SESSION 6C

CULTURAL CONTROL AND INTEGRATED CROP MANAGEMENT

Session Organiser	Dr D R Dent *International Institute of Biological Control, Ascot*
Poster Papers	6C-1 to 6C-15

THE AWARENESS, USE AND PROMOTION OF INTEGRATED CONTROL TECHNIQUES OF PESTS, DISEASES & WEEDS IN BRITISH AGRICULTURE AND HORTICULTURE

N J BRADSHAW
ADAS, St Agnes Road, Gabalfa, Cardiff, CF4 4YH, UK

C J PARHAM
ADAS, Wharf Road, Guildford, Surrey, GU1 4RP, UK

A C CROXFORD
Department of the Environment, Romney House, 43 Marsham St, London, SW1P 3PY, UK

ABSTRACT

A postal survey of farmers and growers in England, Scotland and Wales covering nine major sectors of agricultural and horticultural production indicated that many were confused by the terms Integrated Pest Management and Integrated Crop Management. Different sectors had different levels of awareness and understanding of IPM/ICM and respondents in all sectors indicated that there was not enough information available on the subject. There was a very strong influence of produce outlet on the awareness of IPM/ICM practices in some but not in all sectors. Face to face communication from crop consultants, the agrochemical industry and the food companies were the most commonly used and trusted sourcesof information on pest, disease and weed control techniques.

INTRODUCTION

In the White Paper on the Environment, 'This Common Inheritance'(Department of the Environment (DoE), 1990), the Government made the commitment to limit pesticide use to the minimum necessary for effective control of pests compatible with the protection of human health and the environment. In 1995, the annual report of 'This Common Inheritance', which covered both the White Paper and the Sustainable Development Strategy (DoE., 1995), made further commitments to pesticide minimisation by signalling the development of guidance on Integrated Pest Management(IPM) and Integrated Crop Management(ICM). As part of this commitment, in October 1995, the DoE commissioned ADAS to survey British farmers and growers to determine the level of awareness and extent of use of ICM and IPM techniques.

Information was needed on farmers' and growers' awareness of these concepts, how extensively they are currently being used and what barriers exist which discourage a wider adoption of IPM/ICM practices in the context of controlling crop pests, diseases and weeds. The survey was required to identify the most important sources of information used by farmers and growers on pest, disease and weed control technology to determine the most cost effective means of promoting IPM/ICM principles to the target population. The survey results were also intended to provide a baseline so as to monitor future changes in attitudes and practices which may occur as a result of Government actions and policies.

MATERIALS AND METHODS

A postal survey was conducted of a broad sample of farmers and growers to ensure that representative data were collected from all of the nine different cropping sectors identified. Nine questionnaires were designed, requesting the same core information but were 'customised' to be relevant to the different sectors. They were self completion tick box in design to encourage acceptable response rates and to ensure that quantifiable data was obtained. The questionnaires were designed as a survey of pest, disease and weed control and not IPM/ICM to ensure that respondents were not biased towards IPM/ICM principles. The questionnaires were 'piloted' with a small number of farmers and growers from each of the sectors before being mailed out to addresses from specific databases for each product sector. In total 4,280 questionnaires were sent out, covering England, Scotland and Wales.The nine sectors targetted and a breakdown of the number of questionnaires sent out and returned is given in Table 1.

A single question at the end of the questionnaire asked specifically about the awareness and understanding of the terms IPM and ICM. This was a measure of **awareness** but not **use** of these techniques. Respondents were asked to indicate whether they had obtained any information from a number of different sources concerning pest, disease and weed control techniques and to rank the top 5 influencers in order of importance. The main practical influence which might affect uptake of IPM/ICM practices is that of the market place ie.outlets giving a particular requirement for the use of specific techniques. To determine the extent to which outlets affected respondents' awareness of IPM/ICM, a `Chi square' test was carried out on the responses to the question on understanding of the terms IPM and ICM against the issue of whether outlets specified the use of these techniques or not.

Other questions were designed to measure underlying attitudes which would reveal how progressive or traditional respondents were in their approach to pest, disease and weed control, how environmentally sensitive they were and where their priorities lay in their business as a whole when selecting and applying pesticides. A question relating to business priorities was intended to gauge attitudes to environmental considerations in relation to what were considered to be other major factors involved in running a farm business. Respondents were also asked how strongly they agreed or disagreed with a number of statements concerning pesticides. Other statements were included to find out farmers'and growers' priorities when choosing a method of pest, disease and weed control, what issues they considered important when selecting and applying pesticides and what techniques were actually being used by respondents in the various sectors. All these factors are also measures of the extent to which farmers and growers are aware of the IPM/ICM philosophy but the results are not reported here.

RESULTS

The overall response to the survey was 26% (1,163 returns) although this ranged from 17% to 43% according to the individual sectors. The responses by sectors are given in Table 1.

Awareness of the terms IPM/ICM (Table 1)

The responses to this question showed how familiar farmers and growers were with the actual terms themselves. A similar number of respondents indicated that they had heard of both of the terms IPM(785) and ICM(794). The horticulture sectors (with the exception of mushrooms) were more familiar with the term IPM than either of the arable sectors. The top fruit, protected edibles and hops sectors indicated the highest level of awareness of IPM which is not surprising as these techniques are already being practiced by growers or attempts have been made to develop them for these sectors. In protected crops for example, IPM techniques were developed in response to pesticide resistance problems and this sector was able to successfully adopt IPM because of their controlled environment conditions. There was generally a similar level of awareness of the term ICM across both the horticulture and arable sectors although horticulturalists (with the exception of mushroom and bedding plant producers) scored highest. Arable respondents were more familiar with the term ICM than with the term IPM.

Table1. Number of questionnaires sent out and returned and responses to the terms IPM and ICM from each of the sectors.

Sector	No. questionnaires sent out	No. questionnaires for analysis	% Returns	% who have heard of IPM	% who have heard of ICM
Arable - cereals	1000	223	22	40	62
Arable - roots	500	103	21	44	61
Top fruit	600	255	43	95	82
Soft fruit	500	168	34	78	71
Field vegetables	500	138	28	62	70
Prot. edibles	500	128	25	83	72
Bedding plants	300	50	17	74	58
Hops	130	39	30	82	77
Mushrooms	250	59	24	46	49
Total (mean)	4280	1163	(26)	(67)	(67)

Understanding of the terms IPM and ICM (Table 2)

Arable farmers had a lower perceived level of understanding of the term IPM shown by the mean overall scores compared with the horticulture sectors (except mushrooms) and fewer claimed complete understanding.This is probably because IPM is a much 'older' term within the horticulture sector and has evolved from the term 'biological control'. The protected edibles sector had the greatest number claiming a complete understanding, almost certainly because effective IPM techniques were first introduced for insect pest control in tomatoes and cucumbers (and more recently sweet peppers) some 20 years ago. Both the arable and the horticultural sectors except for bedding plants and mushrooms appeared to have a similar appreciation of the term ICM as indicated by the overall mean score. For both IPM and ICM, the mean scores suggested that a large proportion of UK farmers and growers only have a vague idea of their meaning or admit to being confused. Most encouragingly, responses to other questions indicated that the industry wants to know more about IPM and ICM, with the exception of top fruit and protected edibles sectors, both of which already use IPM in practice.

Effect of outlets on the awareness and uptake of IPM/ICM techniques within sectors (Table 3)

The number and percentage of respondents with outlets requiring specific techniques of pest, disease and weed control is given in Table 3 together with the Chi-square analysis for each of the sectors. Where the the Chi-square figure is >7.82 (p= 0.05:df = 3) there was a significant effect of outlet on the awareness of IPM/ICM. The results clearly indicated that outlets do have a direct influence in the cereals, top fruit, field vegetables, protected edibles, hops and mushroom sectors. Most particularly notable is that the cereals, field vegetables and protected edibles sectors are influenced in terms of ICM and all the others in terms of IPM. Outlets are therefore a useful route for passing on information to farmers and growers.

Table 2. Perceived level of understanding of the terms IPM and ICM

Sector	%Understand completely		% Clear understanding		% Rough idea		% Confused		Mean score	
	IPM	ICM	IPM	ICM	IPM	ICM	IPM	ICM	IPM	ICM
Arable cereals	1	4	12	21	52	50	34	25	3.18	2.95
Arable roots	2	4	18	26	56	50	24	20	3.02	2.85
Top fruit	21	9	55	38	20	42	5	13	2.09	2.59
Soft fruit	10	7	42	29	37	47	11	18	2.49	2.75
Field veg.	10	12	26	30	40	36	24	23	2.78	2.70
Prot. edibles	38	23	30	20	22	35	11	21	2.06	2.55
Bedding plants	27	12	27	6	29	41	18	41	2.39	3.16
Hops	13	13	39	34	32	29	16	24	2.50	2.63
Mushrooms	7	5	18	12	33	42	42	40	3.11	3.18

Mean score represents: 1 = Understands completely; 2 = Clear understanding
3 = Rough idea but need more explanation ; 4 = Confused by the term.

Table 3. Numbers and percentages of respondents who have outlets requiring the use of specific methods of pest, disease and weed control and the extent to which this affected their awareness of IPM and ICM.

Sector	Number with outlet specifying controls	% with outlet specifying controls	Chi square result for IPM	Chi square result for ICM
Arable - Cereals	36	16	2.302	**15.858**
Arable - Roots	33	32	5.418	2.576
Top fruit	171	67	**15.1489**	5.363
Soft fruit	75	45	5.553	2.774
Field vegetables	80	58	4.065	**12.742**
Prot. edibles	63	49	**11.418**	**26.769**
Bedding plants	5	10	3.606	6.437
Hops	24	62	**9.063**	2.536
Mushrooms	25	42	**8.429**	6.738

Promoting the use of IPM/ICM practices

Several aspects were considered in relation to the promotion of IPM/ICM practices. These were:-

1.Where do farmers/growers currently obtain trustworthy information on any farming issues ?
2.What are the underlying barriers/attitudes and influences which need to be recognised and addressed in any communication with the target population ?
3.How much interest is there in the topic area which would make the population receptive to the information ?
4.How much information is already available and what do the population think of it ?

Sources of information on pest, disease and weed control (Table 4)

By combining respondents use of a particular information source with their ranking of its influence it was possible to identify those sources influencing the most farmers and growers. The responses to this question are summarised in Table 4. Over all the sectors, verbal/human communication from crop consultants, the agrochemical trade and, possibly, food companies were the most commonly used and trusted sources of information. These were closely followed by levy bodies and literature such as R&D reports, probably due to their specific nature. The national press and media, the farming press and training organisations were not perceived as important information sources, probably reflecting the general coverage of complex farming issues particularly by the national and farming press. Government publications only had a very limited influence, perhaps because of their availablility and style or due to the complexity of the subject areas.

Although, the various sectors gave similar response patterns there were some notable exceptions. Arable root growers, for example, rated training organisations highly and this almost certainly reflects the influence of the Potato Marketing Board and the industry sponsored sugar beet research at Brooms Barn Experimental Station. Bedding plant growers considered trade representatives and research reports to be most important. This probably reflects the small but specialist nature of this sector and the value attached to research funded by the Horticultural Development Council which is their only source of 'near market' research information. Hop growers ranked food companies very highly, again reflecting the specialised nature of the sector and also their close relationship with the brewing companies. Finally, mushroom growers considered Government publications important (possibly in connection with Environmental Health and related issues) but this sector also rated contact and exchange of information within their own community as being very important. These results indicate that the most effective way of influencing farmers and growers is through respected and trusted providers of advice ie crop consultants or trade organisations.

Availability of information on non-pesticide techniques of pest, disease and weed control

Respondents were also asked about the availability of information on non-pesticide techniques of pest, disease and weed control - whether there was **enough information** available, whether it was to **clear and easy understand**, whether it was **impartial** and whether they would like **more information.** All sectors indicated that there was not enough information on this topic which was relevant to their cropping sector although this was less of a concern for the protected edibles sector. Nevertheless, more than 50% of respondents even in this sector still identified a need for more information. Across all sectors, except protected edibles, more than 50% of respondents felt that the information available was confusing and more than 70% did not consider the information impartial. This strongly indicated that there is a need for clearly presented impartial information. These results could also be interpreted as indicating that confusion exists within the industry concerning IPM/ICM and, in particular, precisely what is meant by these terms. All sectors indicated a very strong desire for more information with >90% of respondents expressing a need.

Table 4. The importance of different sources of information on pests, disease and weed control methods - mean of all sectors.

Information source	Overall ranking	Overall mean score
Crop consultants	1	2.17
Trade representatives etc.	2	2.66
Food companies etc.	3	2.93
Other literature e.g. R & D Reports	4	2.96
Levy bodies	4	2.96
Other farmers/growers	6	3.11
Government publications	7	3.16
Promotional events etc.	8	3.19
Training organisations	9	3.21
Farming press	10	3.36
National press & media	11	3.69

Overall mean score = arithmetic mean of the 'mean scores' for each sector. Overall ranking = ranking of overall mean scores.

DISCUSSION

Farmers and growers are confused by the terms IPM/ICM and what is meant in terms of their approach to farming. There is a need to reach a concensus view between all interested parties on a definition of IPM/ICM. ICM could be considered to be Good Agricultural Practice incorporating good husbandry and the survey suggests that many farmers and growers are already doing this. Good husbandry could be defined as a biologically sympathetic and economically sustainable method of farming - wrapping it up in the term ICM could be considered as convenient and expedient. The survey also suggested that most farmers and growers are market driven and if that means adopting ICM principles they will. However, there are indications that outlet specified production guidelines and protocols are not perceived as means of minimising the harmful effects of pesticides in the environment but more as tools to satisfy consumer requirements.

ACKNOWLEDGEMENTS

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CULTURAL INPUTS INTO INTEGRATED CROP MANAGEMENT AND MINIMIZING LOSSES OF PROCESSING TOMATOES TO PESTS IN THE US

C A EDWARDS, M F HUELSMAN, E N YARDIM AND W D SHUSTER
Environmental Science Program, The Ohio State University, 1735 Neil Avenue, Columbus, Ohio 43210, USA

ABSTRACT

Using different fertility sources and weed control measures over two seasons, we evaluated the effects of these inputs on the incidence of arthropod pests, predators and diseases in processing tomatoes *(Lycoperiscon esculentum)*. The weed control measures included: recommended rate of herbicides, use of a cut/blown mulch, maintaining weeds below threshold levels by cultivation, and a control where no weed control was applied. The fertility treatments included: recommended rate inorganic fertilizer, 50% of recommended rate, an equivalent rate of composted manure and a no added fertility control plot. Arthropod populations studied included: potato aphids (*Macrosiphum euphorbiae),* green peach aphids (*Myzus persicae),* flea beetles (*Epitrix* sp.) and minute pirate bugs (*Orius* sp.). In the first year, 1994, weed cover was correlated positively with higher predator populations. In the weed treatments, pest populations were correlated positively with the rate of disease incidence. In 1995, aphid populations were significantly higher in the inorganically-fertilized plots than in other fertility treatments. For both years, the incidence of early blight (*Alternaria solani)* was higher in plots treated with herbicide than other weed control measures.

INTRODUCTION

Traditionally, pest control depended upon crop rotations, soil cultivations and various well-established cultural practices while fertility was provided by organic inputs. This changed from the 1950 s, to an almost total dependency upon pesticides and inorganic fertilizers, followed in the last 30 years, by the gradual development of integrated pest management programme which combine more limited pesticide use with cultural and biological control techniques. One shortcoming of these programme has been that pest, disease and weed management programme have usually been developed independently and often in isolation from considerations of the effects of overall farm practices.

The practices a farmer employs for weed control, or the type of fertility amendments used, can have a considerable effect on the success of an integrated pest management scheme. Many interactions between both weed control measures or fertility inputs and arthropod populations have been documented, but they have rarely been considered together. In conventional farming, the use of inorganic fertilizers has been shown to increase pest attacks on arable crops (NRC, 1991). Drinkwater *et al.*(1995) suggested that soil fertility management practices affect how carbon and nitrogen are processed in the soil and can in turn effect both plant-pathogen and plant-herbivore interactions. Funderburk *et al.* (1991) reported a direct correlation between high rates of fertilization with inorganic fertilizers and insect pest damage in soybeans. The use of organic matter can lower the incidence of pests and diseases by increasing species diversity that can favour natural enemies (Altieri, 1985; Edwards, 1987). Horn (1981) reported that pest populations were higher in weed-free plots of cabbage while predator numbers increased in plots where weed remained uncut. Weed populations can be increased as a result of insecticide use which kills the natural enemies of the weeds (Smith, 1982). Rodenhouse *et al.*(1992) demonstrated the effect of uncultivated corridors in soybean fields on the diversity and abundance of arthropods. Therefore, projects that describe how individual inputs influence pest control through interactions in a systems context are valuable and practical (Edwards, 1989)

Our goal is to show that by changing soil fertility, weed control inputs and observing crop yields, combined with a knowledge of pest, predator and disease incidence it may be possible to draw conclusions about the interactions between components of the cropping system and their contribution to the quality and magnitude of crop yield. Vegetable cropping systems are particularly useful to examine. Nearly all horticultural crops grown in the US have at least one major pest (Wilson *et al.*,1982) and disease, and many have several. There is a need to design integrated production systems for vegetables that are not dependent upon chemicals but that maintain high yields.

MATERIALS AND METHODS

This project was part of a larger experiment in 1994 and 1995, involving peppers (*Capsicum annuum*) and cucumbers (*Cucumis sativus*) as well as processing tomatoes (*Lycoperiscon esculentum),* which used a replicated Latin square design to compare the effects of various weed control methods and fertility inputs on insect populations and disease incidence. In this paper, we address the effects of four weed management strategies and four fertility inputs on pest, predator and disease incidence on processing tomatoes.

Plots measured 4.5m x 4.5m with four replicates per treatment. Raised beds were used and the tomatoes were planted in rows with 37 cm row spacing, with beds on 1.5 m centres. The fertility treatments consisted of applications of the recommended rate of inorganic fertilizers, 50% recommended rate inorganic, an equivalent rate of composted cattle manure and a control plot. Weeds were controlled using full rates of appropriate pre-plant herbicides and were maintained throughout the season by hand-hoeing. All fertilizer applications were based on spring soil test results; fertilizer was applied broadcast in a split application; remaining nitrogen was sidedressed at flowering.

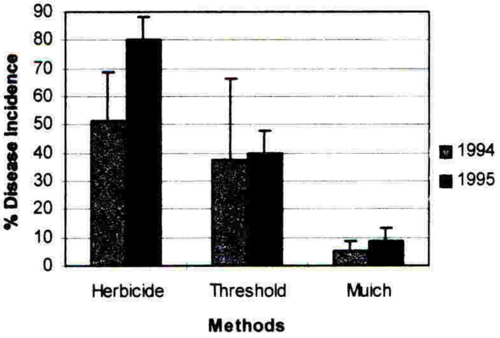
The weed treatments included the use of recommended rates of herbicides, maintaining weeds below threshold levels by cultivation, use of cut/blown mulch and a control with no weed control measures. The herbicide-treated plots received trifluralin (0.9kg a.i./ha) pre-plant and paraquat dichloride (0.56kg a.i./ha) throughout the season to maintain weed control. All sprays were applied using a Durand Wayland W100 boom sprayer with 280 l/ha at $3.1x10^5$ Pa with Tee Jet 8002 flat fan spray tips. The mulch was cut ryegrass; sown the preceding fall, cut with a forage blower and raked from a wagon onto the mulch plots. The mulch was applied initially at a thickness of 15cm and reapplied throughout the season to maintain 100% soil cover. The threshold cultivation treatment plots were maintained by hand-hoeing all weeds, within 20cm of each plant, whenever a threshold treatment level of weed populations had been reached.

No insecticides or fungicides were applied to any of the plots, since insect and disease populations that resulted from fertility or weed control treatments were the larger context of this experiment. Pest and predator populations and incidence of disease were measured on a weekly basis by scouting. Arthropod populations counted included aphids (*Macrosiphum euphorbiae* and *Myzus persicae)*, flea beetles (*Epitrix* sp.) and minute pirate bugs (*Orius* sp.). Early blight (*Alternaria solani*), because of its economic importance in tomato production, was the only disease studied. Disease incidence was measured by counting percent affected leaves per plant. All parameters were totaled for each plots in both seasons. These totals were then compared using ANOVA techniques.

RESULTS

Not all treatments showed significant effects on pest, predator and/or disease incidence. The significant relationships ($P<0.05$) are shown in the graphs below. The incidences of early blight in the weed management plots were significant between treatments for 1994 and 1995 (Figure 1). The mulch treatment plots had lower levels of disease in both years. There was no disease in the control plots because the tomato plants died due to weed pressure.

Figure 1. Early Blight Incidence in Weed Management Plots 1994-95



There were significant differences between in aphid numbers between treatments in 1995 for both the fertility and weed treatments. The tomato plants in the mulch treatment had the highest population of aphids in the weed management plots (Figure 2). In the fertility management plots, the tomato plants receiving 100% recommended inorganic fertilizer had considerably higher aphid populations (Figure 3).

The only significant differences in predator numbers between treatments were in the weed management plots in 1994. The threshold treatment plots supported the largest population of minute pirate bugs (Figure 4).

Figure 2. Aphid Populations in Weed Management Plots 1995

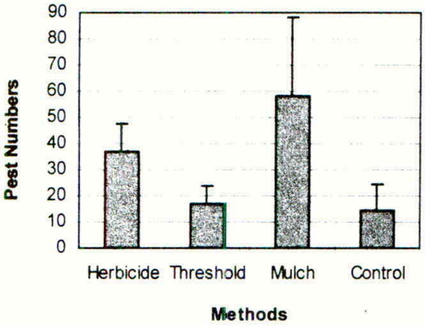


Figure 3. Aphid Populations in Fertility Management Plots 1995

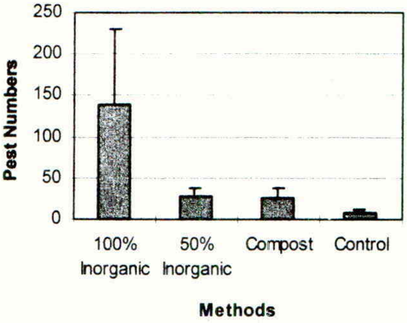


Figure 4. Minute Pirate Bug Population in Weed Management Plots 1994

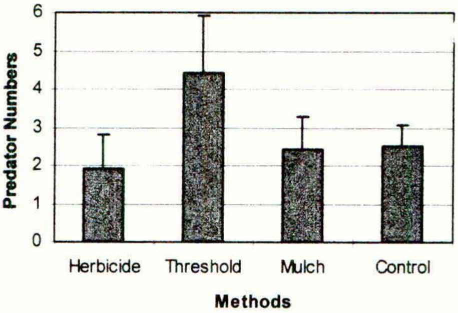


Figure 5. Tomato Yields in Fertility Management Plots 1994-95

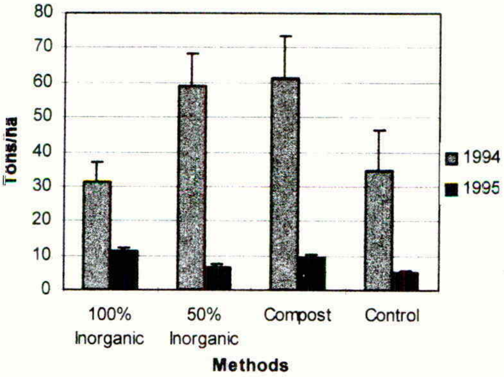
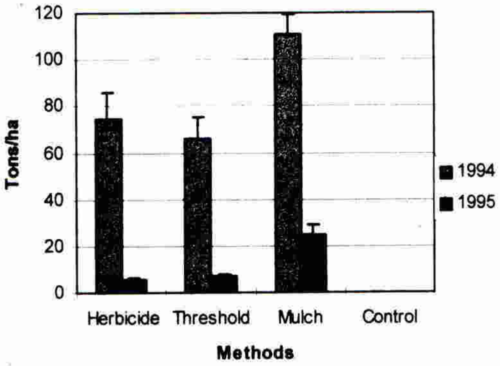


Figure 6. Tomato Yields in Weed Management Plots 1994-95



The average yields obtained for each treatment over the two years of the experiment for both the fertility and weed treatments are summarized in Figs. 5 and 6. The 1995 yields were greatly reduced as compared to the 1994 yields due to extreme weather conditions and theft.

DISCUSSION

Over the two seasons, several significant interactions between inputs and pest incidence occurred. In 1994, the tomato plots with the densest weed cover (threshold treatment) also supported the largest populations of predators. Probably the diverse vegetation provided the best habitat for minute pirate bugs. Additionally, populations of aphids and flea beetles were correlated negatively with minute pirate bug populations. Both interactions were significant at probability levels less than 0.05. The threshold treatment appears to promote higher populations of the predator (minute pirate bug). In the second year of study, herbicide failures and adverse environmental conditions led to weedy conditions in nearly all plots, therefore differences in insect numbers between treatments were minimized.

In 1995, the aphid and flea beetle populations in the mulch plots in the weed experiment were significantly higher than in the other treatments. These results, combined with the disease data showing the lowest incidence of disease in the mulch plots, confirmed a relationship reported by Hatcher *et al.* (1994). They showed that diseased plants supported lower populations of pests than healthier plants. Hence, greater populations of insect pests should be found on the plant with the lowest incidence of disease. The disease data indicated that the plants in the mulch plots had a significantly lower incidence of early blight compared to the plants receiving the other weed control measures. The relative vigour of the mulched tomato plants was also confirmed by the yield data. In both 1994 and 1995, the mulch plots produced the highest yields. Also in 1995, those plants which received the 100% recommended inorganic fertilizer had significantly higher aphid populations than those with other fertility inputs. There is some speculation that that this type of fertilization makes a plant more attractive to a diversity of arthropod pests, especially sucking insects such as aphids (Kowalski & Visser, 1979)

This study demonstrates that interactions between key inputs and pests can be very significant factors in vegetable management programme. Development of new management programme for farmers can take advantage of systems based research such as that described here to help close the gap between component research and a systems-based application to the field scale.

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SUCCESSFUL BIOLOGICAL CONTROL OF THE MAJOR POSTHARVEST DISEASES ON APPLE AND PEAR WITH A NEW STRAIN OF *CANDIDA SAKE.*

I VIÑAS, J USALL, N TEIXIDÓ, E FONS
Postharvest unit. CERTA. Centre UdL-IRTA. 177 Rovira Roure Av., 25198 Lleida, Catalonia, Spain

J OCHOA DE ERIBE
SIPCAM INAGRA SA. Prof. Báguena,5. 46009 Valencia, Spain

ABSTRACT

Biological control using microbial antagonists has been considered as a desirable alternative to the use of chemicals. Following a large screening programme a strain of *Candida sake* (CPA-1) was found to be particularly effective in controlling the three major postharvest pathogens on pome fruits in the Mediterranean Area; *Penicillium expansum* (blue-mold*), Botrytis cinerea* (gray-mold) *and Rhizopus nigricans* (Rhizopus rot). In laboratory experiments *C.sake* completely controlled *B.cinerea* and *R.stolonifer* on apples and showed more than 80% of control of *P.expansum* on apples and pears. In controlled atmosphere storages *P.expansum* rot was effectively controlled (97%), but was more effective at 3% than 1 or 21% oxygen. In semi-commercial and commercial trials with cv. Golden Delicious apples effective control of postharvest diseases was achieved in various cold storage conditions.

INTRODUCTION

Postharvest losses in fruits caused by fungal decay can be extensive and economically relevant, and can be reduced by postharvest treatments of fruits with fungicides.

The development of fungicide resistance by the major postharvest pathogens (Bertrand and Saulie-Carter, 1978; Dekker and Georgopoulos, 1982; Viñas *et al*., 1991), and environmental and consumer concern for public safety have raised the interest in alternative methods to control such diseases.

Biological control using microbial antagonists has been considered as a desirable alternative to the use of chemicals. The control of major postharvest pathogens through application of biological agents was reported for stone fruits (Pussey and Wilson, 1984), apples (Janisiewicz, 1987), citrus (Wilson and Chalutz, 1989), and other fruits (Janisiewicz, 1990).

For effective biological control yeasts have been considered good candidates because of their ability to rapidly colonize fruit surfaces, survive environmental stress and utilize nutrients more rapidly than the pathogens.

A screening programme was initiated in 1989 to isolate and identify from plant surfaces (fruits and leaves of apple and pear trees) naturally occurring bacteria and yeast having potential as biocontrol agents effective against postharvest disease fungi found in the Mediterranean area, including *Penicillium expansum* Link, *Botrytis cinerea* Pers. and *Rhizopus stolonifer* (Ehrenb.) Lind. A strain of *Candida sake* (CPA-1) was found particulary effective in controlling these diseases.

MATERIALS AND METHODS

Pathogens. *P.expansum*, *B.cinerea* and *R.stolonifer* were isolated from decayed apples after several months in storage. These isolates were the most aggressive ones in our collection and caused the largest lesions on inoculated apples. The fungi were maintained on potato-dextrose agar (PDA) with periodic transfers through apple. The inocula consisted of aqueous conidial suspension of 10^3, 10^4 or 10^5 conidia per milliliter. The suspensions were prepared from 10-, 14- and 7-day-old cultures of *P.expansum*, *B.cinerea* and *R.stolonifer*, respectively.

Fruits. The apple cultivar Golden Delicious and the pear cultivar Blanca de Aranjuez were used in all experiments. Fruits were obtained from commercial orchards in Lleida, Catalonia, that used standard cultural practices. For screening tests, the fruits were used following harvest or after a short term (no longer than 3 months) of regular storage at 1°C.

The antagonist suspensions were prepared by growing cultures in nutrient yeast dextrose broth (NYDB) for 24-48 h at 25 ± 1° C with shaking at 150 rpm. The medium was then centrifuged at 7000 rpm for 10 min and cells were resuspended in 50 ml of water. Desired concentrations were obtained by adjusting the suspension according to a standard curve with a spectrophotometer.

Laboratory screening. This method was used to determine the effectiveness and usefulness of the potential antagonists selected against *P.expansum*, *B.cinerea* and *R.stolonifer*. To determine the dilution end point at which selected antagonists would still prevent decay development, experiments were conducted with fruits previously stored at 1° C.

Surface sterilized fruits were wounded, at the stem (top) and calyx (bottom) end. The wounds were 3x3 mm and 3 mm deep. Three fruits constituted a single replicate and each treatment was replicated three times. Twenty-five microliters of appropriate concentration of an aqueous suspension of *C. sake* was applied to each wound. This was followed by inoculation with twenty microliters of an aqueous suspension of pathogen spores ($1x10^3$, $1x10^4$ and $1x10^5$ conidia/ml). The concentration of the conidial suspensions were determined with a hamatocytometer. Lesion diameter was measured after 5, 7 and 10 days of incubation of *R.stolonifer*, *P.expansum* and *B.cinerea*, respectively, at 20 ± 1° C and 75 ± 5% relative humidity in plastic trays. Duncan´s Multiple Range Test was used to test for separation of means at P=0.05.

Small-scale trials of the antagonist under commercial storage conditions. Golden Delicious apples were treated as described previously to evaluate the effectiveness of *C.sake* to controlling *P.expansum* under commercial storage conditions. Twenty apples constitued a single replicate and each treatment was replicated three times. The lesion diameters were measured 60 days after cold storage at 1° C and 21% O_2; 3% O_2, 3% CO_2 or 1% O_2, 1% CO_2 on plastic trays. Duncan's Multiple Range Test was used to test for separation of means at P=0.05.

Semi-commercial trials under cold storage conditions. Golden Delicious apples following harvest were submerged for 30 s in the *C. sake* aqueous suspension at 1.6×10^4 or 1.6×10^6 colony forming units (cfu)/ml. After 1 hour the fruits were submerged again for 30 s in a conidial suspension of *P.expansum* (10^4 conidia/ml). Sixty apples constituted a single replicate and each treatment was replicated three times. The number of fruits with rot development were measured after 8 months in cold storage at 1° C and 21% O_2. Duncan's Multiple Range Test was used to test for separation of means at P=0.05.

Commercial trial under controlled atmosphere conditions. Golden Delicious apples following harvest were randomly chosen and stored in bin palox containing around 1800 fruits each and drenched with a solution of Imazalil at commercial doses, with *C.sake* at $6{,}5 \times 10^4$ and with *C. sake* 3×10^5 cfu /ml, respectively, plus a non-treated set of palox as control. Everything was done following standard industrial procedures. Each treatment was replicated four times.

The treated fruits were stored for 9 months under CA at 1° C, 3% O_2 and 3% CO_2 in a commercial room, filled to completion with similar apples under standard commercial treatments. After the storage period the number of fruits with any rot development was counted in each sample.

RESULTS

Identification of the antagonist. The most promising isolate CPA-1 was sent to the Centraalbureau voor Schimmelcultures (Delft, Netherlands) for identification.. The organism CPA-1 was identified as *Candida sake* (Saito & Ota) Van Uden & Buckley and depositated in Patent Culture Collection (Colección Española de Cultivos Tipo, Valencia. Spain).

Antagonist activity of *C.sake* on apples and pears at 25° C. The antagonist yeast, strongly inhibited development of gray mold, blue mold and black mold lesions on apples and pears. No lesions developed on the apples treated with the three concentrations of the antagonist (7.5×10^5, 1.6×10^6 and 2.6×10^6 cfu/ml) and 10^3 or 10^4 conidia/ml of *B.cinerea* . At 10^5 conidia/ml of *B.cinerea* and at the two higher concentrations of the antagonist, the control was absolute. On pears, *C. sake* only controlled *B. cinerea* at 10^3 conidia/ml, while no effective control (less than 50% of rot reduction) was shown at 10^4 and 10^5 conidia/ml doses.

C.sake reduced or completely controlled *P.expansum* rot development at wounds on apples and pears. Lesion diameter and percentage of wounds infected with *P.expansum* were reduced by increasing concentrations of the antagonist.

No lesions developed on apples protected with *C.sake* at 1.6×10^6 and 2.6×10^6 cfu/ml at 10^3 conidia / ml of *P.expansum* and *R.stolonifer*. At 10^4 or 10^5 conidia/ml of *R.stolonifer* a small lesion or total control was observed at the two higher concentrations tested of the antagonist.

Small-scale trials of C. sake under commercial storage conditions.
In controlled atmosphere storage the control by *C. sake* at 2.4×10^6 cfu/ml was effective in all gas levels tested. At 3% O_2 the control was more effective, achieving 97% rot reduction with respect to the control (Table 1).

Table 1. Effect of the antagonist on rot diameters (cm) caused by *P.expansum* on wounded Golden Delicious apples.

	Concentration of C.sake (CPA-1)	
Gas levels	0 cfu/ml	2.4×10^6 cfu/ml
21% O_2	3.9 a	1.1 b
3% O_2 - 3% CO_2	4.1 a	0.1 b
1% O_2 - 1% CO_2	2.9 a	0.6 b

*Fruits were wounded and inoculated with antagonists at referred doses *and P.expansum* at 10^4 conidia/ml, and stored for 60 days at 1° C and the indicated atmosphere gas levels. Numbers with the same letter are not significantly different according to a Duncan's Multiple Range Test (P=0.05)

Semi commercial trials under cold storage conditions.
C. sake at the highest concentration tested reduced significantly the percentage of rotten fruits (74% reduction) with respect to the control (Table 2).

Table 2. Effect of the antagonist on the percentage of rot by *P. expansum* on Golden Delicious apples.

Concentration of *C. sake*	% of rotten fruits
0 cfu/ml	8.4 a
1.6×10^4 cfu/ml	4.2 ab
1.6×10^6 cfu/ml	2.2 b

*Commercial not-wounded fruits were submerged in an aqueous suspension of *C. sake* at referred doses and *P. expansum* at 10^4 conidia/ml, and stored for 8 months at 1° C. Numbers with the same letter are not significantly different according to a Duncan's Multiple Range Test (P=0.05)

Effectiveness of *C. sake* in a commercial trial under controlled atmosphere.
At the concentration of 3.0 x 10^5 cfu/ml *Candida sake* showed a capacity as an inhibitor of decay similar to the most effective fungicide allowed in the marked for postharvest disease control on pome fruits. The reduction of decay was significant with respect to the control (Table 3).

Table 3. Effectiveness of various treatments against decay agents on Golden Delicious apples.

Treatment	% of fruits with rot development
0	1.30 a
6.5 x 10^4 cfu /ml of *C. sake*	0.89 ab
3.0 x 10^5 cfu /ml of *C. sake*	0.70 b
Imazalil (commercial dose)	0.74 b

*Commercial not-wounded fruits were drenched in commercial conditions with an aqueous suspension of *C. sake* or solution of Imazalil as indicated, and stored for 9 months at 1° C, 3% CO_2 and 3% O_2. Numbers with the same letter are not significantly different according to a Duncan´s Multiple Range Test (P=0.05)

DISCUSSION

Candida sake, the strain that was the most effective antagonist against fungal diseases, is a very suitable organism for postharvest disease control as *C.sake* has never been found to be associated with warm-blooded animals (Hurley *et al.*, 1987). It is also ubiquitous in nature and a major component of the epiphytic community on mature fruits (Beech and Davenport, 1970).

It can be expected that yeasts isolated from fruit surfaces, as well as *C. sake*, may be more effective biocontrol agents because they are phenotypically adapted to this niche and, thus, are able to more effectively colonize and compete for nutrients and space on the fruit suface. Habitat specialization appears common in the hodgepodge, anamorphic species known as *Candida* (Kreger van Rij, 1984).

The concentration of the antagonist needed to obtain control as low enough to be considered for commercial use. The control capacity was satisfactory at low temperatures common in cold storage, and at the commercial gas combinations utilized to controlled atmosphere storage.

The facilities used commonly in the packinghouses for these treatments are also suitable for their use with *C. sake* as tested, and this makes this antagonist more promising since it does not require additional investments to be used commercially.

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A COMMERCIALLY VIABLE LOW-COST STRATEGY FOR THE MANAGEMENT OF SEED WEEVIL POPULATIONS ON WINTER OILSEED RAPE IN THE UK

D V ALFORD
ADAS Boxworth, Boxworth, Cambridge, CB3 8NN, UK

K F A WALTERS
Central Science Laboratory, Sand Hutton, York, YO4 1LZ, UK

I H WILLIAMS, A K MURCHIE
IACR-Rothamsted, Harpenden, Herts., AL5 2JQ, UK

ABSTRACT

Application of insecticides to control populations of cabbage seed weevil (*Ceutorhynchus assimilis*) on winter oilseed rape in England & Wales is rarely justified; also, on the rare occasions when the number of of weevils exceed economic thresholds, they usually do so by only a small amount. The pteromalid wasp *Trichomalus perfectus* is a widely distributed and increasingly important enemy of seed weevil and it is capable of exerting considerable natural control of this pest; control of seed weevil populations will also prevent the development of infestations of brassica pod midge (*Dasineura brassicae*). By not spraying with insecticide or, alternative, by at least avoiding post-flowering insecticide treatments and by minimizing other insecticide applications, natural populations of *T. perfectus* will be increased. These are then likely to exert sufficient control of seed weevil that (irrespective of year-to-year cycles in pest abundance) spraying will be unnecessary, and significant savings in pest management costs can then be made. Minimizing or avoiding pesticide use on this important crop is also environmentally desirable.

INTRODUCTION

Strategies for managing the main spring/summer pests of oilseed rape (pollen beetle, *Meligethes* spp., mainly *M. aeneus*; cabbage seed weevil, *Ceutorhynchus assimilis*; brassica pod midge, *Dasineura brassicae*; and, to a lesser extent, cabbage aphid, *Brevicoryne brassicae*) are based on a set of economic treatment thresholds: for pollen beetle, 15 adults/plant at the green- to yellow-bud growth stages; for seed weevil, 2 adults/plant during flowering or 1 adult/plant in crops prone to pod midge attack; for cabbage aphid, 10% plants infested post-flowering. Experiments in commercial crops have recently confirmed the validity of these thresholds on modern oilseed rape cultivars grown using current farm practices (Walters & Lane, 1992, 1994; Ellis *et al.*, 1995). Of these pests, seed weevil is the most important on winter rape in the UK (Alford *et al.*, 1991), and control of this species forms the basis for the strategy identified in the present paper.

Farmers often spray routinely against seed weevil, and this unnecessary use of insecticides is highlighted by comparing current Pest Monitoring and Pesticide Usage Survey data (Lane & Walters, 1994). Recent field and laboratory experiments have shown that the pteromalid wasp *Trichomalus perfectus* is an important and widely distributed natural enemy of seed weevil in England & Wales (Alford *et al.*, 1995a, 1995b, 1995c). This parasitoid is also important in continental Europe (e.g. von Rosen, 1964; Lerin, 1987) and is capable of exerting high levels of natural control, often killing in excess of 70% of seed weevil larvae. In this paper, an economically justified and practical strategy, that relies mainly on natural biological control, is proposed for the management of seed weevil populations on winter oilseed rape in England & Wales. Control of this pest will also prevent the development of pod midge infestations, as the female midges usually lay their eggs in weevil-damaged pods.

METHODS

The data discussed were obtained from multi-site field experiments at various locations in England (Bedfordshire, Cambridgeshire, Hertfordshire, Yorkshire) from 1992 to 1994 (see Alford *et al.*, 1995a, 1995b, 1995c), in which the impact of insecticides on the efficacy of natural populations of *Trichomalus perfectus* for controlling seed weevil was assessed. These data were supplemented by contemporaneous laboratory-based studies of parasitoids (e.g. Murchie, 1996) and by data from stratified pest and parasitoid monitoring on commercial crops throughout the main rape-growing areas of England & Wales (see Walters & Lane, 1994).

RESULTS

The results of the multi-site field experiments (e.g. Table 1) confirmed that, in unsprayed plots, parasitism of seed weevil larvae by larvae of *T. perfectus* was often above 50% (sometimes exceeding 90% in individual plots). There was also evidence that, prior to laying eggs, adult females of *T. perfectus* fed directly from and, thereby also killed, seed

Table 1. Effect of insecticides on parasitism of seed weevil (*Ceutorhynchus assimilis*) larvae by *Trichomalus perfectus* (1993 data).

Treatment (timing)	Mean level of parasitism (%)
Untreated	65
Alphacypermethrin (flowering: GS 4.8)	71
Alphacypermethrin (post-flowering: GS 6.1)*	61
Triazophos (post-flowering: GS 6.1)	11

GS = Growth Stage (see Sylvester-Bradley & Makepeace, 1984)
* Experimental treatment only

weevil larvae, enhancing the beneficial effects of this natural enemy. The pyrethroid insecticide alphacypermethrin, when applied conventionally during flowering, appeared to have little or no detrimental effect on levels of parasitism. When application of this insecticide was delayed until parasitoid adults were active in crops (i.e. post-flowering), there was some evidence of a decline in parasitism. However, this decline was far less than that seen when triazophos was applied at a similar time (Table 1) (see also, Alford *et al.*, 1995a). Co-incidentally, in commercial crops nationally the recent decline in the use of triazophos appears to have led to a rapid and general increase in the incidence of parasitism of seed weevil by *T. perfectus* (Table 2). Samples from fields with the highest levels of

Table 2. Relationship between the decline in the use of triazophos and parasitism of seed weevil (*Ceutorhynchus assimilis*) larvae by *Trichomalus perfectus*.

Year	Area of rape grown ('000 ha)	Area treated with a pyrethroid* ('000 ha)	Area treated with triazophos ('000 ha)	Recorded level of parasitism (%)
1990	343.8	219.0	48.2	8 ± 15
1991	387.8	247.1	72.7	4 ± 5
1992	362.9	168.2	5.4	5 ± 7
1993	314.8	159.9	2.1	48 ± 31
1994	333.9	165.6	2.7	49 ± 22
1995	301.3	196.5	5.2	58 ± 26

*Between 1 April and harvest in each cropping year

Table 3. Infestations of pollen beetles (*Meligethes* spp.) at green/yellow bud (threshold = 15 adults/plant) and seed weevil (*Ceutorhynchus assimilis*) during flowering (threshold = 2 adults/plant) in commercial winter oilseed rape crops, 1990–95.

Year	No. of crops	% crops with >10 pollen beetles/plant	% crops with >15 pollen beetles/plant	% crops with >1.5 seed weevils/plant	% crops with >2 seed weevils/plant
1990	68	2.5*	0.0*	7.4	5.9
1991	81	2.5	0.0	3.8	2.5
1992	86	2.3	1.2**	2.3	2.3
1993	67	0.0	0.0	0.0	0.0
1994	73	0.0	0.0	0.0	0.0
1995	71	4.2	0.0	0.0	0.0
Total	446	1.9	0.2	2.2	1.8

* Based on samples from 40 crops only ** One crop with 15.6 adults/plants

parasitism also tended to include largest numbers of 'dead' (but apparently unparasitized) larvae, possibly reflecting increased 'host feeding' by the adult parasitoids.

Pest monitoring from 1990 to 1995 indicated that populations of seed weevil and pollen beetle rarely approached or reached levels that justified application of an insecticide (Table 3). When populations did exceed recommended treatment thresholds, they usually did so by only a small margin. For example, average seed weevil infestations of more than 2.5 adults/plant were recorded in only six (0.58%) of the 1,033 crops sampled during the full 15-year (1981–1995) monitoring period, and never from 1991 onwards.

DISCUSSION

In the mid-1970s, a period during which few insecticide applications were made to winter rape in the UK, high levels of natural control of seed weevil were exerted by *T. perfectus*, often in excess of 70% (Alford, D V *in litt.*). Since then, the area of rape sprayed with insecticide has increased dramatically, peaking in 1990 when 390,000 ha of rape were sown and over 546,000 ha received an insecticide treatment (equivalent to over 1.4 treatments/ha) and levels of parasitism greatly declined (see Alford *et al.*, 1995c). On the basis of pest monitoring data and current treatment thresholds, extensive spraying against insect pests on winter rape in spring/summer cannot be justified. For example, the 1994 Pesticide Usage Survey (Garthwaite *et al.*, 1995) reported that a total of 266,052 ha received chemical treatments during April to July (= 80% of the area grown), in spite of only a small number of crops being genuinely at risk during the same period. Even allowing for the inherent statistical inaccuracies of surveys, a large proportion of the crops sprayed in 1994 would not have benefitted from the insecticide treatment. Although susceptible to many pests, the crop is able to compensate for large amounts of insect damage, and infestations of seed weevil (or other pests) are rarely significant enough to require the application of insecticides. However, the perceived 'high' treatment thresholds for pests such as seed weevil (at least in part a consequence of the adult insects being very noticeable when on the crop), often cause concern to farmers; this leads to lack of confidence, fears of crop losses and, hence, often to routine and unnecessary spraying.

Probably as a result of the recent decline in the use of triazophos, levels of parasitism of seed weevil larvae are now increasing spectacularly throughout the main rape-growing areas of England & Wales. Indeed, the overall effectiveness of *T. perfectus* at controlling seed weevil is such that it now allows the promotion of a robust biological control strategy in which, irrespective of year-to-year cycles in pest abundance, spraying against seed weevil could be virtually, if not entirely, eliminated, to the overall benefit of farmers. On a crop so attractive to pollinating and other non-target invertebrates, avoiding or at least minimizing the use of insecticides would also have considerable environmental benefits.

Our proposed strategy, to take advantage of the increasing level of natural parasitism, requires only a minor development of current practices. As presently recommended, crops of winter rape should be sampled for adults seed weevil during flowering, using the beating-tray method (Lane & Walters, 1994). Only if samples clearly indicate a population in excess of the current economic threshold of two weevils/plant (adjusted downwards, if necessary, to take account of pod midge) should an insecticide be applied. However, in recognition of the expected beneficial role of parasitoids, if a spray is required, then a relatively harmless pyrethroid should be used during flowering and post-flowering sprays totally avoided. Because of the established beneficial effects of *T. perfectus*, farmers should now have increased confidence when applying thresholds, as any under-estimates resulting from errors in pest population assessments are likely to be corrected by the activity of natural control agents, thus avoiding the risk of even small losses. Further, since survey data have shown conclusively that so few crops nationally exceed recommended treatment thresholds and that these exceptions usually do so by only a small margin, the risks of crop losses from not spraying, even in any expected 'worse cases', are still negligible. A fail-safe option to spray if absolutely necessary is still there and, by using a pyrethroid at flowering, this will have minimal impact on the basic no-spray strategy. However, cost effectiveness and overall long-term benefits would be lost if farmers perceived the latter option to be acceptable as a routine.

Management of populations of seed weevil on winter oilseed rape needs to be considered in relation to other 'spring/summer' pests, particularly pod midge and pollen beetle. Once again, insecticides should be applied only if current thresholds are exceeded. Pod midge is attacked by various parasitoids (Williams & Walton, 1990; Murchie, 1996) and, because of the main timing of their activity, these will probably also be affected adversely by post-flowering applications of insecticides. Pollen beetle is also attacked by parasitoids; these are often abundant on brassica seed crops but they are known to be susceptible to insecticides applied in May or early June (Winfield, 1963). Unfortunately, no up-to-date data on oilseed rape are available but numbers of such parasitoids will probably be reduced when chemicals are applied against 'spring/summer' pests on winter rape, whether during the bud stages (against pollen beetle) or later (against seed weevil). Thus, parasitoids of pests such as pod midge and pollen beetle need to be considered and safeguarded if an overall biological control strategy for the main pest complex on winter oilseed rape in spring/summer is to become a reality. In subsequent years, this could lead to a general reduction in the size of pest populations in crops, reducing even further the need to spray. In addition, it may eventually enable a future re-assessment of the treatment thresholds to increase the population level at which spraying is required, by assuming a greater natural mortality of the pests. Consideration of such parameters should be included in a future decision support system, where such data and complex relationships can be elucidated (see Lane & Walters, 1995).

Winter rape, as a major arable crop, is unique in being able to offer genuine opportunities for natural biological control of an important pest complex. The parasitoids are there and effective, and they cost nothing. These are compelling reasons why farmers should utilize and safeguard this natural resource.

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THE ROLE OF INTEGRATED CROP MANAGEMENT FOR THE CONTROL OF NOVEL GENOTYPES OF POTATO LATE BLIGHT IN THE USA

W W KIRK
Room 35 Plant Biology Building, Dept. Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824, USA

ABSTRACT

The predominant genotype of potato late blight in the USA and Canada in recent years is the US8-A2 mating strain. A general description of the factors leading to a renewal of emphasis on an integrated approach to potato light blight management is described. The efficacy of fungicides developed and commonly used in Europe introduced into the USA under an emergency registration procedure is reported from trials in Michigan, USA. Results from 1996 will be presented in the poster presentation. Protection programs using residual and semi-systemic fungicides have proved more effective than disease containment strategies.

INTRODUCTION

The North American potato industry is currently confronting a unique and historical phase in terms of plant pathology. The A2 strain/US8 genotype of the potato late blight pathogen (*Phytophthora infestans*) has spread throughout the US and Canada into areas not previously affected by this devastating disease (Hamm et.al., 1995; Deahl et.al., 1995a). During recent years in North America, methods for the control of late blight such as the use of fully systemic fungicides such as metalaxyl based products (Ciba Agriculture) and the breeding of potato cultivars with specific major-gene resistance for the predominant genotype of late blight (US1/A1 mating type), may have inadvertently led to the selection and development of genotypes of the late blight pathogen more able to survive (Deahl et.al., 1995a). A nationwide study was initiated (Fry, 1995) to monitor changes in the population structure of late blight in North America. Knowledge of such changes may provide answers for the development of future long term control strategies.

Integrated crop management strategies for late blight control in potatoes include several methods but often emphasise the use of one or more of the component methods over others. In North America, the most reliable component for disease control has been chemical control. Many states reviewed their chemical control recommendations after it was found that the predominant genotypes in North America were metalaxyl-insensitive (Deahl, 1995b). Since 1994, more emphasis has been placed on the other components of integrated crop management for late blight control such as cultural practices, use of late blight prediction models, reduced sensitivity cultivars, increased use of ground rigs to apply fungicides, monitoring of and legislation against potato culls (Plissey pers.comm.) and grower education programs. In this paper, some of the methods revived or receiving increased interest will be described. Of special note during 1995 and 1996 was the emergency registration of fungicides not previously registered or tested in the US or Canada under the Section 18 emergency registration procedure of the USDA. The efficacy of these fungicides under US conditions in 1995 will be briefly described.

Basic biology of potato late blight

The potato late blight pathogen has a limited host range. Important hosts common in agriculture include the *Solanum* species potato, tomato and hairy nightshade. The factors influencing crop infection have been fully described and the environmental conditions conducive to disease development are well known (Harrison,1993). However, the initial infection phases of disease establishment from seed tuber/pieces to an aerial epidemic are not well understood (Deahl, 1995b).

Initial infection during wet, humid and cool periods can take only minutes to a few hours to establish (Coffey and Gees, 1991). The initial infection period is also poorly understood in that even plants well protected with fungicides can be infected (Kirk and Cortright, 1995). Sporangia produced from the initial infection foci spread and form new lesions on host tissue. There is renewed speculation in the US about the movement of sporangia between plants and crops. Sporangia can be spread in air, by rain or irrigation water and it is thought that some mechanical spread may be possible by means of agricultural equipment and personnel.

The various stages of the disease and the effect of different groups of chemicals at these stages are shown as presently understood in Table 1. The fungal stages are shown as the developmental sequence from sporangiophore formation to oospore formation (the spores formed by sexual coupling between compatible mating types). The table by Schwinn and Margot (1991) has been expanded to include the active ingredients registered under the Section 18 emergency use clause by the USDA.

Little is known about the mechanism of the survival of the pathogen on potato tubers over-wintering either in storages, in cullpiles, or as volunteers surviving in the soil. Spread from tuber to tuber is unlikely under current storage regimes. Recent work has shown that if tubers are actively sporulating during critical times such as immediate pre-planting, healthy tubers can be infected (Deahl unpublished). Marshall and Stevenson in Wisconsin (1996) have shown that infected young sprouts can successfully emerge after being inoculated artificially. Normally, infected sprouts die prior to emergence but it is now clear that some infected sprouts emerge to infect neighboring plants.

RESULTS AND DISCUSSION

It is thought that the rapid incursion of the US8 genotype was due to several factors. The genotype may be more virulent than the US1 (A1 strain) within a wider range of environmental parameters such as temperature and humidity. There are no data published yet to confirm this hypothesis. Some controlled environment work does suggest that some lines of the US8 genotype are more virulent on potatoes than some of the US1 genotypes under similar conditions (Legard et.al., 1995).

Controlled environment studies at Michigan State University using isolates collected from Michigan confirmed that some lines of the US8 genotype are more virulent than some lines of the US1 genotype but this was not consistent. The fact that the US8 genotype was predominant in the US in 1995 suggests its high level of fitness in comparison with other genotypes. The US8 genotype is insensitive to metalaxyl. In the years before the invasion of the US8 strain, late blight was relatively easy to control in North America. Ridomil (metalaxyl) prepacked products were usually applied when late blight lesions were first seen in a crop. This control measure

Table 1. Comparative action of residual and systemic fungicide sprays on the late blight disease cycle

	Residual Fungicides				Systemic Fungicides			
Fungal/disease stage	Copper compounds	Tin compounds	Chlorothalonil	EBDCs	Metalaxyl sensitive strains	Propamocarb	Dimethomorph	Cymoxanil
Sporangiophore formation	-	*	?	-	-	***	***	-
Zoospore formation	?	?	?	?	?	***	-	-
Zoospore release (from primary sporangia)	***	***	***	**	-	-	*	**
Zoospore germination	***	***	***	**	-	-	-	**
Appressorium formation	*	*	-	?	-	-	-	**
Initial penetration	-	*	-	*	-	-	-	**
Growth inside leaf	-	-	-	*	***	***	**	*
Lesion formation	-	-	-	-	***	***	**	*
Sporulation (secondary sporangia)	-	**	-	-	***	***	***	-
Tuber blight	*	*	-	-	***	***	***	?
Oospore formation	?	?	-	-	?	?	**	?

*** : strong action   **: good action   *: weak action   -: no action   ?: not known
information from Schwinn and Margot (1991); Manufacturers R&D departments; Trials from MSU 1995 (Kirk and Cortright, 1995; Lacy and Cortright, 1995)

worked until metalaxyl-resistant strains of the late blight fungus occurred in crops. Ciba Agriculture argues that using the Ridomil-prepacked products curatively was not the recommended application technique. Local interpretations of the recommendations may have led in part to the selection of metalaxyl-resistant strains of late blight. Late blight infections are difficult to control once started and curative measures often fail to be effective. This is true of both A1 (metalaxyl sensitive) genotypes and A2 (metalaxyl insensitive) genotypes.

Fungicides applied in a preventative program to control potato late blight are shown in Table 2. The products used in this comparison were chlorothalonil (Bravo 720) and mancozeb (Penncozeb DF) in comparison with a standard program containing three applications of a metalaxyl-based prepack program alternated and completed with mancozeb applications (all rates are full recommended rates). These trials were inoculated with spore suspensions of a US8/A2 genotype and irrigated frequently to provide late blight conducive conditions (Kirk and Cortright, 1995). All treatments gave almost complete control of late blight in comparison with the untreated plots. The products registered under the Section 18 provision of the USDA also gave almost complete control when applied in protectant programs (Table 2). The efficacy of formulated products containing propamocarb plus chlorothalonil (Tattoo C), dimethomorph plus mancozeb (Acrobat MZ) and cymoxanyl plus mancozeb (Curzate M8), the section 18 materials, were compared when applied three times at seven day intervals after late blight had reached 10% foliar infection (NIAB scale equivalent) throughout the crop (Table 3). The level of control of the propamocarb plus chlorothalonil and dimethomorph plus mancozeb products was similar but not statistically superior to metiram plus triphenyltin acetate (Polyram plus Super Tin) in terms of disease development ($p = 0.05$). The intention of these diverse experiments was to demonstrate to growers that containment programs were unable to adequately control late blight once the disease was established.

Varietal resistance

There are no commercial varieties currently grown in the US that display resistance to the US8 genotype of potato late blight. In controlled environment studies and in field trials inoculated with US8 potato late blight and untreated with fungicides at MSU (Douches et.al. in press) no commercial cultivar or advanced breeding line withstood the disease. At present therefore, selection of commercial cultivars less susceptible to US8 genotypes is not an option to growers in the US implementing holistic crop health strategies.

Application techniques

In trials at University of Wisconsin, a comparison of application techniques is underway. Initial results suggest that chemical distribution through the canopy (chlorothalonil, Bravo 720) is least effective with chemigation techniques. This is unfortunate as many growers in the Rocky Mountain states of North America could effectively cover their crops with this method. The distribution of the chemical was measured at three levels in the canopy. The best deposition was applied by the ground rig treatment at moderate to high water volume. Aerial application also gave adequate coverage of the foliage. High water volume applications are generally the most effective protection strategies as surface protectants need to cover as much exposed green tissue as possible. If late blight spores germinate on unprotected green tissue they can initiate infection. Generally, late blight infections begin in areas of the crop that are under-protected. These are the areas that are inaccessible by traditional application techniques, for example, beneath irrigation

Table 2. Control of potato late blight with fungicides(selected results), Kirk and Cortright (1995).

Chemical	Rate Form/ha	Spray Schedule	% Late Blight[1]							Yield (t/ha)	
			8/8	8/14	8/17	8/21	8/28	9/2	9/6	>5 cm diameter	Total
Untreated			0.0a	3.25 b	5.00 b	9.3 bc	75.0 b	86.3 d	92.5 e	19.9 c	22.0 c
Bravo 720 6FL	0.5 l 1.0 l	7 day first 4 appns 7 day to season end	0.0a	0.28a	0.35a	1.0a	1.6a	4.3abc	6.3abcd	27.1ab	28.8ab
Dithane DF Ridomil MZ 72WP	2.25 kg 2.25 kg	14 day alt'nate 14 day alt'nate	0.0a	0.05a	0.18a	0.2a	2.0a	3.5ab	4.5ab	26.0ab	28.1ab
Curzate M8	1.5 kg	7 day	0.0a	0.9a	0.3a	1.9a		3.3ab	4.5ab	28.8ab	31.6a
Penncozeb 75DF	2.25 kg	7 day	0.1 b	0.13a	0.15a	0.6a	1.3a	2.0a	4.8abcd	29.3a	31.3a
Tattoo C 6.3FL Penncozeb 75DF	1.3 l 2.25 kg	7 day 2 appns then 14 day alternate	0.00a	0.65a	0.43a	0.8a	2.1a	2.3a	3.8a	29.1a	31.5a

Table 3. Control of potato late blight with fungicides after infection is established. (Kirk and Cortright, 1995).

Chemical	Rate Form/ha	Spray schedule	% late blight[1]				
			8/17	8/21	8/28	9/2	9/6
Untreated			13.3a[3]	22.5a	83.8a	88.8a	95.0a
Champ 2FL + Bravo ZN 4FL	0.75 l 0.88 l	7 day[2]	7.8a	14.8ab	36.2 b	42.5 b	50.0 b
Polyram 80DF + SuperTin 80WP	2.25 kg 0.18 kg	7 day	6.0ab	13.3ab	21.3 c	26.3 c	30.0 c
Tattoo C 6.3FL	1.3 l	7 day	3.8 b	6.8 b	12.5 c	16.3 c	25.0 c
Acrobat MZ	2.5 kg	7 day	3.8 b	6.5 b	10.8 c	15.0 c	20.0 c
Curzate M8 72WP	1.4 kg	7 day	7.0ab	12.0ab	23.8 c	36.7 b	41.3 b

[1] Percent of foliage infected as estimated visually on dates indicated

[2] Applications began on 8/10/95 when late blight infected about 10% of the foliage and were completed on 8/21/95

[3] Means followed by the same letter are not significantly different (Student-Newman-Keuls test, p=0.05)

NB US formulations calculated from US measurement system, therefore formulated rates do not correspond to European euivalents.

pivots, near trees, under pylons and telegraph poles and beside domestic dwellings and roads. Growers are advised that these areas should either remain unplanted or be protected by fungicides applied by ground rig. Fungicide application techniques may change in the future as late blight is a disease that requires a continuous protection strategy. Pivot irrigation is a standard requirement for potato production in the Rocky Mountain states of North America and may provide the answer to application techniques in the future. Low output volume spray nozzles and pumps mounted on special booms attached to irrigation rigs along with increased pivot speeds may allow the effective distribution of fungicides to the potato crop during periods when other application techniques are not feasible.

Environmental monitoring

The prevailing weather in many parts of North America are not conducive to late blight epidemics. The areas in North America traditionally affected by late blight are those which experience cooler and more humid summers than the western Rocky Mountain states. These areas also experienced serious crop losses and high disease control costs during 1994. During 1995, these areas have so far suffered least crop losses although the control measures have remained costly but effective. The key to effective disease control lies in the timing of the application of fungicides. Many growers have installed weather stations equipped with a late blight epidemic prediction model to better time applications of fungicides. The most commonly used system in the mid-West of the US is Blitecast which was developed for North America at Penn State University, Pennsylvania. Blitecast is installed in the ENVIROCASTER weather and crop monitor developed by Neogen Food Tech. of Lansing, Michigan. The blight prediction model incorporates two separate models, one based on temperature, rainfall and humidity and the other on duration of leaf wetness measured by a leaf wetness sensor.

Continuous monitoring of the environment within the potato field enables the grower to measure the occurrence of a blight conducive period(s) and therefore to time the start of the blight spray program. The Blitecast system accumulates severity values on a day-degree accumulation basis from measurements of relative humidity, daily rainfall and average daily temperatures. After the crop is at a critical stage defined as the crop meeting within rows, an accumulation of 18 severity values indicates that a blight conducive period has occurred. This can occur over a period from one to several weeks and in dry seasons may not occur at all. It has been shown over several years in Michigan by Lacy (pers. comm.), and by Fry at Cornell that the first lesions in untreated plots appear about seven days after the threshold of 18 severity values has occurred. The Blitecast model was developed during the period when the A1/US1 strain was predominant. The US8 genotypes of late blight may be infective under wider or different humidity and temperature levels than the US1 genotype. Some growers in Michigan in 1995 used an accumulation of 15 severity values to time the initiation of their spray programs.

Weather monitoring may encourage grower dependence on a single disease control method. A further limitation is the time taken to communicate a blight conducive period to the grower. Weather monitoring and the use of predictive models is effective only in the immediate area where the instruments are positioned. The microclimate within the potato canopy on the same farm can vary between fields and within the same field. Blight conducive conditions will be greatest in fields that are on short crop rotation cycles (volunteers), sheltered fields, fields near water and in irrigated fields.

In 1995, the late blight epidemic was less severe than expected in Michigan. Despite the higher than normal accumulation of severity values recorded throughout Michigan. The very high temperatures experienced throughout much of the mid-Western states of North America, dried leaf surfaces quickly and allowed the application of fungicides as prescribed by the Blitecast model.

Fungicide programs and vine desiccation

Programs containing the fungicides described above applied at the recommended interval as determined by blight risk are appropriate insurance programs to prevent disease development. When programs for whatever reason are interrupted and late blight becomes established in crops, various strategies can be used for disease containment. Some strategies that were available to growers in Michigan in 1995 are shown in Table 6. More than one fungicide was suggested for any given situation as availability of certain products was limited. All fungicides should be applied according to the label recommendation for the minimum spray interval. In situations where it is unlikely that a spray can be applied exactly according to the label, the interval between sprays should be decreased rather than extended.

Infected areas to be killed with Diquat should only be desiccated following an application of fungicide to the healthy portion of the field. To limit spore showers onto the soil it is recommended in Michigan that growers continue to apply e.g. EBDC fungicides until the haulm is completely dead.

CONCLUSION

Efficiency, mechanization, increased labor costs, sociological and other economic pressures have led many potato production units to be rigid and resistant to change. The structure of the potato industry in many parts of Europe is similar to that in North America and changes in the focus or balance of disease, weed, nematode and insect pressure has led to many growers suffering losses from which recovery is impossible. The rate at which the late blight epidemic has spread through North America is alarming and may lead to the end of many potato production units. In the longer term, a reassessment of current crop protection techniques may lead to an industry more able to resist the ravages of nature.

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Future emphasis in integrated potato crop management strategies may require a renewed focus on issues previously thought to be unimportant in the holistic approach to crop health, such as pre-planting seed treatments and re-calibration of thresholds for initiation of epidemics.

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DAILY DISPERSAL OF BENEFICIAL GROUND BEETLES BETWEEN AREAS OF CONTRASTING VEGETATION DENSITY WITHIN AGRICULTURAL HABITATS

P A CHAPMAN, G ARMSTRONG
SAC Aberdeen, 581 King Street, Aberdeen, AB24 5UA, UK

ABSTRACT

Increasing the vegetation density of crops, for example intercropping vegetables with clover, is thought to increase the activity of beneficial, predatory arthropods, such as carabid beetles, but competition from the clover can reduce the yield of the crop. The effect of competition could be reduced by alternating intercropped and monocropped strips, but this would only be useful if the presence of densely vegetated areas also increased the activity of carabids in adjacent sparsely vegetated areas. Thus, experiments were carried out to determine whether daily movements occurred between the contrasting habitats. The results suggested that some nocturnal carabid species moved from dense clover onto open ground at night and that the distance of movement was dependent on the size of the beetles. Results from a cereal crop adjacent to dense grass indicated that this effect applied in general to contrasting habitats. Thus, partial intercropping may be an effective compromise between enhanced carabid activity and crop yield loss.

INTRODUCTION

Carabid beetles (Coleoptera: Carabidae) are well known for their beneficial role as predators of crop pests such as cabbage root fly and aphids (Coaker and Williams, 1963, Edwards *et al.*, 1979). One way of enhancing their activity in agricultural ecosystems is to increase the diversity and density of the vegetation within the crop (O'Donnell and Coaker, 1975). This provides more food, shelter from predation and a favourable microclimate, with higher humidity, which is important for many carabid species (Thiele, 1977). In vegetable crops, increased vegetation density can be achieved by allowing natural weed cover to develop (Armstrong and McKinlay, 1994) or by intercropping with unrelated plant species such as clover (Theunissen *et al.*, 1991), although the use of clover, in particular, usually results in a considerable reduction in yield of the main crop (O'Donnell and Coaker, 1975, Armstrong and McKinlay, 1994). Dense vegetation within cereals, consisting of semi-permanent weedy or grass strips, has been found to increase carabid activity in the adjacent crop (Thomas, 1990, Lys *et al.*, 1994). These strips are thought to serve as overwintering sites that enable early colonisation of the crop in the spring. However, it is also possible that carabid activity in the sparsely vegetated crop is increased because beetles shelter in the densely vegetated areas by day and move out to forage in the open by night when the temperature is lower, humidity higher and darkness offers protection from predators. This is most likely in the case of nocturnal species whose activity is limited by humidity and temperature (Kegel, 1990). If such daily movements do occur, strips of clover, rather than a continuous understorey, may be a useful compromise in intercropped vegetables, as competition would be reduced, but the activity of beneficial carabid beetles would still be increased across the whole crop.

The experiments described in this paper were carried out between 1994 and 1996 and aimed to determine whether there were daily movements of carabid beetles between dense and open vegetation. In order that the results could be used in developing improved systems of intercropping in vegetables, most of the work concerned the movements of carabids between plots of clover-intercropped and adjacent, monocropped cabbages. This work was supported by a laboratory experiment with one carabid species where dense clover and bare ground were the contrasting habitats. In 1996, predatory activity was recorded in an open cereal crop adjacent to dense silage grass, and with the inclusion of these results, it is possible to generalise about the effects of contrasting vegetation types.

MATERIALS AND METHODS

Movement of carabids between dense and open vegetation

Movements of carabids between clover-intercropped and weeded, monocropped cabbages were investigated indirectly by the use of exclusion barriers between 16 and 30 August 1994 at Woodside, near Elgin. Two pairs of adjacent intercropped and monocropped plots (each 10m ×10m) were used. Plastic barriers (20 cm high) were set up at mid-day around one pair of plots, so that they were enclosed from the surrounding area and from each other. The other pair of plots was not enclosed. Carabids were collected from all four plots, using nine pitfall traps per plot. After one week, the barriers were moved to the other pair of intercropped and monocropped plots, and a second week of pitfall trapping was carried out.

Daily activity patterns in dense and open vegetation

Time-sorted pitfall trapping was used to measure carabid activity during the day and night in clover-intercropped and monocropped cabbages at Craibstone, Aberdeen, between 11 July and 10 August 1995. There were six plots, each 5m×5m, of which half was intercropped and half was hand-weeded. Six dry pitfall traps were placed in each half plot and trapping was carried out between 8 a.m. and 8 p.m. on five consecutive days. Each day the carabids caught were identified and released. This daytime trapping was followed by five nights of trapping between 8 p.m. and 8 a.m. and then the whole procedure was repeated.

Effect of contrasting vegetation densities on the behaviour of *Pterostichus melanarius*

The habitat preference and daily activity patterns of one carabid species, *Pterostichus melanarius,* were studied in twelve soil-filled trays (30cm×60cm). Half of the surface in each tray was densely covered with clover and the other half was bare. Ten *Drosophila* pupae, each loosely glued to a 1cm×1cm card, were placed in each half tray and one beetle was placed in each tray. The trays were kept under natural day-length and the amount of predation was recorded after a ten hour period during the night. The beetles and prey were then replaced and the daytime predation was similarly recorded. The whole sequence was repeated three times.

Daily activity of predatory arthropods in cereals adjacent to a grass sward

The effect of areas of denser vegetation on the role of predatory arthropods in adjacent, open crop environments was studied in a plot of oats adjacent to an unmown grass plot (each plot 26m×64m) at Tulloch farm, Aberdeen (11-12/6/96). Ten rows of *Drosophila* pupae were placed at one metre intervals away from the edge of the grass into the oats. There were fifty pupae per row, each one metre apart. The number of prey eaten was recorded after eight hours during the night. The experiment was then repeated for eight hours during the day.

RESULTS

Movement of carabids between dense and open vegetation

Eighteen species of carabids were recorded and these were grouped according to size (small: <8.5mm; large: >8.5mm) using the measurements given by Lindroth (1974), and by the generally accepted daily activity pattern (Thiele, 1977, Luff, 1978). This resulted in three groups of species for analysis: large nocturnal (4 species), small nocturnal (9 species) and small diurnal (5 species). Fewer large carabids were caught in the enclosed plots, but the number of small beetles, whether diurnal or nocturnal, were not significantly affected by enclosure within each intercropped and monocropped plot pair (Table 1). The effect of intercropping differed between the three groups of species: the large, nocturnal species were more active in the intercropped areas, whereas the small nocturnal species were significantly more active in the monocropped plots. The small diurnal species were more commonly caught in the intercropped plots, but in this case the effect of vegetation type was not significant. There was a significant interaction between enclosure and intercropping for the small nocturnal species: numbers were similar in the enclosed and open plots, but in the enclosed plots they was no significant difference between intercropped and weeded treatments, while in the open plots, significantly more were caught in the weeded treatment.

Table 1. Mean (± S.E.M.) numbers of carabid beetles caught in clover-intercropped and monocropped cabbages that were either enclosed by a barrier or left open (16-30/8/94). Two way analysis of variance: n.s. P>0.05; ** P<0.01; *** P<0.001 (d.f. = 68).

Treatment		Carabid group Large Nocturnal	Small Nocturnal	Small Diurnal
Open	Intercropped	6.39 ± 0.76	2.22 ± 0.32	0.50 ± 0.17
	Monocropped	4.22 ± 0.55	7.17 ± 0.77	0.39 ± 0.12
Enclosed	Intercropped	4.28 ± 0.59	3.28 ± 0.51	0.89 ± 0.24
	Monocropped	2.28 ± 0.39	4.28 ± 0.53	0.33 ± 0.11
Effect of enclosure		**	n.s.	n.s.
Effect of intercropping		**	***	n.s.
Interaction		n.s.	**	n.s.

Daily activity patterns in dense and open vegetation

During the day, over twice as many species were recorded in the intercropped as in the monocropped areas, but during the night the same number of species was recorded in each habitat (Table 2). Most of the species collected were trapped in higher numbers at night, and were classed as 'nocturnal', although they also occurred during the day. The remaining species were found in higher numbers by day and were classed as 'diurnal'. The 'nocturnal' carabids were found in similar numbers in both habitats during the night, but by day their activity tended to be confined to the intercropped areas. However, the 'diurnal' species were always collected in higher numbers in the monocropped areas, regardless of the time of day (Table 3).

Table 2. Total number of carabid species caught by day and by night in clover-intercropped and monocropped cabbages, 11/7-10/8/95.

	Intercropped	Monocropped	Ratio Inter: Monocropped
Day	11	5	2.2
Night	17	17	1.0

Table 3. Mean (± S.E.M.) number of beetles caught by day and night in clover-intercropped and monocropped cabbages, 11/7-10/8/95.

		Intercropped	Monocropped
'Diurnal' carabids	Day	0.67 ± 0.17	2.11 ± 0.37
	Night	0.22 ± 0.08	1.19 ± 0.20
'Nocturnal' carabids	Day	0.86 ± 0.18	0.19 ± 0.07
	Night	2.28 ± 0.31	2.42 ± 0.12

Effect of contrasting vegetation densities on the behaviour of *Pterostichus melanarius*

The levels of predation in the clover and on bare soil by night were similar. By day predation was significantly lower in both habitats, but proportionally more so on the bare soil (Table 4).

Table 4. Average numbers of prey eaten by *Pterostichus melanarius* in trays half covered with clover and half left bare, during the day and night. Regression analysis: n.s. $P>0.05$; ** $P<0.01$; *** $P<0.001$.

	Clover	Bare	Clover v. Bare	Proportion on bare soil
Night	7.47	6.36	n.s.	0.46
Day	2.92	0.81	**	0.22
Night v. Day	***	***		

Daily activity of predatory arthropods in cereals adjacent to a grass sward

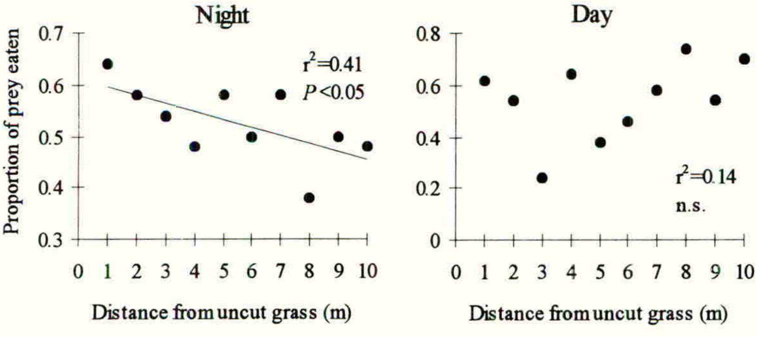

Figure 1. Proportion of artificial prey eaten by night and by day in spring-sown oats at 1m intervals away from the edge of unmown grass, 11-12/6/96

During the night there was a significant negative relationship between the numbers of prey eaten in the oats and the distance from the edge of the unmown grass. By day, although the level of predation was similar to that at night, there was no significant effect of distance.

DISCUSSION

The experiment using exclusion barriers showed that some carabids moved between the dense vegetation of the intercropped plots and the adjacent sparse vegetation of the monocropped plots. The small nocturnal species were less active in the monocropped areas and more active in the intercropped areas when the plots were enclosed than when they were open. As the barriers were erected during the day, this result suggests that enclosure prevented movement from the intercropped areas into the monocropped areas at night. The numbers of large nocturnal carabids caught were reduced overall by the exclusion barriers, but there was no significant effect on their distribution between intercropped and monocropped plots. This suggests that the large beetles foraged over a much larger area than the plots during one week and thus the scale of the experiment was probably too small for these species as daily movements would not occur within just one pair of plots. The diurnal species, though small, showed no effect of enclosure, suggesting that they remained within the same plot by day and night.

The day and night pitfall trapping showed that those carabid species that were most active at night were more or less equally active in the dense and open vegetation at that time, whereas by day, their activity, such as it was, tended to be restricted to the dense vegetation of the intercropped plots. The more diurnal species were more active on the open ground, even when they occurred at night. These results support the findings of the exclusion barrier experiment: that it is the nocturnal carabids which make daily movements from dense vegetation onto the open ground. However, the time-sorted trapping did not actually show that movement occurred. The laboratory experiments with the most abundant of the large, 'nocturnal' species, *P. melanarius*, showed that this species hunted in the clover by day but foraged equally in both the clover and the open ground at night. As this result was obtained from the behaviour of individual beetles, it proved that there was daily movement between dense vegetation and open ground, and that beetles in the open areas did not simply remain in the open by day. The artificial prey transects used a different pair of contrasting vegetation types and confirmed that it is possible to generalise about the effects of dense and open vegetation in agricultural systems. The presence of the unmown grass increased the activity of nocturnal predators (not just carabids) in the adjacent oats. The short distance into the crop over which there was a decrease in predation suggests that this was a result of daily movements into the crop, rather than spring emigration from the grass (e.g. Thomas, 1990). This, coupled with the lack of an effect on diurnal predators supports the conclusions from the previous experiments: that there was movement of predators from dense into open vegetation, but that only nocturnal predators behave in this way.

This study shows that areas of denser vegetation within crops, such as might be provided by clover or grass strips, do not just serve as overwintering sites which enable early crop colonisation (Thomas, 1990, Lys *et al.*, 1994). They also provide a daytime habitat for nocturnal species, which can then move into adjacent, more open parts of the crop by night. The results from the day and night trapping and the laboratory experiment also suggest that these nocturnal species do not just rest in the dense vegetation by day but can be active, demonstrating the plasticity in daily activity patterns that enables normally nocturnal species to be active under conditions of low light intensity and high humidity (Luff, 1978, Kegel, 1990). Such behaviour would enhance their beneficial role even further. Therefore, strip management would retain the benefits of intercropping, in terms of increasing carabid activity, while reducing the problem of yield loss in the main crop through competition with the intercrop.

ACKNOWLEDGEMENTS

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QUANTIFYING THE IMPACT OF POLYPHAGOUS INVERTEBRATE PREDATORS IN CONTROLLING CEREAL PESTS AND IN PREVENTING QUANTITY AND QUALITY REDUCTIONS

J M HOLLAND, S R THOMAS
The Game Conservancy Trust, Fordingbridge, Hampshire, SP6 1EF,UK

ABSTRACT

Exclusion barriers were used to quantify the effect of polyphagous invertebrate predators on cereal aphids and orange wheat blossom midge within the LINK Integrated Farming System Project. Exclusion experiments demonstrated that polyphagous predators can reduce a late aphid infestation by up to 31%. A greater impact was found when the aphid population developed more slowly. However, the polyphagous predators did not reduce the number of tillers infested or prevent the recommended spary threshold being reached. Aphid predation helped to preserve grain protein to a small extent (0.4%) in one field but effects may be larger if aphids infest the crop earlier in the season. Polyphagous predators did not feed on orange wheat blossom midge eggs on the ear but reduced by 22% the number of larvae which were able to return to the soil after leaving the ear. Sowing date was shown to govern the time over which a crop may be susceptible to aphids and midge. Late drilling made the crop more susceptible to a late aphid infestation but reduced by 50% the number of midge per ear because the crop was at a less susceptible stage during oviposition. Consequently the number of midge returning to the soil was lower by 80%.

INTRODUCTION

Studies using predator exclusion experiments have shown that polyphagous predators can contribute to cereal aphid control. Where their numbers were experimentally reduced significant negative correlations were found between predator abundance and aphid density (Sunderland *et al*., 1980; Chambers *et al*., 1983; Chiverton, 1986). In 1993 and 1994 another pest, the orange wheat blossom midge (OWBM), *Sitodoplosis mosellana* Géhin, reached outbreak levels over large areas of UK cereals (Oakley, 1994). Polyphagous predators may contribute to control of this pest by feeding on the larval stages in the soil, on larvae when they pupate and on larvae when they return to the soil (Oakley, *et al*., 1993). Cereal aphids and OWBM may decrease cereal yields and grain quality (Oakley, 1994) but the widespread use of broad-spectrum insecticides used to control midge numbers in cereals during 1994 has also highlighted potentially damaging environmental impacts.

In 1992 the LINK Integrated Farming Systems Project was set up to develop an integrated farming system (IFS) and to compare this with conventional farm practice (CFP) (Ogilvy *et al*., 1994). During the course of studies to evaluate the effect of polyphagous predators on cereal pests within the two farming systems, exclusion barriers were used to reduce experimentally polyphagous predators within fields operating these two farming systems. The subsequent effect on cereal aphids and midge populations and grain quality were determined in both systems and compared to adjacent non-enclosed areas.

MATERIALS AND METHODS

The experiment was conducted in north Hampshire in four 5-ha plots in two separate fields sown with winter wheat which were part of the LINK IFS project based at this site. Within each field one plot was managed using an integrated farming system the other conventionally. Within each of the plots five polyphagous predator reduction areas and five control areas were established, randomising their positions within each plot. The predator reduction areas consisted of an area (8 x 8 m) surrounded by a polythene enclosure (60 cm high, buried 30 cm). These were erected between the tramlines in February 1995 thus creating an area from which polyphagous predators could be excluded whilst existing predators within the areas were trapped out using pitfall traps.

Predator monitoring

Pitfall traps were used to obtain an estimate of predator activity during the aphid infestation period. The total number of Carabidae (transformed log x+1) caught were compared using two-way ANOVA with plot and treatment (exclusion and control areas) as variables. The analysis was repeated for Staphylinidae and Linyphiidae. Suction samples were also taken at monthly intervals from April until July to provide a measure of invertebrate densities. The number of Carabidae, Staphylinidae and Araneae (transformed log x+1) was compared between the plots and between treatments using two-way ANOVA.

Cereal aphid monitoring

The number of cereal aphids on the ear and flag leaf were recorded twice per week for five weeks on 20 marked ears. This period covered the main aphid infestation period. Total mean number of aphids per tiller (transformed log x+1) and percentage of tillers infested transformed (arc sine √%/100) were compared between the plots and treatments using two-way ANOVA.

Orange Wheat Blossom Midge monitoring

To determine the effect of predation on OWBM, the density of pupae in the soil was estimated from soil cores once the enclosed and control areas had been established and immediately prior to harvest. The number of OWBM larvae per ear and number of grains infested per ear was recorded at GS83 on 10 ears in each enclosed and control area within each plot and compared, after log x +1 transformation using two-way ANOVA.

Grain yield and quality

Grain yields from 10 x 0.1 m^2 quadrats was collected in each area. Samples were analysed for hectolitre weight, Hagberg falling number (HFN), and percentage grain protein. The yield and quality factors were compared for the plots and treatments using two-way ANOVA.

RESULTS

Predators

The number of Carabidae captured in the pitfall traps differed significantly between plots (F=28.3, P<0.001, d.f. 3,32) and between areas (F=500, P<0.001, d.f. 1,32). Overall there were 88% fewer Carabidae captured in the enclosed compared to the control areas. The activity of Staphylinidae was more evenly distributed between the plots and only differed significantly (F=24.6, P<0.001, d.f. 1,32) between areas. There were 43% fewer captured in the enclosed compared to the control areas. The predominant taxa in all of the sample dates were the Aleocharinae and *Tachyporus* species, both of which fly readily and would not be excluded by the enclosures. The Araneae differed significantly between plots (F=11.4, P<0.001, d.f. 3,32), areas (F=474, P<0.001, d.f. 1,32) and there was an interaction (F=4.2, P<0.05, d.f. 3,32). Overall there was a 74% reduction of Araneae activity in the enclosed compared to the control areas. The activity was lowest in plots 1 and 4, the two managed using an integrated farming system (IFS).

Very few Carabidae were captured, less than 1 m^2, in the suction samples and their numbers did not differ significantly between the plots or the areas. Staphylinidae density differed significantly between plots (F=37.3, P<0.001, d.f. 3,32) and areas (F=12.6, P<0.001, d.f. 1,32) with 25% less in the enclosed areas. They were more abundant in plots 1 and 4 the IFS plots, but the reduction in the enclosed areas was poor in these plots. The density of Araneae also differed significantly between plots (F=21.2, P<0.001, d.f. 3,32) and areas (F=5.2, P<0.05, d.f. 1,32) with a 21% reduction in the enclosed areas.

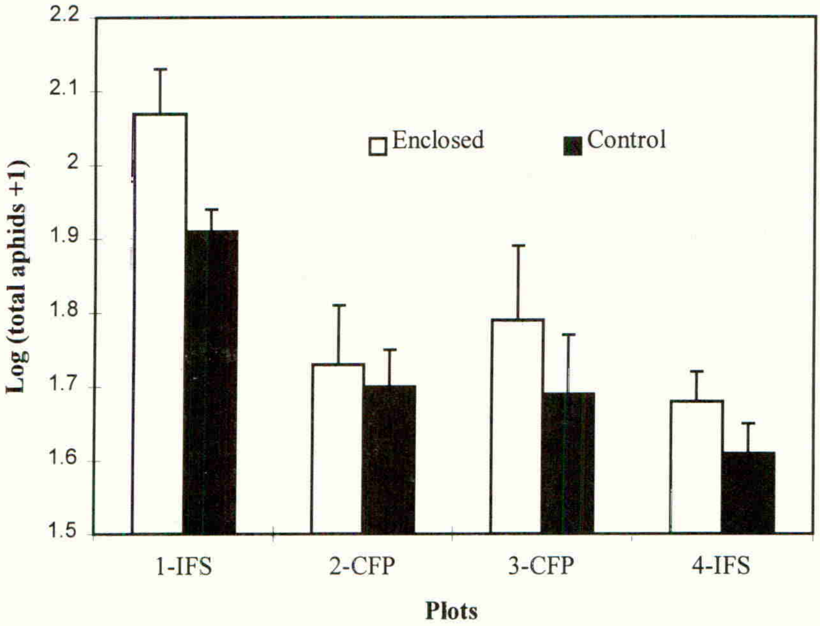
Cereal aphids

The predominant species, Sitobion avenae F. (grain aphid), exceeded ADAS spray thresholds (>66% of ears infested between GS61 and 73) on the 26 June in plots 1 and 2 and on the 28 June in plots 3 and 4 when the crop was at GS71. The time taken to reach the threshold from the start of monitoring was 10 days later in the IFS control areas compared to the CFP control areas in field 1, however in field 2 the peak was reached 4 days earlier in the IFS control areas. The percentage of ears infested continued to increase after they reached the spray threshold and reached 100% in plot 1 and 90% in plots 2, 3 and 4. The total number of aphids on the ear and flag leaves differed significantly between plots (F=11.5, P<0.001, d.f. 3,32) and between treatments (F=4.3, P<0.05, d.f. 1,32). The greatest difference between the control and enclosed areas occurred in plot 1 when the total number of aphids was 31% higher in the enclosed areas (Fig. 1). In the other plots the increases were 8, 21 and 15% for plots 2, 3 and 4 respectively.

Orange Wheat Blossom Midge

The number of OWBM per ear differed significantly (F=8.7, P<0.001, d.f. 3,32) between the plots (Table 1) being most abundant in those plots managed conventionally for both the enclosed and control areas. The same significant between farming systems effect (F=7.0, P<0.001, d.f. 1,32) was also found for the number of grains infested per ear. Number of OWBM pupae in the soil did not differ between the plots or control and enclosed areas in March. In July after the OWBM had fed on the ear and returned to the soil numbers differed significantly (F=33.9, P<0.01, d.f. 1,32) with more in the enclosed (2.23 kg soil^{-1}) compared to the control (1.73 kg soil^{-1}) areas. There were also significantly (F=264.2, P<0.001, d.f. 1,32) more in the plots managed conventionally (3.05 kg soil^{-1}) compared to those managed using the integrated system (0.63 kg soil^{-1}).

Figure 1. Total number of aphids (transformed (log x +1) on marked tillers.



Grain yield and quality

Yield only differed significantly (F=7.1, P<0.001, d.f. 3,32) between the plots (Table 2) and was higher from plots 3 and 4. Grain protein differed significantly (F=11.8, P<0.001, d.f. 3,32) between the plots but not between the enclosed and control areas. Protein was approximately 0.4% lower in the enclosed areas in plots 1 and 2, but was equivalent to or higher in the enclosed compared to the control areas of plots 3 and 4 (Table 2). Protein was higher in grain from the conventionally managed plots, probably because nitrogen inputs were greater in line with the management prescriptions for ocnventional fields. Hagberg falling number was similar in all plots and did not differ between enclosed and control

Table 1. Mean number of OWBM per ear, number of grains infested per ear and density of pupae in the soil for enclosed and control areas within each plot.

Plot	OWBM per ear		Number of grains with OWBM		OWBM pupae per kg soil in March	OWBM pupae per kg soil in July	
	Enclosed	Control	Enclosed	Control		Enclosed	Control
1-IFS	0.68	0.60	0.64	0.80	0.5	0.6	0.9
2-CFP	1.16	0.90	0.18	0.80	1.8	3.5	2.4
3-CFP	1.48	1.52	1.44	1.30	0.2	3.9	2.4
4-IFS	0.64	0.94	0.60	0.78	0	0.9	0.4
SE	0.17	0.19	0.15	0.17			

Table 2. Yield and quality of grain from enclosed and control areas within each plot.

Plot	Grain weight (kg m^{-2})		Protein (%)		Hagberg Falling Number		Hectolitre wt (kg/hl)	
	Enclosed	Control	Enclosed	Control	Enclosed	Control	Enclosed	Control
1-IFS	0.51	0.55	9.96	10.34	354	358	79.0	79.0
2-CFP	0.55	0.55	10.18	10.56	356	345	80.7	80.9
3-CFP	0.71	0.59	10.44	10.44	355	356	84.4	84.9
4-IFS	0.64	0.65	9.86	9.74	360	368	85.0	84.4
SE	0.02	0.04	0.08	0.13	8	6	0.8	0.7

areas. Hectolitre weight was significantly (F=33.7, $P<0.001$, d.f. 3,32) greater in plots 3 and 4 compared to plots 1 and 2. There was no difference between enclosed and control areas.

DISCUSSION

In the first year of this two year study cereal aphids were encouraged by the long, hot dry weather in which temperatures regularly exceeded 30°C and only 34 mm of rain fell between 20 April and 10 July 1995. Conversely ground beetle activity declined during these relatively extreme conditions. With such conditions it was not surprising that aphid predators failed to prevent aphid populations reaching spray thresholds. However, the exclusion technique demonstarted that polyphagous predators had some impact on aphid populations but they were not sufficient to prevent a spray recommendation.

Aphid abundance was most strongly influenced by the date the crop was sown. Plot 1 (IFS) sown on 24 November 1994, had the highest infestation because it was behind the other plots in its development and thereby remained at a more susceptible stage for aphid infestation longer into the summer. The aphid population also increased more slowly in this plot which allowed the predators more time to exert an effect. Where the aphid population developed rapidly (plot 2) there was little difference between the enclosed and control areas.

More midge larvae were found in the grain from the CFP plots, probably because these plots were sown earlier and subsequently the ear was at a more vulnerable stage when the adults were ovipositing. A similar effect was also found in 1994 (Holland *et al.* In press). Polyphagous predators did however, reduce the number of larvae returning to the soil by 23%. Floate *et al.* (1990) also found that Carabidae and Staphylinidae were likely to predate more extensively on larvae when they vacate the ear and seek overwintering sites in the soil than when they emerge from the soil in June. This highlights the importance of only using insecticides when midge thresholds are exceeded and ensuring they are correctly timed so that beneficial insects are preserved.

Despite the differences in aphid abundance grain yield was unaffected. This was because although aphids were first recorded in the crop at GS61, they did not reach the threshold until GS71-73 which is at the end of the period when control is recommended. This, therefore, indicated that no yield benefit would be derived from spraying late aphid infestations even if the populations are increasing rapidly. Late aphid infestations may reduce quality (Oakley *et al.*, 1993).

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RELATIONSHIPS BETWEEN POLYPHAGOUS PREDATOR DENSITY AND OVERWINTERING HABITAT WITHIN ARABLE FIELD MARGINS AND BEETLE BANKS

K L COLLINS, A WILCOX, K CHANEY
Crop and Environmental Research Centre, Harper Adams, Newport, Shropshire TF10 8NB

N D BOATMAN
Allerton Research and Educational Trust, Loddington House, Loddington, Leicestershire LE7 9XE

ABSTRACT

Polyphagous predator populations were assessed between two conventional hedgebanks and a beetle bank, over three years. Different grass species were also studied to indicate which species supports the highest density of predators. In the third year the beetle bank compared favourably in terms of predator density to the hedgebanks. The grass species which sustained the highest predator densities over two years were *Arrhenatherum elatius*, *Phleum pratense* and *Dactylis glomerata*.

INTRODUCTION

Studies have demonstrated that many of the polyphagous arthropod predators which are found in cereal fields play an important role in lowering the numbers of aphid pests on arable crops (e.g. Chiverton, 1986, 1987). Many species of such predators overwinter in field boundary habitats, particularly within strips of perennial vegetation found at the base of hedgerows (Sotherton, 1995), before dispersing into the crop during spring. Farm intensification has led to the removal of hedgerows and even those field boundaries that still exist are often of reduced quality and do not create the ideal habitat for these invertebrates (Sotherton, 1995, Barr *et al.*, 1993).

Thomas *et al.* (1991), suggested replacing these disappearing habitats with experimental linear grassy ridges, situated within the centres of cereal fields, which are now generally referred to as ‘beetle banks’. They also showed that these habitats can support high densities of polyphagous predators.

An experiment reported in this paper compares predator densities in a newly created beetle bank, with adjacent field margins over a three year period. Thomas *et al.* (1991) compared four species of grass (*Dactylis glomerata*, *Holcus lanatus*, *Lolium perenne* and *Agrostis stolonifera*). The first two were found to support high densities of predators, but seed of *H. lanatus* is expensive and difficult to obtain. Therefore, a second experiment was set up to examine a wider range of grass species and mixtures for their suitability in providing favourable overwintering habitat, based on overwintering predator densities.

MATERIALS AND METHODS

1. Comparison of polyphagous predator species composition and density within a beetle bank and two conventional hedgebanks

The study was undertaken in an 18.3 ha arable field with clay soil (Denchworth/Hanslope series), on the Loddington Estate, Leicestershire. There were three experimental areas; the first a 400m long beetle bank (2.5m wide x 0.5m high) that was initially sown with a mixture of the grass species *Dactylis glomerata* and *Holcus lanatus* during autumn 1992; the second and third consisted of 400m hawthorn hedges, one on the western side of the field running parallel to the beetle bank (hedge 1) and the other on the eastern side of the field (hedge 2). Hedge 2 was taller and for most of its length formed the edge of a belt of mature deciduous woodland. Hedge 1 divided the arable field from a pasture with a concrete yard at one end. All three sites were divided into four 100m blocks.

Vegetation assessment

The percentage cover of each species within the ground vegetation layer at each of the three sites was assessed in a non-destructive manner during the summer of 1993, 1994 and 1996. Ten random assessments per block were made using a $0.25m^2$ quadrat

Assessment of polyphagous predator composition

During the mid-winter of 1993/4, three random soil samples per block were collected by taking cores to a depth of approximately 14cm, using a cylindrical borer of 11.5cm in diameter. Each soil core was sealed in a plastic bag and stored at 4°C, to inhibit predation prior to sorting. The cores were left for no longer than a week in cold storage. The samples were rigorously hand sorted, and all invertebrates collected, were stored in 70% ethanol. The same procedure was adopted in 1994/5, but hedge 1 was not sampled. In 1995/6, the sampling programme was extended and ten random soil cores were sampled from each block on the beetle bank and hedge 1 and five from hedge 2.

Analyses

Data relating to predator density were analysed using two-way analysis of variance (ANOVA) with year (1993,1994 & 1995) and habitat type (beetle bank & hedge 2) as the factors for all predators combined and the major individual taxonomic groups. A separate one-way ANOVA was then performed to compare similar predator densities between 1993 and 1995 within hedge.

2. Assessment of overwintering habitat preference for different grass species

This study was performed on two 360m long beetle banks (2m wide) situated in a 8.57 ha field with similar soil type, also on the Loddington Estate. Each bank was divided into twenty 18m long sections, each containing one of nine different grass treatments, sown in spring 1993. The tenth treatment was allowed to naturally regenerate. Five of the grass treatments contained single grass species namely: *Dactylis glomerata*, *Arrhenatherum elatius*, *Festuca rubra*, *Phleum pratense* and *Cynosurus cristatus*, these plus the natural regeneration treatments were all sampled. Both invertebrates and ground cover were sampled using the procedures previously described, taking three random cores and three $0.25m^2$ quadrats per treatment.

Analyses

Data relating to predator density were analysed using two-way analysis of variance (ANOVA) with year (1994 & 1995) and vegetation treatment as the factors for all predators combined and the major taxonomic groups. Individual differences between treatment means were determined by t-tests where appropriate.

RESULTS

1. Comparison of polyphagous predator species composition and density within a beetle bank and two conventional hedgebanks

Vegetation

Within the beetle bank, there was a general increase in the mean percentage cover of *D. glomerata*, dicotyledonous species and areas of bare ground/litter from 1993 to 1996. By 1995 the beetle bank was dominated by *D. glomerata*. *H. lanatus* and several other monocotyledonous species declined over the same period. Both hedgebanks were dominated by *Elymus repens*, in addition to a large proportion of leaf litter.

Polyphagous predator composition

Mean predator density was significantly greater within hedge 2 when compared to the beetle bank over the whole three year period ($F_{1,102} = 16.8$, $p<0.001$), there was also a significant interaction between year and habitat type ($F_{2,102} = 3.48$, $p<0.03$,) (see Fig. 1). Mean predator densities were significantly greater in hedge 2 in 1993 ($t_{22} = 5.33$, $p<0.001$) and 1994 ($t_{22} = 5.49$, $p<0.001$) but in 1995 there was no significant difference between the two habitats ($t_{58} = 1.05$, $p>0.05$). Overall mean predator density within the beetle bank increased between 1993 and 1995, though this was not significant ($t_{58} = 1.05$, $p>0.05$) and remained stable for hedge 2 ($t_{38} = 0.07$, $p>0.05$). Mean predator density declined significantly from 1993 to 1995 within hedge 1 ($F_{1,50} = 4.55$, $p<0.04$) and was comparable with beetle bank densities in 1995 (see Fig. 1).

Carabidae

Carabid density was also significantly greater within hedge 2 over the whole three year period ($F_{1,102} = 5.40$, $p<0.02$) and interaction with year was also significant ($F_{2,102} = 3.77$, $p<0.03$). Carabid density within hedge 2 was significantly higher than the beetle bank in 1994, ($t_{22} = 2.96$, $p<0.01$), but there was no significant difference in 1993 ($t_{22} = 0.98$, $p>0.05$) or 1995 ($t_{58} = 0.49$, $p>0.05$). Overall densities on the beetle bank increased over the three year period and in 1995 actually exceeded those found in hedge 2. Carabid density was greater in 1993 compared to 1995 in hedge 1, though the difference was not significant ($F_{1,50} = 3.45$, $p<0.07$).

Staphylinidae (excluding *Tachyporus hypnorum* and *Tachyporus chrysomelinus*)

Staphylinid density was significantly greater within hedge 2 when compared to the beetle bank over the three years ($F_{1,102} = 29.96$, $p<0.001$). There was a significant interaction between year and habitat ($F_{2,102} = 3.81$, $p<0.03$). Mean staphylinid density was significantly higher in hedge 2 for all years; 1993 ($t_{22} = 3.56$, $p<0.001$), 1994 ($t_{22} = 6.62$, $p<0.001$) and 1995 ($t_{58} = 2.03$, $p<0.05$). A general increase in staphylinid abundance was observed over the three years on the beetle bank, but overall densities were low compared to the other two habitats (see Fig. 1).

Tachyporus spp. (*Tachyporus hypnorum* and *Tachyporus chrysomelinus*)

These *Tachyporus* spp. were separated from other staphylinids because they have been ranked highly as aphid predators by Sunderland and Vickerman (1980).

There was no significant effect of habitat ($F_{1,102} = 0.86$, $p>0.05$) or year and habitat type ($F_{2,102} = 0.58$, $p>0.05$) for the two *Tachyporus* species. There was also no significant change in *Tachyporus* species density between 1993 and 1995 within hedge 1 ($F_{1,50} = 0.42$, $p>0.05$).

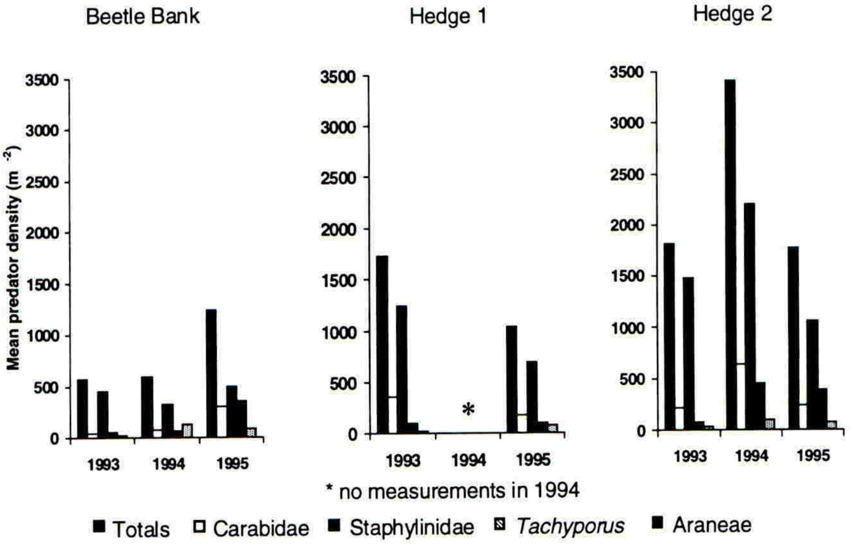
Araneae

There was no difference in Araneae density between hedge 2 and the beetle bank over the whole three year period ($F_{1,102} = 0.10$, $p>0.05$). However, Araneae density was significantly higher in 1994 across both habitats ($F_{2,102} = 3.57$, $p<0.03$). The interaction between habitat type and year was not significant ($F_{2,102} = 0.36$, $p>0.05$).

2. Assessment of overwintering habitat preference for different grass species

The grass species have established well in all plots. *A. elatius* established best in terms of competition from other invading plant species.

Total predator ($F_{5,132} = 2.13$), carabid ($F_{5,132} = 2.13$) and staphylinid ($F_{5,132} = 2.06$) densities were higher in *A. elatius*, *D. glomerata* and *P. pratense* and lowest in *C. cristatus*, though these differences were not significant ($p<0.07$, in each case). Total predator density generally increased between 1994 (972 m^{-2}) and 1995 (1367 m^{-2}) across all treatments though this difference was not significant ($F_{5,132} = 2.06$, $p>0.05$). Mean staphylinid densities were significantly higher ($F_{5,132} = 6.98$, $p<0.01$), in 1995 (606 m^{-2}) than in 1994 (298 m^{-2}), but Araneae densities were greater ($F_{5,132} = 4.19$, $p<0.04$) in 1994 (982 m^{-2}) than in 1995 (616 m^{-2}). There was a significant interaction between treatment and year for carabid density. In 1994, significantly greater ($t_{22} = 2.99$, $p<0.01$) carabid densities were found within *D. glomerata* (452 m^{-2}) compared to 1995 (145 m^{-2}) and in 1995 mean carabid density was significantly higher ($t_{22} = 2.44$, $p<0.05$) within *A. elatius* plots (260 m^{-2}) compared to 1994 (77 m^{-2}). The *Tachyporus* species were significantly higher ($t_{22} = 2.23$, $p<0.05$) in *A. elatius* in 1994 (857 m^{-2}) compared to 1995 (270 m^{-2}).



* no measurements in 1994

Figure 1. Mean densities per m^2 for total polyphagous predators and groups of predators, for hedge 1, hedge 2 and the beetle bank in 1993, 1994 and 1995.

DISCUSSION

The first study has shown that over three years the beetle bank has matured into a suitable site for overwintering polyphagous predators, with total predator density being comparable to that in surrounding hedgebanks, during the third year.

Generally all the predator groups have increased within the beetle bank. This increase follows the development of the tussock structure of *D. glomerata* and *H. lanatus*. As the tussocks mature they become more dense and accumulate greater amounts of dead plant material at their bases, this creates a more stable temperature environment in the winter, which aids overwintering survival (Dennis *et al.*, 1994). By 1995, the beetle bank was dominated by *D. glomerata* and total predator density compared favourably with densities found by Thomas *et al.* (1991) for this grass species.

Sunderland and Vickerman (1980) ranked polyphagous predators according to their potential usefulness as cereal aphid predators. The increase in predator densities within the beetle bank was linked with an increase in those species that are ranked highly as cereal aphids predators. By the winter of 1995, although total predator density was higher in hedge 2, the proportion of highly ranked cereal aphid predators, was higher in the beetle bank. This included such species as *Demetrias atricapillus* and *Agonum dorsale*, which disperse mainly by walking. The beetle bank could enable these predators to reach the middle of the field early in the season and prey on cereal aphids whilst their numbers are still low, thus helping to prevent aphid populations reaching threshold levels (Chiverton, 1987).

Total predator density was highest in hedge 2, throughout the three years. This probably resulted from Staphylinidae making up a large percentage of the total. Staphylinids were the most abundant group within all three habitats and years. The potential usefulness of many species of staphylinids in aphid control is questionable, particularly as a large proportion of the Staphylinidae sampled were from the family Aleocharinae which are not thought to be major aphid predators (Sunderland *et al.*, 1987).

In the second study it was found that *Arrhenatherum elatius*, *Phleum pratense* and *Dactylis glomerata* supported the highest densities of polyphagous predators. Monitoring will continue to determine which of these species provides the most adequate overwintering conditions, in the long term.

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THE IMPACT OF CHEMICAL AND MECHANICAL WEED CONTROL MEASURES ON INVERTEBRATES ON SET-ASIDE FOLLOWING CEREALS

S J MOREBY
The Game Conservancy Trust, Fordingbridge, Hants, SP6 1EF, U K

ABSTRACT

The impact on invertebrates of weed control in rotational set-aside fields by cutting or chemical treatment were studied. Groups of beneficial insects (predators and bird food) were sampled to look for any changes caused by these contrasting management practices. Few significant reductions were found, however most groups declined after treatment. Possible implications on arable wildlife are discussed.

INTRODUCTION

Under current regulations, cereal stubble fields left to naturally regenerate a vegetational cover after harvest as they become areas of rotational set-aside can be managed to control weeds in a number of ways. The vegetation can be cut at any time, sprayed with a non-residual herbicide after mid-April or the field can be ploughed after 1st May. While a derogation can be obtained from MAFF to leave a field unmanaged for wildlife conservation, most farmers were concerned about possible increased weed problems within crops the following year and as a result used one or more of the above methods. In 1994, out of 76 farmers surveyed, 72% sprayed, 16% cut and 12% ploughed their rotational set-aside as a first management option (Thompson,1995).

Cereal fields, particularly the headland area, can be an important source for plant and invertebrate food for many farmland birds (O,Connor & Shrubb,1986; Potts,1986). The value of natural regeneration set-aside following cereals has been studied in some detail. Certain of the important invertebrate food groups such as caterpillars and chrysomelids have been shown to be more numerous within cereals compared to set-aside, while others such as Heteroptera, Auchenorrhyncha and Curculionidae can be as or more numerous in set-aside (Moreby & Aebischer,1992).

With the removal of potential insect rich sites within cereal fields by intensive management practices and the reduction in the cereal acreage, it is important to maximize the beneficial effect of set-side. However, the impact of mechanical control by cutting, the use of herbicides or cultivation, could have detrimental effects on beneficial invertebrates, and as a result have an indirect effect on other farmland wildlife, particularly on young birds requiring insect foods during June and July.

This paper presents initial results of research into the effect of set-aside management on beneficial invertebrate groups as a result of cutting and spray application with glyphosate, the most widely used treatment in 1994.

MATERIALS AND METHODS

The study was carried out on farms around the Hampshire-Wiltshire-Dorset borders. Most farms in this area had several fields in set-aside each year and therefore to simplify the analysis only one field was sampled per farm. This study gives the results from 21 farms, 13 of which treated their fields with glyphosate, five managed by cutting and five had fields which were left unmanaged during the course of the study. Pre-treatment samples were collected over two days in late May and post-treatment samples collected over three days at the end of June. By this date all sprayed fields had been treated for a minimum of 21 days and mechanically managed fields had been cut between 3-28 days prior to the post-treatment samples being collected. Within the field, invertebrate samples were collected from the field boundary (0m), 3m from the edge into the headland and at 50m into the field. The results of only the 3m headland data will be given in this paper.

Five samples each covering an area of 0.5 m^2 were collected per site using a D-vac suction insect sampler (Dietrick,1961). These samples were then frozen, prior to storage in 90% alcohol. Insects were initially sorted and identified to the family or species level, but some were then pooled for analysis.

All data were log(n+1) transformed and differences between treatments were analysed using ANOVA. A paired t-test was used to compare the pre- and post-treatment data within fields and a t-test between pairs of treatment. Due to multiple testing, results were only declared significant at the P=0.01 level.

Beneficial invertebrates were divided into two groups. The first, the aphid predators, contained spiders, parasitic Hymenoptera (Braconidae, Chalcidoidea, Ichneumonidae), Carabidae, aphid-specific predators (Coccinellidae, Neuroptera larvae, Syrphidae larvae, and Cantharidae adults) and highly-ranked polyphagous predators (Sunderland & Vickerman,1980) (*Forficula auricularia, Agonum dorsale, Tachyporus chrysomelinus, T. hypnorum, Bembidion lampros* and *Demetrias atricapillus.* The second group of bird food invertebrates consisted of Auchenorryncha, Heteroptera, caterpillars (Lepidoptera and Tenthredinidae larvae), Chrysomelidae and Curculionidae.

RESULTS

For predatory invertebrates no significant differences were found between pre and post treatment sampling dates within fields. The only significant difference between treatments (P<0.01) occurred for parasitic Hymenoptera between sprayed and uncut fields (Table 1).

The arable bird food groups also showed a similar lack of significant treatment differences (Table 2). Within fields, the pre and post treatment differences were significant in the sprayed fields for the three pooled groups Total 'Other' Heteroptera, Total Heteroptera and Total Bird Foods (P<0.001). No significant differences were found within the cut and un-cut fields. Between treatments, differences were found for *Calocoris norvegicus,* the most numerous heteropteran species and total bird food groups only, both between sprayed and un-cut treatments (P<0.01).

Table 1. Mean densities of predatory invertebrates per 0.5m^2 collected by D-vac.

	Sprayed Fields		**Cut Fields**		**Uncut Fields**		**F-Ratio/T-test**
	Mean Pre/Post ± SE	Paired T-test	Mean Pre/Post ± SE	Paired T-test	Mean Pre/Post ± SE	Paired T-test	All Treatments (Between Treatments)
Spiders	12.77 ± 2.45 6.51 ± 1.01	NS	9.53 ± 2.13 7.60 ± 5.04	NS	19.73 ± 8.39 20.53 ± 10.74	NS	0.91 NS
Parasitica	15.85 ± 3.01 14.61 ± 2.33	NS	23.20 ± 6.10 12.47 ± 2.36	NS	7.80 ± 1.50 67.07 ± 21.41	NS	8.73 ** (sp/uc 3.31 **)
Carabidae	0.67 ± 0.20 0.13 ± 0.06	NS	0.07 ± 0.07 0.00	NS	1.07 ± 0.39 0.13 ± 0.13	NS	1.93 NS
Aphid specific predators	0.13 ± 0.07 0.33 ± 0.11	NS	0.33 ± 0.26 1.33 ± 1.17	NS	0.00 1.07 ± 0.50	NS	1.61 NS
Highly-ranked polyphagous predators	0.57 ± 0.16 0.77 ± 0.06	NS	0.13 ± 0.08 0.13 ± 0.08	NS	0.80 ± 0.50 0.13 ± 0.13	NS	1.24 NS

sp = sprayed uc = uncut cu = cut ** = P< 0.01 *** = P< 0.001

Table 2. Mean densities of arable bird food groups per $0.5m^2$ collected by D-vac.

	Sprayed Fields Mean Pre/Post ± SE	Paired T-Test	**Cut Fields** Mean Pre/Post ± SE	Paired T-Test	**Uncut Fields** Mean Pre/Post ± SE	Paired T-Test	**F-Ratio/T-test** All Treatments/ (Between Treatments)
Auchenorryncha	7.36 ± 1.86 5.56 ± 2.14	NS	15.07 ± 6.86 3.60 ± 6.71	NS	5.40 ± 2.72 10.87 ± 3.77	NS	2.40 NS
Calocoris norvegicus	0.05 ± 0.05 0.03 ± 0.03	NS	0.47 ± 0.39 0.13 ± 0.13	NS	0.13 ± 0.08 1.06 ± 0.52	NS	7.80 ** (sp/uc 3.74 **)
Predatory Heteroptera	0.10 ± 0.06 0.41 ± 0.13	NS	0.20 ± 0.13 0.20 ± 0.13	NS	0.27 ± 0.19 1.53 ± 0.81	NS	1.24 NS
Stenedomini	1.41 ± 0.80 0.05 ± 0.05	NS	0.33 ± 0.15 0.13 ± 0.08	NS	3.40 ± 2.68 2.60 ± 1.20	NS	1.31 NS
Total Other Heteroptera	7.33 ± 2.08 0.41 ± 0.14	***	2.40 ± 0.95 7.34 ± 6.17	NS	3.87 ± 0.90 1.07 ± 0.25	NS	3.64 NS
Total Heteroptera	8.72 ± 2.40 0.90 ± 0.23	***	3.40 ± 1.15 7.80 ± 6.13	NS	7.67 ± 2.31 6.27 ± 1.97	NS	4.72 NS
Caterpillars	0.21 ± 0.08 0.03 ± 0.03	NS	0.07 ± 0.07 0.00	NS	0.00 0.13 ± 0.13	NS	2.03 NS
Chrysomelidae	0.46 ± 0.16 0.67 ± 0.03	NS	0.13 ± 0.08 0.07 ± 0.07	NS	0.60 ± 0.16 0.13 ± 0.08	NS	0.86 NS
Curculionidae	0.64 ± 0.33 0.33 ± 0.06 NS	NS	0.20 ± 0.13 0.13 ± 0.13 NS	NS	0.13 ± 0.08 0.00 NS	NS	1.24 NS
Total bird food insects	17.90 ± 3.28 6.77 ± 2.25	***	18.93 ± 6.62 21.67 ± 13.08	NS	14.20 ± 4.80 37.60 ± 19.98	NS	5.80** (sp/uc 3.00 **)

sp = sprayed uc = uncut cu = cut ** = $P< 0.01$ *** = $P< 0.001$

DISCUSSION

Most of the significant within field and between treatment differences were found on sprayed plots. By 21 days after spraying the chemical treatment had had time to turn the vegetation brown, where as at similar time intervals (up to 28 days), cut set-aside would have had considerable time to re-grow. This re-growth could provide habitats for increasingly mobile stages of some phytophagous insects and hence mask the immediate effects of the treatment.

The effect of management on the bird food invertebrates (Table 2) showed a general decrease in numbers after treatment compared to an increase in the untreated fields. While a number of groups such as the Chrysomelidae, which occur in low densities have been found to be more numerous in cereals compared to set-aside, the two numerically most important groups, Auchenorryncha and Heteroptera, can be more numerous on set-side (Moreby & Aebischer, 1992; Moreby & Sotherton, 1995). These two groups were also the dominant food groups in this study. The post-treatment reductions of these important groups and particularly of the Auchenorrhyncha, could result in many rotational fields being deficient in suitable food items at a time when they are most important for chicks and nestlings.

In conclusion the detrimental impact of management practices to control weed problems can reduce densities of many beneficial invertebrates in rotational natural regeneration set-side. However, management by spraying compared to cutting will be non-destructive to the vegetation structure and so safe-guard any mammals or birds nesting in the field compared to cutting or cultivation (Poulsen & Sotherton,1992). This study shows that invertebrates will decline as the vegetation dies, but not as quickly or as completely as may have been thought, and this window could allow ground nesting birds time to take their chicks to more favorable feeding areas.

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THE EFFECT OF SOME CROP ROTATIONS ON DECREASE OF CLUBROOT, *PLASMODIUM BRASSICAE*, IN SOILS

J ROBAK
Research Institute of Vegetable Crops, Skierniewice, Poland

ABSTRACT

The effect of various crops on inactivation of resting spores of *Plasmodiophora brassicae* has been investigated in microplots and field-trial. The decrease of disease incidence was observed when tomato, cucumber, leek, buckwheat and bean were grown, as well as when the plots were fallowed. Evidence of fungal decrease was found by cultivation twice on this same for a short period (3-5 weeks) plots a preceding "catch crops" according to the Bochow and Stearcke (1984) method. This experiments indicates a marked decrease of fungal quantity in the heavily infested field soil.

INTRODUCTION

Clubroot, caused by the fungus *Plasmodiophora brassicae* Woronin, is a most serious disease of the cruciferous in all producing regions in Poland. The efficacy of control measures that have been recomended until now is rather low and new methods are being sought to meet the requirements of higher efficiency as well as ecology. The main source of infestation are infested transplants and lack of proper crop rotation. However the rotation is not easy because the fungus infects over 200 plant species. *Plasmodiophora brassicae* was found as being endemic to muck soils of Poland (Robak, 1990 a). In this case, the effect of various plants on survival of resting spores in soil was examined following suggestions of Buczacki (1980), Bochow & Staercke (1984), Ikegami (1985) & Yamagishi (1986).

MATERIALS AND METHODS

The experiments started in 1988 in microplots located on Experimental Field at Institute of Vegetable Crops in Skierniewice.

Each plots 1 m^2, field with sandy loam soil. The plots were evenly infested with *Plasmodiophora brassicae* spores (pathotype ECD 17/312/31) before the trial to obtain final concentration of 3×10^6/cm^3 of soil.

In the second experiments similar microplots 1 m^2 were filled with six types of soil: sandy loam, czernozem, alluvial, loess, rendzina and muck soil.

Initial spore density was estimated as above. In this experiment plants listed in tables 1 and 2 were grown for the whole vegetative period, and fallow soil served as a check.

The density of *Plasmodiophora brassicae* was assayed by biotest using uniformly susceptible Chinese cabbage cv. "Granaat" as the test plants.

Samples of 2 dcm^3 of soil from each plot were collected after crop harvest during the autumn time.

Steamed low peat and muck soil were added at the rate 1:3 to increase of conductivity of tested soil samples (Robak & Williams, 1989). The plastic pots (22 x 16 x 6 cm size) were fielled with this mixture. Seeds of the test plants were directly sown into test soil, and pots were placed in the greenhouse with air temperature of 22-24^{0}C days and 20-21^{0}C nights. Days and nightlight was supplemented with light presure sodium lamps to provide 24 h light period.

Constant soil humidity was provided through capillary watering of the wick to a water tank extending to the reservoir of the growing system. The method is designed for a space efficient (600 plants/m^2) and reliable screening after 7 days for root hair infection and after 35 days for clubs formation on roots.

Disease symptoms were scored using Williams (1987) scale, where:

- 0 — no symptoms
- 1 — small nodular galls
- 3 — larger nodular or spherical galls
- 5-7 — increasingly large fusiform galls on lateral and main roots
- 9 — large galls extending into hypocotyl.

The disease index (DI) was caulated according to the formula:

$$DI = \frac{\sum_{i=0}^{9} (i \times j)}{n}$$

where: n — total number of plants scored
i — number of clubrot symptoms class
j — number of plants in i class.

RESULTS

Results obtained with twenty two preceding crops for the decreasing density of *Plasmodiophora brassicae* spores in heavily infested soil are shown in tables 1-2.

Table 1. Decrease of clubroot fungus by cultivation of different preciding crops on heavily infested soil during 1989-1992.

Preciding crops	Disease index of test plants in soil samples after their cultivation (rate 0-9^0)			
	1989	1990	1991	1992
	Disease index	Disease index	Disease index	Disease index
1. Check - infested soil	9 d	9 d	8.8 d	8.7 c
2. Fallow soil	0.5 a	1 ab	6.8 c	2.1 a
3. Oats	4.4 bc	2.8 ab	-	-
4. Wheat	2.8 b	2.2 ab	4.8 b	-
5. Buckwheat	1.1 ab	2.7 ab	2.8 ab	2.6 ab
6. Been	1.5 ab	2.3 ab	6.3 a	-
7. Corn	5.9 bc	-	-	-
8. Vetch + Oats	1.2 ab	6.8 cd	-	-
9. Perennial ryegrass	2 b	-	-	-
10. Red clover	5.4 bc	5.8 c	-	-
11. Tomato	-	0.5 a	2.7 ab	2.2 a
12. Cucumber	-	1.2 ab	1.2 a	1.8 a
13. Carrot	-	-	7.3 c	5.3 b
14. Onion	-	-	-	5.6 b
15. Radish "catch crop"	-	3.5 b	2.6 ab	2.2 a
16. White mustard "catch crop"	-	-	-	2 a
17. Lettuce	-	-	-	2.8 ab
18. Savory	5.5 bc	6.1 c	-	-

Means within a column followed by the same letter do not differ significantly ($P < 0.05$).

Table 2. Decrease of clubroot fungus by cultivation of different preciding crops on heavily infested soil during 1993-1995.

Preciding crops	Disease index of test plants (rate 0-9^0)		
	1993	1994	1995
1. Check - infested soil	8.9 c	9.0 f	9.0 d
2. Fallow soil	2.0 a	2.6 b	5.4 bc
3. Buckwheat	5.2 b	5.6 de	-
4. Chicory	7.2 d	-	-
5. Lettuce	4.6 ab	-	-
6. Bean	6.9 c	5.7 de	-
7. White mustard "catch crop"	4.4 a	1.2 a	3.9 b
8. Japanise radish "catch crop"	-	-	7.9
9. Tomato	7.2 d	4.7 d	4.7 b
10. Cucumber	4.6 ab	3.0 c	5.2 bc
11. Onion	6.2 c	-	8.8 de
12. Garlic	-	1.8 ab	9.0 e
13. Celerac	-	-	6.5 c
14. Leek	-	-	3.1 c
15. Potato	-	3.9 cd	8.9 d
16. Check - soil applied MTF-651 4 kg/ha	-	-	1.6 a

Means within a column followed by the same letter do not differ significantly ($P < 0.05$).

Although the whole year continuosly cultivated crops as: tomato, cucumber, leek, buckwheat, been and fallow soil markedly decreased clubroot symptoms of susceptible host plants (chinense cabbage cv. Granaat) used in biotest for assaying soil samples of each crop in greenhouse study.
Also evidence of fungal decrease was found by cultivation for the short pereiod (3-5 weeks) twice, on this same plots, a preciding "catch crop" white mustard to follow the Bochow & Staercke (1984) method. No evidence of fungal decrease was found by cultivation of several other preceding crops listed in table 4. Result obtained from trials on different types of soil are shown in table 3.

Table 3. Decrease of clubroot fungus by cultivation of different preciding crops on different type infested soil.

Preciding crops	Disease index of test plant (rate 0-9^0)					
	Type of soils					
	Sandy loam	Czernozem	Alluvial	Loess	Rendzina	Muck soil
1. Check-infested soil	9 e	9 e	9 e	9 e	9 e	9 e
2. Garlic	9 e	8 e	9 e	3 c	3.3c	6.8d
3. Buckwheat	9 e	9 e	9 e	9 e	1.5b	5.9cd
4. White mustard "catch crop"	1.8b	0 a	0 a	0.1ab	0.3ab	1 b
5. Fallow soil	1.7b	1.5b	9 e	5.2cd	0 a	0.4ab

Means within a column followed by the same letter do not differ significantly ($P < 0.05$)

Table 4. The list of experimental preciding crops following the rate of suitability for decreasing of clubroot *(Plasmodiophora brassicae)* in soils. Examined during 1988-1995.

Preciding crops	The influence of different crops on elimination of *P. brassicae* resting spore (score in rate 0-5^0)
	The most suitable species
1. Fallow soil	5
2. Tomato	5
3. Cucumber	5
4. White mustard "catch crop"	5
5. Leek	5
The moderate species	
6. Buckwheat	4
7. Garlic	3
8. Bean	3
9. Oats	3
10. Wheat	3
11. Peppermint	3
The week species	
12. Vetch + Oats	2
13. Corn (Sweet)	1
14. Japanese radish	1
15. Radish	1
16. Celerac	1
17. Lettuce	1
The species with no evidence influence	
18. Potato	0
19. Carrot	0
20. Onion	0
21. Perennial ryegrass	0
22. Savory	0
23. Red clover	0
24. Chicory	0

The variant with white mustard cultivated for the short period, twice on this same plots as a "catch crops" showed evidence of the decrease in the amount of clubroot symptoms examined potted soil samples in greenhouse study. The best effect was found on alluvial and czarnozem, but on loess soil and rendzina only slight effect of decrease was observed.

The whole year continuosly cultivated buckwheat and garlic markedly decreased clubroot only on rendzina soil and loess.

Whole year fallow soil markedly decreased clubroot symptoms only on muck soil, sandy loam and czernozem.

DISCUSSION

Only six variant with preceding crops out of 22 examined through the seven year of study were effective for decreasing density of *Plasmodiophora brassicae* in heavy infested soil in Poland. The rate of decrease of clubroot symptoms on different preceding crops differed in the consecutive year of study. It propably depends from numerous factors such as physical and chemical soil properties, an important role my also play soil temperature and humidity as well as natural soil suppresivness – a new factor that has not yet been defined in detail (Hsiew, Yang 1985). This factors could also explain the surprising results in this experiments and also another results obtained by Rod (1988).

The variant with white mustard as a "catch crop" a highly susceptible crop showed evidence of the decrease of clubroot symptoms in examined soil samples. The method published by Bochow & Staercke (1984) claim that young plant roots of *P. brassicae* host induce resting pathogen spores to germinate, and their developmental cycle is then interrupted by the early termination of plant growth. But accidentaly extending of cultivation such susceptible "catch crop" might result in multiplication of the spores in the soil. For this reason Yamagashi (1985) and Ikegami (1985) recomend to use as a "catch crop" resistant cruciferous crops such as: Japanise radish or some cultivars of turnip, swede, radish or resistance rapes.

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WESTERN CORN ROOTWORMS AND CROP ROTATION: HAVE WE SELECTED A NEW STRAIN?

M E Gray, E Levine, K L Steffey

Department of Crop Sciences, University of Illinois, Center for Economic Entomology, Illinois Natural History Survey, 172 Natural Resources Building, 607 East Peabody Drive, Champaign, Illinois 61820, USA

ABSTRACT

The rotation of maize and soybean in much of the maize production areas of the United States and Canada has been the principal management strategy advocated for the control of the western corn rootworm (*Diabrotica virgifera virgifera* LeConte). Because of the general acceptance of this management approach, soil insecticide use on maize acres has decreased by 50% in Illinois since the late 1970s. In 1995, producers throughout east-central Illinois and northwestern Indiana suffered severe western corn rootworm larval injury in maize that had been rotated routinely on an annual basis with soybean, in some instances for decades. Investigations in 1994 and 1995 indicated clearly that western corn rootworm adults were laying at least some of their eggs in soybean fields in east-central Illinois and northwestern Indiana. The potential economic and environmental consequences of this behavioral shift are enormous. Our hypothesis suggests that growers may have selected inadvertently for a new strain of western corn rootworm because of the routine practice of rotating maize with soybean.

INTRODUCTION

Western and northern corn rootworms, (*Diabrotica virgifera virgifera* LeConte) and (*Diabrotica barberi* Smith & Lawrence), respectively, are destructive root-feeding insects of maize (*Zea mays*) throughout much of the United States and Canada. Adults of both species occasionally interfere with the pollination process because of their propensity to feed on fresh silks emerging from ear tips. The biology and management of these species have been reviewed extensively (Levine & Oloumi-Sadeghi, 1991).

The rotation of maize with soybean (*Glycine max*) or another crop has been and continues to be the most effective method of preventing economic losses caused by western and northern corn rootworms. The value of this rotational practice has been recognized for some time; maize produced in a 2-year rotation with soybean yields 5 to 20% more than non-rotated maize (Bullock, 1992). The greater use of soil insecticide and fertilizer in non-rotated maize may not compensate for the yield advantages of growing maize in rotation with soybean. The definitive explanation for the yield benefits of crop rotation is not lucid; enhancement of soil physical properties and organic matter may play a role.

Although the rotation of maize and soybean has been an effective management strategy for western and northern corn rootworms, injury to the root systems of maize planted after soybean has been documented. To date, the two primary explanations for rootworm larval injury in rotated maize are: 1) oviposition by corn rootworm beetles in fields other than maize, or 2) prolonged diapause of some northern corn rootworm eggs. The fact that northern corn rootworm eggs can exhibit prolonged diapause has been known for many years (Chiang, 1965); however, prolonged diapause in a small percentage of western corn rootworm eggs was proved conclusively only recently (Levine *et al.*, 1992). Reports of injury to roots in rotated maize were somewhat common throughout the Midwest during the 1980s and always attributed to prolonged diapause of the northern corn rootworm. Steffey *et al.* (1992) reported that economic corn rootworm injury in rotated maize occurred in only 1.7% of Illinois fields. These findings were reported widely and contributed to a steady decline in soil insecticide use in rotated maize.

Many farmers who grow maize do not practice crop rotation because of economic factors like the need for a high volume of grain required by most livestock producers. The use of soil insecticides on many of these farms is significant. In Illinois, 1,133,144 ha of non-rotated maize were grown in 1990, and 88% of these hectares were treated with a soil insecticide at planting (Pike & Gray, 1992). However, research conducted in 1990 and 1991 on the farms of 29 Illinois producers revealed that only 45% of non-rotated maize fields had economic root injury (Gray *et al.*, 1993). Data from these Illinois studies suggested that farmers were using more soil insecticides than necessary for corn rootworm control on non-rotated maize hectares. Soil insecticide use on maize rotated with soybean has declined significantly since the late 1970s; by the early 1990s, Pike & Gray (1992) estimated that growers were treating approximately 13% of these hectares (375,556 ha) each spring. If corn rootworms adapt to a rotation of maize and soybean, soil insecticide use will increase substantially. The potential economic and environmental consequences are sobering. Preliminary evidence suggests that an adaptation to crop rotation by the western corn rootworm has occurred in some counties of east-central Illinois and northwestern Indiana.

GENESIS OF THE PROBLEM

In June of 1987, severe corn rootworm larval injury was reported in rotated maize fields in Ford County in east-central Illinois. The injury was confined to six seed production fields located within a 1.6 square km area. Since 1987, we have attempted to explain the cause of this injury. We have verified that the root injury was caused by the western corn rootworm. This was unexpected because the northern corn rootworm, to date, has been the species implicated in injury to rotated maize. Our initial hypothesis to explain the root injury in seed production fields focused upon the frequent use of pyrethroid insecticides for corn earworm (*Helicoverpa zea* Boddie) control during the first two weeks of August. This treatment time coincides with the onset of egg laying by rootworm beetles. In several laboratory investigations, we showed that western corn rootworm beetles were repelled from treated corn and subsequently laid eggs in untreated soybean. Although we were relying upon laboratory evidence, we attempted to attribute the root injury in rotated maize seed production fields to this repellency phenomenon.

In 1993, we began to receive a few more reports of corn rootworm larval injury in rotated maize. All reports emanated from east-central Illinois, and, unlike 1987, commercial as well as seed-production fields were involved. Also, several of the affected commercial fields were not associated with a history of pyrethroid use in adjacent fields the previous season. Collections of beetles in soybean and maize fields revealed that the western corn rootworm was the predominant species. Eggs were obtained from the collected beetles and subjected to natural soil temperature conditions in our laboratory. Eighty-three percent of the western corn rootworm eggs hatched in June 1994 after a single winter. Eleven percent of the eggs were subjected to temperatures simulating another winter. By the summer of 1995, 75% of these eggs had died and 25% remained unhatched. These observations led us to believe that prolonged diapause of western corn rootworm eggs probably was the explanation for the root injury in rotated maize observed in 1993.

In 1994, reports of corn rootworm larval injury occurred again throughout a larger area of east-central Illinois. Pyrethroid use near these fields had been minimal in 1993. In order to check for the prolonged diapause trait, eggs were obtained from western corn rootworms reared from larvae collected from rotated maize fields that had severe root injury. In the laboratory, the eggs were subjected to temperatures they would encounter in the field. By September of 1995, most of the eggs had either hatched or died, suggesting again that prolonged diapause was not a primary factor in explaining western corn rootworm larval injury in rotated maize fields in east-central Illinois.

June and July of 1995 brought about an unprecedented number of reports of corn rootworm larval injury in rotated maize across east-central Illinois and northwestern Indiana. Root injury was severe in many of the affected fields and yield losses were catastrophic for many producers. Corn rootworm larval injury was evaluated between 17-19 July 1995 in 16 rotated maize fields that belonged to growers who suspected that serious rootworm damage had occurred. Ten roots from each of 16 fields in a five-county area were rated for injury using the Iowa State University 1- to-6 scale (Hills & Peters, 1971). Average root ratings for several of the fields were near or above a root rating of 4.0 (one node of roots destroyed), suggesting that economic loss was possible (Table 1). Corn plants with root ratings of 4.0 or greater often are susceptible to physiological and harvesting losses.

Large densities of western corn rootworm beetles in 1995 also were responsible for silk feeding in many of the maize fields and interfered greatly with the pollination process. In addition, delayed planting, a late egg hatch (mid-June), and very prolonged hot and dry conditions in July worsened the impact of larval injury to the root systems. Producers throughout east-central Illinois who had always relied upon crop rotation as an effective strategy to manage corn rootworms were seeking solutions for this perplexing problem by the end of the 1995 growing season. The only viable explanation forwarded by entomologists was that western corn rootworm adults seemed to be laying their eggs in soybean and in maize in east-central Illinois and northwestern Indiana. The more fundamental question, why was this occurring remains unanswered.

Table 1. Results of rotated maize survey of rootworm injury in east-central Illinois, July 17 - 19, 1995.

County	Location	Root Rating[a]
Champaign	Dewey, Field 1	4.50
Champaign	Dewey, Field 2	3.85
Champaign	Dewey, Field 3	3.40
Champaign	Gifford	3.85
Iroquois	Loda	4.55
Iroquois	Wellington, Field 1	3.80
Iroquois	Wellington, Field 2	3.50
Kankakee	Grant Park	3.95
Livingston	Dwight	3.05
Livingston	Emmington	2.90
Livingston	Forrest	3.30
Livingston	Pontiac	4.20
Livingston	Saunemin, Field 1	2.70
Livingston	Saunemin, Field 2	4.90
Livingston	Saunemin, Field 3	3.45
Vermilion	Rossville	3.60
Average	---------	3.72

[a] The root rating system used was the Iowa State University root-rating scale: 1 - no visible damage or only a few minor feeding scars; 2 - some roots with feeding scars but none eaten off to within 1.5 inches of the plant; 3 - several roots eaten off to within 1.5 inches of the plant but never the equivalent of an entire node of roots destroyed; 4 - one node of roots destroyed or the equivalent; 5 - two nodes of roots destroyed or the equivalent; and 6 - three or more nodes of roots destroyed (Hills & Peters, 1971).

SEEKING EXPLANATIONS

In an effort to understand why western corn rootworm beetles were presumably laying eggs in certain soybean fields, we designed a questionnaire that was sent to growers who reported that they had corn rootworm larval injury in rotated maize. The questionnaire also was included in the July 14, 1995 issue (no. 17) of the University of Illinois sponsored *Pest Management & Crop Development Bulletin*. Seventy-five questionnaires were returned. In summary, the majority of the rotated maize fields with rootworm larval injury in 1995 did not have infestations of volunteer corn or grassy weeds in their soybean fields in 1994, which could have attracted egg-laying beetles. Also, injury did not seem to be related to any particular tillage system, amount corn stalk residue, row width, soybean maturity group, soybean planting date, or seed corn production activity and pyrethroid use.

As we did in 1994, we sampled soybean fields in east-central Illinois from late July to early September 1995 for corn rootworm adults. The predominant species found was the western corn rootworm. More than 70% of the western corn rootworm beetles collected were females. Sweep net samples ranged from 0 to 143 western corn rootworm beetles per 100 sweeps in the seven fields we surveyed from late July to early September. Densities of the beetles generally peaked early in August and were much lower by the end of the month. Dissections of beetles collected on July 25 and August 2, 1995 revealed that the females were ready to begin laying eggs. During this same time period, soybean fields in southwestern Illinois were sampled for western corn rootworm adults. Interestingly, no western corn rootworm beetles were found. Crop consultants and extension advisers in other areas of the state (outside of east-central Illinois) confirmed that very few, if any, western corn rootworm adults were being found in soybean fields during the 1995 growing season. However, western corn rootworms were being found routinely in soybean fields in approximately an eight-county area of Illinois where the agricultural landscape has been dominated for decades by a routine and annual rotation of maize and soybean.

Why were western corn rootworm adults found commonly in soybean fields in east-central Illinois in 1995? In an attempt to answer this question, food choice tests were conducted in the laboratory to determine if western corn rootworm beetles would feed on soybean foliage. Gravid female beetles were collected from a soybean field in east-central Illinois and compared with gravid female beetles collected from a cornfield near Mead, Nebraska. Beetles from Mead, Nebraska were used because of the heavy concentration of continuous corn in that area of the Corn Belt. We believed that differences in feeding behavior would be evident if we were dealing with a new strain of western corn rootworms. Both populations of beetles in the feeding preference study readily devoured corn leaves before feeding on soybean foliage. If beetles from both geographic locations were starved for 24 hours and then given no choice of host plant, they would consume soybean leaves. Both populations of western corn rootworm beetles readily consumed soybean blossoms.

Western corn rootworm beetles from both states also were released into separate large greenhouse cages. Full-grown potted maize and soybean plants were placed in opposite ends of each cage. Plants were replaced after six days and the study was replicated five times. Overall, the female beetles from Illinois laid 51.6% of their eggs in the soybean pots compared with 28.6% for the Nebraska population. Soil samples taken in October 1995 from three east-central Illinois soybean fields that were adjacent to injured maize revealed that significant western corn rootworm oviposition had taken place (10 to 18 viable eggs in twelve 0.5 liter soil samples). No viable eggs were present in soil samples taken in July 1995 from soybean fields. This confirms our belief that the rootworm larval injury in rotated maize is caused by oviposition in soybean

Our current hypothesis is that the routine crop rotation of maize and soybean in east-central Illinois and northwestern Indiana has selected for a strain of western corn rootworm that oviposits in soybean fields. If this hypothesis is correct, maize production throughout the Corn Belt could be affected in a dramatic fashion. Impressive dispersal of this species has occurred rather recently. Western corn rootworms were of little concern to maize production in the United States before the 1950s because this species occupied a small area in the west-central United States. As producers began to irrigate large areas of non-rotated maize in the western Corn Belt, western corn rootworm beetles moved eastward. As the eastward migration progressed, larvae were exposed to chlorinated hydrocarbon insecticides that had been used to treat irrigated soils. Western corn rootworms developed resistance quickly to commonly used insecticides like aldrin and heptachlor. The resistant strain dispersed from southeastern Nebraska in 1961, and by 1973, resistance for this species was confirmed throughout much of the Midwest (Gray & Luckmann, 1994). Because western corn rootworms can disperse rapidly, maize growers in neighboring states are watching the current situation with apprehension.

Research was conducted on the farms of more than 20 producers in east-central Illinois during the summer of 1996. Rotated maize on these farms was evaluated for larval injury and adjacent soybean fields were monitored for western corn rootworm adults. This research is an attempt to develop economic thresholds for western corn rootworm beetles. Fourteen producers left four untreated check strips (no soil insecticide used) in their rotated maize. Many of the fields were 0.4 to 0.8 km in length; the most common treatment width was six rows. Fifteen roots were dug throughout the length of each untreated strip, as well as in four treated strips (120 roots per field). All roots were washed and evaluated for root injury using the Iowa State root rating scale (Hills & Peters, 1971).

Only two of the fields had average root injury above a rating of 3.0 (some pruning noticed, but never an entire node of roots destroyed) in the untreated check strips. Eight of the fields had minor to moderate injury, with a range of mean root ratings in the check strips of 2.07 to 2.93. Four fields had very little root injury and root ratings in the check strips averaged 1.48 to 1.97. Despite the widespread severity of injury in rotated maize during 1995, rootworm injury in our cooperators' fields during 1996 was not as intense. However, even in non-rotated maize, only 40 to 50% of fields have economic infestations of corn rootworm larvae (Gray *et al.*, 1993). This underscores the importance of following recommended management strategies for this challenging insect pest, such as scouting for beetles and using economic thresholds.

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CULTURAL CONTROL OF WHEAT BULB FLY IN ROTATIONAL SET-ASIDE

J E B YOUNG and G A TALBOT
ADAS Boxworth, Boxworth, Cambridgeshire, CB3 8NN, UK

ABSTRACT

The effect of soil cultivation and ground cover of rotational set-aside land on the oviposition of wheat bulb fly (*Delia coarctata*) was studied on mineral and organic soils in Cambridgeshire. Fewer eggs were laid on fallow soil cultivated to produce a smooth tilth before the July/August oviposition period than on soil that remained in a rough, ploughed condition. Soil-disturbing, secondary cultivations during the oviposition period increased the number of eggs laid. Ground cover provided by white mustard sown in May, or naturally regenerated and mown wheat stubble, eliminated or severely reduced the number of eggs laid compared with the fallow treatments. There was inconclusive evidence that the burial of eggs by autumn ploughing may reduce larval invasion of the crop. The yields of the wheat crops sown after the set-aside were unaffected by wheat bulb fly attack, largely as a result of early sowing in the autumn. Cultural control strategies to reduce damage by the pest and to minimise associated insecticide use are discussed.

INTRODUCTION

Oviposition by wheat bulb fly (*Delia coarctata*) takes place during July and August on the bare soil found in fallows or freshly cultivated fields, or on soil hidden beneath the canopy of root crops (Gratwick, 1992). The eggs hatch in January or February and the neonate larvae die unless the field has been sown with a host crop. Wheat, rye and barley crops are attacked, economic damage usually being restricted to the eastern counties of Britain (Gough, 1957). The stem-boring larvae cause the appearance of a withered and yellow central leaf or 'deadheart' of the affected shoot.

Winter wheat has proved to be a popular choice of crop to grow after rotational set-aside. In many cases the wheat is potentially at high risk of attack by wheat bulb fly because management of the preceding set-aside frequently creates summer fallows by implementing early cultivations before or during oviposition. Such cultivations enable the grower to control grass weeds and provide an early autumn entry for wheat. This study is investigating the effects of set-aside management and soil cultivations on wheat bulb fly oviposition. The objective is to define the best cultural control strategies to limit or eliminate the risk of wheat bulb fly oviposition in rotational set-aside that will be sown with winter wheat. This paper summarises the results obtained in the 1994/95 cropping year, the second year of a three year study.

MATERIALS AND METHODS

The experiment commenced in spring 1994 at two sites in Cambridgeshire: a commercial farm at Ramsey (mineral soil), and ADAS Arthur Rickwood (organic soil). The experiment at each site is of a large plot (12 m × 24 m) randomised block design with four replicates of seven treatments. Each plot is surrounded by a buffer area each 12 m wide (minimum) of mown cereal re-growth to isolate the plots and allow access by farm machinery. Seven treatments were applied to create varying conditions of soil tilth or exposure during oviposition:

1. *Rough, undisturbed tilth*: ploughed May/June; power-harrowed September/October.
2. *Smooth, undisturbed tilth*: ploughed and power-harrowed (& rolled at Rickwood) in May/June.
3. *Rough, disturbed tilth (A)*: ploughed May/June; power-harrowed July/August, and September/October.
4. *Rough, disturbed tilth (B) plus autumn ploughing*: ploughed May/June; power-harrowed July/August; ploughed and power-harrowed September/October.
5. *White mustard cover crop (A)*: ploughed May/June, power-harrowed (& rolled at Rickwood) and sown with mustard in June; power-harrowed September/October.
6. *White mustard cover crop (B) plus autumn ploughing*: ploughed, power-harrowed (& rolled at Rickwood) and sown with mustard in May/June; ploughed & power-harrowed September/October.
7. *Natural regeneration of wheat stubble*: mown in summer as required; ploughed (Ramsey) or power-harrowed (Rickwood) September/October.

All treatments were applied with commercial farm machinery. The mustard cover crop was topped once at Rickwood during the summer to prevent seed returning to the soil. The herbicide glyphosate (Roundup, Monsanto plc) was applied at the product rate of 3.0 litres ha^{-1} to control weed re-growth on Treatments 1, 2, 3 & 4 at Rickwood on 29 July 1994 and to Treatments 1 & 2 at Ramsey on 17 August 1994. Soil surface profile (tilth roughness) measurements were done at both sites following the various May/June and July/August cultivations of Treatments 1 to 4; a ranging pole 2 m long was placed horizontally on the soil surface and the maximum vertical distance between the pole and the soil surface recorded at a minimum of five locations per plot which were meaned prior to analysis. Ground cover by green vegetation or plant debris was assessed visually on a percentage scale over the entire area of each plot by at least two observers in late July or early August.

The flight activity of adult wheat bulb flies was monitored with four water traps at each site weekly during July and August. Each water trap was made of white plastic (33 cm long × 23 cm wide × 5 cm deep). The traps were covered with chicken wire to exclude vertebrates and fitted with reservoir bottles (2 litres) to maintain water levels. The number of wheat bulb fly eggs was estimated in September 1994 by taking 16 cores/plot, each 7.5 cm diameter. The coring depth was varied from 10 cm to 25 cm according to the depth of cultivation in each plot. Eggs were extracted by a standard process involving wet sieving, elutriation and flotation in magnesium sulphate solution. A purpose-built apparatus, based on a modified Salt and Hollick method (Salt & Hollick, 1944), was used to separate eggs from soil.

In early October 1994, winter wheat (cv. Rialto at Ramsey; cv. Hunter at Rickwood) was sown after each treatment and was managed as a conventional crop except for the exclusion of wheat bulb fly insecticides. Treatments 4 and 6 differed from Treatments 3 and 5 respectively by the addition of further ploughing pre-sowing in September or October. Autumn ploughing was included to observe the effect of this operation on the survival of wheat bulb fly larvae. The remaining Treatments 1, 2 & 7 received seedbed cultivations appropriate to each site: at Ramsey the plots were ploughed and power harrowed in September, whilst at Rickwood the plots were rotovated and power harrowed only. Plant establishment was assessed prior to the onset of wheat bulb fly attack by counting plants in six paired rows (0.5 m long) per plot at each site. Wheat bulb fly larval damage was assessed by sampling and dissecting 50 plants taken from six random points per plot. Grain yield was measured at harvest with two plot-length cuts taken from the centre of each plot, using a Sampo 2025 plot combine harvester.

RESULTS

Wheat bulb fly adult flight activity

Males were caught only during the first half (11 July–8 August) of the trapping period; females tended to be more abundant than males and their flight period extended into August (Table 1). Similar observations were made by Long (1958), who noted the emergence of male flies commenced before the females and that the life span of the male was shorter than that of the female. Peak catches of female flies occured in the weeks ending 15 August and 8 August at Ramsey and Rickwood, respectively.

Table 1. Mean numbers of adult wheat bulb flies caught in water traps (no./trap/week).

Trapping period		Male flies		Female flies*	
From	To	Ramsey	Rickwood	Ramsey	Rickwood
11 July	18 July	1.35	0.3	0.0	0.5 (0)
18 July	25 July	0.5	0.5	0.5 (0)	1.3 (20)
25 July	1 August	0.5	0.0	0.8 (0)	1.0 (75)
1 August	8 August	1.0	0.0	2.5 (30)	3.8 (40)
8 August	15 August	0.0	0.0	3.0 (42)	2.8 (0)
15 August	22 August	0.0	0.0	2.0 (50)	1.0 (50)
22 August	30 August	0.0	0.0	2.5 (40)	0.3 (100)

* Numbers in parentheses are percentage of females with eggs

Soil surface roughness

The effects of the various cultivations on soil surface roughness were most pronounced on the clay soil of Ramsey where Treatment 1 (rough undisturbed) contained the most uneven and cloddiest surface (Table 2). By August, the surface of Treatment 2 (smooth undisturbed) had weathered down to a flat condition at both sites. The use of secondary cultivations during the oviposition period (Treatments 3 & 4; rough disturbed) broke the surface down at Ramsey whilst on the organic peat at Rickwood the hard-baked condition of the soil prevented further breakdown of large clods.

Ground cover

On the bare soil plots (Treatments 1–4) weed regrowth was minimal, allowing full access to the soil surface by the egg-laying flies. The mustard cover crops established more successfully and provided greater ground cover at Rickwood than at Ramsey (Table 2). The naturally regenerated and mown cereal stubble also provided a considerable degree of ground (soil) cover, a large element of which was provided by cereal trash lying on the soil surface.

Egg numbers

Most eggs were found at Ramsey in Treatment 1 (rough undisturbed). Of the bare soil treatments, Treatment 2 (smooth undisturbed) contained the fewest eggs at both sites. The application of secondary cultivations during the oviposition period (Treatments 3 & 4; rough disturbed) failed to increase egg numbers in comparision with Treatment 1 (rough disturbed) at Ramsey. However, at Rickwood, the secondary cultivations of Treatments 3 & 4 resulted in these treatments having the largest egg numbers at that site. The ground cover provided by Treatment 7 (natural regeneration) greatly reduced the number of eggs laid. To a lesser extent, the same was true of Treatments 5 & 6 (mustard cover crop) which, owing to the poorer ground cover provided, were less effective in reducing egg numbers at Ramsey than at Rickwood.

Pest attack and crop yield

The proportions of plants attacked by wheat bulb fly larvae and the numbers of larvae found followed a similar pattern to the numbers of eggs assessed in the autumn (Table 2). However, the estimated numbers of larvae showed a poor relationship to egg numbers, particularly in those treatments where relatively large numbers of eggs were laid. This suggested a large mortality of eggs or larvae prior to plant invasion, an observation that has been made in previous studies (Young, 1992). The burial of eggs through autumn ploughing in Treatment 4 appeared to reduce plant attack and larval numbers compared with non-ploughed Treatment 3. This was not true of the mustard cover crop, where the burial of eggs by ploughing of Treatment 6 did not reduce plant attack or larval numbers compared with non-ploughed Treatment 5. The wheat crops were established successfully with no differences in plant populations between treatments. There were no statistically significant differences in yield between the treatments. The poor yield of Treatment 7 (natural regeneration) at Rickwood was not associated with pest attack but was thought due to soil structural problems, as this treatment had not been ploughed since 1992. However, the lowest yielding treatment at Ramsey was Treatment 1 (rough undisturbed), which contained the largest egg and larval numbers and yielded at least 0.12 t ha^{-1} less than the other treatments at this site.

DISCUSSION

Wheat bulb fly preferred to lay eggs in a rough rather than a smooth soil surface, confirming earlier work (Raw, 1960; Young, 1994a). The reasons for this are not fully understood. A rough tilth probably presents a greater surface area with more cracks in which eggs may be laid. Eggs laid in a rough tilth may also be better protected from predators such as carabid beetles, which are known to prey on wheat bulb fly eggs (Ryan, 1973). For the first time in this study, the application of secondary cultivations to fallow soil during the oviposition period resulted in an increase in the number of egg laids, suggesting that the fly prefers to lay eggs in freshly disturbed soil.

Table 2. The effect of set-aside management and cultivation on mean soil surface roughness (after July/August cultivation), ground cover (in August), wheat bulb fly infestations, crop damage and yield.

Site & Treatment*	Soil surface roughness (mm) & date assessed	Ground cover (%) & date assessed	Egg count (nos. m^{-2}) & date assessed	% plants invaded & date assessed	Nos. larvae m^{-2} & date assessed	Grain yield t ha^{-1} @ 85% dm & harvest date
Ramsey	1 Aug. 94	1 Aug. 94	2 Sep. 94	30 Mar. 95	30 Mar. 95	5 Aug. 95
1. Rough undisturbed	84	1	1088	57	183	9.12
2. Smooth undisturbed	22	4	336	25	65	9.34
3. Rough disturbed (A)	36	0	820	51	163	9.29
4. Rough disturbed (B)	36	0	752	35	94	9.24
5. Mustard cover (A)	NA	71	120	6	13	9.62
6. Mustard cover (B)	NA	45	172	13	32	9.44
7. Natural regeneration	NA	68	4	3	7	9.29
SEM (18 df)	3.1 (9 df)	5.4	107	5.7	27.7	0.139
Rickwood	8 Aug. 94	27 Jul. 94	9 Sep. 94	5 Apr. 95	5 Apr. 95	4 Aug. 95
1. Rough undisturbed	40	3	44	23	42	10.81
2. Smooth undisturbed	13	7	16	4	4	10.98
3. Rough disturbed (A)	53	1	340	36	69	10.28
4. Rough disturbed (B)	40	3	276	24	52	10.19
5. Mustard cover (A)	NA	81	4	2	2	9.98
6. Mustard cover (B)	NA	83	16	1	2	10.64
7. Natural regeneration	NA	80	0	2	2	9.30
SEM (18 df)	3.9 (9 df)	7.7	33.8	4.6	15.1	0.396

* Treatments suffixed (A): wheat bulb fly eggs incorporated with non-inversion cultivations pre-sowing of wheat
Treatments suffixed (B): wheat bulb fly eggs buried by ploughing pre-sowing of wheat

There was also circumstantial evidence that burial of eggs through autumn ploughing may result in a higher mortality of eggs and neonate larvae, thereby reducing the extent of plant invasion. However, this observation requires further investigation before firm conclusions may be drawn. There was minimal effect of pest attack on crop yield, owing to the relatively early sowing. This is typical of most wheat grown after set-aside; these crops are sown before the end of October and are well tillered and able to compensate for damage at the time of larval invasion (Young, 1994b).

The results suggest several cultural control options to minimise wheat bulb fly attack in wheat. Where rotational set-aside is fallowed prior to autumn-sown wheat, wheat bulb fly egg numbers will be minimised by creating a smooth soil surface before oviposition begins in July. Secondary cultivations during the oviposition period should be avoided. The use of a mustard cover crop or prolonging ground cover by leaving naturally regenerated cereal stubble uncultivated until early September have also proved effective for excluding wheat bulb fly. In combination with early autumn sowing (September/October), these cultural control measures will reduce economic damage by wheat bulb fly and minimise the need for insecticides.

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CEREAL CLOVER BICROPPING: EFFECTS ON WHEAT STEM-BASE AND ROOT DISEASES

M L DEADMAN, M J SOLEIMANI, P N NKEMKA
Department of Agriculture, The University of Reading, P O Box 236, Earley Gate, Reading, RG6 6AT, UK

R O CLEMENTS
IGER - North Wyke Research Station, Okehampton, Devon, EX20 2SB

G DONALDSON
IACR - Long Ashton Research Station, Long Ashton, Bristol, BS18 9AF

ABSTRACT

Over a three year period the various factors which affect the incidence and severity of wheat stem-base and root diseases in cereal-clover bicrops have been assessed. The factors can be divided into three categories: those which tend to decrease disease (sieving out of spores, rapid trash decomposition), those which increase disease (more conducive microclimatic conditions for spore germination and disease development, cross infection of pathogens between intercrop components) and those which can either increase or decrease incidence and severity depending on the particular disease under investigation (altered nutrient especially N status of the soil). These various factors are fully described and discussed in relation to observations from field trials and other work.

INTRODUCTION

The current demand for methods of cereal production using reduced input levels and providing high quality grain has led to an increasing interest in alternative wheat cultivation techniques. Reduced, or controlled input systems under investigation include LIFE (Jordan *et al.*, 1995), TALISMAN (Bowerman *et al.*, 1995), RISC (Easson *et al.*, 1995) and SCARAB (Green *et al.*, 1995). These systems aim to reduce pesticide and fertilizer inputs through lower frequencies (SCARAB) or lower doses (RISC, TALISMAN, LIFE) of agrochemicals in some cases within rational crop rotations (TALISMAN, LIFE).

An alternative reduced input method involves the intercropping of winter wheat in a permanent clover understorey (Jones & Clements, 1993). The clover, once established, can survive as perennial ground cover into which the wheat is directly drilled. The clover continues to grow at the base of the wheat canopy, and after wheat harvest rapid clover growth is removed by cutting before the succeeding wheat crop is drilled. Using this method N input levels can be reduced from 150-200 kg N/ha for a conventional crop to 50 kg N/ha. Furthermore pest numbers appear to be greatly reduced in the intercrop system (Clements *et al.*, 1995). Weeds, especially annual grasses can be problematical in the permanent clover, but low doses of selected herbicides have been found to provide adequate control (R O Clements, personal communication). Although yields in wheat-clover intercrops are reduced (perhaps to 60% of the conventional crop), because inputs are greatly reduced the gross margin remains at about 90% of that for conventional crops (Clements *et al*., 1995). The incidence and severity of fungal diseases in the intercropped wheat relative to a conventional crop varies with the disease. *Septoria* appears to be slightly reduced in intercrops whilst the relative levels of stem-base *Fusarium* and Eyespot (*Pseudocercosporella herpotrichoides*) appear to change with successive crops (Soleimani *et al*., 1995). Over a three year period the patterns of stem-base Fusarium and eyespot disease development in intercropped wheat and clover has been compared with that in monocropped wheat plots. Similar patterns were assessed for one year for take-all. In this paper various factors which influence the impact of these diseases in intercrops are described and their potential to cause damage within the system is discussed.

FIELD-BASED INVESTIGATIONS

Field trials, consisting of eight treatments (Table 1) each replicated three times were established at IACR Long Ashton. Each season all plots received 75 kg/ha P and K fertilizer; the high input plots received 140 kg/ha N whilst the low input plots received no N. During the growing season the conventional input plots received the growth regulators fluroxypyr, chlormequat and choline chloride, the herbicides chloridazon, ethofumesate and triclopyr, the fungicides tebuconazole, chlorothalonil, propiconazole and cyproconazole and the insecticide pirimicarb. The low input plots received no herbicides, no growth regulators, only one fungicide (propiconazole at 0.25 the recommended rate) and the insecticide pirimicarb (Soleimani *et al*., 1995).

Table 1. Summary of treatments used to evaluate the effect of cereal-clover intercrops on disease severity on winter wheat cv. Hereward

Treatment	Clover cv.	Ploughed or not	Input
A	Donna	No	High
B	Donna	No	Low
C	Milkanova	No	High
D	Milkanova	No	Low
E	None	No	High
F	None	No	Low
G	None	Yes	High
H	None	Yes	Low

Disease levels were assessed as described in Deadman *et al*., (1996) and expressed as areas under disease progress curves (Table 2). The results indicate that eyespot was more severe in 1994/95 than 1993/94; the incidence of *F. avenaceum* was similar in the same years. The results show significant differences in disease incidence between each of the been directly drilled.

EFFECTS OF BICROPPING ON SPORE DISPERSAL

There is no experimental data to confirm whether cereal-clover intercropping limits the dispersal of wheat pathogen spores or the spread of wheat diseases in the field. However, experiments carried out under the controlled conditions within a rain tower have shown a sieving effect brought about by the clover (Soleimani, Deadman & McCartney, 1996). Using trays filled with soil (no crop) or sown with wheat only (monocrop) or wheat-clover intercrops (intercrop) and an eyespot or *Fusarium* spore suspension as a source of inoculum, it was found that twice as many spores reached the base of the wheat canopy in the monocrop compared to the bicrop. In the absence of a crop twice as many spores were caught as in a monocrop (Soleimani *et al.*, 1996). This effect would certainly reduce the amount of eyespot or *Fusarium* inoculum reaching the stem base of healthy plants having been removed from diseased neighbours. The effect may even be greater since in their experiments Soleimani *et al.* (1996) used a spore suspension which received direct 'hits' from the simulated rain. In the field the inoculum itself would be shielded to some extent by the clover canopy. In a subsequent experiment (Soleimani *et al.*, 1996) it was shown that spores landing on the clover canopy were themselves more easily redispersed than spores landing on bare soil such that the sieving effect may be short-lived.

TRASH DECOMPOSITION IN BICROPS

Stubble and trash play a significant part in the transfer of disease between seasons. In the case of the cereal-clover bicropping system significant amounts of trash remain after grain harvest. This would represent a situation equivalent to a direct drilled monocrop system (treatments E and F). Analyses of trash and stubble from treatments A to H has shown (Nkemka, Soleimani & Deadman, unpublished) that trash persistence during the growing season is significantly less within the bicrop compared to a direct drilled monocrop. Between March and June the amount of trash within monocrops is four times greater than in bicrops. Presumably the greater level of earthworm and microbial activity within the clover canopy has an accelerating effect on the rate of trash decomposition.

The mean numbers of *G. graminis* ascospores produced per g of trash has been found to be similar within monocrop and bicrop plots so the actual level of inoculum generated reflects closely the amount of trash remaining within the plots and is therefore approximately four times as high in a direct drilled monocrop than in a bicrop (Nkemka, Soleimani & Deadman, unpublished). The effect that this removal of inoculum has on the development of take-all in the field is unclear.

CHANGES IN MICROCLIMATE WITHIN BICROPS

Within a wheat-clover bicrop where the canopies of the two crops are growing closely together, the microclimate is likely to be altered significantly. This is especially going to treatments for each year. Generally, treatments receiving high levels of N (bicrop treatments A and C, monocrop treatments E and G) had more disease than low input treatments (bicrop treatments B and D, monocrop treatments F and H). This was especially clear for eyespot and *F. avenaceum* in 1993/94 and for *F. avenaceum* in 1994/95 (high level input bicrop treatments were lost in that year).

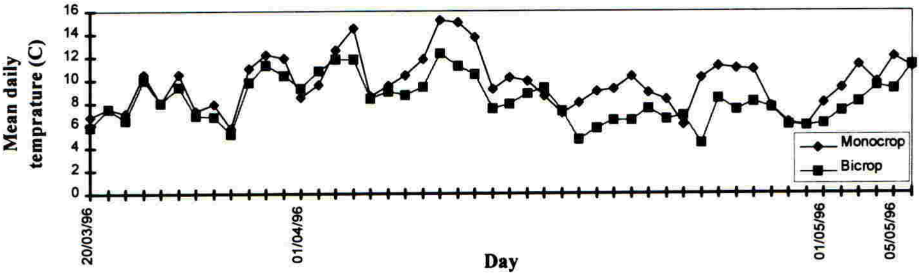
Table 2. Area under disease progress curves for *Pseudocercosporella herpotrichoides* (P.h.), *Fusarium avenaceum* (F.a.), *Microdocium nivale* (M.n.) and *Geaumannomyces gramminis* (G.g.) for 1993/94, 1994/95 and 1995/96 from wheat-clover bicrop and wheat monocrop experimental plots

Treatment	1993/94		1994/95			1995/96
	P.h.	*F.a.*	*P.h.*	*F.a.*	*M.n.*	G.g.
A	2297	4649	N/A	N/A	N/A	75
B	2255	4296	4483	4735	1925	97
C	2112	4890	N/A	N/A	N/A	66
D	2120	4135	6330	4885	3040	127
E	2487	6071	3672	5628	2278	115
F	1920	3852	2703	3055	1970	106
G	2643	6175	5573	5920	3511	87
H	2232	4485	7668	5105	3862	78

In 1993/94 bicrop and monocrop treatments at equivalent levels of N did not differ significantly in the level of eyespot. In the same year monocrop treatments receiving high N levels had more *F. avenaceum* infection than other treatments. In 1994/95 differences in *F. avenaceum* and *M. nivale* incidence were generally small. For eyespot the two low input bicrop treatments (B and D) showed higher incidence than the direct drill monocrop treatment (F) but less so than the plough treatment (H). In all cases variation between plots was high and few differences between treatments were significant (Table 2). Between successive years, for all of the treatments, there was a significant correlation in the incidence of *F. avenaceum* ($r=0.803$, d.f.=14, $P<0.05$), but not for eyespot ($r=0.185$, d.f.=14, $P>0.05$). Within seasons there was a significant correlation between the levels of eyespot and *F. avenaceum* in 1993/94 ($r=0.895$, d.f.=14, $P<0.05$) and the levels of eyespot and *M. nivale* in 1994/95 ($r=0.884$, d.f.=14, $P<0.05$); the correlation was not significant between the levels of eyespot and *F. avenaceum* in 1994/95 ($r=0.538$, d.f.=14, $P>0.05$).

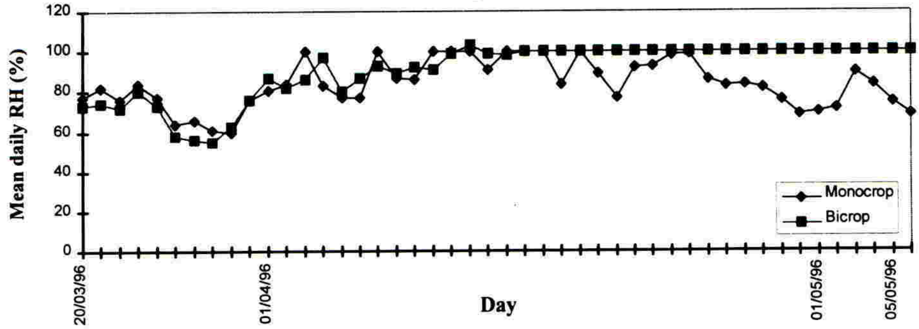
In the bicrop plots take-all was more severe in the low input treatments (B and D) compared to those treatments receiving conventional levels of N (plots A and C). This trend was reversed in the monocrop plots although here differences between treatments were smaller. Monocrop treatments had more severe take-all than bicrop plots at high N levels; at reduced N input levels there were no clear differences between monocrop and bicrop treatments. Within the monocrop treatments, at both N input levels, those plots which were ploughed suffered less take-all than those plots which where the wheat had be the case at the base of the wheat crop - the site of infection for eyespot and *Fusarium*. Field studies using temperature and humidity probes placed within monocrop and bicrop plots indicate that during the early part of the season when the clover plants are still growing close to the ground, temperature differences between treatments are small (Figure 1). As the season progresses the increased clover growth produces shading at the base of the wheat stems and consequently temperatures fall relative to those in a monocrop.

Figure 1. Comparison between air temperature in wheat monocrops and wheat-clover bicrops, March-May 1996



The pattern for humidity (Figure 2) suggests that as the season progresses that conditions at the wheat stem-base become more humid in a bicrop compared to a wheat monocrop. Indeed for long periods within the season the air within the clover canopy remains saturated. This occurs during the time when the clover canopy is developing rapidly, eventually providing complete ground cover between the wheat plants.

Figure 2. Comparison between Relative Humidtity in wheat monocrops and wheat-clover bicrops, March-May 1996



The peak period for eyespot infection is November to March (Hollins & Scott, 1980). Hollins & Scott (1980) have suggested that increased evaporation, leading to reduced moisture on and in the host tissue is an important cause of reduced rates of eyespot infection in summer compared to spring months. In the current study the humidity at wheat stem-base level was little different between monocrops than bicrops up until April; subsequently it remained significantly higher within the bicrop treatments, perhaps continuing to cause new infections for a longer period in these plots.

The optimum temperature for eyespot infection to occur is in the range 4-19°C (mean 7°C, Fitt, 1992). Spore production by *P. herpotrichoides* is highest at a temperature of 5°C (Fitt, 1992). Data obtained from temperature probes within wheat monocrops and cereal clover bicrops indicates that during the time when eyespot infection is high the temperature within the bicrops is significantly lower and the number of days when conditions are favourable for infection are significantly higher (Figures 1 and 2).

INFECTION CROSS OVER BETWEEN BICROP COMPONENTS

Fusarium avenaceum is a severe pathogen of wheat in UK (Jenkinson & Parry, 1994). It is also recognized as a serious pathogen of clover and other legumes (Booth, 1971). Within wheat-clover bicrops the pathogen has previously been shown to cause significant levels of disease on the cereal crop (Soleimani *et al.*, 1995). Although the broad host range of this pathogen is well established (Booth, 1971), the degree of host specialization within a single isolate of the species is unclear.

Using two *F. avenaceum* isolates from clover and a single isolate from wheat, taken from cereal-clover field trials, Deadman & Soleimani (unpublished) inoculated wheat seedlings under controlled conditions. Plants were assessed for symptoms after 10 weeks growth in a glasshouse at 20 C using the Disease Index Rating (DIR) of Celetti *et al.* (1990). The number of tillers produced by each plant was also noted.

The mean Fusarium DIR score resulting from inoculation by each isolate (Table 3) indicated that infection was greatest in wheat inoculated with a wheat isolate of *F. avenaceum*. Wheat inoculated with *F. avenaceum* from clover caused less severe disease than the wheat isolate but significantly more severe infection than the control.

Table 3. Mean Disease Index Rating (DIR) and tiller number on wheat (cv. Hereward) inoculated with isolates of *F. avenaceum* originating from wheat and clover plants in experimental bicropping trials

Treatment	Mean DIR	Tiller number
F. a (clover 1)	74.38	3.70
F. a (clover 2)	69.38	3.50
F. a (wheat 1)	90.63	1.80
Control	10.00	3.68
LSD	8.78	0.86

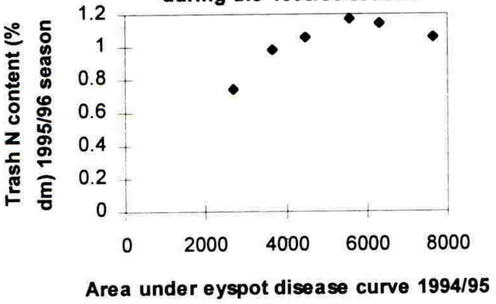
Wheat tiller number was shown to be significantly lower in those wheat plants inoculated with *F. avenaceum* isolated from wheat. Tiller number in those plants infected with *F. avenaceum* from clover was found to be not significantly different from the control. From these results it is clear that within bicrops there could be a significant risk to the wheat crop from inoculum originating from the clover component. It would appear that the pathogen could be able to maintain pathogenicity and virulence on the legume crop during the period between harvest of one wheat crop and the drilling of the next.

NUTRIENT STATUS OF THE CROP

The level of nutrient (especially nitrogen) in the crop has a significant affect on it's susceptibility to disease. This in turn is a reflection of the level of available soil nutrient. In field trials assessing the effect of bicropping on disease incidence measurements of available N within the top 30 cm of soil, taken in September 1995, showed that the reduced input bicrop plots (treatments B and D) had the highest N levels (R O Clements, personal communication), this despite the fact that these plots had received no additional 'bag' nitrogen.

Samples of trash were taken during the 1995/96 growing season and assessed from N content. Results showed that those plots with plant material which had the highest N level also had the highest levels of eyespot during the preceding season (Figure 3). Although the relationship between trash N and disease level appears not to be linear, further work is required before the exact relationship can be fully determined.

Figure 3. Relationship between eyespot severity 1994/95 and trash N content collected during the 1995/96 season



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INTERCROPPING AS POSSIBLE METHOD OF CABBAGE PEST CONTROL IN POLAND

K WIECH
Agricultural University, Al. 29 Listopada 54, 31-425 Kraków, Poland

ABSTRACT

Early white cabbage (cv. Pierwszy zbiór) and late white cabbage (cv. Kamienna glowa) were treated with pesticides, left untreated, undersown with white clover (cv. Podkowa). The undersown did not effect damage caused by cabbage root fly (*Hylemyia brassicae*) to early cabbage but significantly decreased the number of flea beetles (*Phyllotreta sp.*)

In the case of late cabbage, when clover completely covered the soil it reduced the number of cabbage aphid (*Brevicoryne brassicae*) (both alate and wingless forms) and cabbage moth (*Mamestra brassicae*). No effect was observed in case of diamondback moth (*Plutella maculipennis*) and small cabbage white (*Pieris rapae*).

Undersowing reduced the weight of early cabbage heads by 25% and late cabbage by 46%. Less competitive white clover cultivar is reqiured for further experiments.

INTRODUCTION

Intercropping and mixed cropping is a traditional practice in the tropics helping to reduce losses from pest attact (Perrin, 1977, Rish et al., 1983, Altieri & Letourneau, 1983).In the temperate zone reduction in pest numbers resulting from intercropping have been reported by several authors (Theunissen & den Ouden, 1980, Tukahirwa & Coaker, 1982, Uvah & Coaker 1984, Theunissen et al.,1992, Theunissen, 1994, Finch & Edmonds, 1994), although the mechanisms involved in such situations is not always clear. Present trends towards monocultural crop production covering large areas can be disadvantageous from the IPM point of view. In Poland where the average area of farm is about 3-4 ha and herbicide/pesticide practices are highly expensive, intercropping seems to be a promising solution of pest problems.

Previous studies showed that white clover undersown in late white cabbage effectively reduced the number of some pests (Wiech, 1991). The objective of thepresent experiment was to find if the same goal can be achieved for early cabbage.

MATERIALS AND METHODS

The investigation was carried out in 1995 at Agriculture University Experimental Station. The experiment was laid out as a randomized block with three treatments each replicated four times. The treatments were cabbages (early and late cvs.) treated with pesticides, cabbages not treated and cabbages undersown with white clover (cv. Podkowa).

Each plot measured 50 m^2 (5x10 m) and contained 200 cabbage plants, using a spacing of 50 cm both within and between rows. White clover (10 kg/ha) was sown on 3 April, white cabbage plants of early cv. Pierwszy Zbiór were transplanted into the field on 20 April, and late cabbage cv. Kamienna Glowa on 5 June. Isofenphos was applied immediately after

transplanting to all plants in the control plots. To keep the control plots "pest free" the treated plots were sprayed with phosalone at the rate of 6 ml/plot and etafenproks -4.5ml/plot when 20% of plants has been infested by aphids or caterpillars.
Sampling methods were similar to those described by Theunissen *et al.* (1992) and Finch & Edmonds (1994). Ten plants were selected and marked at random from each plot. The number of aphids and caterpillars were recorded weekly from the marked plants. Cabbage root fly damage was assessed on 15 June by counting the infested plants. The number of cabbage moth caterpillars was assessed at harvest of early and late cabbage.
The effect of the clover on the yield of cabbage was estimated on the days of harvest by weighing of all plants from each plot.

RESULTS

Undersowing early white cabbage with white clover did not effect the degree of plant infestation by cabbage root fly (*E. brassicae*) and the number of cabbage moth caterpillars (*M. brassicae*). The more pronounced effect of intercropping was observed in the case of flea beetles although the interrows were only partly covered by clover.

Table 1. The effect of pesticides and undersowing with white clover on the occurrence of main cabbage pests.

	Treatments		
Pests	Cabbage treated with pesticides	Cabbage without pesticides	Cabbage undersown with white clover
EARLY CABBAGE			
% of plants damaged by cabbage root fly	0.375 a	15.00 b	8.60 b
Number of flea beetles	6.000 a	46.00 b	13.00 a
Number of cabbage moth caterpillars	9.500 a	10.00 a	5.50 a
LATE CABBAGE			
Number of cabbage aphid alate	166.500 b	139.50 b	32.70 a
Number of cabbage aphid wingless forms	375.500 a	1564.20 c	701.00 b
Number of diamondback moth caterpillars	4.000 a	32.70 b	36.00 b
Number of small cabbage white eggs	9.000 a	9.00 a	12.50 a
Number of small cabbage white caterpillars	0.250 a	1.75 ab	2.25 b
Number of cabbage moth caterpillars	0.500 a	6 .75 b	2.75 b

Means followed by the same letter within a horizontal columns are not significantly different (P=0.05), according to Duncan`s multiple-range test

Undersowing late cabbage with white clover affected the colonization rate and establishment of cabbage aphid (*B. brassicae*). The initial growth of white clover was not fast enough to cover the interrow space sufficiently to disturb cabbage root fly egg-laying. The number of alate found on monocrop plants, differed significantly from those found on the undersown plants. The numbers of larvae produced reflected the numbers of alate.

Mixed cropping did not influence the number of diamondback moth (*P. maculipennis*) caterpillars and pupae as well as egg-laying by small cabbage white (*P. rapae*).

Undersowing cabbage with white clover significantly reduced cabbage yield both in early and late cabbage. The reduction was due to the competition between two crops. Although the late cabbage heads from the plots with white clover were only about 50-60 % as heavy as those from the insecticide treated plots the heads were of similar quality in case of both treatments.

Table 2. The effect of pesticides and undersowing white clover on cabbage yield.

	Treatments		
	Cabbage treated with pesticides	Cabbage without pesticides	Cabbage undersown with white clover
EARLY CABBAGE			
Cabbage yield/plot (kg)	224.00 b	177.40 a	156.50 a
Mean weight of cabbage head (kg)	1.39 b	1.22 ab	1.04 a
LATE CABBAGE			
Cabbage yield/plot (kg)	375.50 c	312.80 b	229.50 a
Mean weight of cabbage head (kg)	2.27 b	1.83 b	1.23 a

Means followed by the same letter within a horizontal column are not significantly different (P=0.05) according to Duncan`s multiple-range test.

DISCUSSION

Establishing and maintaining white clover was the main problem in Kraków. Our local cv. Podkowa grew as tall as cabbage and never stopped growing. It was difficult to keep clover in desired height so it was necessary to apply regular mowing. *Trifolium subterraneum* (cv. Geralton), recommended by Theunissen & Edmonds (1994) is not available in Poland so we have to look for cultivars other than cv. Podkowa, local small growing cvs. or ecotypes to minimize competition with cabbage.

Satisfactory, adverse effect on pest species was obtained only when the undersown crop covered the soil completely. It was visible only in late cabbage, particularly in the case of cabbage aphid and cabbage moth. Fewer aphids landed on the cabbage plants undersown with clover. It was partly due to their phototactic reaction and, probobly more importantly, to their optomotor reaction to the plants "looming up" along their path (Kennedy *et al.*, 1961).

The infestation of cabbage heads by cabbage moth was reduced significantly and according to Theunissen (1994) it was due to itercrop-nonspecific factors which include effects produced in the main crop, irrespective of the intercrop used. The decrease in amount of cabbage moth caterpillars could be caused by predation. Higher number of carabids was observed in undersown cabbage by Wiech (1991) and Finch & Edmonds (1994).

The reduction of cabbage yield in Kraków was even higher than observed in Wellesbourne by Finch & Edmonds (1994), resulting from the disturbance to the roots during transplanting and drought in June and partly in July. Undersowing early cabbage with white clover didn`t secure plants from pest attack. Since earlier sowing of white clover is not possible in Poland, this method can not be recommended as the effective tool of pest control on early cabbage. Further studies should be continued however, on undersowing with white clover to control pests of late cabbage.

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SUPPRESSIVE EFFECT OF SOME GROWING MEDIUM AMENDMENTS ON CYCLAMEN FUSARIUM WILT

T M O'NEILL
ADAS Arthur Rickwood, Mepal, Ely, Cambridgeshire CB6 2BA, UK

A R FINLAY*
HRI Efford, Lymington, Hampshire SO41 0LZ, UK

ABSTRACT

Following inoculation of cyclamen with *Fusarium oxysporum* f. sp. *cyclaminis*, fusarium wilt developed rapidly in plants grown in standard sphagnum peat and a dark-coloured Russian peat and relatively slowly in plants grown in a light-coloured Finnish peat. Amendment of sphagnum peat with 40% v/v composted bark and paper, composted larch and spruce bark, composted pine bark, matured pine bark, processed oilseed rape straw or wood fibre or 1% w/v chitin gave 24-82% control 25 weeks after inoculation. Amendment with 40% v/v coir or perlite was ineffective. The disease suppressive effect observed with matured pine bark was not removed by leaching with water or by autoclaving.

INTRODUCTION

Fusarium wilt of cyclamen, caused by *Fusarium oxysporum* f. sp. *cyclaminis*, is one of the most common and serious diseases affecting production of potted cyclamen in the UK. The fungus causes vascular discoloration in the corm, leaf yellowing, wilting and eventually plant death (Tompkins & Snyder, 1972). Losses of more than 50% of plants have occurred on individual nurseries in England in recent years. There appears to be no varietal resistance and fungicides provide only partial control (O'Neill, 1995).

Suppression of root diseases in horticultural crops has been demonstrated following addition of organic matter to the growing medium (Hoitink *et al.*, 1991). Garibaldi (1988) found that the incidence of cyclamen fusarium wilt was reduced in composted poplar bark and earthworm compost, compared to plants grown in sphagnum peat, and Hoitink *et al.* (1987) reported that the disease was reduced in media containing composted hardwood or pine bark. Chitin reduced the incidence of fusarium wilt in beans and radish (Mitchell & Alexander, 1961). The mechanism of disease suppression by organic amendments is not fully understood and may involve stimulation of microbial populations, release of chemicals inhibitory to pathogen growth or alteration of physical characteristics of the growing medium (Hoitink *et al.*, 1991). The objective of the work described here was to investigate the effect of adding various peats and organic amendments on development of cyclamen fusarium wilt and assess their influence on plant growth. Substances selected were primarily those which have shown promise when evaluated as growing medium alternatives to peat, or when used as diluents with peat.

*Present address: Year Round Flowers, 16 Arcade Chambers, Bognor Regis, Sussex PO21 1LL

MATERIALS AND METHODS

Four experiments were carried out during 1991 and 1992. Experiment 1 examined the effect of growing medium amendments on plant growth in the absence of fusarium wilt. Experiments 2, 3 and 4 examined the effect of a range of growing medium amendments on control of fusarium wilt. Experiments were of randomised block design with four replicates. Plots consisted of 20 plants (Experiments 1-3) or 10 plants (Experiment 4). Results were examined by analysis of variance; significance is indicated as * $P<0.05$, ** $P<0.01$, *** $P<0.001$ and NS=not significant.

Pathogen isolate, inoculum production and inoculation

An isolate of *F. oxysporum* f. sp. *cyclaminis* was obtained from diseased cyclamen corms in 1990 and maintained on potato dextrose agar (PDA). A spore suspension was produced as previously described (O'Neill, 1992) and diluted to 1 x 10^3 spores/ml. Plants were inoculated with 100 ml of a 10^3/ml spore suspension in water, poured onto the growing medium surface around the pot edge. Plants were inoculated 15 days (Experiment 2), or 18 days (Experiments 3 & 4) after potting.

Plants and growing media

Young plug-grown cyclamen plants, cv. Sierra White with Eye, were potted in 12 cm half- pots of Irish sphagnum peat (Bord na Mona), in Irish special peat (Bord na Mona), a Finnish peat (Finnfibre; Vapo grade), a Russian peat (D L Coutts; Novobalt grade) or Irish sphagnum peat (60% by volume) mixed with amendment (40% by volume). The amendments and their sources were: matured pine bark (Cambark Fine); fine wood fibre (J McLauchlan Horticulture); composted larch and spruce bark (Sinclair Ltd); composted pine bark (Melcourt Ltd); composted bark and paper (Sinclair Ltd); processed oilseed rape straw (Bridgemere Fi-Pro straw); coir (Goldengrow Ltd) and Perlite (Silva Perle). In addition, Irish sphagnum peat was mixed with 1% w/v crushed crab shells (Sigma Chemicals; chitin). Plants were potted on 13 June 1991 and 12 June 1992. A base fertiliser consisting of 0.4 kg/m^3 ammonium nitrate, 0.75 kg/m^3 potassium nitrate, 1.2 kg/m^3 single superphosphate, 2.5 kg/m^3 dolomitic lime and 0.4 kg/m^3 of trace element (frit WM 255) was added to all growing media. An additional 1 kg/m^3 ground chalk was added to all-peat media; additional ammonium nitrate was added to coir, wood fibre, bark/paper, composted pine bark and processed straw (0.2 kg/m^3) and to matured pine bark (0.4 kg/m^3). Liquid feed was applied with every watering from one month after potting. Growing media were prepared in a rotary mixer and samples were subject to chemical analysis and determination of air-filled porosity (AFP) before potting. Chemical analysis of growing media was by standard ADAS methods; AFP was used to assess drainage characteristics and was determined by the method of Bragg & Chambers (1988). Where required, bark was autoclaved twice for 15 mins at 107 KPa, and leached by soaking in water three times for 24 hours, using two volumes of water to one volume of bark. Bark leachates obtained by soaking matured pine bark in water were tested for antifungal activity. Leachates were incorporated into PDA plates and inoculated with a 5 mm diameter plug of *F. oxysporum* f. sp. *cyclaminis*. Plates were incubated at 23 °C and colony diameters measured after 7 days.

Site details

Experiments were carried out in heated greenhouses in Hertfordshire (Experiments 2-4) and at HRI Efford, Hampshire (Experiment 1). Potted cyclamen were stood on wire-mesh benches and watered from overhead (Experiments 1-3), or on solid benches on capillary matting (Experiment 4). All plants were shaded for two weeks after potting and during hot weather. Grey mould (*Botrytis cinerea*) was controlled by high volume sprays of iprodione (Rovral WP) and by picking-off affected lower leaves. No fungicides were applied for control of fusarium wilt. Plants were initially placed pot thick and spaced once as growth occurred.

Assessments

Plants were assessed every 14 days and those that were severely wilting were removed and examined for fusarium wilt. The disease was identified from sporulation of fusarium on petiole bases and/or vascular staining within the corm. Identification was confirmed by isolation onto PDA from a sample of at least 10 plants from each experiment. The height and spread of uninoculated plants were measured. Plant quality (0-unmarketable, 5-excellent) was assessed when plants were ready for marketing and again after 11 weeks in a shelf-life room (illuminated with 1,000 lux, 12 hours daily) at HRI Efford. The number of actinomycete bacteria in sphagnum peat and sphagnum peat amended with 1% w/v crushed crab shells was determined in January 1993; the growing medium from around 10 plants was bulked and total actinomycete numbers were measured as described by Gregory & Lacey (1963).

RESULTS

No fusarium was isolated from any of the plant samples tested before potting and no fusarium wilt occurred in uninoculated plants (Experiment 1). In Experiments 2-4, the first symptoms of fusarium wilt were first observed around 4 weeks after inoculation.

Experiment 1

Effects of growing medium amendments on plant growth are shown in Table 1. Coir, perlite and wood fibre amendments all slightly reduced plant height and spread and diminished overall plant quality when assessed 22 weeks after potting (28 November). Nitrogen and potassium levels were found to be slightly lower in these media than in unamended peat. None of the treatments markedly affected shelf life.

Experiment 2

The incidence of dead plants was reduced by amendment of peat with matured pine bark, wood fibre and chitin but not by coir, a high initial pH or perlite. By 15 August, six weeks after inoculation, the incidence of dead plants in unamended peat was 72% while in peat/wood fibre, peat/bark and peat/chitin it was 35, 49 and 58% respectively (Fig 1). The degree of disease suppression declined with time and by 22 November more than 90% of plants in all treatments were dead. The initial AFP of growing media was not affected by addition of bark, coir or perlite; wood fibre alone increased AFP, from 13.2 to 16.7. The initial pH of media was 4.8 - 5.1, apart from the treatment where extra ground chalk was added (pH 5.6).

Table 1. Effect of growing medium amendments on plant quality, size and root extent of cyclamen (Experiment 1).

Growing medium	Plant quality (0-5)		Plant size (cm) 28 Nov[c]		Rooting (0-5)
	13 Sept[a]	5 Nov[b]	Height	Spread	18 Nov
Peat (Irish sphagnum)	4.41	2.95	10.84	27.24	3.11
Peat/bark	4.21	3.05	10.35	26.22	3.27
Peat/coir	4.14	2.11	10.09	24.00	3.34
Peat/perlite	4.13	2.16	10.24	24.48	2.71
Peat/wood fibre	4.18	2.00	9.68	24.21	3.71
Peat/chitin	4.54	3.18	10.86	27.32	3.39
SED (15 d.f.)	0.268	0.247	0.418	0.705	0.352
Significance	NS	***	**	***	NS

[a] 13, [b] 20 and [c] 24 weeks after potting

Table 2. Effect of growing medium amendments on incidence of fusarium wilt (Experiment 3)

Treatment	% dead plants at intervals (weeks) after inoculation		
	11 weeks	17 weeks	23 weeks
Peat (Irish sphagnum)	50.6	78.1	90.0
Peat/bark[a]	21.2	57.5	68.7
Peat/autoclaved bark[a]	16.2	43.7	55.0
Peat/leached bark[a]	17.5	43.7	61.2
Peat/composted larch+spruce bark	22.5	37.5	50.0
Peat/composted bark+paper	5.0	17.5	35.0
Peat/composted pine bark	10.0	22.5	31.2
Peat/wood fibre	5.0	10.0	16.2
Peat/straw	8.7	18.7	35.0
Finnish peat	13.7	25.0	38.7
Irish special peat	22.5	55.0	76.2
Russian peat	48.7	76.2	88.7
SED (33 d.f.)	7.96	7.40	6.54
Significance	***	***	***

[a] Matured pine bark

Experiment 3

Fusarium wilt occurred first in plants in the standard sphagnum peat, 4 weeks after inoculation and did not occur until nine weeks after inoculation in plants in Finnish peat, peat/wood fibre and peat/composted bark and paper. The number of plants affected by wilt increased steadily in the standard peat and Russian peat and more slowly in plants in Finnish peat and in sphagnum peat amended with wood fibre, oilseed rape straw, composted pine bark and composted bark and paper (Table 2). Wood fibre was the most disease suppressive amendment. On 2 December, 1993, 23 weeks after inoculation, 90% of plants in sphagnum peat had died from fusarium wilt compared with 16% of plants in peat/wood fibre. The disease suppressive effect observed with matured pine bark was not removed by water-soak or autoclave pre-treatments. None of the leachates from matured pine bark inhibited mycelial growth of *F. oxysporum* f. sp. *cyclaminis* on agar plates.

Experiment 4

The number of plants affected by wilt increased most rapidly when plants were grown in sphagnum peat (Fig 2). Amendment of sphagnum peat with 1% chitin and 40% matured pine bark were both effective in reducing fusarium wilt (Fig 2). The total number of actinomycete bacteria was increased approximately 20-fold by addition of crab shells, from 2.5×10^6 to 5.5×10^7 /g fresh weight of growing medium.

DISCUSSION

There was a marked difference in the rate at which fusarium wilt developed when cyclamen plants were grown in different types of peat. Irish sphagnum peat and a Russian peat were conducive to disease development and a Finnish peat was very suppressive. Garibaldi (1988) also reported that sphagnum peat was highly conducive to cyclamen fusarium wilt. Soil acidity is known to affect some fusarium wilt diseases. However, the peats used in these experiments all had a similar pH value at potting (pH 5.2 - 5.4) indicating that degree of acidity is unlikely to be responsible for different rates of development of cyclamen fusarium wilt. Increasing the initial pH of sphagnum peat from 5.2 to 5.6 had no effect on the development of fusarium wilt (Experiment 2).

Of the four peats examined, the Finnish one was lightest in colour and the least decomposed. Tahvonen (1993) isolated a number of *Streptomyces* species from young, light-coloured surface peats and demonstrated that both the peat and the bacteria obtained from it suppressed development of fusarium wilt of carnation caused by *Fusarium oxysporum* f. sp. *dianthi*. Darker peats from deeper layers contained smaller proportions of *Streptomyces* spp. and failed to suppress carnation fusarium wilt. Possibly the suppression of cyclamen fusarium wilt in Finnish peat, compared to development of the disease in other unamended peats, was due to differences in numbers of antagonistic bacteria.

All of the growing medium amendments except coir and perlite reduced the development of cyclamen fusarium wilt. Composted pine bark, composted bark and paper, wood fibre and chitin appeared to be more effective than other amendments. The greater degree of disease

Figure 1. Effect of some growing medium amendments on incidence of fusarium wilt (Experiment 2)

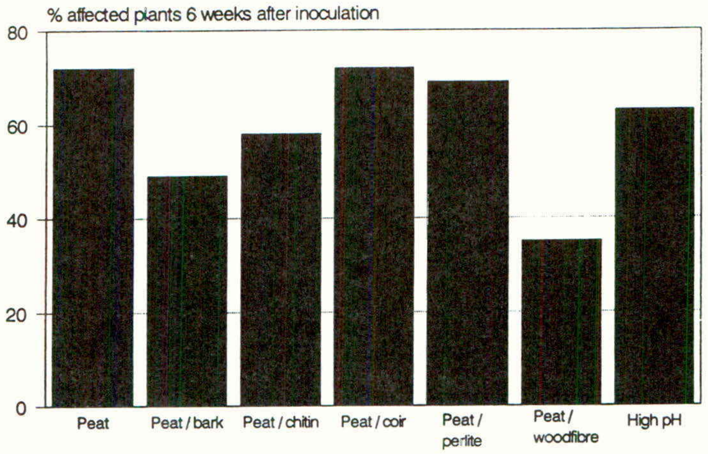
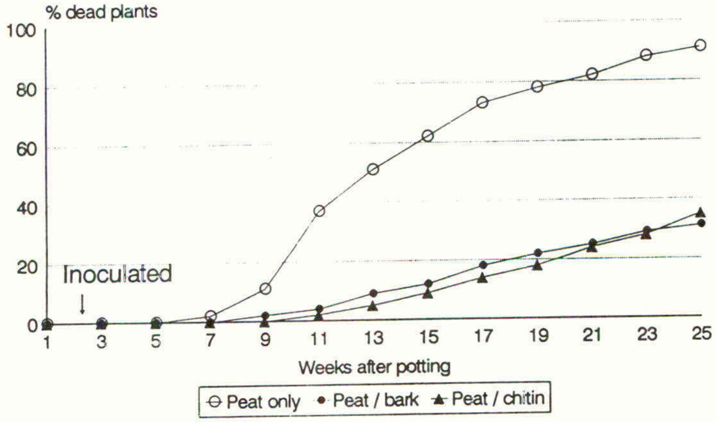


Figure 2. Effect of matured pine bark and chitin on incidence of cyclamen fusarium wilt (Experiment 4)



suppression given by the composted barks compared to matured bark, is in agreement with Hoitink & Fahy (1986) who reported a greater degree of disease suppression with older barks.

Neither leaching pine bark in water nor autoclaving it removed its suppressive effect on cyclamen fusarium wilt. The first result indicates that disease suppression is not due to a water-soluble inhibitor. The second suggests that suppression is not due to the presence of a heat-labile chemical inhibitor and is not associated with micro-organisms introduced on bark. However, it is possible that incorporation of bark with peat may influence the development of micro-organisms introduced in the peat or with young plants. To determine the mechanism of fusarium suppression by bark, other aspects which need to be considered in more detail are nitrogen nutrition, media aeration and drainage.

Incorporation of 1% chitin in Experiment 4 resulted in very good and persistent control of cyclamen fusarium wilt. Fusarium cell walls contain chitin (Fukamizo *et al.*, 1992) and amendment with chitin resulted in a 20-fold increase in the number of actinomycetes, bacteria which are known to produce chitinolytic enzymes. Hence this control effect may be due to enzymatic breakdown of fungal cell walls by chitinolytic microflora. More detailed studies are required to confirm that suppression of cyclamen fusarium wilt by chitin amendment is mediated by an increase in chitinolytic microflora.

Bark and chitin, at the rates used, suppressed fusarium wilt without adversely affecting plant growth, flowering or shelf-life. Although they did not provide complete control of the disease, these amendments should be considered as a component of an integrated wilt control strategy. Other control measures to supplement disease suppression by amendments include the use of healthy planting material, nursery hygiene and fungicide drenches. An integrated strategy is particularly important on nurseries which have a history of severe losses from fusarium wilt. Further work is needed to investigate the factors affecting the degree and reliability of fusarium wilt suppression under different growing conditions and at different inoculum levels, in order to facilitate their use in cyclamen production.

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