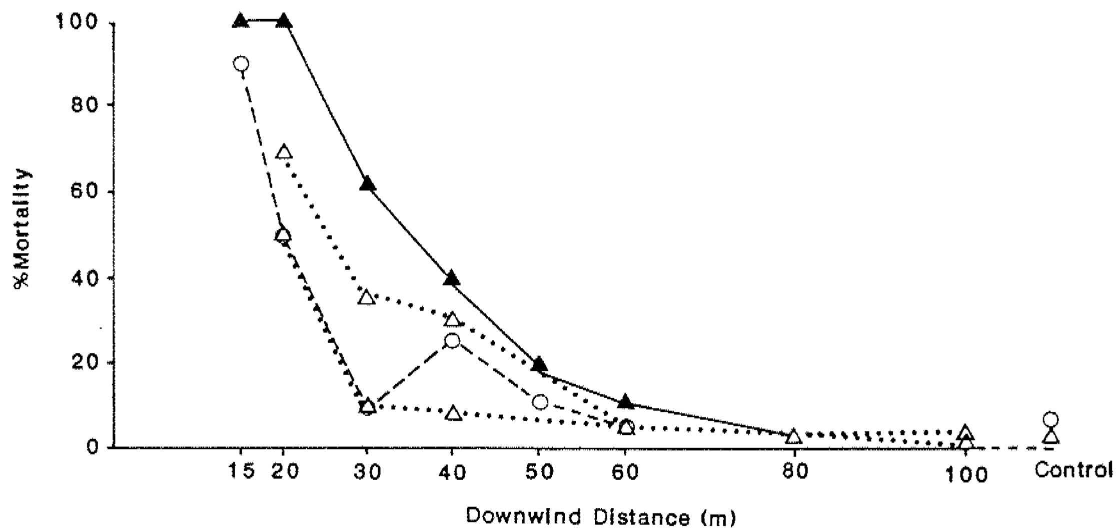
Table 5.2. Percentage mortality of 2-day-old *P. brassicae* larvae from topical applications of carbaryl.

Concentration x10^5 (%)	No. tested	% mortality
360	22	90.9
240	58	79.3
180	96	54.2
120	98	43.9
60	78	16.7
30	76	25.0
15	76	7.9
7.5	15	0
Control	77	1.3

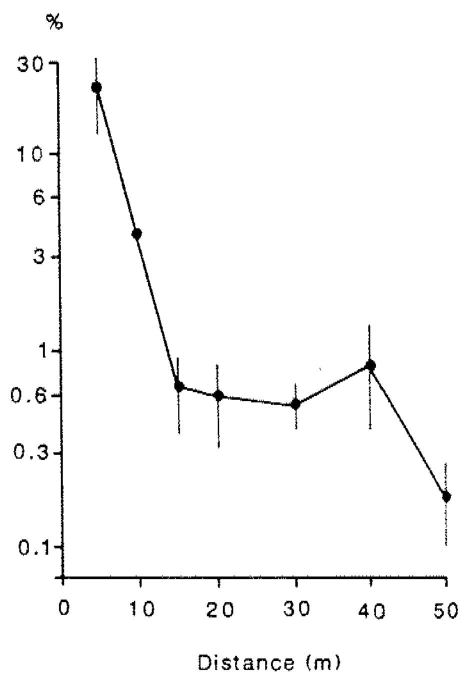
Table 5.3. Field bioassays from orchard spraying at Colne: mean % mortality of *P. brassicae* larvae from pairs of transects in two trials with chlorpyrifos on 3.7.91. Mean wind speed 0.23 m s^{-1}.

Distance (m)	I		II
5	-		14.5
10	7.2		13.2
15	-		16.4
20	5.4		6.3
25	-		9.8
30	5.7		10.9
40	5.4		-
50	4.1		-
60	5.5		-
Control	3.8		7.1
Mean larvae/station		26.7	

Fig. 5.3(a). Bioassays of spray drift trials at West Walton using 2-day old Pieris brassicae larvae (see Table 5.1). Circles show mean mortalities from cypermethrin trial, open triangles show mean mortalities for two pairs of transects in carbaryl trial. Solid triangles give the envelope of all worst cases.



(b). Profile of drift deposition on water-sensitive papers from cypermethrin trial.



was thought likely to cause uneven deposition. Note that the modal wind direction was somewhat oblique to the lines of trees (Fig. 5.2d). In Trial 1 with cypermethrin, a small peak in mortality at 40 m occurred in both transects and in the water-sensitive papers during the earlier spray run (Fig. 5.3b). Even if this was a consistent feature under those particular conditions, the result is seen in Fig. 5.3a to fall within the broader picture afforded by Trial 2.

The uppermost line in Fig. 5.3 traces the worst cases out of all six transects in the two trials, since protective measures against environmental damage may need to take account of these rather than average conditions. They indicate that drift of cypermethrin and carbaryl can have major effects between 30-40 m, and detectable effects between 50-60 m downwind.

Carbaryl is intrinsically less toxic to *P. brassicae* than cypermethrin (Table 5.2) but it is applied at a very much higher rate. Thus the contact "field hazard index" for *P. brassicae* larvae (rate/LD_{50}), when it is used for thinning Bramley apples, is 506. When used as an insecticide for codling moth at 3.8 litre ha^{-1} (1710 g a.i. ha^{-1}) the field hazard index would be 401. The contact field hazard index for cypermethrin is 108 (see Table 4.2) but this has additional stomach action.

The results for Trial 3 at Colne are summarized in Table 5.3. There was no significant mortality in the first pair of transects above that recorded in controls, and less than 20% mortality in the second pair of transects even at 5 m. This confirmed the lack of drift within a well sheltered orchard under virtually calm conditions.

5.3 EFFECTS OF SHELTER ON WIND SPEEDS

5.3.1 Methods

A comparison of wind speeds in different parts of the first three of these orchards was made on 21 May 1991. Six counting anemometers (Vectair ECS 3/R/EC) were taped to the tops of 1 m poles which were stuck into the ground at selected locations in each orchard and run simultaneously for 20 minutes. The number of revolutions were recorded on individual counters and were noted every two minutes. A recording anemometer (Vectair R500), which produced a trace of wind speed and direction, and which had been used in earlier drift studies, was stationed alongside one of the counting anemometers and the trace likewise marked every two minutes. A separate calibration exercise was carried out to provide comparability between the six counting anemometers. The counts from the orchards were then converted into mean wind speeds by comparison with the continuous recording anemometer.

In the West Walton orchard, wind speeds were measured at four locations during a drift bioassay trial on 3 July 1991 (see above). Two anemometers were situated within the orchard just upwind of a sprayed area, and two were placed 10 m out from the eastern boundary in tramlines within a field of wheat. One of the latter was behind a section of shelterbelt while the other was opposite an unsheltered part of the boundary.

5.3.2 Results

The positions of the anemometers, and mean wind speeds recorded in these four orchards, are shown in Fig 5.2a-d. The results for the first three orchards were obtained within a period of just over three hours under consistent weather conditions. The free wind speed of 3.6 m s^{-1}, recorded at the southern extremity of the Somersham orchard in a field of wheat, was equivalent to a gentle to moderate breeze, force 3-4 on the Beaufort Scale (about 5.4 m s^{-1} at 10 m height). Readings obtained from the chart recording anemometer showed a variation of about ±1.2 m s^{-1} in any two minute period, and a variation of up to ±2.0 m s^{-1} over a 20 minute period.

This comparative study showed that mean wind speeds varied nearly as much within each orchard as between orchards. The Dry Drayton orchard was unusual in straddling a ridge so that the highest and most exposed ground was the central north-south axis with the ground falling away to the west, east and north. Thus, although the most northerly anemometer was in an area clear of fruit trees it was evidently sheltered by the land form from the westerly wind; it gave a much lower reading than one on the ridge 250 m to the south-east, although the latter was close to a shelterbelt. The gap between shelterbelts just to the north of that point was again noted as being particularly exposed during a drift study on 23 May when the wind was from the north.

At the Somersham orchard, the five anemometers within the orchard all had distinctly lower readings than the one on the southern extremity surrounded by wheat. The anemometer on the eastern edge had a higher reading than the one on the western edge (next to a shelterbelt) despite the 240 m wide area of fruit trees upwind.

At Colne, on the other hand, the three anemometers on the north-western, windward, edge of the orchard all showed much higher wind speeds than those on the downwind edge and in the middle. The anemometer just behind the poplar shelterbelt had a marginally higher reading than the one just outside on the northern corner. The lowest value of 0.8 m s^{-1} was recorded at a point on the south eastern edge where there was no perimeter shelter, so spraying that edge of the orchard under those conditions would produce relatively little drift into the adjacent field.

At West Walton on 13 June 1991, the two anemometers in the middle of the orchard had markedly higher readings than the two within the wheat field downwind of the orchard. Thus, the orchard itself again appeared to provide cumulative shelter, but the presence of a good boundary shelterbelt near the north-eastern corner evidently reduced the wind speed still more, and would provide a useful barrier to spray drift out of the orchard.

5.4 EFFECT OF SHELTER ON DRIFT DEPOSITION

To demonstrate the effect of an orchard shelterbelt on spray drift, one ideally needs to compare results in the presence and absence of the shelterbelt while all other variables are kept constant. In practice, this is rarely possible, especially during a commercial spraying programme. Even if there are incomplete shelterbelts to provide such comparisons they are unlikely to be in the appropriate places when spraying is done. Drift within an orchard is subject to turbulence and eddies caused by the rows of fruit trees themselves, while access to neighbouring land for measuring drift out of the orchard is not always possible.

The following two trials studied drift in the Dry Drayton orchard using water-sensitive papers to detect discontinuities in deposition attributable to shelterbelts. As mentioned earlier, problems over timing prevented the use of bioassays.

5.4.1 Methods

Trial 4, Dry Drayton, 23 May 1991; chlorpyrifos.
The wind was from the north so three rows of water-sensitive papers were laid out to the south of compartment 2A which was particularly exposed to wind from this quarter (see site description above and Fig. 5.2a). Transect 1 was placed along a closely mown grassy swathe between a block of apple trees and a concrete track at about 30° to the prevailing wind (Fig. 5.4a). Transect 3 ran more or less directly downwind from the same starting point, through a gap in the central shelterbelt, and then diagonally through the lines of apple trees. Transect 2 took an intermediate course passing through the alder shelterbelt. The papers were held horizontally about 11 cm above the ground at 10 m spacing from 10 to 60 m downwind. They were taken up after eight rows of trees (55 m) had been sprayed. A recording anemometer was placed on the concrete track in the gap between the shelterbelts.

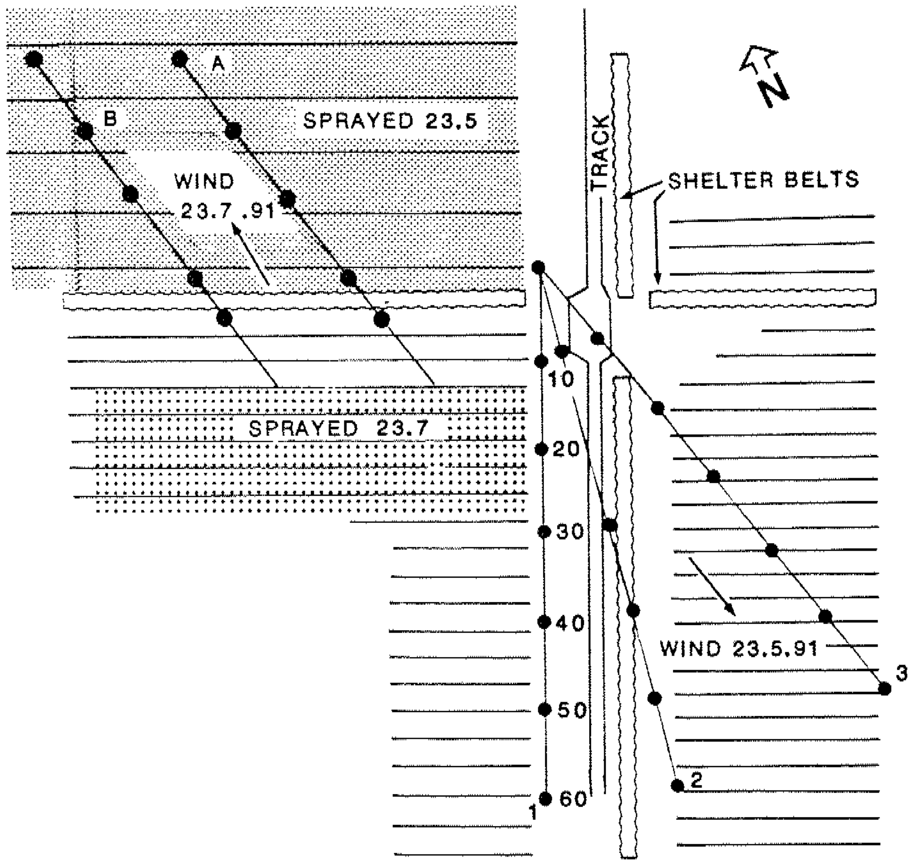
Trial 5, Dry Drayton, 23 July 1991; diflubenzuron.
The wind was from the south, and drift was measured from five rows of trees sprayed near the northern edge of compartment 2. (The two rows nearest this edge were unsprayed) (Fig. 5.4a). Two parallel transects were laid out 20 m apart diagonally through an alder shelterbelt and then through four rows of apple trees in compartment 2A. The recording anemometer was placed close to where it had been in trial 4, and, in addition, two counting anemometers were placed near the beginning and middle of the transect lines to record the effect of the shelterbelt.

5.4.2 Results

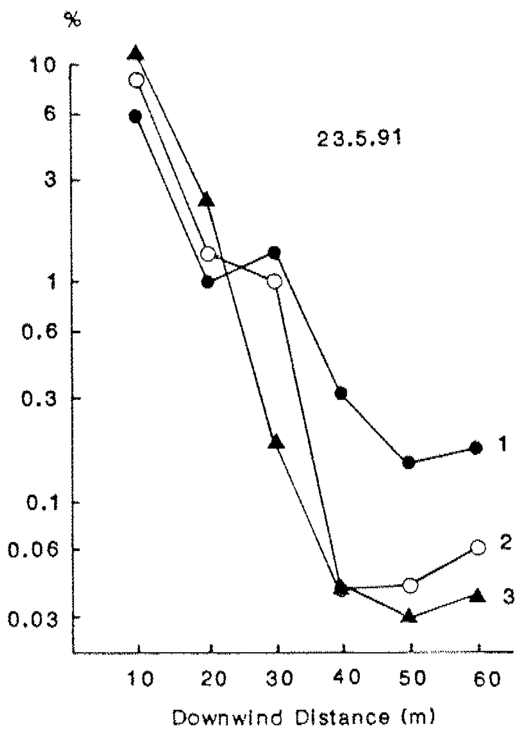
In Trial 4, the modal wind speed was about 3.5 m s^{-1} (range 2.0-5.0) on the exposed track. The water-sensitive papers showed a similar decrease in deposition in all three transects from 10 to 20 m, with largest values in transect 3 which was aligned most directly downwind (Fig. 5.4b). From 20 to 30 m, however, deposition declined most markedly in transect 3 where it entered the adjoining orchard block and received partial shelter from the track-side belt of alders. At 40 m, this shelterbelt clearly had a marked effect in reducing deposition on transect 2, which from then on had similar deposition to transect 3, while deposition on transect 1 declined more slowly. Note that the more distant targets on transect 1 would receive increasing shelter from the block of fruit trees lying directly north (upwind) of them.

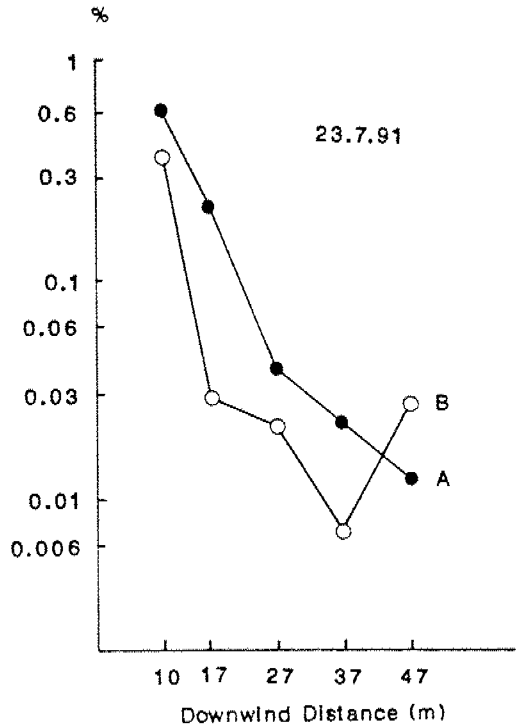
Larvae were not available for bioassay on this occasion, and the relative toxicity of chlorpyrifos has not been determined. However, if these deposition results are compared with those from Trial 1 at West Walton, they indicate that an insecticide with field hazard rating comparable to cypermethrin (and applied in the same volume of

Fig. 5.4(a). Areas of the Dry Drayton orchard used in two drift deposition trials showing rows of apple trees, shelterbelts, two sprayed areas and lines of targets.



(b). Profiles of drift deposition on water-sensitive papers resulting from the two trials in (a).





water) would cause significant mortality up to 30 m in the absence of shelter (deposition ≥ 1%).

The wind speed in Trial 5 ranged from 1.0 to 4.0 m s^{-1} on the track over a period of 30 minutes, with a mean of 3.1 m s^{-1} in front of the shelterbelt and 2.2 m s^{-1} behind it, i.e. a 29% reduction over the 17 m interval. The drift deposition profiles (Fig. 5.4c) are less readily interpreted in terms of relative shelter since both transects were theoretically subject to similar conditions. Deposition was generally an order of magnitude lower than in Trial 4 up to 30 m. This may have been due partly to the lower wind speed and partly to the shelter effect from the two unsprayed rows on the northern edge of the sprayed block. The shelterbelt at 13 m appeared to have little immediate effect on reducing deposition on transect A, but deposition values from 17 m onwards were all very low and subject to local sampling effects.

5.5 DISCUSSION

The bioassay trials with cypermethrin and carbaryl at West Walton showed effects of insecticide drift at much greater distances than were recorded from hydraulic spraying of field crops. In the latter case, buffer zones up to 24 m were suggested for cypermethrin to limit mortality to 10%, whereas 50-60 m would be required in the case of air-assisted orchard sprayers. In practice, where the rows of fruit trees were parallel to a boundary, the outer side of the outermost row would be sprayed with only the inward-facing jets. The next pass of the sprayer is therefore likely to be at least 10 m from the orchard boundary. In the first trial at West Walton, for example, the bioassay sample situated 50 m from the sprayed trees was about 38 m into the arable field.

The south east corner of that orchard was particularly exposed to northerly wind but the wind speed on that occasion was only 2 m s^{-1} so it cannot be considered a worst case. Parts of the Colne and Somersham orchards had similar unsheltered sections of perimeter; any spraying of the narrow tongue of orchard projecting southward in the latter site (Fig. 5.2b) would be very prone to drift.

Faull (1991) states that, under the Control of Pesticides Regulations 1986, the pyrethroid acaracide/insecticide fenpropathrin must not be applied by air-assisted sprayers within 80 m of surface waters and ditches. This ruling applies whether or not there are good shelterbelts around an orchard or hop garden because it is not possible to define situations where shelter would be considered fully effective. Our comparative study on wind speeds in four orchards showed that there was considerable variability between different parts of the same orchard under a particular prevailing wind but relatively sheltered and unsheltered positions were not always easy to predict. Local factors, such as topography and the funnelling of wind through gaps in shelter, are important in determining the reading at any particular point, and changes in wind direction are bound to alter the relative values obtained. These wind speed values were all obtained at about mid-crop height. Readings taken above crop height, at the maximum height reached by spray, would be noticeably higher and probably less subject to variation across an orchard in the absence of a boundary or internal shelterbelt.

The lowest wind speed readings were obtained at Colne where perimeter and internal belts of 10 m tall poplars, coupled with flat topography, provided the greatest shelter. At Dry Drayton and Somersham, the internal shelterbelts were of grey alder *Alnus incana* or Italian alder *A. cordata*. These can grow to 15 m on suitable soils, and are easily kept trimmed to 7.5-9 m with good leaf production from top to bottom (as at East Malling, for example). ADAS also recommends the common or black alder *A. glutinosa* for damper soils (MAFF, 1986). *A. incana* and *A. glutinosa* cease to grow once they start to bear seed. For this reason, the *A. incana* is being replaced by *A. cordata* in the most recent plantings at Dry Drayton (K. Basham, pers. comm.).

Apart from the effective use of shelter in orchards, drift could be significantly reduced in practice by modifying orchard spraying equipment so as to limit spray height near the sprayer to crop height. Walklate (1991) has made computer simulations of drift assuming a force 2 wind (3 m s^{-1} at 10 m) and crop height of 2.5 m. He showed that a drift reduction of 70-80% at 20 m could be obtained by eliminating 41% of the total spray flux above crop height.

5.6 CONCLUSIONS

Bioassays from two trials with air-assisted spraying of insecticides showed that harmful effects can be detected 50-60 m downwind. Since neither trial was conducted under particularly drift-producing conditions, these figures should be considered minimal in fixing buffer zones to protect sensitive sites.

Poplars and willows can reduce wind speeds through an orchard significantly but they need to be sufficiently tall and continuous to be most effective. They should ideally be around the whole perimeter to take account of different wind directions. Alders are favoured for giving effective internal windbreaks.

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