HGCA

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IMPROVING THE EFFICACY OF CHEMICAL CONTROL OF WHEAT BULB FLY

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IMPROVING THE EFFICACY OF CHEMICAL CONTROL OF WHEAT BULB FLY

by

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HGCA Project No. 1996

Final Report 2000

Improving the efficacy of chemical control of wheat bulb fly

CONTENTS

ABSTRACT

Wheat bulb fly (*Delia coarctata*) is a frequent and serious pest of cereals in eastern and north eastern areas of the UK. Wheat and barley are often attacked when sown after crops such as potatoes, sugar beet and vining peas or on land which was bare fallow during the summer months. The chemical control of wheat bulb fly has relied heavily on the use of organophosphorus insecticides. In recent years, many of these have been withdrawn, leaving a much diminished range of products to combat the pest. The aim of this project was to investigate ways of optimising the use and performance of some of the currently available wheat bulb fly insecticides. There were two themes of research in the project. Firstly, the use of the systemic insecticide dimethoate was investigated to establish if the efficacy of this chemical could be improved by manipulating a range of factors including; spray timing in relation to the developmental stages of the crop and pest; spray application rates and spray volumes; sequential applications and the use of adjuvants. Secondly, a recently approved synthetic pyrethroid seed treatment, tefluthrin (Evict), was evaluated to determine its efficacy and value in wheat bulb fly control strategies. Variable levels of pest control were obtained with dimethoate. In general, targetting different larval instars or crop growth stages had little impact on insecticide efficacy. However, there was some indication that dimethoate sprays applied to coincide with peak invasion by first instar (stage) larvae was more effective in preventing yield loss than later applied sprays. Spray volume, at 100, 200 and 300 litres/ha, did not to influence the level of pest control. A two-spray programme of dimethoate applied at the full label-recommended rate, timed to coincide with peak invasion by first instar (stage) larvae, with the second spray applied 10–14 days after the first, gave better control of wheat bulb fly larvae and crop damage than single sprays. The use of the adjuvants LI-700, Arma, Slippa and Actipron with one or two sprays of dimethoate did not improve the level of pest control or reduce crop damage. There were no significant increases in yield in response to any of the dimethoate treatments, owing primarily to compensatory crop growth and favourable weather. Tefluthrin seed treatment was compared with chlorpyrifos egg-hatch sprays (timed to coincide with the start of hatch of wheat bulb fly eggs) and an untreated control. In addition, the need for one or two follow-up sprays of dimethoate was also studied. Tefluthrin seed treatment reduced wheat bulb fly larval numbers and crop damage and improved crop yield by only 3% in the two December-sown crops studied. Chlorpyrifos sprays gave a lower level of control compared with tefluthrin, but their performance was disadvantaged by the organic soil at one site and a late-germinating crop at the other. There was no benefit in yield from following-up the seed treatment or egg hatch sprays with additional sprays of dimethoate, although dimethoate did give some control of larvae and crop damage. The results highlighted the ability of wheat to compensate for attack and a continuing need to develop systems to predict in which crops the control of wheat bulb fly will be cost-effective.

SUMMARY

Wheat bulb fly (*Delia coarctata*) is a frequent and serious pest of cereals in eastern and north eastern areas of the UK. The fly lays its eggs on bare or partially covered soil in July and August. Wheat and barley are attacked, normally when sown after crops such as potatoes, sugar beet and vining peas or on land which was fallowed (e.g. set-aside) during the previous summer. In most years, egg hatch and larval invasion of the crop starts in January and continues until late March. Each larva feeds within an individual stem or tiller and migrates between shoots as it grows, eventually completing three larval instars (stages) prior to pupation in April. Attacked shoots turn yellow and die, giving rise to the well known 'deadheart' symptoms.

The chemical control of wheat bulb fly has traditionally relied heavily on the use of organophosphorus insecticides. In recent years, many of these have been withdrawn, leaving a much diminished product range with which to combat the pest. Seed treatments and egg hatch sprays are available as preventive treatments designed to kill larvae before they penetrate the plants. Egg hatch sprays are applied to coincide with the start of egg hatch in early January. In contrast, deadheart sprays, in the form of dimethoate, are the final line of defence against the pest. This systemic insecticide cannot prevent the initial phase of larval invasion but kills maggots already feeding within plants and prevents the secondary phase of damage as larvae move between shoots.

The three-year HGCA research project titled 'Improving chemical control options for wheat bulb fly' started in autumn 1996. The project was done at field sites in Cambridgeshire and North Yorkshire and comprised of two distinct parts, the overall aim of which was to refine recommendations and guidelines to obtain maximum efficacy from two wheat bulb fly insecticides. In Part I, the efficacy of dimethoate against wheat bulb fly was investigated in relation to range of factors capable of influencing the performance of this product. In Part II, the efficacy of the recently released synthetic pyrethroid seed treatment, tefluthrin (Evict) was evaluated in comparison with chlorpyrifos egg hatch sprays, alone, or in combination with follow-up sprays of dimethoate.

PART I: Investigation and optimisation of the efficacy of dimethoate against wheat bulb fly

The objective of Part I of the project was to investigate ways of improving the performance of dimethoate against wheat bulb fly in three contrasting studies (Studies 1–3) over three cropping years.

Study 1. The effect of crop growth stage and age of larvae on the efficacy of dimethoate against wheat bulb fly

Study 1 investigated the interactions between crop growth stage and the age of larvae at the time of treatment on the efficacy of dimethoate. The aim of this work was to define the optimum stage of larval development and crop growth stage at which to treat with dimethoate against the pest.

In autumn 1996, winter wheat (cv. Riband) was drilled on three sowing dates at two sites, one on a commercial farm near Littleport, Cambridgeshire and the other at ADAS High Mowthorpe, North Yorkshire. The trials were of a two-way factorial, fully randomised block design. The drilling dates ranged from mid-October to late January. The contrasting drilling dates were intended to provide winter wheat of differing growth stages at the time of wheat bulb fly larval attack. The progress of wheat bulb fly egg hatch and larval invasion of the crop was monitored at regular intervals during the critical period from early January to late March. Dimethoate (40% EC) was applied in sprays of 200 litres water/ha at the label rate of 1.7 litres of product/ha on three occasions, each coinciding with peak development of the first, second or third larval instars (stages), from early March to mid-April.

Although there was no statistically significant benefit of the dimethoate sprays on larval control or crop yield, there was a consistent trend towards yield increases ranging from 5% to 12% from the first and second instar sprays applied to the first and second drillings at High Mowthorpe (Figure A). Increases in ear numbers were also noted in the same group of treatments, providing further evidence that these yield increases were attributable to the control of wheat bulb fly.

The disappointing level of wheat bulb fly control found with dimethoate in Study 1 confirms the observations by many farmers of the variable efficacy of this insecticide against the pest. There was no clear evidence in this work to suggest that crop growth stage, alone, or in interaction with larval growth stage, influenced the performance of dimethoate. However, there was some indication in the fertile ear counts and yield data from High Mowthorpe to confirm that applying dimethoate whilst the majority of the larvae are small and in their first instar, has the best chance of success in preventing further yield loss once an attack is in progress.

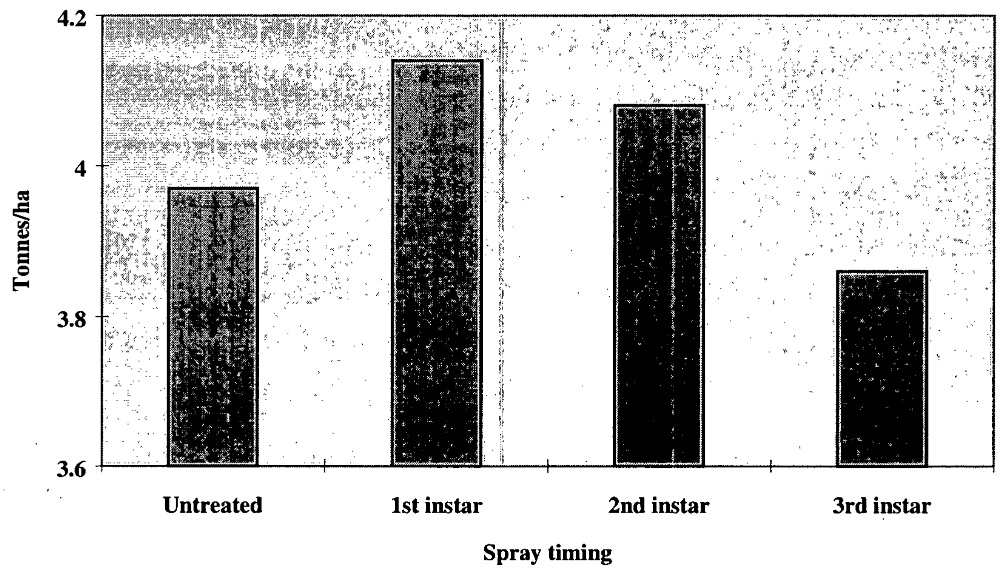

Figure A. The effect on the yield winter wheat of dimethoate applied against contrasting stages of wheat bulb fly larval development in Study 1 at High Mowthorpe. Yields are means of three sowing dates. SED (32 d.f.) 0.124.

Study 2. The effect of dose-rate, frequency and volume on the efficacy of dimethoate against wheat bulb fly.

The objective of Study 2 was to investigate if varying the rate or number of applications of dimethoate influences its efficacy against wheat bulb fly. The effect of reducing or increasing spray volumes on the activity of dimethoate against the pest was also investigated. There were four dimethoate treatments comprising the product applied applied as a single spray at 1.7 l/ha (full label rate) or 3.4 l/ha, or as two-spray programmes at 1.7 or 0.85 l/ha. All of these treatments were applied in each of three water volumes of 100, 200 or 300 l/ha.

The work was done on two sites; one on a commercial farm near Littleport, Cambridgeshire and the other at ADAS High Mowthorpe. Each trial was of a two-way factorial plus untreated control, fully randomised block design. The plots were sown on 12 November 1997 at High Mowthorpe and 25 November 1997 at Littleport to produce crops at differing growth stages at the time of wheat bulb fly egg hatch and larval invasion. The first dimethoate sprays were applied at the optimum timing of peak invasion by first instar larvae, as indicated by regular monitoring to determine the progress of egg hatch and larval invasion. The second sprays were applied 7–14 days later.

At Littleport, wheat bulb fly control was poor with no significant differences between any of the dimethoate rates or spray volumes. There was a better standard of control at High Mowthorpe. At this site and across all dimethoate treatments, tiller damage was reduced by 39% and the number of live larvae by 81%, compared with untreated ($P < 0.001$). Furthermore, the lowest numbers of live larvae were associated with the single, high-rate spray of dimethoate (3.4 l/ha) and the double spray of standard label-rate dimethoate (1.7 l/ha) (Figure B). However, there was no effect of spray volume on product efficacy. Although dimethoate treatment reduced numbers of wheat bulb fly larvae there was no effect on crop yield.

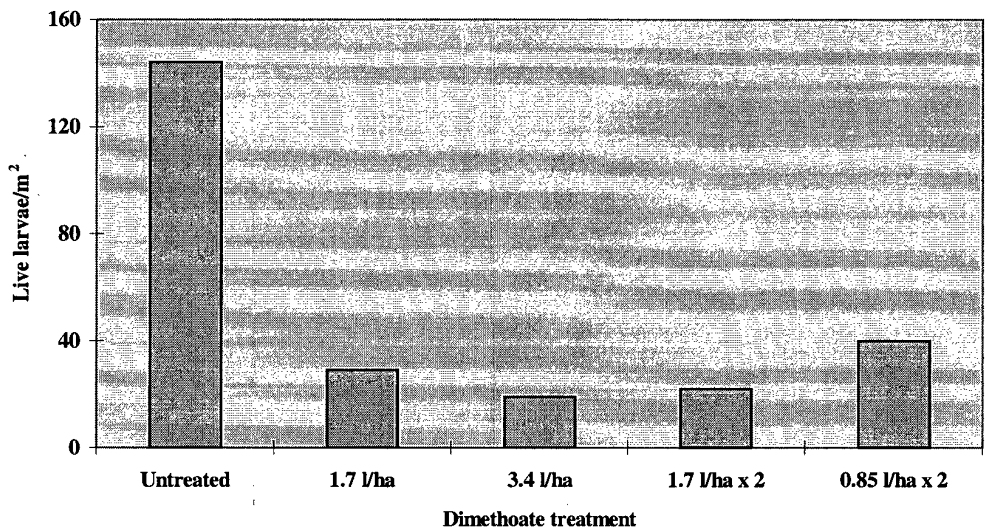

Figure B. The effect of various dimethoate application rates and sequences on the survival of wheat bulb fly larvae in Study 2 at High Mowthorpe. SED (36 d.f.) 11.22.

The results of Study 2 further confirmed the unreliable and inconsistent control of wheat bulb fly by dimethoate. High Mowthorpe was the more responsive of the two sites. At High Mowthorpe, tiller damage was reduced by 39% and larval numbers by 81% following dimethoate treatment. In contrast, results at Littleport were poor, with only a 2% reduction in tiller damage and a 19% reduction in larval numbers. There was no reduction in the relative levels of pest control from reducing spray volumes to 100 l/ha. This finding is re-assuring in the light of an increasing trend to reduce spray volumes. Although at High Mowthorpe a single spray at 3.4 l/ha gave the best larval control it did not improve yield in comparison with the approved two-spray programme at 1.7 l/ha. Therefore, the approved label rate remains the preferred option. Despite the good control of wheat bulb fly larvae at High Mowthorpe, there was no subsequent effect on yield, emphasising the ability of many crops to grow away from and compensate for pest attack.

Study 3. The use of adjuvants to enhance the efficacy of dimethoate against wheat bulb fly.

In the third cropping year of the project, the objective of Study 3 was to evaluate a range of adjuvants for use in conjunction with dimethoate against wheat bulb fly. Many types and makes of adjuvants are on the market and their use has been the subject of much interest in recent years. This study set out to investigate if the use of adjuvants is warranted to improve the uptake and efficacy of dimethoate against wheat bulb fly. Four contrasting types of commercially available adjuvants were selected for the work:

1. LI-700. A penetrating, acidifying surfactant containing 350 g/l modified soya lecithin, 100 g/l alkylphenylhydroxypolyoxyethylene and 350 g/l propionic acid.

2. Arma. A penetrating adjuvant containing 500 g/l alkoxylated fatty amine plus 500 g/l polyoxyethylene monolaurate.

3. Slippa. A liquid concentrate formulation containing 655 g/l polyalkyleneoxide modified heptamethyltrisiloxane plus non-ionic wetters.

4. Actipron. An adjuvant oil containing 97% highly refined mineral oil.

The adjuvants were applied individually, as per their label recommendations, in mixture with full label-rate dimethoate deadheart sprays as single- and two-spray programmes in comparison with dimethoate alone and an untreated control. All treatments were applied in a spray volume of 200 litres of water per hectare, timed to coincide with peak invasion by first instar wheat bulb fly larvae as indicated by frequent crop monitoring. There were two trial sites; one on a commercial farm at Stuntney, Cambridgeshire and the other at High Mowthorpe, North Yorkshire. Each used a two-way factorial plus untreated control, fully randomised block design.

None of the adjuvants applied with dimethoate improved the standard of wheat bulb fly control or resulted in any benefits in crop yield, compared with the use of dimethoate alone. Dimethoate application significantly reduced tiller damage and the number of live larvae, compared with the untreated control ($P < 0.05$). At Stuntney, the proportion of tillers damaged by wheat bulb fly was reduced by 33% and at High Mowthorpe by 58% ($P < 0.05$). The equivalent mean reductions in the numbers of live larvae across all dimethoate treatments were 61% at Stuntney and 63% at High Mowthorpe ($P < 0.001$). Across both sites, a single spray of dimethoate reduced tiller damage by an average of 41% and the number of live larvae by 53%, whilst the two-spray programme reduced tiller damage by an average of 51% and live larvae by 72%. Therefore, two sprays of dimethoate were more effective at controlling larvae than one (Figure C). This observation confirmed similar findings in earlier work (Study 2) of this project.

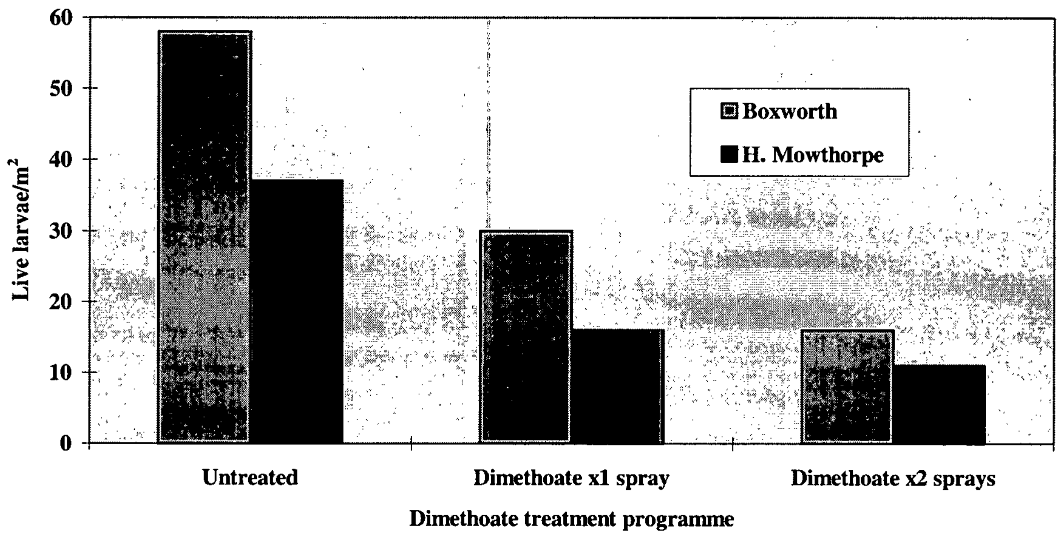

Figure C. The effect of one- or two-spray programmes of dimethoate on the survival of wheat bulb fly larvae in Study 3. SEDs (30 d.f.): Boxworth, 6.93; High Mowthorpe, 5.71.

Despite the relatively heavy attack by wheat bulb fly at both sites, the effect of early (October) sowing combined with favourable weather and vigorous tillering in late winter/early spring resulted in compensatory crop growth and the lack of a yield response to treatment. The absence of yield increases in response to dimethoate sprays in continued the trend observed in Studies 1 and 2 and emphasised that information on the severity of wheat bulb fly attack, weather conditions, crop growth rate and yield potential is critical in determining when treatment is likely to be cost-effective. An improved understanding of the factors which influence crop compensation is required in order to develop a reliable system to predict the need for treatment against this pest.

PART II: Evaluation of tefluthrin seed treatment for integration with wheat bulb fly control strategies

The tefluthrin study took place over two cropping years, 1997–99. The objectives of this work were to evaluate the efficacy of tefluthrin (Evict) seed treatment against wheat bulb fly, to assess how best it should be integrated with existing control strategies and to establish the value of additional sprays of dimethoate later in the season.

Field experiments were undertaken at Stuntney, Cambridgeshire (organic soil) in 1997/98 and ADAS High Mowthorpe in 1998/99 in December-sown wheat crops. The experiments were of a two-way factorial, fully randomised block design. The seed treatment was compared with chlorpyrifos egg hatch sprays (timed to coincide with the start of egg hatch) and an untreated control. The need to follow up insecticide treatment at drilling or at egg hatch with one- or two-spray programmes of dimethoate, once plant invasion was underway, was also studied. The chlorpyrifos (48% w/v EC) egg hatch sprays and dimethoate (40% w/v EC) deadheart sprays were applied at their respective label recommended rates of 1.5 l/ha and 1.7 l/ha in 200 litres water/ha. Egg hatch and plant invasion were monitored at frequent intervals to enable correct timing of the egg hatch and deadheart sprays.

At High Mowthorpe, the crop was slow to germinate and plant establishment took place during the early stages of larval attack. Consequently, some plants were killed pre-emergence. Tefluthrin seed treatment subsequently improved plant establishment in March and April at High Mowthorpe ($P < 0.05$). By April, the mean plant population of the tefluthrin treatments exceeded that of the untreated control by 71 plants/m^2. Chlorpyrifos was not as effective as tefluthrin in controlling plant loss probably because it was unable to penetrate the soil to sufficient depth to kill wheat bulb fly larvae underground. At Stuntney, fewer plants ($P < 0.05$) were recorded in plots with tefluthrin treated seed (256 plants/m^2), compared with those sprayed with chlorpyrifos (278 plants/m^2) or the untreated control (274 plants/m^2). It is possible that the seed treatment mayhave reduced or delayed germination at this site.

Tefluthrin and chlorpyrifos significantly reduced the percentage of tillers attacked at Stuntney and High Mowthorpe ($P < 0.001$). At both sites, the tefluthrin seed treatment had the lowest level of tiller invasion (Figure D). However, at Stuntney it was less effective than at High Mowthorpe, with a 40% reduction in the proportion of tillers damaged at Stuntney in comparison with an 85% reduction at High Mowthorpe. The dimethoate sprays also significantly reduced tiller damage at High Mowthorpe ($P < 0.01$) but not at Stuntney.

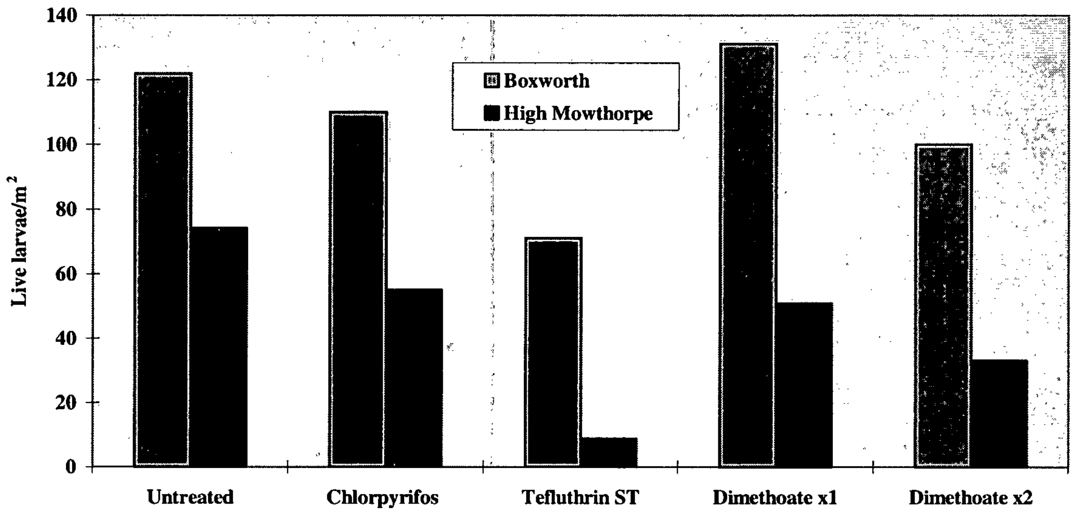

Figure D. The effect of tefluthrin seed treatment, chlorpyrifos egg hatch spray and dimethoate deadheart sprays on the survival of wheat bulb fly larvae. SEDs (24 d.f.): Boxworth 15.32; High Mowthorpe, 8.37.

At both sites, lowest numbers of larvae surviving treatment were recovered in tefluthrin treated plots and most in the untreated control. Tefluthrin was more effective at controlling larvae at High Mowthorpe than at Stuntney. At High Mowthorpe, larval numbers were reduced by 88% and at Stuntney by 40%, in comparison with the untreated control. At High Mowthorpe there was also a significant difference in numbers of surviving larvae between dimethoate treatments ($P < 0.001$). Following two sprays of dimethoate at High Mowthorpe, larval numbers were 58% lower than in the untreated plots and 31% lower where only a single application was made. This observation confirmed the findings of dimethoate Study 2 in which two sprays of dimethoate gave better control of wheat bulb fly than one. Data from Stuntney showed the same trend but differences were not statistically significant.

There was a significant difference in yield between treatments applied to prevent larval invasion at Stuntney ($P < 0.05$). Tefluthrin treated plots had a 2.4% higher yield and chlorpyrifos treated plots a 2.0% higher yield than the untreated control. A similar trend in yield data was recorded at High Mowthorpe although differences were not statistically significant. There was no yield benefit of follow-up sprays of dimethoate at either site.

The performance of chlorpyrifos egg hatch sprays was poorer than anticipated, possibly due to the effect of an organic soil type at Stuntney and a less than optimum timing of application at High Mowthorpe. Although follow-up sprays of dimethoate were unnecessary at both sites, it would be unwise to rule out the need for additional insecticide treatments in the presence of heavy attacks by the pest.

Tefluthrin seed treatment was a useful and valuable tool in the control of wheat bulb fly in December-sown crops at a time when the availability of alternative organophosphorus products is under threat. The low yield response to insecticides observed in this work suggest there is a continuing need to be able to predict more precisely when treatments are likely to be cost-effective. This will involve an improved understanding of the biology of the interaction between pest attack and wheat physiology and how this influences the ability of the crop to compensate for wheat bulb fly damage.

Key messages

- Dimethoate sprays targeted against first instar (stage) larvae are likely to be more effective than later sprays in preventing yield losses.

- Two sequential applications of dimethoate applied at full label-rate gave better control than a single application.

- The use of adjuvants with dimethoate did not improve wheat bulb fly control.

- Tefluthrin seed treatment effectively controlled wheat bulb fly in December-sown wheat without the need for additional treatments.

- There is a need to predict more accurately which crops will respond cost-effectively to justify insecticide treatment.

- Compensatory crop growth in response to wheat bulb fly damage may render chemical treatments unnecessary and uneconomic.

Recommendations for future research

- To develop a reliable decision support system to predict where and when insecticide treatment against wheat bulb fly is likely to be cost-effective and to reduce unnecessary treatment, taking account of pest biology and the compensatory response of the crop.

- To develop an integrated pest management (IPM) strategy against wheat bulb fly which will reduce dependence on insecticides and exploit biological and cultural control methods, including an understanding of the ability of wheat to compensate for damage by the pest.

TECHNICAL DETAIL

Introduction

Wheat bulb fly ranks amongst the most serious insect pests of winter wheat in Great Britain. A recent HGCA-funded Research Review (No. 33) highlighted how a number of changes in arable agriculture could significantly affect control of wheat bulb fly and stressed the need for the development of more integrated and sustainable means of combating the pest. Chemical control of wheat bulb fly has relied heavily on the use of organophosphorus insecticides and the number of products available has declined severely in recent years. Therefore, the options available to farmers for the chemical control of wheat bulb fly are now seriously restricted. Consequently, there is an urgent need to optimise the use of the few remaining insecticides available against this pest and to devise strategies which will enable the farmer to become less reliant on their use.

Deadheart sprays are systemic insecticides targeted at young wheat bulb fly larvae feeding within wheat shoots at the onset of the typical 'deadheart' symptoms, which develop as the central leaves of attacked shoots turn yellow, wither and die. These sprays do not prevent the initial invasion of plants by larvae but are designed to minimise the secondary phase of attack as the larvae grow and move from shoot-to-shoot. Until recent years, two insecticides were available for use as deadheart sprays – omethoate (Folimat) and dimethoate (various products). Omethoate was generally regarded to be more effective than dimethoate. The subsequent withdrawal of omethoate caused great concern as this left dimethoate as the only remaining insecticide available for use as a deadheart spray against wheat bulb fly. Field experience suggests that the standard of control gained from dimethoate is often variable. Typically, between 30 and 60% of larvae may be killed by a single spray of dimethoate. Yield increases resulting from the use of dimethoate against wheat bulb fly can also be unpredictable. Crops that are well tillered by the time of attack are unlikely to benefit from dimethoate treatment whilst yield increases of up to 0.9 t/ha have been observed on late sowings with heavy infestations of the pest (Young & Ellis, 1996).

Therefore, it has, therefore, become increasingly important to apply dimethoate precisely for maximum benefit. The timing of dimethoate sprays in relation to larval invasion, crop growth stage and the developmental stage of the larvae are known to be crucial factors in determining the outcome of treatment (Griffiths & Scott, 1969; Maskell & Davis; 1974). In some instances, more than one application of dimethoate may be required to obtain an acceptable standard of control. Furthermore, there has been much interest in the use of various spray adjuvants to improve the activity of dimethoate. A better understanding of the factors affecting the performance of dimethoate against wheat bulb fly will help identify the most appropriate and cost-effective means of using this insecticide. Improved precision of use will also reduce wasteful applications and ensure environmental risk is minimised.

The three-year project reported here aimed to improve and develop the cost-effective use of dimethoate against wheat bulb fly with a series of three contrasting studies (identified as Studies 1–3). Each study focused on the following critical factors affecting the performance of dimethoate, none of which have been investigated in-depth before:

- The effect of crop growth stage and larval developmental stage.
- The effect of dose-rate, frequency of application and spray volume.
- The effect of various commercially available spray adjuvants.

Part I

Investigation and optimisation of the efficacy of dimethoate against wheat bulb fly

Study 1: The effect of crop growth stage and age of larvae on the efficacy of dimethoate against wheat bulb fly.

Introduction, Study 1

In the first cropping-year of the project, the objective of Study 1 was to investigate possible interactions between crop growth stage and the age of larvae at the time of treatment, on the performance of dimethoate. Therefore, the study was designed to indicate the relative efficacy and optimum timing of dimethoate against wheat bulb fly at a range of crop and pest developmental stages. Study 1 comprised three sowing dates at two sites to produce contrasting crop growth stages at the time of larval invasion. Dimethoate sprays were applied to each sowing at three contrasting timings to coincide with maximum activity of the first, second and third developmental stages (instars) of the larval population.

Methods & materials, Study 1

Individual experimental sites were located on a commercial farm near Littleport, Cambridgeshire and at ADAS High Mowthorpe, Yorkshire, during the 1996/97 cropping season. Pre-drilling egg numbers were determined at each site by taking soil samples in autumn 1996. A minimum of 20 × 10 cm diameter cores were taken from each prospective trial site. The samples were each of a sufficient depth to exceed the depth of soil cultivation. Wheat bulb fly eggs were extracted from the soil using a modified Salt and Hollick technique which entailed soaking, wet sieving and flotation of eggs in a saturated solution of magnesium sulphate.

The trials were of a two-way factorial, fully randomised block design. Each treatment was replicated four times, giving a total of 48 plots per site. Untreated guard (discard) plots were added to the ends of each experimental area for use as destructive sampling areas to monitor wheat bulb fly egg hatch and larval invasion. Plots were drilled with winter wheat (cv. Riband) using tractor mounted Ojyørd or Fiona drills. At the Littleport site, plot size was 24 m × 2 m at 2.5 m centres. At the High Mowthorpe site, plot size was 24 m × 3 m at 3.3 m centres. The seed rates of each drilling were adjusted to suit local conditions and to attain a target plant population of 200–250 plants/m^2. The treatments comprised of three contrasting sowing dates intended to provide contrasting growth stages of crop at the time of attack (Tables 1.1, 1.2 & 1.3).

Single sprays of dimethoate were applied to each drilling at three timings, each coinciding with peak development of the first, second or third larval instars (developmental stages). At both sites, a standard commercial formulation of dimethoate (Portman Dimethoate 40; 40% dimethoate w/v EC) was applied at the label recommended rate of 1.7 litres of product per hectare in 200 litres of water per hectare. The sprays were applied by CO_2-pressurised Oxford knapsack sprayer at the Littleport site and by a self-propelled Plot-Master sprayer at High Mowthorpe. All sprays were applied as medium quality sprays at 200kPa pressure.

The crop protection and husbandry programme followed normal commercial farm practice at each site. Wheat bulb fly insecticides applied to the surrounding field crops were excluded from the experimental areas.

The progress of wheat bulb fly egg hatch was monitored by extracting and examining eggs from soil samples taken from each site at approximately weekly intervals from early January until March. Likewise, the progress of larval invasion and development was monitored in samples of 50 plants sampled from discard plots at approximately weekly intervals from early January until late March. The results of the monitoring of wheat bulb fly egg hatch and plant invasion were used to trigger the dimethoate sprays.

The plant establishment of each drilling was assessed as soon as plant emergence was judged to be complete and the majority of plants were at the one- or two-leaf growth stage. Plants were counted in eight 0.5 m paired lengths of row per plot (i.e. a total row length of 8 m per plot).

Table 1.1. Description of drilling date and dimethoate treatments applied in HGCA project Study 1, 1996/97.

Treatment	Target drilling date	Dimethoate spray timing
1	Late-October	Untreated
2	Late-October	At first instar
3	Late-October	At second instar
4	Late-October	At third instar
5	Mid-November	Untreated
6	Mid-November	At first instar
7	Mid-November	At second instar
8	Mid-November	At third instar
9	Mid-December	Untreated
10	Mid-December	At first instar
11	Mid-December	At second instar
12	Mid-December	At third instar

Table 1.2. Drilling dates at Littleport and High Mowthorpe in Study 1, 1996/97.

Drilling	Littleport	High Mowthorpe
1	22 October 1996	15 October 1996
2	15 November 1996	13 November 1996
3	31 January 1997	11 December 1996

Table 1.3. Dimethoate spray dates and corresponding crop growth stages at Littleport and High Mowthorpe in Study 1, 1997.

Site	**Spray timing**	**Date of spray**	**Crop growth stage***		
			Drilling 1	**Drilling 2**	**Drilling 3**
Littleport	1st instar	3 March	22	12	09
	2nd instar	10 March	23	13	10
	3rd instar	24 March	24	21	11
H. Mowthorpe	1st instar	14 March	22	20	10
	2nd instar	25 March	23	21	11
	3rd instar	18 April	24	22	22

* After Tottman & Broad (1987).

The effect of treatment on the extent of larval invasion and crop damage was assessed by examining plant samples taken from each plot approximately two weeks after the application of the final dimethoate spray. The objective of this assessment was to determine the effect of treatment on the final, maximum, level of wheat bulb fly damage following each treatment. Six plants were removed from ten randomly selected sampling points per plot to obtain 60 plants per plot. The plants were dissected under a low-power microscope to determine the number of larvae and the proportion of plants and tillers attacked.

The population density of wheat ears was assessed during June or July by counting the number of fertile tillers in six randomly selected 0.1 m^2 quadrats per plot. Crop yield was assessed by harvesting plots with a small-plot combine harvester. Sub-samples of grain were taken from each plot at harvest for measurement of moisture content and specific weight (bulk density).

All results were subjected to analysis of variance (ANOVA) using a GENSTAT program.

Results, Study 1

Wheat bulb fly egg count, hatch and plant invasion

At each site in autumn 1996, wheat bulb fly egg numbers were well above the 2.5 million eggs/ha action threshold for autumn-sown wheat. There were 5.3 and 9.2 million eggs/ha at High Mowthorpe and Littleport respectively.

Egg hatch was detected at the Littleport site in early January. However, at High Mowthorpe, hatch did not occur until later in the month (Figure 1.1). Subsequently, the main phase of larval invasion took place in late February. The dimethoate sprays targeted against peak development of first instar larvae were delayed by 7–10 days at both sites owing to persistently windy or wet weather. The sprays applied against the second and third instar larvae were, however, applied on or close to target dates at each site (Figures 1.2 & 1.3).

Crop establishment

The first and second drillings at Littleport, together with the first drilling at High Mowthorpe, all resulted in well established crops with plant populations within the normal range (200–300 plants/m^2) for commercial crops (Table 1.4). However, adverse weather and soil conditions resulted in crop establishment problems in the final (third) drilling at Littleport and the second and third drillings at High Mowthorpe. At Littleport, the final drilling was delayed until late January 1997 by wet or frozen soil conditions. The final drilling at High Mowthorpe was sown on 11 December 1996 but plant establishment was seriously delayed by freezing soil conditions in late December and early January. Therefore, the late drillings at both sites suffered from slow and variable emergence. Consequently, the germination of these late drillings coincided with wheat bulb fly larval invasion and many plants were destroyed by larvae underground in a pre-emergence attack. The plant population of the final (third) sowing at High Mowthorpe was too low and late emerging to permit reliable assessment of the plant population and calculation of larval numbers/m^2 (Tables 1.4 & 1.6).

Tiller damage, larval control and crop yield

There was no statistically significant evidence that any of the dimethoate sprays, applied to any of the drillings, resulted in control of tiller damage (Table 1.5) and larval numbers (Table 1.6), or gave increases in ear numbers (Table 1.7) and crop yield (Table 1.8).

At the Littleport site, the highest yield increase (6%, 0.2 t/ha) was seen in association with the second instar spray of the third drilling and ear numbers in this treatment were also 3% greater than untreated. However, a trend of yield increases of 6% (0.43 t/ha) and 12% (0.36) was noted in the first instar sprays of the first and second drillings, respectively, at High Mowthorpe. Increases in ear numbers, ranging from 11% in the first drilling to 34% in the second drilling, were also associated with the first instar sprays, providing evidence that the yield increases were linked with wheat bulb fly control. The greatest increases in ear numbers and yield were, therefore, consistently associated with the first instar spray of the second drilling at High Mowthorpe.

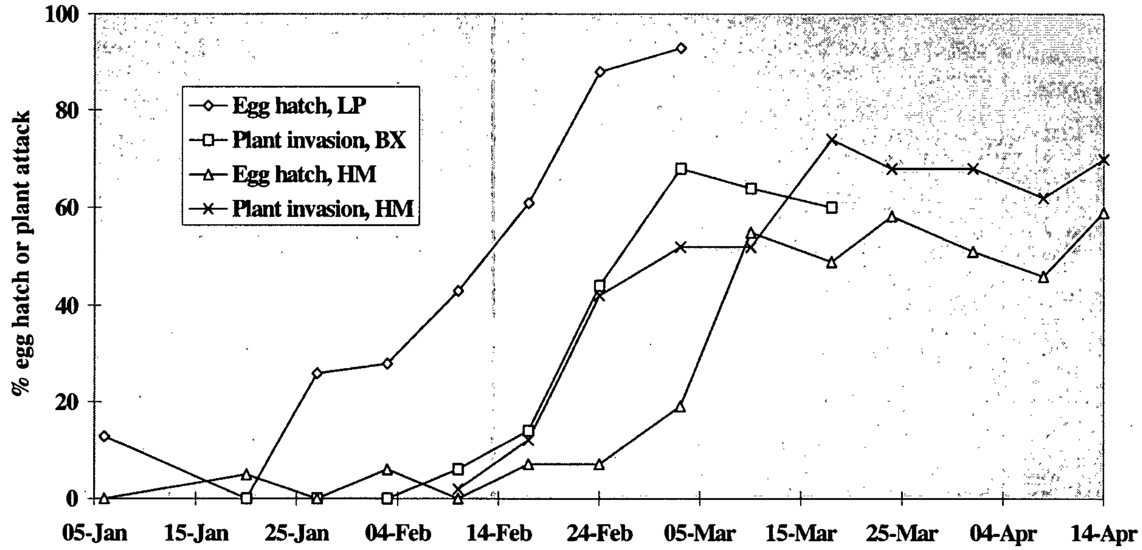

Figure 1.1. The progress of wheat bulb fly egg hatch and plant invasion in Study 1 at Littleport, Cambridgeshire (LP) and High Mowthorpe, North Yorkshire (HM), 1997.

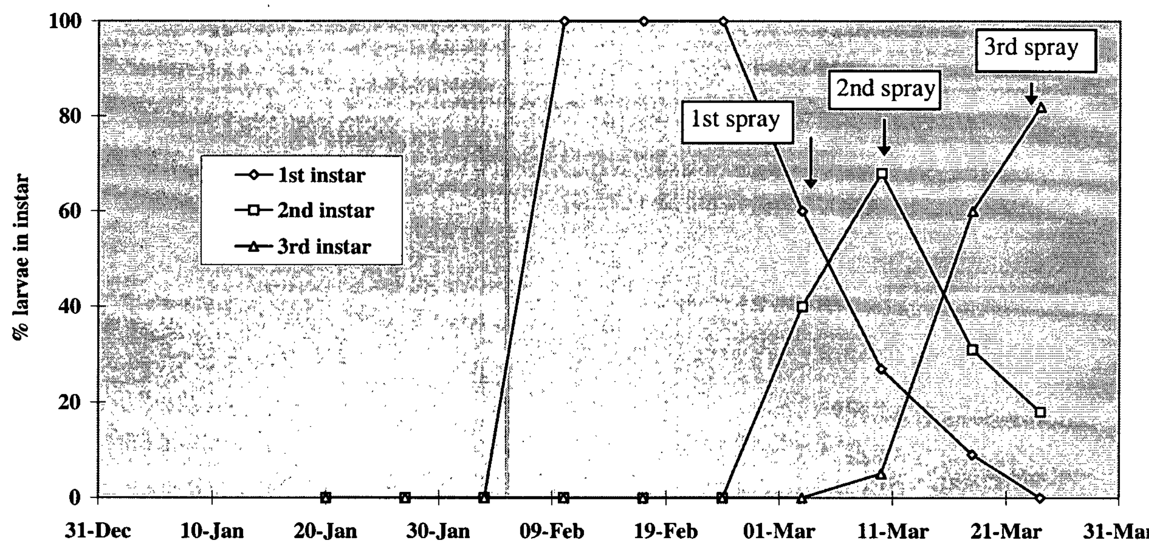

Figure 1.2. The development of wheat bulb fly larval instars and the timing of dimethoate sprays in Study 1 at Littleport, 1997.

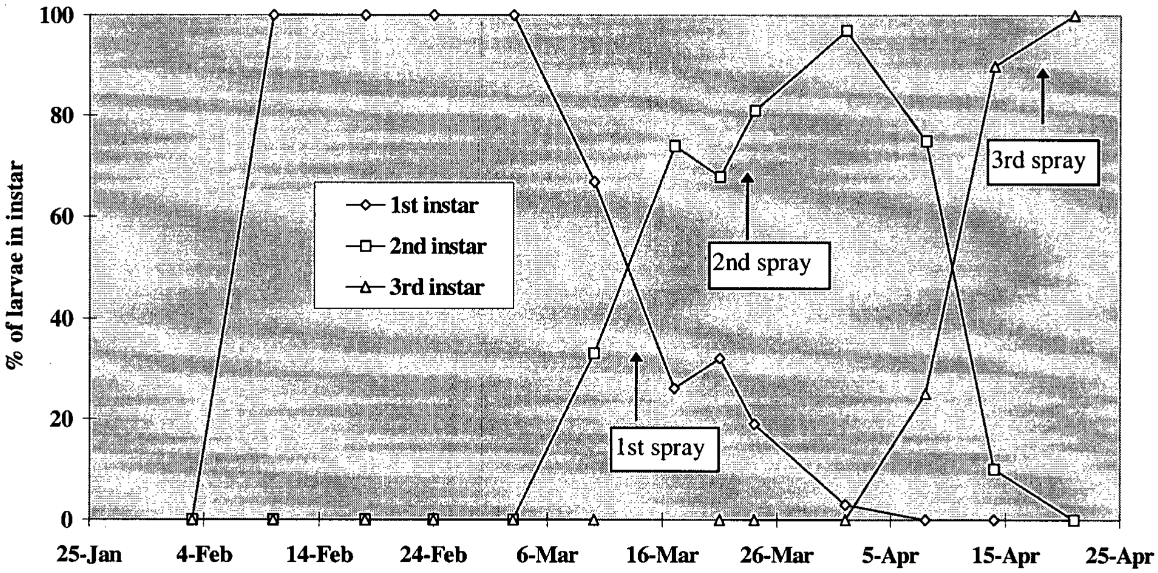

Figure 1.3. The development of wheat bulb fly larval instars and the timing of dimethoate sprays in Study 1 at High Mowthorpe, 1997.

Table 1.4. Plant establishment of winter wheat (cv. Riband), Study 1, 1996/1997. Littleport assessment dates – first drilling 11/12/96; second drilling 3/3/97; third drilling 24/3/97. High Mowthorpe* – first drilling 13/2/97; second drilling 18/3/97 (plants/m^2).

Spray timing	Drilling 1	Drilling 2	Drilling 3	Mean
Littleport				
1. Untreated	236	205	90	177
2. First instar	230	219	70	173
3. Second instar	237	221	77	178
4. Third instar	241	229	71	180
Mean	236	219	77	
SEDs (33 d.f.):	for comparison of drilling means = 5.23, $P = < 0.001$ for comparison of spray timing means = 6.03, $P = 0.65$ for comparison of means within the body of the table = 10.45, $P = 0.17$			
High Mowthorpe				
1. Untreated	252	54	na	153
2. First instar	260	61	na	160
3. Second instar	250	53	na	151
4. Third instar	258	62	na	160
Mean	255	57	na	
SEDs (21 d.f.):	for comparison of drilling means = 5.2, $P = < 0.001$ for comparison of spray timing means = 7.4, $P = 0.51$ for comparison of means within the body of the table = 10.4, $P = 0.99$			

* Third drilling not assessed at High Mowthorpe owing to delayed emergence of plants.

Table 1.5. The mean proportion of tillers attacked by wheat bulb fly in Study 1, 1997, assessed 14 days and 10 days after final treatment at Littleport and High Mowthorpe respectively (% tillers attacked).

Spray timing	Drilling 1	Drilling 2	Drilling 3	Mean
Littleport				
1. Untreated	34.9	58.1	35.1	42.7
2. First instar	29.9	65.8	42.5	46.0
3. Second instar	28.7	62.2	34.1	41.6
4. Third instar	38.1	65.4	52.3	52.0
Mean	32.9	62.9	41.0	
SEDs (33 d.f.):	for comparison of drilling means = 3.76, $P = < 0.001$ for comparison of spray timing means = 4.34, $P = 0.10$ for comparison of means within the body of the table = 7.52, $P = 0.66$			
High Mowthorpe				
1. Untreated	18.7	2.2	2.0	7.6
2. First instar	13.9	2.7	0.4	5.7
3. Second instar	17.6	2.5	0.5	6.8
4. Third instar	19.0	2.9	0.7	7.5
Mean	17.3	2.6	0.9	
SEDs (27 d.f.):	for comparison of drilling means = 1.39, $P = < 0.001$ for comparison of spray timing means = 1.60, $P = 0.60$ for comparison of means within the body of the table = 2.77, $P = 0.82$			

Table 1.6. The mean numbers of wheat bulb fly larvae surviving treatment in Study 1, 1997, assessed 14 days and 10 days after final treatment at Littleport and High Mowthorpe* respectively (nos. live larvae/m^2).

Spray timing	Drilling 1	Drilling 2	Drilling 3	Mean
Littleport				
1. Untreated	199.0	95.2	29.8	108.0
2. First instar	185.2	85.6	12.5	94.4
3. Second instar	113.3	103.1	24.0	80.1
4. Third instar	138.9	127.3	20.8	95.6
Mean	159.1	102.8	21.8	
SEDs (33 d.f.):	for comparison of drilling means = 12.89, $P = < 0.001$ for comparison of spray timing means = 14.88, $P = 0.34$ for comparison of means within the body of the table = 25.77, $P = 0.05$			
High Mowthorpe				
1. Untreated	12.8	0.8	na	6.8
2. First instar	10.7	0.9	na	5.8
3. Second instar	12.3	1.0	na	6.6
4. Third instar	5.5	1.0	na	3.2
Mean	10.3	0.9	na	
SEDs (21 d.f.):	for comparison of drilling means = 2.27, $P = < 0.001$ for comparison of spray timing means = 3.22, $P = 0.67$ for comparison of means within the body of the table = 4.55, $P = 0.64$			

* Not completed for third drilling at High Mowthorpe owing to late emergence of plants.

Table 1.7. Mean numbers of fertile tillers of winter wheat in Study 1, 1997 (ears/m^2).

Spray timing	Drilling 1	Drilling 2	Drilling 3	Mean
Littleport				
1. Untreated	490	201	248	313
2. First instar	539	212	249	333
3. Second instar	550	187	256	331
4. Third instar	505	192	221	306
Mean	521	198	243	
SEDs (33 d.f.):	for comparison of drilling means = 18.7, $P = < 0.001$ for comparison of spray timing means = 21.59, $P = 0.52$ for comparison of means within the body of the table = 37.39, $P = 0.85$			
High Mowthorpe				
1. Untreated	419	135	20	191
2. First instar	463	181	12	219
3. Second instar	438	157	18	204
4. Third instar	414	152	16	194
Mean	433	156	16	
SEDs (33 d.f.):	for comparison of drilling means = 10.9, $P = < 0.001$ for comparison of spray timing means = 12.6, $P = 0.15$ for comparison of means within the body of the table = 21.7, $P = 0.56$			

Table 1.8. Mean yields of winter wheat, cv. Riband in Study 1, 1997 (t/ha @ 85% d.m.).

Spray timing	Drilling 1	Drilling 2	Drilling 3	Mean
Littleport				
1. Untreated	8.34	3.25	2.92	4.84
2. First instar	8.45	2.98	2.79	4.74
3. Second instar	8.48	3.05	3.12	4.88
4. Third instar	8.38	2.82	2.55	4.59
Mean	8.41	3.03	2.84	
SEDs (33 d.f.):	for comparison of drilling means = 0.164, P = <0.001 for comparison of spray timing means = 0.189, P = 0.42 for comparison of means within the body of the table = 0.327, P = 0.89			
High Mowthorpe				
1. Untreated	7.61	3.05	1.26	3.97
2. First instar	8.04	3.41	0.98	4.14
3. Second instar	7.97	3.21	1.06	4.08
4. Third instar	7.75	2.82	1.01	3.86
Mean	7.84	3.12	1.08	
SEDs (32 d.f.):	for comparison of drilling means = 0.107, P = < 0.001 for comparison of spray timing means = 0.124, P = 0.13 for comparison of means within the body of the table = 0.214, P = 0.20			

Discussion, Study 1

The findings from the first year study, in which the effect of crop and larval developmental stages on the efficacy of dimethoate was investigated, suggested that wheat bulb fly control with dimethoate may be variable and unreliable, reflecting comments often received from farmers. The attempts to improve the standard of control from single sprays of dimethoate by optimising spray timing in relation to crop and larval growth met with little success. The underlying reasons for the poor control and lack of contrast between the performance of the various treatments is not fully understood. Although the early sprays targeted against first larvae were delayed by severe weather, this delay was not unrealistic in terms of commercial practice and is not thought to have seriously compromised the efficacy of these treatments.

There was some evidence from the ear counts and crop yields at High Mowthorpe to confirm that applying dimethoate whilst the majority of the larvae are small and in their first instar has the best chance of success. However, there was no firm evidence to suggest that crop growth stage, alone, or in interaction with larval growth stage, influenced the performance of dimethoate. These findings are in agreement with much earlier work. Griffiths and Scott (1969) noted that systemic sprays (including dimethoate) had the most effect when applied soon after larvae had entered the plant but found no evidence that spraying should be delayed until plants have a large enough leaf area to absorb spray efficiently. Maskell and Davis (1974) also found that applying deadheart sprays when the larvae are in their first or second instar gave the greatest benefit. Once the larvae moult into third instar, they migrate to adjoining tillers and are also less easily poisoned by insecticide than earlier instars. Therefore, the potential yield response to spraying whilst the majority of larvae are in their third instar is much reduced compared with earlier deadheart sprays timed to coincide with peak invasion by first instar larvae.

Study 2. The effect of dose-rate, frequency and volume on the efficacy of dimethoate against wheat bulb fly.

Introduction, Study 2

In the second cropping year of the project, the objective of Study 2 was to investigate if an increase in the current label-recommended rate of dimethoate is merited, or if double applications of full or reduced rates of dimethoate are more effective than single applications. The effect of reducing or increasing spray volumes on the activity of dimethoate against wheat bulb fly was also investigated. Dimethoate was applied at the optimum time at peak invasion by first instar larvae, as indicated regular monitoring to determine the state of egg hatch and larval invasion. The dimethoate treatments were all applied in 100, 200 or 300 litres of water per hectare in a factorial design which incorporated a range of dimethoate rates in single- or double-spray programmes.

Methods & materials, Study 2

Individual experimental sites were located on a commercial farm near Littleport, Cambridgeshire and at ADAS High Mowthorpe, Yorkshire, during the 1997/98 cropping season. Pre-drilling egg numbers were determined at each site by taking soil samples in autumn 1997. A minimum of 20 × 10 cm diameter cores were taken from each prospective trial site. The samples were each of a sufficient depth to exceed the depth of soil cultivation. Wheat bulb fly eggs were extracted from the soil using a modified Salt and Hollick technique which entailed soaking, wet sieving and flotation of eggs in a saturated solution of magnesium sulphate.

The trials were of a two-way factorial plus untreated control, fully randomised block design. Each treatment was replicated four times, giving a total of 52 plots per site. Untreated guard (discard) plots were added to the ends of each experimental area for use as destructive sampling areas to monitor wheat bulb fly egg hatch and larval invasion. Plots were drilled with winter wheat (cv. Hereward) using a tractor mounted Ojyørd drill at the Littleport site and a Fiona drill at the High Mowthorpe site. At the Littleport, plot size was 24 m × 2 m at 2.5 m centres and drilling took place on 25 November 1997, whilst High Mowthorpe was drilled on the 12 November 1997 with plot sizes of 24 m × 3 m at 3.3 m centres. The seed rates of each drilling were adjusted to suit local conditions and to attain a target plant population of 200–250 plants/m^2.

The progress of wheat bulb fly egg hatch was monitored by extracting and examining eggs from soil samples taken from each site at approximately weekly intervals from early January until March. Likewise, the progress of larval invasion and development was monitored in samples of 50 plants sampled from discard plots at approximately weekly intervals from early January until late March. The results of the monitoring of wheat bulb fly egg hatch and plant invasion were used to trigger the dimethoate sprays.

At both sites, a standard commercial formulation of dimethoate (Portman Dimethoate 40; 40% dimethoate w/v EC) was applied in a range of treatments which included single or double sprays at the label recommended rate of 1.7 litres of product/ha or two-spray programmes of 1.7 and 0.85 litres of product/ha (Table 1.9). All of the dimethoate treatments were subsequently applied in spray volumes of 100, 200 or 300 litres of water per hectare. The first dimethoate sprays (T1) were applied to coincide with peak invasion by first instar larvae, whilst the second dimethoate sprays (T2) were applied 8 days after the first spray at Littleport and 10 days after the first application at High Mowthorpe (Table 1.10). The sprays were applied by CO_2-pressurised Oxford knapsack sprayer at the Littleport site and by a self-propelled Plot-Master sprayer at High Mowthorpe. All sprays were applied as medium quality sprays at 200kPa pressure.

The high rate of dimethoate (3.4 litres/ha) exceeded the maximum approved dose. Therefore, Administrative Experimental Approval (AEA) was obtained from the Pesticide Safety Directorate (PSD) before proceeding with the work. In addition, grain harvested from plots treated with the high rate of dimethoate was destroyed.

The crop protection and crop husbandry programme followed normal commercial farm practice at each site. Wheat bulb fly insecticides applied to the surrounding field crops were excluded from the experimental areas.

Plant establishment was assessed at each site before the treatments were applied. Plants were counted in ten 0.5 m paired lengths of row selected at random across the trial areas. The effect of treatment on the extent of larval invasion and crop damage was assessed at each site by examining plant samples taken from each plot 20 days after the application of the final dimethoate sprays at both sites. The objective of this assessment was to determine the effect of treatment on the final, maximum, level of wheat bulb fly damage following each treatment. Six plants were removed from ten randomly selected sampling points per plot to obtain 60 plants per plot. The plants were dissected under a low-power microscope to determine the number of larvae and the proportion of plants and tillers attacked.

The population density of wheat ears was assessed during June or July by counting the number of fertile tillers in six randomly selected 0.1 m^2 quadrats per plot. Crop yield was assessed by harvesting plots with a small-plot combine harvester. Sub-samples of grain were taken from each plot at harvest for measurement of moisture content and specific weight (bulk density).

All results were subjected to analysis of variance (ANOVA) using an appropriate GENSTAT program.

Table 1.9. Description of dimethoate treatments applied in Study 2, 1997.

Treatment no.	Insecticide	Product rate	Spray volume	Spray timing*
1	Untreated	na	na	na
2	Dimethoate	1.7 litres/ha	100 litres/ha	T1
3	Dimethoate	1.7 litres/ha	200 litres/ha	T1
4	Dimethoate	1.7 litres/ha	300 litres/ha	T1
5	Dimethoate	3.4 litres/ha	100 litres/ha	T1
6	Dimethoate	3.4 litres/ha	200 litres/ha	T1
7	Dimethoate	3.4 litres/ha	300 litres/ha	T1
8	Dimethoate	1.7 litres/ha	100 litres/ha	T1 & T2
9	Dimethoate	1.7 litres/ha	200 litres/ha	T1 & T2
10	Dimethoate	1.7 litres/ha	300 litres/ha	T1 & T2
11	Dimethoate	0.85 litres/ha	100 litres/ha	T1 & T2
12	Dimethoate	0.85 litres/ha	200 litres/ha	T1 & T2
13	Dimethoate	0.85 litres/ha	300 litres/ha	T1 & T2

* T1 @ peak invasion by first larvae; T2, 10–14 days after T1.

Table 1.10. Dates and corresponding crop growth stages of the dimethoate applications in Study 2, 1997.

Site and treatment	Date	Crop growth stage*
Littleport		
Dimethoate @ T1	09/03/98	22
Dimethoate @ T2	17/03/98	23
High Mowthorpe		
Dimethoate @ T1	09/02/98	21
Dimethoate @ T2	19/03/98	22

* After Tottman & Broad (1987).

Results, Study 2

Wheat bulb fly egg counts, hatch and plant invasion

Wheat bulb fly egg numbers were well above the 2.5 million eggs/ha threshold at both sites. Soil sampling indicated that there were 10.0 million eggs/ha at Littleport and 4.7 million/ha at High Mowthorpe. Egg hatch was first detected at both sites on 12 January 1998 (Figure 1.4). The main phase of egg hatch occurred in the last half of February. Larval invasion of the crop also increased sharply in late February and early March. Consequently, the first dimethoate sprays (T1) were applied at both sites on the 9 March, whilst the second sprays (T2) were applied 8 days and 10 days later at Littleport and High Mowthorpe respectively. At the time of the first sprays, the larval population comprised of 77% and 53% first instar larvae at Littleport and High Mowthorpe, respectively. Crop growth stages at the time of the first sprays were GS22 (main shoot plus two tillers) at Littleport and GS 21 (main shoot plus one tiller) at High Mowthorpe. The application of the second sprays was delayed at High Mowthorpe owing to adverse weather conditions. Nevertheless, the sprays at this site were not deemed to be too late, as 50% of the larvae remained at their first instar at the time of the second sprays on the 19 March.

Plant establishment

The crops were established successfully and contrasting crop growth stages were achieved between the two sites. Plant populations were assessed on 3 March 1998 at Littleport (GS 22) and on 5 January 1998 (GS 12) at High Mowthorpe. Uniform plant populations were obtained at both sites. At Littleport there was an average of 241 plants/m^2, whilst at High Mowthorpe there was an average population of 389 plants/m^2.

Tiller damage and larval control

Plant samples to assess the effect of treatment on the proportion of tillers damaged by wheat bulb larvae and the numbers of larvae surviving treatment were taken at the Littleport site on 6 April 1998 and 8 April 1998 at High Mowthorpe (20 days after final treatment at both sites). At Littleport there were no significant differences between any of the dimethoate rates or spray volumes and the level of wheat bulb fly control was poor (Tables 1.11 & 12). Across all dimethoate treatments, the number of live larvae was reduced by only 14%, compared with the untreated at the Littleport site. Control of larvae was better at High Mowthorpe than at Littleport. Across all dimethoate treatments at High Mowthorpe, tiller damage was reduced by 39% and the number of live larvae by 81%, compared with untreated ($P < 0.001$). At High Mowthorpe, the lowest numbers of live larvae were associated with the single, high-rate spray of dimethoate (3.4 l/ha) and the double spray of full label-rate dimethoate (1.7 l/ha).

Ear counts and crop yield

Ear counts were made on the 28 July 1998 at Littleport and on 24 June 1998 at High Mowthorpe. At High Mowthorpe, there were differences ($P < 0.05$) between the mean ear counts of the dimethoate treatments, which indicated the greatest population of fertile ears was associated with the double spray programme of half-rate dimethoate (Table 1.13). However, this observation could not be correlated with the levels of wheat bulb fly control obtained with this treatment in terms of tiller damage and live larvae. The experiments were harvested on 21 August 1998 at Littleport and on the 14 September at High Mowthorpe. Crop yields were unaffected by treatment at both sites (Table 1.14).

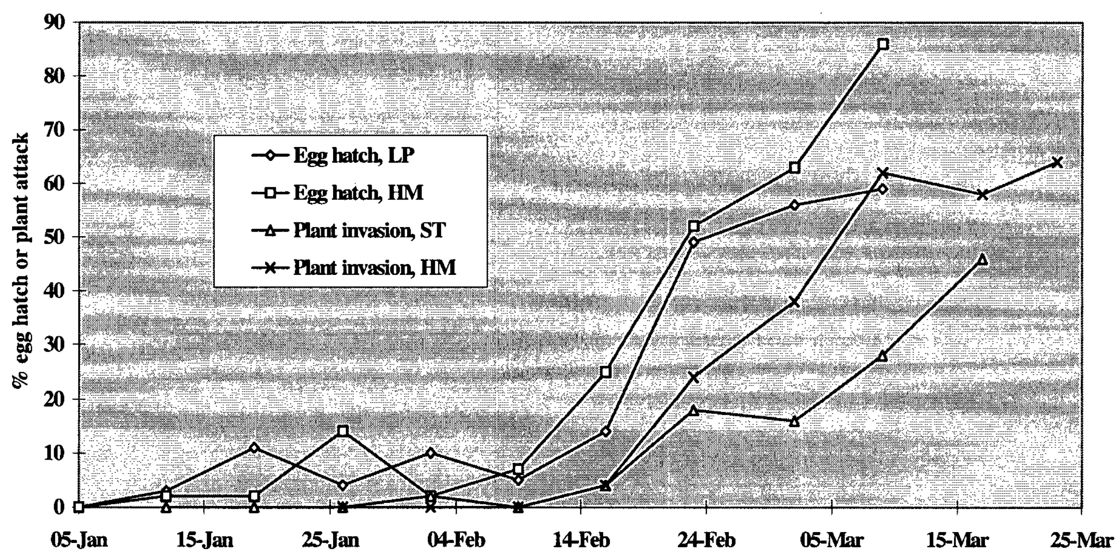

Figure 1.4. The progress of wheat bulb fly egg hatch and plant invasion in Study 2 at Littleport, Cambridgeshire (LP) and High Mowthorpe, North Yorkshire (HM), 1998.

Table 1.11. The mean proportion of tillers attacked by wheat bulb fly larvae in Study 2, 1998, assessed 20 days after final treatments at Littleport and High Mowthorpe (% tillers attacked).

Dimethoate rate		**Spray volume (litres/ha)**			**Mean**
		100	**200**	**300**	
Littleport					
Untreated	13.5				
Dimethoate 1.7 l/ha @ T1		15.0	10.9	11.2	12.4
Dimethoate 3.4 l/ha @ T1		11.5	10.5	16.0	12.7
Dimethoate 1.7 l/ha @ T1 & T2		11.4	17.2	13.7	14.1
Dimethoate 0.85 l/ha @ T1 & T2		13.7	13.2	15.2	14.1
Mean		12.9	12.9	14.0	13.3
SEDs (36 d.f.):	Comparison of dimethoate rate means = 2.49, $P = 0.66$ Comparison of spray volume means = 2.41, $P = 0.70$ Comparison of untreated and mean of all treated plots = 2.24, $P = 0.94$ Comparison of means within the body of the table = 3.05, $P = 0.19$				
High Mowthorpe					
Untreated	16.5				
Dimethoate 1.7 l/ha @ T1		9.5	10.4	11.8	10.5
Dimethoate 3.4 l/ha @ T1		9.1	10.1	9.2	9.5
Dimethoate 1.7 l/ha @ T1 & T2		9.7	10.2	9.1	9.6
Dimethoate 0.85 l/ha @ T1 & T2		11.0	9.9	9.7	10.2
Mean		9.8	10.1	10.0	10.0
SEDs (36 d.f.):	Comparison of dimethoate rate means = 1.55, $P = 0.75$ Comparison of spray volume means = 1.50, $P = 0.93$ Comparison of untreated and mean of all treated plots = 1.40, $P = < 0.001$ Comparison of means within the body of the table = 1.90, $P = 0.85$				

Table 1.12. The mean numbers of wheat bulb fly larvae surviving treatment in Study 2, 1998 assessed 20 days after final treatments at Stuntney and High Mowthorpe (nos. live larvae/m^2).

Dimethoate rate		**Spray volume (litres/ha)**			**Mean**
		100	**200**	**300**	
Littleport					
Untreated	41.0				
Dimethoate 1.7 l/ha @ T1		32.5	20.5	25.3	26.1
Dimethoate 3.4 l/ha @ T1		31.3	30.1	45.8	35.7
Dimethoate 1.7 l/ha @ T1 & T2		37.4	55.4	30.1	41.0
Dimethoate 0.85 l/ha @ T1 & T2		41.0	28.9	44.6	38.2
Mean		35.5	33.7	36.5	35.2

SEDs (36 d.f.): Comparison of dimethoate rate means = 10.43, $P = 0.22$
Comparison of spray volume means = 10.10, $P = 0.91$
Comparison of untreated and mean of all treated plots = 9.40, $P = 0.55$
Comparison of means within the body of the table = 12.77, $P = 0.24$

High Mowthorpe					
Untreated	143.9				
Dimethoate 1.7 l/ha @ T1		33.1	27.2	25.3	28.5
Dimethoate 3.4 l/ha @ T1		15.6	23.3	17.5	18.8
Dimethoate 1.7 l/ha @ T1 & T2		17.5	29.2	19.5	22.0
Dimethoate 0.85 l/ha @ T1 & T2		37.0	44.7	37.0	39.5
Mean		25.8	31.1	24.8	27.2

SEDs (36 d.f.): Comparison of dimethoate rate means = 11.22, $P = 0.06$
Comparison of spray volume means = 10.87, $P = 0.62$
Comparison of untreated and mean of all treated plots = 10.12, $P = < 0.001$
Comparison of means within the body of the table = 13.75, $P = 0.99$

Table 1.13. Mean numbers of fertile tillers of winter wheat in Study 2, 1998 (ears/m^2).

Dimethoate rate		Spray volume (litres/ha)			Mean
		100	200	300	
Littleport					
Untreated	567				
Dimethoate 1.7 l/ha @ T1		561	555	564	560
Dimethoate 3.4 l/ha @ T1		562	536	537	545
Dimethoate 1.7 l/ha @ T1 & T2		541	553	512	535
Dimethoate 0.85 l/ha @ T1 & T2		532	534	552	539
Mean		549	544	541	545

SEDs (36 d.f.): Comparison of dimethoate rate means = 19.3, *P* = 0.30
Comparison of spray volume means = 18.7, *P* = 0.81
Comparison of untreated and mean of all treated plots = 17.4, *P* = 0.21
Comparison of means within the body of the table = 23.6, *P* = 0.49

Dimethoate rate		Spray volume (litres/ha)			Mean
		100	200	300	
High Mowthorpe					
Untreated	958				
Dimethoate 1.7 l/ha @ T1		1007	966	965	979
Dimethoate 3.4 l/ha @ T1		940	954	965	953
Dimethoate 1.7 l/ha @ T1 & T2		950	963	949	954
Dimethoate 0.85 l/ha @ T1 & T2		952	1038	1010	1000
Mean		962	980	972	972

SEDs (36 d.f.): Comparison of dimethoate rate means = 25.9, *P* = 0.04
Comparison of spray volume means = 25.0, *P* = 0.54
Comparison of untreated and mean of all treated plots = 23.3, *P* = 0.57
Comparison of means within the body of the table = 31.7, *P* = 0.18

Table 1.14. Mean yields of winter wheat in Study 2, 1998 (tonnes/ha @ 85% d.m.).

Dimethoate rate		**Spray volume (litres/ha)**			**Mean**
		100	**200**	**300**	
Littleport					
Untreated	8.61				
Dimethoate 1.7 l/ha @ T1		8.42	8.66	8.51	8.53
Dimethoate 3.4 l/ha @ T1		8.57	8.36	8.15	8.36
Dimethoate 1.7 l/ha @ T1 & T2		8.63	8.31	8.27	8.40
Dimethoate 0.85 l/ha @ T1 & T2		8.48	8.42	8.62	8.50
Mean		8.53	8.44	8.39	8.45

SEDs (36 d.f.): Comparison of dimethoate rate means = 0.252, $P = 0.75$
Comparison of spray volume means = 0.244, $P = 0.66$
Comparison of untreated and mean of all treated plots = 0.227, $P = 0.49$
Comparison of means within the body of the table = 0.308, $P = 0.72$

High Mowthorpe					
Untreated	8.64				
Dimethoate 1.7 l/ha @ T1		8.43	8.65	8.72	8.60
Dimethoate 3.4 l/ha @ T1		8.55	8.65	8.50	8.57
Dimethoate 1.7 l/ha @ T1 & T2		8.60	8.50	8.63	8.58
Dimethoate 0.85 l/ha @ T1 & T2		8.50	8.45	8.61	8.52
Mean		8.52	8.57	8.61	8.57

SEDs (36 d.f.): Comparison of dimethoate rate means = 0.108, $P = 0.76$
Comparison of spray volume means = 0.105, $P = 0.37$
Comparison of untreated and mean of all treated plots = 0.097, $P = 0.44$
Comparison of means within the body of the table = 0.132, $P = 0.35$

Discussion, Study 2

The results of Study 2, in which the effect of various dimethoate rates, sequential applications and spray volumes was investigated, provided further evidence of the inconsistent levels of wheat bulb fly control with this insecticide. High Mowthorpe was the more responsive of the two sites. In terms of reducing tiller damage and larval numbers, the performance of dimethoate was acceptable at High Mowthorpe but poor at Littleport.

There was evidence to show that a two-spray programme of dimethoate, applied at the full label rate of 1.7 l/ha gave the best standard of pest control at High Mowthorpe. The range of spray volumes studied had no effect on the efficacy of dimethoate. There was no reduction in the relative levels of pest control from decreasing spray volumes to 100 l/ha. This finding is re-assuring in the light of an increasing trend to reduce spray volumes.

It should be noted that the highest rate of dimethoate applied in this studied (3.4 litres of product/ha) exceeded the maximum approved label-recommended rate of 1.7 litres of product/ha. It is illegal for farmers to apply pesticides at rates exceeding those recommended on the product label. The high rate applied in this study was used for experimental purposes only, to compare the relative efficacy of a single treatment at 3.4 l/ha with two of 1.7 l/ha.

Despite the high numbers of wheat bulb fly eggs, the resulting level of attack did not significantly reduce crop yield owing to a combination of factors. Egg and larval mortality was high at both sites, especially on the organic soil at Littleport. At Littleport, the average number of larvae in the untreated plots in early April amounted to only 4% of the egg population as assessed the previous autumn. At High Mowthorpe, the equivalent figure was 58%. High levels of mortality between the egg and late larval stages is commonly observed in wheat bulb fly and has been noted in previous work, especially on organic soils (Young, 1992). The reasons for these high mortalities are not clearly understood but are thought to be linked with the physical characteristics of the soil, which may impede larval migration to the soil surface prior to plant invasion (Young & Ellis, 1996). In addition to the poor survival of eggs and larvae, the crops tillered well – growing away from and compensating for pest damage to such an extent that there was ultimately no effect of wheat bulb attack on crop yield at either site.

Study 3: The use of adjuvants to enhance the efficacy of dimethoate against wheat bulb fly.

Introduction, Study 3

In the third cropping year of the project, the objective of Study 3 was to evaluate a range of adjuvants for use in conjunction with dimethoate against wheat bulb fly. Many types and makes of adjuvants are on the market and their use has been the subject of much interest in recent years. This study set out to investigate if the use of adjuvants is warranted to improve the uptake and efficacy of dimethoate against wheat bulb fly. Four contrasting types of commercially available adjuvants were selected for the work:

1. LI-700. A penetrating, acidifying surfactant containing 350 g/l modified soya lecithin, 100 g/l alkylphenylhydroxypolyoxyethylene and 350 g/l propionic acid.

2. Arma. A penetrating adjuvant containing 500 g/l alkoxylated fatty amine plus 500 g/l polyoxyethylene monolaurate.

3. Slippa. A liquid concentrate formulation containing 655 g/l polyalkyleneoxide modified heptamethyltrisiloxane plus non-ionic wetters.

4. Actipron. An adjuvant oil containing 97% highly refined mineral oil.

The adjuvants were applied individually, as per their label recommendations, in mixture with full label-rate dimethoate deadheart sprays as single- and two-spray programmes in comparison with dimethoate alone and an untreated control. All treatments were applied in a spray volume of 200 litres of water per hectare, timed to coincide with peak invasion by wheat bulb fly first instar larvae.

Methods & materials, Study 3

Individual experimental sites were located on a commercial farm at Stuntney (near Ely), Cambridgeshire and at ADAS High Mowthorpe, Yorkshire, during the 1998/99 cropping season. Pre-drilling egg numbers were determined at each site by taking soil samples in autumn 1998. A minimum of 20 × 10 cm diameter cores were taken from each prospective trial site. The samples were each of a sufficient depth to exceed the depth of soil cultivation. Wheat bulb fly eggs were extracted from the soil using a modified Salt and Hollick technique which entailed soaking, wet sieving and flotation of eggs in a saturated solution of magnesium sulphate.

The trials were of a two-way factorial plus untreated control, fully randomised block design. Each treatment was replicated four times, giving a total of 52 plots per site. Untreated guard (discard) plots were added to the ends of each experimental area for use as destructive sampling areas to monitor wheat bulb fly egg hatch and larval invasion. Pre-established commercial crops of winter wheat were selected for the work at both sites. At Stuntney, winter wheat cv. Soissons, sown on 20 October 1998 (after onions) was marked out on 26 February 1999. At High Mowthorpe, winter wheat cv. Hereward sown on 21 October 1998 (after potatoes) was marked out on 12 March 1999. At both sites, individual plot size was 24 m × 3 m.

The progress of wheat bulb fly egg hatch was monitored by extracting and examining eggs from soil samples taken from each site at approximately weekly intervals from early January until March. Likewise, the progress of larval invasion and development was monitored in samples of 50 plants sampled from discard plots at approximately weekly intervals from early January until late March. The results of the monitoring of wheat bulb fly egg hatch and plant invasion were used to trigger the dimethoate sprays.

At both sites, a standard commercial formulation of dimethoate (Portman Dimethoate 40; 40% dimethoate w/v EC) was applied in a range of treatments which included single or double sprays of dimethoate plus adjuvant in comparison with single or double sprays of dimethoate alone and an untreated control (Table 1.15). The dimethoate was applied at the standard label recommended rate of 1.7 litres of product/ha in 200 litres of water per hectare. The first dimethoate sprays (T1) were applied to coincide with peak invasion by first instar larvae, whilst the second dimethoate sprays (T2) were applied 7–10 days later. The sprays were applied by CO_2-pressurised Oxford knapsack sprayer at the Littleport site and by a self-propelled Plot-Master sprayer at High Mowthorpe. All sprays were applied as medium quality sprays at 200kPa pressure.

Table 1.15. Description of dimethoate and adjuvant treatments applied in Study 3, 1999.

Treatment No.	*Insecticide* [1]	*Adjuvant* [2]	*Timing* [3]
1	Untreated	Untreated	Untreated
2	Dimethoate	Nil	T1
2	Dimethoate	Nil	T1 & T2
4	Dimethoate	LI-700 @ 0.5% v/v	T1
5	Dimethoate	LI-700 @ 0.5% v/v	T1 & T2
6	Dimethoate	Arma @ 0.15% v/v	T1
7	Dimethoate	Arma @ 0.15% v/v	T1 & T2
8	Dimethoate	Slippa @ 0.2% v/v	T1
9	Dimethoate	Slippa @ 0.2% v/v	T1 & T2
10	Dimethoate	Actipron @ 2% v/v	T1
11	Dimethoate	Actipron @ 2% v/v	T1 & T2

[1] Dimethoate (40% w/v EC) applied at 1.7 litres (product) in 200 litres water/ha.

[2] Adjuvant dose rates are expressed as percentage concentration of adjuvant in total spray volume, i.e. 1% adjuvant = 1 litre adjuvant in 100 litres of spray volume.

[3] T1 = peak invasion by 1st instar larvae. T2 = 10–14 days after T1.

The crop protection and crop husbandry programme followed normal commercial farm practice at each site. Wheat bulb fly insecticides applied to the surrounding field crops were excluded from the experimental areas.

The plant establishment was assessed at each site before the treatments were applied. Plants were counted in ten 0.5 m paired lengths of row selected at random across the trial areas. The effect of treatment on the extent of larval invasion and crop damage was assessed at each site by examining plant samples taken from each plot 15 days after final treatment at Stuntney and 34 days after final treatment at High Mowthorpe. The objective of this assessment was to determine the effect of treatment on the final, maximum, level of wheat bulb fly damage following each treatment. Six plants were removed from ten randomly selected sampling points per plot to obtain 60 plants per plot. The plants were dissected under a low-power microscope to determine the number of larvae and the proportion of plants and tillers attacked.

The population density of wheat ears was assessed during June or July by counting the number of fertile tillers in six randomly selected 0.1 m^2 quadrats per plot. Crop yield was assessed by harvesting plots with a small-plot combine harvester. Sub-samples of grain were taken from each plot at harvest for measurement of moisture content and specific weight (bulk density).

All results were subjected to analysis of variance (ANOVA) using an appropriate GENSTAT program.

Results, Study 3

Wheat bulb fly egg counts, hatch and plant invasion

Wheat bulb fly egg numbers were generally low in autumn 1998 and some difficulties were experienced in locating fields with egg numbers in excess of the 2.5 million eggs/ha action threshold for autumn-sown wheat. At Stuntney, the pre-drilling egg population was 3.8. million eggs/ha, whilst at High Mowthorpe there was 1.0 million eggs/ha. Egg hatch was detected at Stuntney on the 4 January 1999 whilst the start of egg was slower at High Mowthorpe and was not detected at that site until the 18 January 1999 (Figure 1.5). The main phase of egg hatch occurred during late February at Stuntney and during March at High Mowthorpe. The first dimethoate sprays (T1) were applied at Stuntney on the 10 March, when 65% of the larvae present were in their first developmental instar. By the time of the first spray at Stuntney, the early-sown crop at this site was in a well tillered condition at growth stage 24 (main shoot plus four tillers). In comparison, at High Mowthorpe, the first dimethoate sprays were applied on the 17 March whilst 92% of larvae were at first instar and the crop was at GS 21 (main shoot plus one tiller). The second dimethoate sprays were applied 7–10 later, on the 17 March at Stuntney and the 30 March at High Mowthorpe.

Plant establishment

The trial crops were established successfully and uniform plant populations were achieved at both sites. The plant populations were assessed at Littleport on 11 March 1999 and on 15 March 1999 at High Mowthorpe. The average plant populations of the crops were 202 plants/m^2 at Stuntney and 251 plants/m^2 at High Mowthorpe.

Tiller damage and larval control

Post-treatment plant samples were taken to assess the proportion of tillers damaged by wheat bulb fly and the number of surviving larvae. The Stuntney site was sampled on the 1 April 1999, 15 days after the final dimethoate treatments were applied. By this time, the Stuntney crop was at GS 25, 30 (main shoot plus five tillers). At High Mowthorpe, the plant samples were taken on the 3 May 1999, 34 days after application of the final treatments, by which time the crop was at GS 24, 32 (main shoot plus four tillers).

Taken as a mean across all dimethoate treatments, the application of dimethoate significantly reduced tiller damage and the number of live larvae at both sites, compared with the untreated control ($P < 0.05$) (Tables 1.16 & 1.17). At Stuntney, the proportion of tillers damaged by wheat bulb fly was reduced by 33% and at High Mowthorpe by 58% ($P < 0.05$) (Table 1.16). The equivalent mean reductions in the numbers of live larvae across all dimethoate treatments were 61% at Stuntney and 63% at High Mowthorpe ($P < 0.001$) (Table 1.17). Across both sites, a single spray of dimethoate reduced tiller damage by an average of 41% and the number of live larvae by 53%, whilst the two-spray programme reduced tiller damage by an average of 51% and live larvae by 72%. Two sprays of dimethoate were, therefore, more effective than one, particularly in controlling larvae. This observation confirms similar findings in earlier work (Study 2) of this project.

None of the adjuvants tested, in one- or two-spray programmes, significantly improved the control of wheat bulb fly larvae or plant damage (Tables 1.16 & 1.17).

Ear counts and crop yield

Fertile tiller populations were assessed on 28 July 1999 at Stuntney and on 26 August at High Mowthorpe. The crop was subsequently harvested on the 27 August 1999 at High Mowthorpe. However, it was not possible to harvest the crop at Stuntney as it was harvested in error by a commercial contractor. There was no effect of treatment on ear populations at either site (Table 1.18). In the absence of yield data, the pre-harvest ear counts made at the Stuntney site indicated that there were unlikely to be any differences in yield between treatments. Therefore, the absence of yield data for this site was judged not to have seriously compromised the work.

At High Mowthorpe, the mean yield of dimethoate without adjuvant was 0.31 t/ha less than that of the untreated control ($P < 0.05$) (Table 1.19). However, the mean yields of dimethoate plus LI-700, Arma, Slippa or Actipron were not significantly different from untreated. In addition, the mean yields of dimethoate plus Arma, Slippa or Actipron (but not LI-700) were significantly greater than that of dimethoate alone ($P < 0.05$). The underlying reasons for these yield differences were unclear as they did not correspond to the observed levels of pest control. There were no yield differences between the one- and two-spray programmes of dimethoate. Despite the relatively heavy attack by wheat bulb fly at both sites, the effect of early (October) sowing combined with favourable weather and vigorous tillering in late winter/early spring evidently resulted in compensatory crop growth and a lack of positive yield responses to any of the dimethoate treatments, with or without adjuvant.

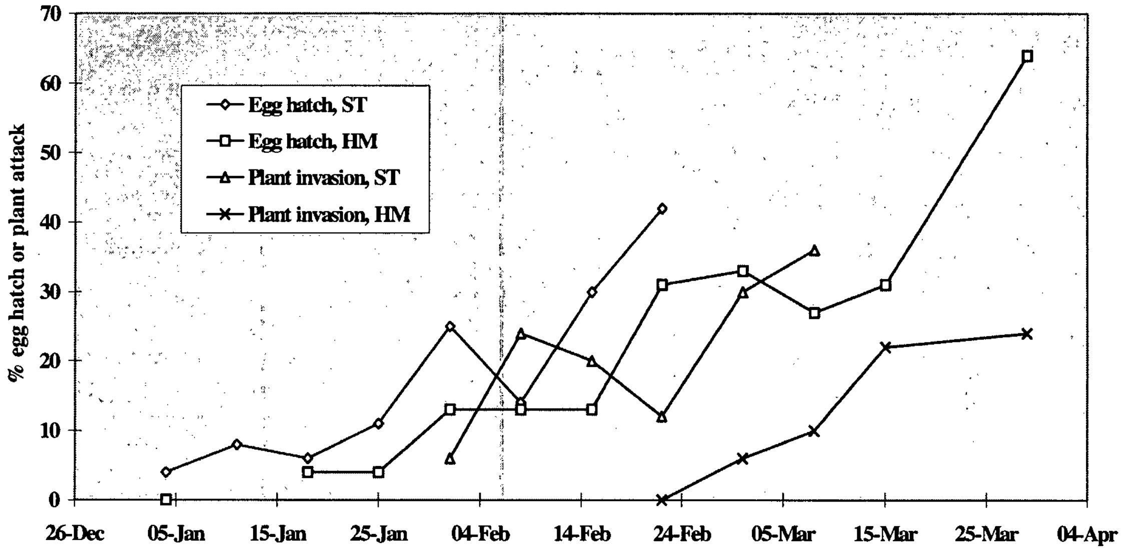

Figure 1.5. The progress of wheat bulb fly egg hatch and plant invasion in Study 3 at Stuntney, Cambridgeshire (ST) and High Mowthorpe, North Yorkshire (HM), 1999.

Table 1.16. The mean proportion of tillers attacked by wheat bulb fly larvae in Study 3, 1999, assessed 15 and 34 days after treatment at Stuntney and High Mowthorpe respectively (% tillers attacked).

Dimethoate treatment		Spray programme		
		Single spray	Double spray	Mean
Stuntney				
1. Untreated	13.4			
2. Dimethoate alone		9.6	9.8	9.7
3. Dimethoate & LI-700		8.4	9.7	9.1
4. Dimethoate & Arma		10.9	7.8	9.4
5. Dimethoate & Slippa		10.9	6.3	8.6
6. Dimethoate & Actipron		9.2	7.4	8.3
Mean		9.8	8.2	9.0

SEDs (30 d.f.): comparison of dimethoate treatment means = 2.35, $P = 0.95$
comparison of spray programme means = 2.10, $P = 0.20$
comparison of untreated and mean of all treated plots = 2.01, $P = 0.04$
comparison of means within the body of the table = 2.71, $P = 0.55$

Dimethoate treatment		Single spray	Double spray	Mean
High Mowthorpe				
1. Untreated	13.4			
2. Dimethoate alone		6.8	4.8	5.8
3. Dimethoate & LI-700		6.7	4.6	5.6
4. Dimethoate & Arma		5.7	5.6	5.7
5. Dimethoate & Slippa		6.6	6.1	6.3
6. Dimethoate & Actipron		4.7	4.4	4.6
Mean		6.1	5.1	5.6

SEDs (30 d.f.): comparison of dimethoate treatment means = 1.29, $P = 0.56$
comparison of spray programme means = 1.15, $P = 0.14$
comparison of untreated and mean of all treated plots = 1.11, $P = < 0.001$
comparison of means within the body of the table = 1.49, $P = 0.81$

Table 1.17. The mean numbers of wheat bulb fly larvae surviving treatment in Study 3, 1999, assessed 15 and 34 days after treatment at Stuntney and High Mowthorpe respectively (nos. live larvae/metre^2).

Dimethoate treatment		Spray programme		
		Single spray	Double spray	Mean
Stuntney				
1. Untreated	57.6			
2. Dimethoate alone		30.3	17.2	23.7
3. Dimethoate & LI-700		20.2	17.2	18.7
4. Dimethoate & Arma		33.3	18.2	25.8
5. Dimethoate & Slippa		41.4	12.1	26.8
6. Dimethoate & Actipron		22.2	13.1	17.7
Mean		29.5	15.6	22.5

SEDs (30 d.f.): comparison of dimethoate treatment means = 7.75, $P = 0.51$
comparison of spray programme means = 6.93, $P = 0.002$
comparison of untreated and mean of all treated plots = 6.64, $P = < 0.001$
comparison of means within the body of the table = 8.95, $P = 0.34$

Dimethoate treatment		Single spray	Double spray	Mean
High Mowthorpe				
1. Untreated	36.7			
2. Dimethoate alone		13.7	9.5	11.6
3. Dimethoate & LI-700		20.4	10.5	15.4
4. Dimethoate & Arma		16.0	13.9	14.9
5. Dimethoate & Slippa		15.5	10.6	13.0
6. Dimethoate & Actipron		13.7	8.9	11.3
Mean		15.9	10.7	13.3

SEDs (30 d.f.): comparison of dimethoate treatment means = 6.38, $P = 0.90$
comparison of spray programme means = 5.71, $P = 0.13$
comparison of untreated and mean of all treated plots = 5.46, $P = < 0.001$
comparison of means within the body of the table = 7.37, $P = 0.96$

Table 1.18. Mean numbers of fertile ears of winter wheat in Study 3, 1999 (ears/m^2).

Dimethoate treatment		**Spray programme**		
		Single spray	**Double spray**	**Mean**
Stuntney				
1. Untreated	568			
2. Dimethoate alone		538	563	550
3. Dimethoate & LI-700		559	542	551
4. Dimethoate & Arma		566	556	561
5. Dimethoate & Slippa		535	546	541
6. Dimethoate & Actipron		568	557	562
Mean		553	553	553

SEDs (30 d.f.): comparison of dimethoate treatment means = 16.0, $P = 0.46$
comparison of spray programme means = 14.3, $P = 0.94$
comparison of untreated and mean of all treated plots = 13.7, $P = 0.27$
comparison of means within the body of the table = 18.4, $P = 0.45$

Dimethoate treatment		Single spray	Double spray	Mean
High Mowthorpe				
1. Untreated	389			
2. Dimethoate alone		394	398	396
3. Dimethoate & LI-700		388	393	390
4. Dimethoate & Arma		403	410	407
5. Dimethoate & Slippa		390	384	387
6. Dimethoate & Actipron		354	400	377
Mean		386	397	391

SEDs (30 d.f.): comparison of dimethoate treatment means = 17.3, $P = 0.32$
comparison of spray programme means = 15.5, $P = 0.22$
comparison of untreated and mean of all treated plots = 14.8, $P = 0.86$
comparison of means within the body of the table = 20.0, $P = 0.41$

Table 1.19. Mean yields of winter wheat, cv. Hereward at High Mowthorpe in Study 3, 1997 (t/ha @ 85% d.m.).

Dimethoate treatment		Spray programmes		
		Single spray	Double spray	Mean
High Mowthorpe				
1. Untreated	9.56			
2. Dimethoate alone		9.35	9.14	9.24
3. Dimethoate & LI-700		9.45	9.34	9.40
4. Dimethoate & Arma		9.45	9.56	9.51
5. Dimethoate & Slippa		9.52	9.52	9.52
6. Dimethoate & Actipron		9.37	9.63	9.50
Mean		9.43	9.44	9.40

SEDs (30 d.f.): comparison of dimethoate treatment means = 0.116, $P = 0.03$
comparison of spray programme means = 0.103, $P = 0.84$
comparison of untreated and mean of all treated plots = 0.099, $P = 0.23$
comparison of means within the body of the table = 0.133, $P = 0.15$

Discussion, Study 3

None of the adjuvants tested in combination with dimethoate improved the standard of wheat bulb fly control in the two crops studied. This result contrasts with a limited amount of earlier work using LI-700 with dimethoate and omethoate deadheart sprays which indicated that this adjuvant improved the level of wheat bulb fly control in some circumstances (Young & Talbot 1988). However, in both the current study and that of Young and Talbot (1988) there was no significant yield benefit from use of adjuvants.

Dimethoate, with or without adjuvant, resulted in an acceptable level of pest control at both sites in Study 3, with overall reductions in tiller damage and larval numbers averaging 46% and 62% respectively. A programme of two sprays of dimethoate (10–14 days apart), with the first timed to coincide with peak invasion by first instar larvae, gave better control than a single spray, confirming earlier work in Study 2 of this project.

The absence of yield increases in response to the dimethoate sprays in Study 3 continued a trend observed in earlier work of this project (Studies 1 and 2). The results once again highlight that information on the severity of wheat bulb fly attack, weather conditions, crop growth rate and yield potential is critical in determining when dimethoate sprays are likely to be cost-effective. An improved understanding of this complex relationship is required in order to facilitate the development of a reliable predictive system.

Part II.

Evaluation of tefluthrin seed treatment for integration with wheat bulb fly control strategies

Introduction

Wheat bulb fly control has become more difficult in recent years as, owing to legislative and marketing pressures, the number of insecticides approved for use against the pest has steadily diminished. This problem was highlighted in the HGCA Research Review No. 33: Impact of Changes in Arable Agriculture on the Biology and Control of Wheat Bulb Fly. The withdrawn insecticides include carbophenothion and chlorfenvinphos seed treatments, fonofos seedbed granules, fonofos egg hatch spray and omethoate deadheart spray. Therefore, the options available to farmers for the chemical control of wheat bulb fly are now seriously restricted.

For the first time in many years, a new insecticide is now available. Autumn 1997 saw the release of a promising new wheat bulb fly seed treatment in the form of tefluthrin (Evict) from Zeneca. This product is now approved for use against wheat bulb fly in barley and wheat although the product is now marketed by Bayer.. Tefluthrin is a soil-active synthetic pyrethroid. It is relatively insoluble and has a highly active vapour phase. The seed treatment has been developed as a controlled release microencapsulated formulation for improved persistence. In contrast with organophosphorus seed treatments such as fonofos, tefluthrin has the added advantage of being of low toxicity to seed-eating birds.

Tefluthrin seed treatment has generated great interest and the need for an impartial assessment of how best it may be integrated in current wheat bulb fly control strategies. The aim of this project was to evaluate tefluthrin in comparison with egg hatch sprays as a means of preventing plant invasion by wheat bulb fly larvae and also to investigate whether the seed treatment eliminates the need for additional insecticide sprays, targeted at larvae within plants (deadheart sprays), later in the season.

Methods & materials

Individual study sites were located on a commercial farm near Stuntney, Cambridgeshire during the 1997/98 cropping season and at ADAS High Mowthorpe, Yorkshire, during 1998/99. Pre-drilling egg numbers were determined at each site by taking soil samples in the autumn. A minimum of 20 × 10 cm diameter cores were taken from each prospective trial site. The samples were sufficiently deep to exceed the depth of soil cultivation. Wheat bulb fly eggs were extracted from the soil using a modified Salt and Hollick technique which entailed soaking, wet sieving and flotation of eggs in a saturated solution of magnesium sulphate.

The experiment investigated the efficacy of tefluthrin seed treatments against wheat bulb fly and the need for follow up sprays of dimethoate to control any larvae which invaded plants. There were two treatments designed to prevent plant invasion by wheat bulb fly larvae; tefluthrin seed treatment (Evict; 100 g/l CS) and a chlorpyrifos egg hatch spray (Dursban 4; 480 g/l EC). An untreated control was also included. There were two follow-up deadheart spray treatments of dimethoate (Portman Dimethoate 40; 40% dimethoate w/v EC); a single spray, two sprays at 10–14 day intervals plus an untreated control. The first dimethoate sprays were timed to coincide with peak larval invasion by first instar wheat bulb fly larvae. The experiment was laid out as a 3 × 3, two-way factorial design in four randomised blocks with one complete set of treatments per block. There was a total of 36 plots at each site. The full treatment list is given in Table 2.1.

Plots were drilled with wheat using a tractor mounted Ojyørd drill at Stuntney and a Fiona drill at High Mowthorpe. Plot size was 24 m × 2 m at 2.5 m centres at Stuntney and 24 × 3 m with 3.3 m centres at High Mowthorpe. The seed rates were adjusted to suit local conditions and to achieve a target plant population of 200–250 plants/m^2. Untreated guard plots were added to the ends of each experimental area and used to monitor wheat bulb fly egg hatch and larval invasion. Spring wheat cv. Chablis was drilled at Stuntney on 17 December 1997. At High Mowthorpe, winter wheat cv. Riband was drilled on 21 December 1998. The late drilling dates were chosen to maximise damage by wheat bulb fly and provide a rigorous test of the insecticide programmes.

Sprays were applied at Stuntney using a CO_2-pressurised Oxford knapsack sprayer and by a self-propelled Plot Master sprayer at High Mowthorpe. All sprays were applied in 200 litres water/ha using medium spray-quality nozzles at 200 kPa pressure. Chlorpyrifos and dimethoate were applied at their full label-recommended rates of 1.5 and 1.7 litres product/ha, respectively. Sprays of chlorpyrifos were applied to coincide with the start of egg hatch and those of dimethoate to coincide with the peak invasion by first instar larvae. The second dimethoate treatment was applied 10–14 days after the first.

The crop protection and husbandry programme followed normal commercial farm practice at each site. Wheat bulb fly insecticides applied to the surrounding field crops were excluded from the experimental areas.

Table 2.1. Treatment list for Stuntney and High Mowthorpe, tefluthrin studies 1997–99

Treatment	Insecticides at drilling or egg hatch	Follow up deadheart sprays
1	Untreated	Untreated
2	Untreated	Dimethoate @ T_1
3	Untreated	Dimethoate @ T_1 & T_2
4	Tefluthrin seed treatment	Untreated
5	Tefluthrin seed treatment	Dimethoate @ T_1
6	Tefluthrin seed treatment	Dimethoate @ T_1 & T_2
7	Chlorpyrifos @ egg hatch	Untreated
8	Chlorpyrifos @ egg hatch	Dimethoate T_1
9	Chlorpyrifos @ egg hatch	Dimethoate @ T_2

T_1 = treatment at peak first instar larval invasion.

T_2 = 10–14 days after T_1.

The progress of wheat bulb fly egg hatch was monitored by extracting and examining eggs from soil samples taken from each site at approximately weekly intervals from early January until March. Likewise, the progress of larval invasion and development was monitored in samples of 50 plants sampled from discard plots at approximately weekly intervals from early January until late March. The results of the monitoring of wheat bulb fly egg hatch and plant invasion were used to trigger the chlorpyrifos and dimethoate sprays.

The plant establishment of each drilling was assessed as soon as plant emergence was judged to be complete with the majority of plants at the one- or two- leaf growth stage. Plants were counted in eight × 0.5 m paired lengths of row per plot (i.e. a total row length of 8 m per plot).

The effect of treatment on the extent of larval invasion and crop damage was assessed by examining plant samples taken from each plot approximately two to three weeks after the application of the final dimethoate spray. The objective of this assessment was to determine the effect of treatment on the final, maximum, level of wheat bulb fly damage following each treatment. Six plants were removed from each plot at ten randomly selected sampling points to give 60 plants per plot. These were dissected under a low-power microscope to determine the proportion of plants and tillers attacked and the number of wheat bulb fly larvae present. The density of wheat ears was assessed during June or July by counting the number of fertile tillers in six randomly selected 0.1 m^2 quadrats per plot. Crop yield was assessed by harvesting plots with a small-plot combine harvester. Sub-samples of grain were taken from each plot at harvest for measurement of moisture content and specific weight (bulk density).

Results

Wheat bulb fly egg count, hatch and plant invasion

Wheat bulb fly egg numbers at Stuntney in 1997 were 6.5 million/ha, which was well above the 2.5 million eggs/ha action threshold for autumn sown wheat. At High Mowthorpe in 1998 there were only 1.0 million eggs/ha and this reflected the general low level of egg laying by the pest throughout Yorkshire. However, a seed treatment is advised for December sown crops at 1.0 million eggs/ha and above, so it was decided that this would be a sufficiently high level of pest pressure to evaluate the experimental treatments.

At Stuntney, egg hatch was first recorded on 12 January when 4% of eggs had hatched. Application of chlorpyrifos was delayed by bad weather until 28 January (GS 22) by which time 16% of eggs had hatched. Larval invasion was first detected on 16 February and the first dimethoate sprays was applied on 9 March (GS 24) when 28% of plants had been attacked and 77% of larvae were at first instar. The second spray was applied eight days later on 17 March.

At High Mowthorpe, first egg hatch was recorded on 19 January 1999 when 3.7% of eggs had hatched. At this stage there was little or no plant emergence so application of the egg hatch spray of chlorpyrifos was delayed until 27 January. By this time plant emergence was underway, although not complete, and only 4.0% of wheat bulb fly eggs had hatched. Plant invasion was first recorded on 1 March 1999. The first dimethoate spray was applied on 17 March (GS 12) by which time 25% of plants had been invaded and 96% of larvae were at first instar. The second dimethoate spray was applied on 30 March, thirteen days after the first.

Plant establishment

Plant counts were undertaken on 2 February 1998 (GS 22) at Stuntney and 4 March (GS 12) and 7 April 1999 (GS 21) at High Mowthorpe. At Stuntney and High Mowthorpe plant establishment differed significantly ($P < 0.05$) between treatments applied to prevent plant invasion by wheat bulb fly larvae (Table 2.2). At Stuntney, least plants were recorded in the tefluthrin seed treatments and most where chlorpyrifos egg hatch treatment was used. At High Mowthorpe, most plants were found in the tefluthrin seed treatment plots and least in the untreated control. This difference was more evident in April than in March. There was also a significant difference in plant establishment between dimethoate treatments at High Mowthorpe in March ($P < 0.05$). Dimethoate increased plant stand and a single spray was more effective than two sprays. This effect had disappeared by April.

Tiller invasion by wheat bulb fly larvae

Plant samples to assess levels of larval invasion were taken on 27 March 1998 at Stuntney and 20 April 1999 at High Mowthorpe. At High Mowthorpe, there was a significant interaction ($P < 0.05$) between all treatments in the proportion of infested tillers (Table 2.3). This was probably due to the very low levels of tiller invasion in the tefluthrin treatment, compared with chlorpyrifos treated plots and the untreated control. The tefluthrin and chlorpyrifos treatments, applied to prevent tiller invasion, significantly ($P < 0.001$) reduced the percentage of tillers attacked at Stuntney and High Mowthorpe (Table 2.3). At both sites, the tefluthrin seed treatment gave the lowest level of tiller invasion. However, at Stuntney it was less effective than at High Mowthorpe, with a 40% reduction in the proportion of tiller damage at Stuntney, compared with an 85% reduction at High Mowthorpe. The dimethoate sprays also significantly reduced tiller damage at High Mowthorpe ($P < 0.01$) but not at Stuntney.

Number of surviving wheat bulb fly larvae

The number of surviving larvae/m^2 differed significantly ($P < 0.001$) between treatments applied to prevent plant invasion at both Stuntney and High Mowthorpe (Table 2.4). At both sites, lowest numbers of larvae were recovered in tefluthrin treated plots and most in the untreated control. Tefluthrin was more effective at controlling larvae at High Mowthorpe than at Stuntney. At High Mowthorpe, larval numbers were reduced by 85% and at Stuntney by 40% in comparison with the untreated control. At High Mowthorpe there was also a significant difference in surviving larvae between dimethoate treatments ($P < 0.001$). Following two sprays of dimethoate at High Mowthorpe, larval numbers were 57% lower than in the untreated plots and 31% lower where only a single application was made, confirming the findings in earlier work (Study 2) of this project. Data at Stuntney showed the same trend but differences were not statistically significant.

Numbers of fertile ears

Numbers of fertile tillers were assessed on 18 August at High Mowthorpe and they differed significantly ($P < 0.05$) between treatments applied at drilling or at egg hatch (Table 2.5). Greatest numbers were recorded in tefluthrin treated plots and least in the untreated control, reflecting differences in found in plant establishment (see above). Crop lodging prevented the assessment of fertile tillers at the Stuntney site.

Yield

Plots were harvested at Stuntney on 27 August 1998 and at High Mowthorpe on 28 August 1999 (Table 2.6). There was a significant difference in yield between treatments applied to prevent larval invasion at Stuntney ($P < 0.05$). Tefluthrin treated plots had a 2.4% higher yield and chlorpyrifos treated plots a 1.9% higher yield than the untreated control. A similar trend in yield data was recorded at High Mowthorpe although differences were not statistically significant. There was no effect of follow up dimethoate sprays on yield at either site.

Table 2.2 Mean plant establishment at Stuntney in 1998 and High Mowthorpe in 1999 (plants/m^2).

Dimethoate treatment	Treatment at drilling or at egg hatch			
	Untreated	Tefluthrin seed treatment	Chlorpyrifos @ egg hatch	Mean
Stuntney – March 1998				
Untreated	269.8	254.0	277.8	267.2
Dimethoate @ T_1	282.3	254.0	285.0	273.9
Dimethoate @ T_1 & T_2	269.3	259.5	270.3	266.3
Mean	273.8	256.0	277.7	
SEDs (24 d.f.): for comparison of drilling or egg hatch treatment means = 8.31, $P = 0.04$; for comparison of dimethoate treatment means = 8.31, $P = 0.06$; for comparison of means within the body of the table = 14.39, $P = 0.86$				
High Mowthorpe – March 1999				
Untreated	247.5	281.8	265.5	264.9
Dimethoate @ T_1	270.5	292.0	278.3	280.3
Dimethoate @ T_1 & T_2	274.8	269.5	271.5	271.9
Mean	264.3	281.1	271.8	
SEDs (24 d.f.): for comparison of drilling or egg hatch treatment means = 5.80, $P = 0.03$; for comparison of dimethoate treatment means = 5.80, $P = 0.05$; for comparison of means within the body of the table = 10.05, $P = 0.12$				
High Mowthorpe – April 1999				
Untreated	175.0	268.0	210.0	217.7
Dimethoate @ T_1	194.8	252.3	199.3	215.4
Dimethoate @ T_1 & T_2	198.3	259.5	213.3	223.7
Mean	189.3	259.9	207.5	
SEDs (24 d.f.): for comparison of drilling or egg hatch treatment means = 7.24, $P = 0.00$; for comparison of dimethoate treatment means = 7.24, $P = 0.51$; for comparison of means within the body of the table = 12.54, $P = 0.27$				

Table 2.3. The mean proportion of tillers attacked by wheat bulb fly larvae at Stuntney in 1998 and High Mowthorpe in 1999, assessed 10 and 21 days after final treatments, respectively (% tillers attacked).

Dimethoate treatment	**Treatment at drilling or at egg hatch**			
	Untreated	**Tefluthrin seed treatment**	**Chlorpyrifos @ egg hatch**	**Mean**
Stuntney				
Untreated	24.1	14.2	23.5	20.6
Dimethoate @ T_1	24.4	14.4	24.0	20.9
Dimethoate @ T_1 & T_2	23.1	14.5	23.7	20.4
Mean	23.9	14.4	23.7	
SED (24 d.f):	for comparison of drilling or egg hatch treatment means = 1.80, $P = 0.00$ for comparison of dimethoate treatment means = 1.80, $P = 0.96$ for comparison of means within the body of the table = 3.12, $P = 0.99$			
High Mowthorpe				
Untreated	17.9	1.8	12.0	10.6
Dimethoate @ T_1	10.5	1.7	7.7	6.6
Dimethoate @ T_1 & T_2	7.8	1.2	6.6	5.2
Mean	12.1	1.5	8.8	
SEDs (24 d.f.):	for comparison of drilling or egg hatch treatment means = 1.09, $P = 0.00$ for comparison of dimethoate treatment means = 1.09, $P = 0.00$ for comparison of means within the body of the table = 1.88, $P = 0.02$			

Table 2.4. The mean number of wheat bulb fly larvae surviving treatment at Stuntney in 1998 and High Mowthorpe in 1999, assessed 10 and 21 days after final treatments, respectively (nos. live larvae/m^2).

Dimethoate treatment	**Treatment at drilling or at egg hatch**			
	Untreated	**Tefluthrin seed treatment**	**Chlorpyrifos @ egg hatch**	**Mean**
Stuntney				
Untreated	121.9	70.5	109.9	100.7
Dimethoate @ T_1	130.6	66.4	87.6	94.9
Dimethoate @ T_1 & T_2	99.9	78.1	67.9	82.0
Mean	117.4	71.7	88.5	
SEDs (24 d.f.): for comparison of drilling or egg hatch treatment means = 8.85, $P = 0.00$; for comparison of dimethoate treatment means = 8.85, $P = 0.12$; for comparison of means within the body of the table = 15.32, $P = 0.14$				
High Mowthorpe				
Untreated	73.5	9.1	54.7	45.8
Dimethoate @ T_1	50.8	4.9	38.6	31.4
Dimethoate @ T_1 & T_2	33.1	4.5	21.3	19.7
Mean	52.5	6.2	38.2	
SED (24 d.f.): for comparison of drilling or egg hatch treatment means = 4.83, $P = 0.00$; for comparison of dimethoate treatment means = 4.83, $P = 0.00$; for comparison of means within the body of the table = 8.37, $P = 0.06$				

Table 2.5. Mean numbers of fertile tillers at High Mowthorpe, 1999 (ears/m^2).

Dimethoate treatment	Treatment at drilling or at egg hatch			
	Untreated	Tefluthrin seed treatment	Chlorpyrifos @ egg hatch	Mean
Untreated	325.4	356.3	302.5	328.1
Dimethoate @ T_1	322.1	341.7	335.8	333.2
Dimethoate @ T_1 & T_2	302.1	343.8	334.6	334.6
Mean	316.5	347.2	324.3	

SED (24 d.f): for comparison of drilling or egg hatch treatment means = 12.17, $P = 0.05$
for comparison of dimethoate treatment means = 12.17, $P = 0.86$
for comparison of means within the body of the table = 21.07, $P = 0.33$

Table 2.6. Mean yields of wheat at Stuntney in 1998 and High Mowthorpe in 1999 (t/ha @ 85% DM).

Dimethoate treatment	Treatment at drilling or at egg hatch			
	Untreated	**Tefluthrin seed treatment**	**Chlorpyrifos @ egg hatch**	**Mean**
Stuntney				
Untreated	8.05	8.15	8.18	8.13
Dimethoate @ T_1	8.08	8.29	8.26	8.21
Dimethoate @ T_1 & T_2	7.99	8.26	8.15	8.13
Mean	8.04	8.23	8.20	
SEDs (24 d.f.):	for comparison of drilling or egg hatch treatment means = 0.065, $P = 0.02$ for comparison of dimethoate treatment means = 0.065, $P = 0.39$ for comparison of means within the body of the table = 0.113, $P = 0.87$			
High Mowthorpe				
Untreated	12.21	12.49	12.31	12.34
Dimethoate @ T_1	12.08	12.59	12.30	12.32
Dimethoate @ T_1 & T_2	12.23	12.58	12.17	12.33
Mean	12.17	12.55	12.26	
SEDs (22 d.f.):	for comparison of drilling or egg hatch treatment means = 0.172, $P = 0.11$ for comparison of dimethoate treatment means = 0.172, $P = 0.99$ for comparison of means within the body of the table = 0.298, $P = 0.95$			

Discussion

Tefluthrin seed treatment was an effective means of limiting plant invasion by wheat bulb fly larvae at both sites and produced a significant yield benefit (2.4%) at the Stuntney site. Although data from High Mowthorpe did not produce statistical significance, there was a trend for the highest yield to be recorded in the tefluthrin treated plots. In view of the very high egg counts at Stuntney (6.5 million eggs/ha) it might have been expected that a higher yield response would have been recorded in a December-sown crop. This may be due to poor egg viability at the Cambridgeshire site or high mortality of larvae before they invaded host plants. High levels of pre-invasion mortality have been noted in earlier work (Young, 1992). Despite egg numbers at Stuntney being six times greater than at High Mowthorpe, there was only an approximate two-fold difference in the level of tiller invasion and numbers of surviving larvae. In addition, it is likely that favourable weather over winter allowed rapid establishment and helped crops grow away from and compensate for pest damage. The relationship between egg numbers and yield loss and the potential of the crop to compensate for pest attack, are areas of interest which are likely to become increasingly important in attempting to develop an integrated approach to wheat bulb fly control, which minimises reliance on pesticides. The limited choice of insecticides available for control of this pest suggests that further research on biology of wheat bulb fly attack should be given high priority.

There was little evidence to suggest that there was any need to follow up a tefluthrin seed treatment with dimethoate sprays. Although at both sites dimethoate treatments reduced the numbers of surviving wheat bulb fly larvae, this did affect crop yield. This result is in agreement with the results of the dimethoate studies in Part I of this project. In this work, dimethoate often reduced numbers of larvae but never produced an associated, significant, yield response. However, should new products become available as deadheart sprays, their cost effectiveness in combination with tefluthrin seed treatments should be evaluated.

The performance of the chlorpyrifos egg hatch spray was poorer than anticipated at both sites. In a recent review of wheat bulb fly control, the efficacy of insecticide treatments against wheat bulb fly and showed that on average a spray of chlorpyrifos at egg hatch produced a yield response of between 14 and 23% (Young and Ellis, 1996). In contrast, in the work reported here, yield responses were smaller and of the order of 2% at Stuntney and 0.7% at High Mowthorpe. At Stuntney, the activity of chlorpyrifos may have been reduced by the organic soil. At High Mowthorpe, the egg hatch treatment was applied before full emergence and therefore would not have been able to protect plants which were attacked below the soil surface.

In summary, tefluthrin seed treatment is a useful and valuable tool in the control of wheat bulb fly in December-sown crops, at a time when the availability of alternative organophosphorus products is under threat. Overall, there was little or no benefit from applying dimethoate as a follow-up treatment to the seed or egg hatch treatments. However, a two-sprays of dimethoate gave better levels of pest control than a single spray. Further work is now needed to establish whether earlier sown crops will benefit from a seed treatment. In addition, the low yield responses to insecticide treatment observed in this work suggest there is a continuing need to be able to predict more precisely when insecticide treatments against wheat bulb fly are likely to be cost-effective. This will involve an improved understanding of the biology of the pest and how crops respond to and compensate for pest attack.

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