SESSION 7C

DEVELOPMENTS IN ARABLE CROP PROTECTION FOR THE 1990s

SESSION ORGANISERS	DR J. F. JENKYN DR D. M. GLEN
POSTERS	7C-1 to 7C-34

A NEW UNIFORM DECIMAL CODE FOR GROWTH STAGES OF CROPS AND WEEDS

H. BLEIHOLDER, E. WEBER

BASF AG, 6703 Limburgerhof, West Germany

T. VAN DEN BOOM, H. HACK, A. WITZENBERGER

Bayer AG, PF-E/Herbizide, 5090 Leverkusen, West Germany

PETER D. LANCASHIRE

Bayer UK Limited, Eastern Way, Bury St Edmunds, Suffolk IP32 7AH

P. LANGELÜDDEKE

Hoechst AG, Pflanzenschutz-Forschung, 6234 Hattersheim, West Germany

R. STAUSS

Ciba-Geigy AG, Division Agro, 4002 Basel, Switzerland

ABSTRACT

A universal scale (the BBCH Scale) using a decimal code for the description of the growth stages of most agricultural crops and weeds is presented. The scale and codes are based on the well-known Zadoks code for cereals.

THE BBCH SCALE AND CODE

The crop and weed growth stage scale described here was jointly developed by BASF, Bayer, Ciba-Geigy and Hoechst and is known as the BBCH scale. It is designed to be applicable to all crops and weeds, whether annual or perennial; sexually or vegetatively propagated. To achieve this phenologically equivalent growth stages (eg seed germination, tuber sprouting and bud burst) are grouped together. Figure 1 shows three examples: cereals, oilseed rape and cleavers (*Galium aparine*).

The scale is described by a two-digit decimal code based on Zadoks *et al* (1974). The use of this single scale and code for all crops makes it easier to remember for farmers, agronomists and technicians. A single regular code for all crops is also easier to use in a computer system than the many codes currently in use.

REFERENCES

Zadoks, J. C.; Chang, T. T.; Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Research*, **14**, 415-421.

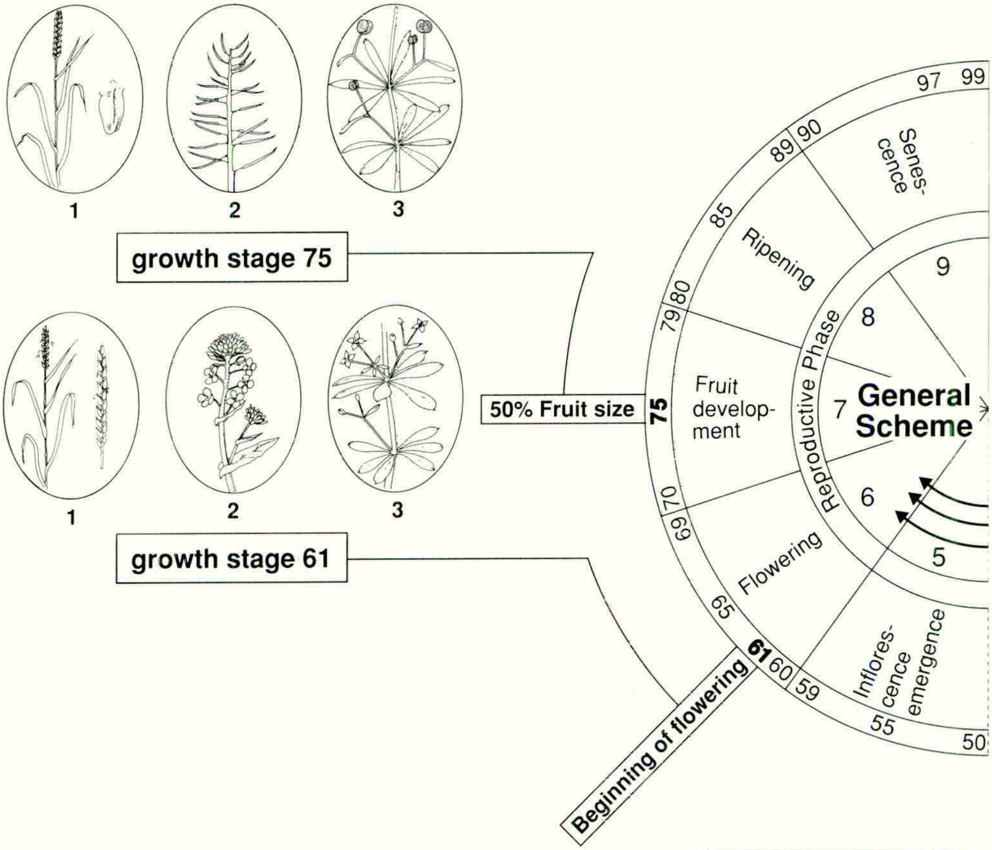
Bleiholder, H.; Van den Boom, T; Langelüddeke, P.; Stauss, R. (1989). Einheitlich Codierung der phänologischen Stadien bei Kultur- und Schadpflanzen. *Gesunde Pflanzen*, **41** (11), 381-384.

Witzenberger, A.; Van den Boom, T.; Hack, H. (1989). Erläuterungen zum BBCH-Dezimal-Code für die Entwicklungsstadien des Getreides - mit Abbildungen. *Gesunde Pflanzen*, **41** (11), 384-388.

7C—1

BBCH scale – A universal description of phenologically equivalent growth stages of crops and weeds.

Examples: cereals **1**, oilseed rape **2**, cleavers **3**



← Principal growth stages may run parallel in these developmental periods

By H. Bleiholder, E. Weber (BASF AG), T. van den Boom, H. Hack, A. Witzenberger (Bayer AG), Peter D. Lancashire (Bayer UK), P. Langelüddeke (Hoechst AG) and R. Stauß (Ciba-Geigy AG)

BBCH scale
BASF
BAYER
CIBA-GEIGY
HOECHST

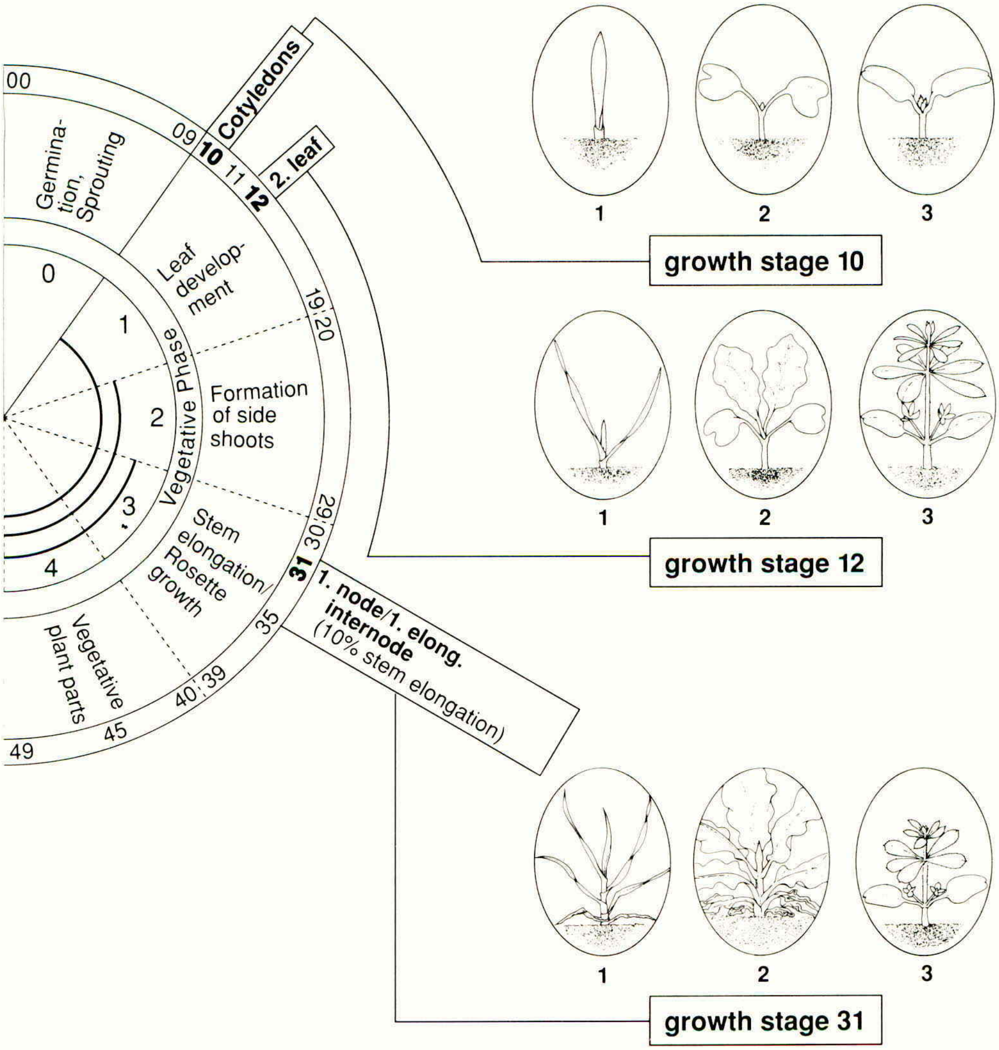

Cotyledons
2. leaf
00
09
10
11
12
Germina-
tion,
Sprouting
0
Leaf
develop-
ment
1
19;20
Formation
of side
shoots
2
Vegetative Phase
29;30
31
3
Stem
elongation/
Rosette
growth
4
1. node/1. elong.
internode
(10% stem elongation)
35
40;39
Vegetative
plant parts
45
49
1
2
3
growth stage 10
1
2
3
growth stage 12
1
2
3
growth stage 31

Table 1. BBCH growth stages of crops and weeds

M = Monocotyledones
D = Dicotyledones
P = Perennial plants
G = Gramineae
V = Vegetatively propagated plants
= All plants

BBCH Code		Definition
0		**Germination; sprouting; bud development**
00		Dry seed (seed dressing takes place at this stage)
	V	Perennating organs dormant;
	P	Winter dormancy or resting period
01		Beginning of seed imbibition;
	PV	Beginning of bud swelling
03		Seed imbibition complete;
	PV	End of bud swelling
05		Radicle (root) emerged from caryopsis (seed);
	V	Vegetative propagules or perennating organs forming roots
06		Elongation of radicle, formation of root hairs and/or lateral roots
07	M	Coleoptile emerged from caryopsis
	D	Hypocotyl with cotyledons or shoot has broken through seed coat;
	PV	Beginning of sprouting or bud-breaking
08	D	Hypocotyl with cotyledons growing towards soil surface;
	PV	Shoot growing towards soil surface
09	M	Emergence: coleoptile breaks through soil surface;
	D	Cotyledons break through soil surface (except in case of hypogeal germination);
	DV	Shoot or leaf breaks through soil surface;
	P	Buds show green tips
1		**Leaf development (main shoot)**
10	M	First true leaf emerged from coleoptile;
	D	Cotyledons completely unfolded;
	P	First leaves separating
11		First true leaf, leaf pair or whorl unfolded;
	P	First leaves unfolded
12		2 true leaves, leaf pairs or whorls unfolded
13		3 true leaves, leaf pairs or whorls unfolded
		... similarly for stages 14 to 18 ...
19		9 or more true leaves, leaf pairs or whorls unfolded
		(Tillering, side shoot development or stem elongation may occur at an earlier stage or side shoots may not be formed at all. In this case continue with stages 21 or 31.)

Table 1. BBCH growth stages of crops and weeds (continued)

2		**Formation of side shoots; tillering**
21		First side shoot visible;
	G	First tiller visible
22		2 side shoots visible;
	G	2 tillers visible
23		3 side shoots visible;
	G	3 tillers visible
		... similarly for stages 24 to 28 ...
29		9 or more side shoots visible;
	G	9 or more tillers visible
3		**Stem elongation or rosette growth (main shoot); shoot development**
31		Stem (rosette) 10% of final length (diameter);
	G	1 node detectable
32		Stem (rosette) 20% of final length (diameter);
	G	2 nodes detectable
33		Stem (rosette) 30% of final length (diameter);
	G	3 nodes detectable
		... similarly for stages 34 to 38 ...
39		Maximum stem length or rosette diameter reached;
	G	9 or more nodes detectable
4		**Development of harvestable vegetative plant parts; booting**
41		Harvestable vegetative plant parts begin to develop;
	G	Flag leaf sheath extending
43		Harvestable vegetative plant parts have reached 30% of final size;
	G	Flag leaf sheath just visibly swollen (mid-boot)
45		Harvestable vegetative plant parts have reached 50% of final size;
	G	Flag leaf sheath swollen (late-boot)
47		Harvestable vegetative plant parts have reached 70% of final size;
	G	Flag leaf sheath opening
49		Harvestable vegetative plant parts have reached final size;
	G	First awns visible
5		**Inflorescence emergence (main shoot); initiation of vegetatively propagated organs; ear or panicle emergence**
51		Inflorescence or flower buds visible;
	G	Beginning of heading;
	V	Initiation of vegetatively propagated organs
55		First individual flowers visible (still closed);
	G	Half of inflorescence emerged (middle of heading)
59		First flower petals visible;
	G	Inflorescence fully emerged (end of heading)

Table 1. BBCH growth stages of crops and weeds (continued)

6		**Flowering (main shoot); formation of vegetatively propagated organs (main shoot)**
61		Beginning of flowering: 10% of flowers open or 10% of plants in bloom
63		30% of flowers open or 30% of plants in bloom
65		Full flowering: 50% of flowers open or 50% of plants in bloom; first petals fallen or dry
67		Flowering finishing: majority of petals fallen or dry
69		End of flowering: fruit set visible
7		**Development of fruit; growth of vegetatively propagated organs**
71		Small fruits visible or fruit has reached 10% of final size;
	G	Caryopsis watery ripe
73		First fruits have reached final size or fruit has reached 30% of final size
75		50% of fruits have reached final size or fruit has reached 50% of final size;
	G	Milky ripe stage;
	V	Vegetatively propagated organs have reached 50% of final size
77		70% of fruits have reached final size or fruit has reached 70% of final size;
	V	Vegetatively propagated organs have reached 70% of final size
79		Nearly all fruits have reached final size typical of species or variety
8		**Ripening or maturity of fruit and seed (including vegetatively propagated organs); colouration of fruit**
81		Beginning of ripening or fruit colouration
85		Advanced ripening or fruit colouration typical of species or variety;
	G	Dough stage;
	V	Vegetatively propagated organs have reached final size
88		Fruit begins to soften (species with fleshy fruit)
89		Fully ripe; fruit shows full-ripe colour typical of species or variety; beginning of fruit abscission;
	V	Vegetatively propagated organs have reached full ripeness
9		**Senescence; beginning of dormancy**
91	P	Shoot development completed, foliage still green
93		Leaves begin to change colour or fall
95		50% of leaves discoloured or fallen
97		End of leaf fall; plants or above ground parts dead or dormant;
	P	Plant resting or dormant
99		Harvested product (Post-harvest or storage treatment takes place at this stage. Seed-treatment takes place at stage 00.)

ECONOMIC APPRAISAL FOR SPRAYING WINTER FIELD BEANS

P. BOWERMAN

Agricultural Development and Advisory Service, Boxworth Experimental Husbandry Farm, Boxworth, Cambridge CB3 8NN

ABSTRACT

The effects of wheeling winter beans with a conventional tractor or a high-clearance sprayer during flowering and pod filling were compared at Boxworth in 1985, 1986 and 1988. Wheeling at late flowering was the most damaging resulting in yield losses of nearly 5% and 4% with the tractor and high-clearance sprayer respectively. The implications of losses from wheeling damage when deciding whether to apply a pesticide are discussed.

INTRODUCTION

Driving a tractor mounted sprayer through a tall crop of winter sown field beans (*Vicia faba*) causes damage. The resulting loss in yield of seed may outweigh the benefits of the spray being applied. There are four main times after the start of flowering when sprays may be applied to winter field beans; mid-flowering and/or late flowering for fungicides, post-flowering for fungicides or insecticides and 5-10 days before harvest for desiccants.

There is little published information on the losses caused by the passage of a sprayer through a crop. Consequently, a series of trials was done at Boxworth in 1985, 1986 and 1988 to determine the yield losses associated with wheeling at various stages of growth from early flowering, and to compare the effects of a conventional tractor and mounted sprayer with a specialised high clearance machine.

MATERIALS AND METHODS

Treatments were combinations of spray machinery and timings :

Machinery
1. Sprayer mounted on tractor
2. Self-propelled high-clearance sprayer

Timings
1. Unwheeled
2. Early flowering
3. Late flowering
4. Early + late flowering

Additional timings with self propelled high clearance sprayer
1. Post-flowering
2. Early + late + post flowering
3. Desiccation stage (except 1985)
4. Early + late flowering + desiccation stage (except 1985)

Machinery

1. Tractor, tyre width (conventional tyres) 40cm, minimum ground clearance (at front axle) 37cm; plastic sheeting on underbody; mounted sprayer.

2. Self propelled high-clearance sprayer; tyre width (row crop wheels) 23cm; minimum ground clearance 100cm.

The trial design was a fully randomised block with four replications and two untreated plots per replicate. The trials were sited on commercial crops of cv. Banner in 1985 and 1986, and cv. Bourdon in 1988. All husbandry treatments for the trials were applied across the plots at right angles to the direction of the treatment wheelings. Plot length was 24 metres and yields were taken with a combine (width 2.62 metres) incorporating the wheeled area plus the unwheeled crop immediately adjacent to the wheelings. Treatment yields were calculated assuming a 24 metre wide spray boom.

Treatment application dates were as in Table 1.

TABLE 1. Treatment timing

Time of treatment	1985	1986	1988
Early flowering (2-10 nodes with flowers open)	29 May	3 June	10 May
Late flowering (pods developing on lower nodes)	28 June	26 June	15 June
Post flowering (no flowers present)	11 July	9 July	6 July
Desiccation (most pods black, most leaves shed)	-	20 Aug.	19 Aug.

RESULTS

Crop height

Crop height was measured at the time of the first three treatments (Table 2).

TABLE 2. Heights, (cm), of unwheeled crop

	1985	1986	1988
Early flowering	71	77	60
Late flowering	131	124	140
Post-flowering	143	123	164

Lodging

The crop started lodging in 1985 between early and late flowering and was completely lodged by harvest. No lodging occurred in 1986 but the crop lodged completely just prior to wheeling at the desiccation stage in 1988.

Yield

Yields from the harvested area over wheelings are presented in Table 3

TABLE 3. Yield (t/ha at 85 per cent dry matter) of crop harvested over area of wheeling

Machine	Time of wheeling	1985	1986	1988
	Not wheeled	4.14	5.71	5.99
Tractor	Early flowering	4.13	5.36	6.38
	Late flowering	1.87	3.69	3.53
	Early + late flowering	2.34	4.51	3.43
High clearance sprayer	Early flowering	4.22	5.30	5.79
	Late flowering	2.49	4.37	3.61
	Early + late flowering	2.93	4.39	5.47
	Post-flowering	2.41	4.29	3.62
	Early + late + post-flowering	2.63	3.79	3.34
	Desiccation	-	5.29	4.82
	Early + late flowering + desiccation	-	4.02	3.88
	SED untreated v treated	± 0.170	± 0.132	± 0.649
	SED treated v treated	± 0.197	± 0.152	± 0.749

The change in yield resulting from wheeling the crop was calculated based upon wheelings at 24 metres centre i.e. a sprayer with a boom width of 24 metres (Table 4).

Damage in terms of percentage yield lost was least in 1986 when the crop was shortest and did not lodge. In addition to the crop being run down by the wheels of both machines the tractor pushed the crop over each year at the early flowering timing. However, there was no yield loss from the passage of either machine through the crop at the early flowering stage.

Wheeling the crop with the tractor at late flowering caused most yield loss in the first two years. Passing through the crop with the tractor at early flowering and following the same wheel marks at late flowering resulted in a lower yield loss in two years and a similar loss in the third year compared with the earlier timing alone.

TABLE 4. Yield losses due to wheelings expressed as a percentage of non - wheeled crop and based upon 24 metre centres

Machine	Time of wheeling	% change in yield 1985	1986	1988	Mean
Tractor	Early flowering	0.0	0.6	-0.7	0.0
	Late flowering	6.0	3.8	4.5	4.8
	Early + late flowering	4.7	2.2	4.7	3.9
High clearance sprayer	Early flowering	-0.2	0.8	0.5	0.4
	Late flowering	4.4	2.5	4.3	3.7
	Early + late flowering	3.2	2.5	1.0	2.2
	Post-flowering	4.6	2.6	4.3	3.8
	Early + late + post-flowering	4.0	3.6	4.8	4.1
	Desiccation	-	0.8	2.1	(1.4)*
	Early + late flowering + desiccation	-	3.2	3.8	(3.5)*

* ( ) two years data only

The high clearance sprayer at late flowering and when combined with the early flowering timing usually resulted in smaller losses than the use of the tractor at the same times. The losses caused by the late and post-flowering wheelings with the high clearance sprayer were similar each year.

In the two years that the high clearance sprayer was used to wheel the crop at the time when desiccants would be applied the losses were less than those incurred at late and post-flowering.

Seed moisture content was 1-2% greater where the crop was wheeled at late flowering in the first two years.

DISCUSSION

Crop effect

Damage (yield loss) does occur by wheeling winter beans during the late flowering and ripening stages. The crop between the wheelings was not permanently flattened at the early flowering stage by the underbody of the machines, so the crop on either side of each wheeling was able to compensate for damage caused by the wheels and no yield loss resulted.

The passage of the tractor at late flowering pushed the crop down permanently between the wheelmarks and broke off some of the stems at or near ground level. Passage by the high clearance sprayer at this stage usually only caused the crop to lean.

The losses found in these trials were greater than those reported in Sweden on Vicia faba beans (Nilsson et al. 1981), where the losses recorded were 2.0-4.5% with a tractor-mounted sprayer and 10 metre boom, but the yield penalties incurred were similar to those found with the same machines passing through winter oilseed rape (Ogilvy, 1989).

Boom width

Using a 24m sprayer boom, the number of passes through the crop is half the number required for a 12m sprayer, so yield losses are half those from the smaller boom. This is the main advantage of using contractor's high clearance machines as they often have wider booms than conventional on-farm equipment.

Benefits from late season sprays

Applying pesticides routinely to winter beans costs money, causes wheeling losses and will not guarantee any returns unless pest and disease thresholds are reached. A 5% loss of yield from a crop yielding 3.5 t/ha (at £150/t), would be worth £26/ha. Responses of at least 4-5% are required to pay for wheeling losses and the cost of a contractor at £11 per hectare (Nix, 1989), and in addition there are the chemical costs.

Yield losses of 1.5% can occur from wheeling at the desiccation timing if no other late season wheeling has been done. Direct combining, without desiccation, avoids this loss.

ACKNOWLEDGEMENTS

The author thanks Dr. P.G. Stapleton who was responsible for the work in the initial years.

REFERENCES

Nilsson, C.; Svensson, E.; Danielsson, P. (1981) Traffic injury through weed control in Barley, Spring rape and Faba beans. Vaxtskyddsnotiser **45**, pp 173-176

Nix, J. (1989) Farm Management Pocketbook, twentieth edition (1990) Wye College, University of London, pp 116.

Ogilvy, S.E. (1989) The effect of late wheeling damage on the yield of winter oilseed rape. Aspects of Applied Biology 23, Production and Protection of oilseed rape and other brassica crops pp 177-182.

THE USE OF INNOVATIVE AGRICULTURAL PRACTICES IN A FARM SYSTEMS CONTEXT FOR PEST CONTROL IN THE 1990 S

CLIVE A. EDWARDS, BENJAMIN R. STINNER

Department of Entomology, The Ohio State University, 1735 Neil Avenue, Columbus, Ohio 43210, U.S.A.

ABSTRACT

Traditionally, pest control depended upon crop rotations, soil cultivations and various well-established cultural practices. This changed in the 1950's to an almost total dependency upon pesticides, followed in the last 30 years, by gradual development of integrated pest management programs which combine more limited pesticide use with cultural and biological control techniques. The shortcomings of these techniques have been that pest, disease and weed management programs have usually been developed independently with relatively little integration between them and often in isolation from consideration of the effects of overall farm practices. Pest control in the 1990's must move inevitably towards an integrated whole farm approach where interactions between all the inputs of cultivations, fertilizers, rotations, related cultural practices and chemical and biological pest control are considered in a systems context. Such systems must include: integrated management of pests, diseases and weeds combined with appropriate cultivations and fertilizer inputs together with innovative techniques such as strip-cropping, intercropping, successional cropping, use of live and dead mulches, and controlled weed growth. How these individual components influence pest control through interactions in a systems context are described and practical examples of how fertilizers, cultivations and innovative practices impact upon pest control in a farm systems context are given.

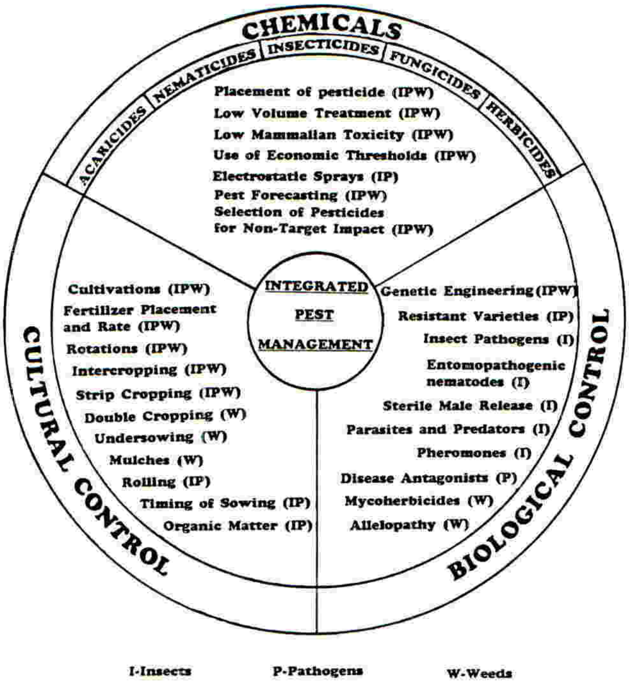
INTRODUCTION

Agricultural has moved progressively from culturally-based practices through a more mechanized agriculture to its current heavy dependence upon agrochemicals. Similarly, pest control has moved from techniques based on cultural practices to a strong dependence upon pesticides. The latter phase of chemical dependence began after the Second World War, with the discovery of the organochlorine and organophosphate insecticides and the hormonal herbicides. With the onset of the 1960's, an increased environmental awareness and greater attention to the mammalian toxicity of pesticides, there was pressure to use less toxic chemicals much more carefully. Nevertheless, the disciplinary nature of agricultural education has led to most decisions on the use of pesticides being based on the effectiveness of a pesticide against a particular pest, rather than on its potential side-effects on beneficial and other organisms and the environment. The aim of this paper is to consider pest control measures in relation to all of the other components and interactions, in a farm systems context.

INTEGRATED PEST, DISEASE AND WEED MANAGEMENT

The progressive development of systems of integrated pest control and management began with the classic publication of Stern *et. al* (1959). The original concept emphasized

Figure 1. Potential of integrated pest mangement



the blending of biological and chemical control measures which broadened (Smith & Reynolds, 1965) to "a system which uses all suitable methods in as compatible a manner as possible" and led to a definition by FAO (1967): "A pest management or integrated control system, in the context of the association environment and the population dynamics of the pest species, which utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations levels below those causing economic injury". However, neither this definition nor that of Norton & Holling (1976) "to develop alternative, ecologically desirable tactics for use in suppressing major pests" emphasizes the implicit need to decrease the use of pesticide. It is important to note that integrated pest management is not merely the use of pesticides only when necessary to avoid economic damage, which is normally termed "supervised control". However, many of the techniques examined as components of integrated pest management, such as development of economic injury thresholds, use of pheromones in pest monitoring, use of selective pesticides etc., have already have been incorporated into present day pest control practices and have led to a very much more rational use of pesticides. Although successful integrated pest management programs have been developed for glasshouse crops, orchards and some field crops such as cotton, adoption of truly integrated pest management programs has been relatively slow. The main short-fall in the development of integrated pest management in arable crops has been the implementation of truly integrated control programs where entomologists, plant pathologists and weed specialists work together with agronomists and plant breeders where appropriate (Figure 1). Only such an interdisciplinary effort could produce a sound integrated crop protection program which should include protection of crops against animal pests, diseases and weeds, using all available alternative, ecologically and environmentally desirable means including manipulation of farm practices, with minimum possible use of chemical pesticides.

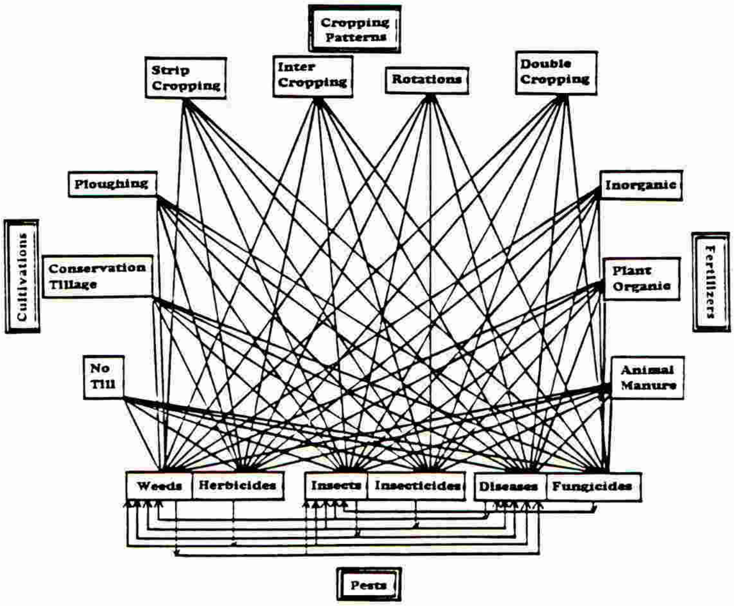
THE CONCEPT OF PEST MANAGEMENT IN A FARM SYSTEMS CONTEXT

The idea that pest management should be considered in a farm management context was proposed by Vereijken *et al.* (1986). He suggested that a farming system consists of five main components: cultivations, fertilization, cropping patterns, crop protection and farm economics.

Central to this pattern is **farm economics** which includes all inputs such as: land, labour, buildings, machines, chemicals and seed, balanced against yield and profits. A farming system is not just the sum of all of its components but a complex with intricate interactions. The concept of the central position of farm economics is in striking contrast to the perception of many integrated control specialists who have assumed that plant protection is the central component. Crop protection is only one important part of the system and its needs and implementation depend on the demands and changes in the rest of the system.

Crop protection measures, whether chemical or biological all interact strongly with cultivations, fertilizers and cropping patterns (Figure 2). Only in such a system can undesirable ecological and environmental effects such as pollution of soil and water by pesticides be truly minimized. In general, integrated farming takes the various impacts on ecosystems and society much more into account than does normal pesticide use. It considers effects on (a) the quality and quantity of produce, (b) the economic viability of the system, (c) employment, public health and well being of persons associated with agriculture, (d) needs for energy and non-renewable resources, (e) the quality and diversity

Figure 2. Interactions between crop protection and farm practices



of the landscape (clean environment), (f) the preservation of the fauna and flora. Currently, the conventional approach to crop production has (a) and (b) as its main objectives but takes insufficient account of the other aspects on which the effects have sometimes been undesirable or even harmful. In recent years, there have been increasing demands for a better balance between these various influences, based on a growing awareness of problems caused by conventional farming. Hence, the increasing need for the integrated farming systems approach. Integrated farming systems of the kind proposed could: (i) Maximize profits by lower costs of purchased chemicals. (ii) Minimize food contamination. (iii) Decelerate the development of resistance to chemicals. (iv) Lessen the environmental impact of pesticides on beneficial organisms, wildlife and man.

INNOVATIVE PRACTICES WITH INFLUENCES ON PEST CONTROL

Traditional agriculture in temperate countries has depended upon deep ploughing, use of inorganic fertilizers and chemical pesticides, in large fields with crops grown in monoculture or biculture. Such practices encourage the carryover of pests, diseases and weeds from one year to the next, by minimizing overall diversity and disturbance. All of the basic components can be modified by introducing newer practices which will decrease the adverse effects of pests and lessen the need for pesticides. Examples are:

1. Cultivations

Traditionally, **mould board ploughing** inverted the soil and buried crop residues and weeds before the preparation of a seed bed for the succeeding crop. Progressively, since the 1960s, there has been a trend towards less and shallower tillage culminating in the practice of killing the previous crop with herbicides and planting the next crop directly into the plant residues. This has been termed **direct drilling** in Europe or **no till** in the U.S. and usually involves special machinery. The changes in soil displacement and disturbance, location of plant residues and weed ecology all influence the incidence of pests and diseases. **Conservation tillage** leads to a completely different spectrum of weeds, with lower populations of those species that need to have their seeds buried to germinate and higher numbers of species that are controlled by cultivation. Similarly, some diseases and insect pests decrease in severity with less cultivations and others increase. Of 45 studies surveyed by Stinner & House (1990) involving 51 pest species damage by 28% increased with decreasing tillage, that by 29% showed to significant influence of tillage and 43% decreased with decreasing tillage. Thus, tillage plays a major role in pest incidence and should be taken into account in designing farm management systems that maximize pest control. An example of how pests and their predators are affected by tillage is given in Figure 3.

2. Fertilizers

There is good evidence that **inorganic fertilizers** can increase pest attack and the need for use of pesticides. When inorganic fertilizers are broadcast over a field they promote weed growth between the crop rows and increase the need for herbicides; whereas, placement of the fertilizer in the row would minimize this effect (Edwards, 1989). Inorganic fertilizers can increase the incidence of leaf diseases such as cereal leaf disease (Jenkyn & Finney, 1981) and they can also increase the incidence of pests such as cereal aphids (Kowalski & Visser, 1979).

Organic fertilizers tend to decrease attacks by diseases (Hoitink & Fahy, 1986) by promoting the activity of fungal antagonists. They also decrease attacks by many invertebrate pests by increasing species diversity in favor of natural enemies (Altieri, 1985;

Edwards, 1989) by providing alternative food for marginal pests and by promoting the activity of pest antagonists such as fungi that attack nematodes (Kerry, 1988) and other pests and by building up populations of arthropod predators of pests by providing them with alternative food sources.

3. Cropping Patterns

Multiple cropping, i.e. growing more than one crop in a single field was common in earlier agriculture and is still the main pattern in tropical countries. In temperate countries there has been an increasing tendency to grow crops in monoculture or biculture over extended periods, and multiple cropping systems are much less common in developed countries than they once were. Multiple cropping includes traditional annual sequential cropping or crop rotations, but also such innovative practices as: growing two crops in the same field in a single season, intercropping or undersowing (where two or more crops are grown in the same field, usually in alternate rows,) and strip cropping with two crops grown in strips wide enough to allow independent cultivation and treatments but narrow enough to allow ecological interactions (Francis, 1986). Multiple cropping systems increase diversity both in terms of habitat structure and species thereby minimizing pest, disease or weed incidence (Stinner & Blair 1989). Such innovative cropping patterns have considerable potential for incorporation into integrated lower chemical input farming systems. Examples of how rotations and alternate strip cropping affect pests and diseases are given in Figures 3 and 4.

Figure 3. Effects of tillage and rotations on corn (maize) pests and their predators

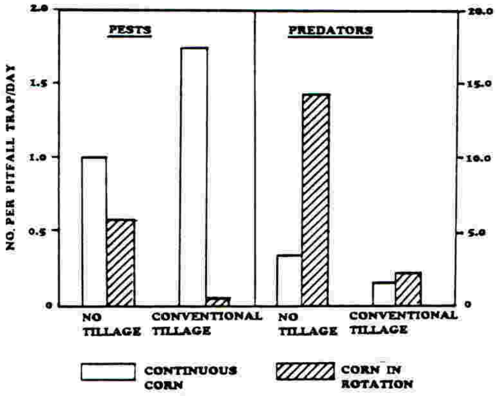
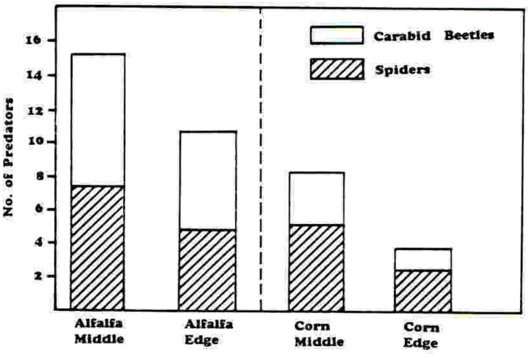


Figure 4. The influence of strip-cropping on natural enemies of pests.



INTEGRATION INTO A FARMING SYSTEM

There is considerable knowledge on how some agricultural practices impact upon pest management (Edwards, *et al.*, 1988; Edwards, 1987, 1989; Edwards & Regnier, 1989). We need more data on how some of the more innovative practices interact with pest attack. There are already computer-based farming advisory systems for pest control (Willson *et al.*, 1987). These need further development into a whole farm system context taking account of the impact of all farm inputs upon pest attack and management.

REFERENCES

Altieri, M.A. (1985) Diversification of agricultural landscapes - a vital element for pest control in sustainable agriculture. **In:** *Sustainable Agriculture and Integrated Farming Systems*. T.C. Edens, C. Fridge, and S.L. Battenfield (Eds.), Michigan State University Press, pp. 124-136.

Edwards, C.A. (1987) The concept of integrated systems in lower input/sustainable agriculture. *American Journal of Alternative Agriculture* **2**(4), 148-152.

Edwards, C.A. (1989) The importance of integration in sustainable agricultural systems *Agriculture, Ecosystems and Environment* **21**, 25-35.

Edwards, C.A.; Regnier, E.E. (1989) Designing integrated low-input farming systems to achieve effective weed control. *Brighton Crop Protection Conference - Weeds*, 1989, **3**, 585-90.

Edwards, C.A; Stinner, B.R.; Creamer, N. (1988) Pest and Disease Management in Integrated Lower Input/Sustainable Agricultural Systems. *Brighton Crop Protection Conference - Pests and Diseases, 1988,* **3**, 1009-16.

FAO (1967) Report of the First Session of the FAO Panel of Experts on Integrated Pest Control. Rome: FAO.

Francis, C.A. (Ed.) (1986) *Multiple Cropping Systems*. New York. MacMillan Publishing Co.

Hoitink, H.A.J.; Fahy, P.C. (1986) Basis for the control of soil-borne plant pathogens with composts. *Annual Review of Phytopathology* **24**, 93-114.

Jenkyn, J.F.; Finney, M.E. (1981) Fertilizers, fungicides and sowing date. **In:** *Strategies for the Control of Cereal Diseases*. J.F. Jenkyn and R.T. Plumb (Eds.), Oxford: Blackwell, pp. 179-188.

Kerry, B. (1988) Fungal parasites of cyst nematodes. *Agriculture, Ecosystems and Environment* **2A**, 293-305.

Kowalski, R.; Visser, P.E. (1979) Nitrogen in a crop-pest interaction: cereal aphids. **In** *Nitrogen as an Ecological Factor*. J.A. Lee, S. McNeill and I.H. Rorison (Eds.), Oxford: Blackwells.

Norton, G.A.; Holling, C.S. (1976) *Conference on Pest Management*. Laxenburg, Austria: International Institute for Applied Systems Analysis, 236 pp.

Smith, R.F.; Reynolds, H.T. (1965) Principles, definitions and scope of integrated pest control. *Proceedings of FAO Symposium on Integrated Pest Control,* **1**, 11-17.

Stern, V.M.; Smith, R.F.; van den Bosch, R.; Hagen, K.S. (1959) The integrated control concept. *Hilgardia,* **29**, 81-101.

Stinner, B.R.; Blair, J.M. (1989) Ecological and agronomic characteristics of innovative cropping systems for sustainable agriculture. **In:** *Sustainable Agricultural Systems*, C.A. Edwards, P. Madden, R.H. Miller, and G. House (Eds.), Ankeny, Iowa: Soil and Water Conservation Society, 123-140.

Stinner, B.R.; House, G.J. (1990) Arthropods and Other Invertebrates in Conservation Tillage Agriculture. *Annual Review of Entomology,* **35**, 299-318.

Vereijken, P.; Edwards, C.A.; El Titi, A.; Fougeroux, A.; Way, M.J. (1986) Study Group on "Management of Farming Systems for Integrated Control. Bulletin 10BC/WPRS. 1986/IX/2. 34 pp.

Willson, H.; Hall, F.; Lennon, J.; Funt, R. (1987) Market Model. *A Decision Support Program From the Computer Advisory System for Horticulture* (CASH) Publ. The Ohio State University. 64 pp.

CONSERVATION AND MANIPULATION OF APHID PARASITOIDS

W. POWELL, W.J. BUDENBERG, U.M. DECKER & A.F. WRIGHT

Department of Entomology and Nematology, AFRC Institute of Arable Crops Research,
Rothamsted Experimental Station, Harpenden, Herts., AL5 2JQ

ABSTRACT

Parasitoids often make a substantial contribution to the natural control of aphids, particularly following mild winters. Therefore, parasitoids need to be conserved on farmland and methods to enhance their impact on aphid pests need to be developed. The ability of some parasitoids to transfer between different hosts was demonstrated, emphasizing the potential value of non-pest aphids as reservoir hosts. However, parasitoid genotype seems to have a strong influence on host-transfer ability. Semiochemicals (behaviour-controlling chemicals) govern the host finding and attack behaviour of parasitoids and so offer opportunities for manipulating parasitoids in the field. Behavioural responses by parasitoids to semiochemical cues from aphids, honeydew and plants have been detected in the laboratory. More information is needed on local parasitoid population ecology and behaviour in the field to allow effective conservation and manipulation.

INTRODUCTION

Insect parasitoids are used as biological pest control agents throughout the world and they have been successfully established in classical biological control attempts about three times as often as predators (Greathead, 1986). Parasitoids have been used successfully for the control of aphids both in the field (Hughes, 1989) and in glasshouses (Ramakers, 1989). In Britain aphids are important pests on a range of crops and most of these aphids are attacked by indigenous parasitoid species which form an important part of the natural enemy fauna inhabiting farmland. Parasitoids often make a substantial contribution to the natural control of aphids on major crops such as cereals, particularly following mild winters (Wratten & Powell, in press). If mild winters become more frequent as a consequence of global warming, aphid parasitoids will become more valuable as natural pest control agents in the field.

It is important, therefore, to conserve parasitoid populations within the farmland ecosystem and to develop methods of enhancing their activity in crops, both of which require a thorough understanding of parasitoid ecology and behaviour. Powell (1986) reviewed various ways of enhancing parasitoid activity in crops and two approaches are currently being investigated at Rothamsted. These are the use of alternative, non-pest aphids as reservoir hosts and the use of semiochemicals to manipulate parasitoid behaviour. This work is complemented by studies of the local population ecology of aphid parasitoids on arable farmland.

ALTERNATIVE HOSTS

Many of the parasitoid species which attack aphids on crops also attack other, non-pest aphids in semi-natural habitats. It has been suggested that these alternative hosts are important for maintaining local parasitoid populations when pest aphids are scarce and for building up parasitoid numbers early in the year (Perrin, 1975; Stary, 1986). However, their potential value depends upon the ability of parasitoids to transfer between different host species and, more importantly, their willingness to do so in the field.

TABLE 1. Effect of rearing host on mean number of aphids killed per *Aphidius ervi* female per 24 h in host-switching trials. Forty nymphs were provided for each parasitoid and between 7 and 10 parasitoids were used with each test host.

Rearing Host -	*A. pisum*		*M. carnosum*	
Test Host -	*A. pisum*	*M. carnosum*	*M. carnosum*	*A. pisum*
Mean Number of Aphids killed per Parasitoid	28.6	1.3	17.8	18.2

The parasitoid *Aphidius ervi*, which attacks the cereal aphids *Sitobion avenae* and *Metopolophium dirhodum*, the pea aphid *Acyrthosiphon pisum* and the nettle aphid *Microlophium carnosum*, has been used to study host transfer ability in the laboratory (Cameron *et al*., 1984; Powell & Wright, 1988). Female *A. ervi* reared on *M. carnosum* readily attacked *A. pisum*, causing the same rate of aphid mortality on both hosts, but females reared on *A. pisum* were reluctant to attack *M. carnosum*, causing very low aphid mortality on the new host (Table 1). In these trials each female parasitoid was given access to forty nymphs of either *A. pisum* or *M. carnosum* for a period of 24 h. Subsequent electrophoretic studies showed that the laboratory *A. ervi* population that was maintained on *A. pisum* had a lower genetic variability than the population maintained on *M. carnosum*. Moreover, when the two populations were cross-mated, the reluctance of females reared on *A. pisum* to attack *M. carnosum* often disappeared if their male parent had been reared on *M. carnosum* (Table 2).

These results indicate that parasitoids generally are capable of transferring between different host species within their normal host range, but that parasitoid genotype has a strong influence on this ability. The influence of genotype most probably operates via the parasitoids behavioural responses to the semiochemical cues which determine host recognition (Powell & Wright, 1988). This emphasizes the importance of conserving a broad genetic base in wild populations of parasitoids.

TABLE 2. Effect of parental host on mean number of aphids killed per *Aphidius ervi* female per 24 h in host-switching trials. The attack rate on *M. carnosum* was influenced by the host species on which the male parent of the parasitoids tested had been reared.

Rearing Host	-	*A. pisum*		*A. pisum*	
Host of mother	-	*A. pisum*		*A. pisum*	
Host of father	-	*A. pisum*		*M. carnosum*	
Test Host	-	*A. pisum*	*M. carnosum*	*A. pisum*	*M. carnosum*
Mean Number of Aphids killed per Parasitoid		28.6	1.3	19.2	16.0

SEMIOCHEMICALS

In order to find and successfully attack suitable hosts, parasitoids make a series of behavioural responses to environmental cues. Several steps, including habitat location, host location and host acceptance, have been identified in their host finding and selection behaviour (Vinson, 1984). Behaviour-controlling chemicals such as kairomones, synomones and pheromones (collectively called semiochemicals) act as cues for behavioural responses at all these steps. These semiochemicals originate from host species, host byproducts such as honeydew and from host food-plants. The influence of these semiochemical stimuli offers opportunities for manipulating parasitoid behaviour in the field in order to enhance their impact on crop pests (Powell, 1986).

Examples of ways in which semiochemicals might be used to manipulate parasitoids include:

a. to attract and retain parasitoids during the early stages of pest infestation when a favourable pest: parasitoid ratio is critical for efficient control (plant synomones; aphid kairomones),
b. to increase the search times and attack rates of parasitoids (plant synomones, aphid kairomones),
c. to disrupt the host finding and host acceptance behaviour of hyperparasitoids and so reduce their impact on primary parasitoid populations (parasitoid kairomones),
d. to monitor parasitoid and hyperparasitoid abundance and activity as an aid to pest forecasting (parasitoid pheromones).

To develop such methods of parasitoid manipulation and to test their viability it is essential to elucidate the exact behavioural responses stimulated by the various semiochemicals. Olfactometer trials showed that *Aphidius rhopalosiphi* and *A. ervi*, both of which attack cereal aphids, respond to volatiles from host aphids and from their food plants (Powell & Zhang, 1983). Both sexes responded to plant volatiles but only females responded to aphid volatiles. The semiochemicals from host food-plants probably serve as cues during habitat location, after which other chemical cues come into play to stimulate and maintain the searching behaviour of female parasitoids on the plants.

Honeydew acts as a searching stimulus, intensifying searching activity in contaminated areas (Gardner & Dixon, 1985; Budenberg, 1990). In laboratory trials *A. rhopalosiphi* spent significantly longer searching areas of filter paper contaminated with honeydew solution than areas treated only with deionised water. The honeydew seems to function principally as a contact kairomone since the response did not occur when direct contact with contaminated paper was prevented by means of a fine-mesh gauze (Budenberg, 1990).

When a searching female parasitoid encounters an aphid it must be able to recognise the aphid as an appropriate host and also be stimulated to oviposit. Here again, semiochemicals play a significant role. In the laboratory female *A. rhopalosiphi* were stimulated to attack small granules of vermiculite attached to wheat plants by treating the granules with aqueous extracts of the cereal aphid *S. avenae* or with aqueous wheat leaf extracts (Decker, 1988). This suggests that plant synomones as well as aphid kairomones are involved in host recognition and acceptance. This conclusion is supported by the results of recent work on host switching (Powell & Wright, unpublished). In these experiments some parasitoid species showed distinct host preferences, expressed as lower attack rates on the less preferred hosts. However, these attack rates significantly increased in the presence of leaves from the food-plants of the most favoured host.

LOCAL POPULATION ECOLOGY

Efficient conservation and manipulation of aphid parasitoids will depend upon a sound understanding of their local ecology. For example, demonstrating the ability of parasitoids to switch between different host species in laboratory trials does not prove that they actually do this to any significant extent in the field. The crucial question is: how much movement of individuals, and hence exchange of genetic material, occurs between local populations attacking different hosts and/or occupying different habitat patches? This is important in view of the apparent influence of genotype on the host selection behaviour of parasitoids. This question is currently being addressed at Rothamsted where electrophoretic techniques are being used to compare allele frequencies in local populations of *A. ervi* as an indication of the degree of genetic interchange between these populations.

CONCLUSIONS

It is necessary to conserve aphid parasitoid populations on farmland as they are important components of the natural enemy community. The use of non-pest aphids as reservoir hosts and the use of semiochemicals to manipulate parasitoid behaviour offer opportunities for the future enhancement of their activity in field crops. However, more work is needed on parasitoid ecology and behaviour in the field to ensure the effective development of conservation and manipulation strategies.

ACKNOWLEDGEMENTS

W. Budenberg was funded by a studentship from the Lawes Agricultural Trust and U.M. Decker was funded by a studentship from the C.E.C.

REFERENCES

Budenberg, W.J. (1990) Honeydew as a contact kairomone for aphid parasitoids. Entomologia experimentalis et applicata, 55, 139-148.

Cameron, P.J.; Powell, W.; Loxdale, H.D. (1984) Reservoirs for *Aphidius ervi* Haliday (Hymenoptera; Aphidiidae), a polyphagous parasitoid of cereal aphids (Hemiptera; Aphididae). Bulletin of Entomological Research, 74, 647-656.

Decker, U.M. (1988) Evidence for semiochemicals affecting the reproductive behaviour of the aphid parasitoids *Aphidius rhopalosiphi* De Stefani-Perez and *Praon volucre* Haliday (Hymenoptera: Aphidiidae) - A contribution towards Integrated Pest Management in cereals. Ph.D. Thesis, University of Hohenheim, Germany

Gardner, S.M.; Dixon, A.F.G. (1985) Plant structure and the foraging success of *Aphidius rhopalosiphi* (Hymenoptera: Aphidiidae). Ecological Entomology, 10, 171-179.

Greathead, D.J. (1986) Parasitoids in classical biological control. In: Insect Parasitoids, J. Waage and D. Greathead (Eds). 13th Symposium of the Royal Entomological Society of London. London: Academic Press, pp. 289-318.

Hughes, R.D. (1989) Biological control in the open field. In: World Crop Pests. Aphids. Their Biology, Natural Enemies and Control, A.K. Minks and P. Harrewijn (Eds). Amsterdam: Elsevier, Vol. C., pp. 167-198.

Perrin, R.M. (1975) The role of the perennial stinging nettle, *Urtica dioica*, as a reservoir of beneficial natural enemies. Annals of Applied Biology, 81, 289-297.

Powell, W. (1986) Enhancing parasitoid activity in crops. In: Insect Parasitoids, J. Waage and D. Greathead (Eds). 13th Symposium of the Royal Entomological Society of London. London: Academic Press, pp. 319-340.

Powell, W.; Wright, A.F. (1988) The abilities of the aphid parasitoids *Aphidius ervi* Haliday and *A. rhopalosiphi* De Stefani-Perez (Hymenoptera: Braconidae) to transfer between different known host species and the implications for the use of alternative hosts in pest control strategies. Bulletin of Entomological Research, 78, 683-693.

Powell, W.; Zhang, Z.L. (1983) The reactions of two cereal aphid parasitoids, *Aphidius uzbekistanicus* and *A. ervi* to host aphids and their food-plants. Physiological Entomology, 8, 439-443.

Ramakers, P.M.J. (1989) Biological control in greenhouses. In: World Crop Pests. Aphids. Their Biology, Natural Enemies and Control, A.K. Minks and P. Harrewijn (Eds). Amsterdam: Elsevier, Vol. C, pp. 199-208.

Starỳ, P. (1986) Creeping thistle, *Cirsium arvense*, as a reservoir of aphid parasitoids (Hymenoptera, Aphidiidae) in agroecosystems. Acta entomologica bohemoslovaca, 83, 425-431.

Vinson, S.B. (1984) Parasitoid host relationships. In: Chemical Ecology of Insects, W.J. Bell and R.T. Cardé (Eds), New York: Chapman and Hall, pp. 205-233.

Wratten, S.D.; Powell, W. (in press) Cereal aphids and their natural enemies. In: The Ecology of Temperate Cereal Fields, L.G. Firbank, N. Carter, J.F. Darbyshire and G.R. Potts (Eds.), Symposium of the British Ecological Society. Oxford: Blackwell Scientific Publications.

ECOSYSTEM DIVERSIFICATION TO ENCOURAGE NATURAL ENEMIES OF CEREAL APHIDS.

M.B. THOMAS & S.D. WRATTEN

Department of Biology, Building 44, The University, Southampton, SO9 5NH.

ABSTRACT

In order to enhance the predatory potential of native natural enemies of cereal aphids, such as certain species of Carabidae, Staphylinidae and Araneae, overwintering habitats were created in the centres of three cereal fields. These habitats recreated the important features of natural field boundaries necessary to support high densities of overwintering predators.

Successional change altered the balance of predator community structure from initial dominance by pioneer species to more permanent specialised species. By the third winter, the predator communities were dominated by species normally restricted to overwintering in established natural boundaries.

Studies on predator emigration showed that the overwintering predator populations from the new habitats could influence dispersal patterns in the spring, providing an even spread of predators throughout the crop early in the season.

INTRODUCTION

Sotherton (1984, 1985) showed that some field boundary types are of particular importance in providing overwintering refuges for many species of polyphagous invertebrate predator in arable field systems. The removal of natural boundary structures associated with farming intensification in conventional arable systems (Davies & Dunford 1962; Edwards 1970; Greaves & Marshall 1987) has therefore resulted in a reduction in overwintering habitat. In an attempt to redress the natural balance, new habitats have been created to provide improved overwintering conditions for polyphagous predators in arable land. Rather than just manipulate or create boundary habitats however, field size has been reduced by creating linear "island" habitats which are effectively facsimiles of boundary underbanks, at the field centre. The aim of this paper is to present details of successional change in overwintering predator community structure, during the first three years of habitat establishment. Also, to investigate the influence of the new habitats at the time of predator dispersal in the spring.

MATERIALS AND METHODS

Although three within-field habitats were created, data are presented for only one.

Site description

The within-field refuge took the form of an earth-ridge island habitat (0.4m high, 1.5m wide, 290m long) created at the centre of a 20 ha winter wheat field in autumn 1987. Six-meter long sections of the ridge were sown (spring, 1987) with various grass species in a linearly randomised block design. The treatments sown were (1) Dactylis glomerata, (2) Lolium perenne, (3) Agrostis stolonifera, (4) Holcus lanatus, (5) mixture of three species

(A. stolonifera absent), (6) mixture of four species, (7) a bare ground control and (8) a pollen and nectar source flower treatment.

Predator sampling

During winter 1987/88, ground-zone quadrat surface-searching (six 0.1m^2 quadrats per treatment replicate) was carried out in all treatments. During the second winter (1988/89), three destructive samples (turves of 0.04m^2, 0.1m deep) were taken from each replicate of the single grass species treatments. This process was repeated in winter 1989/90 with four destructive samples taken from each single grass species treatment replicate.

During the 1989/90 winter, natural field boundaries were also sampled. Ten destructive samples (one every 5m) were taken from a representative 50m section of each boundary surrounding the adjacent field.

To assess spring predator dispersal, transects of vacuum-net (Thornhill 1978) samples (at 0m, 3m, 10m, 30m, and 60m from one ridge) were taken at weekly intervals from April to late May 1989. Samples at each distance in an individual transect comprised 15 contiguous 0.092m^2 sub-samples of 10 seconds' duration each, parallel to the ridge. Samples were taken from five transects running at right angles to the ridge adjacent to the Dactylis glomerata treatments in each of five blocks.

RESULTS

Although all treatments were sampled in winter 1987/88, only data for the four single-grass species treatments are presented. These were the only treatments sampled in all winters and therefore the only ones to provide data on changes in predator community structure through time.

Beetles of the family Carabidae were divided into "boundary" carabids (those species that are dependent on boundary habitats as overwintering refuge sites e.g. Agonum dorsale, Bembidion lampros, Demetrias atricapillus (Sotherton 1984,1985)) and "open-field" carabids (i.e. those species that have regular patterns of dispersion in agricultural land and are present at the field centres even during the winter period e.g. Bembidion obtusum, Notiophilus bigutattus and Trechus quadristriatus (Sotherton 1984,1985)). The number of boundary carabids, as a proportion of the total number of both types in the different treatments over the three winters, plus the average proportion of boundary carabids from the four natural boundaries surrounding the adjacent field (sampled during the 1989/90 winter), are presented in Table 1.

The table shows the carabid population to be dominated by open-field species during the first winter. Few boundary carabid species were found on either ridge at this time. Following this, there was a significant increase in the proportion of boundary carabids through time (one-way analysis of variance of proportions ($\sqrt{}$arcsine transformation) for each treatment between years, followed by Tukey's (1949) test). In the final winter, proportions of boundary carabids were at their highest in all treatments except for Lolium perenne, which showed no significant difference between second and third winters (A. stolonifera $F_{2,63} = 27.72$, $P < 0.001$; D. glomerata $F_{2,63} = 39.02$, $P < 0.001$; H. lanatus $F_{2,63} = 90.52$, $P < 0.001$; L. perenne $F_{2,63} = 32.92$, $P < 0.001$). A further analysis of variance between proportions of boundary carabids in the ridge treatments and proportions in the natural boundaries surrounding the adjacent field (the four boundaries being pooled), showed there was no significant difference between the ridge treatment and the natural boundary communities taken as a whole, during the final winter ($F_{4,130} = 0.84$, $P = 0.505$).

Temporal changes in the ratio of Lycosid:Linyphiid spiders in the various treatments on the ridges are also presented in Table 1. One-way analysis of variance (log(n+0.1) transformation) revealed a significant increase through time in the lycosid:linyphiid ratio in the four grass treatments (A. stolonifera $F_{2,50} = 15.04$, $P < 0.001$; D. glomerata $F_{2,52} = 33.15$, $P < 0.001$; H. lanatus $F_{2,53} = 20.29$, $P < 0.001$; L. perenne $F_{2,60} = 19.26$, $P < 0.001$). Similar to the Carabidae, there was no significant difference between the ridge treatment and natural boundary lycosid:linyphiid ratios ($F_{4,102} = 0.71$, $P = 0.585$).

TABLE 1. Mean proportion of boundary carabids and mean ratio of Lycosidae:Linyphiidae overwintering on one within-field ridge during 1987/88, 1988/89, 1989/90 winters. Different letters indicate significant between-year differences for individual treatments, at the 5% level (one-way analysis of variance, followed by Tukey's test).

Boundary carabids	Winter 1987/88	Winter 1988/89	Winter 1989/90
Agrostis stolonifera	0.18 ± 0.077 (c)	0.44 ± 0.078 (b)	0.87 ± 0.034 (a)
Dactylis glomerata	0.12 ± 0.045 (c)	0.56 ± 0.113 (b)	0.84 ± 0.067 (a)
Holcus lanatus	0.06 ± 0.043 (c)	0.67 ± 0.060 (b)	0.89 ± 0.059 (a)
Lolium perenne	0.09 ± 0.035 (b)	0.85 ± 0.284 (a)	0.90 ± 0.059 (a)
Natural boundaries	-	-	0.83 ± 0.039
Lycosid:linyphiid ratio			
Agrostis stolonifera	0.00 (b)	0.30 ± 0.186 (b)	1.22 ± 0.460 (a)
Dactylis glomerata	0.04 ± 0.017 (b)	0.20 ± 0.107 (b)	1.25 ± 0.291 (a)
Holcus lanatus	0.04 ± 0.019 (b)	0.22 ± 0.079 (b)	1.16 ± 0.330 (a)
Lolium perenne	0.00 (c)	0.79 ± 0.494 (b)	1.05 ± 0.296 (a)
Natural boundaries	-	-	1.47 ± 0.387

The results of the 1989 emigration study for the carabid beetle Demetrias atricapillus and the staphylinid beetle Tachyporus hypnorum, are presented in Figures 1 and 2 respectively. Asterisks beneath the figures denote significant differences at the 5% level between distances along transects for individual dates (one-way analysis of variance (√arcsine transformation of proportions of totals caught/date) followed by Tukey's test). Figure 1 shows significantly higher proportions of D. atricapillus immediately adjacent to the ridge up until 3/5/89, after which the proportions tended to become more evenly distributed with no significant differences between distances. Figure 2 shows two significant peaks of proportions (0m and 60m) of T. hypnorum until 18/4/89. Although no consistent spatial patterns occurred following this, significantly lower proportions of T. hypnorum were found on the ridge than in the crop by the end of the study.

DISCUSSION

Analysis of carabid communities revealed considerable changes over the three years of the study. The proportion of boundary to open field carabids on the ridge did not differ boundary carabids was achieved via clear successional changes over the three years. Open-field carabids, already represented at the field centre, dominated the carabid community during the ridge's infancy. As ridge maturity increased, so did the proportion of boundary carabids, until the final year, where this group of species was dominant.

Succession was also apparent within the spider community. The low lycosid:linyphiid ratio during the 1987/88 winter indicated a dominance by the linyphiid spiders on both ridges in the first year. Following this, the ratio increased until the final year, where the lycosid:linyphiid ratio on both ridges did not differ significantly from the ratios in the natural boundaries bordering the respective adjacent fields. This change in the ratio of Lycosidae:Linyphiidae therefore probably reflected succession from pioneer species (r-strategists i.e. Linyphiidae) towards more permanent and specialised (K-strategist i.e. Lycosidae) species (Nentwig 1988).

The results of the spring study suggested that the ridge, by providing a nucleus predator population at the field centre from which emigration could take place, enhanced field colonisation thus improving the opportunity for biocontrol. This was particularly apparent for Demetrias atricapillus, which following a period of close association with the ridge habitat appeared to penetrate the field resulting in a uniform dispersion through the crop. A similar pattern was observed for Tachyporus hypnorum, although as this species has a more rapid dispersal than D. atricapillus (Coombes & Sotherton, 1986) the influence of the natural hedgerow population as well as the ridge population could be seen. That is, the observed dispersion pattern was achieved via emigration from both ridge and hedgerow sources resulting in higher numbers away from, rather than adjacent to, the ridge habitat.

The successional changes which were observed as the ridge habitat matured, indicated a shift away from initial dominance by pioneer species, towards more permanent specialist species. Although this change may only be over a small range of the r-K-continuum, the increased spatial heterogeneity provided by the ridges could be considered to be sufficient to provide an increase in stability of the agro-ecosystem as a whole (Mader 1988; Nentwig 1988). As conventional arable systems tend to provide fragmented and unstable environments (Wratten 1990), such habitat creation schemes could provide a useful measure to strengthen natural control mechanisms disrupted by intensive food production (Mader 1988).

ACKNOWLEDGEMENTS

We thank the staff of the Leckford Estate for their provision of study sites. This work was funded by a M.A.F.F. contract awarded to Southampton University and The Game Conservancy jointly.

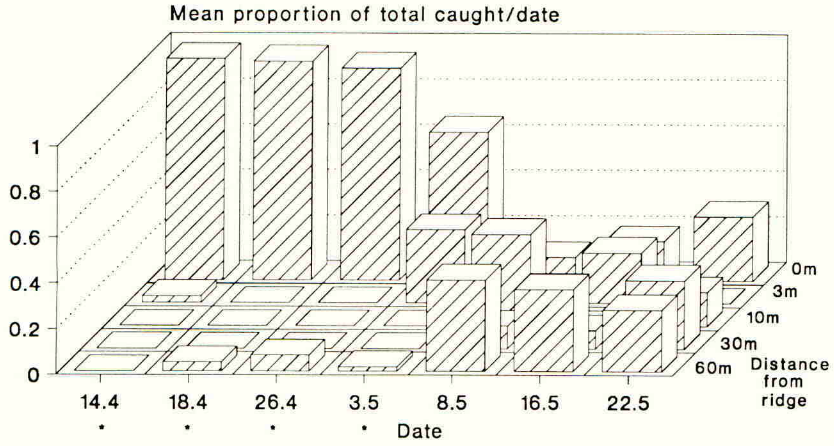
REFERENCES

Coombes, D.S.; Sotherton, N.W. (1986). The dispersal and distribution of polyphagous predatory Coleoptera in cereals. Annals of Applied Biology, **108**, 461-474.

Davies, E.T.; Dunford, W.J. (1962). Some physical and economic considerations of field enlargement. University of Exeter, Department of Agricultural Economics Publication No. 133.

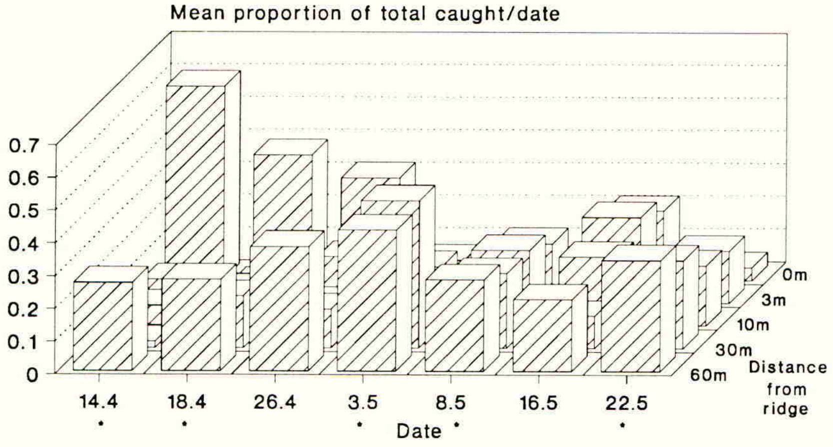
Edwards, A.J. (1970). Field size and machinery efficiency. In: Hedges and hedgerow trees, M.D. Hoopes and M.W. Holdgate (Eds), Monks Wood Symposium No.4. The Nature Conservancy.

FIGURE 1.
Emigration of *Demetrias atricapillus*, spring 1989.



• Denotes significant between-distance differences at the 5% level.

FIGURE 2.
Emigration of *Tachyporus hypnorum*, spring 1989.



• Denotes significant between-distance differences at the 5% level.

Greaves, M.P.; Marshall, E.J.P. (1987). Field Margins: definitions and statistics. Field Margins, J.M. Way and P.W. Greig-Smith (Eds) BCPC Monograph, Thornton Heath: BCPC Publication, pp 3-11.

Mader, H.-J. (1988) Effects of increased spatial heterogeneity on the biocenosis in rural landscapes. Ecological Bulletins, **39**, 169-179.

Nentwig, W. (1988) Augmentation of beneficial arthropods by strip management I. Succession of predacious arthropods and long-term change in the ratio ofphytophagous and predacious arthropods in a meadow. Oecologia, **76**, 597-606.

Sotherton, N.W. (1984). The distribution and abundance of predatory arthropods overwintering on farmland. Annals of Applied Biology, **105**, 423-429.

Sotherton, N.W. (1985). The distribution and abundance of predatory Coleoptera overwintering in field boundaries. Annals of Applied Biology, **106**, 17-21.

Thornhill, E.W. (1978). A motorised insect sampler. Pans, **24**, 205-207.

Tukey, J.W. (1949). One degree of freedom for non-additivity. Biometrics, **5**, 232-242.

Wratten, S.D. (1990). Farm-scale spatial dynamics of predators and parasitoids in agricultural landscapes. In: Species Dispersal in Agricultural Landscapes, R. Bunce (Ed). London, New York, Bellhaven Press pp 221-237.

A simulation study of aphid damage and control strategies in cereals

X. ZHOU, N. CARTER

AFRC Institute of Arable Crops Research, Rothamsted Experimental Station,
Harpenden, Herts AL5 2JQ

ABSTRACT

The rose-grain aphid *Metopolophium dirhodum*, migrates to cereals in spring and early summer. It occasionally causes serious yield loss, such as in 1979. A simulation model accurately predicted the yield loss in 1979 (12%) and indicated that a single spray at mid-milky ripe stage resulted in the maximum profit. The net returns of no-control, prophylactic and control based on forecasting were investigated with different outbreak probabilities and forecast accuracies. Forecasting is the best strategy when predictions are accurate. With low outbreak frequency, as in recent years, no-control is better than prophylactic control.

INTRODUCTION

Cereal aphids, mainly *Sitobion avenae* and *Metopolophium dirhodum*, are important sporadic pests in Western Europe (Oakley *et al.*, 1988). Accurate forecasting of yield loss is essential to avoid economic loss and overuse of insecticides. *S. avenae* is thought more damaging than *M. dirhodum* and models have been developed to predict its peak aphid density, yield loss and economics of control strategies (Entwistle & Dixon, 1986, 1987; Mann *et al.*, 1986; Watt, 1983; Watt *et al.*, 1984). However, *M. dirhodum* can cause serious yield loss e.g. in 1979. This study used a simulation model to investigate damage caused by *M. dirhodum* and the economics of several control strategies.

METHODS

Aphid population development model

The model incorporated aphid immigration (using 12.2m suction trap samples), development, survival, reproduction, morph determination (winged or wingless adults) and crop development (Zhou *et al.*, 1989). The model accurately predicted aphid population development in a multidisciplinary field experiment in 1979 when an outbreak occurred (Prew *et al.*, 1983; Zhou *et al.*, 1989).

Yield loss

Yield loss by *M. dirhodum* varies with crop growth stage (Wratten *et al.*, 1979; Lee *et al.*, 1981; Holt *et al.*, 1984). In the model, before the start of booting (GS 40) or after early dough (GS 83), it was assumed that no yield loss occurred. Between these growth stages, the daily rate of yield loss per aphid unit (one aphid unit is equal to one adult or fourth instar nymph or three first to third instar nymphs) was estimated as a proportion of potential yield when uninfested (Zhou *et al.*, 1989 for details).

Insecticide

Insecticide persistence in the field (R_T, mortality rate) declined exponentially (Eqn. 1). The upper (R_p) and lower (R_b) mortality rates were set arbitrarily at 90% and 25% respectively. The rate was zero if below R_b.

$$R_T = R_p \, e^{((Log(R_b) / Lgt) / T)} \qquad (1)$$

Where Lgt was the period of insecticide persistence (7 days); T was the number of days after the spray was applied.

Aphid control strategies

Three control options were considered: no control, prophylactic and one based on forecasting. The economics of the first two depended on the aphid population levels on crop and the cost of control (George & Gair, 1979) (Table 1).

Table 1 A payoff matrix of no control and prophylactic control strategies under non-outbreak and outbreak situations

	No control	Prophylactic
Non-outbreak	$B_{nn} = y_e y_{pr}$	$B_{ny} = y_e y_{pr}(1 - w_{ls}) - C_{ctl}$
Outbreak	$B_{yn} = y_e y_{pr}(1 - L_{ap})$	$B_{yy} = y_e y_{pr}(1 - w_{ls})(1 - Ls_{ctl}) - C_{ctl}$

Where B was the relative economics (£/ha), y_e the expected yield/ha, y_{pr} grain price (£/t), L_{ap} proportion of yield lost to aphids without control, w_{ls} wheeling loss, Ls_{ctl} the damage caused by the aphid population after an insecticide application and C_{ctl} the cost of control.

The relative economics (C, £/ha) of the three options also depended on the probability of an outbreak (P_{ot}) and for control based on a forecast, the prediction accuracy (P_{fr}) (Eqn 2-4)

No-control: $$C_{bn} = B_{yn}P_{ot} + B_{nn}(1 - P_{ot}) \qquad (2)$$

Prophylactic control: $C_{pc} = B_{ny}(1 - P_{ot}) + B_{yy}P_{ot}$ (3)

Control based on forecast: $C_{fc} = B_{nn}(1 - P_{ot})P_{fr} + B_{yy}P_{ot}P_{fr} + B_{ny}(1 - P_{ot})(1 - P_{fr}) + B_{yn}P_{ot}(1 - P_{fr})$ (4)

Grain price was assumed to be £100/t. Wheeling loss due to application of the insecticide was 3% of the expected yield (Entwistle & Dixon, 1987), and the cost of insecticide and labour was £13.5/ha (Anon., 1988). The expected yield was assumed to be 7t/ha.

RESULTS

In an outbreak year, 1979, the yield loss predicted by the model was 11.5%, similar to that in the field (Zhou *et al.*, 1989). Most yield loss occurred from the mid-milky ripe stage (GS 75) to early dough (GS 82) when the crop had the highest aphid population density. Net return increased when one spray was applied at the beginning of anthesis (GS 61) to a maximum (£30/ha) at mid-milky ripe stage (GS 75) and thereafter decreased rapidly.

When two applications were applied, with the first application at different crop growth stages and with different intervals between the two applications, the highest net return was in the area between the two profit lines of £21/ha (Fig. 1). The greatest profit was achieved if the second application was between mid-milky ripe stage (GS 75) and the beginning of dough (GS 82) no matter at what crop growth stage the first application was applied. However the profit from one application at mid-milky ripe stage was still greater than the maximum profit obtained with the two-spray programme. In addition, the intensity of the profit lines between £21 to £7/ha on the upper right hand side in Fig. 1 means that the net returns from control were sensitive to the timing of the two applications, especially at higher growth stages (Fig. 1).

If the outbreak probability was 0.3 and the forecast accuracy for outbreaks and non-outbreaks was 0.8, spraying according to a forecast was a more profitable strategy than prophylactic control but only slightly better than no-control measures. No-control was a much more profitable strategy than prophylactic spraying because the risk of unnecessary aphicide use was high for the latter (70%) (Fig. 2A). If the outbreak probability was 0.8 then spraying according to a forecast was an economically better strategy than no control because the latter resulted in the high risk of severe yield loss especially from mid-flowering (GS 65) to late milky ripe stage (GS 77). Spraying according to a forecast was similar to prophylactic control but was slightly worse than the latter strategy during the milky ripe stage. Prophylactic control was more economic than no control, especially during the milky ripe stage (Fig. 2C). When the outbreak probability was 0.5, spraying according to a forecast was better than the other two strategies, and no-control was a better strategy than prophylactic spraying before mid-anthesis (G.S. 65) but *vice versa* after that growth stage (Fig. 2B).

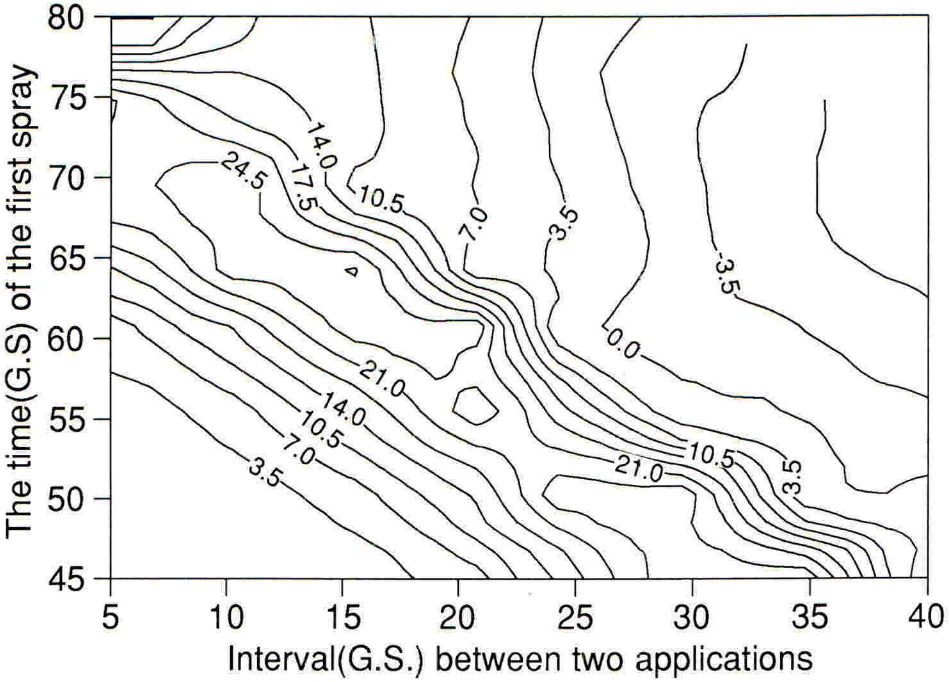


Fig. 1 Relationship between net return of control (shown as contour lines), time of the first spray and interval to the second spray.

If a control decision had to be made early in the season when the aphid population density was low, for instance at mid-booting (GS 45), no-control was the best strategy regardless of the outbreak probability and forecasting accuracy . If the decision was made later in the season, e.g. at the beginning of the milky-ripe stage (GS 70), spraying according to a forecast was more likely to be a better strategy compared with no-control when the forecasting accuracy and outbreak probability were high. Prophylactic spraying was the worst strategy early in the season, unless forecasting accuracy was very low and the outbreak probability was high.

DISCUSSION

The model of Watt *et al.*(1983) did not allow for resurgence of aphid populations following an insecticide spray. In addition, the rate of aphid population development was fixed at a high rate and so the maximum density depended only on the size of the initial aphid density and crop growth stage. This resulted in the maximum profit occurring when the spray was early in the season. This could lead to the overuse of pesticides. In this study, however, the resurgence of the aphid population after a spray was modelled. In such circumstances, the model predicted, using data from 1979, that the maximum profit occurred when the spray was at the mid-milky ripe stage. The model also indicated that one spray at this stage was the best control strategy while two sprays were actually applied in the field in 1979 (Prew *et al.*, 1983).

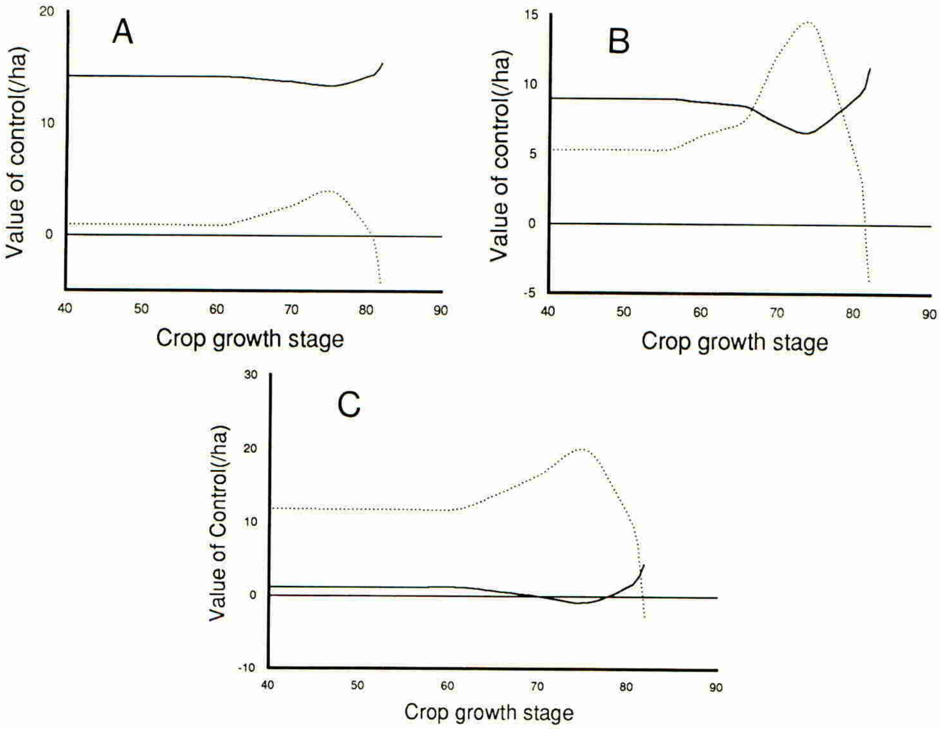


Fig. 2 Comparison of net return between forecast based control, no control and prophylactic control when the outbreak probability was 0.3 (A), 0.5 (B) and 0.8 (C); and forecast accuracy was 0.8 (- forecast based control against prophylactic control and ... against no control)

The profitability of the three strategies; prophylactic control, no-control and control based on a forecast, depends on the outbreak probability and forecasting accuracy (Fig. 2). Forecasting is the best strategy when its accuracy was high. Prophylactic control is better compared with no control, especially during mid- to end of the milky ripe stage (GS 75 to 79) when the outbreak probability is high. However, the outbreak frequency of *M. dirhodum* in recent years has been low and in theory no control would be a more profitable strategy than prophylactic control. Furthermore, prophylactic spraying results in unnecessary environmental pollution.

ACKNOWLEDGEMENT

The work was supported by the British Council and the Chinese Education Committee. We thank Dr. J. Mumford for supervising X. Zhou.

REFERENCES

Anon. (1988). U.K. Food and Farming in Figures. Government Statistical Service, M.A.F.F..

Entwistle, J.C.; Dixon, A.F.G. (1986). Short-term forecasting of peak population density of the grain aphid (*Sitobion avenae*) on wheat. Annals of Applied Biology, **109**, 215-222.

Entwistle, J.C.; Dixon; A.F.G. (1987). Short-term forecasting of wheat yield loss caused by the grain aphid (*Sitobion avenae*) in summer. Annals of Applied Biology, **111**, 489-508.

George, K.S.; Gair, R. (1979). Crop loss assessment on winter wheat attacked by the grain aphid, *Sitobion avenae* (F.) 1974-77. Plant Pathology, **28**, 143-149.

Holt, J.; Griffiths, E.; Wratten, S.D. (1984). The influence of wheat growth stage on yield reduction caused by the rose-grain aphid, *Metopolophium dirhodum*. Annals of Applied Biology, **105**, 7-14.

Lee, G.; Stevens, D.J.; Stokes, S.; Wratten S.D. (1981). Duration of cereal aphid populations and the effects on wheat yield and bread making quality. Annals of Applied Biology, **98**, 169-178.

Mann, B.; Wratten, S.D.; Jepson, P. (1986). Pest advisory packages and their development for a viewdata system. 1986 British Crop Protection Conference, Pests and Diseases, **7**, 1027-1031.

Oakley, J.N.; Wratten, S.D.; Dixon, A.F.G.; Carter, N. (1988). The biology and control of cereal aphids. Home Grown Cereals Authority Review.

Prew, R.D.; Church, B.M.; Dewar, A.M.; Lacey, J.; Penny, A.; Plumb, R. T.; Thorne, G.N.; Todd, A.D.; Williams, T.D. (1983). Effects of eight factors on the growth and nutrient uptake of winter wheat and the incidence of pests and diseases. Journal of Agricultural Science, **100**, 363-382.

Watt, A.D. (1983). The influence of forecasting on cereal aphid control strategies. Crop Protection, **2**, 417-429.

Watt, A.D.; Vickerman, G.P.; Wratten, S.D. (1984). The effect of the grain aphid, *S. avenae* (F.), on winter wheat in England: an analysis of the economics of control practice and forecasting systems. Crop Protection, **3**. 209-222.

Wratten, S.D.; Lee, G.; Stevens, D.J. (1979). Duration of cereal aphid populations and the effects on wheat yield and quality. 1979 British Crop Protection Conference, Pests and Diseases, 1-8.

Zhou, X.; Carter, N.; Mumford, J. (1989). A simulation model describing the population dynamics and damage potential of the rose grain aphid, *Metopolophium dirhodum* (Walker) (Hemiptera: Aphididae), in the UK. Bulletin of Entomological Research, **79**, 373-380.

IS IT POSSIBLE TO LIMIT SLUG DAMAGE USING CHOICE OF WINTER WHEAT CULTIVARS?

A.M. SPAULL, S. ELDON

The Scottish Agricultural College - Edinburgh, Crop Protection Department,
West Mains Road, Edinburgh, EH9 3JG.

ABSTRACT

Ten cultivars of winter wheat were tested under laboratory conditions so that the fate of individual grain could be monitored. Untreated seeds of the following cultivars were used: Apollo, Avalon, Boxer, Galahad, Longbow, Mercia, Motto, Norman, Parade and Slepjner. Damage to seeds by the field slug *Deroceras reticulatum* was measured after 1, 2 and 5 days. Grain hollowing was scored as a crude percentage of individual seeds. In general, cv. Avalon showed the greatest damage and Slejpner also tended to be heavily grazed. Only the cv. Parade showed any tendency not to be eaten by slugs, having a smaller damage score in all assessments. Differences in seed damage may depend on release of sugars and other solutes and is under investigation.

INTRODUCTION

Slugs are major UK pests of winter wheat and potatoes and, in winter wheat alone, molluscicide use, including application, is calculated to cost some £20 million annually, yet damage to seeds and seedlings is not reliably controlled (Glen, 1989). Thus, the cost of slug damage must be added to this figure to derive an overall annual cost of these pests. While it is recognised that cultivations influence damage, other forms of cultural control have been little tested, although Glen *et al.*(in press) found that sowing at 40mm depth, rather than 20mm gave as much protection from slug damage as a broadcast application of methiocarb pellets.

It is recognised that potato cultivars differ in their susceptibility to attack by slugs and this characteristic is tested in new maincrop cultivars (Port & Port, 1986). Atkin (1979) found that cultivars with a low total-protein content were preferred, but starch, glycoalkaloid and phenolic acid content have all been implicated (Storey, 1985). Some preferences have been found between species of wheat, where those with a high total-nitrogen content in the seed were attacked more by slugs (Port & Port, 1986). Nothing is known about differences amongst commercial cultivars of winter wheat; we tested the susceptibility to attack by *Deroceras reticulatum* of several cultivars of winter wheat.

MATERIALS AND METHODS

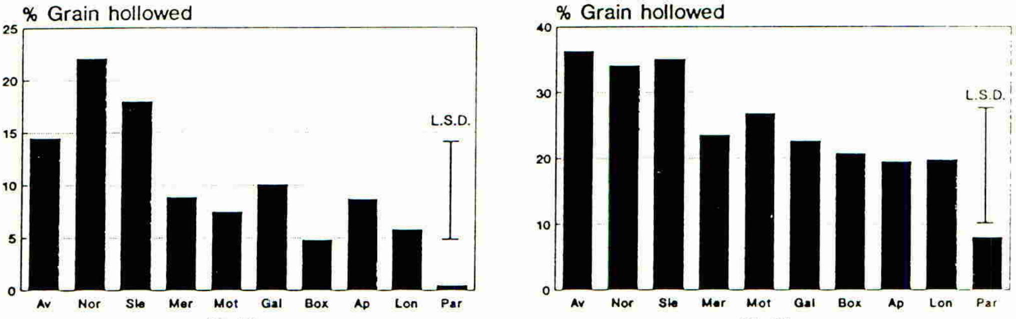
Untreated seeds of ten cultivars of winter wheat were used : cvs. Apollo, Avalon, Boxer, Galahad, Longbow, Mercia, Motto, Norman, Parade and Slejpner. Tests were conducted under laboratory conditions, at a temperature of 18-21 °C: Four seeds of a cultivar were arranged on well-moistened filter paper in the base of a 9cm petri dish such that the seeds were equidistant from each other and the edge of the dish. A single adult specimen of the field slug, *Deroceras reticulatum* was introduced at the centre of the dish and the lid replaced and held with parafilm. The lid was marked so that the individual seeds could be identified. All slugs used in feeding tests had been collected from the field during the previous two weeks and maintained at 18- 20°C on a common diet (lettuce leaves) for at least 7 d before use. Ten replicate dishes were used for each cultivar and observations made after 1, 2 and 5 d. Grain hollowing was scored as a crude percentage of individual seeds.

Water-soluble carbohydrate content was determined by standard methods from some of the test cultivars by boiling 200 seeds (approx. 10 g) for three minutes in 25 ml distilled water, macerating them and then centrifuging at 4000 g for 3 mins. before testing the supernatant. Electrical conductivity was also assessed using similar samples and measured over a 3 d period at 20°C to estimate leaching of electrolytes as the seed germinated (Mathews & Powell, 1981). The water-soluble carbohydrate content of the soaking water was tested on each occasion. These two assessments were also made at temperatures of 5 and 10°C; tests lasted 3 d.

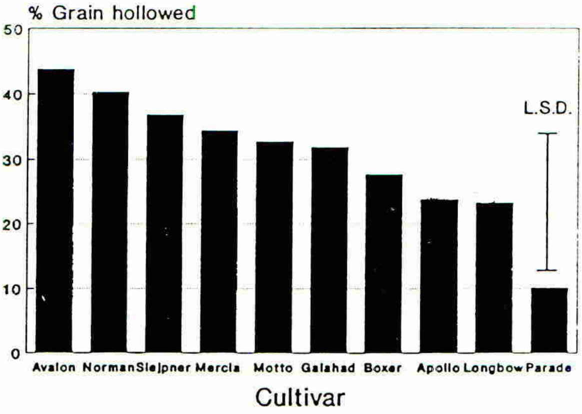
Figure 1. Percentage grain hollowed by *Deroceras reticulatum*

a) Day 1

b) Day 2



c) Day 5



RESULTS

When slug damage was measured after 1 d differences were already apparent. Cv. Parade had been grazed significantly less than the cvs. Galahad, Avalon, Slejpner and Norman (Fig. 1a). The following day cv. Parade continued to be less attacked than seed of cvs. Motto, Norman, Slejpner and Avalon but was no longer significantly different from cv. Galahad (Fig. 1b). After 5 d, cv. Parade had been the least attacked (10% hollowed) and cv. Avalon the most (44% hollowed); while the two extremes were significantly different there was considerable overlap among the remaining cultivars tested (Fig. 1c).

Electrical conductivity measurements made after 24 h differed significantly between cultivars; those from Motto and Avalon were greater than from Slejpner, which had significantly higher conductivity than the remaining cultivars tested (Table 1). The following day Avalon, Motto and Longbow had the greatest conductivity and Parade the least. After 3 d, electrical conductivity from cv. Parade remained significantly smaller than the other cultivars and Avalon, Motto and Longbow continued to give amongst the highest measurements (Table 1).

TABLE 1. Electrical conductivity (μS) of leachate from Winter Wheat cultivars. (expressed per g seed)

Cultivar	Day 1	Day 2	Day 3
Apollo	9.3	15.1	20.5
Avalon	14.3	18.3	21.6
Galahad	6.9	14.8	20.4
Longbow	7.4	19.7	25.8
Mercia	8.4	13.1	18.7
Motto	14.0	19.6	23.7
Parade	7.8	10.9	12.6
Slejpner	11.6	14.5	17.2
SE	0.70	1.16	1.51

TABLE 2. Total water soluble sugar content of seven cultivars of Winter Wheat (glucose equivalents).

Cultivar	$g/l \times 10^{-2}$
Apollo	3.9 a
Avalon	5.9 b
Galahad	5.9 b
Longbow	4.6 a
Mercia	6.9 b
Parade	0.3
Slejpner	2.3

a,b figures not signifcantly different according to Duncan's Multiple Range test.

The total water soluble sugar content was estimated from seven cultivars. Cv. Parade had a significantly smaller water soluble sugar content than all the other cultivars tested; the cvs. Galahad, Avalon and Mercia had the largest sugar content (Table 2).

TABLE 3. Effect of three temperatures on electrical conductivity and leaching of water soluble sugars (glucose equivalents).

a) Day 1

Cultivar	Conductivity µS			Sugars mg/l		
Temp°C	5	10	20	5	10	20
Avalon	10.21	10.70	10.80	0.17	0.12	0.38
Longbow	8.01	8.58	11.05	0.38	0.38	0.83
Parade	7.05	6.07	7.60	0.19	0.24	0.56
Slejpner	7.84	8.18	9.06	0.07	0.14	0.40
SED = 0.412				0.055		
Mean	8.28	8.38	9.63	0.20	0.22	0.54

b) Day 2

Cultivar	Conductivity µS			Sugars mg/l		
Temp°C	5	10	20	5	10	20
Avalon	10.55	17.75	18.81	1.19	1.69	1.80
Longbow	8.07	12.04	18.36	2.04	3.38	1.36
Parade	7.11	10.57	10.69	0.67	1.25	0.46
Slejpner	8.60	12.16	13.98	0.90	1.89	1.73
SED = 0.954				0.224		
Mean	8.58	13.13	15.46	1.20	2.05	1.34

c) Day 3

Cultivar	Conductivity µS			Sugars mg/l	
Temp°C	5	10	20	5	10
Avalon	11.32	17.17	20.75	1.93	3.08
Longbow	9.29	13.72	21.88	3.17	4.43
Parade	7.16	10.81	12.57	1.46	2.27
Slejpner	8.69	12.43	17.12	1.71	2.39
SED = 0.744				0.223	
Mean	9.12	13.53	18.08	2.07	3.04

Electrical conductivity and leaching of water soluble sugars were affected by temperature (Table 3), both were usually greater at 20°C than at 5°C and less from cv. Parade than cv. Avalon. Cvs. Slejpner and

Longbow were intermediate, sometimes significantly greater than Parade but less than Avalon, although cv. Longbow had the largest water-soluble sugar content in the leachate at 5 and 10°C after 2 days and at 20°C after 3 days. After 3 days the interaction between cultivar and water-soluble sugar content of the leachate or its electrical conductivity were similar. At 5 and 10°C cv. Parade was significantly less than Slejpner and Longbow, which were significantly less than Avalon. At 20 °C, Longbow was significantly greater than Slejpner but no different from Avalon.

DISCUSSION

Port & Port (1986) reported that differences occurred between the level of attack from *Deroceras reticulatum* suffered by a range of wheat species: the preference appeared to be for those species with a larger total nitrogen content in the seed. These authors also suggested that there were few differences amongst cultivars of winter wheat. Our results indicate that some cultivars are attacked to a greater extent than others by *D.reticulatum*, although, to date, this has been demonstrated only under laboratory conditions. In five days, a mean of 44% of each seed of the most susceptible cultivar (Avalon) was hollowed, compared with 10% hollowing of the least susceptible cultivar (Parade). It is possible, however, that the method used may have diminished the extent of hollowing, as it is suspected that contact with conspecifics may encourage feeding (Airey, 1987).

The basis for cultivar preferences is unclear. However, it is recognised that slugs are generally attracted to sugars (Henderson & Parker, 1986) and this information is exploited when formulating compounds as molluscicides (Kelly & Martin, 1989). Thus, a cultivar that exuded sugary solutes during the earlier stages of germination might be predicted to be more attractive to slugs. Electrical conductivity was used as an indirect assessment of all electrolyte leakage and was greatest after three days at room temperature from cvs. Avalon, Motto and Longbow and least from cv. Parade. Electrolyte leaching was affected by temperature, being slowest at 5°C and greatest at 20°C. Cv. Parade always had the smallest and cv. Avalon the largest conductivity, indicating more rapid leakage of electrolytes.

The total water-soluble sugar content also broadly reflected the distinction between cvs. Avalon and Parade in the feeding tests. Cv. Parade had the smallest total water-soluble sugar content and cv. Avalon was amongst the group with the greatest content. The release of water-soluble sugars into the surrounding water was also influenced by temperature in the tests and was greatest at 20°C and least at 5°C. Cv. Parade had the smallest water-soluble sugar content after three days and cv. Avalon the largest, at all temperatures.

The pattern of release of water-soluble sugars did not fully reflect the pattern of electrolyte leakage, since sugars would form only a part of solutes present; nevertheless, it formed a useful, simple measure that corresponded well with differences in feeding damage by *D. reticulatum*. In the feeding tests (conducted at room temperature), cv. Avalon had been attacked significantly more than cv. Parade; other cultivars were not significantly different from either extreme. Other cultivars tested had similar total sugar contents, yet were less severely grazed by slugs in feeding tests; however, only cv. Avalon had both a large total water-soluble sugar content and a more rapid rate of solute leaching.

It has been suggested (Johnston *et al.*, 1989) that 'resistance' to slug attack in potato cultivars may involve the enzymic oxidation of phenolics to quinones; ie. that susceptibility to slug feeding injury might result from some balance between chemicals that attract and those that repel the slug. Our results indicate that cultivars of winter wheat may differ enough in the amount of at least one attractant for some protection to be afforded to those cultivars that leach relatively smaller amounts. Further testing is now required in less artificial conditions.

ACKNOWLEDGEMENTS

This work was funded by the Home-Grown Cereals Authority, whose support we gratefully acknowledge. We thank Dr Carol Duffus for helpful discussion on aspects of the analyses.

REFERENCES

Airey, W.J. (1987) The influence of food deprivation on the locomotor activity of slugs. *Journal of Molluscan Studies* **53**, 37-45.

Atkin, J.C. (1979) Varietal susceptibility of potatoes to slug attack. PhD Thesis, University of Newcastle upon Tyne.

Glen, D.M. (1989) Understanding and predicting slug problems in cereals. In: *Slugs and Snails in World Agriculture*, I. Henderson (Ed.), *BCPC Monograph No. 41*, Thornton Heath: BCPC Publications, pp. 253-262.

Glen, D.M.; Milsom, N.F.; Wiltshire, C.W. (in press) Effect of seed depth on slug damage to winter wheat. *Annals of Applied Biology*.

Henderson, I.F.; Parker, K.A. (1986) Problems in developing chemical control of slugs. Aspects of Applied Biology **13**, 341-347.

Johnston, K.A.; Kershaw, W.J.S.; Pearce, R.S. (1989) Biochemical mechanisms of resistance of potato cultivars to slug attack. In: *Slugs and Snails in World Agriculture*, I. Henderson (Ed.), *BCPC Monograph No. 41*, Thornton Heath: BCPC Publications, pp. 281-288.

Kelly, J.R.; Martin, T.J. (1989) Twenty-one years with methiocarb bait. In: *Slugs and Snails in World Agriculture*, I. Henderson (Ed.), *BCPC Monograph No. 41*, Thornton Heath: BCPC Publications, pp. 131-145.

Mathews, S.; Powell, A. (1981) Electrical conductivity test. In: *Handbook of Vigour Test Methods*, D.A. Perry (Ed.), The International Seed Testing Association, Switzerland, pp. 37-41.

Port, C.M.; Port, G.R. (1986) The biology and behaviour of slugs in relation to crop damage and control. *Agricultural Zoology Reviews* **1**, 255-299.

Storey, M. (1985) The varietal susceptibility of potato crops to slug damage. PhD. Thesis, City of London Polytechnic.

INVESTIGATION OF THE BIOLOGY AND CONTROL OF GOUT FLY (*Chlorops pumilionis*) IN AUTUMN AND SPRING SOWN CEREALS

J. N. OAKLEY

ADAS, Government Offices, Coley Park, Reading, RG1 6DT

J. E. B. YOUNG

ADAS, Government Buildings, Brooklands Avenue, Cambridge, CB2 2DR

S. F. B. COUSINS

Framlingham Agronomy Ltd, New Road, Framlingham, Suffolk, IP13 9AT

M. FROST

ICI Agrochemicals, Woolmead House, Bear Lane, Farnham, Surrey, GU9 7UB

M. FROMENT

ADAS, Bridgets EHF, Martyr Worthy, Winchester, Hampshire, SO21 1AP

ABSTRACT

The control of gout fly damage on winter and spring cereals was studied in replicated trials and on a field scale in Suffolk and Hampshire. Effective chemical control was obtained from sprays targeted at the young larvae as they began to feed within the shoot.

INTRODUCTION

The level of gout fly (*Chlorops pumilionis*) damage has increased dramatically in parts of south and east England over the past four years. Damage has been confined to early-emerging (September and early October) crops of winter wheat and barley and, with the exception of 1990, to late sown crops of spring wheat and barley. Up to 90 % of the central shoots of winter cereals have been attacked and up to 96 % of the tillers on spring cereals. The larva causes a swelling of the shoot when it is attacked prior to stem extension, which results in the death of the shoot. A lesser swelling associated with reduced stem elongation follows later attacks. Each larva only attacks one shoot. The increasing levels of damage reported have followed a trend to earlier sowing of winter cereals. The pest is generally distributed throughout northern and central Europe (Zadoks & Rijsdijk, 1984) extending through European Russia to Iran (Smirnov & Fedoseeva, 1976).

There are two generations a year with adults on the wing in May and June and again from August to October. When studied by Frew (1924) winter cereals were rarely sown early enough to be attacked by the autumn generation, the main overwintering host was couch grass (*Agropyron repens*) that grew as a weed in arable land. Frew noted that established stands of couch grass were rarely attacked, younger tillers being preferred. During the second world war an increase in the area of winter cereals led to earlier drilling. Lilly (1947) noted high levels of damage in Devon and Cornwall, which he related to the time of drilling of affected winter and spring cereal crops. To avoid further attacks Lilly recommended that wheat in the south-west should be drilled after 12 October. In previous outbreaks a high level of parasitism, caused by the parasitic wasps *Stenomalina micans* and *Coelinidea niger*, has been recorded in the summer generation of larvae (Goodliffe, 1942). Very little parasitism has been recorded during the current outbreak with a continuation of high population levels in affected areas from one generation to the next. Young & Cousins (1990) carried out an opportunist trial on an established infestation applying sprays in December and February and obtained some control from omethoate applied in December. They concluded that an earlier application that coincided with the end of larval invasion should achieve a higher standard of control.

BIOLOGY AND LIFE CYCLE

Flies of the over-wintering generation emerge in May and lay their eggs on the upper leaves of cereal plants in June. Tillers with flag leaves emerging appear to be preferred. The main oviposition period usually coincides with this stage in crops sown between the end of March and the end of April. In 1989 the highest level of damage was recorded on a crop of spring wheat sown on 31 March. Emergence of the flies would appear to be controlled mainly by accumulated temperature and following the mild winter of 1989/90 this occurred in late April in Hampshire and the peak oviposition occurred around 20 May. In 1990 the highest levels of damage were subsequently recorded on crops sown between the third week of February and the first week of March with significant levels of damage also recorded in November sown wheat. The larvae feed within the upper leaf sheath causing a groove in the straw. Where feeding commences before the ear begins to emerge it remains trapped within the sheath. Feeding may cause distortion of the ear and results in a reduction in yield of about half on effected ears.

The larvae feed for about one month before they pupate within the leaf sheath. Flies of the next generation emerge in August, mate in September and lay their eggs from late September to early October. Egg laying may be extended to early November in mild autumns. A strong preference is shown for newly-emerged shoots with most of the eggs being laid on the first leaf, mainly on the upper side and along the line of ribbing in the leaf. Some eggs are laid on the leaf sheath. Eggs are laid singly, but females do not avoid leaves with eggs present on them, so distribution within a crop is initially random. As eggs are laid mainly on the earlier plants to emerge, where emergence is protracted the later-emerging plants will be free of eggs and so the distribution between plants appears aggregated.

The development of attack was monitored in three fields in which trials were established in the autumn of 1989. At Bridgets Experimental Husbandry Farm in Hampshire a crop of winter wheat cv. Pastiche, that was sown on 21 September and emerged from 27 September, was monitored. Two yellow sticky traps were positioned in the field on 26 September and changed weekly. The traps were a standard Trappit type (Agralan, Brickyard Works, Ashton Keynes, Swindon) of 260 by 100 mm and were suspended from canes just above ground level. The catches are shown in Fig. 1. A sample of one hundred plants was collected from the study area on each occasion and taken back to the laboratory where unhatched and hatched eggs were recorded and the plants dissected to check for the presence of larvae. These results are also shown in Fig. 1. The number of adults caught increased rapidly after crop emergence with the majority of oviposition occurring between one and two weeks from crop emergence. Larvae hatched after approximately 10 days and the majority successfully colonised shoots. The apparent reduction in egg numbers between 10 and 17 October occurred because plants continued to emerge after egg laying had ceased. The first sign of larval damage, a tattering of the central leaf, was recorded on 7 November.

Figure 1. Biological Monitoring of Gout Fly, Bridgets EHF

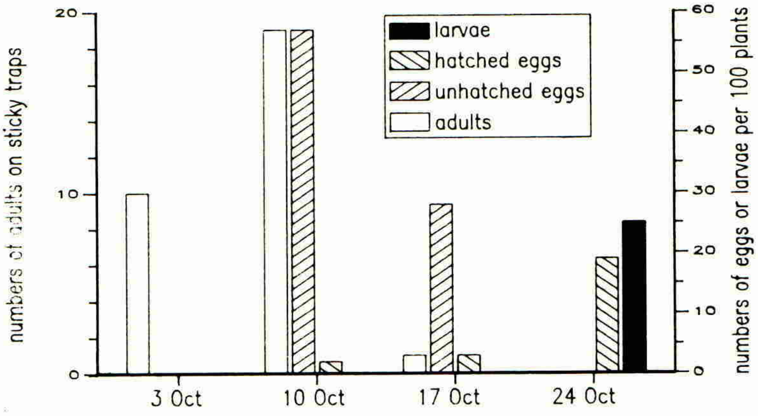
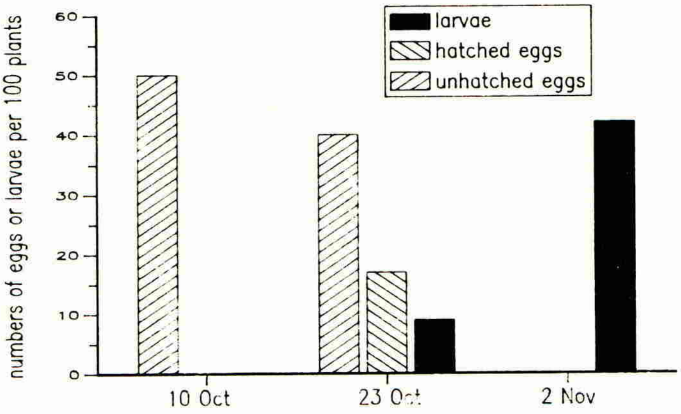


Figure 2. Biological Monitoring of Gout Fly, Pakenham, Suffolk



A field of winter wheat cv. Hornet, at Pakenham, Suffolk was also monitored. This crop was sown on 18 September, but dry soil conditions delayed emergence until about 1 October. Emergence was patchy but an earlier-emerging part of the field was selected for monitoring and the chemical control trial. The number of eggs was recorded on samples of 32 to 50 plants on three occasions between 10 October and 2 November. The results are shown in Fig. 2. A field of winter barley cv. Magie in Woodbridge, Suffolk, sown on 17 September, was first visited on 18 October when 26 % of plants were found to have eggs present with none hatched. The crop was re-sampled on 2 November by which time all the eggs had hatched and larvae were found in 36 % of plants.

CHEMICAL CONTROL

Trials were done in the three monitored fields where a range of insecticides were applied at two or three timings. Timings were designed to test their efficacy against larvae hatching from eggs or against larvae within the plant. Sprays were applied by hand-held sprayers at 200 l/ha. Trials were laid out in randomised blocks with four replicates. The insecticides were applied either at the rates recommended for the control of frit fly or barley yellow dwarf virus (BYDV) vectors. The trial at Bridgets EHF was conducted for the Bridgets Crop Centre and the results remain confidential to the members.

The results from the Pakenham trial are shown in Table 1. Samples consisting of 50 plants per plot were taken on 27 February and assessed for damage. The first treatments were applied after the beginning of egg hatch. The only treatment to give a significant control of damage was the systemic material, omethoate, applied on the 23 October ($p < 0.05$). None of the treatments applied on 7 November reduced damage.

TABLE 1. Percentage of plants and tillers attacked in the Pakenham trial.

Treatment	Timing	Rate (kg ai/ha)	Percentage plant attack (angles)		Percentage tiller attack (angles)	
untreated			50.0	(45.0)	9.6	(18.06)
cypermethrin	23 Oct	0.025	49.7	(44.8)	9.8	(18.23)
cypermethrin	23 Oct & 7 Nov	0.025 x 2	37.6	(37.3)	7.2	(15.58)
cypermethrin	7 Nov	0.025	47.8	(54.9)	14.2	(22.17)
triazophos	23 Oct	0.84	42.2	(40.5)	8.4	(16.82)
omethoate	23 Oct	0.64	25.2	(30.1)	4.8	(12.69)
omethoate	7 Nov	0.64	52.4	(46.4)	9.9	(18.32)
chlorpyrifos	23 Oct	0.72	48.1	(43.9)	9.9	(18.34)
demeton-S-methyl	7 Nov	0.24	57.3	(49.2)	11.4	(19.76)
SED (30 df)				(6.00)		(2.331)

The results from the Woodbridge trial are shown in Table 2. Samples of 50 plants per plot were taken on 27 February and assessed for damage. Only omethoate gave any control at the first spray timing. A very good control of damage was given by omethoate at the second timing, when all the larvae were present in the plants and actively feeding ($p < 0.001$).

TABLE 2. Percentage of plants and tillers attacked in the Woodbridge trial.

Treatment	Timing	Rate (kg ai/ha)	Percentage plant attack	(angles)	Percentage tiller attack	(angles)
untreated			23.5	(29.0)	4.9	(12.82)
cypermethrin	18 Oct	0.025	37.1	(37.5)	8.2	(16.64)
cypermethrin	18 Oct & 7 Nov	0.025 x 2	31.4	(34.1)	6.5	(14.78)
cypermethrin	7 Nov	0.025	34.9	(36.2)	7.7	(16.10)
triazophos	18 Oct	0.84	25.0	(30.3)	4.8	(12.68)
omethoate	18 Oct	0.64	10.5	(18.9)	2.1	(8.40)
omethoate	7 Nov	0.64	5.4	(13.5)	1.2	(6.20)
SED (24 df)				(4.49)		(1.794)

DISCUSSION

The effect of autumn damage on yield is still unclear. Winter cereals appear to recover well from attacks effecting up to 50 % of plants but reports of yield loss following damage to 70 to 90 % of plants have been received. Young & Cousins (1990) found no significant yield response to control in a trial where the percentage of damaged tillers was reduced from 22 to 9 by a spray of omethoate applied in December. The trials reported here will be harvested to provide further information about the effect on yield.

Two possible timings were identified for chemical control in the autumn. Either a contact insecticide can be applied just before the eggs hatch or omethoate may be applied just after hatch. The first window is a very narrow one, with only a week available after the first possible detection of eggs and the last effective spray date. The use of omethoate after egg hatch may prove an easier treatment to use in practice. The spray needs to be applied before damage symptoms are obviously visible or the tiller may still become gouted. The second spray at Pakenham may have been applied after this critical timing, failing to reduce damage expression although still killing larvae.

Good control of BYDV transfer with omethoate was also noted in the Woodbridge trial and the control of both problems may be possible from one well timed spray. General observations where pyrethroids were applied at conventional BYDV timings on a field scale suggest that no control of gout fly was obtained. However, the rest of the trial field at Bridgets EHF was sprayed with cypermethrin on 19 October, just before the eggs hatched, and gave an 80% control of gout fly damage.

The testing of control measures for spring cereals is at an earlier stage of development. Three field scale trials were done on spring wheat crops in 1990. Control with sprays of chlorpyrifos ranged from 30 to 38 % from a single application after eggs were detected.

Gout fly eggs, whilst small, are readily detected by trained crop walkers, and could form the basis for an economic action threshold. Derron

(1984) noted the need to consider integrated pest management for gout fly. Where conditions allow, one to two weeks delay in drilling would lessen the amount of gout fly damage, and also reduce the risk from BYDV.

ACKNOWLEDGEMENTS

We wish to thank Messrs Bryant and Foskett for allowing field work and Messrs Cooper and Mitham for information.

REFERENCES

Derron, J. O. (1984). Seuil de tolerance et technique intensives. *Revue Suisse d'Agriculture*, **16**, 59-63.

Frew, J. G. H. (1924). On *Chlorops taeniopus* Meig. (The gout fly of barley). *Annals of Applied Biology*, **11**, 175-219.

Goodliffe, F. D. (1942). Studies on insects bred from barley, wheat, maize and oats. *Bulletin of Entomological Research*, **32**, 309-325.

Lilly, A. H. R. (1947). Investigations on the gout fly (*Chlorops pumilionis* Bjerk) in Devon and Cornwall. *Annals of Applied Biology*, **34**, 551-561.

Smirnov, E. S.; Fedoseeva, L. I. (1976). Grass flies of the genus *Chlorops* (Diptera, Chloropidae) in the fauna of the Soviet Union; key for identification. *Zoologicheskii Zhurnal*, **55**, 1659-1676.

Young, J. E. B.; Cousins, S. F. B. (1990). Evaluation of the insecticides dimethoate and omethoate against gout fly larvae in winter wheat. *Tests of Agrochemicals and Cultivars* No 11 (*Annals of Applied Biology* **116**, Supplement), 32-33.

Zadoks, J. C.; Rijsdijk, F. H. (1984). *Agro-ecological atlas of cereal growing in Europe. III. Atlas of cereal diseases and pests in Europe. Pudoc, Wageningen, Nederlands.*

TRIAL RESULTS ON USE OF LAMBDA-CYHALOTHRIN FOR PEST CONTROL IN AGRICULTURAL CROPS IN POLAND

S. PRUSZYNSKI, M. MROWCZYNSKI

Plant Protection Institute, ul. Miczurina 20, 60-318 Poznan, Poland

ABSTRACT

From 1983 to 1990 research on the effectiveness of lambda-cyhalothrin in Poland showed that insecticide applied at the rate of 5.0-7.5 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*)
  - cabbage seed weevil (*Ceutorhynchus assimilis*)
  - brassica pod midge (*Dasyneura brassicae*)
potato - Colorado beetle (*Leptinotarsa decemlineata*)
field bean - bean aphid (*Aphis fabae*)
  - *Sitona* beetles
  - bean beetle (*Bruchus atomarius*)
pea - pea aphid (*Acyrthosiphon pisum*)

Dynamics of lambda-cyhalothrin residues in cereals and legumes were also studied.

INTRODUCTION

Lambda-cyhalothrin belongs to the new generation of photo-stable pyrethroids. In earlier researches this compound has been demonstrated to be highly effective in controlling some important pests (Jutsum *et al.*, 1984; Northwood & Verrier, 1986; Perrin, 1986; Wilson & Trevenna, 1986). From 1983 to 1990 extensive researches were carried out using lambda-cyhalothrin for the control of the most important pests of agricultural crops in Poland.

Postive results in these trials, together with results of studies on residue disappearance were the background to the registration of lambda-cyhalothrin for use in Poland.

MATERIALS AND METHODS

Experiments were laid out with individual plots of 20 m^2 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.

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

Lambda-cyhalothrin was applied as 'Karate 2.5 EC' at the rate of 5.0-7.5 g AI/ha according to the pest controlled. Standard insecticides, cypermethrin ('Cymbusz 10 EC'and 'Cymbusz 25 EC'), deltamethrin ('Decis 2.5 EC') and pirimicarb ('Pirimor 50 DP' and 'Pirimor 50 DG') were applied at the rates recommended for use in Poland.

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

For the determination of lambda-cyhalothrin residues, the method developed by the Department of Pesticide Residues of the Plant Protection Institute in Poznan and described in an earlier publication (Pieczonka & Mrowczynski, 1989) was used.

RESULTS

Results obtained are presented in Tables 1-10.

TABLE 1. Control of cereal leaf beetle (*Lema* spp.) on winter wheat (1987-1989)

Active ingredient	Rate g AI/ha	% Mortality 1 DAT*	3 DAT	7 DAT	10 DAT	Yield (t/ha)
Lambda-cyhalothrin	5	98	98	99	98	7.46
Lambda-cyhalothrin	6.25	100	99	99	100	7.50
Lambda-cyhalothrin	7.5	100	100	100	100	7.51
Deltamethrin	7.5	98	99	99	98	7.48
Untreated	-	-	-	-	-	7.02

* DAT = day after treatment.

TABLE 2. Control of cereal aphid (*Sitobion avenae*) on winter wheat (1987-1989)

Active ingredient	Rate g AI/ha	% Mortality 1 DAT*	3 DAT	7 DAT	Yield (t/ha)
Lambda-cyhalothrin	5	93	95	97	7.65
Lambda-cyhalothrin	6.25	98	98	99	7.77
Lambda-cyhalothrin	7.5	100	100	100	7.81
Pirimicarb	125	100	100	100	7.83
Untreated	-	-	-	-	7.24

* DAT = day after treatment.

TABLE 3. Control of Colorado beetle (*Leptinotarsa decemlineata*) on potatoes (1983-1989)

Active ingredient	Rate g AI/ha	% Mortality			
		1 DAT*	3 DAT	7 DAT	10 DAT
Lambda-cyhalothrin	5	93	96	92	91
Lambda-cyhalothrin	6.25	98	99	98	97
Lambda-cyhalothrin	7.5	99	100	99	98
Lambda-cyhalothrin	10	100	100	100	100
Cypermethrin	25	98	100	98	98
Deltamethrin	7.5	97	98	98	96

* DAT = day after treatment.

TABLE 4. Control of rape stem weevil (*Ceutorhynchus napi*) on winter oilseed rape (1984-1985)

Active ingredient	g AI/ha	% of undamaged plants
Lambda-cyhalothrin	6.25	90
Lambda-cyhalothrin	7.5	97
Lambda-cyhalothrin	10	100
Cypermethrin	25	92
Deltamethrin	7.5	93
Untreated	-	12

TABLE 5. Control of cabbage stem weevil (*Ceutorhynchus quadridens*) on winter oilseed rape (1984-1990)

Active ingredient	Rate g AI/ha	% of undamaged plants	Yield (t/ha)
Lambda-cyhalothrin	6.25	72	3.87
Lambda-cyhalothrin	7.5	79	4.01
Lambda-cyhalothrin	10	91	4.13
Cypermethrin	25	74	4.00
Deltamethrin	7.5	76	4.04
Untreated	-	7	3.42

TABLE 6. Control of pollen beetle (*Meligethes aeneus*) on winter oilseed rape (1984-1990)

Active ingredient	Rate g AI/ha	1 DAT*	3 DAT	7 DAT	Yield (t/ha)
Lambda-cyhalothrin	5	98	99	99	4.01
Lambda-cyhalothrin	6.25	99	100	100	4.03
Lambda-cyhalothrin	7.5	100	100	100	4.10
Lambda-cyhalothrin	10	100	100	100	4.14
Cypermethrin	25	97	99	98	4.02
Deltamethrin	7.5	98	99	100	4.08
Untreated	-	-	-	-	3.42

* DAT = day after treatment.

TABLE 7. Control of cabbage seed weevil (*Ceutorhynchus assimilis*) and brassica pod midge (*Dasyneura brassicae*) on winter oilseed rape (1984-1990)

		% of pods damaged by		
Active ingredient	Rate g AI/ha	*C. assimilis*	*C. assimilis* + *D. brassicae*	Yield (g/ha)
Lambda-cyhalothrin	5	2.1	2.4	41.3
Lambda-cyhalothrin	6.25	1.2	1.3	41.9
Lambda-cyhalothrin	7.5	0.8	1.0	42.5
Lambda-cyhalothrin	10	0.5	0.6	43.1
Deltamethrin	7.5	0.6	0.8	42.7
Untreated	-	14.2	18.7	31.2

TABLE 8. Control of *Sitona* beetles on pea (1985-1989)

Active ingredient	Rate g AI/ha	% of undamaged plants
Lambda-cyhalothrin	5	95
Lambda-cyhalothrin	6.25	97
Lambda-cyhalothrin	7.5	100
Cypermethrin	25	97
Deltamethrin	7.5	98
Untreated	-	8

TABLE 9. Control of *Sitona* beetles on field beans (1985-1989)

Active ingredient	Rate g AI/ha	% of undamaged plants
Lambda-cyhalothrin	5	93
Lambda-cyhalothrin	6.25	95
Lambda-cyhalothrin	7.5	100
Cypermethrin	25	97
Deltamethrin	7.5	97
Untreated	-	10

TABLE 10. Control of bean aphid (*Aphis fabae*) on field beans (1985-1989)

Active ingredient	Rate g AI/ha	% Mortality			
		1 DAT*	3 DAT	7 DAT	10 DAT
Lambda-cyhalothrin	6.25	93	95	94	92
Lambda-cyhalothrin	7.5	96	98	98	97
Pirimicarb	125	94	94	93	94
Pirimicarb	250	97	98	100	99

* DAT = day after treatment.

In Fig. 1 the persistence of lambda-cyhalothrin residues in oat and pea plants are presented. In other analyses no lambda-cyhalothrin residues obove 0.005 mg/kg in field bean and pea seeds have been found.

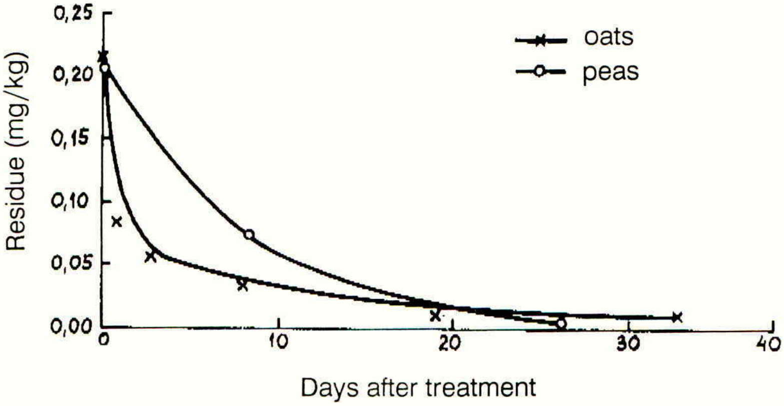


Fig. 1. Disappearance of lambda-cyhalothrin in oats and pea

DISCUSSION

In considering the results presented in this paper, special attention should be drawn to three facts.

Firstly, lambda-cyhalothrin was highly effective in controlling all pest species on which experiments were carried out. In the majority of cases satisfactory efficacy was obtained when 5 g AI/ha was used. The efficacy of lambda-cyhalothrin applied at the rate of 6.25 and 7.5 g AI/ha was comparable with standard products.

The second fact, which is very important for Polish agriculture, is the increasing economic importance of some pest species, which occurred last year in numbers considerably greater than observed in earlier years. This concerns amongst others: cereal leaf beetle (*Lema* spp.), pests of oilseed rape (*Ceutorhynchus napi*, *C. quadridens*, *C. assimilis* and *Dasyneura brassicae*), as well as *Sitona* spp. on legumes.

Thirdly, attention should also be paid to the considerable yield increase obtained from treatments. For example, in the case of cereal leaf beetle control on cereals, the yield increase amounted to 0.44-0.49 t/ha, and in the case of cereal aphid (*Sitobion avenae*) control, the increase amounted to 0.41-0.59 t/ha. In oilseed rape, especially high yield increases, amounting to 1.01-1.19 t/ha, have been obtained as the result of controlling pod pests (*C. assimilis* and *D. brassicae*).

REFERENCES

Jutsum, A.R.; Collins, M.D.; Perrin, R.M.; Evans, D.D.; Davies, R.A.H.; Ruscoe, C.N.E. (1984) PP321 - a novel pyrethroid insecticide. *1984 British Crop Protection Conference - Pests and Diseases*, 2, 421-428.

Northwood, P.J.; Verrier, C. (1986) PP321: control of major pests of oil seed rape in west Europe. *1986 British Crop Protection Conference - Pests and Diseases* 2, 745-752.

Perrin, R.M. (1986) PP321 - a pyrethroid for the control of plant virus vectors. *1986 British Crop Protection Conference - Pests and Diseases* 3, 989-996.

Pieczonka, G.; Mrowczynski, M. (1989) Study on pyrethroid residues in cereals. *29 Sesji Naukowej Instytutu Ochrony Roslim Czesc* II, 247-251 (in Polish).

Wilson, D.; Trevenna, J. (1986) PP321: control of the major pests in UK horticultural crops. *1986 British Crop Protection Conference - Pests and Diseases* 1, 323-330.

EVALUATION OF AN INSECTICIDAL SEED TREATMENT, IMIDACLOPRID, FOR CONTROLLING APHIDS ON SUGAR BEET.

Alan M. Dewar, Lisa A. Read.

A.F.R.C. Institute of Arable Crops Research, Broom's Barn Experimental Station, Higham, Bury St. Edmunds, Suffolk, IP28 6NP, U.K.

ABSTRACT

Imidacloprid applied to sugar-beet pellets had repellent activity against resistant clones of *Myzus persicae* in the laboratory. In field trials in 1989 and 1990, imidacloprid applied as a seed treatment or as a granule gave as good control of aphids and better control of virus yellows than the recommended rate of aldicarb. It therefore has potential as an alternative to aldicarb for controlling aphids in sugar beet, and, as a seed treatment offers an environmentally-safer method of application than is possible with broad-spectrum sprays, or granules applied in the furrow.

INTRODUCTION

The incidence of virus yellows in sugar beet in Europe has increased sharply over the last three years following three relatively mild winters which have allowed substantial overwintering survival of both the viruses causing yellows and their aphid vectors, principally *Myzus persicae* (Cariolle, 1990). In the U.K., national incidence of virus has risen from *ca* 2% in 1987 to almost 20% in 1989 with further increase predicted in 1990 (Dewar & Smith, 1990).

Current recommendations for controlling aphids and virus in beet when early migration of aphids is expected include the use of aldicarb granules applied at drilling, followed by approved aphicidal sprays if necessary after the efficacy of aldicarb has declined (Dewar 1986). Growers who use other granules, or who do not possess an applicator, must rely on insecticidal sprays. However, the efficacy of aphicidal sprays has proved short-lived on young rapidly-growing plants, resulting in the need for two or more applications if aphid immigration continues over a long period. Also, the continuing increase in proportion of *Myzus persicae*, which are resistant to insecticides has rendered some products impotent, and resulted in reduced performance of others (Dewar *et al.*, 1988a; Smith *et al.*, 1990).

The advent of a new insecticide, NTN 33893, (proposed common name imidacloprid) (Schmeer *et al* 1990), which has aphicidal properties when applied as a seed-treatment to sugar-beet pellets, has offered an alternative method for controlling aphids and virus. This paper describes some of the laboratory and field experiments to assess the efficacy of imidacloprid against aphids on sugar beet with particular reference to resistant clones of *Myzus persicae*. The data presented is necessarily only a selection of that available, but is representative of the total information collected.

MATERIALS AND METHODS

Laboratory experiments

Seed treatments were applied during the seed-pelleting process by Germaine's of King's Lynn. Imidacloprid was applied at three rates, *viz.* 30,70, and 110 g a.i. per unit of naked seed (equivalent to 100,000 seeds) and compared with an untreated control. Subsequent analysis of seed loadings showed that the highest rate was close to 90g a.i./unit, while the lower rates were close to the target.

Apterous adults or fourth instars of moderately resistant (R_1) and highly resistant (R_2) clones of *M. persicae* (Sawicki & Rice, 1978), which had been cultured on sugar-beet plants, were separately clip-caged, 5 per cage, onto the undersurface of paired leaves of sugar-beet plants (cv Rex) grown in 15cm pots in SHL professional all-purpose compost in a glasshouse. After 24hrs exposure, aphids were recorded as dead, feeding or walking around the cage (Dewar *et al*, 1988b).

First assessments were made as soon as the first pair of true-leaves were large enough to accept clip cages (15mm diamter) - 23 days after sowing. Subsequent assessments were made 30, 36, 43 and 50 days after sowing when the plants had 4, 6, 8 and 10 leaves respectively. Aphids were always caged on the first pair of true-leaves irrespective of the total number of leaves per plant. It is difficult to place clip cages on young leaves in a manner which would prevent aphids from escaping, due to the undulating nature of young leaf surfaces.

Data on the proportion of aphids dying, feeding or walking round the cage was transformed (logits) prior to analysis using a generalised linear model.

Field experiments

Broom's Barn Farm

The initial field experiment was a late-sown trial to allow comparisons of efficacy under high pest pressure (Dewar, 1990).

In 1989, imidacloprid at 70g a.i./unit was compared with untreated seed, of the same batch and variety used in the glasshouse tests, sown with or without aldicarb granules. Aldicarb, 'Temik 10G', was applied at 7.6kg/ha (38g/100m) using a Horstine Farmery applicator. The trial was drilled on 16 May, with a plot size of 6 rows by 12m; seeds were sown 18.2 cm apart within rows spaced 50cm apart and treatments were replicated 4 times.

Assessment of aphid numbers was made on 5-10 plants per plot, depending on plant size, 30, 38, 42 and 55 days after sowing when plants were at the 2-4, 4-8, 8-10 and 10-12 leaf stages respectively. Aphids were classified as apterous or alate; black or green. Virtually all black aphids were *Aphis fabae*, but the green aphids included two species - *M.persicae* and *Macrosiphum euphorbiae*, whose young nymphs are difficult to distinguish in the field. Subsamples of green aphids were subsequently identified in the laboratory to determine the proportions of each species present.

Commercial Crop

Having tested the efficacy of new insecticides in a situation designed to maximise pest pressure, further evaluation was done in a more realistic, commercial situation, with plot sizes large enough to assess the effects of treatments on virus incidence.

In 1990, among other treatments applied in a large field trial within a commercial sugar beet crop near Sandy in Bedfordshire, imidacloprid was applied as a seed treatment at 45 and 90 g a.i/unit and compared with an untreated control and granular formulations of imidacloprid (5GR) at 12 kg/ha and aldicarb at 7.6 kg/ha. Both granules were applied in the furrow at drilling with untreated seed using a Horstine Farmery applicator on 28 March. Treatments were replicated 4 times in randomised blocks, with a plot size of 10 rows by 20m.

Aphid numbers were assessed as before, on 4-12 plants per plot depending on plant size, on nine occasions from 25 April to 15 June. Virus yellows incidence was assessed on three occasions, viz, 12 June, 25 June and 12 July, prior to preparation of this paper. Virus assessments were made within an area 6 rows by 15m i.e. 45 m^2 per plot.

Data on aphid numbers were transformed logarithmically, and virus data using the angular transformation, prior to analysis of variance using Genstat 5.

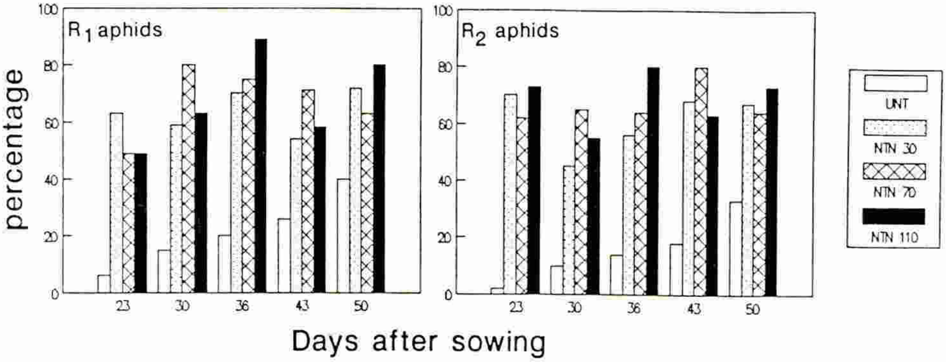
RESULTS

Laboratory experiments

There were no consistent effects of any of the imidacloprid treatments on mortality of either R_1 or R_2 clones of *M.persicae*. The maximum number killed in any of the five assessments was 17% (R_2 aphids 23 days after sowing on plants treated with 70 g a.i. per unit), compared to 5% on the untreated. However, most of the surviving aphids of both clones were recorded walking round the cage after 24 hrs exposure on all three insecticide treatments, while most of those on untreated plants were feeding (Fig. 1). There were no significant differences between the rates of application. This suggests that all three rates of seed treatment were acting as a repellent and were equally effective against moderately and highly resistant aphids.

There was a gradual increase in proportion of both R_1 and R_2 aphids walking round the cage on untreated plants as the experiment progressed, suggesting that the leaves on which they were placed were becoming unpalatable. If this is taken into account in the results from treated plants, the repellent effect of treatments must have gradually deteriorated, although the results show a fairly consistent effect throughout the experiment.

FIGURE 1. The proportion of resistant *Myzus persicae* walking around the cage after 24hr exposure to imidacloprid (Imd) applied as a seed treatment to sugar beet pellets



Field experiments

Broom's Barn 1989

Late-sown sugar beet invariably attracts much larger numbers of aphids, both green and black, than commercial crops sown in March or April. Thus the large number of green aphids found on untreated plants at the 2-leaf stage, 30 days after sowing, was exceptionally high. Nevertheless, both aldicarb and imidacloprid significantly reduced aphid numbers, with imidacloprid giving best control, particularly of green wingless aphids (Table 1a). More than 75% of green aphids on this date were *M.persicae* - the remainder *M.euphorbiae*. By 38 days after sowing (June 23), imidacloprid was still giving significantly better control of green wingless aphids than aldicarb but there were significantly larger numbers of both winged and wingless *A.fabae* on imidacloprid-treated plots than on those treated with aldicarb (Table 1b).

Forty-two days after sowing, imidacloprid-treated plants had more than twice as many black aphids but half as many green aphids as aldicarb-treated plants, giving a higher total number of aphids (Table 1c) not significantly different from untreated plots. Fifty-five days after sowing, neither treatment was giving good control of black aphids and green aphids had all but disappeared (Table 1d).

TABLE 1 **The effects of aphicidal seed treatments and granules on the number of aphids (log n+1)in sugar beet : Broom's Barn 1989. Figures in brackets are back-transformed values minus 1.**

	Aphid numbers per plant				
Treatment	***bw**	**bnw**	**gw**	**gnw**	**Total**
a) 30 days after sowing					
Untreated	0.17(0.5)	0.12(0.3)	0.42(1.7)	1 (33.7)	1.57(36.3)
Aldicarb	0.15(0.4)	0.11(0.3)	0.32(1.1)	1.06(10.6)	1.11(11.8)
Imidacloprid S.T.#	0.09(0.2)	0.04(0.1)	0.21(0.6)	0.28(0.9)	0.46(1.9)
S.E.D. (9 d.f)	0.051	0.051	0.073	0.161	0.158
b) 38 days after sowing					
Untreated	0.09(0.2)	0.80(5.4)	0.18(0.5)	1.40(23.9)	1.49(30.0)
Aldicarb	0.04(0.1)	0.28(0.9)	0.20(0.6)	1.19(14.3)	1.25(16.7)
Imidacloprid S.T.	0.18(0.5)	0.67(3.7)	0.26(0.8)	0.70(4.0)	1.00(9.1)
S.E.D. (36 d.f)	0.041	0.161	0.081	0.167	0.171
c) 42 days after sowing					
Untreated	0.54(2.5)	1.39(23.7)	0.25(0.8)	0.99(8.8)	1.57(35.8)
Aldicarb	0.44(1.8)	1.07(10.7)	0.25(0.8)	0.70(4.0)	1.27(17.5)
Imidacloprid S.T.	0.73(4.4)	1.40(23.9)	0.28(0.9)	0.41(1.6)	1.50(30.6)
S.E.D. (36 d.f)	0.104	0.142	0.079	0.120	0.116
d) 55 days after sowing					
Untreated	0.76(4.7)	1.63(41.2)	0.09(0.2)	0.30(1.0)	1.68(47.3)
Aldicarb	0.81(5.4)	1.40(24.1)	0.02(0.05)	0.11(0.3)	1.49(30.0)
Imidacloprid S.T.	0.80(5.3)	1.45(26.9)	0 (0)	0.02(0.05)	1.53(32.9)
S.E.D. (36 d.f)	0.123	0.102	0.038	0.047	0.096

* b= black g = green w = winged nw = wingless #S.T. = seed treatment

Commercial crop: Sandy, Bedfordshire 1990.

First aphids were found as early as 25 April indicating a very early migration. Approximately 50% were *M.persicae* and the rest *M.euphorbiae*; *A.fabae* was virtually absent until June. For simplicity, data from only three assessments are presented.

On 9 May, 42 days after sowing, there was over 1 aphid per plant in the untreated plots, many of them winged. All insecticide treatments, both granules and seed treatments, significantly reduced the number of wingless aphids, but had only a moderate (insignificant) effect on winged aphids (Table 2a). By 16 May, at the 4-6 leaf stage, numbers had risen to over three per plant on untreated plants, and nearly two per plant in aldicarb plots, but were significantly less in all plots treated with imidacloprid, whether applied as a granule or as seed treatments (Table 2b). These differences were due to lower numbers of wingless aphids; there was no significant effect on alates. These effects still persisted at the 6-8 leaf stage on 23 May, even though aphid numbers declined slightly on untreated and aldicarb plots due to predation (Table 2c). Differences between treatments gradually declined throughout June, but aphid numbers also declined due to increasing predator activity.

TABLE 2 **The effects of aphicidal seed treatments and granules on the number of aphids (logn+1) in sugar beet: Sandy, Bedfordshire 1990. Figures in brackets are back-transformed values minus 1**

Treatment	**Aphid numbers per plant** **gw**	**gnw**	**Total**
a) <u>9 May</u>			
Untreated	0.17(0.5)	0.22(0.7)	0.34(1.2)
Aldicarb granules	0.10(0.3)	0.03(0.1)	0.14(0.4)
Imidacloprid 45 S.T.#	0.13(0.4)	0.08(0.2)	0.20(0.6)
Imidacloprid 90 S.T.	0.07(0.2)	0.03(0.1)	0.09(0.2)
Imidacloprid granules	0.09(0.2)	0.01(0)	0.10(0.2)
S.E.D.	0.052	0.034	0.048
b) <u>16 May</u>			
Untreated	0.24(0.7)	0.51(2.3)	0.62(3.3)
Aldicarb granules	0.23(0.7)	0.34(1.2)	0.45(1.8)
Imidacloprid 45 S.T.	0.21(0.6)	0.05(0.1)	0.24(0.7)
Imidacloprid 90 S.T.	0.16(0.5)	0.04(0.1)	0.19(0.6)
Imidacloprid granules	0.19(0.5)	0.04(0.1)	0.22(0.7)
S.E.D.	0.052	0.059	0.062
c) <u>23 May</u>			
Untreated	0.19(0.6)	0.52(2.3)	0.59(2.9)
Aldicarb granules	0.25(0.8)	0.29(1.0)	0.44(1.8)
Imidacloprid 45 S.T.	0.22(0.6)	0.08(0.2)	0.30(1.0)
Imidacloprid 90 S.T.	0.22(0.6)	0.09(0.2)	0.29(1.0)
Imidacloprid granules	0.22(0.6)	0.11(0.3)	0.30(1.0)
S.E.D.	0.069	0.076	0.076

g = green w = winged nw = wingless #S.T. = seed treatment

First virus symptoms were recorded at the end of May - amongst the earliest ever recorded. Both beet yellows virus (BYV) and beet mild yellowing virus (BMYV) were detected in the trial field. By 12 June, over 20% of plants in the untreated plots were showing symptoms, and all insecticide treatments significantly reduced the incidence of infected plants (Table 3). The higher rate of imidacloprid seed treatment gave the best control, significantly better than aldicarb and imidacloprid granules. By 25 June all imidacloprid-treated plots had significantly lower virus infection than aldicarb plots, which in turn was significantly lower than the untreated.

TABLE 3 **The effects of aphicidal seed treatments and granules on the incidence of virus yellows in sugar beet : Sandy, Bedfordshire 1990.**

Treatment	**angular % plants infected (angle transformation)** **<u>12 June</u>**	**<u>25 June</u>**	**<u>12 July</u>**
Untreated	28.48(22.7)	47.56(54.5)	56.03(68.8)
Aldicarb granules	22.34(14.4)	34.70(32.4)	42.70(46.0)
Imidacloprid 45 S.T.	19.62(11.3)	26.75(20.3)	35.25(33.3)
Imidacloprid 90 S.T.	17.75(9.3)	23.88(16.4)	29.23(23.8)
Imidacloprid granules	21.34(13.2)	26.59(20.0)	30.93(26.4)
S.E.D.	1.502	1.669	1.873

N.B. Figures in brackets are back-transformed values. S.T. = seed treatment

Virus symptoms developed rapidly during June and by 12 July nearly 70% of plants were infected in the untreated plots. Aldicarb significantly reduced infection to 46%, but the best treatment, imidacloprid seed treatment at the higher rate, reduced this by half to only 24%, which was significantly lower than the seed treatment at the lower rate.

DISCUSSION

The laboratory results suggested that imidacloprid applied as a seed treatment was acting as a repellent againt *Myzus persicae* apterae, and that this effect persisted for seven weeks after sowing in pots even with the lowest rate.

The results from the Broom's Barn field trial demonstrated the excellent control given by imidacloprid seed treatment against green aphids, particularly *M.persicae* which were deterred from colonising the young beet plants up to 7 weeks after sowing in this trial, giving significantly better control than aldicarb. However, the same control was not afforded of *A.fabae.* Other trials have shown good efficacy against this species in crops sown earlier, although results were more variable than with *M.persicae* (Schmeer *et al.*, 1990).

In the Sandy trial in 1990 where very few black aphids were present, imidacloprid applied as a seed treatment or a granule gave excellent control of green aphids for over eight weeks after drilling, again significantly better than aldicarb during late May. This was reflected in the development of virus symptoms during June and July where the higher rate of imidacloprid seed treatment, reduced virus symptoms to one third that of untreated and half that of aldicarb by 12 July. Since virus symptoms, especially BMYV, can take 3-8 week to become visible after initial infection (Smith 1989), these results are almost certainly due to the control of aphids during May. These results suggest that this chemical, applied as a seed treatment, offers an alternative to aphicidal granules.

ACKNOWLEDGEMENTS

We thank Bayer for supplying imidacloprid, Germain's of King's Lynn for applying seed treatments, Sara Smith of IACR Rothamsted for providing *M. persicae,* Gina Smith of Rothamsted for analysing data, and Basil Ream for providing the trial site in 1990.

REFERENCES

Cariolle, M. (1990). La jaunisse virale en Europe: evolution recente, incidence, donnees epidemiologiques et schema d'avertissements. *Proceedings of the 53rd Winter Congress of the Institut International de Recherches Betteravieres,* 307-322.

Dewar, A. M. (1986). Forecasting and control of virus yellows and aphids in sugar beet. *British Sugar Beet Review,* **54**, 49-52.

Dewar, A. M. (1990). New active ingredients for controlling aphids and virus yellows in sugar beet. *Proceedings of the 53rd Winter Congress of the Institut International de Recherches Betteravieres,* 399-408.

Dewar, A. M.; Devonshire, A.; ffrench-Constant, R. (1988a). The rise and rise of the resistant aphid. *British Sugar Beet Review,* **56**, 40-43.

Dewar, A. M.; Read, L. A.; Thornhill, W. A. (1988b). The efficacy of novel and existing aphicides against resistant *Myzus persicae* on sugar beet in the laboratory. *British Crop Protection Conference - Pests and Diseases 1988* **1**, 477-482.

Dewar, A. M.; Smith, H. G. (1990). The continuing story of virus yellows. *British Sugar Beet Review* **57**(2), 17-19.

Sawicki, R. M.; Rice, A. D. (1978). Response of susceptible and resistant peach-potato aphids, *Myzus persicae* (Sulzer), to insecticides in leaf-dip bioassays. *Pesticide Science*, **9,** 513-516.

Schmeer, H. E.; Bluett, D. J.; Meredith, R; Heatherington, P. J. (1990). Field evaluation of imidacloprid as an aphicidal-insecticidal seed treatment in sugar beet and cereals with particular reference to virus vector control. *Brighton Crop Protection Conference - Pests and Diseases* 1990 (In Press).

Smith, H. G. (1989). Distribution and infectivity of yellowing viruses in field grown sugar-beet plants. *Annals of Applied Biology* **114**, 481-487.

Smith, S. D. J.; Dewar, A. M.; Devonshire, A. L. (1990). Resistance of *Myzus persicae* to insecticides applied to sugar beet. *Proceedings of the 53rd Winter Congress of the Institut de Recherches Betteravieres,* 379-398.

THE DEVELOPMENT OF TEFLUTHRIN AS A NEW SEED TREATMENT FOR THE CONTROL OF SOIL-INHABITING PESTS OF SUGAR-BEET SEEDLINGS.

G.H. WINDER

A.F.R.C. Institute of Arable Crops Research, Broom's Barn Experimental Station, Higham, Bury St. Edmunds, Suffolk IP28 6NP.

ABSTRACT

Tefluthrin and, to a lesser extent, carbosulfan and furathiocarb applied to sugar-beet seed during pelleting, controlled damage to developing seedlings by soil-inhabiting pests. The current commercial treatment, methiocarb, had little or no effect. Tefluthrin seed treatment gave similar control to soil-applied granular pesticides at sites where pest damage occurred. If used commercially, it should provide an environmentally satisfactory alternative to granular pesticides where arthropod soil-inhabiting pests are the primary target.

INTRODUCTION

Feeding damage to seedlings by soil-inhabiting pests remains one of the main causes of poor or uneven establishment of sugar-beet crops. Damage is usually caused by one or more members of the 'soil pest complex', which includes collembola (e.g. *Onychiurus armatus*), symphylids (e.g. *Scutigerella immaculata*), millipedes (e.g. *Blaniulus guttulatus*, *Brachydesmus superus*), and pygmy beetle (*Atomaria linearis*). In most affected fields several pests are present and it is difficult to apportion blame for the damage.

At present all sugar-beet seed for the U.K. market is pelleted, and to combat soil pest attack methiocarb at 2g a.i./kg of unpelleted seed is incorporated in the pellet. In addition about 60% of the crop is treated either with a granular pesticide at sowing or with gamma-HCH sprayed and worked into the seedbed (Dewar & Cooke, 1986).

Field trials in 1982-3 indicated that several insecticidal seed treatments, including carbofuran, carbosulfan and furathiocarb, had little or no detrimental effect on seed viability, even at relatively high doses, and were at least as effective in preventing pest damage as the commercial methiocarb treatment (Winder & Cooper, 1984).

Further trials in 1984-1986 showed the potential of seed treatments with the carbamates, carbosulfan and furathiocarb, and the synthetic pyrethroid tefluthrin as replacements for methiocarb, giving information on efficacy and dosage (Winder, 1986). This paper summarises plant establishment data from 26 trials in 1986-9 for carbosulfan, furathiocarb and tefluthrin at rates at or near those likely to be used if the treatment is introduced commercially. Granule treatments applied at sowing were included in the 1988-89 trials; the results obtained are compared with those from the seed treatments. The results of similar treatments obtained in 1990 in six 'Growers' trials conducted by British Sugar plc, are also included.

MATERIALS AND METHODS

At the beginning of each season, seed of standard commercial varieties was specially pelleted by Germain's (UK) Ltd. for these trials. Pelleting was by their EB3 process, incorporating a thiram steep to combat seedborne *Phoma* plus 4.5g thiram/unit (=100,000 seeds) in the pellet and, in 1988 and 1989, 10.5g hymexazol 'Tachigaren'/unit to combat soil-borne fungal disease, in particular *Aphanomyces* (Dewar *et al.*, 1988).

The insecticides were incorporated in the pellet during the pelleting process. This paper discusses the performance of seed without insecticide, with the standard methiocarb treatment (2g a.i./unit), with carbosulfan (45g a.i.), with furathiocarb (60g a.i.) and tefluthrin (10 and/or 15g a.i.). The carbosulfan, furathiocarb and tefluthrin (10g a.i.) rates are those which, as a result of earlier work, manufacturers' data and economic considerations, will be used if the treatments are introduced commercially. The tefluthrin 10g a.i. rate was chosen part way through these trials and was not tested in 1986 and 1987; data for tefluthrin at 15 g a.i./unit are used instead in those years.

Seed germination under standard laboratory conditions was satisfactory, and the treatments discussed here had, on average, little or no effect on germination (Table 1).

TABLE 1. Laboratory germination of seed.

Treatment (g a.i./unit)		% Germination at 14 days (% abnormals in parentheses) 1986	1987	1988	1990	Average
Untreated control		88(8)	99(1)	95(1.3)	93(3.0)	94(3.3)
methiocarb	(2)	89(5)	98(1.5)	90(1.3)	95(1.8)	93(1.2)
carbosulfan	(45)	89(4)	94(4.3)	94(2.8)	95(1.8)	93(3.2)
furathiocarb	(60)	87(8)	96(1.5)	96(1.3)	94(1.8)	93(3.2)
tefluthrin	(10)	-	95(3.3)	95(1.0)	96(2.0)	93(3.3)
	(15)	87(7)	-	92(1.0)		

The field trials were of randomised block design with plots of 3 or 6 rows x 15m or more according to site. All were sown to stand, i.e. at 16-18 cm spacing, using standard commercial precision drills.

Insecticide granule treatments applied along the seed furrow at sowing were included in the 1988 and 1989 trials: carbofuran (3g a.i./100m of row) was used at seven sites, aldicarb + gamma-HCH (3.15 + 0.65g a.i./100m) at two sites, carbosulfan (3g a.i./100m) and benfuracarb (3g a.i./100m) at one site each.

The trials were sown by Broom's Barn or British Sugar agricultural development staff at sites selected because of a previous history of soil-pest damage. Most were situated on soils with a high silt component in either the Fens or the Yorkshire Wolds.

Untreated areas at each site were sampled for soil pests at sowing or during the subsequent weeks using straw bait traps (Dewar & Cooper, 1985) and/or soil cores taken round seedlings. Table 2 indicates which pests were present at those sites where statistically significant improvements in plant establishment were obtained.

TABLE 2. Soil pests at the 9 sites where there were significant improvements in plant establishment.

Trial	Soil# type	Onychiurids	Blaniulidae	*Brachydesmus*	*Scutigerella*	*Atomaria*
Grindale 1986	Calc ZL	+++	+	+	-	-
Baston Fen 1987	ZCL	-	++	-	-	+
Nordelph 1987	Peaty L	++	+++	++	-	++
Stilton 1987	ZCL	-	+	+	-	+
Southorpe 1987	ZCL	-	++	+	-	++
Llandrinio 1988	ZCL	++	++	++	+++	+
Baston Fen 1988	ZCL	+	+	++	-	-
Sutton Bridge 1989	ZL	+	++	++	++	+++
Baston Fen 1989	ZCL	+	+	+	+	++

- none found + present ++ numerous +++ very numerous

\# Z=silt, L=loam, C=clay (for further details see MAFF pamphlet 3001)

Seedlings were counted on several occasions at each site. The data described here were obtained at the last count, usually at the end of May or in June, when the plants had reached at least the 4-8 rough leaf stage, and were judged large enough to survive further attack by the soil pest complex.

A series of simple 'Growers' trials were conducted by British Sugar in 1989 and 1990, testing seed treated with methiocarb (2g a.i./unit), furathiocarb (60g a.i./unit) or tefluthrin (10g a.i./unit) with or without granules drilled along the seed furrow at sowing.

RESULTS

Significant increases in plant establishment were obtained in nine of the 26 trials (Table 3). At these sites tefluthrin was the most effective treatment increasing the average establishment from 58% to 80%; carbosulfan and furathiocarb were less effective both giving average establishments of 66% respectively. Methiocarb was not significantly better than the untreated.

TABLE 3. Plant establishment (as % of seeds sown) at sites where pest attack occurred, also average plant establishment for all 26 trials.

Treatment (g ai/unit)	un- treated	methio- carb (2)	carbo- sulfan (45)	furath- iocarb (60)	teflu- thrin (10)	(15)	Granules	SED
Grindale 1986	64	67	68	70		79*		3.9
Baston Fen 1987	60	55	75*	76*		78*		4.5
Nordelph 1987	70	73	80*	83*		89*		3.4
Stilton 1987	64	73	66	67		88*		6.4
Southorpe 1987	77	68	76	85		88*		4.5
Llandrinio 1988	33	34	47*	37	67*	76*	43	6.9
Baston Fen 1988	60	63	60	67	75*	71	64	6.9
Sutton Bridge 1989	18	23	49*	31*	72*		64*	4.8
Baston Fen 1989	73	75	75	79	84*		80	4.5
Average	58	59	66	66	80#			
Average (all 26 trials)	69	67	71	71	78#			

* Significant increases (P = 0.05)

\# Average used in calculating this figure in trials where both rates tested

The average establishment obtained with untreated seeds at all 26 sites was 69%; tefluthrin increased this to 78% and carbosulfan and furathiocarb to 71%. Methiocarb was ineffective (Table 3). It is assumed that pest damage was controlled at some of the sites where there were no significant differences because tefluthrin increased average establishment from 74% to 77% in these trials.

TABLE 4. Average plant establishment as % of numbers of seed sown in trials where granules were included 1988-89.

	Untreated	methio- carb (2)	carbosul- fan (45)	furathio- carb (60)	teflu- thrin (10)	granule
All 11 trials	64	63	66	64	76	68
4 trials with significant differences	46	49	58	54	75	63

The granular pesticide treatments applied in the 11 trials in 1988-89 to plots sown with untreated seed were on average less effective than tefluthrin seed treatment

(Table 4). Results of the four trials where significant differences in establishment occurred are shown in Table 3. In these four trials tefluthrin seed treatment gave an average seedling establishment of 75%, compared with 63% with granules (Table 4). The granules used were carbosulfan at one site and carbofuran at the three other sites.

Similar results were obtained in the six 'Growers' trials where pest damage occurred (Table 5). Better plant establishment was obtained with tefluthrin seed treatment than with either methiocarb or furathiocarb seed treatments or the granules used with methiocarb treated seed.

TABLE 5. Plant establishment (%) in 'Growers' trials 1990 where pest damage occurred.

Site	Soil type(see Table 2)	methiocarb (2)	furathiocarb (60)	tefluthrin(10)	methiocarb + granules	Granule a.i. (g a.i./100m)
Bourne	ZCL	44	50	59	52	furathiocarb (3)
Thorney	ZC	46	60	75	57	carbosulfan (3)
Turves	ZC	33	29	57	38)	(aldicarb + gamma-
Benwick	ZCL	42	42	60	50)	(HCH (3.15 + 0.65)
N.Newbald	Calc L	67	74	89	81)	(
Ramsey	ZCL	23	31	49	45	aldicarb (3.8)
Average		43	48	65	54	

DISCUSSION

The trials show that, for the purpose of soil pest control, tefluthrin was the best of the seed treatments under test and gave as good protection as granular pesticides in trials which included both treatments, and where soil pest damage occurred. Carbosulfan and furathiocarb were less effective, whilst the standard methiocarb seed treatment proved ineffective. Similarly, seed treated with tefluthrin (6, 12, 45 g a.i./unit) improved establishment more than carbofuran (15, 30g a.i./unit) and furathiocarb (30, 60g a.i./unit) and was equal to carbofuran granules in a series of trials throughout Europe in 1988 (Dewar, 1989).

Tefluthrin seed treatment offers the possibility of using smaller quantities of pesticide to obtain control of soil-pest damage equal to that obtainable with the currently-used granule treatments. Because the pesticide is in the seed pellet, it is placed close to the location where it will subsequently be required to protect the developing seedling, none of it being along the row between the seeds as occurs with granules. A trial at Broom's Barn in 1988 showed that tefluthrin seed treatment did not have any deleterious effects on non-target organisms whereas the granule treatments and, in particular, gamma-HCH spray, applied to the seedbed at sowing, decreased numbers (Dewar *et al.*, 1990).

Tefluthrin is therefore recommended as a seed treatment for sugar beet where soil pest control is required. However, although control of flea beetle attacking the foliage of small beet seedlings has been reported (Winder & Dewar, 1985) tefluthrin is not systemic nor has it been shown to be nematicidal. It cannot therefore replace granule treatments such as aldicarb where control of aphids and virus yellows or Docking disorder is required.

ACKNOWLEDGEMENTS

The author is grateful for the help given by various growers, Germains U.K. Ltd. and the Agricultural Development Department of British Sugar plc, especially J. Prince, who also gave permission to use data from their 'Growers' trials.

REFERENCES

Dewar, A.M. (1989). Results of the Co-operative Trials on Pesticides in Pelleted Seeds 1987-1988. *Proceedings of 52nd Winter Congress*. International Institute for Sugar Beet Research, Bruxelles. 163-178.

Dewar, A.M., Asher, M.J.C., Winder, G.H., Payne, P.A. (1988). Recent developments in sugar-beet seed treatment In: *Applications to Seeds and Soil*, T.J. Martin (Ed.), *BCPC Monograph No. 39*, Thornton Heath: BCPC Publications, 265-270.

Dewar, A.M.; Cooke, D.A. (1986). Recent developments in the control of nematode and soil-arthropod pests of sugar beet. *Aspects of Applied Biology 13*. Crop protection of sugar beet and crop protection and quality of potatoes: Part 1, 89-99.

Dewar, A.M.; Cooper, J.M. (1985). 'To Treat or not to Treat? Prospects for forecasting Soil Pest Damage. *British Sugar Beet Review* **53(4)**, 39-40.

Dewar, A.M.; Thornhill, W.A.; Read, L.A.; Brown, R.D.; Cole, J.F.; Everett, C.J. (1990). The Effects of Tefluthrin on Beneficial Insects in Sugar Beet. *Brighton Crop Protection Conference - Pests and Diseases 1990* (in Press).

Winder, G.H. (1986). Developments in use of insecticide treatments of sugar-beet seed. *Aspects of Applied Biology 13*. Crop protection of sugar beet and crop protection and quality of potatoes: Part I, 165-176.

Winder, G.H.; Cooper, J.M. (1984). New sugar beet seed treatments: potential for better seedling-pest control. *Proceedings of the 1984 British Crop Protection Conference - Pests and Diseases*, 785-790.

Winder, G.H.; Dewar, A.M. (1985). Decreased severity of flea beetle damage to sugar-beet seedlings associated with experimental insecticide treatments incorporated in pelleted sugar-beet seed. *Tests of Agrochemicals and Cultivars* **6**, 30-11.

RESPONSES TO PATHOGEN AND PEST CONTROL IN LINSEED

B.D.L. FITT, A.W. FERGUSON

AFRC Institute of Arable Crops Research, Rothamsted Experimental Station,
Harpenden, Herts, AL5 2JQ, UK

ABSTRACT

The effect of pathogen and pest control on linseed (cv. Antares) at Rothamsted was studied in 1988, 1989 and 1990. In 1988, when the summer was wet, fungicide spray treatments decreased the incidence of *Alternaria*, both on the upper leaves before harvest and on the seed after harvest, and increased grain yields by 28%. In 1989, when the summer was dry, fungicides increased yield by 10% and decreased disease incidence slightly. *Thrips angusticeps* (the field thrips) and *Aphthona euphorbiae* (the large flax beetle) were identified as the most important potential pest insects. No yield response to insecticide treatments was detected in 1988 or 1989 when insects were few. There was evidence in 1988 that thrips encouraged flower abortion and in 1990 that flea beetles hindered plant establishment.

INTRODUCTION

There has been a large increase in linseed grown in the UK in the last few years; 1,000 ha were grown in 1984 and 37,300 ha in 1990. This increase has occurred because the EC and the UK have a large deficit (90%) in oils for industrial uses. Experience suggests that as the area of a crop increases so do pest and disease problems. Diseases caused by *Alternaria* spp., *Botrytis cinerea, Fusarium oxysporum* f.sp. *lini* and *Sclerotinia sclerotiorum*, which occurred when flax was grown extensively in the UK in the 1940s (Muskett and Colhoun, 1947), have also been identified recently in commercial linseed crops. *Alternaria* is a pathogen of international importance on linseed and estimates of yield loss as high as 28-60% have been made in India (Chauhan and Srivastava, 1975). The *Alternaria spp.* that infect linseed survive on plant debris and contaminated seed, which then germinates extremely poorly (Gill, 1987; Mercer *et al.*, 1989). In 1988, the incidence of *Alternaria* seed infection in the UK reached 85% (Mercer, pers. comm.). Fungicide spray treatments have often failed to prevent infection of the seed or to give a yield response (Hardwick and Mercer, 1989, Mercer *et al.*, 1989). Several *Alternaria spp.* have been isolated from linseed (Neergard, 1945) but *Alternaria linicola* is usually regarded as the most important (Muskett and Colhoun, 1947). Prochloraz seed treatment does decrease but not completely control *Alternaria* in the subsequent crop (Mercer *et al.*, 1988). Iprodione was widely used to control *Alternaria* on seed, but resistance to this fungicide is now common (Mercer *et al.*, 1988).

In 1942 in England and Wales injury to flax was caused by tortricid moths, wireworms, flea-beetles, leatherjackets and slugs but not by thrips (K. Walters, pers. comm.). In continental Europe, where until recently flax and linseed have been grown more extensively than in UK, thrips (*Thrips angusticeps* and *T. linarius*) and flax flea beetles (*Longitarsus parvulus* and *Aphthona euphorbiae*) are considered to be particular pests (Franssen and

Mantel, 1962; Beaudoin, 1989). Both thrips and flea beetles have now been recorded in UK linseed crops. *T. angusticeps and T. linarius* feed through sucking mouthparts and create areas of necrosis in the plant tissues (Bonnemaison and Bournier, 1964). Linseed is most vulnerable to thrips at two stages: heavy infestations of *T. angusticeps* at the seedling stage damage terminal buds, distort leaves and can kill plants; damage to developing flower buds leads to seed losses and flower abortion (Franssen and Kerssen, 1962; Beaudoin, 1989). In the Netherlands, yield was increased by 30% when insecticide was applied to control *T. angusticeps* (Franssen and Kerssen, 1962). Flax flea beetles cause the most serious injury to linseed just before and just after plant emergence. Adult beetles feed by biting plant tissues and leave characteristic leaf-notches; plants can be killed or their growth retarded (Beaudoin, 1989). The purpose of the study reported here was to assess the effects of pest and pathogen control on plant growth and yield and to identify the agents responsible for plant injury.

MATERIALS AND METHODS

The studies were made on fields in their second or third year of linseed (cv. 'Antares') on Rothamsted Experimental farm in 1988, 1989 and 1990 (Table 1). Two factors, 'insecticides' and 'fungicides' were tested at two levels

TABLE 1. Details of field experiments

	1988	1989	1990
Variety	Antares	Antares	Antares
Date sown	13/4	21/4	22/3
Date harvested	28/10	4/9	
No. blocks (of 4 plots)	3	6	6
Area per plot (m^2)	40	30	45
Insecticide spray treatments (dates)	Dme (6/5,20/5,6/6 20/6,19/7,5/8, 18/8)	Dme (19/5,5/6, 19/6,25/7)	γ HCH (11/4,25/4) Dme (11/4, 25/4,9/5, 22/5,12/7, 26/7) Tph (5/6)
Fungicide seed treatments	No experimental treatment*	Pcl	Pcl
Fungicide spray treatments (dates)	Be+Ipr (6/6,19/7, 18/8)	Ipr (19/6) Pcl (4/7)	Ipr(15/6) Pcl (20/6) Cbe+Mnb (3/7)

Key to symbols: *All seed in 1988 was treated with iprodione plus benomyl

Insecticides: Dme = deltamethrin @ 7.5 g/ha; γHCH = Gamma HCH @ 280 g/ha; Tph = triazophos @ 420 g/ha.

Fungicides: Be = benomyl @ 550 g/ha; Ipr = iprodione @ 500 g/ha; Pcl = prochloraz @ 500 g/ha; Cbe = carbendazim @ 280 g/ha; Mnb = maneb @ 1600 g/ha.

(with and without) in all combinations. The insecticide regime was designed to give full insect control and treatments were applied at 2-week intervals except during flowering (to safeguard pollinators). Fungicides were applied 2 or 3 times during flowering to protect the upper leaves and capsules.

Each year the height and growth stage (GS; Turner, 1987) of the crop and the incidence of diseases (*Alternaria, Botrytis, Oidium*) on cotyledons, leaves and then capsules was recorded regularly. Insects were sampled (usually 2-weekly) by sweep net and visual examination of plants; thrips were extracted from plant samples by shaking in 70% ethanol (Lewis, 1973). Pathogens were isolated from diseased tissues to confirm their identity. Samples of ten plants per plot were taken immediately post-flowering (GS10) and when capsules were brown (pre-harvest, GS11). These plants were examined in detail to assess damage from pests and diseases to leaves, stems, flowers and capsules. Seed from ten capsules per plot was tested to identify any pathogens present.

In 1989 and 1990 crop emergence was assessed on six 0.5 m row-lengths per plot in early May. Numbers of airborne pathogen spores were monitored continuously from May until harvest with a Burkard spore sampler placed in the centre of the experimental area. In 1990 the numbers of thrips present at the flower bud stage (GS6) were assessed by passing a damp white board (21 x 30 cm) in three sweeps through the top of the crop, as recommended by the Institute Technique Agricole du Lin, Paris (Beaudoin, pers. comm.). Additional visual assessments of pathogen (e.g. *Alternaria*) and pest (e.g. flea beetle) damage were made as necessary. Meteorological records, including temperature and rainfall, were obtained from a meteorological station situated 0.5-1 km from the experiment sites in all three seasons.

RESULTS

The pathogen *Alternaria linicola* was isolated from dark brown lesions on cotyledons, stem bases and leaves; *A. linicola, A. alternata* and *A. infectoria* were isolated from seeds. *Botrytis cinerea* (grey mould) was isolated from infected capsules and seeds and *Oidium lini* (powdery mildew) was observed on leaves and capsules. *Fusarium oxysporum* f. sp. *lini* and *Verticillium dahliae* were isolated from infected roots or stem bases of wilted plants and *F. oxysporum lini* was isolated from seeds. Spores of *Alternaria* spp. and *Oidium lini* were collected by the Burkard sampler in 1989 and 1990, with 1989 maxima of 250 and 1800 spores/m^3, respectively, and 1990 maxima of 50 and 2200 spores/m^3, in July/August. In 1988 dark brown *Alternaria* lesions were observed on cotyledons of some plants in June (GS5) but there was little evidence of disease until the crop approached maturity. July and August were wet (155 mm rain on 36 rain days) with a mean temperature of 15°C and chocolate-brown patches, caused by *Alternaria*, developed on 60% of upper leaves by mid-August (GS10). Fungicide spray treatments greatly decreased the incidence of *Alternaria* at GS10 and increased yield by 28% (Table 2). The incidence of plants with capsules infected by *Botrytis* or leaves infected by mildew was, respectively, <1% and <5%. Fungicide spray treatments also decreased the incidence of *Alternaria* (mostly *A. linicola*) on seeds from 40 to 10%. The incidence of *Botrytis* on seeds was <5% and very little *Fusarium* was isolated.

In 1989 emergence was *c*. 50% on all plots and fungicide seed treatments decreased the incidence of *Alternaria* on cotyledons from 10 to 5% and on stem bases from 14 to 2% at GS5. July and August were hot and dry (85 mm rainfall on 18 rain-days with a mean temperature of 17.5°C) and little *Alternaria* developed on leaves (Table 2) whereas the incidence of powdery mildew was 100% on all plots by late July. Fungicide treatments decreased the incidence of *Alternaria* on seeds from 40% in unsprayed plots to 13%, but >50% of the isolates were of *A. alternata* or *A. infectoria* rather than *A. linicola*. There was a 10% yield response to fungicide spray treatments. In 1990 the incidence of *Alternaria* lesions at emergence was 10% in all plots. During hot dry weather in May, June and July the incidence of *Alternaria* and *Botrytis* remained low. However, the incidence of mildew increased to 100% in unsprayed plots by mid-July (GS9) but was reduced to 47% by fungicide treatments.

TABLE 2. Effects of fungicide and insecticide treatments on incidence of diseases on leaves and seeds and on yields of linseed in 1988 and 1989.

Year	Measurement	None	Fung.	Ins.	Fung. + Ins.	SED	Degrees of freedom
1988	% leaves with *Alternaria*†	56	12	61	10	11.2	6
	% seeds with *Alternaria*‡	36	6	45	10	5.8	6
	Grain yield (t/ha)*	2.0	2.6	1.9	3.1	0.34	6
	Oil yield (kg/ha)	779	1018	725	1242	130	6
	1000 grain wt (g)	8.3	8.6	8.1	8.6	0.13	6
1989	% leaves with *Alternaria*†	14	6	10	8	2.9	15
	% seeds with *Alternaria*‡	43	8	27	18	16.8	15
	Grain yield (t/ha)*	1.3	1.4	1.3	1.4	0.13	15
	Oil yield (kg/ha)	493	541	497	536	49.3	15
	1000 grain wt (g)	7.3	7.2	7.4	7.3	0.13	15

† Visual assessment of crop on 18 August 1988; sample of 10 plants/plot on 17 July 1989

‡ Samples taken 22 August 1988, 17 August 1989; >90% *A. linicola* in 1988; <50% *A. linicola* in 1989

* Mean yield per plot at 90% dry matter

The following potential pest species were found: thrips (*Thrips angusticeps*); the large flax beetle (a flea beetle, *Aphthona euphorbiae*); the flax tortrix moth (*Cnephasia interjectana*); mirids; leaf miners; leaf hoppers. Of these, thrips and flea beetles appeared the most injurious. Thrips caused leaf distortion and terminal bud and flower damage and two generations of larvae were found. Flea beetle feeding notches were particularly abundant on seedlings in 1990 and new generation adults emerged each year in July and August. Near to scrubby boundaries mirids were probably responsible for plant injury which was sometimes marked and was similar to that caused by thrips. No aphid colonies were found.

Numbers of insects in 1988 and 1989 were too few to give a measure of the efficacy of the insecticide treatment and there were no significant effects of this treatment on yield (Table 2). In 1990 flea-beetle feeding damage to seedlings was decreased on insecticide treated plots (Table 3); at flower bud stage (GS6) the total numbers of thrips and of flea beetles were each halved in plots treated with insecticide compared to those without (mean no. thrips per 3 sweeps of board per plot: 7.5 and 15.6 respectively, SED 2.62; mean no. flea beetles per 6 sweeps of net per plot: 1.8 and 4.2 respectively, SED 0.82). Emergence counts in 1990 indicated a small improvement in plant establishment in insecticide treated plots which is consistent with control of flea beetles (Table 3).

TABLE 3. Effect of insecticide treatment in 1990 on % plant emergence and % plants with flea beetle feeding damage (mean per plot).

Measurement	Treatment	Days from sowing				
		29	35	40	43	53
% plant emergence	Insecticides	34	57	61	62	62
	No insecticides	31	52	60	57	60
	SED (15 d.f.)	1.7	2.4	2.7	2.0	2.5
% plants with flea beetle feeding damage	Insecticides	4	-	7	12	-
	No insecticides	12	-	20	41	-
	SED (15 d.f.)	2.6	-	3.2	3.5	-

In 1988 all flower heads in a sample of 2 plants per plot were examined immediately post flowering (GS10). Fewer flower heads had aborted or were aborting in plots treated with insecticide than in those without (25% and 32% respectively; total flower heads 472 and 360 respectively). However there were no differences between treatments pre-harvest (GS11). In 1989 45% of flower heads aborted post flowering (GS10). This was probably due to herbicide damage and no treatment effects could be observed. In 1990 thrips damage appeared more widespread on plots than in previous years. There was no evidence of interactions between insecticide and fungicide treatments.

DISCUSSION

These results suggest that *Alternaria* spp. can cause substantial yield losses in UK linseed crops in a wet season like 1988, when fungicide spray treatments gave a 28% yield response associated with control of disease on the upper leaves. Furthermore they suggest that fungicide spray treatments can greatly decrease the incidence of *Alternaria* on seeds. Seed infection can reduce yields through decreasing emergence of linseed crops (Mercer *et al.*, 1989). However, no yield responses to fungicide sprays or decrease in incidence of seed-borne infections have been observed in some other UK trials (Hardwick & Mercer 1989; Mercer *et al.*, 1989). Our experiments suggest that *A. linicola,* which was the predominant *Alternaria* spp. in 1988, was considerably more damaging than *A. alternata* or *A. infectoria*, which were more common in 1989, when the weather was hot and dry. There has been no evidence that other pathogens such as *Botrytis* or *Oidium* caused yield losses in these experiments, or that the 10% yield response to fungicide treatments in 1989 was associated with disease control.

In the south-east of England, as in France (Beaudoin, 1989), it seems likely that thrips and flea beetles may become the most important insect pests of linseed. Mirids may cause injury near to scrubby field boundaries. Experimental insecticide treatments were only moderately successful in decreasing insect numbers on plots in 1990. This may partly be because of the small scale of the experiment and the mobility of the insects, particularly flea beetles. The absence of a yield response to insecticides in 1988 and 1989 reflected low pest numbers but insects, probably thrips, seemed to encourage flower abortion in 1988 and flea beetles probably reduced plant establishment in 1990. The summers of 1989 and 1990 have been favourable to many insects but the increase in the area of linseed grown may also affect pest abundance. Studies of the incidence, timing and distribution of pest infestation and plant injury and of the benefits of insect control are likely to become increasingly important.

ACKNOWLEDGEMENTS

We thank M. Arnold, S. Brown, S. Burhenne, J.W. Cook and R.A. Gutteridge for practical assistance, A.D. Todd for the statistical analyses, and J.C. David, T. Lewis and A.M. Riley for identification of *Alternaria* species, thrips and tortrix moths respectively.

REFERENCES

Beaudoin, X. (1989) Disease and pest control. In: *Flax: Breeding and Utilisation*, G. Marshall (Ed), Brussels and Luxembourg, ECSC, EEC, EAEC, pp. 81-88.

Bonnemaison, L.; Bournier, A. (1964) Les thrips du lin: *Thrips angusticeps* Uzel et *Thrips linarius* Uzel (Thysanoptères). *Annales Épiphyties*, **15**, 97-169.

Chauhan, L.S.; Srivastava, K.N. (1975) Estimation of yield loss caused by blight disease of linseed. *Indian Journal of Farm Science* **3**, 107-109.

Franssen, C.J.H.; Mantel, W.P. (1961) De door tripsen veroorzaakte beschadigingen in het vlasgewas en het voorkómen daarvan [Preventing damage by thrips in flax]. *Tijdschrift over Plantenziekten*, **67**, 39-51.

Frannssen, C.J.H.; Kerssen, M.C. (1962) Aerial control of thrips on flax in the Netherlands. *Agricultural Aviation*, **4**, 50-54.

Gill, K.S. (1987) *Linseed*. New Delhi: Indian Council of Agricultural Research.

Hardwick, N.V.; Mercer, P.C. (1989) Fungicide spray timing for disease control in linseed. *Tests of Agrochemicals and Cultivars* (*Annals of Applied Biology* **114**, *Supplement*) **10**, 48-49.

Lewis, T. (1973) *Thrips: Their Biology, Ecology and Importance*. London, New York: Academic Press.

Mercer, P.C.; McGimpsey, H.C.; Ruddock, A. (1988) The control of seed-borne pathogens of linseed by seed treatments. *Tests of Agrochemicals and Cultivars (Annals of Applied Biology* **112**, *Supplement*) **9**, 30-31.

Mercer, P.C.; McGimpsey, H.C.; Ruddock, A. (1989) Effect of seed treatments and sprays on the field performance of linseed. *Tests of Agrochemicals and Cultivars*, (*Annals of Applied Biology* **114**, *Supplement*) **10**, 50-51.

Muskett, A.E.; Colhoun, J. (1947) *The Diseases of the Flax Plant*. Belfast: W & G Baird.

Neergard, P. (1945) *Danish Species of Alternaria and Stemphylium. Taxonomy. Parasitism. Economical Significance*. London: Oxford University Press.

Turner, J.A. (1987) *Linseed Law*. Hadleigh: BASF.

DEVELOPMENT AND CONTROL OF *BOTRYTIS* IN UK SUNFLOWER CROPS

V.J. CHURCH, C.J. RAWLINSON, B.D.L. FITT

AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts, AL5 2JQ. UK

ABSTRACT

In 1985-1988, when rainfall during July and August was slightly above average, the incidence of *Botrytis* increased rapidly as sunflower heads matured so that >50% of heads were infected by harvest; in 1989 when rainfall in July and August was only 75% of average little disease developed. Fungicide spray treatments decreased the incidence of *Botrytis* and increased grain and oil yields by 20% in 1988 only. In initial assessments early-sown plots and early-maturing varieties generally had more *Botrytis* than late-sown plots or late-maturing varieties. However, there was no evidence that sowing date or variety influenced susceptibility and late-sown plots or late-maturing varieties developed as much disease as early-sown plots or early-maturing varieties when they reached a similar stage of maturity.

INTRODUCTION

Sunflower is a spring-sown crop producing high quality edible oil and protein meal for stock feed. The UK market potential is 1-2x10^{5}t per year to replace current imports of sunflower grain and soya meal (Anon., 1988). However, <1000 ha of sunflowers are being grown commercially because most varieties currently available mature slowly under normal UK conditions. For sunflower to become a viable alternative crop for the UK, early maturing varieties, which can be harvested at the latest in September, are required. Furthermore, an effective strategy is needed for controlling grey mould (*Botrytis cinerea*) on sunflower heads, which is the main disease problem in the UK (Rawlinson & Dover, 1986). When *Botrytis* infection occurs late in the season it may cause yield loss by increasing seed loss during harvesting (Lamarque, 1985). Early infection, however, may cause losses in both yield and oil quality by decreasing the weight of seeds and by partially hydrolysing the oil to form free fatty acids.

Grey mould can develop on sunflower seedlings, stems and leaves, but only if *Botrytis* gains entry through wounds. Generally sunflowers are not susceptible to *Botrytis* until production of pollen has begun on heads during flowering. Senescing flower parts, especially the corolla, stigma, anthers and bracts, are very susceptible to infection (Ladsous *et al.*, 1988) which is stimulated by the presence of pollen (Chu Chou & Preece, 1968; Bekesi, 1982). The conidia of *Botrytis* are dispersed from sources of inoculum, such as crop debris, to the susceptible tissue primarily by wind, although dispersal by rain splash can also occur (Jarvis, 1980; Fitt *et al.*, 1985). The development of grey mould on sunflower heads is favoured by periods of warm wet weather since germination, infection and sporulation of *B. cinerea* are optimal at 20°C in the presence of water on the host surface (Jarvis, 1980; Harrison, 1988).

In France, *Botrytis* on sunflower has been controlled by the application of protectant and systemic fungicide sprays during flowering and by breeding more resistant varieties (Courtillot *et al*., 1973). Cultural methods such as crop rotation, plant hygiene and choice of seed rate can also be important in controlling *Botrytis* in other crops (Maude, 1980). This paper describes the development of *Botrytis* on sunflower crops in relation to variety, sowing date, seed rate and fungicide treatment in 1985-1989.

MATERIALS AND METHODS

Sunflower experiments were sown on sites at Rothamsted between late March and early May at seed rates of 8 - 12 seeds/m^2. Up to 20 different varieties were used in these experiments, but Sunbred 246 was included each year. Nitrogen was applied as Nitrochalk (28%N) at 300-400 kg/ha and herbicides were applied at and after sowing: trifluralin at 1kg and linuron, pre-emergence, at 0.5kg in 200 l/ha. Plots were covered with bird-proof nets from emergence until harvest. Flowering occurred between mid-July and mid-August, generally over a 10 day period for any one treatment. In the 1987-1989 experiments desiccant (diquat) was applied at 0.6-0.8 kg ion in 440 l/ha before harvest. Plots were either combine harvested or hand harvested and threshed with a stationary combine harvester. Rainfall and temperature were recorded at a meteorological station *c*. 1 km from the experimental sites.

In 1988, one experiment examined the effects of seed rate, with cv. Vincent sown at 6, 8, 10, 12 or 14 seeds/m^2. Another examined the effects of fungicide rates with carbendazim plus vinclozolin applied to cv. Sigco 47 at 0.25kg plus 0.5kg in 220 l/ha, respectively, or at two or three times this rate, on five occasions between 7 July and 15 August. In both these experiments there were four randomized blocks, each of five 2.5 x 8m plots. In 1989, the seed rate experiment included cvs Sigco 47 and Vincent sown at 8, 12, 16 or 20 seeds/m^2 in three randomised blocks of eight 2.5 x 8m plots. In the fungicide experiment with cv. Sigco 47, prochloraz (0.5kg) plus vinclozolin (0.5kg in 220 l/ha) was applied twice during flowering with either a standard hydraulic sprayer (Wilson, 1972) or a motorised knapsack mist blower (Solo Junior 410). In 1988 and 1989 concentrations of airborne *Botrytis* spores were monitored continuously between June and September with a Burkard spore sampler (Fitt *et al*., 1985).

RESULTS

In the seasons 1985-1988, when rainfall was slightly above average in July-August, >60% of heads of cv. Sunbred 246 were infected with *Botrytis* by harvest (Table 1); the incidence of *Botrytis* on other varieties was similar. However in 1989, when rainfall in July-August was only 75% of average and the temperature was *c*. 2°C higher than average, the incidence of *Botrytis* on cv. Sunbred was only 4% at harvest. In the seasons favourable for disease the incidence of *Botrytis* lesions increased rapidly just before harvest; in cv. Vincent sown at 6 seeds/m^2 the incidence on 2

August, 19 August, 2 September and 12 September 1988 was respectively 0.6, 7.9, 35.9 and 63.5%. The severity of lesions, assessed as the proportion of the back of the head covered by lesions, increased at a similar rate over this period. In 1988, five applications of carbendazim + vinclozolin decreased the incidence of *Botrytis* (assessed on 26 August) and increased grain and oil yields by 20% (Table 2).

However, in 1989, when the concentration of airborne *Botrytis* spores during the flowering period was only one tenth of that in 1988, little disease developed and fungicide sprays did not increase yields greatly. In 1985, 1986 and 1987 fungicide treatments increased yields by only 6, 3 and 3% respectively.

TABLE 1. Incidence of *Botrytis* on sunflower (cv. Sunbred 246) at harvest in relation to July/August rainfall and temperature, 1985-89.

	1985	1986	1987	1988	1989
% heads infected	67	61	76	68	4
rainfall (mm)	112	148	122	155	85
rain days (no.)	33	25	28	36	18
mean temp. (°C)	15.3	15.1	15.4	15.0	17.5

TABLE 2. Effects of fungicide* sprays on incidence of *Botrytis* and yield of sunflower (cv. Sigco 47) in relation to airborne spore concentrations in 1988 and 1989.

Treatment	% heads infected	Grain yield (t/ha)	Oil yield (kg/ha)	Concentration of *Botrytis* conidia (spores/m^3)▿
1988	(26 Aug.)	(6 Sept.)		
Nil	17.6	0.99	355	466
Fung.	4.8	1.21	438	
SED (13d.f.)	1.88	0.075	27.8	
1989	(17 Aug.)	(22 Aug.)		
Nil	6.1	2.60	1058	46
Fung.	5.4	2.65	1078	
SED (6d.f.)	1.04	0.087	38.8	

* Carbendazim + vinclozolin on 7, 15 & 26 July, 3 & 15 August 1988; prochloraz + vinclozolin on 12 & 19 July 1989. Data are for the highest fungicide rate in 1988 and for the hydraulic sprayer in 1989.

▿ Concentration of airborne spores during flowering period: 12-30 July 1988, 8-18 July 1989.

There was no evidence of differences in susceptibility between varieties or of effects of sowing date on susceptibility in these experiments; the incidence of *Botrytis* appeared to be related to crop maturity. Thus on 30 August 1988 there was most *Botrytis* on early-sown plots of Sigco 47 (an early-maturing variety) and least on late-sown plots of Sunbred 246 (a late-maturing variety) (Table 3). However, by 15 September the incidence of *Botrytis* had increased greatly on plots which had little disease on 30 Aug. The effects of seed rate on *Botrytis* were equivocal; in 1988 the incidence was greatest at the lowest seed rate but in 1989 it was greatest at the highest rate (Table 4).

TABLE 3. Effects of variety and sowing date on incidence of *Botrytis* (% heads infected) on sunflowers in 1988.

Assessment date/ variety	Sowing date					
	17 Mar	5 Apr	15 Apr	25 Apr	11 May	SED (18 d.f.)
30 Aug.						
Sigco 47	67.9	46.5	32.2	29.4	4.0	4.73
Sunbred 246	4.2	8.6	0	0	0	
15 Sept.						
Sigco 47	*	*	*	53.2	3.6	8.79
Sunbred 246	11.7	37.2	21.4	55.6	30.6	

* Harvested

TABLE 4. Effects of seed rate on incidence of *Botrytis* on sunflower (cv. Vincent) in 1988 and 1989.

Assessment date		% heads infected					SED
1988	seeds/m^2	6	8	10	12	14	(12 d.f.)
19 Aug.		7.9	4.9	5.7	3.0	3.7	2.81
12 Sep.		63.5	49.6	52.7	50.9	45.8	3.51
1989	seeds/m^2		8	12	16	20	(11 d.f.)
31 Aug.			7.0	9.5	13.6	15.7	4.63

DISCUSSION

Our results suggest that *Botrytis* will not be a problem in UK sunflower crops when July and August are dryer than average (Tables 1 & 2). However, it can cause significant yield loss in average seasons when concentrations of airborne conidia are high (Table 2), conditions favour infection and sporulation (Jarvis, 1980; Harrison, 1988) and there is much disease by harvest (Table 1). Whilst the incidence of *Botrytis* increased first on early-sown, early-maturing varieties (Table 3), these results suggest that the development of *Botrytis* was related to crop maturity and provide no evidence that variety, sowing date or seed rate affect susceptibility (Tables 3 & 4).

Fungicide spray treatments (carbendazim plus vinclozolin) decreased the incidence of *Botrytis* and increased yield significantly in 1988. As five treatments were applied in that year it suggests that the correct timing of such treatments is difficult. The carbendazim component of these treatments may have been ineffective since > 50% of isolates tested were MBC-resistant. The pattern of disease development, with a gradual increase in the incidence and severity of infections as crops matured, suggests that the plants became susceptible during flowering, as in France (Ladsous *et al.*, 1988). Thus the best strategy against *Botrytis* in UK sunflowers may be to desiccate when seed moisture content has fallen to *c.*30% and to harvest early, before the crop has matured sufficiently for *Botrytis* to develop. Early desiccation and harvesting, in seasons where *Botrytis* is favoured, also maximises the oil yield recovered from the early-maturing varieties which are most suitable for UK conditions (Church & Rawlinson, unpublished).

REFERENCES

Anonymous (1989) Alternative crop and livestock enterprises for UK agriculture. Report of the Novel Crops and Livestock Enterprise Review Group. *Ministry of Agriculture Fisheries and Food.* 115pp.

Bekesi, P. (1982) New inoculation method for infecting sunflower by *Botrytis cinerea* Pers. *Acta Phytopathologica Academiae Scientiarum Hungaricae* **17**, 221-224.

Chu Chou, M; Preece, T.F. (1968) The effect of pollen grains on infections caused by *Botrytis cinerea* Fr. *Annals of Applied Biology* **62**, 11-22.

Courtillot, M; Lamarque, C.; Juffin, M.P.; Rapilly, F. (1973) Recherches de moyens de lutte contre le *Botrytis* du tournesol (*B. Cinerea* Pers.): choix des methodes et des dates d'intervention en fonction des aspects biologiques et épidémiologiques de la maladie. *Phytiatrie Phytopharmacie* 22, 189-200.

Fitt, B.D.L.; Creighton, N.F.; Bainbridge, A. (1985). Role of wind and rain in dispersal of *Botrytis fabae* conidia. *Transactions of the British Mycological Society* **85**, 307-312.

Harrison, J.G. (1988) The biology of *Botrytis* spp. on *Vicia* beans and chocolate spot disease - a review. *Plant Pathology* **37,** 168-201.

Jarvis, W.R. (1980) Epidemiology. In: *The Biology of Botrytis*, J.R. Coley-Smith, K. Verhoeff, W.R. Jarvis (Eds), London: Academic Press, pp 219-247.

Ladsous, O.; Tourvielle, D.; Says-Lesage, V. (1988) Recherches des sites de pollution, d'infection et de sporulation de *Botrytis cinerea* sur le capitule de tournesol. *Informations Techniques de la Centre Technique Interprofessionel des Oléagineux Metropolitains* **105**, 15-20.

Lamarque, C. (1985) Evolution permanente de la situation phytosanitaire de tournesol en France. *Phytoma*, April 1985, 20-24.

Maude, R.B. (1980) Disease control. In: *The Biology of Botrytis*, J.R. Coley-Smith, K. Verhoeff, W.R. Jarvis (Eds), London: Academic Press, pp 275-307.

Rawlinson, C.J. & Dover, P.A. (1986). Pests and diseases of some new and potential alternative arable crops for the United Kingdom. *Proceedings 1986 British Crop Protection Conference - Pests and Diseases* **2**, 721-732.

Wilson, J.C. (1972) A spraying machine for small plot experiments. *Experimental Husbandry* **21,** 25-26