Some factors affecting the efficiency of water-traps for capturing cabbage root flies

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SUMMARY

Several factors influencing the efficiency of water-traps in capturing cabbage root flies were studied at Wellesbourne in 1971 and 1972. In both the laboratory and field, approximately twice as many flies were caught in fluorescent as in non-fluorescent yellow traps. Depending upon trap density, addition of a source of the attractant allylisothiocyanate (ANCS) increased the numbers of females captured by approximately twofold in fluorescent traps and from two- to sevenfold in non-fluorescent traps. Traps were equally efficient irrespective of whether the ANCS was renewed every 2, 3, 4 or 5 days. On the first day of trapping, the number of flies caught per unit area was linearly related to the square root of the number of traps in that area. On the following days the rate was probably in equilibrium with the combined effect of immigration and the rate of development of responsive flies in the trapping zone. Most males were caught 30 cm above the soil surface and most females at soil level. Traps 120 cm above the soil surface caught few flies.

Populations of marked flies were released into large field cages containing both a section of hedgerow and a plot of cauliflowers. Even after a week, only 81% of the males and 55% of the females had been recaptured from the most responsive of these captive populations. Furthermore, only 30% of females were recaptured when they were more than 8 days old, the age at which most probably enter the new host-crop.

INTRODUCTION

Interest in trapping to control or monitor populations of insects has been stimulated both by the isolation of specific attractants and by improvements in trap design (Wolf, Kishaba & Toba, 1971). The number of insects caught is a function of the attractiveness of the trap, the activity and responsiveness of the insects and the population density (Southwood, 1966). Krasnyuk (1931) demonstrated that the colour yellow attracted adult cabbage root flies (Erioischia brassicae (Bouché)) while Hawkes (1969) used ‘mimosa’ yellow (BS 0001) water-traps to recapture flies in dispersal experiments. In addition to using colour as the attractant, Mellor & Woodman (1935) sought an attractant that could be mixed in poison bait to kill female cabbage root flies before they laid. Of the twenty-three substances tested in small tins under balloon fly-traps, yeast, allyl mustard oil (allylisothiocyanate – ANCS) and glycine proved the most attractive. Addition of ANCS made the water-trap of
Hawkes (1969) ten to eleven times as effective during maximum immigration into the crop, but only about sevenfold thereafter (Wallbank, 1972a).

This paper describes some factors affecting the capture of cabbage root flies and several ways of improving the efficiency of the basic trap (Hawkes, 1969).

**MATERIALS AND METHODS**

Water-traps were used in preference to sticky traps because the flies caught are easily recovered by straining through a sieve and remain in good condition for identification. The traps used were variously coloured 15 cm diameter plastic dishes filled 4 cm deep with a solution of 20 ml Teepol/l. Except in the trap-height experiment, they were placed on the soil surface.

All the flies released were from a laboratory culture reared on swede illuminated for 16 h per day and maintained at 18 ± 1 °C and 65 ± 5 % r.h. (Finch & Coaker, 1969).

Cauliflowers, cv. Finney's 110, were planted at 0.6 × 0.6 m spacing on square plots each containing 1600 plants, on 14 April 1972. Experiments were also made on 1 ha plots of swede (cv. Eclipse) and Brussels sprouts (experimental breeding lines) planted with spacings of 0.2 and 1 m between the rows, respectively.

**Trap colour – fluorescent and non-fluorescent traps**

Of the gloss paints which he tested, Hawkes (1969) found that yellow was generally the most attractive colour with ‘mimosa’ (BS 0001) the most attractive shade. Prokopy & Boller (1971), however, showed that fluorescent yellow traps captured more European cherry fruit flies (Rhagoletis cerasi (L.)) than gloss yellow traps. A range of fluorescent colours was therefore compared in the laboratory, using non-fluorescent ‘mimosa’ traps as a standard for comparison.

Five fluorescent traps were painted either fire orange, aurora pink, blaze, saturn yellow or signal green and, together with a standard non-fluorescent trap, were equally spaced around the outer edge of a slowly rotating (0.25 r.p.m.) 2 m diameter turntable enclosed in a cage containing 2000 cabbage root flies. The cage was housed in a room illuminated at 1500 lux by fluorescent strip lights for 16 h/day and maintained at 18 ± 1 °C and 55 ± 5 % r.h. The numbers of flies caught in each trap were recorded each day and the ratios of the numbers caught in the variously coloured fluorescent traps, as compared with the non-fluorescent trap, were calculated.

**Fluorescent and non-fluorescent yellow traps**

*Laboratory tests.* Three fluorescent and three non-fluorescent yellow traps were compared on the turntable apparatus described above. Approximately 1000 0–2 day-old flies of each sex were placed in the cage and the numbers caught each 1·5 h period from 09.00 to 16.30 h on the following 4 days counted.

*Field tests.* One of the cauliflower plots was divided into four equal subplots of 20 × 20 plants and four identical fluorescent ‘saturn’ yellow or non-fluorescent ‘mimosa’ yellow traps were spaced 6 m apart in a square arrangement through each
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of the sub-plots. Traps of the same colour and type were placed in diagonally opposite sub-plots. Flies were collected each Monday, Wednesday and Friday from 28 April to 9 June 1972, sexed and counted.

Trap odour

Fluorescent and non-fluorescent traps with ANCS. Fluorescent and non-fluorescent yellow traps containing ANCS were arranged in a field plot in a similar way to that described in the previous experiment. The ANCS was allowed to evaporate from cotton-roll wicks (Wallbank, 1972b) dipping into the chemical in 7 ml vials supported in the middle of each of the sixteen plastic traps (Fig. 1). The wick was covered with a cork-topped cylinder of 10 mesh/cm Tygan to prevent rain splashing the ANCS into the trap and so dissolving the plastic. The numbers of cabbage root flies captured/trap/day during the flight period of the first generation (28 April to 9 June) were compared directly with those captured in traps without ANCS.

Renewal of attractant. To determine how often the ANCS needed to be replenished, nine fluorescent yellow traps were spaced 8 m apart, through each of five plots containing 1600 plants. Water traps were present on one plot and water traps containing ANCS, hereafter referred to as ANCS traps, on the other four. The ANCS was renewed after 2, 3, 4 or 5 days. The water-traps were placed on a plot adjacent
to the plot on which the ANCS was renewed every 5 days, the other three plots all being more than 250 m from this site. Flies were collected every Monday, Wednesday and Friday and the mean numbers of flies captured/trap/wk were compared.

**Trap height**

To determine the height at which the traps were most efficient, fluorescent yellow ANCS traps were supported on canes 0, 30, 60 and 120 cm above the soil surface. The traps were equally spaced, not less than 4 m apart, through plots of cauliflowers (13–15 June), Brussels sprouts (18–21 July) and swedes (7–9 September). On each crop, there were three replicates of each treatment. The numbers of flies caught on each of three consecutive days were recorded.

**Trap spacing**

In 1971 a plot of 120 rows x 120 m of swedes was divided into five equal 24 x 24 m sub-plots and, on 9 September, one, four, nine, sixteen and twenty-five non-fluorescent yellow ANCS traps were equally spaced over the respective sub-plots. The numbers of flies caught were recorded over 3 days. On 16 September 1971 approximately one-half of the same plot was divided into ten 12 x 12 m sub-plots and non-fluorescent ANCS traps were compared with similar numbers of water-traps sited on adjacent plots for a further 3 days. This permitted comparisons between ANCS and water traps spaced from 2.2 to 17.5 m apart.

In the same field in 1972, the efficiencies of a similar series of from one to twenty-five fluorescent water-traps or ANCS traps/10 x 10 m sub-plot were compared for 3 days beginning 7 September.

**Response of the insect to the traps**

To determine whether the responsiveness of the flies to the traps changed as the former aged, flies of known ages were released into a field cage measuring 15.2 x 3.0 x 1.8 m high and covered with 10 mesh/cm Tygan. The cage contained a 3 m section of hedgerow and sixty mature cauliflower plants. Using a two-stage marking technique (Finch & Skinner, 1973a), 0–4 day-old flies were marked on the ptilinum with one of four fluorescent powders and were then sprayed on the body with one of six oil-soluble dyes, thus specifically identifying each batch of flies with one of a combination of twenty-four marks (Finch & Skinner, 1973a). Neither marking the flies or the handling involved appeared to affect their subsequent behaviour. Batches of 200 of each sex of from 0–1 to 15–16 day-old flies were each specifically marked and then released into the field cage on 6 July 1972. The numbers of flies recaptured in two fluorescent ANCS traps were recorded daily for a week.

**RESULTS**

**Trap colour**

The saturn yellow fluorescent trap was 1.4 times more attractive than the non-fluorescent trap, whereas the signal green was only equally as attractive and the blaze, fire-orange and aurora pink were less attractive, the ratios being 0.7, 0.2 and 0.1 respectively.
To compare the efficiencies of the fluorescent and non-fluorescent yellow traps, the numbers of flies caught in the laboratory and in the field tests are shown on a logarithmic scale in Fig. 2 (Williams, 1951). The relative efficiencies of the traps were similar in both tests, approximately twice as many of each sex being caught in the fluorescent as in the non-fluorescent traps.

Fig. 2. The mean numbers of cabbage root flies caught by yellow water traps in the laboratory (1.5 h sampling) and in the field (2 day sampling). ●, fluorescent; ○, non-fluorescent traps. Vertical bars represent L.S.D.'s ($P = 0.05$).

Table 1. Mean number of cabbage root flies (Erioischia brassicae Bouche) caught/trap/day during the first generation of flies (April to June 1972) by fluorescent and non-fluorescent traps with or without the addition of allylisothiocyanate

<table>
<thead>
<tr>
<th>Trap colour</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allylisothiocyanate</td>
<td>L.S.D. ($P = 0.05$)</td>
<td>L.S.D. ($P = 0.05$)</td>
</tr>
<tr>
<td>Present</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Fluorescent yellow</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>Non-fluorescent yellow</td>
<td>11</td>
<td>7</td>
</tr>
</tbody>
</table>

Trap odour

The mean numbers of flies captured/trap/day during the first generation of flies in 1972 are shown in Table 1. Without ANCS, approximately twice as many males and females were caught in the fluorescent as in the non-fluorescent traps. An approximate two-fold increase in capture also occurred when ANCS was added to
either type of trap. Furthermore, at the 6 m trap spacing used, fluorescent water-traps were as efficient in capturing both sexes as non-fluorescent ANCS traps.

Renewal of attractant. To eliminate the effects of the considerable variation in the numbers of flies present during the build-up and the decline of the populations at the various sites, only data for those weeks when the geometric mean number of flies caught/site exceeded ten were included in the analysis (Fig. 3). Weeks 1–4 of the generation were analysed for males and weeks 2–5 for females to allow for the difference in the times of emergence. The numbers of males captured varied approximately fourfold between the plots on week 2, when the population was at

![Fig. 3. The mean numbers of cabbage root flies caught per week at 0.05 ha cauliflower plots.](image)

about maximum. Those captured at the plot containing water-traps were therefore directly comparable only with those at the adjacent ANCS site where the attractant was renewed every 5 days, because both sets of traps were sampling the same population of flies. At these two sites, approximately twice as many males were caught by the ANCS traps as by the water traps. The numbers of females captured were similar at all four sites containing ANCS traps, demonstrating that the traps were equally efficient whether the ANCS was renewed every 2, 3, 4 or 5 days.

Trap height

Similar numbers of both males and females were captured in the three different crops. The results were therefore pooled and expressed as the mean numbers of flies caught/trap/day. Most males \((P = 0.05)\) were caught when the traps were 30 cm above the soil surface and most females when the traps rested on the soil \((P = 0.05)\). There was a sharp decline in trapping efficiency as the trap height was raised above 30 cm and at 120 cm only one or two flies were caught each day.
Fig. 4. The mean number of cabbage root flies caught per trap per day by fluorescent ANCS traps positioned at various heights above ground level in a crop. Vertical bar represents L.S.D. \((P = 0.05)\).

Fig. 5. The numbers of male and female cabbage root flies caught per day by non-fluorescent ANCS traps spaced evenly through each of five 24 m square sub-plots of a swede crop. \(\circ\), 10 September; \(\bullet\), 11 September; \(\triangle\), 12 September 1971.
Trap spacing

On the first day of trapping (10 September 1971), the trapping rate (flies caught/day) of the ANCS traps placed evenly over each of the 24 m square sub-plots was linearly related to the square root of the number of traps per sub-plot, that is, per unit area.

Table 2. Mean number of female cabbage root flies caught/trap/day on 17, 18 and 19 September 1971 by non-fluorescent ANCS traps spaced evenly through five 12 m square sub-plots of a swede crop

<table>
<thead>
<tr>
<th>No. of traps</th>
<th>1</th>
<th>4</th>
<th>9</th>
<th>16</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. ix. 73</td>
<td>53</td>
<td>31</td>
<td>25</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>18. ix. 73</td>
<td>13</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>19. ix. 73</td>
<td>16</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 6. The mean numbers of female cabbage root flies caught at various trap spacings in a crop of swedes. ——, non-fluorescent traps in 1971; ———, fluorescent traps in 1972; ○, water-traps; ●, ANCS traps. Vertical bars represent s.E.'s.

(Fig. 5). Traps continued to catch flies throughout the three days of the experiment, but the rate of trapping declined after the first day apparently because it was approaching a maximum as the numbers of flies caught equalled the numbers of responsive flies developing in, or migrating into, the trapping zone. Removing the traps for a few days allowed the females in the area to become more uniformly...
distributed and the same equilibria occurred when trapping was resumed on 17 September on the 12 m square sub-plots (Table 2).

Depending upon trap spacing, non-fluorescent ANCS traps caught 2–7 and fluorescent ANCS traps 1·6 to 2·4, times as many females per trap as the comparable non-fluorescent and fluorescent water-traps in 1971 and 1972, respectively (Fig. 6).

Irrespective of spacing, similar numbers of females were caught by each non-fluorescent water-trap. In contrast, the number captured in fluorescent water-traps increased until the traps were 5 m apart and at this spacing they were as efficient as non-fluorescent ANCS traps.

There was a linear relationship between the logarithm of the number of flies caught and the logarithm of the distance between traps, except when fewer than two flies were caught/trap/day (Fig. 7). The slopes for the two sexes did not differ significantly (P = 0·001), indicating that density had no effect on the trapping of either sex. Above a certain minimum population, trap performance was therefore independent of fly numbers.


Response of the insects to the traps

Significantly more ($P = 0.05$) males than females were caught when flies more than 3 days old were released into cages (Table 3). Most males were recaptured when the flies were 3–7 days old at the time of release and most females when 5–6 days old. In addition, most males were caught on the 2 days following their release whereas females were caught at a much slower rate over the week. Even after a week, however, only 81% of the males and 55% of the females were recaptured from the most responsive of the ‘captive’ populations. Furthermore, only about 55% of the males and 30% of the females were recaptured when flies more than 8 days old were released.

<table>
<thead>
<tr>
<th>Age of flies released (days)</th>
<th>0–1</th>
<th>1–2</th>
<th>2–3</th>
<th>3–4</th>
<th>4–5</th>
<th>5–6</th>
<th>6–7</th>
<th>7–8</th>
<th>8–9</th>
<th>9–10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>46</td>
<td>58</td>
<td>70</td>
<td>81</td>
<td>80</td>
<td>78</td>
<td>76</td>
<td>59</td>
<td>53</td>
<td>47</td>
</tr>
<tr>
<td>Females</td>
<td>52</td>
<td>44</td>
<td>55</td>
<td>44</td>
<td>55</td>
<td>53</td>
<td>36</td>
<td>32</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Trap size had earlier been investigated by Hawkes (1969) who found that catch normally increased, though not proportionally, with size. A 15 cm diameter trap was used for the present experiments because it is easy to handle and maintain.

The location was also known to affect the efficiency of traps. Hawkes (1968) concluded that water-traps were least attractive when placed along hedgerows, though this may in part be caused by the tendency for herbage to grow over them. Traps containing attractant are placed in hollows or dense growth were not efficient if the restricted air movement prevented diffusion of the attractant vapours (Beroza, 1970). In the present experiments, all traps were placed between the rows of a crop and were presumably equally attractive. Furthermore, the positions of the traps were not changed during the experiments because use of traps for one day affects the fly population available for capture the next (Fig. 5), a fact realised by workers comparing the efficiency of light traps (Williams, French & Hosni, 1955). In the field, non-fluorescent water-traps caught males most efficiently when placed along the hedgerows and crop-interfaces and females when placed through the crop (Finch & Skinner, 1973c). Although, in one instance, the total numbers of females eventually captured along a hedgerow were similar to those captured through a crop, at an adjacent site, those caught in the crop were younger and, as a result, reduced the infestation from 31 to 13 eggs/plant (Finch & Skinner, 1972). If the purpose of
trapping is to reduce oviposition, the time taken to capture the available flies could be more important than the number eventually caught.

The laboratory experiments with fluorescent traps confirmed that colour discrimination by the flies is the basis of their response to yellow (Hawkes, 1970). Under both laboratory and field conditions, the fluorescent yellow traps caught approximately twice as many flies as non-fluorescent traps (Fig. 2). These results were not unexpected, however, since the laboratory lights had an emission spectrum with a sharp peak at 590 mµ (Veen & Meijer, 1962) and were chosen for their similarity to daylight. A possible biological explanation of cabbage root fly response to yellow is that, although their host plants appear green and not yellow to the human eye, in the part of the spectrum where green leaves reflect most light (500–600 mµ), yellows reflect considerably more energy than either oranges or greens (Prokopy & Boller, 1971). Similarly, the enhanced response to fluorescent yellow could also be predicted since Prokopy & Boller (1971) have shown that this type of paint converts short wavelength energy into longer wavelength energy and so emits more than 100% of the incident visible energy.

Efficiency is the most important characteristic of a trap since this has a greater influence on reduction of insect numbers than has a similar increase in trap-density (Wolf et al. 1971). Efficiency can be improved by changing the colour of the trap or by adding an attractant, such as allylisothiocyanate for the cabbage root fly. It has been known for about a century that plants of the family Cruciferae produce characteristic mustard oil glucosides which, on enzymic hydrolysis, normally yield glucose, sulphuric acid and the corresponding mustard oils, most of which are isothiocyanates (Kjaer, 1963). Under field conditions, a solution of 1% ANCS in water attracts flea-beetles (Feeny, Paauwe & Demong, 1970). The undiluted chemical also attracts cabbage root flies (Wallbank, 1972a) and it may be possible to use a lower concentration, although Müller (1971) failed to attract this fly using 0.3% ANCS in the field. In addition to diluting the attractant, the volatilization can be effectively reduced by decreasing the exposed surface of the wick. Positioning the wick so that from 100 to 0.8% of it was exposed, failed to affect efficiency on three separate occasions in 1972 (S. Finch & G. Skinner, unpublished data) whereas, Wallbank (1972a) reduced the numbers of flies caught by 40% when only 25% of the wick was exposed. During all four experiments, however, populations were low and only twice as many flies were caught in the ANCS traps as in the water-traps. In contrast, Eckenrode & Arn (1972) caught similar numbers of cabbage root flies in cone-traps using either host plants or allyliso-thiocyanate as the attractant, renewing the 0.5 ml ANCS source in one instance only after 50 days. These results and the data in Fig. 3 therefore suggest that all that is required is for some attractant to be present. In the experiments of Eckenrode & Arn (1972) and in those of Glass, Roelofs, Arn & Comeau (1970), polyethylene caps were used for the slow release of the attractant. The polyethylene caps of the ANCS traps at Wellesbourne (Fig. 1) were also permeated by the concentrated vapour of the ANCS and were probably also releasing the chemical at a slow rate over a long period of time.

Although solutions of sinigrin, allylisothiocyanate and β-phenylethylamine stimulated females to oviposit, they were less effective than juice squeezed from the ‘root’
of swede, a favoured host of the cabbage root fly (Traynier, 1965), suggesting that the chemicals tested provided only a partial explanation of the stimulating effect. The same is probably true of the attractant allylisothiocyanate, since forty or more thiocyanates have been isolated, mainly from crucifers, and several frequently occur together in a particular species, giving it a characteristic composition (Kjaer, 1963). Furthermore, twice as many flies have been caught in traps containing phenyl isothiocyanate than in traps containing water (S. Finch & G. Skinner, unpublished data), indicating that attraction is associated with the thiocyanate and not the allyl moiety. Allylisothiocyanate, therefore, is associated both with arresting female cabbage root flies at brassica crops (Wallbank, 1972a) and with stimulating females to oviposit (Traynier, 1965).

In the field cages, males were caught more readily than females (Table 3) probably the result of greater trivial activity by the males rather than of a difference in the attractiveness of the traps to the two sexes (Hawkes, 1969; Finch & Skinner, 1973c). The poor recapture of females released when more than 8 days old (Table 3) in these 'captive' populations illustrates the difficulty of capturing immigrant females, many of which are probably more than 8 days old when they arrive at a host-crop (Finch & Skinner, 1973b).

More males were caught 30 cm above the soil surface than at other elevations (Fig. 4). Although traps were positioned through a Brussels sprouts crop in one of the three experiments, the sprouts were small, and the 30 cm trap height corresponded approximately to plant height in all three experiments. Since most females were caught at ground level, presumably they spent much of their time ovipositing. Furthermore, many attractant vapours, including ANCS are heavier than air and will tend to fall when the air is still, forming a layer of high concentration near to the ground. Many insects have accommodated their behaviour to this and pursue odours while flying just above the ground (Beroza, 1970). This may explain why cabbage root flies are mainly caught close to the ground.

It is important to know if traps used to study dispersion in a population are attracting individuals from outside the area. This does not appear to be so with non-fluorescent water-traps (Finch & Skinner, 1973c) since the number of flies caught per trap was apparently independent of trap density (Fig. 6). Hawkes (1969) showed that such traps were attractive only within a range of 0.75 m. At the closest spacing (2.2 m) used in these experiments, therefore, there was no overlapping of the trapping areas. Some overlapping was apparent, however, when fluorescent yellow traps were less than 5 m apart, indicating a trapping range of c. 2.5 m for this type of trap. When ANCS was added to either type of yellow trap, relatively more females were captured at the wider trap spacings, but even at 8 m, the maximum spacing tested, the trapping areas still appeared to overlap, since the number of flies caught continued to increase. Furthermore, the ten- to eleven-fold increase in the effectiveness of ANCS traps compared to non-fluorescent water-traps was obtained by Wallbank (1972a) when the traps were 10 m apart. Similar increases in trap efficiency can be deduced indirectly from the present experiments. By assuming a mean of seven females/trap to be the number caught by each non-fluorescent water-trap (Fig. 6), an elevenfold increase in trap efficiency
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can be obtained for females by interpolation of the results in Fig. 7. Similarly, when the relationship in Fig. 6 is extrapolated to the 10 m trap spacing used by Wallbank (1972a), an eightfold increase in trap efficiency results from the addition of ANCS to a non-fluorescent trap.

The trap described in this paper is suitable either for detecting infestations of cabbage root fly or for determining distribution and rate of dispersal. The physical design of the trap, including position, elevation and colour appear to be finalized and further improvement in efficiency will therefore depend on finding an attractant, or combination of attractants, more potent than ANCS. Although ANCS is associated with oviposition behaviour, it is possible that a more potent attractant could be found from among chemicals governing feeding or mating activity. The rate of recapture of cabbage root flies in field cages suggests that an attractant five to ten times as potent as ANCS would probably be sufficient to control field populations.

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REFERENCES


