SESSION 6C

CROP PROTECTION IN ARABLE CROPS

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RECENT STUDIES ON CHEMICAL AND CULTURAL CONTROL OF WHEAT BULB FLY

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ABSTRACT

Field trials to investigate chemical control strategies for wheat bulb fly and the varietal susceptibility of wheat to this pest are described. Sowing before November is highlighted as an effective cultural means of reducing yield losses. In contrast, later sown crops were more vulnerable to damage and cost-effective yield increases were observed following multiple treatments, the strategy of which is discussed. None of the wheat varieties tested differed in susceptibility to attack. Although there appeared to be no constraint on the use of lower yielding bread-making varieties, the use of robust high-yielding feed wheats is suggested in fields with a high pest pressure because of their greater tillering and yield potential.

INTRODUCTION

Wheat bulb fly (*Delia coarctata*) is a common pest of wheat and barley in eastern areas of England. Oviposition occurs in July and August on exposed soil surface in fallows, freshly cultivated fields, or on the soil beneath the canopy of root crops. On hatching in January or February the larvae die unless the field has been sown with a host crop. Wheat and barley are susceptible to attack when they are sown after fallow, potatoes, sugar beet, peas or early-harvested crops such as oilseed rape which require soil cultivation during oviposition.

The three larval instars are passed inside the host plant. Older larvae may move between plants as well as between tillers. Larval feeding causes the appearance of a withered and yellow central leaf or "deadheart" of the attacked shoot. Pupation occurs in the soil in April and May. Adult flies emerge in June, completing a single generation per year. Sowing before or during October has now become common practice, and is an effective cultural means of minimising losses to wheat bulb fly. Early sowing and the decline of fallowing have reduced the scale of damage in recent times compared with that of twenty or more years ago.

Late-sown crops of winter wheat (or early-sown spring wheat or spring barley) are very susceptible to wheat bulb fly damage as they often remain at pre-tillering growth stages during the critical January to March period when the larvae are invading the crop (Bardner, 1968). Winter wheat continues to be sown in late autumn in many areas of eastern England, particularly after sugar beet or potatoes in fenland districts, where wheat bulb fly continues to be a constant threat. The work reported here covers investigations on the chemical control of wheat bulb fly and the varietal susceptibility of wheat which were conducted during 1987-1991.

CHEMICAL CONTROL TRIALS

Chemical control measures remain a vital means of combating wheat bulb fly damage effectively. Farmers have a wide range of chemical control options including seed treatments, granules or sprays applied at sowing, sprays applied at, or just before, the start of egg hatch and deadheart sprays applied at the onset of plant damage. The object of these trials was to evaluate the chemical measures adopted for wheat bulb fly control at sites representing the varying levels of risk to field attack, enabling the identification of the most appropriate and cost-effective control strategies.

Materials and methods

As part of a larger series of trials, three trials were done at sites with the following categories or risk based on egg numbers: low risk, 0.6 million eggs/ha, Guilden Morden, Cambridgeshire; medium risk 1.0 million eggs/ha, Terrington, Norfolk; high risk, 2.9 million eggs/ha, Weston, Hertfordshire. The risk of wheat bulb fly damage was estimated by sampling egg populations at each trial site in the autumn. Eggs were extracted from the soil by a process of wet sieving, elutriation and flotation adapted from that described by Gough (1947).

Each trial was of a randomised block design with two sowing dates of winter wheat cv. Mercia. Plot size was 2m x 24m. Four core treatments were applied to each trial: 1) untreated; 2) omethoate (0.64 kg AI/ha) spray applied when larval damage was first seen (deadheart spray); 3) a "full" treatment regime of fonofos seed treatment (1.0 g AI/kg), fonofos granules (1.4 kg AI/ha) applied at sowing, fonofos spray (0.88 kg AI/ha) applied at the start of egg hatch (egg hatch spray) and an omethoate (0.64 kg AI/ha) deadheart spray; 4) fonofos seed treatment (*ibid*). The full treatment was not applied as a commercially viable recommendation but to give maximum control of the pest for damage assessment purposes. Additional treatments were applied according to the level of risk, including, at the high risk site, a tank mixture of chlorpyrifos (0.72 kg AI/ha) plus dimethoate (0.68 kg AI/ha) applied at peak egg hatch. All other additional treatments were combinations of treatments (or parts of), with details as listed above.

Fonofos seed treatment was applied by the seed merchant in conjunction with an organo-mercury seed treatment for seedling diseases. Fonofos granules were drilled with the seed or broadcast manually prior to surface incorporation at drilling. Sowing dates were classified as either "early" (October-sown) or "late" (November-sown). Sprays were applied at a volume of 200 l/ha using a carbon dioxide gas pressurised knapsack sprayer operating at 200 kPa with medium spray quality nozzles. The timing of egg hatch and deadheart sprays was determined by frequent monitoring of egg hatch and larval invasion. Treatment efficacy was assessed by dissecting samples of 50 randomly selected plants per plot in March or April. Yield was corrected to 85% dry matter.

Results

TABLE 1. The effect of treatment on percentage tillers attacked (angular transformations), live larvae/m^2, and yield.

Treatment	% tillers attacked		Live larvae /m^2		Yield as % of untreated (t/ha)	
	E	L	E	L	E	L
A) Low risk site						
1. Untreated	13	12	21	16	8.5	7.1
2. Omethoate	9	8*	15	4*	100	102
3. Full Treatment	6*	1*	1*	0*	99	110*
4. Fonofos S.T.	12	9	22	5*	102	111*
SED (9 d.f.)	2.4	1.7	3.9	4.1	0.18	0.12
B) Medium risk site						
1. Untreated	19	18	31	15	7.9	7.3
2. Omethoate	16	13*	5	7*	100	102
3. Full Treatment	8*	6*	1*	0*	105	110*
4. Fonofos S.T.	17	11*	37	1*	104	108*
5. Fonofos S.T. & omethoate	16	11*	7*	0*	104	110*
SED (12 d.f.)	1.8	1.7	10.0	2.9	0.18	0.14
C) High risk site						
1. Untreated	23	21	41	40	7.1	4.8
2. Omethoate	21	15	38	21	98	115*
3. Full Treatment	4*	9	3*	2	108*	137*
4. Fonofos S.T.	24	19	72*	43	100	123*
5. Fonofos S.T. & omethoate	22	16	36	17	99	134*
6. Fonofos spray	20	15	43	10	101	122*
7. Fonofos S.T. & spray	16	15	29	14	102	131*
8. Chlorpyrifos & dimethoate	20	19	36	27	97	111*
SED (16 d.f.)	3.5	4.1	11.0	13.7	0.18	0.19

* - Significantly different from untreated at $P < 0.05$
E - early (October) sowing, L - late (November) sowing
S.T. - seed treatment

VARIETAL SUSCEPTIBILITY TRIALS

Six field trials, each of a randomised block factorial design, were sited in Cambridgeshire (3 sites), Lincolnshire (2 sites) or Warwickshire (1 site) between 1988 and 1991. The objective was to evaluate a cross-section of modern wheat varieties in order to identify those varieties which respond badly and fail to recover adequately from wheat bulb damage.

The full treatment gave significant reductions in tiller damage on one organic and three mineral soil sites, the deadheart spray on two mineral soil sites, ($P < 0.05$). This observation was partially reflected in the yield responses to treatment (Table 3). Significant yield increases ($P < 0.05$) were restricted to the full treatment of the late sowings at the same sites. However, none was found following the deadheart spray.

TABLE 3. The effect of insecticidal treatment, sowing date and soil type on grand means of percentage tillers attacked and grain yield.

Treatment & Sowing		Organic soil		Mineral soil	
		% tillers attacked*	Yield **	% tillers attacked*	Yield **
Untreated	E	13	9.03	21	9.11
	L	18	6.96	21	7.84
Full Treatment	E	11 (18)	101	8 (62)	101
	L	8 (53)	115	5 (76)	110
Deadheart spray	E	13 (2)	100	16 (25)	100
	L	18 (0)	102	16 (23)	100

E - early sowing L - late sowing
* - figures in parentheses are percentage reduction in damage
** - expressed as percentage of untreated (t/ha)

DISCUSSION

Chemical control trials

The findings of the chemical control trials have highlighted the importance of early sowing (before November) as an effective cultural means of reducing the yield losses caused by wheat bulb fly. Later sown crops are inherently more vulnerable to damage and, in high risk fields, cost-effective yield increases were gained from the use of insecticides.

The results of the high-risk (Table 1) site agree with the earlier work of Maskell & Gair, (1986b), demonstrating the value of a multiple treatment strategy for late-autumn sowings where the egg count is greater than a threshold 2.5 million eggs/ha. However, high-risk fields must be correctly identified to justify the expense of multiple treatments which would otherwise be uneconomic and environmentally unacceptable on a large scale. In contrast, the early sowings (Table 1) were generally unresponsive to treatment, indicating that preventive treatment is rarely warranted on well established crops sown before November.

The fonofos seed treatment gave cost-effective yield increases in the late sowings at all sites (Table 1), again confirming earlier work (Maskell & Gair, 1986a) showing wheat bulb fly seed treatments to be more effective in late-autumn sowings. The combination of a seed treatment followed by a deadheart spray as a strategy for late-sown, high-risk, fields has several advantages: seed treatment is a low-cost preventive treatment with accurate targeting and minimal environmental exposure of active ingredient, and the deadheart spray may be applied in strict response to crop damage thresholds.

Materials and methods

Each trial consisted of six wheat varieties sown "early" (October) and "late" (November), sited in fields at high risk of wheat bulb fly damage with more than five million eggs/ha. Site numbers 1, 3 and 5 were located on organic fen soils, whilst sites 2, 4 and 6 were on mineral soils. Three treatments were imposed on the wheat varieties: 1) untreated; 2) a full treatment regime of fonofos granules at sowing, fonofos spray at egg hatch and omethoate deadheart spray; 3) omethoate deadheart spray. The full treatment was not intended to represent commercial practise, but was applied to obtain a measure of the maximum possible reduction in damage for loss assessment purposes. All application rates and methods were as given in the chemical control trials. Seed rates were standardised at 350 or 400 seeds/m^2.

Agronomic management was conducted according to the normal requirements of each farm for a conventional crop of winter wheat. Prophylactic treatments were applied for weed and disease control to prevent any disruption by these factors. Wheat bulb fly larval damage was assessed by examining random samples of 50 plants per plot for external symptoms of attack in March or April. A synthetic pyrethroid insecticide (cypermethrin or deltamethrin) was applied overall to each trial in November or December in order to suppress any confounding effect from invasion of the crop by larvae of the yellow cereal fly (*Opomyza florum*).

Results

There were no statistically significant differences between the varieties in their response solely to wheat bulb fly attack. Therefore, grands means have been presented to give an overview of the varietal characteristics (Table 2). The late sowing of Riband at one site was excluded from the results in Table 2 as this variety was, for reasons unknown, singled out and badly damaged by pheasants during crop establishment, resulting in unacceptably low plant populations.

TABLE 2. The effect of wheat variety on the grand means of tillers per plant, percentage tillers attacked and grain yield.

Variety (no. sites)		Tillers/plant (March/April)	% tillers attacked	Yield	
				U	F
Beaver	(4)	5.4	12	9.4	107
Apostle	(2)	4.9	14	7.7	102
Riband*	(2)	4.9	15	8.9	108
Hornet	(4)	4.9	11	8.6	102
Slejpner	(2)	4.8	14	8.2	107
Apollo	(6)	4.6	13	8.7	104
Hereward	(2)	4.3	15	7.8	110
Pastiche	(2)	4.5	11	7.7	103
Mercia	(6)	4.2	16	7.8	107
Tonic	(6)	4.1	15	8.1	105

* excluding the late sowing at one site.
U = Untreated yield (t/ha).
F = Yield response of the full treatment (percentage of untreated).

Varietal susceptibility trials

There were insufficient differences in the amount of tiller damage between varieties to suggest that any of them were intrinsically more or less susceptible or resistant to wheat bulb fly attack (Table 2). Earlier work (Raw, 1967) indicated that varieties with the greatest tillering capacity are those best able to tolerate and recover from wheat bulb fly damage, although they favoured a greater survival of the pest. The feed or general purpose varieties Apollo, Beaver and Riband tended to tiller more and yield higher than the bread-making quality varieties Hereward, Mercia and Tonic (Table 2). When subjected to attack by wheat bulb fly, the use of a robust high yielding feed variety would be a secure choice according to these findings. However, when grain quality is of importance there would appear to be no serious constraint on the use of bread-making varieties in the presence of the pest.

The overall standard of control obtained from the insecticide treatments was poor. The full treatment gave a lower level of control of tiller damage at the organic soil sites, probably because of the pesticide absorption effect of the fen peat soil which can reduce the efficacy of residual pesticides. The yield increases obtained from the full treatment of the late sowings again demonstrate the vulnerability of late-sown crops to wheat bulb fly.

Further work should be directed at identifying the biochemical and genetic nature of wheat bulb fly resistance found in oats and in identifying the biochemical nature of host location and preference. Gene transfer technology may now offer a means of developing new varieties of wheat incorporating resistance to wheat bulb fly.

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INCIDENCE OF POLLEN BEETLES IN WINTER OILSEED RAPE AND EVALUATION OF THRESHOLDS FOR CONTROL

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ABSTRACT

The results of a monitoring scheme show that a sustained increase in pollen beetle incidence in winter oilseed rape crops occurred from 1987 onwards. Possible explanations for the increase are discussed. Farmer concern about this increase has led to many routinely controlling very small infestations in crops. These treatments are shown to be neither economically justified nor environmentally desirable.

INTRODUCTION

Winter oilseed rape occupies the third largest arable area in the UK after wheat and barley, with over 400 000 ha grown in 1991 (MAFF Agricultural Census). Pollen beetles (*Meligethes* sp.) are an economically important pest of the crop if present in large numbers at the susceptible green/yellow bud stage, when they cause bud abortion by chewing through the sides of unopened buds to reach the pollen (Nilsson, 1987). The winter crop is often past the susceptible growth stages when pest invasion occurs in spring, but annual mean infestations have shown a sustained increase since 1987 (Lane & Walters, 1992), and the larger numbers of beetles active in early spring may put more winter crops at risk.

The current UK pollen beetle treatment thresholds for winter oilseed rape of 15 beetles/plant or 5/plant on a backward crop (Lane & Walters, 1992), were developed for the now outdated single-low varieties and were largely based on an extrapolation of data from work on mustard and spring oilseed rape. Treatment thresholds used in other European countries were developed for use primarily in the more susceptible spring-sown oilseed rape as an economic return is rarely obtained from pollen beetle control in winter varieties in these areas. The thresholds proposed range from 0.5-5 beetles/plant (data from the 1986 IOBC/WPRS Working Group on Integrated Pest Control in Oilseed Rape), much lower than in the UK.

Farmers have reacted to the increase in pollen beetle incidence by examining control practices for the pest and are concerned about the lower thresholds used in Continental Europe, about the use of the current UK thresholds in modern double-low varieties and that damage caused by attack after the green/yellow bud stage may be economically significant. Between 1988 and 1990 the area of oilseed rape treated with insecticide doubled (Davis *et al.*, 1991), and routine use of pre-flowering treatments resulting from such uncertainty may have contributed to this increase. This paper discusses possible causes of the recent increase in pollen beetle incidence and reports the results of the first two years of work investigating treatment thresholds for UK winter-sown crops.

MATERIALS & METHODS

Monitoring

Between 1981 and 1991 a stratified sampling programme was undertaken to determine the population levels of pollen beetle in commercial winter oilseed rape crops in England and Wales. In each year between 51 and 81 crops were sampled, representing all popular modern varieties. The number of crops sampled in each region of England and Wales was stratified according to the proportion of the national hectarage grown in five regions (North, Midlands and West, East, South East, South West).

Between 1981 and 1987 samples were taken from each field at three growth stages (GS: Sylvester-Bradley & Makepeace, 1984): early to mid-flowering on the main raceme (GS 4.2-4.5); mid to late flowering on the main raceme (GS 4.7-4.9); and between the end of flowering on the main raceme and the end of all flowering. After 1987 an additional visit was made at the green/yellow bud growth stage (GS 3.3-3.7). At each visit the tops of 20 plants from a transect across the field were beaten into a white tray and the numbers of pollen beetle adults caught were recorded.

Damage assessment

Randomised block designs consisting of 2 blocks of 5 treatments and using a minimum plot-size of 40m x 40m were established in 2 crops of winter oilseed rape in 1990 and 4 in 1991. At each site an insecticide was applied as a single spray treatment at the green bud growth stage (GS 3.3), at early to mid-flowering (GS 4.3-4.5), and late flowering (GS 4.8-4.9). In addition there was a multiple spray consisting of an insecticide applied at each of these timings, and an untreated control. Deltamethrin (Decis) was applied at 250ml product/ha in at least 300 l water/ha at both sites in 1990, and alphacypermethrin (Fastac) at 200ml product/ha in at least 300 l water/ha to all sites in 1991, using high clearance spraying equipment. Immediately before each spray, and at intervals between treatments determined by the crop growth rate, the tops of 20 plants in a transect across untreated plots, plots about to be sprayed and plots that had already been sprayed were beaten into a white tray. The numbers of adult pollen beetles caught were recorded. A similar sample was taken between the end of flowering on the main raceme and the end of all flowering.

During seed development (GS 6.2) the number of racemes on each of 20 plants/plot was counted. The main and third lowest raceme of the plants were collected and the number of blind stalks (remains of aborted buds) on each was counted. All plots were harvested using a plot-combine when ripe, and the weight of seed produced was recorded. Dry weight (at 91% DM), percentage oil content (at 100% DM) and glucosinolate levels were determined from a sub-sample of seed from each plot. Details of the location of sites and cultivars grown are given in table 1.

RESULTS

Pollen beetle incidence

Annual monitoring of pollen beetle incidence on oilseed rape showed that a large increase in population levels occurred in 1987 which has subsequently been sustained (Fig.1). It has been suggested that the observed increase was concurrent with, and the result of, the rapid increase in the hectarage of oilseed rape. This hypothesis was tested by calculating mean pollen beetle populations per plant and crop area grown, for each region in each year. Beetle incidence was correlated with crop area both between region/within years, and within region/between years.

Relating beetle incidence in each region to crop area, between regions/within years, very low correlation coefficients (<0.42, N=5) were obtained in all but one of the eleven years (1986: 0.97). As pollen beetles are univoltine, adult incidence may be related to crop area in the previous year. Repeating the analysis to test this gave a similar result: correlation coefficients were low (<0.40, N=5) except in 1986 when it reached 0.98. Pooling the data from all years gave correlation coefficients of only 0.33 (N=45) for crop area from the current year and 0.36 (N=45) for the previous year's crop area. Correlating beetle incidence within regions/between years gave very variable correlation coefficients of 0.21-0.80 (N=11) when incidence was related to crop area in the same year and 0.45-0.82 (N=11) when it was related to crop area in the previous year.

Thus although the lack of consistently high correlation coefficients does not disprove an effect of crop area, the increased pollen beetle incidence cannot be explained by the increase in crop area alone.

Damage assessment

Pollen beetle numbers remained low throughout the sampling period in all the experiments, with the highest counts at each site ranging from 0.70 to 5.85 beetle per plant (Table 1). At the susceptible green/yellow bud stages (GS 3.3-3.7) beetle numbers ranged from 0.15 to 2.15 per plant.

Deltamethrin applied at the green or yellow bud stage reduced adult numbers in comparison to untreated plots for at least 16 days after treatment at site 2, and Alphacypermethrin for at least 13 and 30 days at sites 5 and 6 respectively. Lower population levels and late activity of

Fig. 1 Mean number of pollen beetles per plant (bars), and total area of winter oilseed rape grown (-) in England and Wales 1981-1991

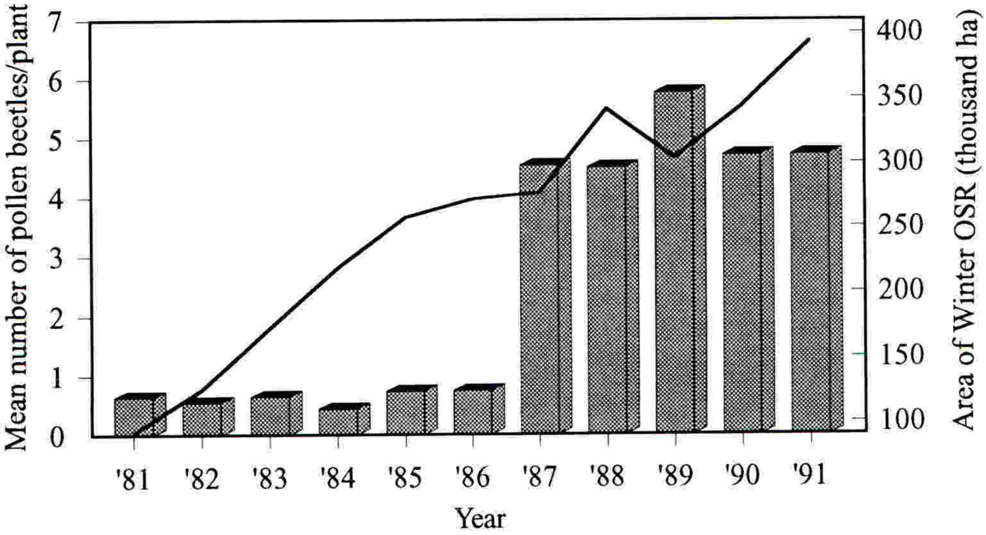

TABLE 1. Details of crops and mean numbers of pollen beetles per plant in untreated plots at each site

Site	Year	Location	Cultivar	Growth Stage		
				3.3.-3.7	4.3-4.5	4.8-4.9
1	1990	N. Yorkshire	Libravo	0.15	1.67	0.40
2	1990	Herefordshire	Doublol	0.20	2.98	3.68
3	1991	N. Yorkshire	Falcon	0.15	1.03	0.46
4	1991	Hampshire	Libravo	0.19	0.18	0.70
5	1991	Cambridgeshire	Lictor	1.80	1.30	0.25
6	1991	Herefordshire	Lictor	2.15	4.80	5.85

adult pollen beetles resulted in a rapid re-invasion of treated plants after application of both chemicals at these growth stages at sites 1, 3 and 4, and no sustained reduction in numbers occurred after spraying. Thus, chemical treatments applied at sites in which migration occurred before the susceptible stage resulted in a lasting reduction in pollen beetle numbers. When migration did not occur until after this stage, treatment effects were lost due to rapid re-invasion of treated areas.

Damage indices, yield and quality

The low numbers of pollen beetles in this study were reflected in a very low incidence of blind stalks on plants from untreated plots at all six sites. Analysis of variance showed that there were no significant differences between treatments in the numbers of blind stalks on either the main, or the third lowest secondary raceme (Table 2).

Work in Sweden has related reduction in blind stalks after control of pollen beetle in spring rape to significant yield increases (Nilsson, 1987). Pollen beetle damage in the Swedish trials resulted in a mean of between 167.0 and 646.0 blind stalks/plant in untreated plots compared with between 3.2 and 41.3 in treated plots. In the current experiments, the

TABLE 2. The mean number of blind stalks on the main and third lowest raceme of twenty plants per plot

Treatment	Raceme	Site					
		1	2	3	4	5	6
Untreated	Main	9.2	11.8	3.8	7.2	8.2	6.4
	3rd lowest	5.4	14.0	4.8	8.2	4.5	5.5
GS3.3-3.7	Main	7.7	12.0	7.3	7.9	7.07	4.9
	3rd lowest	4.6	13.2	6.4	8.0	4.02	8.5
GS4.2-4.5	Main	7.9	11.3	8.0	10.7	9.10	8.5
	3rd lowest	4.5	12.2	8.6	9.0	5.30	5.9
GS4.8-4.9	Main	9.1	14.3	4.8	10.5	7.33	10.0
	3rd lowest	4.7	14.1	6.5	8.3	4.47	5.9
Multiple	Main	8.4	13.0	4.4	8.2	6.15	4.8
Treatment	3rd lowest	3.8	14.1	8.3	6.2	4.10	2.6
F	Main	0.91	0.56	1.07	0.44	0.80	2.76
F	3rd lowest	0.80	0.29	1.89	0.61	0.50	3.04

TABLE 3. The Effect of Insecticide Treatment on Yield (t/ha at 91% Dry Matter)

Treatment timing	Site					
	1	2	3	4	5	6
Untreated	3.47	3.10	2.70	2.70	3.20	2.67
GS3.3-3.67	3.47	3.28	2.80	2.69	3.18	2.80
GS4.2-4.5	3.44	3.26	2.92	2.69	3.35	2.80
GS4.8-4.9	3.55	3.24	2.82	2.85	3.18	2.78
Multiple Treatment	3.48	3.37	2.89	2.62	3.28	2.77
F	0.93	0.55	0.77	0.84	0.2	0.24

mean number of blind stalks per plant (T) in each plot was estimated from:

$$T = (\Sigma N S + M)/20$$

where N=number of secondary racemes, S=number of blind stalks on the third lowest secondary raceme and M=number of blind stalks on the main raceme. Means of between 39.7 and 116.5 blind stalks/plant were found in the untreated plots of the six sites, much lower than the numbers found in the earlier work. A similar range was found in plots treated at the green/yellow bud stage (37.1-110.7) and in plots treated at the later growth stages (24.2-119.8). Thus the numbers of blind stalks in this experiment series were much lower than in an earlier study in which significant yield responses were obtained, and were not significantly reduced by any of the treatments applied at any of the sites.

No significant differences in yield were found between treated and untreated plots at any of the sites (Table 3). Thus controlling pollen beetle populations of 0.15-2.15 beetles per plant at the green/yellow bud stage, and of 0.70-5.85 beetles/plant during the flowering period did not result in a consistent yield increase. Similarly, no significant differences between treated and untreated plots in oil content or glucosinolate content of the seed, were found at any of the sites.

DISCUSSION

At least three explanations have been proposed for the sustained increase in pollen beetle population levels in oilseed rape that has occurred since 1987. Most frequently it is linked to the increase in area of oilseed rape grown in the UK, but this hypothesis has not been tested statistically. In this study no significant relationship was found between pest numbers and crop area on either a national or regional scale. This does not preclude an effect of crop area but does indicate that it is not the dominant factor influencing pollen beetle numbers. The replacement of single- with double-low oilseed rape varieties has also been proposed as an explanation of the increased incidence of pollen beetles. Almost none of the crop area was planted with double-low varieties in 1987, 20% in 1988, and 90% in 1989. As pollen beetles are univoltine, adult population levels are dependent on the eggs laid in the previous year and subsequent survival. If the change to double-low varieties increased fecundity or larval survival, the initial increase in population levels would not have occurred until 1989, two years after it was recorded. Alternatively, if double-low varieties were more attractive to adult pollen beetles then the increased incidence would have been first noted in 1988, one year after it occurred. Thus it is unlikely that the increased pollen beetle incidence is the result of the change from single- to double-low varieties. Finally, the increased insecticide usage on oilseed rape in recent years (Davis *et al.*, 1991) may have been a contributory cause of the observed change in pollen beetle incidence. Much of the increase was accounted for by increased use of pyrethroids (Lane & Walters, 1992) and these applications may have reduced numbers of pollen beetle parasites in crops. This hypothesis is currently being investigated.

The use of three continental treatment thresholds (0.5, 0.8, and 1.0 pollen beetles/plant proposed in Denmark, Sweden, and France) were tested in modern double-low varieties of winter oilseed rape grown under UK conditions in this study. Even in those experiments with the highest infestations at the susceptible green/yellow bud stage and where lasting control of pollen beetle was achieved, significant yield responses and significant increases in oil content of the seed were not obtained. Similarly, glucosinolate content of the seed, an important quality parameter which can affect the ease and price at which seed can be marketed, was not affected by the treatments applied. Sprays applied to populations of up to 5.85 beetles per plant during the flowering stages of crops also resulted in no significant yield responses or effect on glucosinolate levels of seeds, and therefore were not cost effective. The number of blind stalks on plants can be used as a measure of the degree of pollen beetle damage in spring rape (Nilsson, 1987). Comparing the number of blind stalks in Swedish trials, where cost-effective control of pollen beetle damage was achieved, with the numbers recorded in the current study indicates that the infestation levels in the UK experiments were not sufficiently high to cause serious damage, and that the plants were probably able to compensate fully for the buds that were lost.

The results of this study indicate that in modern double-low varieties of oilseed rape, control of pollen beetle infestations of up 2.15 beetles/ plant at the susceptible green/yellow bud stage did not give a consistent yield response. Pollen beetles frequently do not invade the crop until after this growth stage, and the low numbers of insects present at the susceptible stage, the lack of residual action controlling late emigration and the lack of yield responses from treating flowering crops indicate that routine early season sprays are unlikely to be cost-effective.

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APHID CONTROL IN POTATOES FROM IMIDACLOPRID, A NEW SYSTEMIC INSECTICIDE FOR APPLICATION TO SEED TUBERS OR IN FURROW AT PLANTING

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ABSTRACT

Between 1990 and 1992 field trials were carried out in the United Kingdom to evaluate imidacloprid as an aphicide in potatoes. Applications were made to seed tubers before or at planting using dry powder and spray treatments, or in-furrow at planting using spray or granule treatments. All forms of application were highly effective and persistent against the aphids *Myzus persicae* and *Macrosiphum euphorbiae*, being comparable to the standard aldicarb granule.

INTRODUCTION

Imidacloprid is a new systemic insecticide, especially suited to root uptake, that has been successfully used against a range of arthropod pests in cereals, sugar beet and potatoes (Elbert *et al.*, 1990, Schmeer *et al.*, 1990). It is highly effective against aphids including strains of *Myzus persicae* which are resistant to other chemical groups (Dewar & Read, 1990; Dewar, 1992). This species is of particular importance in potatoes as it is the main vector of potato leaf roll virus (PLRV), which can cause serious losses in both seed and ware crops (Killick, 1979). *Macrosiphum euphorbiae*, also a vector of PLRV, can build up in large numbers although it does not transmit efficiently under field conditions. Granular insecticides applied to the soil at planting have given substantial reductions in both aphid species and hence the spread of PLRV (Woodford *et al.*, 1983).

Results are presented of replicated field trials carried out in the United Kingdom, to evaluate imidacloprid as an aphicide for potatoes when applied to seed tubers or in-furrow at planting.

MATERIALS AND METHODS

A series of three trials was carried out in both 1990 and 1992, with a single trial in 1991. The maincrop cv. Desirée was used throughout. In 1990 and 1991 the plot size was 10 m x 2 rows, with plant spacings of 25 cm within row and approximately 0.8 m between rows. In 1992 plots were 10 m x 4 rows at the same plant spacing. The experimental design in all trials consisted of randomised blocks with 4 replicates. Imidacloprid was applied as several formulations at a range of rates (see Tables 1-6) at or before planting:

1. The 70 WS dry seed treatment was applied by rolling with tubers in a plastic bag to simulate the "in hopper" method, on the day of planting and also 20-55 days before planting.

2. The 350 FS (flowable) treatment was applied as a spray to seed tubers on a roller table and also at and around tubers in-furrow at planting. In 1990 and 1991, roller table applications were made using a Fischer spinning disc and in 1992 a Microstat spinning disc working with an electrostatic charge was used. In-furrow sprays were applied using Tee Jet 6501 flat-fan nozzles.

3. The granules imidacloprid 5 GR and aldicarb 10 GR (standard treatment) were applied in-furrow at planting using a Granyl applicator. In 1990 and 1991 the maximum rate of aldicarb was used (1707 g AI/ha) to compare imidacloprid for efficacy and long-lasting aphid control. In 1992, lower rates were compared with the mid-rate of aldicarb (1146 g AI/ha).

In all trials a Johnson two-row planter was used and in-furrow application equipment was mounted on this.

All data were analysed statistically by analysis of variance following an appropriate transformation (angular transformation for percentages, square root (count +0.5) for counts).

RESULTS AND DISCUSSION

1990

In 1990 aphids migrated during early crop growth and *Myzus persicae* was the predominant species, except in one trial were *Macrosiphum euphorbiae* was also present at similar levels. Early assessment of aphid control showed very large reductions of both species by imidacloprid and the standard aldicarb. Later assessments showed that the persistence and efficacy of imidacloprid from all formulations, rates, methods and timings of application were at least equal to aldicarb (see Tables 1-3).

TABLE 1. % control of *Myzus persicae* in potatoes from imidacloprid, England 1990 - assessed before crop met between rows.

Site:			Harlow	Deal	Thurston	
Area:			Essex	Kent	Suffolk	
Date planted:			22/3/90	26/3/90	26/4/90	
Days after planting:			64	67	48	
Crop height:			15 cm	16 cm	34 cm	mean
Treatment,	AI rate /100 kg* or/ha,	applied to				
untreated (apterae/30 leaves)			(44.5)	(79.7)	(122.0)	
imida. 70 WS,	25.2 g*,	tubers on 2/3/90	100	92.5	99.8	97.4
imida. 350 FS,	25.2 g*,	tubers on 2/3/90	100	94.0	99.6	97.9
imida. 70 WS,	12.6 g*,	tubers at planting	100	92.5	100.0	97.5
imida. 70 WS,	25.2 g*,	tubers at planting	100	97.5	100.0	99.2
imida. 70 WS,	50.4 g*,	tubers at planting	100	98.4	100.0	99.5
imida. 5 GR,	667.0 g,	furrow at planting	100	91.8	99.4	97.1
aldicarb 10 GR,	1707.0 g,	furrow at planting	100	97.5	99.8	99.1

All treatments were significantly different from the untreated ($P \leq 0.01$)
There were no statistically significant differences between treatments

TABLE 2. % control of *Macrosiphum euphorbiae* in potatoes from imidacloprid, Thurston, Suffolk, England 1990.

Date planted:			26/4/90	
Days after planting:			48	62
Crop height:			34 cm	54 cm
Treatment,	AI rate /100 kg* or/ha,	applied to		
untreated (apterae/30 leaves)			(77.2)	(191.0)
imidacloprid 70 WS,	25.2 g*,	tubers on 2/3/90	100.0	98.0
imidacloprid 350 FS,	25.2 g*,	tubers on 2/3/90	98.4	97.4
imidacloprid 70 WS,	12.6 g*	tubers at planting	99.4	97.4
imidacloprid 70 WS,	25.2 g*,	tubers at planting	99.0	98.0
imidacloprid 70 WS,	50.4 g*,	tubers at planting	99.7	99.2
imidacloprid 5 GR,	667.0 g,	furrow at planting	100.0	99.2
aldicarb 10 GR,	1707.0 g,	furrow at planting	100.0	97.9

All treatments were significantly different from the untreated ($P \leq 0.01$)
There were no statistically significant differences between treatments.

TABLE 3. % control of *Myzus persicae* in potatoes from imidacloprid, England 1990 - assessed after crop met between rows.

Site:			Deal	Thurston	
Area:			Kent	Suffolk	
Date planted:			26/3/90	26/4/90	
Days after planting:			80	62	
Crop stage or height:			in flower	54 cm	mean
Treatment,	AI rate /100 kg* or/ha,	applied to			
untreated (apterae/30 leaves)			(146.7)a	(40.5)a	
imida. 70 WS,	25.2 g*,	tubers on 21/3/90	97.8b	87.7bc	92.8
imida. 350 FS,	25.2 g*,	tubers on 21/3/90	99.7b	87.7bc	93.7
imida. 70 WS,	12.6 g*	tubers at planting	95.6b	87.0bc	91.3
imida. 70 WS,	25.2 g*,	tubers at planting	99.0b	90.7bc	94.9
imida. 70 WS,	50.4 g*,	tubers at planting	99.8b	98.1b	99.0
imida. 5 GR,	667.0 g,	furrow at planting	95.6b	92.0bc	93.8
aldicarb 10 GR,	1707.0 g,	furrow at planting	99.5b	79.0c	89.3

All treatments were significantly different from the untreated ($P \leq 0.01$)
A common suffix denotes no significant difference ($P > 0.05$)

Yield data indicated that there were no losses directly attributable to aphid feeding, with no treatments having a statistically significant effect. This would also indicate that there were no problems with crop safety.

1991

In 1991 some lower rates of imidacloprid were tested, in one trial, following the high levels of effect from all rates in 1990. Against low levels of *M. persicae* all imidacloprid treatments were not significantly different from aldicarb, but there seemed to be a decline in effectiveness at lower rates against a considerable infestation of *M. euphorbiae* (see Table 4). As a direct effect of the large aphid numbers all untreated plots were severely affected by false top roll, which was dramatically reduced by all treatments (Table 4).

TABLE 4. % control of aphids in potatoes from imidacloprid, England 1991

Site:			Thurston, Suffolk		
Date planted:			25/4/91		
Days after planting:			82	82	104
Crop height:			75 cm	75 cm	-
Aphid species:			*Myzus persicae*	*Macrosiphum euphorbiae*	% leaf roll
Treatment,	AI rate /100 kg* or/ha,	applied to			
untreated (apterae/30 leaves)			(27.3)a	(537.0)a	50.0a
imida. 350 FS,	6.3 g*,	tubers on 20/2/91	95.4b	89.4b	1.8b
imida. 350 FS,	12.6 g*,	tubers on 20/2/91	97.2b	95.7c	0.5bc
imida. 350 FS,	25.2 g*,	tubers on 20/2/91	100.0b	99.3cd	0.0c
imida. 5 GR,	233.0 g,	furrow at planting	96.3b	96.7cd	0.4bc
imida. 5 GR,	466.0 g,	furrow at planting	100.0b	98.8cd	1.3bc
imida. 350 FS,	233.0 g,	furrow at planting	93.6b	95.3bc	0.0c
imida. 350 FS,	466.0 g,	furrow at planting	99.1b	97.1cd	0.0c
aldicarb 10 GR,	1707.0 g,	furrow at planting	99.1b	99.8d	0.5bc

% leaf roll (aphid top roll) relates to top 1/3 of crop canopy
All treatments were significantly different from the untreated ($P \leq 0.01$)
A common suffix denotes no significant difference ($P > 0.05$)

As in the previous year, treated plots gave comparable yields to the untreated.

1992

In 1991, although a fall off in effectiveness was indicated at the lowest rates tested, it was most obvious when plots were adjacent to untreated crop, and this became particularly clear as aphid top roll developed. It was considered that on a large scale where such edge effects would be relatively unimportant, there might be no practical difference between the rates tested in 1991. Therefore in 1992 a series of three trials was carried out, testing these lower rates again, but increasing the number of rows per plot from 2 to 4.

The data currently available suggests that against *M. euphorbiae*, imidacloprid compares favourably with aldicarb at 1146 g AI/ha, although against *M persicae* control tends to be lower (see Tables 5 and 6).

TABLE 5. % control of *Macrosiphum euphorbiae* in potatoes from imidacloprid, England 1992

Site:			Thurston	Ramsey	Deal	
Area:			Suffolk	Cambs	Kent	
Date planted:			6/5/92	27/4/92	24/3/92	
Days after planting:			71	78	113	
Growth stage:			early fruit	in flower	fruiting	mean
Treatment,	AI rate /100 kg* or/ha,	applied to				
untreated (apterae/30 leaves)			(73.2)a	(344.0)a	(19.0)a	
imida. 5 GR,	233 g,	furrow at planting	94.8b	77.5b	63.2b	78.5
imida. 350 FS,	233 g,	furrow at planting	90.2b	88.9c	75.0b	84.7
imida. 350 FS,	3.5 g*,	tubers on 10/3/92	93.4b	92.6c	52.6b	79.5
aldicarb 10 G,	1146 g,	furrow at planting	98.0b	81.0b	55.3b	78.1

A common suffix denotes no significant difference ($P > 0.05$)

TABLE 6. % control of *Myzus persicae* in potatoes from imidacloprid, England 1992

Site:			Thurston	Deal	
Area:			Suffolk	Kent	
Date planted:			6/5/92	24/3/92	
Days after planting:			54	78	
Growth stage:			43 cm tall	in flower	mean
Treatment,	AI rate /100 kg* or/ha,	applied to			
untreated (apterae/30 leaves)			(57.3)a	(76.8)a	
imidacloprid 5 GR,	233 g,	furrow at planting	90.7b	89.9b	90.5
imidacloprid 350 FS,	233 g,	furrow at planting	93.9bc	96.4bc	95.1
imidacloprid 350 FS,	3.5 g*,	tubers on 10/3/92	86.9b	96.4bc	91.7
aldicarb 10 G,	1146 g,	furrow at planting	100.0c	99.02c	99.5

A common suffix denotes no significant difference ($P > 0.05$)

SUMMARY AND CONCLUSIONS

Imidacloprid as an aphicide in potatoes offers a high level of efficacy and persistence combined with flexibility of application. Seed treatments can be applied before or at the time of planting using a dry powder treatment or by spraying tubers on a roller table. In-furrow treatments can also be applied as a spray or as a granule.

Results so far have indicated that rates of application as low as 233 g AI/ha (equivalent to 6.3 g AI/100 kg seed tubers) can give comparable control to the standard treatment, aldicarb. However, for consistency against *M. persicae* and *M. euphorbiae* a higher rate would be more appropriate.

No data on virus transmission were obtained as trials were designed to evaluate aphid control. However, work by Woodford & Mann (1992) has shown that through aphid control, imidacloprid can reduce the incidence of PLRV.

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SYSTEMIC EFFECTS OF IMIDACLOPRID ON APHID FEEDING BEHAVIOUR AND VIRUS TRANSMISSION ON POTATOES

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ABSTRACT

In glasshouse experiments, apterous *Myzus persicae* detected imidacloprid applied to the petioles of excised potato leaves at concentrations of 2.5, 5.0 or 25 ppm, and significantly more aphids walked off treated leaves compared with untreated leaves. Electrical Penetration Graphs (EPG) showed that aphids probed for shorter periods on excised potato leaves treated systemically with imidacloprid at 2.5, 5.0 and 25 ppm than on untreated leaves. Imidacloprid decreased the duration of the EPG wave form associated with phloem feeding. In a potato field trial, a granular formulation of imidacloprid (5GR), applied in–furrow at planting at 1.75 or 3.5 g AI/100 m, controlled the spread of potato leafroll virus better than aldicarb 10% granules at 4.3 g AI/100 m or imidacloprid 350 FS applied to the surface of the seed tubers at 12.6 or 25.2 g AI/100 kg before planting.

INTRODUCTION

Granular formulations of systemic organophosphorus or carbamate insecticides, applied at planting, are currently the most effective means of controlling aphids and the spread of potato leafroll virus (PLRV) in seed potato crops (Woodford *et al.*, 1983). However, concern over safety and risks to the environment resulting from the use of such toxic pesticides had led to restrictions on their use on potatoes in some countries. Imidacloprid is a new systemic insecticide with low mammalian toxicity and a different mode of action from that of conventional insecticides (Elbert *et al.*, 1990), which has given excellent control of aphids and virus spread in sugar beet and winter barley (Dewar & Read, 1990; Schmeer *et al.*, 1990). The observation by Dewar & Read (1990) that imidacloprid–pelleted sugar beet seed treatments gave a better control of virus yellows than aldicarb was particularly interesting because it offered a safer alternative to the use of insecticidal granules; they suggested that imidacloprid seed treatment acted as an aphid repellent. This paper describes laboratory experiments on the systemic effects on aphid feeding behaviour of low concentrations of imidacloprid applied to excised potato leaves, and a field trial to assess the systemic efficacy of imidacloprid in preventing the inoculation of PLRV by *Myzus persicae*.

MATERIALS AND METHODS

The experiments were made with *M. persicae* reared on turnip or Chinese cabbage in a controlled environment room at 18°C and 16 h:8 h light:dark photoperiod.

Laboratory experiments

Aphid settling and mortality

Two experiments were done in a glasshouse at *c.* 20°C using excised young/mature leaves from 4–6 wk old plants of potato, cv. Maris Piper. The cut petiole of each leaf was inserted through stretched parafilm into a glass tube containing 30 ml of water or dilutions of imidacloprid 200 SL, a soluble concentrate formulation of imidacloprid containing 200 g AI/litre. After 24 h, five apterous adult *M. persicae*, starved for 6 h, were placed on to each leaf. The tubes were placed in the centre of individual white plastic cylindrical dishes 17 cm diameter, 6 cm deep (No. 40, Pioneer Plastic Containers Ltd, Feltham, England). A 1.5 cm deep moat of weak detergent solution (0.5% 'Teepol') trapped aphids walking off the leaves in experiment 1. For the second experiment, the inside walls of the dishes were coated with PTFE (ICI Fluoropolymers, ICI plc, Blackpool, England) to prevent aphids escaping, and two untreated potato leaves were placed in each dish to provide feeding sites for aphids that walked off the test leaf. The number of aphids alive on the leaf, and the number in the moat were recorded after 18 h (experiment 1) or 24 h (experiment 2). Aphids that left the test leaves in experiment 2 were recorded as either alive (walking or feeding on untreated leaves) or dead. There were 10 replicates of two rates of imidacloprid in experiment 1 and 12 replicates in experiment 2. Each experiment included an untreated water control. The proportion of aphids walking off the test leaves (experiment 1) and the proportions of live or dead aphids that had left the test leaves (experiment 2) were transformed to logits and compared using a generalised linear model.

Electrical monitoring of aphid feeding behaviour

Electrical Penetration Graphs (EPG) were recorded for aphids on potato leaves treated systemically with imidacloprid, as above, and on control leaves. In this method (Tjallingii, 1978), the aphid and leaf form part of a DC circuit. The EPG is a record of the amplified signal generated when the aphid completes the circuit by penetrating the leaf with its stylets. Several EPG wave forms have been classified according to their amplitude, frequency, voltage level and electrical origin (Tjallingii, 1988). One wave form, a prolonged series of small peaks and waves at a low potential level, has been correlated with stylet penetration of phloem sieve elements and sap ingestion (Kimmins & Tjallingii, 1985). Apterous adult *M. persicae*, fed on untreated potato plants for 24 h, were removed and starved for 30 min. A fine gold wire tether (25 µm diameter), *c.* 3 cm long, was attached to the dorsal surface with water-based conducting silver paint. Aphids were allowed to acclimatise on an untreated potato leaf for 1 h, then starved for a further 3 h. The free end of the wire was then connected to a DC amplifier (Tjallingii, 1988) with an input impedance of 10^9 Ω and a gain of x 50 (Murphy Developments, Hilversum, The Netherlands) in a Faraday cage. EPGs were recorded for 3 h on excised potato leaves treated with imidacloprid 200 SL at 2.5, 5.0 and 25 ppm. Records of the number and durations of probes, and of the occurrence of sustained periods of lower potential, were made from aphids on 10 leaves at each concentration of imidacloprid (one aphid/leaf) and on 15 untreated control leaves.

Field trial

A field trial was made at Longforgan, East Perthshire in 1991 to test the effect of tuber or granular applications of imidacloprid on the spread of PLRV from untreated PLRV 'infector' plants to neighbouring treated plants in a crop of initially virus-free potato, cv.

Maris Piper. Three PLRV-infected tubers were planted, one per drill, on 24 April in the centre of plots of seed tubers 8 m long x eight drills, 0.76 m apart. Six treatments (Table 3) were replicated five times in a randomised block layout. The same seed stock (Super Elite I, 35-45 mm) was used for all the treatments. Tubers (25 kg batches) were sprayed with imidacloprid 350FS, 12 days before planting, using a Fischer spinning disk applicator mounted above a roller table. The granules were applied by hand into the open drills shortly after planting, taking care not to apply any granules within 35 cm of each infected tuber.

Aphid assessments

Aphid numbers on untreated plots were monitored at 2 wk intervals on one middle and one lower leaf from each of 10 plants/plot, excluding plants near to the centre of the plots in order not to disturb vectors. All treatments were sampled on 31 July. Because of low natural aphid infestations, each infector plant was inoculated with five apterous adult *M. persicae* on 10 June and *c.* 100 small *M. persicae* nymphs on 24 June.

PLRV assessments

Virus spread was assessed by harvesting six tubers on 2 September from each of two plants on either side of, and in the same drill as, each infector plant. A bulked sample of all treatments, comprising one tuber/plant from 120 plants, was taken from the plot boundaries. The tubers were planted on 27 April 1992. Plants produced by tubers infected in 1991 showed clear symptoms of secondary leaf roll and were counted on 24-26 June 1992.

TABLE 1. The proportion of *M. persicae* leaving potato leaves treated systemically with imidacloprid 200 SL, recorded after 18 h (Experiment 1) or 24 h (Experiment 2), and the proportion of dead aphids in Experiment 2.

Treatment	Proportion leaving Experiment 1	 Experiment 2	Proportion dead Experiment 2
Water control	0.44	0.47	0.35
Imidacloprid 2.5 ppm	0.82	0.90	0.63
Imidacloprid 5.0 ppm	0.86	-	-
Imidacloprid 25.0 ppm	-	1.00	0.83

All treatment effects significantly different from control (P<0.001).

RESULTS

Laboratory experiments

Aphid settling and mortality

Experiment 1: Almost twice as many aphids walked off treated leaves as off untreated leaves (P<0.001) (Table 1). There was no significant difference between the responses to the two rates.

Experiment 2: Most of the aphids that walked off test leaves did not settle on the untreated leaves in the dishes, and there were no significant differences between the proportions of live aphids found on these leaves, but significantly more of the aphids that walked off treated leaves were dead ($\underline{P}<0.001$), compared with those that walked off untreated leaves (Table 1). Significantly more of the aphids from leaves treated with imidacloprid at 25 ppm were dead than those from leaves treated with imidacloprid at 2.5 ppm ($\underline{P}<0.05$).

Electrical monitoring of aphid feeding behaviour

Aphids quickly settled to feed on untreated leaves. On treated leaves they walked for longer periods and probed more often, making a series of brief probes lasting, in total, less than half the total probing time of aphids on untreated leaves (Table 2). The EPG records for most of the aphids on untreated leaves indicated one or more periods of sustained phloem contact. The proportion of aphids on treated leaves that produced this wave form decreased with increasing concentration of imidacloprid and the duration of phloem contact was reduced from almost 2 h on untreated leaves to <11 min (Table 2).

TABLE 2. Effect of systemic application of imidacloprid on the number of probes made by *M. persicae* in 3 h, the number of aphids making phloem contact, and the duration of probing and phloem contact.

Imidacloprid (ppm)	No. of probes	No. aphids making contact	Duration (min) of	
			Probing time	Phloem contact
25.0	5.6	4/10	56	3
5.0	5.3	6/10	70	8
2.5	4.9	7/10	72	11
Untreated control	2.5	13/15	182	118

Field trial

Aphid assessments

Natural infestations of aphids were late and slow to develop. On 31 July, 14 wk after planting, numbers of *Macrosiphum euphorbiae* on all treatments were significantly lower than on untreated plots ($\underline{P}<0.001$). Numbers of *M. persicae* were significantly lower on all treatments, except aldicarb, than on the untreated plots ($\underline{P}<0.01$) (Table 3).

TABLE 3. Effect of tuber or granule treatments on aphid numbers (square root transformation)/20 potato leaves, 14 wk after planting, and on the percentage of tubers infected with PLRV.

Treatment	Aphid numbers *M. persicae*	 *M. euphorbiae*	% infected tubers
Tuber treatments:			
Imidacloprid 350FS (25.2 g AI/100 kg)	1.1	1.2	74.4
Imidacloprid 350FS (12.6 g AI/100 kg)	1.3	1.0	79.7
Granule treatments:			
Imidacloprid 5GR (3.5 g AI/100 m)	0.9	0.4	66.1
Imidacloprid 5GR (1.75 g AI/100 m)	0.9	0.7	64.7
Aldicarb (Temik 10G) (4.3 g AI/100 m)	1.6	3.1	74.2
Untreated control	3.0	7.7	85.8
SED	0.70	1.37	5.10

Virus spread

There were high levels of tuber infection in all the samples from plants close to infectors, but only one tuber in the bulked sample (0.83%) was infected, indicating limited movement of *M. persicae* from the infectors. All the treatments decreased the percentage of infected tubers ($P<0.002$). Imidacloprid granules gave better control than aldicarb ($P<0.05$). The control achieved with imidacloprid 350 FS applied to seed tubers was not significantly different from that with aldicarb granules.

DISCUSSION

Uncaged *M. persicae* detected low concentrations of imidacloprid applied to the petioles of excised potato leaves. In experiment 2, most of the aphids that walked off the leaves onto which they had been placed failed to settle and feed on the available untreated leaves. It is unclear whether a toxicant effect or starvation was responsible for the higher mortality with imidacloprid treatments, but the effect was dose–related (Table 1), suggesting that imidacloprid was acting as an insecticide rather than as a repellent or antifeedant. Indeed, the EPG results showed that aphids did probe treated leaves, but for shorter periods than they did on untreated leaves (Table 2). The correlation of the sustained potential drop EPG wave form with phloem element penetration has been observed only when this pattern is produced for more than 8 min (Kimmins & Tjallingii, 1985). It is unlikely, therefore, that aphids which produced this EPG pattern for shorter periods on treated leaves would have imbibed phloem sap. Although natural infestations of aphids in the field trial were rather low, imidacloprid, including seed tuber treatments, controlled the numbers of *M. euphorbiae* as well as, or better than, aldicarb. It was hardly surprising that some of the imidacloprid–treated plants became infected with PLRV, given their proximity to the large infestations of *M. persicae* that developed on the untreated PLRV infector plants. Nevertheless, in spite of the high inoculum pressure, systemic treatments of imidacloprid controlled virus spread as well as or better than aldicarb granules.

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EFFECT OF IMIDACLOPRID ON TRANSMISSION OF VIRUSES BY APHIDS IN SUGAR BEET.

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ABSTRACT

In laboratory experiments, imidacloprid, applied as a seed treatment at 45 and 90g a.i. per unit of seed, reduced transmission of beet mild yellowing virus (BMYV), but not beet yellows virus (BYV), by *Myzus persicae* confined on young sugar beet plants for three days. The persistence of imidacloprid against BMYV declined between five and seven weeks after sowing. The differential effect of imidacloprid on the two viruses is discussed in relation to feeding behaviour and possible location of the insecticide within the plant.

INTRODUCTION

Imidacloprid is a systemic insecticide which gives good control of aphids on sugar beet when applied to the pelleting material surrounding sugar beet seed, or as a granule applied next to the seeds at drilling (Dewar and Read, 1990; Schmeer *et al*., 1990). In laboratory studies the insecticide has given equivalent control of moderately resistant and highly resistant *Myzus persicae*, as defined by Sawicki & Rice (1978), and thus offers an alternative to the currently available carbamate, organophosphorus and pyrethroid insecticides.

Field experiments in 1990 demonstrated the ability of the seed treatment and granular formulations of imidacloprid to control aphid-transmitted virus yellows disease in sugar beet, giving equivalent or better control than the standard aldicarb (Dewar & Read, 1990). However, the disease is caused by two viruses with quite different properties and the previous study did not discriminate between them. This paper describes the results of laboratory experiments designed to investigate the effects of imidacloprid applied as a seed treatment on the ability of aphids to transmit beet yellows virus (BYV), which has a semi-persistent relationship with the vector (Sylvester, 1956), and beet mild yellowing virus (BMYV), which is a persistent luteovirus (Russell, 1962).

MATERIALS AND METHODS

Treatments

Imidacloprid was applied as a wettable powder (70WS) during the seed-pelleting process by Germain's UK Limited of King's Lynn, at 45 and 90 g a.i. per unit of seed (cv. Rex). One unit of seed contains 100,000 seeds, enough to drill approximately one hectare. Treated seed was compared with untreated seed in the experiments. All seed received basal applications of thiram (5 g a.i./unit) and hymexazol (10.5 g a.i./unit) to control seedling diseases.

Effect of imidacloprid on the transmission of BYV and BMYV

Five adult or fourth instar apterous *Myzus persicae* from a moderately resistant (R_1) clone which had been cultured on sugar beet infected with BYV or BMYV were clip-caged onto the undersurface of the youngest expanded leaf (leaf 1 or 2) on a healthy beet plant at the 4-leaf stage. Twenty plants per treatment were exposed in this way to each virus giving a total of 100 aphids per treatment per virus. The aphids were confined to the plants for 3 days to maximise the opportunities for transmission, and thereafter removed. The plants were then fumigated using nicotine to kill aphids before being transfered to a constant environment room where they were kept for eight weeks at 20°C with a 16 hr photoperiod.

For 8 weeks after inoculation the presence of BYV or BMYV was assessed at weekly intervals in plants exposed to the respective viruses using ELISA techniques described by Smith (1989). This experiment was repeated twice.

The effect of plant age on the efficacy of imidacloprid

Five adult or fourth instar *M.persicae* from the BMYV-infected culture were caged on healthy plants grown from untreated seed and imidacloprid-treated seed (at the 90 g rate only) 2, 3, 4, 5, 6, 7, 8 or 9 weeks after sowing. Plant size ranged from the cotyledon stage to the 12-leaf stage. Whole plant cages were used at the youngest growth stage, but clip cages were used on older plants. The clip-cages were placed on the undersurface of the youngest expanded leaf at each growth stage. For example, on 3-week-old plants, which only had two leaves, aphids were caged on those leaves, but on 8- or 9-week-old plants, which had 12 leaves, aphids were placed on leaves 5 or 6 which were fully expanded. This process relates closely to natural colonisation behaviour, since aphids normally choose young leaves on which to feed. However cages could not be placed on very young expanding leaves because the process of expansion often allows aphids to escape where a leaf vein lifts the cage slightly. Fifteen plants in each age group were exposed to infection for three days; as before, aphids were then removed, the plants fumigated with nicotine, and kept for six weeks in the constant environment room. The presence of BMYV was assessed using ELISA four and six weeks after inoculation, and a plant was deemed to be infected if a positive ELISA reaction was recorded in either of these two tests. This experiment was also repeated twice.

RESULTS

Effects of imidacloprid on virus transmission

BYV transmission

In the first of the two experiments BYV was detected in test plants 2 weeks after exposure to infective aphids, and the percentage of plants which tested positive for BYV increased rapidly and was almost complete after 5 weeks (Fig. 1a). There were no differences in infection between the two imidacloprid treatments and untreated plants.

In the second experiment, the ELISA tests two weeks after infection failed due to technical error, but BYV was detected in 40% of plants three weeks after inoculation (Fig. 1b). Again maximum infection occurred after 5 weeks and there were no differences between treatments.

BMYV transmission

In the first experiment BMYV was also first detected two weeks after inoculation but the maximum proportion detected rose to only 40% in untreated plants after 5 weeks. Both the 45 and 90 g rates of imidacloprid reduced infection substantially (χ^2 = 15.86, $P<0.001$) (Fig. 2a). The apparent slight decline in infection in later tests was probably due to the disparate distribution of virus in older plants (Smith, 1989).

In the second experiment BMYV was detected in over 50% of plants after 3 weeks, reaching a maximum of over 90% after 5 weeks in untreated plants. The two imidacloprid treatments again reduced infection substantially (χ^2 = 22.57, $P<0.001$), but the 45 g rate gave slightly better control than the 90 g rate (Fig. 2b).

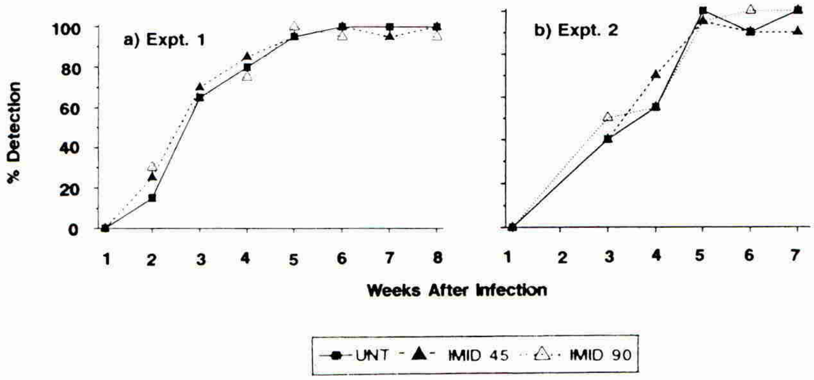

Fig. 1 The effect of imidacloprid (IMID), applied at 45 and 90 g a.i. per unit to sugar beet pellets, on the transmission of beet yellows virus (BYV) by infective aphids caged on treated leaves for 3 days: UNT = untreated.

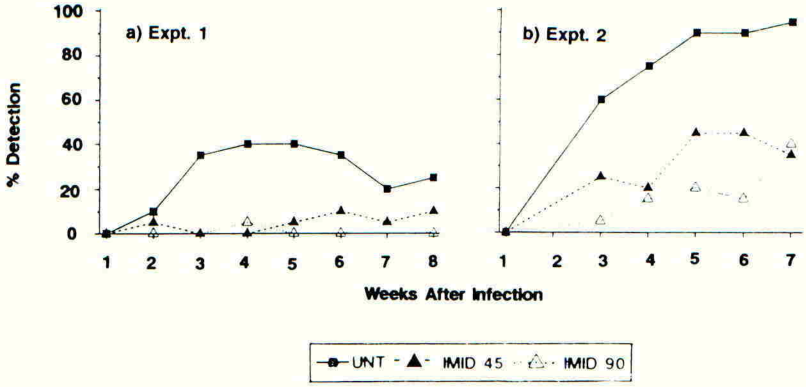

Fig. 2 The effect of imidacloprid (IMID), applied at 45 and 90 g a.i. per unit to sugar beet pellets, on the transmission of beet mild yellowing virus (BMYV) by infective aphids caged on treated leaves for 3 days: UNT = untreated.

Persistence of imidacloprid

The results of the previous trials indicated that only BMYV transmission was reduced by imidacloprid. Therefore the persistence of the insecticide was tested against this virus only.

In Experiment 3 all the untreated plants which were exposed to infective aphids when 3-4 weeks old (at the 2 and 4-leaf stages) were infected by BMYV, but the proportion infected declined to less than 50% in plants which were 6 or more weeks old at the time of exposure (Fig. 3a). Imidacloprid significantly decreased the proportion of 3 and 4 week old plants which became infected (χ^2 = 9.83 and 6.16 respectively; $P<0.05$) but did not decrease infection of plants 5 weeks old or more at the time of infection compared to untreated plants.

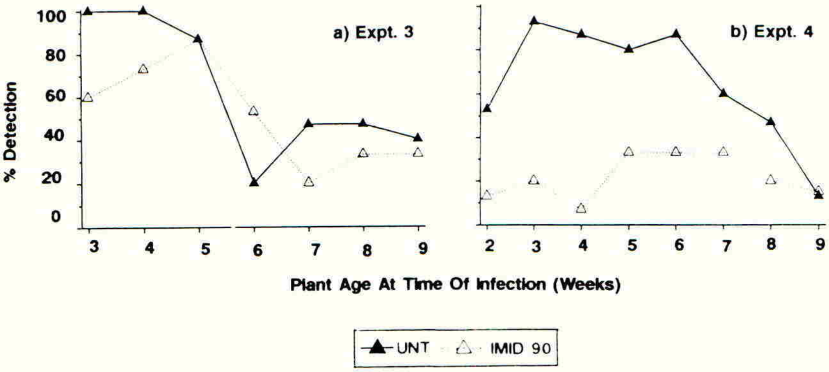

Fig. 3 The effect of plant age on the persistence of imidacloprid (IMID), applied at 90 g a.i. per unit to sugar beet pellets, in controlling BMYV in sugar beet. UNT = Untreated.

In Experiment 4, not all untreated plants became infected when exposed to aphids at two weeks old, but this rose to over 90% when 3 weeks old and thereafter declined as in experiment 3, such that virus was detected in less than 20% of plants which were 9 weeks old at the time of infection. Imidacloprid significantly reduced virus infection in plants up to 6 weeks old (χ^2 = 5.68, 18.69, 22.33, 6.94 and 9.51 for weeks 2, 3, 4, 5 and 6 respectively; $P<0.05$) but not in older plants.

DISCUSSION

Imidacloprid significantly reduced transmission of BMYV in all experiments but had no effect on BYV transmission. This difference probably arises from the properties of the two viruses in relation to the feeding behaviour of the aphid vectors. As a semi-persistent closterovirus, BYV may be transmitted via the mesophyll cells of sugar beet leaves, since it can be found there in BYV-infected plants (Cronshaw *et al.*, 1966) and aphids often probe into and imbibe fluid from those cells (McLean & Kinsey, 1968). Such penetrations can occur within minutes of initial puncturing of the leaf surface, and BYV can certainly be acquired during short penetrations by aphids transferred from infected plants (Watson, 1940). Conversely, BMYV needs to be injected by aphids into the phloem during sustained sieve element ingestion. Although BMYV can be transmitted by viruliferous aphids during a 30 minute feed (Björling & Nilsson, 1966) longer feeds were needed for efficient transmission (Russell 1962) and more recent feeding studies have shown that penetration to the phloem can often take several hours (Tjallingii, 1992).

Since the mode of action of imidacloprid is one of slow poisoning through systemic imbibition, not rapid knockdown as with pyrethroids (Leicht, 1992), aphids infective with BYV may be able to transmit this virus to mesophyll cells before they acquire a lethal dose of the insecticide. Aphids infective with BMYV may be killed or severely poisoned during the probing process before feeding commences, thus preventing or at least reducing the chances of transmission of this virus.

As might be expected, the persistence of imidacloprid declined with time after sowing. Differences between untreated and treated plants were not significant five weeks after drilling in Experiment 3 and 7 weeks after drilling in Experiment 4. The latter result is similar to those from previous field experiments (Dewar & Read, 1990).

The decline in proportion of both untreated and treated plants infected with BMYV as plants aged may be partly a consequence of caging aphids on nutritionally unsuitable leaf tissue. Reproduction of *M.persicae* is poor on old leaves and old plants (Williams, 1985), and, as the leaves mature, aphids move to seek more favourable nutrition (Jepson, 1983). However, it is difficult to cage aphids on young heart leaves due to the increased risk of escape from the cage. It is also more difficult to detect BMYV in old plants because the virus multiplies and spreads more slowly through the plant tissues as the plant matures (Smith, 1989). Thus both mechanisms may have contributed to the apparent decline in infection.

The differential effect of imidacloprid on transmission of the two viruses causing yellows in sugar beet may favour infection of BYV over BMYV. However, this would happen only in those plants which are infected by the primary vector. Subsequent secondary spread of BYV would still be greatly reduced by death of that vector and its offspring after contact with the insecticide as was seen in the field experiments in 1990 (Dewar & Read, 1990).

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CORN ROOTWORMS AND SOIL INSECTICIDES: MANAGEMENT LESSONS FROM ON-FARM STUDIES IN ILLINOIS

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ABSTRACT

The western and northern corn rootworms, *Diabrotica virgifera virgifera* and *D. barberi* respectively, are key pests of corn throughout the midwestern region of the United States. In Illinois alone, approximately 88 percent (1 million ha) of the corn that is not rotated with another crop is treated with a soil insecticide each spring. On-farm participatory research studies conducted in Illinois from 1986 to 1991 indicate that grossly more hectares are being treated than necessary in rotated and continuous corn by producers. In addition, some experiments conducted over a three-year period indicate that corn rootworm survival is actually increased in certain years when a soil insecticide has been applied. This may serve to exacerbate the long-term severity of corn rootworm infestations in much of the major corn-producing areas of the United States.

INTRODUCTION

Western and northern corn rootworms, *Diabrotica virgifera* and *D. barberi* respectively, have the potential to inflict serious economic losses to corn production systems throughout the midwestern region of the United States whenever corn, *Zea mays*, is grown without rotation with another crop. This system of corn production is often referred to as "continuous" corn. The biology, ecology, sampling methodologies, and management tactics for corn rootworms have been thoroughly reviewed (Levine & Oloumi-Sadeghi, 1991).

The use of soil-applied granular insecticides delivered at planting by producers is the predominant strategy for corn rootworm control in the corn belt of the United States. Peak use of granular soil insecticides occurred in the late 1970s and early 1980s when it is estimated that 8,094,000 ha to 12,141,000 ha of corn were treated each spring (Suguiyama & Carlson, 1985). In Illinois, 1,333,144 ha of continuous corn were grown in 1990 and 88 percent of these hectares were treated (997,167 ha) with a soil insecticide targeted primarily at corn rootworms (Pike & Gray, 1992). Despite the recommendation of the Illinois Cooperative Extension Service against the practice of treating first-year corn (corn rotated to another crop annually), producers in Illinois continue to treat approximately 13 percent (375,600 ha) of these crops each spring (Pike & Gray, 1992).

Beginning in 1986, a series of on-farm participatory research projects were initiated throughout the northern half of Illinois in order to: 1) examine the incidence and severity of rootworm damage in cornfields rotated annually with soybeans; 2) evaluate the effectiveness of soil insecticides applied at reduced rates and simultaneously assess the severity of root damage in selected continuous cornfields. In addition, the long-term management ramifications for rootworm populations as a result of annual insecticide applications were evaluated by examining western and northern corn rootworm beetle emergence data from 1983 to 1985. These data were collected from university experimental research farms. These research efforts over a nine-year period (1983-91) are condensed in this paper from a number of articles (Gray *et al.*, 1991; Gray *et al.*, 1992a, 1992b; and Steffey *et al.*, 1992).

EXTENT OF CORN ROOTWORM LARVAL DAMAGE IN CORN AFTER SOYBEANS IN ILLINOIS

Corn root damage caused by western and northern corn rootworm larvae has been discussed in the scientific literature since the 1880s. However, these insects did not become serious pests in the corn belt until farmers started to grow corn without an annual rotation with a nonhost crop. Corn rootworm adults deposit the majority of their eggs in cornfields and larvae can survive and grow to maturity only on the roots of corn and some other grass species in the following year. Therefore, corn grown after a nonhost crop such as soybeans typically escapes rootworm larval injury.

Despite the apparent effectiveness of crop rotation as a management tactic, reports of crop rotation that failed to prevent corn rootworm larval injury have been documented. The two main hypotheses for the occurrence of rootworm larval damage to corn grown in rotation with other crops are: 1) northern corn rootworm beetles deposit eggs in fields other than corn the preceding year, or 2) northern corn rootworm eggs go through a period of prolonged diapause (eggs pass through two or more winters prior to hatching).

Chiang (1965) documented that northern corn rootworm eggs could pass through more than one winter; however, he found that the percentage of eggs with this trait was very small and not likely to be of economic importance. Chiang's research provided more initial support for the hypothesis that lent credence to oviposition in nonhost crops as the primary factor that explained why root injury sometimes occurred in cornfields rotated with other crops. However, other research efforts have not supported the oviposition hypothesis (Boetel *et al.*, 1992). Krysan *et al.* (1986) verified the presence of the prolonged diapause trait in northern corn rootworms from several sites in South Dakota, Iowa, and Minnesota.

In 1986, we began surveys to determine the extent of rootworm larval injury in cornfields planted after soybeans. Surveys were taken in producers' fields in 30, 29, and 30 northern and central Illinois counties during late July in 1986, 1987, and 1988, respectively. Ten fields within each county were sampled, each of which had been planted to soybeans the previous year. No efforts were made to determine whether a soil insecticide had been applied at planting; however, a 1985 pesticide use survey for Illinois (Pike, 1986) revealed that 13.2 percent of the corn grown after soybeans are treated annually.

The root systems of five plants, taken at random, were removed from each field and evaluated for rootworm feeding injury. Each root system was assigned a root rating on the Iowa 1 to 6 scale (Hills & Peters, 1971). In 1989, similar procedures were followed; however, survey efforts were concentrated in 10 counties in the northeastern and eastern regions of Illinois.

From 1986 to 1989, 5,406 root systems were evaluated for corn rootworm larval injury from 1,100 fields in 35 different counties. The results from these surveys reveal that corn rootworm larval injury in corn after soybeans occurs infrequently in Illinois. Only 19 of the 1,100 fields (1.7%) had an average root rating of 3.0 (several roots pruned, but not an entire node) or greater. Turpin *et al.* (1972) suggested that a root rating of 2.5 on the Iowa 1 to 6 scale represented an economic level of damage. Most researchers currently use a root rating of 3.0 as a measure of economic injury; however, Sutter *et al.* (1990) proposed that a rating of 4.0 (one node of roots destroyed) is probably a more accurate economic injury index. If Sutters' threshold is used, almost none of the surveyed fields would have reached this proposed level of economic importance.

The confirmation of the prolonged diapause trait in northern corn rootworms in the mid-1980s prompted manufacturers of soil insecticides to target their efforts at the perceived threat. Several organizations developed promotional campaigns for their products aimed at alerting corn producers to the threat of rootworm larval damage to first-year cornfields. These sales campaigns were overt attempts to extrapolate from "worst case" data to promote the sale of soil insecticides.

Results from these survey efforts were very useful in our educational programs that were designed to show producers that soil insecticides are rarely needed to prevent economic losses caused by rootworms in corn grown after soybeans in Illinois.

OPTIMIZING SOIL INSECTICIDE RATES AND ESTIMATING PREVALENCE OF ECONOMIC INJURY

Identifying an optimum application rate for a given soil insecticide for corn rootworms is important for many reasons: to reduce the risk of environmental contamination; to lessen the potential adverse effects on nontarget organisms; and to save the farmer unnecessary production costs. Beginning in the early 1970s, entomologists at several midwestern universities in the United States have evaluated the root protection provided by applying less than the manufacturers' recommended rate. These experiments were primarily conducted in small plots with single-row treatments.

Most current recommended rates (1.12 to 1.46 kg AI/ha) were established without any knowledge of the ability of many corn hybrids to compensate for corn rootworm injury. Also, current recommended rates were aimed at keeping rootworm injury at or below a root rating of 3.0 on the Iowa 1 to 6 scale. If the new suggested threshold of 4.0 is more accurate, striving to keep root injury below a rating of 3.0 may not be worth the environmental and economic costs of continuing to use soil insecticides at the current rates.

Thus far, universities have been reluctant to recommend the application of soil insecticides at rates below those suggested on the chemical manufacturer's label because of the uncertain legal ramifications. Many farmers also are unwilling to try reduced application rates, primarily because of chemical companies' failure to support this initiative. A primary concern raised by the chemical industry has been the uncertainty over whether producers could calibrate their machinery carefully and effectively deliver less than recommended rates. So as to address this concern, we coordinated 29 on-farm research experiments in ten counties located throughout northern Illinois in 1990 and 1991. All experiments were conducted in plots that had been devoted to corn production the preceding year. Our objectives were as follows: 1) to evaluate the efficacy of reduced soil insecticide rates when applied by farmers with their equipment in large on-farm replicated experiments; and 2) to determine the incidence of economic corn rootworm injury in these continuous corn production systems.

Producers were free to select the product of their choice during the two-year study. The following insecticides were chosen: carbofuran, chlorpyrifos, fonofos, phorate, tefluthrin, and terbufos. Three classes of insecticide chemistry were represented in these experiments. Terbufos was the insecticide most often selected with 15 and 9 farmers using this product in 1990 and 1991, respectively. Based upon the results of our two-year, on-farm study, and small plot efficacy trials conducted for many years, it is evident that farmers who are willing to calibrate their planters to deliver soil insecticides at 3/4 the recommended rate can achieve satisfactory root protection in most instances. Yield differences between recommended and 3/4 insecticide application rates were statistically negligible in 1990 and 1991.

In 1990, 20 of the 29 experiments (69%) had root injury in the untreated areas that averaged 3.0 or above on the Iowa State 1 to 6 scale. The following year, only 6 of 29 trials (21%) had this level of damage in the untreated areas. If the two years are combined, only 26 of the 58 experiments (45%) had roots injured at or above the economic injury level of 3.0. If an economic injury level of 4.0 is used, then not a single experiment in 1991 had this average level of injury in the untreated plots. In 1990, seven of the experiments (24%) had average root injury in the untreated areas at or above a root rating of 4.0. These experiments suggest that regardless of the economic injury level used, farmers in northern Illinois may be using soil insecticides on more continuous corn than necessary.

SOIL INSECTICIDES AND CORN ROOTWORM SURVIVAL: THE INFLUENCE ON LONG-TERM POPULATION MANAGEMENT

The performance of soil insecticides is influenced by the interactions of many factors: corn rootworm larval densities and soil moisture, planting date, enhanced microbial degradation of insecticides, insecticide toxicity, planting-time conditions, and insecticide characteristics such as water solubility and vapour pressure. Soil temperature, pH, moisture, organic matter content, and microbial populations are influenced by tillage practices and therefore, may affect the interaction of insecticides and corn rootworm larvae.

Gray & Tollefson, (1988) determined that survival of western corn rootworms was not affected during the growing season in various tillage plots (no insecticide used). Our research efforts from 1983 to 1985 assessed the influence of three commonly used soil insecticides (carbofuran, chlorpyrifos, and terbufos) on western corn rootworm emergence from different tillage systems (no-till, spring chisel plough, and fall mouldboard plough). Plots were established at the University of Illinois Agricultural Engineering Farm located near Champaign, Illinois in 1983 and 1984 and at the Northwestern Illinois Agricultural Research and Demonstration Center near Monmouth, Illinois in 1985.

Cages that sampled the complete interrow width were used to estimate absolute western corn rootworm emergence. Each cage was placed over a corn plant and was made of a wooden frame to which metal screening was stapled. In 1983 and 1984, 10 emergence cages were used for each replicate combination of tillage and insecticide in split plots (240 total per year). In 1985, 220 cages were used.

Soil insecticide performance has been evaluated traditionally by using root ratings. The results of our research efforts indicate that if soil insecticides are additionally judged on the basis of their ability to reduce rootworm populations, their utility as a management tool is questionable. In 1983, significantly fewer western corn rootworm beetles emerged from the untreated plots (no insecticide used) than from insecticide-treated plots. During 1985, beetle emergence within the row cages was not limited by the use of insecticides. Beetle emergence in 1984 was greater from the untreated plots than from the insecticide-treated plots. Precipitation for June 1984 totaled only 3.1 cm, the driest June of the 3-year study.

These findings help to explain more fully the manner in which soil insecticides affect the dynamics of western corn rootworm survival. It is evident that the commonly accepted practice of using soil insecticides at planting for rootworm control may result in greater beetle emergence instead of reducing survival in certain years. Proponents of the use of soil insecticides argue that the current generation of soil insecticides was designed to prevent excessive root pruning and limit potential yield losses. On the basis of this criterion, the registered soil insecticides can most often be judged successful. However, our results suggest that the long-term severity of rootworm infestations may be exacerbated when soil insecticides are used in certain years.

CONCLUSIONS

These research efforts (1983-91) offer several findings: 1) the incidence and severity of northern corn rootworm damage to first-year corn because of extended diapause is very low in Illinois; 2) reduced application rates (3/4 rates) of several registered soil insecticides perform at comparable levels to that of recommended rates; 3) the incidence and severity of rootworm damage even in continuous corn is greatly overestimated; and 4) in certain years, soil insecticides may favour greater beetle emergence and exacerbate the long-term severity of infestations.

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EFFICACY OF REDUCED-RATE INSECTICIDE USE AGAINST CEREAL APHIDS

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ABSTRACT

One of the aims of reduced insecticide rates in pest control is that a residual population of the pest is maintained to provide food for the natural enemy fauna, so that they will remain in the field and prevent any further pest resurgence. Another is to reduce farmers' variable costs and a third is to reduce pesticide inputs. This paper describes laboratory and semi-field experiments carried out using reduced rates of the insecticides deltamethrin, dimethoate and pirimicarb, against the aphids *Sitobion avenae* and *Rhopalosiphum padi*. The laboratory experiments produced dose-response curves that gave an idea of the range of doses that could be used to give desired levels of pest control. These results were tested under more realistic conditions using mature wheat plants grown in a glasshouse and a polythene tunnel. The results from these experiments suggest that reduced doses can give adequate levels of pest control, retain a residual pest population and reduce variable costs to the farmer.

INTRODUCTION

The cereal aphids *Sitobion avenae*, *Rhopalosiphum padi*, and *Metopolophium dirhodum* are sporadic pests of winter wheat in Great Britain (Carter *et al.*, 1980). The use of insecticides to control these aphids in the summer has increased over recent years (Sly, 1986; Rands *et al.*, 1988). In 1988/89 an increase of 87.2% in the area of UK cereals treated with autumn and winter aphicides was recorded over the previous year (Anon, 1990).

At present few pesticides, with the exception of pirimicarb (Anon, 1992), demonstrate genuine physiological selectivity between pest and predator. The options for obtaining any selectivity relate more to decisions about timing, dose and targeting than the intrinsic selectivity of the insecticide (Taye & Jepson, 1988). Dosage reduction may permit two things; a greater survival rate of natural enemies because of the steeper dose response curves that many predators show in comparison with their prey when treated with insecticides (van Emden, 1989) and the maintenance of a residual pest population to provide food for the conserved natural enemies (Poehling, 1989).

The results of laboratory and semi-field experiments investigating the susceptibility of the aphid pests *S. avenae* and *R. padi* to reduced doses of three insecticides are given below to provide a basis for evaluating the potential of reduced doses of insecticides in pest control.

MATERIALS AND METHODS

Laboratory experiments

Ten fourth-instar *R. padi* were placed on damp filter papers inside glass Petri dishes (9.5 cm diameter) the walls of which were coated with "Fluon" (Poly(tetrafluroethylene)). The dishes were then sprayed with insecticide under a Potter tower which had been calibrated to deliver at a volume equivalent to 200 l/ha. The dishes were sprayed with deltamethrin, dimethoate or pirimicarb. There were 6 concentrations of AI with 5 replicates, for each of the pesticides (see Table 1). Untreated dishes were sprayed with water. After spraying, the aphids were transferred to clean Petri dishes containing new damp filter paper and covered with a ventilated chamber (Wiles, 1992). Aphid mortality was recorded at various intervals over the 24 h after spraying.

LD50 values were calculated by probit analysis (Finney, 1971). Abbot's

Fig.1. 24 h dose-response curves for three insecticides tested against *Rhopalosiphum padi* in Petri dishes.

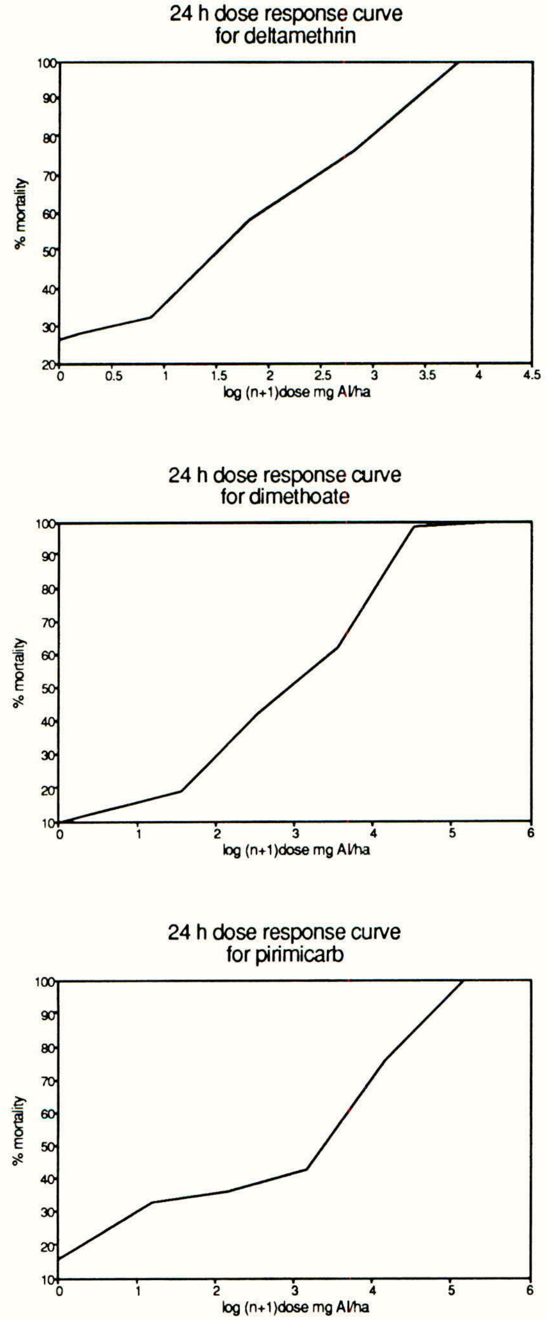
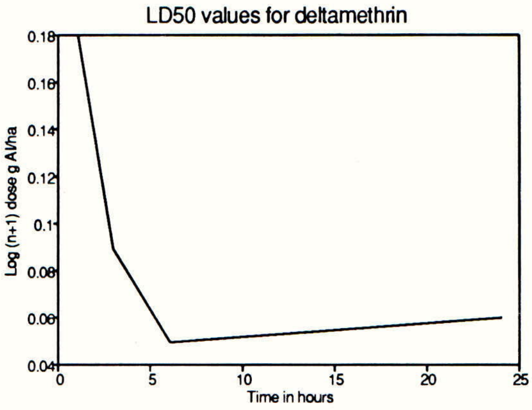
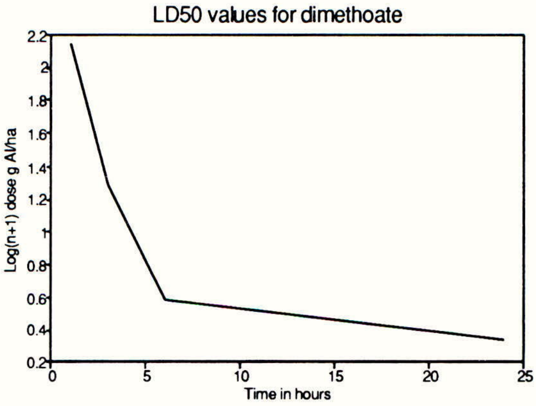
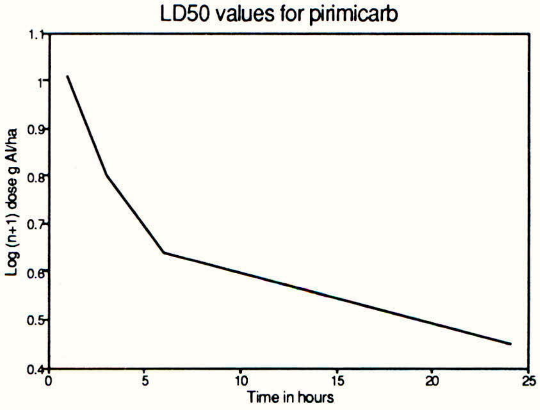


Fig.2. LD50 curves for insecticides tested against Rhopalosiphum padi in relation to time after treatment.







formula was used to correct for mortality in untreated dishes.

Semi-field experiments

Spring wheat seeds (cv. Alexandria) were sown (at a rate equivalent to field density) in a 2:1 mixture of potting compost and sharp sand (this reduces the time to maturity and produces smaller plants). The plants were grown in wooden boxes (300 x 300 x 150 mm) in a glasshouse (20°C 5°C, 16:8 hr daylight) until they reached GS 60 (Tottman, 1987). The plants were then transfered to a polythene tunnel (10 x 3 x 2 m) and infested with a virus-free culture of *S. avenae*. Seven days after infestation the plants were sprayed with deltamethrin (5 doses, 6 replicates, see Table 1); untreated plants were sprayed with water. Before the plants were sprayed they were removed from the polythene tunnel and placed outside on a concrete path. For each treatment all the replicates were arranged in a single line and sprayed at the same time using an Oxford Precision Sprayer (flat fan, 110°, 2 l/min, 2 bar). After spraying the boxes were returned to the tunnel and arranged in a randomised block design once more. The change in aphid numbers was recorded on the ears and flag leaves of 5 marked and 5 unmarked plants for each replicate over the following 7 days.

The experiment was repeated using dimethoate (4 doses, 7 replicates, see Table 1); untreated plants were again sprayed with water. This time, however, the seeds were sown in 22.5 cm pots at a rate equivalent to field density and aphid numbers were recorded only on the ears of ten randomly selected plants.

RESULTS

Fig. 1 shows the 24h dose-response curves for the three different insecticides. In all cases, aphid mortality increased as the dose increased. Fig.2 shows how the LD50 value for each insecticide declined with time over 24 h. The 24 h LD50 values for deltamethrin, dimethoate and pirimicarb are 0.161, 1.194 and 1.847 g AI/ha respectively. These values correspond to 2.5%, 0.4% and 1.3% of their respective field rates. Figs. 3 and 4 show the mean number of aphids per replicate for each treatment in the semi-field experiments. In both experiments the number of aphids increased prior to spraying; after spraying with deltamethrin aphid numbers were reduced in all treatments including the controls. In Fig. 3, with the exception of the field rate, the numbers of aphids increased between 2 and 7 days after spraying, with field rate of the insecticide giving the most sustained control. Aphid numbers were significantly different between the control and field treatment only on the penultimate assessment day ($p< 0.05$). There were no significant differences on the other days between the treatments. From Fig. 4 it can be seen that aphid numbers declined following treatment with all doses of dimethoate, whilst numbers in the controls remained fairly constant.

TABLE 1. Details of pesticides dose rates applied in the laboratory and semi field experiments.

Experiment	Pesticide	Recommended field rates(FR) (g AI/ha)	Treatment as Proportion of FR
laboratory	deltamethrin	6.25	0.0001, 0.001, 0.01, 0.1, 1, 2
	dimethoate	340	
	pirimicarb	140	
semi-field	deltamethrin	6.25	0.03,0.06,0.12, 0.25,1
	dimethoate	340	0.03,0.01,0.3,1

DISCUSSION

In the laboratory experiments all three of the insecticides gave similar levels of control of *R. padi* at the same rates. In these experiments the aphids were removed immediately after spraying to a clean petri dish. Therefore they would have been exposed only to the contact toxicity of the compound. Any residual, systemic or fumigant action of the insecticides would have been minimal. All three insecticides exhibit contact toxicity, although

Fig.3. Mean number of aphids on ears and flag leaves of wheat before and after treatment with deltamethrin (see text for statistics)

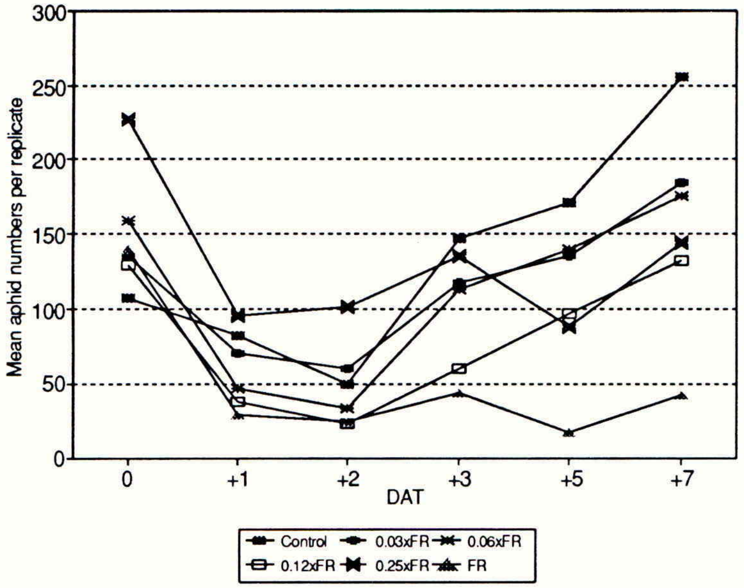
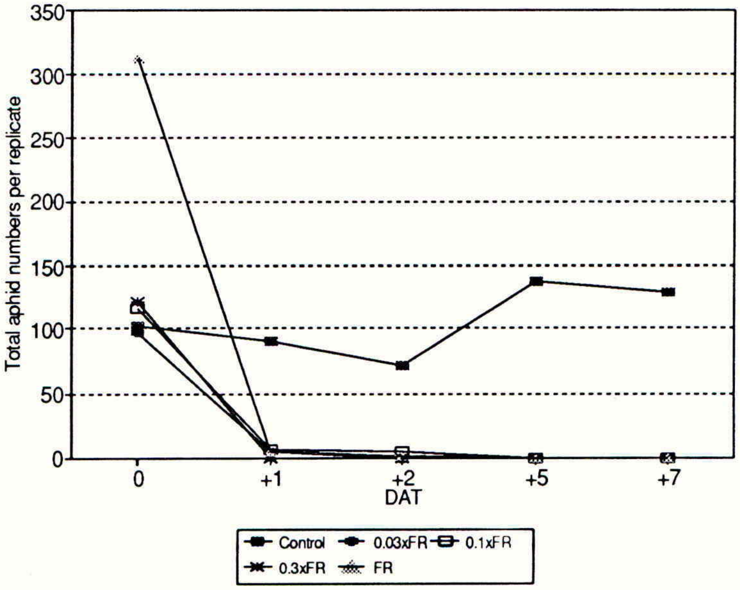


Fig.4. Mean number of aphids on wheat ears before and after treatment with dimethoate



dimethoate has additional systemic properties and pirimicarb has fumigant properties (Anon, 1992). Therefore in the laboratory, if the aphid does not receive a lethal dose by contact it is likely to survive. In the semi-field experiment however, the aphids would have been exposed to the other modes of action of the insecticides. This may explain the differences in the level of control achieved between deltamethrin and dimethoate in the semi-field experiment. The results from Fig. 4 suggest that dimethoate rates can be reduced well below the recommended rate and still give the desired level of pest control. The laboratory work used only substrates that exhibited low levels of structural complexity e.g. a Petri dish. This situation is far removed from that in the field where the aphid may be located between the spikelets on the ear or on the abaxial surface of the flag leaf, where exposure to active ingredients may be very much reduced. However even at the semi-field level, there was still the potential to control the pest with reduced doses. A potential concern about the use of reduced doses is the development of resistance, although to date resistance has only been observed in association with intensive insecticide use. Tabashnik & Croft (1982) demonstrated that low doses of insecticide were likely to reduce the potential for insecticide resistance and also help to enhance biological control.

It has been demonstrated that reduced doses can maintain a residual pest population after spraying that may potentially support a natural enemy population. The stepwise progression from laboratory to semi-field experiments used here now needs to be continued to open fields. The effects of reduced doses on the beneficial fauna in the cereal field ecosystem also need to be assessed.Reduced doses may achieve double savings for the farmer in variable costs and reduced need for repeated sprays due to the conservation of natural enemies.

ACKNOWLEDGEMENTS

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SPREADSHEETS AS RESEARCH TOOLS AND DECISION AIDS FOR CEREAL APHID CONTROL

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ABSTRACT

The use of spreadsheets as research tools and decision aids in crop protection is investigated with particular reference to cereal aphids. A spreadsheet was used to analyse data on the spatial distribution of cereal aphids, produce graphs and create a simple decision aid which can be easily used by crop protection managers. The advantages of spreadsheets over other conventional computerised methods are highlighted.

INTRODUCTION

Spreadsheets are particularly easy to use and edit. They can quickly be used to create visually informative graphs and can be customised for particular applications by making use of the macro programming commands. This makes them ideal as research tools for scientists and as aids for decision makers, such as farmers and other pest managers who must select the most profitable strategy to adopt when dealing with pests. The usefulness of spreadsheets in aiding decision making for pest management is described with reference to cereal aphids in the UK.

CEREAL APHIDS

Sitobion avenae, *Metopolophium dirhodum* and *Rhopalosiphum padi* are the three most important cereal aphid pests in the UK (Carter *et al.*, 1980; Dixon, 1987). *R. padi*, *S. avenae* and to a lesser extent *M. dirhodum* are BYDV transmitters to young cereal crops during the autumn, winter and spring, while *S. avenae* and *M. dirhodum* cause damage to cereals by their feeding in the summer. Incorrect decisions, resulting in unnecessary and unprofitable spraying of cereal crops, can easily arise due to insufficient information on the level of infestation and the profitability of control measures if they are applied.

SPREADSHEETS

Quattro Pro 4.0 (Borland International) was used to construct the model described. Columns are identified by letters and rows by numbers. Individual cells are referred to by the column and row numbers which make up their position on the work sheet. Text, numbers or formulas can be entered in cells which can be cross-referenced to create a network of inter-dependent cells. A variety of functions are provided - mathematical, string, statistical, database, financial, date and time for example. Formulas for large amounts of data need to be entered once only - they can then be copied to other locations and they are adjusted automatically to refer to the new cells to which they relate. For example, if a column of data was entered into cells B1 to B10, and the logarithms of the data were to be placed in column C1 to C10, then "@log(B1)" would be entered into cell C1 and this then copied from C1 to all cells down to C10, without any need for entering the formula separately into each cell, so C10 would contain "@log(B10)".

Graphical output can also be produced very quickly and easily by the use of pull-down menus and by entering relevant data ranges for the graphs. This makes graphing far easier than other popular graphical packages, and the graphs can be exported for use in other packages such as word processing files when producing reports and documents.

All major spreadsheets also include programming commands called macro commands, which can be used either quickly to repeat long, repetitive operations or to customise the spreadsheet for a particular application. All these different capabilities combined make spreadsheets very versatile tools for a wide range of applications.

SAMPLING

The small size and large numbers of cereal aphids make conventional methods of assessing their numbers on cereals (counting the total number of aphids on a set number of shoots or ears) awkward and time consuming, so that a simple but fairly reliable alternative method of assessing cereal aphid numbers in the field is desirable. Current sampling advice is to use counts of incidence where the density of aphids on the crop is estimated from the proportion or percentage of ears/shoots infested with one or more aphids (eg Anon, 1988; Mann & Wratten, 1987). The Agricultural Development Advisory Service (ADAS) advice uses a non-linear regression to estimate the numbers of aphids from incidence levels and is thus not easy to verify using different data or sampling methods. Two other models, however, are easier to use since they employ simple linear regressions. These are a probit model (Ward *et al.*, 1986) and a model developed by Nachman (1984). The incidence-density relationships revealed by these methods are largely dependent on the sampling methods used to determine them, and thus they cannot be used to analyse data which has been collected with a different sample size.

In this study, independent control data from a number of experiments on cereal aphids on winter wheat at Rothamsted between the years 1988 and 1992 inclusive. For each sample, ten groups of 5 shoots were selected haphazardly and aphids counted. Linear regressions were then done using the appropriate transformations for each of the incidence-density models chosen (equations 1 and 2).

Probit model:

$$\log\mu = a_1 \mathrm{Probit}(P_{(i)}) + b_1 \ldots\ldots\ldots\ldots(1)$$

Nachman's model:

$$\log\mu = a_2 \log(-\ln(1 - P_{(i)})) + b_2 \ldots\ldots(2)$$

where a_1, b_1, a_2 and b_2 are estimated by regression, $P_{(i)}$ is the percentage (equation 1) or proportion (equation 2) of infested shoots and μ is the mean density.

The necessary transformations and regressions were done using Quattro Pro 4.0 (Borland International), a spreadsheet. Mean densities and incidence counts were entered into the spreadsheet in separate columns, from which all future calculations were based. The relevant transformation formulae needed only to be entered once in a different column along the same row as the first data entry, and it was then copied down to the row of the last data entry. The formula is automatically adjusted for different values (different cell references) when copied to a different cell - the relative cell references remain unchanged. Spreadsheets normally include a facility whereby regression can be done, so the user needs to input only the ranges containing the relevant data. Results are placed in a table. This facility was used to apply the relevant linear regressions (equations 1 and 2) to data on *S. avenae*, *M. dirhodum* and total aphids per shoot on winter wheat. Counts for total aphids per shoot included records of the above two species, *R. padi* and *M. festucae*. The results of the two regressions for total aphid counts are shown in figures 1 and 2. Using the ADAS economic threshold of 5 *S. avenae* per ear (Anon, 1988) and assuming that 83.8% of aphids per shoot occur on the ear (Entwistle & Dixon, 1987), then the lower limit of the confidence interval for the probit regression model for this aphid predicts that this will occur when 65% of shoots are infested, close to the ADAS estimate of 66% (2/3) as estimated by the lower confidence limit of their non-linear regression. Using Nachman's model, the lower limit is 73% and because the slope of the line is slightly flatter the upper and lower estimates for this model are further apart. For this reason, the probit model is more appealing, but the reasons for the differences between the two models are unclear. The two graphs were produced on the spreadsheet, written to PIC files and then imported into a word processor.

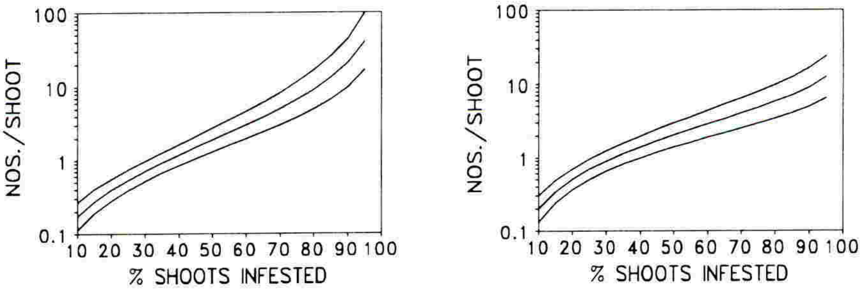

Figure 1.a) Incidence-Density Relationship Using Probit Model for Total Aphids on Winter Wheat

b) Incidence-Density Relationship Using Nachman's Model for Total Aphids on Winter Wheat

DECISION AIDS

Decision aids for farmers provide practical advice by pulling together research findings and expertise, interpreting them in the context of farmers' problems and thereby designing specific recommendations and providing a means of training the farmers and advisors (Norton, 1991). Various computerised research tools have been used for crop protection research and development projects, e.g expert systems (Heong, 1990), conventional programming languages (Carter *et al.*, 1982; Mann & Wratten, 1987; Zhou *et al.*, 1989) and databases (Knight *et al.*, 1992). Little use, however, appears to have been made of spreadsheets. Costello *et al.* (1991) developed a spreadsheet-based user-interface for creation of data input and output files for a non-spreadsheet based simulation model of rice crop production. They chose a spreadsheet because of its built-in graphics and macro programming command facilities, and also because they felt it would save software development time. The model predictions were written to the output file (spreadsheet) where they could quickly and easily be viewed in tabular or graphic format by users inexperienced in computers and/or spreadsheets. However, they felt that the macro commands were awkward to program and that some tasks were relatively slow to perform, in particular the loading of the input spreadsheet, reading the weather data, saving files and selecting and preparing graphs to view. These tasks may have been slowed down because of the transfer of data to and from the spreadsheets and the simulation model.

To illustrate the usefulness of macro commands, a small prototype model for *S. avenae* control was developed on a spreadsheet. The model uses the probit incidence-density model (equation 1) to determine the mean aphid density, and then the forecast peak aphid density and percentage yield loss if calculated using regression models developed by Entwistle & Dixon (1986, 1987). The model created here has not been validated and no claims about its accuracy are made - it merely serves to illustrate the potential use of spreadsheets as use as computerised decision aids. For a discussion of the accuracy of the regression models developed by Entwistle & Dixon (1986, 1987) see Carter *et al.* (1989).

After an opening introduction screen, the first input screen is displayed. Here the user is requested for the expected yield of his crop, the selling price and the growth stage. A prompt is displayed at the top of the screen for each request for information, and the user input is displayed on the screen at the relevant position. The cursor moves to the next position on the input screen automatically. Once all relevant information has been provided on the first screen, a second inputs screen is displayed where the user is requested to make two counts of 50 shoots on sperate days and enter for each count the number of infested shoots and how many days elapsed between the two counts. The model then asks what aphicide the user will apply to his crops if he sprays against aphids. Use is made here of pull-down menus. A menu appears at the top of the screen with a choice of different types of aphicide: pirimicarb; demeton-s-methyl; dimethoate; oxydemeton methyl; or other/don't know. These aphicides were chosen because quotes of their prices had been obtained from a supplier. An average cost is used if the option 'other/don't know' is chosen. These prices are then used to calculate the cost of control and how much money will be obtained from extra yield, if any, by spraying. These results are displayed on a results screen which shows the forecast peak aphid density, the forecast percentage yield loss, the actual amount of yield that will be lost (t/ha) and the financial loss that will be incurred if control measures are not taken. When the user presses a key, a graph of the control economics is displayed. This shows the value of the crop if no control measures are taken, the amount that will be saved if an aphicide is applied and the cost of control measures (figure 3). The total height of the column represents the value of the total potential yield, and the height of the 'Saving if spray' and 'Control costs' sections combined represent the value of lost yield if control measures are not applied. The smaller the 'Saving if spray' column, then the less value will be saved if control measures are taken. The graphical display of this information helps the user to see clearly and simply whether it is worth spraying or not, and the ease of production of graphical output by spreadsheets makes them ideal for this type of application.

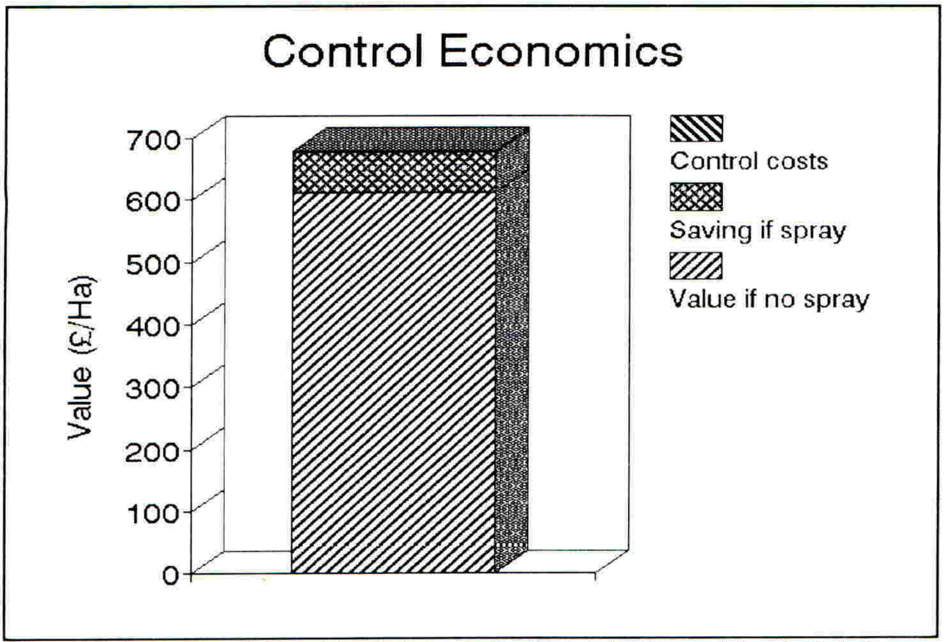

Figure 3 Example of Graphical Output Produced by Spreadsheet Model

DISCUSSION

With the help of macro programming commands, spreadsheets can be used to create a wide variety of easy to use and visually informative decisions aids for crop protection managers. The computer program developed here could be produced quickly and run on a micro-computer with sufficient memory to run Quattro Pro, and thus such programs could be made widely available to anyone with the relevant software. Spreadsheets are widely used by businesses, including farms, so that many potential users will already have the capability to run the program without having to buy whole packages. The program itself occupies just 21,317 bytes of memory on a disk, and so can easily be run from just a single floppy disk providing the relevant spreadsheet package is available. Similar packages would be easy to produce for other spreadsheet programs such as Lotus 1-2-3 or SuperCalc which also include macro programming commands. However, for the program to run correctly data inputs must be typed in correctly or errors occur, and without a substantial amount of error traps, the program has no way of double checking data for errors before accepting it. The program also takes time to prepare graphs on a 80286 computer, a similar problem to that found by Costello *et al.* (1991). Despite this, few problems were encountered with the programming - for the complex task of producing the titles and legends of the graphs, key strokes can be recorded and 'pasted' into the macro at the relevant position, thus saving programming time.

As research tools, spreadsheets are easy to use and quickly manipulate and transform large amounts of data. A variety of graphing options and other tools are available within spreadsheets which allow for complex analysis of data with the minimum of effort and the production of impressive displays for use in documents or presentations.

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SURFACE VERSUS ADMIXED APPLICATIONS OF SLUG PELLETS TO WINTER WHEAT

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ABSTRACT

A series of three replicated, plot-scale field trials was undertaken to assess the effectiveness of molluscicides in preventing slug damage when applied at or immediately after drilling and to investigate methods of slug control using admixed treatments which may be less harmful environmentally than broadcasted treatments. Sites were located in Avon and Warwickshire at which late-autumn sown winter wheat was treated with admixed or broadcasted treatments of methiocarb. Treatments were applied at or immediately after drilling and were compared with untreated control plots. Slug catches in bran-baited refuge traps were significantly reduced by molluscicide treatments at two sites. In Warwickshire, broadcasted treatments were more effective than admixed. At this site, wheat was sown at 5cm depth into a moderately rough tilth. At the other site, wheat was more shallowly-sown into a cloddy seedbed. Here, all treatments, except metaldehyde admixed, significantly reduced slug activity two weeks post-drilling. Percentages of plants grazed by slugs ranged from 12.5-70.4% on untreated plots. Damage was significantly reduced at two sites, where broadcasted treatments were generally more effective than admixed applications.

INTRODUCTION

Slugs are considered by many farmers to be one of the most difficult pest problems to overcome in winter wheat (Glen, 1989), especially first wheats after oilseed rape or beans. As a result of concern about possible damage by slugs, 26% of wheat crops were treated with molluscicides in 1988 (Davis, Garthwaite & Thomas, 1988). Despite this concern, many slug control trials frequently illustrate the variable responses to slug control measures, which suggests that there is considerable scope for better targeting of appropriate control measures.

This paper reports on a series of replicated plot-scale trials undertaken in 1989-1991 to assess the effectiveness of molluscicides in preventing slug damage and to investigate methods of slug control using admixed treatments that minimise environmental risk to non-target invertebrates (Kennedy, 1990). The effects of the treatments on slug activity and on plant damage are reported and the relative merits of the treatments discussed.

MATERIALS AND METHODS

During the autumns of 1989, 1990 and 1991, a total of three replicated plot-scale trials were established within commercial crops of winter wheat (Table 1). Experiments were sited in fields with a history of slug damage.

TABLE 1. Details of field trials in winter wheat.

	Site	Cultivar	Drilling date	Replicates	Plot size
1.	Avon	Galahad	16.11.89	5	10 x 15 m
2.	Avon	Riband	15.11.90	5	10 x 15 m
3.	Warwickshire	Hereward	28.10.91	4	8 x 18 m

Treatments

Winter wheat was treated with admixed or broadcasted treatments of methiocarb (Draza) at 5.5 kg/ha; metaldehyde (PBI Slug Pellets) at 15.0 kg/ha; methiocarb plus metaldehyde (2.75 + 15.0 kg/ha respectively) and methiocarb (2.75 kg/ha) admixed plus metaldehyde (15.0 kg/ha) broadcasted. Treatments were applied at or immediately after drilling and were compared with untreated plots. Treatments, with the exception of the tested products, were applied according to current good-farm practice.

Slug activity

Pre-drilling assessments of slug surface activity were made using ten methiocarb-baited traps over the trial area. Slug numbers per trap (and species) were recorded over 3-7 day periods during periods when soil was moist and suitable for slug activity.

Post-drilling slug activity was recorded using three bran-baited refuge traps (18 cm diameter plant-pot saucers) per plot. Post-drilling activity was slight at site 1 and data are presented from sites 2 and 3 (Tables 2 and 3). Saucer traps were used, as opposed to tile traps, as the former have been shown to provide a better indication of non-juvenile slug activity (Young, 1990; Young *et al.*, 1991).

Damage assessments

Plant counts were done on 5 (6 at site 3) paired 0.5m lengths of row per plot (avoiding plot margins) at the two-leaf stage (Zadoks growth stage 12). Plant damage (grazed leaves) was assessed at the same time and recorded as percentage damaged plants. Data were subjected to analysis of variance after angular transformation (Table 4).

RESULTS

Maximum pre-drilling slug catches at sites 2 and 3 were 2.3 and 3.1 slugs per trap per day respectively. At site 1, slug activity was slight with a mean catch of 0.2 slugs/trap/day. Catches were predominantly *Deroceras reticulatum* at all sites with low numbers of *Arion distinctus* and *A. ater* at site 1 and *Tandonia budapestensis* at site 3.

TABLE 2. Post-drilling slug activity at site 2. Mean number of slugs per three bran-baited traps per plot (transformed data in brackets $\sqrt{(n+1)}$).

Treatment	Dates of assessment			
	23.11.90	30.11.90	7.12.90	14.12.90
1. untreated	1.0 (1.39)a	2.2 (1.70)b	0.4 (1.16)a	0
2. methiocarb broadcast	0.4 (1.16)a	0.6 (1.23)a	0.2 (1.08)a	0
3. metaldehyde broadcast	0.4 (1.16)a	0.2 (1.08)a	0.2 (1.08)a	0
4. meth + meta broadcast	0.2 (1.08)a	0.4 (1.16)a	0.2 (1.08)a	0
5. methiocarb admixed	1.0 (1.39)a	0.6 (1.23)a	0.2 (1.08)a	0
6. metaldehyde admixed	0.8 (1.29)a	0.8 (1.31)ab	0.2 (1.08)a	0
7. meth + meta admixed	0.4 (1.16)a	0.6 (1.23)a	0.4 (1.16)a	0
8. methiocarb+ admixed+ metaldehyde broadcast	1.2 (1.37)a	0.2 (1.08)a	0.2 (1.08)a	0
SED	(0.18)	(0.20)	(0.12)	not analysed
CV (%)	(22.8)	(25.0)	(17.1)	

Transformed values followed by the same letter are not significantly different at $P \leq 0.05$.

TABLE 3. Post-drilling slug activity at Site 3. Mean number of slugs per three bran-baited traps per plot (transformed data in brackets $\sqrt{n}$).

Treatment	Dates of assessment			
	5.11.91	12.11.91	19.11.91	26.11.91
1. untreated	1.8(1.33)a	3.3(1.80)d	4.4(2.07)c	4.2(1.95)c
2. methiocarb broadcast	1.2(1.07)a	0.4(0.55)ab	0.3(0.41)a	1.0(0.95)ab
3. metaldehyde broadcast	1.2(1.02)a	0.3(0.49)ab	1.2(1.07)ab	1.0(0.93)ab
4. meth + meta broadcast	1.7(1.20)a	0.5(0.68)abc	0.2(0.43)a	0.3(0.49)a
5. methiocarb admixed	2.7(1.60)a	1.8(1.32)cd	2.5(1.53)bc	3.1(1.70)c
6. metaldehyde admixed	1.9(1.30)a	1.7(1.15)bcd	2.7(1.66)bc	1.8(1.31)bc
7. meth + meta admixed	2.0(1.33)a	1.7(1.06)bc	2.1(1.33)bc	1.9(1.35)bc
8. methiocarb +admixed+ metaldehyde broadcast	1.3(0.96)a	0.2(0.29)a	0.4(0.43)a	1.1(0.90)ab
SED	(0.38)	(0.33)	(0.36)	(0.31)
CV (%)	(45.6)	(55.4)	(46.2)	(37.7)

TABLE 4. Mean percentage damaged plants at Zadoks GS 12 (angular transformed data in brackets)

Treatment	Site 1	Site 2	Site 3
1. untreated	11.4 (19.6)	70.4 (57.5)	27.8 (31.3)
2. methiocarb broadcast	7.9 (16.0)*	74.8 (61.2)	2.6 (8.3)***
3. metaldehyde broadcast	7.0 (15.0)*	86.6 (69.1)	5.3 (13.3)***
4. meth + meta broadcast	4.4 (12.1)**	80.5 (64.8)	3.9 (10.8)***
5. methiocarb admixed	9.9 (17.9)	77.9 (62.5)	11.2 (17.6)***
6. metaldehyde admixed	13.1 (20.8)	73.5 (60.9)	12.0 (20.0)**
7. meth + meta admixed	9.5 (17.8)	76.2 (61.3)	14.6 (21.8)*
8. methiocarb +admixed+ metaldehyde broadcast	6.1 (14.2)*	75.8 (60.9)	3.8 (10.2)***
SED	(2.24)	(4.70)	(3.57)
CV (%)	(18.8)	(11.9)	(31.2)

*, **, *** significantly different from untreated at P = 0.05, 0.01, 0.001 respectively.

DISCUSSION

Pre-drilling slug activity was most evident at site 3, where a maximum of 21.7 slugs per trap per week was recorded two weeks before drilling. Activity was considerably above the suggested economic threshold of four slugs per trap per week, pre-soil disturbance for drilling (Glen *et al.*, 1992). However, grain hollowing was slight with a mean of 7.1% seeds hollowed by slugs. Depth of sowing was 5.3cm into a moderately-rough tilth (mean surface roughness 3.7cm) - factors which are likely to have limited access by slugs to seed and admixed pellets. No treatment effects on slug activity were noted until 14 days post-drilling when all broadcasted treatments significantly reduced numbers compared with the untreated mean of 3.3 slugs per three bran-baited refuge traps per week. (Table 2).

Admixed treatments at site 3 were less effective and with the exception of methiocarb plus metaldehyde, did not significantly reduce slug numbers. Treatment effects were observable up to four weeks post-drilling. Several interesting differences between treatments were noted (Table 3) . At 15, 22 and 29 DAT, slug numbers were significantly lower following the broadcast application of methiocarb than the admixed treatments.

At site 2, maximum slug activity was recorded 14 days after drilling (Table 2). All treatments, with the exception of metaldehyde admixed, significantly reduced slug activity in refuge traps compared with the untreated. At this site, late-sown winter wheat was drilled into a cloddy seedbed. Because of wet soil conditions at drilling, depth of sowing was shallow with some seeds remaining on the soil surface. Such drillings are usually considered to be at greater risk from slug damage than early-sown crops as wetter conditions promote slug activity and crop emergence is delayed in colder soils so that crops are at risk from slug damage for a longer period (Port & Port, 1986),. In addition, winter wheat in cloddy seedbeds is particularly susceptible to slug damage (Gould, 1961); particularly if drilling depth is shallow (Glen, Milsom & Wiltshire, 1990), as coarse seedbeds enable slugs easily to reach shallowly-sown seeds and admixed pellets (Glen, Wiltshire & Langdon, in press). Activity at site 2 subsequently declined with the onset of frosty conditions. Many environmental factors regulate slug activity in the field; temperature and soil moisture content are usually considered the most important (Port and Young, 1992).

The incidence of slug damage at Zadoks growth stage 12 was highest at site 2 where a mean of 70.4% plants were grazed by slugs at the two leaf stage (Table 4), but molluscicide treatments did not significantly reduce plant damage. Glen *et al* (1992) described positive correlations between the incidence of slug grazing on seedlings and the percentage seeds killed. It is possible that differences in slug damage occurred before or soon after emergence, but more intensive assessments would have been necessary to investigate these aspects further.

Plant damage was significantly ($p \leq 0.05$) reduced by broadcasted applications of slug pellets at site 1, compared with the untreated mean of 11.4% damage (Table 4), but differences between the broadcasted treatments were not significant at $p = 0.05$. Half-rate methiocarb, admixed with the seed, followed by a subsequent broadcasted full-rate treatment of metaldehyde also significantly ($p \leq 0.05$) reduced plant damage compared with the untreated. Admixed treatments alone, did not significantly reduce damage.

At site 3, all broadcasted treatments significantly reduced plant damage (Table 4) and, with the exception of methiocarb admixed, were more effective at reducing slug damage than admixed treatments.

Bourne, Jones & Bowen (1990) described benefits from combining metaldehyde with methiocarb treatments at various rates, chosen so that efficacies of applications in terms of slug activity were not prejudiced. In addition, admixture and sub-surface applications of methiocarb are likely to reduce environmental risks to non-target invertebrates (Kennedy, 1990). Such potential benefits must, however, be balanced with the additional farm management expertise required for successful and profitable mixed-molluscicide treatments to commercial winter wheat crops, particularly at a time when Common Agricultural Policy reforms are likely to lead to reduced crop market prices.

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THE ACTION OF OILSEED RAPE METABOLITES ON OLFACTORY NERVE ACTIVITY AND BEHAVIOUR OF *DEROCERAS RETICULATUM*

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ABSTRACT

A neuroethological approach was used to examine the effects of individual isothiocyanates (glucosinolate metabolites from oilseed rape and other brassicas) on field slugs. Identifying the most active metabolites may allow the development of slug-resistant cultivars whilst retaining low overall glucosinolate levels.

INTRODUCTION

Cruciferous plants contain glucosinolates which, on tissue damage, can be metabolised enzymically to volatile isothiocyanates (Kjaer, 1976). These are known to affect the feeding behaviour of a number of oilseed rape pests (Bartlett & Williams, 1989; Blight *et al.*,1989, Glen *et al.*, 1989).

The field slug, *Deroceras reticulatum*, is a pest of oilseed rape seedlings and of wheat crops following in the rotation (Glen,1989). Selective grazing by slugs on plants with lower glucosinolate content has been demonstrated by Glen *et al.* (1989) and as new cultivars with further reduced glucosinolate levels are introduced, slug damage can be expected to increase.

In recent studies at Portsmouth and Rothamsted, we have developed electrophysiological and behavioural assays to investigate the effects of plant volatiles on slugs. The electrophysiological assay records signals in the tentacular nerve which receives inputs from the olfactory organ, whilst the behavioural assay demonstrates attractant or repellent effects of the chemical on individual animals.

We describe the use of the two techniques to investigate the effects of isothiocyanates on slug chemoreception and locomotory behaviour in the laboratory, and speculate on the possible implications for slug activity in the field.

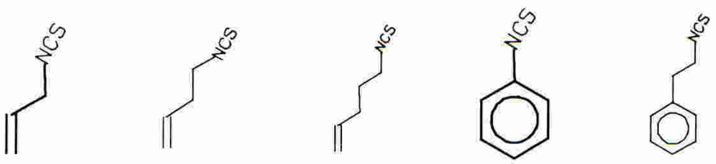
METHODS

Experimental animals

Field slugs, *Deroceras reticulatum*, were collected from Rothamsted Farm and maintained on Chinese cabbage in bowls lined with damp tissue, in a regime of 12h dark at 5°C:12h light at 15°C. Naive animals were used in all trials. They were not pre-treated, e.g. starved, in any way.

Test compounds

Five isothiocyanates were tested (figure 1): 2-propenyl(allyl) (I), 3-butenyl (II), 4-pentenyl (III), phenyl (IV) and 2-phenylethyl (V). Compounds I, IV and V were obtained commercially (Aldrich). Compounds II and III were synthesised in high purity (97%) by conversion of a bromoalkene to the aminoalkene, followed by treatment with thiophosgene and base to produce the required isothiocyanate. They were purified by distillation at reduced pressure.



I allyl isothiocyanate   II 3-butenyl isothiocyanate   III 4-pentenyl isothiocyanate   IV phenyl isothiocyanate   V 2-phenylethyl isothiocyanate

Figure 1: Structures of isothiocyanates tested in electrophysiological and behavioural assays

Electrophysiological assay

Electrophysiological recordings were obtained from the tentacular nerves of slugs after passage of volatiles over the preparation as described by Garraway *et al.*(1992). Test compounds (1 & 10 µg in 10 µl of HPLC grade hexane) were applied to filter paper discs. The solvent was allowed to evaporate and the paper was inserted into the stimulus delivery system. The threshold for perception of these compounds was 0.1µg/µl (Garraway, 1992). There were ten replicates, with each replicate testing all ten treatments (five isothiocyanates at two concentrations) in random order on a single tentacle preparation. Four internal standards of undiluted (+)- fenchone were included to normalize the amplitude measurement, which differed between preparations. The experiments were recorded and datalogged as previously described (Garraway *et al.*,1992). The total duration of a response was estimated from datalogged traces and the average amplitude, spike rise-time and fall-time, inter-spike interval, frequency of spiking and total number of spikes in the response were calculated.

Behavioural assay

Behavioural trials employed tunnel-bifurcate olfactometer units (Garraway, 1992). These were small T-mazes, constructed from stainless steel mesh, in which the slug was forced to approach the T-junction to the two choice chambers via a short tunnel.

A wick was placed under the entrance to each chamber and was either treated with 10 µl of test chemical in solution or with solvent alone as a control. The animal had to cross this boundary and enter a chamber to record a positive result. Individual animals were tested in succession until twenty results were obtained. A binomial probability function was used to assess the significance of the results. If more than fifteen or less than five animals oriented towards a particular chamber, the treatment was considered significantly attractant or repellent, respectively, at the 0.05 probability level. Only 4-pentenyl isothiocyanate (III) and 2-phenylethyl isothiocyanate (V) could be tested in the time available.

RESULTS

Electrophysiological assay

Experiments with a range of compounds showed that the response of the tentacle preparation could be described by three dimensions. These could, in turn, be represented by the variables of the average normalized amplitude (AMP), the natural log of the average spiking frequency (LnFRE) and the natural log of the total number of spikes in the response (LnNOS) (Garraway, 1992; Garraway *et al.*(unpublished). When these parameters were examined, only LnFRE and LnNOS varied significantly between compounds. This information is summarised in Table 1.

Behavioural assay

Of the two compounds tested, only 4-pentenyl isothiocyanate had a significant effect on the orientation of slugs in the T-maze, being repellent at concentrations of 0.1 and 1.0 µg/µl (Table 2).

Table 1: Summary of significant differences between average values for LnFRE and LnNOS elicited by five isothiocyanates presented at two different doses. [x < y = value for x is significantly smaller than that for y]

Variable	Amount of material applied to wick	
	1µg	10µg
LnFRE	Allyl < 4-Pentenyl *** Allyl < 2-Phenylethyl ***	Allyl < 3-Butenyl **
LnNOS		Phenyl < 4-Pentenyl ** 2-Phenylethyl < 4-Pentenyl ***

PROBABILITIES: ** ≤ 0.05 *** ≤ 0.01

Table 2: Results from behavioural assays with two isothiocyanates

Compound	Amount of compound (µg) applied to wick in 10µl hexane	Number of animals orienting towards compound
4-Pentenyl isothiocyanate	0.1	10
	1.0	4 *
	10	3 **
2-Phenylethyl isothiocyanate	0.1	7
	1.0	7
	10	7

PROBABILITIES: * = 0.014 ** = 0.003

DISCUSSION

In the electrophysiological assay all five isothiocyanates showed activity, but allyl isothiocyanate was significantly less active than the 3-butenyl, 4-pentenyl and phenylethyl homologues (Table 1). In addition, it is interesting that the response to phenyl isothiocyanate was lower than the response to phenylethyl isothiocyanate with probability of 0.07, when 1µg of material was applied. Neither allyl nor phenyl isothiocyanate is present in significant amounts in oilseed rape.

A study by Blight *et al.*(1989) showed that the perception of isothiocyanates by the seed weevil, *Ceutorhynchus assimilis*, is mediated by both specialist and generalist receptors. The generalist receptors responded to 3-butenyl, 4-pentenyl and 2-phenylethyl isothiocyanates, whilst the specialist receptors discriminated between the alkenyl and the 2-phenylethyl isothiocyanates. Neither receptor responded to allyl isothiocyanate.

Application of 2-phenylethyl isothiocyanate precursors to oilseed rape decreased the numbers of live cabbage stem flea beetles *Psylliodes chrysocephala* and application of 3-butenyl isothiocyanate reduced feeding by both flea beetles and seed weevils (Griffiths *et al.*, 1989). In the present study, 4-pentenyl isothiocyanate was repellent, whilst no significant response was elicited by the 2-phenylethyl homologue. This correlates with the electrophysiological studies, which show that 2-phenylethyl isothiocyanate is significantly less active than 4-pentenyl isothiocyanate. However, 2-phenylethyl isothiocyanate has previously been ascribed repellent activity for slugs (Airey *et al.*, 1989): its failure to cause a significant response in the behavioural assay may be due to differences in the concentration range over which it was tested.

Although the total glucosinolate content of oilseed rape has been shown to protect seedlings against slug damage (Glen *et al.*,1989), the relative proportions of the individual compounds changes during different growth stages of the plant (Milford *et al.*, 1989). The effect of this on slug grazing is not known (Glen *et al.*,1989). As glucosinolates have been shown to be feeding stimulants to some crucifer-feeding insects (Bartlett & Williams, 1989; Nault & Styer, 1972), and allyl isothiocyanate appears to be attractive to slugs at low concentrations (Airey *et al.*, 1989), it is possible that oilseed rape cultivars with very low levels of glucosinolates may even be actively attractive to slugs.

CONCLUSION

Slugs are apparently able to detect and differentiate between different isothiocyanates and react to them in different ways. This suggests the possibility of breeding for cultivars of oilseed rape with low overall glucosinolate levels, but which retain sufficiently high levels of selected glucosinolates conferring useful protectant properties. Further work is needed to establish more fully which isothiocyanates are most repellent to slugs, and the concentrations of these compounds that are necessary for optimum activity.

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TRIAL RESULTS OF ZETACYPERMETHRIN FOR PEST CONTROL IN AGRICULTURAL CROPS IN POLAND

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ABSTRACT

Research work carried out in Poland in 1991-1992 has shown that the insecticide zetacypermethrin applied at the rate of 7.5-10 g AI/ha effectively controlled the following pests of agricultural crops:

cereals
- cereal leaf beetle (Lema spp.)
- cereal aphid (Sitobion avenae)

winter oilseed rape
- pollen beetle (Meligethes aeneus)
- rape stem weevil (Ceutorhynchus napi)
- cabbage stem weevil (Ceutorhynchus quadridens)
- brassica pod midge (Dasyneura brassicae)

potato
- Colorado beetle (Leptinotarsa decemlineata)

field bean
- bean aphid (Aphis fabae)
- Sitona weevils

pea
- pea aphid (Acyrthosiphon pisum)

The dynamics of zetacypermethrin residues in potato, field bean, winter wheat and winter oilseed rape were also studied.

INTRODUCTION

Zetacypermethrin belongs to a new generation of photostable pyrethroids. In earlier research this compound has been demonstrated to be highly effective in controlling some important pests (internal publication, Plant Protection Institute, Poznań). From 1991 to 1992, intensive research was carried out using zetacypermethrin for the control of the most important pests of agricultural crops in Poland. Positive results in these trials, together with results of studies on residue disappearance were the grounds for registration of zetacypermethrin for use in Poland.

MATERIALS AND METHODS

Experiments were carried out on individual plots of 20 m^2 in area, arranged in randomized blocks with four replicates of each treatment. Treatments were applied with a pneumatic sprayer (Gloria) using 300 litres of spraying liquid/ha.

Times of treatments were determined from the results of observations on the date of appearance and numbers of individual pest species.

Zetacypermethrin was applied as 'Fury 10 EC' and 'Fury 10 EW' at the rate of 7.5-12.5 g AI/ha, as recommended for the appropriate pest.

Standard insecticides, cypermethrin ('Cymbush 10 EC' and 'Cymbush 25 EC'), deltamethrin ('Decis 2.5 EC'), pirimicarb ('Pirimor 50 DP' and 'Pirimor 50 DG') and carbosulfan ('Marshal 25 EC', 'Marshal 25 EW' and 'Marshal 40 CS') were applied at the rates recommended for use in Poland.

Effectiveness was estimated according to methods suitable for individual pest species. Results obtained were compared with plots on which no chemical treatments were applied.

For the determination of zetacypermethrin residues, the method developed by the Department of Pesticide Residues of the Plant Protection Institute in Poznań, Poland, described in an earlier publication (Pieczonka & Mrówczyński, 1989) was used.

RESULTS

The results obtained are presented in Tables 1-10.

TABLE 1. Control of cereal leaf beetle (Lema spp.) on spring barley (1991-1992)

		% Mortality				
Active ingredient	Rate g AI/ha	1 DAT	3 DAT	7 DAT	10 DAT	Yield (t/ha)
Zetacypermethrin	7.5	96	97	98	98	6.40
Zetacypermethrin	10.0	100	100	100	100	6.49
Zetacypermethrin	12.5	100	100	100	100	6.52
Cypermethrin	25.0	97	99	100	100	6.54
Untreated	-	-	-	-	-	6.01

1 DAT = 1 day after treatment.

TABLE 2. Control of cereal aphid (Sitobion avenae) on winter wheat (1991-1992)

Active ingredient	Rate g AI/ha	% Mortality 1 DAT	3 DAT	7 DAT	Yield (t/ha)
Zetacypermethrin	10.0	90	96	97	7.40
Zetacypermethrin	12.5	96	98	98	7.42
Pirimicarb	125	100	100	100	7.57
Untreated	-	-	-	-	6.98

1 DAT = 1 day after treatment.

TABLE 3. Control of Colorado beetle (Leptinotarsa decemlineata) on potatoes (1991-1992)

Active ingredient	Rate g AI/ha	% Mortality 1 DAT	3 DAT	7 DAT	10 DAT
Zetacypermethrin	10	92	95	93	92
Zetacypermethrin	12.5	96	98	98	96
Carbosulfan	250	98	100	99	98
Carbosulfan	375	100	100	100	100
Cypermethrin	25	96	100	97	96
Deltamethrin	7.5	98	98	96	96

1 DAT = 1 day after treatment.

TABLE 4. Control of rape stem weevil (Ceutorhynchus napi) on winter oilseed rape (1992)

Active ingredient	Rate g AI/ha	% Undamaged Plants
Zetacypermethrin	10	88
Zetacypermethrin	12.5	92
Cypermethrin	25	91
Deltamethrin	7.5	92
Untreated	-	51

TABLE 5. Control of cabbage stem weevil (Ceutorhynchus quadridens) on winter oilseed rape (1992)

Active ingredient	Rate g AI/ha	% Undamaged Plants
Zetacypermethrin	10	78
Zetacypermethrin	12.5	85
Cypermethrin	25	84
Deltamethrin	7.5	85
Untreated	-	2

TABLE 6. Control of pollen beetle (Meligethes aeneus) on winter oilseed rape (1992)

		% Mortality		
Active ingredient	Rate g AI/ha	1 DAT	3 DAT	7 DAT
Zetacypermethrin	7.5	90	92	91
Zetacypermethrin	10	95	100	97
Zetacypermethrin	12.5	100	100	100
Cypermethrin	25	95	98	98
Deltamethrin	7.5	96	99	100
Untreated	-	-	-	-

1 DAT = 1 day after treatment.

TABLE 7. Control of cabbage seed weevil (Ceutorhynchus assimilis) and brassica pod midge (Dasyneura brassicae) on winter oilseed rape (1992)

		% Pods Damaged By	
Active ingredient	Rate g AI/ha	C. assimilis	C. assimilis + D. brassicae
Zetacypermethrin	7.5	4.0	6.6
Zetacypermethrin	10	3.3	4.2
Zetacypermethrin	12.5	2.8	3.0
Deltamethrin	7.5	2.6	2.8
Untreated	-	18.1	23.1

TABLE 8. Control of Sitona weevils on pea (1992)

Active ingredient	Rate g AI/ha	% Undamaged Plants
Zetacypermethrin	7.5	91
Zetacypermethrin	10	96
Zetacypermethrin	12.5	100
Cypermethrin	25	98
Deltamethrin	7.5	99
Untreated	-	6

TABLE 9. Control of Sitona weevils on field beans (1992)

Active ingredient	Rate g AI/ha	% Undamaged Plants
Zetacypermethrin	7.5	86
Zetacypermethrin	10	91
Zetacypermethrin	12.5	100
Cypermethrin	25	97
Deltamethrin	7.5	98
Untreated	-	11

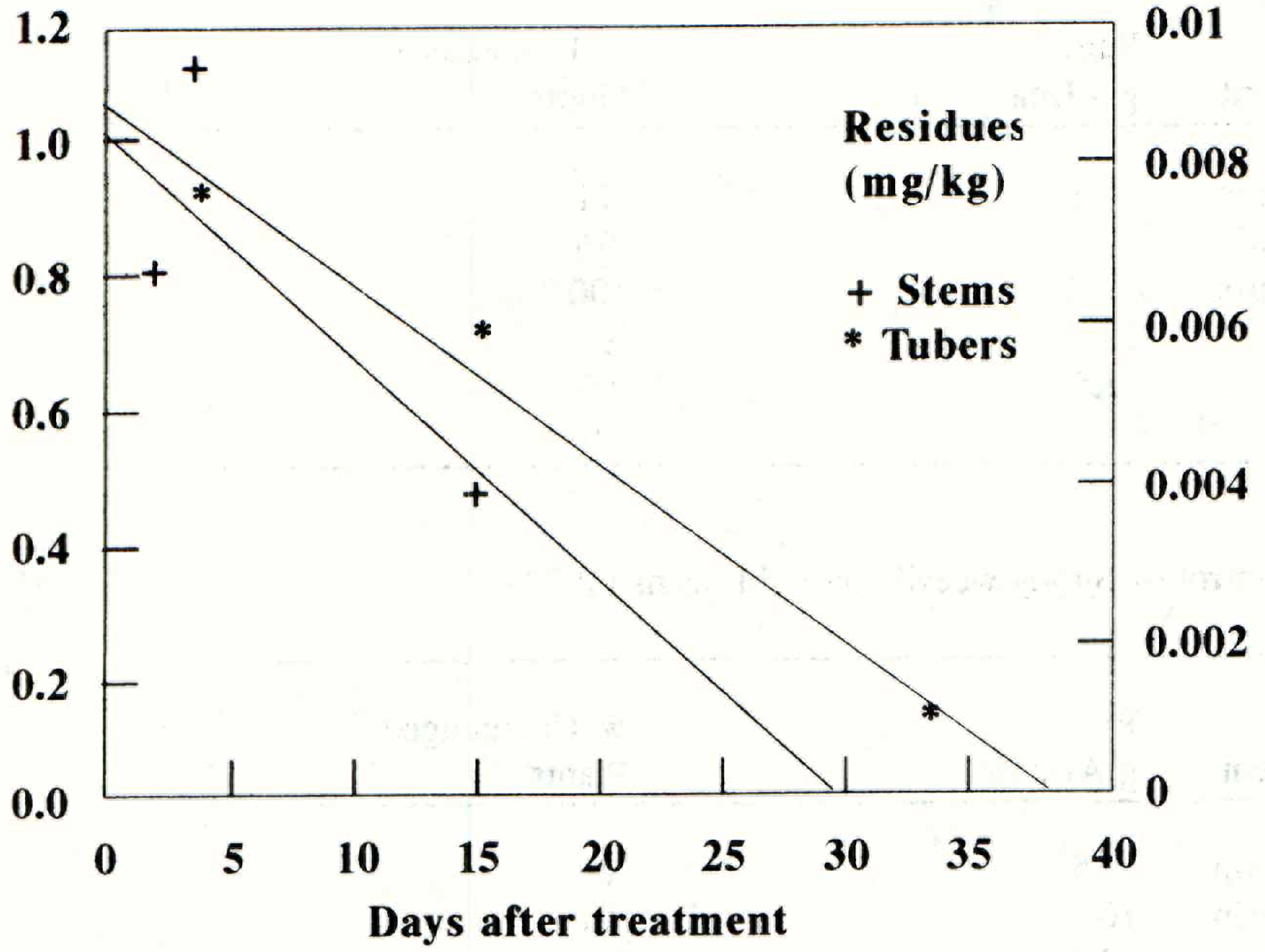
TABLE 10. Control of black bean aphid (Aphis fabae) on field beans (1991-1992)

Active ingredient	Rate g AI/ha	% Mortality 1 DAT	3 DAT	7 DAT	10 DAT
Zetacypermethrin	10	90	91	90	90
Zetacypermethrin	12.5	92	94	96	96
Pirimicarb	125	92	94	95	94
Pirimicarb	250	96	98	100	98

1 DAT = 1 day after treatment.

In Fig. 1 the persistence of zetacypermethrin residues in potato tubers and stems is presented. In other analyses no zetacypermethrin residues above 0.005 mg/kg have been found in field bean, winter oilseed rape and winter wheat seeds.

Fig. 1. Disappearance of zetacypermethrin in potato



DISCUSSION

Special attention should be drawn to three aspects of the results presented here from field observations made during the course of this study.

First, a matter of much concern for Polish agriculture, in 1991 many of the pest species occurred in considerably greater numbers than had been observed in earlier years. This was especially the case for: cereal leaf beetle (Lema spp.), pests of oilseed rape (Ceutorhynchus napi, C. quadridens, C. assimilis and Dasyneura brassicae) and Sitona spp. on legumes.

Second, zetacypermethrin was highly effective in controlling all pest species on which experiments were conducted. In the majority of cases satisfactory efficacy, comparable with that of standard products, was obtained when 10 g AI/ha was used.

Third, attention should also be paid to the considerable yield increase obtained from certain treatments. For example, in the case of cereal leaf beetle control on cereals, the yield increase amounted to 0.39-0.51 t/ha and in the case of cereal aphid (Sitobion avenae) control, the increase amounted to 0.42-0.44 t/ha.

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AN EVALUATION OF THE POTENTIAL OF REDUCED DOSE FUNGICIDE PROGRAMMES IN WINTER WHEAT

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ABSTRACT

In a series of six trials over two years full and reduced dose fungicide programmes were evaluated on two winter wheat cultivars. Disease control was similar for all fungicide programmes whilst some full rate programmes gave greater yields. Reduced dose programmes were usually as or more cost effective, demonstrating that a reduction in fungicide use may be one way growers can lessen input costs.

INTRODUCTION

Within the European Community, reform of the Common Agricultural Policy will force the price of cereals down towards the world price. In order to remain profitable farmers will have to re-evaluate variable costs. In the UK, foliar- and stem-base diseases are and will remain a major threat to yield. Even at grain prices of £80/t the effect of disease is such that control will still be required. However, to sustain gross margins a reduction in fungicide use without substantial loss in yield will be one option to be considered.

When agrochemical manufacturers recommend a dose rate for a fungicide, the rate selected is usually designed to give control under a wide range of climatic and disease situations. Frequently, when the disease pressure is low, climatic conditions are unfavourable for the disease or the host exhibits a high degree of disease resistance, a full rate is unnecessary. Wale (1990) demonstrated that for spring barley where powdery mildew (*Erysiphe graminis*) was the dominant disease, a programme using a low-dose fungicide mixture was as effective at controlling mildew as a full rate programme and resulted in greater profits. In part, careful timing of the fungicide application was important for effective disease control. Low-dose mixtures worked particularly well when used on cultivars with moderate disease resistance. A mixture of fungicides with different modes of action was used to reduce the risk of fungicide resistance developing in pathogens.

The use of reduced fungicide doses on winter wheat offers a different challenge as a complex of diseases threaten the crop. There are, however, recognised growth stages for fungicide application to wheat in Scotland which reflect critical times in crop development in relation to potential yield loss from disease. These are GS 39 and 59 (Munro & Wale, 1987) and 30-32 (unpublished data). The trials reported in this paper examine the potential for reducing fungicide doses at or around these recognised growth stages in two cultivars with different ratings for disease resistance.

MATERIALS AND METHODS

In each of the seasons 1989/90 and 1990/91, three trials were established across Scotland in Roxburghshire (southern site), Aberdeenshire and Easter Ross (northern sites). Two cvs, Apollo and Hornet, with differing disease resistance ratings for mildew (4, 5 respectively), *Septoria tritici* (6, 4) and yellow rust (*Puccinia striiformis*) (7, 3) (Anon., 1989) were grown as main plots in a split plot design where a range of fungicide programmes was evaluated as sub-plot treatments. There were usually four replicates of each programme arranged in a randomised block design within the main plots. Seed for the trials was obtained locally and had single purpose seed treatment only. Drilling took place between 2nd and 10th October in the first year and between 4th and 24th October in the second year. At each trial site fertiliser, herbicide, growth regulator and micro-nutrient applications were uniform across all plots and reflected local agronomic practice. Plot sizes were approximately 20 x 2 m.

Fungicide programmes were broadly similar in each year (Table 1) and comprised 'full-rate' programmes (B,D,H,J) 'half-rate' programmes (C,E,I,K) applied conventionally at GS 31, GS 39-49 and GS 59-69. Two further programmes in each year (F,G,L,M) examined four spray treatments at reduced rate, the first two treatments being at GS30 and 32 (Table 1). Foliar disease was regularly assessed from GS 30 to GS 75-85 in each trial. Stem base disease assessments were made around GS 31 and between GS 59 and 85. Lodging was assessed just prior to harvest. Plots were yielded, the dry matter content measured and yields adjusted to 15% moisture content. The 1000-grain weight was measured from a sample taken at harvest.

RESULTS

In 1990 on cv. Hornet, yellow rust was the most prevalent disease. Initial outbreaks were recorded during or after stem extension. In two trials on the untreated programme (A) yellow rust reached more than 35% mean infection of the top three leaves by grain filling. All fungicide programmes kept yellow rust to low levels, there being no significant difference between them (Table 2A). Mildew reached moderate levels (5-15%) on the untreated programme after flag leaf emergence in two trials. All fungicide programmes restricted mildew to under 2% infection except programme F (data not shown). Like mildew, *S.tritici* reached moderate levels on the untreated programme in two trials. All fungicide programmes kept *S.tritici* to under 3% infection, there being no significant differences between them (Table 2A). By contrast, on cv. Apollo in two trials no foliar diseases exceeded 2% infection. In the third, mildew and yellow rust developed on the untreated controls after GS 39 to between 30 and 40% infection. All fungicide programmes kept infection to under 1% with no significant differences between treatments.

Eyespot (*Pseudocercosporella herpotrichoides*) was absent in two trials and never exceeded 5% tillers infected in the third. Sharp eyespot (*Rhizoctonia cerealis*) was present at all sites and severe at the two northern sites with significant differences in severe category infections (Scott & Hollins, 1975) at one (Table 2A).

TABLE 1. Fungicide programmes for 1989/90 (A-G) and 1990/91 (A,H-M).

Programme code	Timing GS 30	GS 31	GS 32	GS 39-49	GS 59-69
A	-	-	-	-	-
B	-	pc+$^{1}/_{2}$fm	-	pf	fc+$^{1}/_{2}$fd
C	-	$^{1}/_{2}$pc+$^{1}/_{4}$fm	-	$^{1}/_{2}$pf	$^{1}/_{2}$fc+$^{1}/_{4}$fd
D	-	fs+$^{1}/_{2}$fm	-	fs+$^{1}/_{2}$fm	fs+^{1}/2fm
E	-	$^{1}/_{2}$fs+$^{1}/_{4}$fm	-	$^{1}/_{2}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fs+$^{1}/_{4}$fm
F	$^{1}/_{3}$+$^{1}/_{4}$fm	-	$^{1}/_{3}$p+$^{1}/_{4}$fm	$^{1}/_{3}$p+$^{1}/_{4}$fm	$^{1}/_{2}$fc+$^{1}/_{4}$fm
G	$^{1}/_{4}$+$^{1}/_{4}$fm	-	$^{1}/_{4}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fs+$^{1}/_{4}$fm
H	-	pc+$^{1}/_{4}$fm	-	pf	fc+$^{1}/_{4}$fd
I	-	$^{1}/_{2}$pc+$^{1}/_{4}$fm	-	$^{1}/_{2}$pf	$^{1}/_{2}$fc+$^{1}/_{4}$fd
J	-	fs+$^{1}/_{4}$fm	-	fs+$^{1}/_{4}$fm	fs+$^{1}/_{4}$fd
K	-	$^{1}/_{2}$fs+^{1}/4fm	-	$^{1}/_{2}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fs+$^{1}/_{4}$fd
L	$^{1}/_{3}$+$^{1}/_{4}$fm	-	$^{1}/_{3}$p+$^{1}/_{4}$fm	$^{1}/_{3}$p+$^{1}/_{4}$fm	$^{1}/_{2}$fc+$^{1}/_{4}$fd
M	$^{1}/_{4}$+$^{1}/_{4}$fm	-	$^{1}/_{4}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fs+$^{1}/_{4}$fm	$^{1}/_{2}$fc+$^{1}/_{4}$fd

Fungicides

Abbreviation:	Active ingredients (g/l)	Product name	Full dose (l/ha)	Cost (£/ha)
pc	prochloraz (320) + cyproconazole (48)	Sportak Delta	1.25	32.00
pf	prochloraz (225) + fenpropimorph (375)	Sprint	1.75	35.00
fc	flutriafol (470 + chlorothalonil (375)	Impact excel.	2.0	24.00
fs	flusilazole (250) + carbendazim (125)	Punch C	0.8* or 0.625	28.20 or 22.00
p	prochloraz (400)	Sportak 45	1.0	21.70
fm	fenpropimorph (750)	Corbel	1.0	20.80
fd	fenpropidin (750)	Patrol	1.0	20.80

*Higher rate used at GS 30-32

In 1990/91 at the Easter Ross site the GS 39-49 treatment was omitted and the GS 59-69 treatments increased to $^{3}/_{4}$ fc or $^{3}/_{4}$ fs in I, K, L and M. At the southern site, GS 59-69 treatments were increased to $^{3}/_{4}$ fc in I, L and M due to prolonged wet conditions.

TABLE 2. Summary of disease status in two trials after ear emergence.

A Oldmeldrum, Aberdeenshire, 1990

Programme code	% disease on top three leaves at GS71				% tillers with severe Sharp eyespot	
	Yellow rust		*Septoria tritici*			
	Hornet	Apollo	Hornet	Apollo	Hornet	Apollo
A	59.1	0.1	5.0	1.6	27.5	2.5
B	0.3	0.0	0.1	2.4	0.0	2.5
C	1.8	0.0	0.2	1.1	7.5	2.5
D	0.2	0.0	0.1	1.1	27.5	2.5
E	0.8	0.0	0.1	1.5	10.0	7.5
F	1.2	0.2	1.0	1.5	7.7	7.5
G	0.5	0.1	1.4	1.8	12.5	5.0
SED (42 d.f.)	2.28	1.01	7.93			

Mildew never exceeded 1% on any programme. Eyespot was absent

B St Boswells, Roxburghshire, 1991

Programme code	%disease on top three leaves at GS 71					
	Yellow rust		*Septoria tritici*		Mildew	
	Hornet	Apollo	Hornet	Apollo	Hornet	Apollo
A	8.3	0	15.5	5.5	13.0	35.0
H	0.0	0	2.5	1.3	7.5	7.3
I	0.1	0	7.8	3.0	5.8	14.3
J	0.0	0	1.8	1.8	4.5	4.5
K	0.0	0	4.3	2.3	4.0	7.5
L	2.0	0	6.3	2.3	5.3	16.8
M	0.3	0	3.5	1.3	3.3	10.3
SED (21 d.f.)	2.21	-	2.20	0.87	2.24	4.25

In the second year mildew, yellow rust and S.tritici were all prevalent at the southerly site on Hornet (Table 2B). All fungicide programmes significantly reduced disease compared to the untreated, there being no significant difference between them in most instances. Yellow rust was the predominant disease at the second site developing only after ear emergence (29% infection on untreated). At the third site moderate levels of mildew (7%) and S.tritici (9%) developed on the untreated programmes. In general there were few significant differences between fungicide programmes, all of which mostly kept disease to under 2% infection. On Apollo at the two northerly sites there was very little foliar disease, mildew developing on untreated programmes to low levels late in the season. At the third site mildew and *S.tritici* predominated (Table 2B).

Sharp Eyespot incidence was again high at the two northerly sites (>90%) but there was no control or significant difference between programmes. At the third site, eyespot reached an incidence of 30% on both cvs by GS 75. Whilst programme B resulted in significantly less eyespot on Hornet, all other programmes failed to reduce incidence significantly. However, lodging occurred in Hornet (Table 3) but was not obviously related to eyespot infection.

TABLE 3. Mean yields, gross margins (variable and spray costs only) and lodging for three trials in each of two years.

Programme	Yield (t/h)		Gross margin (£/ha)		Lodging (%area)
code	Hornet	Apollo	Hornet	Apollo	Hornet
1990					
A	5.13	7.01	276.0	464.7	11.8
B	9.45	8.25	588.8	469.4	4.7
C	9.21	7.96	620.9	497.2	9.0
D	9.13	7.82	565.1	435.5	13.5
E	8.24	7.63	528.4	468.1	27.6
F	9.16	7.96	612.6	493.4	6.4
G	8.77	7.83	574.5	481.5	18.6
SED (d.f.)	0.122	(119)	12.17	(119)	3.09 (120)
1991					(1 trial only)
A	4.95	5.91	272.3	370.5	22.5
H	8.45	7.29	528.2	414.5	0.1
I	8.11	7.01	529.3	421.7	4.5
J	8.15	6.91	508.7	387.8	12.0
K	7.70	6.71	494.3	398.3	11.8
L	8.14	6.97	527.8	413.3	5.8
M	8.12	6.95	525.2	411.7	13.3
SED (d.f.)	0.045	(135)	4.45	(135)	6.6 (21)

Yield responses to fungicide programmes were greater in Hornet than in Apollo, reflecting the greater incidence and severity of foliar disease in the former. In each trial, programme B produced the highest yield on both varieties. All fungicide programmes significantly increased yield over the untreated. Apart from programme C on cv. Hornet in 1990, all programmes gave a significantly poorer yield than programme B. Programmes E and K frequently produced the lowest yield responses.

The yield responses to fungicide treatment could largely be accounted for by differences in thousand grain weight. In 1990, lodging occurred at all sites, particularly in cv. Hornet. Lodging was consistently and sometimes significantly less in those fungicide programmes where prochloraz was used at GS 30-32. This reduction in lodging was related to sharp eyespot infection at one site (Table 2A) but not apparently related to stem base or foliar disease at the other sites.

DISCUSSION

On both cvs effective control of foliar disease was achieved by all fungicide programmes. This was as true in the situations where disease pressure was generally high, as with Hornet, as in the situation where the disease pressure was generally low, with Apollo. Yield responses reflected the differences in disease pressure on the cvs. Thus, the justification for reducing dose rates was much greater in the low disease situation.

There were few significant differences in disease between fungicide programmes in any trial. Despite this, programme B always gave the highest yield. This suggests that even small differences in disease can still result in yield loss. However, when gross margins were calculated using all variable and spraying costs, programmes C, F, G, I, L and M resulted in equivalent or greater profit (Table 3). The profit was signifcantly greater with programme C and programme F (Apollo) in 1990.

With the cv. Hornet, disease appeared relatively early and progressed continuously thereafter. A three- or four-spray programme was justified. However, as these trials demonstrate there is the opportunity to reduce doses at each timing, although the differences between programmes demonstrate that choice of fungicide is important. A knowledge of the properties of fungicides is important. For example, in these trials, the reduction in lodging in programmes where prochloraz was included between GS 30 and 32 might give added weight to the choice of this fungicide at this timing. With a cv. like Apollo, not only might fungicide dose be reduced but there could be the option to omit one, or even two, sprays to achieve the optimum gross margin.

Further studies on reducing fungicide use on wheat should lead to development of systems whereby the need to treat at any timing is judged on a disease risk/yield loss assessment. This in turn will depend on the level of disease(s) in a crop, the biology of the pathogen(s), cv. disease resistance, preceding weather conditions and previous fungicide applications. Choice of fungicide is also important and the selection and appropriate dose rate will depend on a knowledge of the biological properties, the extent and/or stage of disease development and the growth stage of the crop.

Clearly, decision making on the use of fungicides in wheat is complex but these trials have demonstrated that reduced rates can be used effectively. Success in omitting sprays at conventional timings or reducing doses requires attention to detail, regular crop inspection, accurate disease identification and timely fungicide application. Reduced fungicide use may not be appropriate in all circumstances.

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REDUCED DOSAGES OF FUNGICIDES FOR CONTROLLING WHEAT DISEASES IN DENMARK

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ABSTRACT

The optimal dose and timing of fungicides for control of *Erysiphe graminis*, *Puccinia striiformis* and *Septoria* spp. were tested in experiments using ergosterol biosynthesis inhibiting fungicides. In field trials from 1987-1991 one full dose divided into 2, 3 or 4 applications depending on existing diseases and disease pressure gave good and acceptable control in all seasons. Best effect was found if the fungicide was applied at low disease levels or if spraying was carried out in the latent period. Control of established attack using reduced dosages had considerably less and often unacceptable effect, if spray-intervals were not adjusted to the dosages. In pot trials using artificial inoculation the preventive and curative effects of fungicides on *Septoria tritici* and *Puccinia striiformis* were tested using reduced dosages. The period in which optimal control could be reached decreased when using reduced dosages, but it was still possible to achieve full control even at the lowest rates tested. For *P. striiformis*, timing was found to be more important than dose rate.

INTRODUCTION

Since 1987, there has been an increased interest in Denmark in using reduced and split dosages of fungicides in cereals. Practical farming has, generally, adopted this habit. The interest has been intensified by falling grain prices, which has forced the farmers to find ways of reducing their input cost. This coincides with public and political pressure to reduce pesticide usage.

Trial results have shown a good possibility of using reduced dose rates while still obtaining acceptable control of cereal diseases without an increased risk of yield losses. It is a necessity, however, that treatments are carried out at low disease levels and that spray intervals are adjusted relatively to the dosages used (Jørgensen, 1989 ; Jørgensen & Nielsen, 1989). This report gives details of some of the experiments carried out in wheat to evaluate fungicide dose response in combination with different timing of the application, when controlling *Erysiphe graminis, Puccinia striiformis* and *Septoria* spp..

MATERIALS AND METHODS

Experiments were carried out as field trials and pot trials outdoors or in a greenhouse. The design of the field trials was a randomized complete block with four replicates and a plot size of 25-33 m^2. The fungicides were applied with a knapsack sprayer under low pressure (3 bar), using flat fan nozzles and at 300 l/ha. Eight different cvs have been used. Disease assessments were made as per cent coverage of all green leaves by the individual disease, at approximately

10-day intervals, starting at the first application and finishing at senescence. The plots were harvested with a plot combiner and the grain yields were corrected to 15% moisture content.

For the pot trials spring wheat (cv. Dragon) grown in 8 litre pots was grown outdoors for the *Septoria tritici* trial and winter wheat (cv. Anja) grown in 1 litre pots in a greenhouse was used for the *P. striiformis* trial. The plants were in both cases artificially inoculated and covered with polyethylene for 3 days to maintain constant high humidity. Treatments with fungicides were carried out prior to, as well as several times after the inoculation. The latent period for *Septoria tritici* was 22 days (average temp. 5-10°C) and for *P. striiformis* it was 11 days (average temp. 15-20°C). The attack was assessed on all green parts, which had been inoculated with the fungi.

RESULTS

Field experiments from 1990 gave good information on dose response and optimal timing for control of *P. striiformis* because this disease predominated in most trials in that year. Similarly *Septoria* spp., mainly *S. tritici*, predominated in the trials in 1991.

TABLE 1. Per cent control of diseases in winter wheat in 1990 and 1991 using different doses and timing of broad spectrum fungicide (BSF). Assessment was done at GS 75. Net yield was found after the cost of chemical and application had been deducted.

Treatment	Dose 1) (unit/ ha)	GS at application (Zadoks)	1991			1990		
				Yield and yield increase			Yield and yield increase	
			% *Septoria* spp.	t/ha		% *P.striiformis*	t/ha	
				Gross	Net		Gross	Net
1. Untr.			22.6	6.84	-	65.2	4.58	-
2. BSF	2x1.0	31,39	3.7	1.36	0.74	7.7	3.24	2.62
3. BSF	2x0.5	31,39	6.6	1.08	0.72	10.4	3.01	2.65
4. BSF	2x0.25	31,39	11.7	0.76	0.53	21.3	2.49	2.26
5. BSF	2x0.15	31,39	14.7	0.68	0.50	31.5	2.07	1.89
6. BSF	3x0.5	30,32,51	4.2	1.29	0.79	14.7	2.93	2.39
7. BSF	3x0.33	30,32,51	6.1	1.20	0.79	19.8	2.80	2.39
8. BSF	3x0.15	30,32,51	9.8	0.86	0.59	36.2	2.01	1.74
9. BSF	4x0.25	30,32,39,65	4.9	1.22	0.76	4.6	3.37	2.91
10. BSF	4x0.5	30,32,39,65	1.8	1.54	0.82	-	-	-
No. of trials			6	6	6	6	6	6
LSD ($P<0.05$) excl. untreated			7.3	0.23	-	14.4	6.3	-

BSF=broad spectrum fungicide. 1 or 2 trials were carried out with each of the following products. 1) 1.0 unit/ha=1 litre 'Pluton' (160 g flusilazole+375 g fenpropimorph), 1 litre 'Tilt top' (125 g propiconazole+375 g fenpropimorph), 1 litre 'Matador' (250 g tebucoconazole+125 g triadimenol) or 1.5 litre 'Rival' (338 g prochloraz+563 fenpropimorph).

For both *P. striiformis* and *Septoria* spp. a clear dose response was found both for efficacy data and yield data (Table 1). For *P. striiformis* timing was, however, seen to be more important than dose rate. Three applications using 1/2 dose gave less control than 2 applications also using 1/2 dose. This difference was caused by better timing of the 2 applications, where in particular application at GS 39 was important.

The impact of disease pressure on successful use of reduced dosages was seen in field trials carried out in 1987-1990. Very low dosages have given acceptable disease control for *P. striiformis* (Fig.1) and *E. graminis* (Fig. 2), if application took place before, or at very low levels of, infection. The good effect of low dosages lasted well even when the disease pressure was high later in the season.

The importance of correct timing for optimal control was confirmed for both *S. tritici* and *P. striiformis* in pot trials. In particular, for *P. striiformis*, the dose response was not significant, but the timing had great effect on the per cent control (Fig. 4). A clear dose response was seen for *S. tritici* when treatment was carried out 10 days or more after inoculation (Fig. 3). Application 3 days before inoculation had less effect than curative applications.

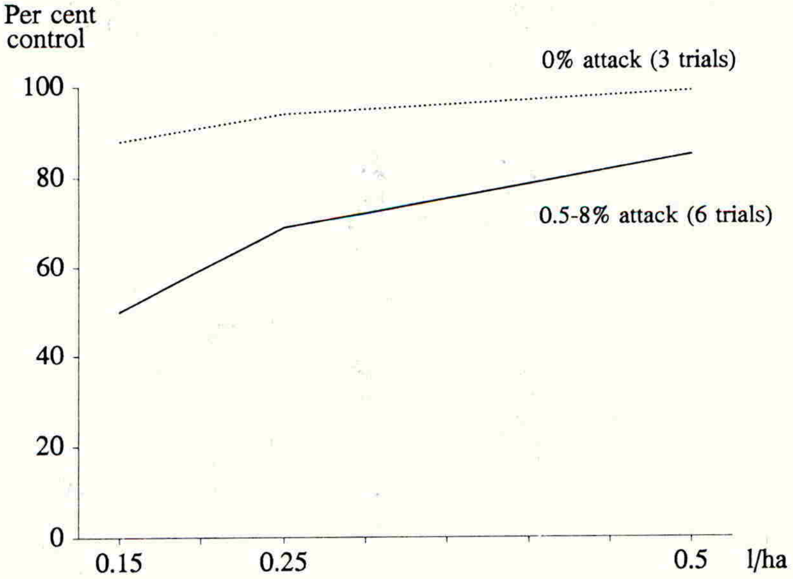

FIGURE 1. Effect of broad spectrum fungicide on *Puccinia striiformis*, depending on the level of attack at the time of 1st application (GS 31). Spraying was performed at GS 31 and GS 45. Severe attacks developed later in all 9 trials. The trials were assessed 3 weeks after 2nd application. 1989 trials.

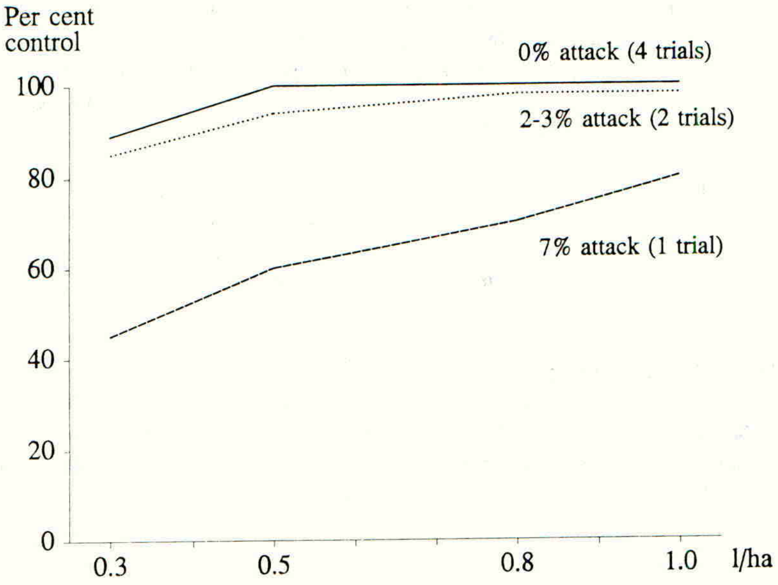

FIGURE 2. Effect of fungicides on *Erysiphe graminis*, depending on the level of attack at the time of first application (GS 31). Spraying was performed at GS 31 and GS 45 using propiconazole (125 g/ha)+fenpropimorph(375 g/ha). The trials were assessed 2-3 weeks after 1st application took place. 1987 and 1988 trials.

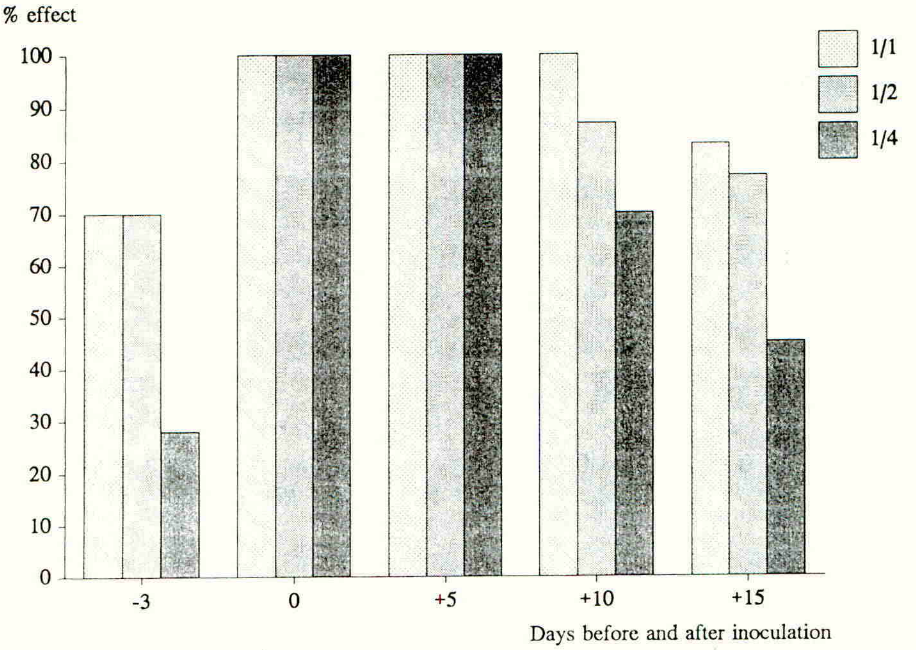

FIGURE 3. Per cent control of *Septoria tritici* by tebuconazole (1/1 = 250 g AI/ha) applied at various dosages and times relative to inoculation. Latent period 22 days.

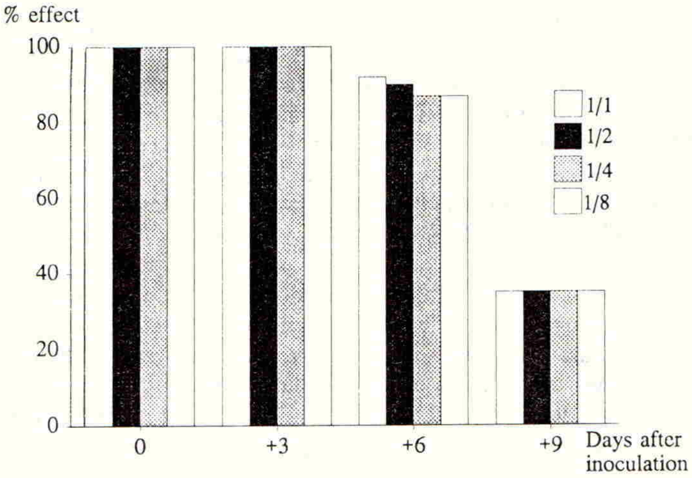

FIGURE 4. Per cent control of *Puccinia striiformis* by triadimenol (1/1 = 125 g AI/ha) applied at various dosages and times relative to inoculation. Latent period 11 days.

PRACTICAL USE OF FUNGICIDES IN WINTER WHEAT IN DENMARK

Practical farming has widely adopted reduced dosages. This has led to an increased number of applications per season (Table 2). Broad spectrum fungicides with a normal dose being 1 l/ha are today used in an average dose of 0.3-0.4 l/ha per treatment for leaf disease control. Similarly the dose of the eyespot product, prochloraz, has been reduced to on average half rate. Instead of using two applications per season the number has been increased to an average of 3.2 applications per season (AIM farmstat, based on the farmstat panel, c. 800 farmers).

TABLE 2. Average number of treatments and average dose of two fungicides commonly used in winter wheat in DK (AIM farmstat).

Year	1987	1988	1989	1990	1991
Average no. of treatments	2.0	2.1	3.1	3.3	3.2
Average dose of propiconazole + fenpropimorph (1 litre = 125+375 g/ha)	0.87	0.60	0.49	0.42	0.36
Average dose of prochloraz (1 litre = 450 g/ha)	0.79	0.75	0.64	0.53	0.50

DISCUSSION

Trials carried out since 1987 have shown good possibilities of using reduced dosages of broad spectrum fungicides which are ergosterol biosynthesis-inhibitors. Several of these products have very similar disease spectrum which opens up the opportunity of pooling trial results.

In the trials different dosages applied 2, 3 or 4 times per season showed that acceptable effects on *Septoria* spp. were obtained using various combinations of reduced dosages. Two applications with dosages less than 0.5 of the normal rate and 3 applications with dosages less than 0.33 gave unacceptable control. Good protective and curative effects on *S. tritici* have been found for several EBI fungicides (Eynard & Shephard, 1990; Jordan *et al.*, 1986). This result was confirmed in the pot trials, which also showed that reduced dosages can be effective, although the period of optimal effect is reduced. Pot trials with reduced dosages on *Septoria nodorum* showed similar results (Jørgensen, 1991).

Four applications using 0.25 of the normal dose were the only reduced dose treatment which gave acceptable control of *P. striiformis*, which confirms that timing is very important when controlling this disease. This result was confirmed in the pot trial, where almost no dose response was seen. However, applications carried out at earing or later show a clear dose response on the fungicide's long time effect (Table 1). The amount of control depends also to a certain degree on disease severity at the time of application (Fig 1); this can, however, be compensated for by more frequent applications.

Results from trials with reduced dosages have created the background for the adjusted dosages which are recommended in the Danish computer program PC-Plant Protection (Secher, 1991). The program contains recommended models for cereals in which reduced and adjusted dosages for individual diseases and attack levels are important key-factors. PC-Plant Protection recommend spraying when very low levels of *E. graminis* and *P. striiformis* attack are found in the field. A risk model based on precipitation is used for control of *Septoria* spp..

The risk of developing fungicide resistance when using reduced dosages has been a very discussed topic. So far no results have proved that the risk is actually increased. An important factor in the Danish recommendation of reduced dosages is, however, that only effective dosages are used in order to minimize selection pressure.

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