**BRIGHTON CROP PROTECTION CONFERENCE - Pests and Diseases - 1994**

# ASSESSING THE ENVIRONMENTAL IMPACT OF PESTICIDES - A SEQUENTIAL MODELLING TECHNIQUE TO INTERPRET AND EXTRAPOLATE LABORATORY AND FIELD DATA

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## ABSTRACT

Assessment of the environmental impact of a pesticide requires consideration of a complex series of experimental results, the use pattern of the compound, and a large number of parameters which may vary spatially and temporally across the landscape. A sequential modelling technique is described which uses detailed modelling to interpret field and laboratory data. Important environmental processes are investigated under reasonable worst-case conditions relevant to the compound being modelled. Results are then extrapolated to national levels using simpler models in order to assess the spatial distribution of environmental vulnerability from existing or expected usage of the pesticide. As example, an assessment of the potential for contamination of water sources by the novel fungicide, epoxiconazole, is described.

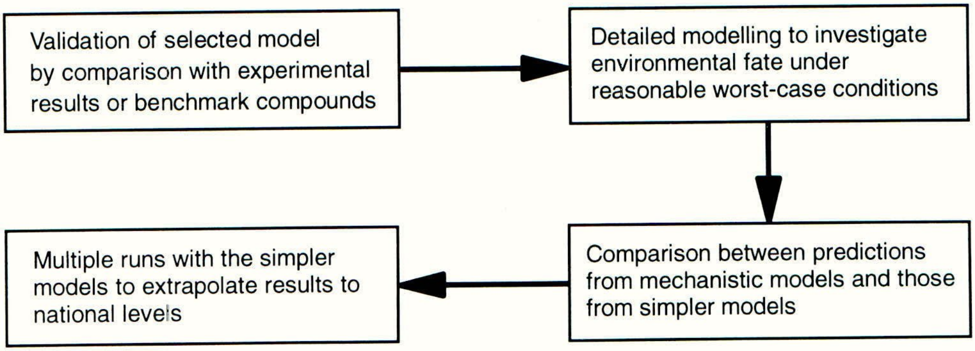
## INTRODUCTION

Evaluation of the environmental fate and behaviour of pesticides is increasingly moving beyond assessment of the properties of the pesticide alone. Total impact of a pesticide on the environment can be more fully investigated by considering the effect of factors which will be specific to a given usage scenario. Thus, for example, it is no longer sufficient to assess solely whether a compound is likely to leach *per se*, but rather to address the extent to which the compound is likely to leach across the range of conditions over its existing or expected use pattern. As the number of factors to be considered in any regulatory assessment increases, so the role of computer modelling in the process increases in importance. Mathematical modelling can be used to maximise the use of complex environmental data packages through interpretation of laboratory and field results and extrapolation to the wider environment. This paper will discuss a sequential methodology for risk assessment and present as example an investigation of the potential for contamination of water sources by the novel fungicide, epoxiconazole.

## MODELLING PROCEDURE

The proposed sequential modelling procedure is outlined in Figure 1. The procedure builds upon field and laboratory studies of environmental fate and behaviour undertaken to support the regulatory submission for a new compound. It is not feasible to undertake such studies using the full range of environmental conditions likely to be encountered within the potential usage areas, so computer modelling is used to extrapolate data from the limited number of studies normally available. A sequential approach is adopted, with each step in the extrapolation process being validated and linked back to the original data. The final environmental impact assessment is made using national soil, cropping and climate datasets.

FIGURE 1 Sequential modelling technique to assess the environmental impact of pesticides



The first step in the process is to simulate field and laboratory results of leaching and persistence using a detailed mechanistic model. A range of such models are available (Wagenet & Rao, 1991), but it is widely accepted that no one model is currently capable of simulating all processes of environmental dissipation. Before selecting a model for simulation purposes, the available field and laboratory data are used to assess which are the most important processes determining the compound's potential environmental impact. The model that incorporates the most rigorous description of these processes can then be selected, although in some cases more than one model may need to be used to adequately simulate all important dissipation mechanisms

Once a model has been selected, it is important to test output against observed data in order to ascertain that relevant processes are adequately described and to determine the level of confidence which can be assigned to model results. Where possible, this validation should be against observed data from experiments in the field. Frequently, such data are not available for new compounds, and so the use of benchmark compounds for comparison between model predictions and observed behaviour can be a useful tool. Ideal benchmarks should resemble the test chemical as closely as possible and be established compounds with a history of results from monitoring in the environment.

Having validated the selected model against measured data and established that it adequately describes the relevant environmental dissipation processes, it can now be used with confidence to make predictions about the behaviour of the compound under other environmental conditions. Detailed mechanistic models require comprehensive data inputs and constraints on the data and time available therefore make their use for a wide range of situations difficult. To overcome this, a number of scenarios are selected which are representative of *reasonable* average or worst-case conditions under the proposed usage. Detailed modelling is thus carried out for a number of scenarios which are specific to a given compound. Although this approach introduces a degree of subjectivity into the modelling procedure, it ensures that predicted environmental concentrations are directly relevant to use of the compound in question.

Detailed mechanistic modelling yields potential environmental concentrations of pesticide in a number of point situations which are indicative of the maximum concentrations expected under the proposed usage. However, the actual environmental impact of a pesticide will depend upon the use pattern of the compound and upon environmental parameters which vary spatially and temporally across the landscape. To take account of this, simpler models with less intensive data requirements can be used and linked to national soil, cropping and climate datasets to give national assessments of the pattern and intensity of environmental impact (Hollis, 1991). In changing from a detailed mechanistic model to a simpler model, it is essential to ensure that the simplifying assumptions inherent in the model do not invalidate model results. Predictions from the simpler model should be compared either with field data for the pesticide in question or with results from the more detailed model.

Having established its validity, the simpler model is run for all possible combinations of categories for environmental factors such as soil, substrate and climate. By using the full range of pesticide properties determined in laboratory and field results, a range of potential environmental concentrations can be calculated. This range is then compared to threshold concentrations, based upon legislative or toxicological considerations, to assign a vulnerability classification to a given scenario (Hollis & Brown, 1993). Maps of vulnerability can be generated using either a geographical information system or the raster-based data manipulation method illustrated later in this paper.

Where impact to an environmental compartment receiving inputs from a wide catchment area (e.g. a major river or an aquifer) is being investigated, the pattern of use of the pesticide in question will be a significant factor. In the first instance, impacts can be refined by considering only those areas suitable for cultivation of the crop(s) to be treated. Alternatively, knowledge of the actual proportion of crop to be treated within a given area can be used to assess the effect of dilution by leachate or drainage from non-use areas in reducing overall impacts within the catchment.

## ASSESSMENT OF THE POTENTIAL FOR CONTAMINATION OF WATER SOURCES BY EPOXICONAZOLE

In order to illustrate the modelling protocol outlined above, an assessment of the potential for contamination of water sources by a novel fungicide is described. The test compound, epoxiconazole, is a triazole fungicide for post-emergence use in cereals. The range of pesticide properties obtained from field and laboratory studies is given in Table 1 and show epoxiconazole to be persistent and only slightly mobile. An initial appraisal of likely fate and behaviour in the environment indicated that significant leaching of the test compound was unlikely to occur under UK conditions, but that the potential for movement to surface waters required investigation. Two applications of 125 g/ha are likely to be applied in spring and summer, but an autumn application is not prohibited and this scenario was also considered. Finally, there is the potential for repeat applications of epoxiconazole in successive seasons, so applications over three years were simulated to investigate any potential for accumulation of the compound in soil.

TABLE 1. Summary of pesticide properties selected for the modelling study

| Property | Epoxiconazole (average case) | Epoxiconazole (worst case) | Propiconazole | Dieldrin |
|---|---|---|---|---|
| Water solubility (mg/l) | 6.6 | 6.6 | 110 | 0.17 |
| Soil DT50 (d) | 84 | 109 | 110 | 1650 |
| Koc (ml/g) | 1568 | 957 | 650 | 9440 |
| Vapour pressure (mm Hg) | $7.5 \times 10^{-8}$ | $7.5 \times 10^{-8}$ | $4.2 \times 10^{-7}$ | $3.8 \times 10^{-6}$ |
| Application rate (g a.i./ha) | 125 | 125 | 125 | 3250 |
| Application dates | 21 Apr<br>21 May | 21 Dec<br>21 Apr | 21 Apr<br>21 May | 15 Sep |

Selection of suitable models and reasonable worst-case scenarios

The main focus of this assessment was the potential for movement of test compound to surface waters in surface runoff and drainflow from arable land. Neither of these hydrological processes is well described by the models which are currently available, but PRZM-2 was selected to investigate surface runoff because it is widely used and well-supported. No established model to simulate movement of pesticides to drains was available at the time of the study. Therefore, this was investigated by using leaching models to simulate vertical movement and then assuming that drainwater concentrations were the same as those in soil water at the appropriate depth below the surface. PRZM-2 and LEACHP were used to simulate this pathway and were also run to check the assumption that leaching to depth would not occur under UK conditions. This was confirmed and it was concluded that concentrations of epoxiconazole in groundwater are very unlikely to exceed 0.1 µg/l.

Leaching and runoff losses for epoxiconazole were simulated from two representative soil types. Soils of the Wick series are deep, free-draining sandy loams which have low water retention and organic matter contents and overlie local aquifers or groundwater bodies at between 2 and 10 metres from the surface. These soils are extensively used for arable cropping and have a high soil leaching potential (NRA, 1992). By contrast, soils of the Brockhurst series are slowly permeable, seasonally wet medium loams over clays which typify an extensive hydrological soil type which produces consistently good yields of cereals when properly drained. Such soils have a high surface water vulnerability and adjacent surface waters respond rapidly to rainfall, either because of runoff via overland flow or saturated upper soil layers or because of rapid bypass flow through cracks and coarse pores to drains.

To calculate movement of pesticide to surface waters, runoff from the Wick soil was simulated using PRZM-2 whilst both runoff and movement to drains at 60 cm depth were simulated for the Brockhurst soil using PRZM-2 and LEACHP. Soils input parameters including slope, structural factors, and management practices were selected to simulate movement under 'average' and 'reasonable worst-case' conditions. Slopes of 2° and 7° and of 2° and 5° were modelled to cover the range of likely conditions on these two soil types and the worst-case scenario for the Wick soil incorporated a slaked surface in order to generate as much runoff as possible.

Weather data were selected from a ten-year run from Rosemaund, near Hereford. This area is representative of the wetter cereal-growing areas in the west of England. The year selected was 1981 (annual rainfall 728 mm) and this was actually the second wettest year in the period, but was selected after blank runs through LEACHP because it gave the largest volume of leachate in late spring after application of epoxiconazole. Four successive sequences of the 1981 data were run to generate a worst-case data set to investigate possible effects of accumulation of pesticide in soil.

### Benchmark compounds

Field results were not available for validation of the detailed modelling carried out. Hence, two benchmark compounds were selected and included in the simulations in order to aid interpretation of model results. The two compounds chosen were propiconazole and dieldrin and the properties of each are given in Table 1. Propiconazole is a fungicide, largely for use on cereals, with similar properties and application details to epoxiconazole. Despite being the 7th most-used pesticide in England and Wales for 1990 in terms of area treated (Davis *et al.*, 1991), this pesticide is not reported to have contaminated water sources (DWI, 1991). Up to four applications of propiconazole can be applied to a crop in one season according to the label, but only two were simulated to enable a closer comparison with epoxiconazole. Dieldrin was chosen as a benchmark as the only pesticide with a large Koc value which has been widely investigated and reported to contaminate surface waters (e.g. Harrod, 1991). In order to simplify simulation of the fate of dieldrin, the parent-daughter relationship between aldrin and dieldrin was ignored and a single application of 3.25 kg/ha dieldrin was modelled to tie in with the last approved agricultural use of aldrin in the UK.

### Results of detailed modelling under reasonable worst-case conditions

As described above, modelling with LEACHP and PRZM-2 predicted that there would be no significant movement of epoxiconazole to depth because of the high degree of sorption to soil materials. Consequently, contamination of groundwater supplies is extremely unlikely under the proposed conditions of use.

The results of using PRZM-2 to simulate movement of epoxiconazole and the two benchmark compounds to surface waters are summarised in Tables 2 and 3 for runoff and erosive losses, respectively. The model predicted that all three pesticides would be present dissolved in runoff and sorbed to sediment moving from the sites simulated. Average concentrations are considerably distorted by predicted concentrations in the first events after application which are known to be greatly overestimated by PRZM-2. The model is currently being modified to resolve this problem (R.F. Carsel, personal communication). Nevertheless, the data could be interpreted as showing a significant potential for epoxiconazole to move into surface waters. However, it should be noted that the simulations are based on a simple scenario looking at edge of field losses from a uniformly sloping field. When looking at the likely effect of such runoff on surface waters, factors such as dilution by stream and other waters and redeposition of eroded sediment before it reaches a water course need to be taken into account. It is therefore necessary to place the predicted concentrations of epoxiconazole into context by comparing them with predicted concentrations of the benchmark compounds.

TABLE 2. Predictions from PRZM-2 for concentrations of pesticides in runoff

| Scenario | Seasonal loss of runoff (mm) | Average pesticide concentration (μg/l) Epoxiconazole | Propiconazole | Dieldrin |
|---|---|---|---|---|
| Wick (average) | 35.5 | 4.9 | 10.0 | 37.0 |
| Wick (worst-case) | 46.5 | 7.6 | 9.3 | 36.2 |
| Brockhurst (average) | 52.8 | 11.3 | 19.3 | 84.9 |
| Brockhurst (worst-case) | 56.6 | 15.4 | 22.1 | 99.6 |

TABLE 3. Predictions from PRZM-2 for concentrations of pesticides sorbed to sediment in runoff

| Scenario | Seasonal loss of sediment (kg/ha) | Average pesticide concentration (mg/kg) Epoxiconazole | Propiconazole | Dieldrin |
|---|---|---|---|---|
| Wick (average) | 105 | 0.3 | 0.2 | 15.0 |
| Wick (worst-case) | 840 | 0.6 | 0.5 | 30.4 |
| Brockhurst (average) | 327 | 1.5 | 1.0 | 75.9 |
| Brockhurst (worst-case) | 1697 | 1.3 | 0.7 | 54.4 |

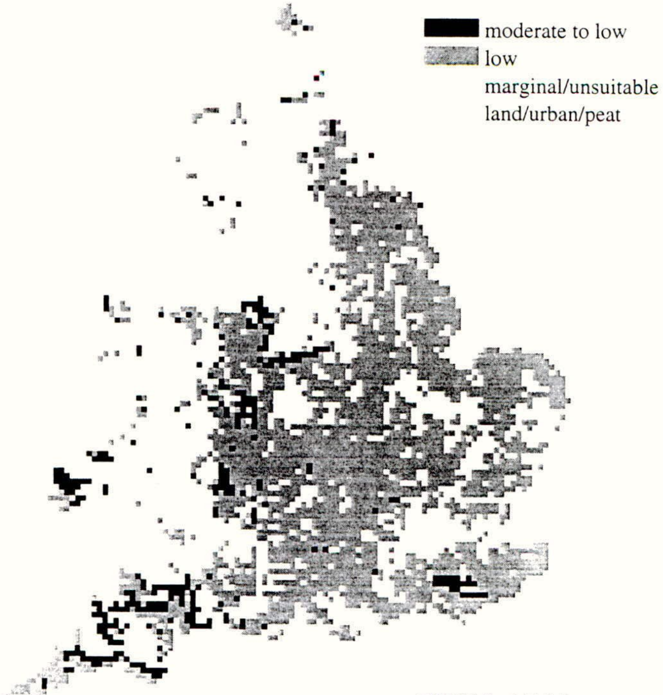
PRZM-2 predicted larger concentrations of propiconazole in runoff than of epoxiconazole, but the former has very rarely been detected above 0.1 μg/l in water supplies in the UK despite its widespread use. In contrast, dieldrin was specifically chosen as a benchmark compound because it had been found in surface waters. However, average concentrations predicted by PRZM-2 (36-100 μg/l in solution and 15-76 mg/kg sorbed to sediment) are considerably larger than maxima reported by Carey & Kutz (1985) in a review of data for the USA of 0.6 μg/l in solution and 5 mg/kg sorbed to sediment. Results for the two benchmarks underline the potentially large differences between concentrations predicted at edge-of-field and those actually found in surface waters after dilution and redeposition of sediment. It was concluded that there was some potential for epoxiconazole to be present in both runoff waters and sediments eroded from fields to which it has been applied, but that subsequent dilution and/or redeposition will be such that it is unlikely to cause significant contamination of any local surface waters.

### National vulnerability assessment for surface waters

In order to aid interpretation of the significance of laboratory and field studies and the detailed modelling described above, a national assessment was made of the vulnerability of surface waters to contamination by epoxiconazole under its proposed usage. The methodology for carrying out the assessment has been described by Hollis (1991) and by Hollis & Brown (1993) and involves linking a simple model to spatial datasets for soil, climate and land suitability. This assessment made no allowance for the actual pattern of application within the potential use area, although this is easily done by overlaying copping data corrected for actual or predicted market share. In order to account for spatial variability, the model is run using the full range of pesticide properties derived from laboratory and field experiments and overall vulnerabilities are derived by comparing predicted concentrations using best- and worst-case properties with an environmental threshold value (in this case 0.1 µg/l). The model assesses total losses to surface waters via surface runoff, lateral flow through the soil and drainflow and so takes account of more processes than considered by PRZM-2.

Generally, concentrations of epoxiconazole predicted to impact upon surface waters were less than 0.1 µg/l. Concentrations of between 0.1 and 0.3 µg/l were predicted for certain soils with a high potential for generating surface runoff in the wetter areas of England and Wales. A 'moderate to low' vulnerability assessment was assigned to these soils indicating a risk of some contamination of surface waters under extreme conditions and assuming worst-case pesticide properties. This result tied in with the more detailed modelling which indicated that surface runoff would be the only major pathway for movement of epoxiconazole to surface waters. No areas of England and Wales were assigned a vulnerability of 'moderate', 'moderate to high' or 'high'. The overall vulnerability assessment for surface waters in England and Wales is shown in Figure 2.

FIGURE 2. Surface water vulnerability assessment for epoxiconazole on land well or moderately suitable for winter wheat or barley



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## CONCLUSIONS

A sequential modelling technique has been described which interprets laboratory and field data to determine dominant environmental processes and fate and behaviour under reasonable worst-case conditions. This information is then extrapolated to the wider environment, thus facilitating identification of the most vulnerable areas and the development of appropriate measures to minimise risk. Only by considering risk on a case by case basis can we optimise protection of the environment and exploitation of the agronomic benefits offered by a given compound.

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## REFERENCES

Carey, A.E.; Kutz, P.W. (1985) Trends in ambient concentrations of agrochemicals in humans and the environment of the United States. *Environmental Monitoring and Assessment* **5**, 155-163.

Davis, R.P.; Garthwaite, D.G.; Thomas, M.R. (1991) Pesticide usage survey report 85. Arable farm crops in England and Wales 1990. MAFF Publications, London.

DWI (1991) Drinking water 1990. A report by the Chief Inspector Drinking Water Inspectorate, HMSO, London.

Harrod, T.R. (1991) Analyses undertaken in support of the study of land use practices and pathways of pesticide residues in the Mount's Bay catchment, Cornwall. SSLRC Research Report for SSLRC Project No. 82/2982.

Hollis, J.M. (1991) Mapping the vulnerability of aquifers and surface waters to pesticide contamination at the national/regional scale. In: *Pesticides in soil and water: current perspectives,* A. Walker (Ed), BCPC Monograph No. 47, Lavenham Press Limited, Lavenham, Surrey, pp. 165-174

Hollis, J.M.; Brown, C.D. (1993) An integrated approach to aquifer vulnerability mapping. In: *Mobility and degradation of xenobiotics. Proceedings of the IX symposium on pesticide chemistry,* Università Cattolica del Sacro Cuore, Piacenza, Italy, pp. 633-644.

NRA (1992) Policy and practice for the protection of groundwater. National Rivers Authority, Almondsbury, Bristol.

Wagenet, R.J.; Rao, P.S.C. (1991) Modelling pesticide fate in soils. In: *Pesticides in the soil environment: processes, impacts and modelling,* H.H. Cheng (Ed), SSSA Book Series No. 2, Madison, Wisconsin, pp. 351-399.

# ARTHROPOD POPULATIONS UNDER CURRENT AND REDUCED-INPUT PESTICIDE REGIMES: RESULTS FROM THE FIRST FOUR TREATMENT YEARS OF THE MAFF "SCARAB" PROJECT

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## ABSTRACT

The MAFF-funded SCARAB project ("Seeking Confirmation About Results At Boxworth") was initiated in 1990 to answer questions raised by the Boxworth project (1981-1988). Boxworth examined effects of intensive pesticide use on wildlife in winter wheat on a farm in eastern England. Monitoring over five years indicated that non-target arthropods were particularly vulnerable to intensive pesticide use. SCARAB aims to determine whether such side-effects of pesticide use also occur in other crops, at other locations, and with current pesticide inputs. In SCARAB, the arthropod populations are routinely monitored at three farms, on each of which fields were split into "Reduced Input Approach" (RIA) and "Current Farm Practice" (CFP) treatments. Data from the first four treatment years of this long-term project indicated that most damage to populations of non-target arthropods was done by autumn- and winter-applied broad-spectrum insecticides. The overall results and their implications are discussed in relation to the ecological effects of pesticides on non-target invertebrates.

## INTRODUCTION

The application of pesticides may cause short-term or long-term effects on non-target arthropod populations. Short-term effects may result from direct or indirect exposure to the chemical and can usually be detected shortly following pesticide applications. On the other hand, long-term effects may be slow to develop and although less obvious initially may become permanent, for example through repeated population perturbations with poor reinvasion from surrounding areas. The short-term (within-season) effects of pesticides on non-target invertebrates have been relatively well-researched in the UK and elsewhere (Çilgi, 1994*a*). A number of field studies have shown adverse effects on arthropod populations following individual pesticide applications (Vickerman & Sunderland, 1977; Powell *et al.*, 1985; Cole *et al.*, 1986; Vickerman *et al.*, 1987; Brown *et al.*, 1988; Smart *et al.*, 1989; Thomas *et al.*, 1990; Pullen *et al.* 1992; Duffield & Aebischer, 1994 *inter alia*). These and other short-term studies examined the effects of single applications of one pesticide whereas in commercial farming practices numerous chemicals may be applied within a season, both as mixtures and repeated applications. For example, according to the UK MAFF 1992 Pesticide Usage Survey Report (Davis *et al.*, 1993), the number of pesticide products applied varied from 3.3 to 13.2 per annum depending on the type of arable crop. Therefore, such studies cannot identify any cumulative effects of repeated exposure to one or a number of chemicals, which may not allow recovery of the exposed populations between treatments.

The MAFF Boxworth project was the first long-term experimental study to investigate non-target effects of pesticides in the UK. Starting in 1981, its main aim was to examine the overall effects of pesticides on birds, small mammals, soil fauna, crop invertebrates and plants in cereal fields at Boxworth Research Centre (Greig-Smith *et al.*, 1992). At the end of the project (i.e. 1988), monitoring had revealed clear effects of the contrasting pesticide inputs indicating that the sustained prophylactic use of a wide range of pesticides was causing harmful effects to some groups of non-target arthropods (Burn, 1992; Vickerman, 1992). Monitoring of birds, small mammals and plants, indicated that there were no obvious long-term effects on these groups under the experimental conditions at Boxworth.

The Boxworth project subsequently led to the setting up of a new long-term project called SCARAB (Seeking Confirmation About Results At Boxworth). The SCARAB project aims to investigate whether such adverse effects occur elsewhere in England in different arable crops, and with pesticide inputs more typical of those in use in the 1990s.

## MATERIALS AND METHODS

A summary of important aspects of the SCARAB project is given below. Further details of its background, design and layout were given elsewhere (Cooper, 1990; Çilgi *et al.*, 1993; Frampton & Çilgi, 1992, 1993).

### Experimental design

The SCARAB experimental set-up involves comparing two different pesticide regimes in seven fields. The study fields range in size from 8 to 32 ha. Each field was split into two halves to allow comparisons between the two contrasting pesticide regimes which will continue for six years. The study fields are sited at three ADAS Research Centres (Drayton, Gleadthorpe and High Mowthorpe) in central and northern England. The crops grown are part of six-course rotations, each typical of the region in which the farm is situated. They include cereals, grass ley, root crops (sugar beet and potatoes), field beans and oilseed rape.

### Pesticide regimes

Two pesticide regimes are compared in the project: "Current Farm Practice" (CFP) represents average pesticide use, based on recent pesticide usage surveys and "Reduced Input Approach" (RIA) represents a managed, lower input of pesticides based on monitoring pests, weeds and diseases in the crop. The RIA regime aims to avoid the use of insecticides if possible. The experimental protocol allows for pesticide treatments to evolve according to changes indicated in the pesticide usage surveys. The only differences between the CFP and RIA halves of the study fields are in pesticide inputs; cropping and husbandry do not differ.

During the baseline year (1989-1990), all fields received only the CFP pesticide input appropriate to the particular crop. This was to allow arthropod populations to be monitored in the study fields prior to the treatment phase of the project. At the start of the 1990-1991 crop year, all fields were split in half. One half of each field retained the CFP regime and the other half was switched to a RIA regime. These contrasting pesticide regimes in each field will continue until harvest in 1996.

Arthropods have been monitored routinely since summer 1990 by pitfall trapping and suction (D-vac) sampling at matched locations in the CFP and RIA areas of each field.

## RESULTS AND DISCUSSION

In the first four treatment years, a total of 132 pesticides (28 insecticides) were applied at full label recommended rates to the CFP halves of the seven study fields. During this time no insecticides were applied to the RIA halves of fields and overall the RIA received less than 50% of CFP fungicides and herbicides. Although the project was designed to evaluate the long-term effects of overall pesticide use, the adverse effects observed so far have been attributed to a handful of insecticides. As yet there is no clear evidence that fungicides and herbicides had any substantial effects on beneficial arthropods.

The beginning of the major arthropod population declines coincided in time with the application of some broad-spectrum insecticides, especially those sprayed in autumn and winter rather than in summer. This was also the case in the Boxworth project (Burn, 1992; Vickerman, 1992). A possible explanation is that species which overwinter in the field are very likely to be exposed to autumn and winter applications when there is little vegetation cover, whereas crop cover is more dense in summer. Five different active ingredients were applied in autumn and winter: the organophosphates chlorpyrifos (in "Field 5" and "Near Kingston") and omethoate (in "South" and "Field 1"), the carbamate aldicarb (in "Balk" and "South") and the synthetic pyrethroids cypermethrin (in "Near Kingston") and deltamethrin (in "Field 1"). Of these, harmful effects of chlorpyrifos both in "Field 5" (Drayton Research Centre) and "Near Kingston" (Gleadthorpe Research Centre) fields were obvious on a range of arthropods (Çilgi *et al.*, 1993). Recovery took longer than six months for many arthropods following the first chlorpyrifos spray in "Field 5" (Figs 1 and 2 show examples from one field). Chlorpyrifos has also been shown to be detrimental to beneficial arthropods, including those affected in the current work, in other studies (Luff *et al.*, 1990; Asteraki *et al.*, 1992).

Although no effect of omethoate was detectable, this compound was applied in "South" field (Gleadthorpe Research Centre) on 3 March 1992 when few beneficial arthropods were trapped. Therefore, potential exposure to the spray would have been minimal for most taxa. However, short-term adverse effects were observed following another application of omethoate on 28 May 1993 when there were relatively high numbers of arthropods in "Field 1" at Drayton Research Centre. No adverse effects of aldicarb were detected in this study which is monitoring epigeal arthropods. Although having broad-spectrum properties, this insecticide was drilled into the soil as granules and probably posed less of a hazard to epigeal arthropods than a surface treatment would have done. In addition, this compound was applied on 5 March 1991 and 10 April 1994 when few non-target arthropods were trapped in "Balk" and "South" fields of Gleadthorpe Research Centre.

In the case of cypermethrin and notably deltamethrin, their clear effects were mainly confined to money spiders (Frampton & Çilgi, 1993). Pyrethroids are well known to be particularly detrimental to spiders (Cole *et al.*, 1986; Brown *et al.,* 1988; Thomas *et al.,* 1990; Pullen *et al.*, 1992). However, these studies have also demonstrated that spiders are able to recover from autumn pyrethroid-induced population perturbation by the following summer. This was also the case in the present study fields, despite the additional herbicide and fungicide use which was not examined at the same time in the studies mentioned above.

Except for Collembola (Fig. 2), consistent and long-lasting differences in excess of two months between the CFP and RIA arthropod catches were not observed after summer applications of insecticides. Applications included the carbamate pirimicarb and the organophosphates dimethoate and triazophos and no long-term effects were evident even for those species considered most likely to be vulnerable (Burn, 1992; Çilgi, 1994*b*). The persistence of major differences between RIA and CFP catches of Collembola (Fig. 2) cannot as yet be unequivocally attributed solely to insecticide use because several species are sensitive to fungicide use (Frampton, 1994). Pirimicarb is widely regarded as a selective aphicide and has been demonstrated as harmless to many beneficial arthropod groups in a number of short-term studies (Cole & Wilkinson, 1984; Powell *et al.*, 1985; Smart *et al.*, 1989). On the other hand, dimethoate is widely considered as broad-spectrum and detrimental to most arthropod groups (Vickerman & Sunderland, 1977; Powell *et al.*, 1985; Cole *et al.*, 1986; Vickerman *et al.*, 1987; Duffield & Aebischer, 1994). However, these studies indicated that recovery always occurred after short-term population reductions. Results from the SCARAB project so far are in line with those of the above studies showing short-term declines in arthropod numbers after a dimethoate spray and no tangible effect of pirimicarb.

A second chlorpyrifos spray applied to "Field 5" in summer 1994 to control frit fly (*Oscinella frit*) in grass had detrimental effects on farmland arthropods (Figs 1 and 2). However, it is too early to determine the persistence of these effects because post-spray data have only been available for a month following the spray application at the time of writing.

Although the results of the first four treatment years of the SCARAB project are broadly similar to those found in the above short-term studies and the long-term Boxworth project, two aspects of the SCARAB project distinguish it substantially from other investigations of the effects of pesticides on non-target arthropods. These are (1) most of the results obtained in the previous short- and long-term studies came from cereal ecosystems, whereas the SCARAB project has been gaining information on the potential harmful effects of pesticides in other arable rotations, and (2) SCARAB was set up to compare the ecological effects of overall current and reduced-input pesticide regimes and will provide information on the environmental impact of reducing pesticide inputs. This is a topical issue as most farmers are now moving closer to sustainable farming in Europe and elsewhere for environmental and/or economical reasons (Holland *et al.*, 1994).

In conclusion, it is important to emphasize that the SCARAB project is an ongoing project and was not designed to monitor effects of individual chemicals so it remains to be seen whether future pesticide use, or cumulative effects of previous applications, will affect arthropod populations. Some serious side-effects of pesticide use at Boxworth did not occur until half-way through the treatment phase of the study and declines in some species appear to have been triggered by atypical weather conditions which led to a combination of unusually

Figure 1. Pitfall trap catches of Coleoptera (all families grouped together) in SCARAB project Field 5 (Drayton).

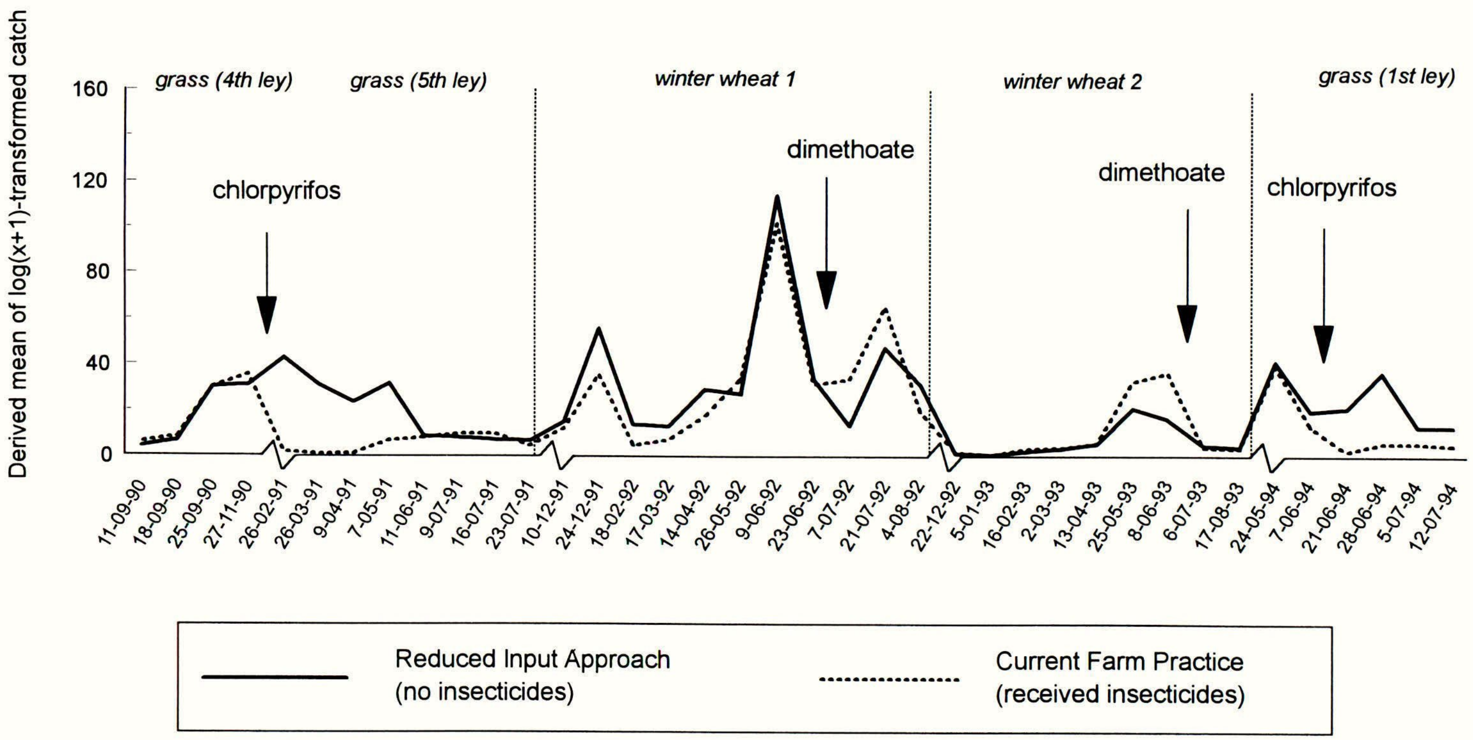
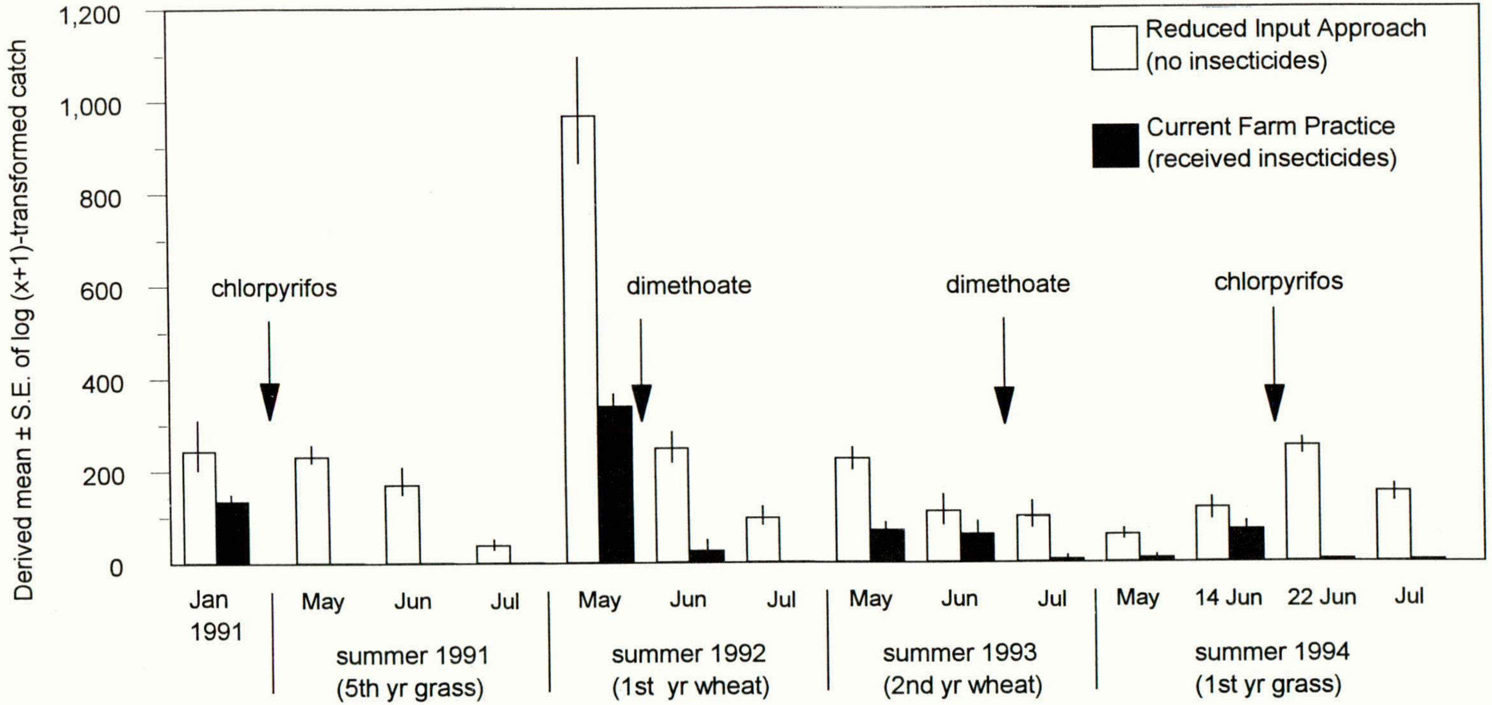


Figure 2. Suction sample catches of Collembola sub-order Arthropleona in SCARAB project Field 5 (Drayton).



late winter pesticide applications and exceptionally poor crop cover in 1986 (Vickerman, 1992). Clearly, the longer the duration of a study, the greater chance it has of including "rare events" which could be ecologically important. Indeed, most ecological studies are short-term (Hassell *et al.*, 1989) and are therefore less likely to detect density dependence and other population mechanisms which operate over long periods. The transient occurrence of species should also be considered, for example the numbers of some species of *Helophorus* (Hydrophilidae) and *Bembidion lunulatum* (Carabidae) were substantially reduced after the chlorpyrifos spray in "Field 5" in January 1991 (Frampton & Çilgi, 1992). However, these beetles have not been trapped in either the RIA or CFP areas of "Field 5" in the subsequent treatment years. This transient occurrence did not enable us to establish a clear relationship between the chlorpyrifos application and the subsequent population reductions, despite intensive monitoring.

## ACKNOWLEDGEMENTS

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## REFERENCES

Asteraki, E.J.; Hanks, C.B.; Clements, R.O. (1992). The impact of two insecticides on predatory ground beetles (Carabidae) in newly-sown grass. *Annals of Applied Biology*, **120**, 25-39.

Brown, R.A.; White, J.S.; Everett, C.J. (1988). How does an autumn-applied pyrethroid affect the terrestrial arthropod community? In: *Field methods for the study of environmental effects of pesticides*, M.P. Greaves, B.D. Smith & P.W. Greig-Smith (Eds), *BCPC Monograph No. 40*, Thornton Heath: BCPC Publications, pp 137-145.

Burn, A.J. (1992). Interactions between cereal pests and their predators and parasites. In: *Pesticides, cereal farming and the environment,* P.W. Greig-Smith, G.K. Frampton & A.R. Hardy (Eds), pp 110-131. HMSO, London.

Çilgi, T. (1994*a*). Effects of pesticides on non-target invertebrates in arable fields and field boundaries. PhD thesis, University of Southampton.

Çilgi, T. (1994*b*). Selecting arthropod "indicator species" for environmental impact assessment of pesticides in field studies. *Aspects of Applied Biology*, **37**, 131-140.

Çilgi, T.; Wratten, S.D.; Frampton, G.K.; Holland, J.M. (1993). The long-term effects of pesticides on beneficial invertebrates- lessons from the Boxworth Project. *Pesticide Outlook*, **4** (4), 30-35.

Cole, J.F.H.; Wilkinson, W. (1984). Selectivity of pirimicarb in cereal crops. *1984 British Crop Protection Conference - Pests and Diseases*, **1**, 311-316.

Cole, J.F.H.; Everett, C.J.; Wilkinson, W.; Brown, R.A. (1986). Cereal arthropods and broad-spectrum insecticides. *1986 British Crop Protection Conference - Pests and Diseases*, **1**, 181-188.

Davis, R.P.; Thomas, M.R.; Garthwaite, D.G.; Bowen, H.M. (1993). *Pesticide usage survey report 108: arable farm crops in Great Britain 1992*. MAFF, London.

Cooper, D.A. (1990). Development of an experimental programme to pursue the results of the Boxworth Project. *1990 Brighton Crop Protection Conference - Pests and Diseases*, **1**, 153-162.

Duffield, S.J.; Aebischer, N. J. (1994). The effect of spatial scale of treatment with dimethoate on invertebrate population recovery in winter wheat. *Journal of Applied Ecology*, **31**, 263-281.

Frampton, G.K. (1994). Sampling to detect effects of pesticides on epigeal Collembola (springtails). *Aspects of Applied Biology*, **31**, 69-76.

Frampton, G.K.; Çilgi, T. (1992). Long-term effects of pesticides on arthropods in U.K. arable crops: preliminary results from the "SCARAB" project. *Aspects of Applied Biology*, **31**, 69-76.

Frampton, G.K.; Çilgi, T. (1993). Boxworth and SCARAB: Approaches to the long-term study of side effects of pesticide use on terrestrial invertebrates. *ANPP & BCPC Second International Symposium on Pesticides Application Techniques*, **2**, 399-406.

Greig-Smith, P.W.; Frampton, G. K.; Hardy, A. R. (Eds) (1992). *Pesticides, cereal farming and the environment*, HMSO, London, 288 pp.

Hassell, M.P.; Latto, J.; May, R.M. (1989). Seeing the wood for the trees: detecting density dependence from existing life-table studies. *Journal of Animal Ecology,* **58**, 883-892.

Holland, J.M.; Frampton, G.K.; Çilgi, T.; Wratten, S.D. (1994). Arable acronyms analysed- a review of integrated arable farming systems research in Europe. *Annals of Applied Biology* (in press).

Luff, M.L.; Clements, R.O.; Bale, J.S. (1990). An integrated approach to assessing effects of some pesticides in grassland. *1990 Brighton Crop Protection Conference - Pests and Diseases*, **1**, 143-152.

Powell, W.; Dean, G.J.; Bardner, R. (1985). Effects of pirimicarb, dimethoate and benomyl on natural enemies of cereal aphids in winter wheat. *Annals of Applied Biology*, **106**, 235-242.

Pullen, A.J., Jepson, P.C. & Sotherton, N.W. (1992). Terrestrial non-target invertebrates and the autumn application of synthetic pyrethroids: experimental methodology and the trade-off between replication and plot size.*Archives of Environmental Contamination and Toxicology*, **23**, 246-258.

Smart, L.E., Stevenson, J.H. & Walters, J.H.H. (1989). Development of field trial methodology to assess short-term effects of pesticides on beneficial arthropods in arable crops. *Crop Protection*, **8**, 169-180.

Thomas, C.F.G., Hol, E.H.A. & Everts, J.W. (1990). Modelling the diffusion component of dispersal during recovery of a population of linyphiid spiders from exposure to an insecticide. *Functional Ecology*, **4**, 357-368.

Vickerman, G. P. (1992). The effects of different pesticide regimes on the invertebrate fauna of winter wheat. In: *Pesticides, cereal farming and the environment*, P.W. Greig-Smith, G.K. Frampton & A.R. Hardy (Eds), HMSO, London, pp 82-108.

Vickerman, G.P.; Sunderland, K.D. (1977). Some effects of dimethoate on arthropods in winter wheat. *Journal of Applied Ecology*, **14**, 767-777.

Vickerman, G.P.; Coombes, D.S.; Turner, G.; Mead-Briggs, M.A.; Edwards, J. (1987). The effects of pirimicarb, dimethoate and deltamethrin on Carabidae and Staphlinidae in winter wheat. *Mededelingen van de Faculteit Landbouwwetenschappen Rijksuniversiteit Gent*, **52**, 213-233.

# PESTICIDE REGULATORY TESTING PROCEDURES WITH BENEFICIAL ARTHROPODS : RECOMMENDATIONS ARISING FROM THE SETAC-ESCORT WORKSHOP

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## ABSTRACT

There has been significant development in testing methods with respect to assessing pesticide effects on non-target arthropods. With the increase in regulatory testing and IPM assessment of products there was a need to bring together relevant experts with the aim of reaching a consensus view on regulatory testing requirements for non-target arthropod species. This was considered to be particularly relevant in the light of the European harmonisation of registration of crop protection products, and support for this initiative was received from the EC. The discussions and recommendations coming from this workshop are summarised, and the implications for interpretation of data, risk assessment and management considered.

## INTRODUCTION

The testing of the effects of pesticides on non-target arthropods for regulatory and integrated pest management (IPM) purposes has been the subject of many discussions. There has been considerable activity in the development of testing methods and strategies, particularly by such groups as BART (Beneficial Arthropod Regulatory Testing Group), IOBC (International Organisation for Biological Control) and EPPO/CoE (European and Mediterranean Plant Protection Organisation with the Council of Europe). In view of these activities, and the development by the European Commission of Council Directive 91/414/EEC concerning the placing of plant protection products on the market, a need for consensus in the regulatory testing requirements, and risk assessment for non-target arthropods was recognised.

To help work towards this consensus in testing, a three day workshop was organised by members of BART, IOBC, EPPO/CoE in conjunction with SETAC-Europe and with the support of the European Commission (DGVI). The workshop brought together 35 scientists and technical experts, principally from European countries, experienced in areas related to non-target arthropod testing.

The objective of the workshop was to develop a guidance document for the testing of the effects of pesticides to non-target arthropods for regulatory purposes, particularly with respect to EC Directive 91/414/EEC, and which could also be used in conjunction with the risk assessment scheme for arthropod natural enemies developed by EPPO/CoE (EPPO/CoE, 1994).

To achieve this objective the participants of the workshop were split into five working groups and summaries from each are provided in the following sections.

## SELECTION OF TEST SPECIES

The need to select a limited number of species for testing to predict risk was recognised, since it would be impossible to test all species that may be exposed. The selected species should also belong to the group of arthropod natural enemies, since information on the potential use in IPM systems may also be obtained. However it was agreed that registration testing cannot provide the detailed information required for IPM recommendation, and that the valuable work of the IOBC would need to continue to fulfil this requirement.

### Recommended test species

The selection of test species should be based upon their sensitivity to pesticides, relevance in the field environment and amenability. Two main crop categories, arable and orchards, were identified. The arable category includes all vegetable, cereal and forage crops. The orchard category includes vineyards and glasshouse crops because of the overlap of species occurring in these environments. Some outlets requiring unique studies were also identified e.g. forestry and citrus. Species were also categorised into four functional groups, parasitoids, predatory mites, ground dwelling predators and foliage dwelling predators.

On the basis of these criteria a table of preferred test species was drawn up (Table 1), and using this the the numbers of tests and species required to fulfil EC regulatory requirements was considered.

### Authorisation of active ingredient (Annex II)

It was recommended that in order to fulfil the Annex II data requirements of the EC Directive, two sensitive standard test species and two species relevant to the intended use of the product are tested (Table 1). The recommended standard species are *Aphidius rhopalosiphi* and *Typhlodromus pyri*, results from *Trichogramma cacoeciae* and *Amblyseius sp.* may be preferable if ring tests show these species to be suitable and more sensitive. The test substance to be used to fulfil Annex II requirements should be the lead formulation rather than the active ingredient.

TABLE 1. Selection of the relevant test species.

| **Crop Type** | **Parasitoids** | **Predatory Mites** | **Ground Dwelling Predators** | **Foliage Dwelling Predators** |
|---|---|---|---|---|
| Orchard | *Aphidius rhopalosiphi*<br>*Trichogramma cacoeciae*<br>*Leptomastix dactylopii*[1]<br>*Drino sp.*[2] | *Typhlodromus pyri*<br>*Amblyseius sp.*[5] | *Pardosa sp.*[4]<br>*Poecilus cupreus* | *Orius sp.*[5]<br>*Episyrphus balteatus*<br>*Chrysoperla carnea*<br>*Coccinella septempunctata* |
| Arable crops | *A. rhopalosiphi*<br>*T. cacoeciae* | | *P. cupreus*<br>*Pardosa sp.*[4]<br>*Aleochara bilineata*[3] | *E. balteatus*<br>*C. carnea*<br>*C. septempuntata* |

[1] *Leptomastix sp.* to be tested with priority if the intended use is in citrus.

[2] *Drino sp.* to be used with priority if the intended use is in forests.

[3] *A. bilineata* to be used with priority if the intended use is in vegetables.

[4] *Pardosa.* The species is not specified as field catches are used.

[5] The exact species of anthocorid and *Amblyseius* will be identified once validated methods become available.

## Authorisation of preparations (Annex III)

If during tests under Annex II, significant effects are observed, two additional species should be tested under Annex III. These two species should be relevant to the intended use of the product and should preferably belong to different taxonomic groups than those tested under Annex II.

Additional formulations of a product which are not comparable to the lead formulation already tested, will need to be tested using the two most sensitive species identified under the Annex II tests, since this will enable a comparison to be made.

## SEQUENTIAL TESTING

As with other areas of risk and fate assessment a tiered testing approach is adopted for non-target arthropod species. This subject was covered by two groups at the workshop. One considered laboratory and extended laboratory tests the other semi-field and field tests.

### Laboratory tests

Laboratory tests are the first step in evaluating the potential risk posed by an agrochemical product to non-target arthropod fauna, and as with other areas of ecotoxicity assessment these tests are designed to represent worst case with maximum exposure. However unlike other areas of regulatory testing the guidelines for non-target arthropod testing are not as well established, and certain criteria were identified which could be applied to all tests at this level.

These tests should be carried out in accordance with fully ring tested and validated methods, as with other areas of ecotoxicological assessment. Although guidelines for each of the species listed in Table 1 are not yet available, it is hoped that one outcome of the workshop will be the initiation of a ring testing and validation programme. For each of the species the test guideline needs to include species specific trigger values for successive tiers of testing, for the appropriate end points, including sublethal effects *e.g.* knockdown, and parasitism.

For these tests the lead formulation should be applied at a rate equivalent to the maximum recommended field application rate to an inert substrate, *e.g.* glass or sand.

### Extended laboratory tests

Where significant treatment-related effects are observed in the initial laboratory tests, further testing is required as part of the sequential testing regime as proposed by EPPO. This may be addressed through extended laboratory tests, which aim to answer specific questions on product toxicity, or which aim to reproduce test conditions which are closer to a field situation e.g. using treated plants or soil with the same or different life stages of the test species. These tests should again follow appropriate published guidance documents, where available.

### Semi-field and field tests

Products which have demonstrated effects in the preceding steps within the sequential testing regime will trigger further testing at the semi-field and field level. It is therefore important to have confidence in the previous steps *i.e.* to screen out the harmless products. Semi-field and field tests should represent realistic worst case situations. The semi-field test like the laboratory tests is a single species test. The field test however may be single or multi species, and is the only test in the testing scheme using completely field-based populations.

#### Semi-field tests

As with the laboratory tests, ring tested and validated semi-field methods are still required for some of the species listed in Table 1. These tests offer the next level of reality since tests are performed in the field in an appropriate crop using enclosures or cages, under natural climatic conditions. In most cases the tests will use laboratory cultured animals, released into the cage or enclosure before, or immediately after spraying, depending on the test species and method used. As with the laboratory tests, the end points will be species and method specific, including both mortality and sublethal effects.

### Field tests

The objective of the field test is usually to confirm or reject a perceived effect found in the laboratory or semi-field tests. As in the previous tests they should be used to monitor the effects of a single product only, under realistic worst case conditions. The field test offers the maximum degree of reality, but the data may be difficult to interpret due to the dynamic nature of the system, the number of variables present and the interactions taking place. Field tests should be carried out at the appropriate time of use for the product, and should incorporate the maximum recommended application rate, and number of applications. Unlike the previous tiers of testing it is not possible to follow a specified protocol for field trials. There are a number of variables which will be site and study specific, and at this level of testing some flexibility is necessary to ensure the specific areas of concern, identified in the previous tests, can be addressed. However some basic rules for the design of quality field trials were identified. There was also a recommendation that guidance documents to cover trials in specific crop environments should be prepared.

## PRINCIPLES OF TESTING

Under this heading a number of key issues were debated which crossed the boundaries of all the other groups. These included which products should be tested and at what rates. The issue of extrapolation at various levels was also addressed.

### Products to be tested

In addition to the lead formulation tested to fulfil the Annex II EC directive data requirements, other formulations which are not comparable and all co-formulations, containing more than one active ingredient, should be tested in the initial laboratory assessments. However, in the case of co-formulations, where one of the active ingredients has previously been shown to be harmful, testing could be carried out at one of the higher tiers of testing immediately.

### Application rates

A product typically applied once in a season, must be applied in the laboratory tests at the maximum recommended rate in terms of an amount/unit area. An exception to this is for products being applied as high volume sprays to certain types of crop such as those in orchards and vineyards. These are not typically sprayed as a two dimensional structure, as is the case for most arable crops. In high volume applications it is recognised that the deposit falling on any one surface will be approximately 40 percent of the total, and the amount applied may be adjusted accordingly, to represent a more realistic exposure.

Where a product is recommended for use two or three times per season, the application in the laboratory test should be made at twice the maximum recommended application rate. If the test species is harmed at this rate, i.e. exceeding the recommended threshold values, testing of the maximum application rate should be considered.

For products recommended for use four or more times per season, with a re-application interval of 14 days or less, further testing is required incorporating the proposed re-application regime to assess the build-up of sublethal and residue effects. It is likely that this could be most effectively achieved in an extended laboratory, semi-field or field test.

### Extrapolation

The issue of extrapolation at a number of levels was considered. It was recommended that effects on beneficial species tested, may be extrapolated to non-target species to give an indication of risk to non-target species of the same taxonomic group and the same trophic level. In addition, extrapolation between beneficial species in the same taxonomic group also appears feasible, at least for some groups.

Because behaviour and ecology are restricted in controlled laboratory tests, extrapolation between species would appear to be more justified at this level of testing. In semi-field conditions extrapolation between species will be more difficult because the behaviour becomes more relevant. Even similar species can behave quite differently, which may result in different exposure, and thereby alter the toxicity observed. However for the majority of cases, “harmlessness” as demonstrated in the laboratory tests can be extrapolated to field conditions for the species tested.

## INTERPRETATION OF DATA : RISK ASSESSMENT AND MANAGEMENT

The data generated through the sequential testing regime for beneficial arthropods has to be used to assess risk and ultimately to make recommendations on the use of the product to limit the risk to beneficial and non-target species.

### Risk assessment

For the purpose of classification three situations were defined together with guidance of unacceptable thresholds (Table 2)

i) Within crop non-target arthropods (non-IPM) :- These species are normally subjected to perturbations through agricultural practices, including, but not restricted to, the application of crop protection chemicals. However it is desirable to limit the impact on this group.

ii) Within crop natural enemies in IPM situations :- In these situations it is necessary to maintain the natural control capacity.

iii) Off crop non-target arthropods :- These organisms represent a natural reservoir for arthropod populations and species diversity, and may provide food for other non-target species e.g. chicks of game birds, and again it is desirable to limit impact to this group.

As was identified in the extrapolation section (principles of testing), the beneficial species recommended for testing can indicate potential risk to non-target species, and it would be possible to further minimise the risk to all non-target arthropods through a system of specific label requirements, incorporating a risk classification, low, medium or high, according to the EPPO risk assessment scheme and, where appropriate, specific use restrictions. This should include a recommendation of the suitability of the product for use in IPM systems, where the appropriate data are available.

Table 2 Classification of unacceptable risk

| **Situation** | **Threshold Guidance** |
|---|---|
| i) within crop non-target arthropods non IPM | unacceptable[2] if :<br>- no recovery occurs within reasonable time (maximum time *e.g.* one season)<br>- it causes an economically important pest resurgence |
| ii) within crop natural enemies IPM practised | unacceptable[2] if :<br>- measurable effects[1] occur on natural enemies that regulate pest populations which are of economic importance. |
| iii) off crop non-target arthropods | unacceptable[2] if :<br>- ecologically significant effects[1] occur on non- targets (only evaluate for products in the high risk category at the maximum use rate) |

[1] measureable effect based on EPPO low risk category, i.e., >30% reduction or when available,
species specific threshold values.

[2] 'Unacceptable' effects should not prevent registration, but should be managed through appropriate label restrictions.

## Risk management

Label restrictions, where required, should be simple and clear and include the risk category, (low, medium or high), to major taxonomic groups of non-target arthropods. Where necessary, appropriate use restrictions to protect within and off-crop non-target arthropods from significant effects may be recommended, e.g. buffer zone recommendations.

## DISCUSSION

The EPPO/CoE risk assessment scheme for arthropod natural enemies was accepted as forming an adequate basis for risk assessment, however several recommendations for modifications were made, these include:

i) Incorporation of species and test specific trigger values for higher tiers of testing, as opposed to the blanket 30 percent difference from controls currently used for all end points. It is hoped this will be addressed through method validation and ring testing to be initiated as a result of this workshop.

ii) Reference should be included to the extrapolation from the test species to wider taxonomic groups. A data review of laboratory, semi-field and field data could provide the necessary support for this recommendation.

iii) Additional safety factors may not be required since terrestrial non-target habitats are generally extensive and unbounded, in contrast to confined aquatic habitats. Again a full data review would confirm this proposal.

iv) The analysis of uncertainty should be applied to all risk categories, not only low.

v) Within the scheme, the option should be available to move directly from Annex II laboratory tests to semi or full field tests.

vi) Validation of the EPPO risk assessment scheme, using available data bases would be advantageous.

The area of regulatory testing and non-target arthropods is still relatively new, and the recommendations made at the ESCORT workshop represent the current state of the art. However as our knowledge and understanding of the complex systems involved increases, these recommendations will require review and undoubtedly some amendment.

## ACKNOWLEDGEMENTS

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## REFERENCES

OEPP/EPPO (1994) Decision making scheme for the environmental risk assessment of plant protection products; chapter 9, Arthropod natural enemies. Bulletin OEPP/EPPO, **24**, (1), 17-35

# Session 6C

# Rationalising Fungicide use on Cereals

| | |
|---|---|
| Chairman | Dr K Brent |
| Session Organiser | Dr P E Russell |
| Papers | 6C-1 to 6C-5 |

# THE DEVELOPMENT OF AN INTEGRATED DECISION MODEL BASED ON DISEASE THRESHOLD TO CONTROL *SEPTORIA TRITICI* ON WINTER WHEAT

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## ABSTRACT

A series of field trials was carried out in the UK to develop a threshold based decision system to control Septoria leaf blotch on winter wheat. The basic elements of the model are inoculum development, rainfall distribution, cultivar susceptibility and fungicide activity. Field studies showed that a disease threshold value based on incidence of infection on two indication leaf layers is able to provide information about the need for a fungicide treatment. The precise timing is determined by the retrospective amount and distribution of rainfall as well as cultivar susceptibility. The fungicide specific protectant and curative activity is a further element which needs to be considered.

## INTRODUCTION

Leaf blotch caused by *Septoria tritici*, perfect stage *Mycosphaerella graminicola,* has been reported as a major problem on winter wheat, especially when grown in maritime climates. Results from the UK (Thomas *et al*., 1989) and Northern Germany (Ceynova *et al*., 1993) demonstrated that the pathogen can cause considerable yield loss if the infection level on the upper leaves becomes severe and that this was related to rainfall during stem elongation. However, the occurrence of suitable infection criteria can not consistently be correlated with severe *Septoria tritici* infections (Polley & Thomas, 1991). Cultivar choice, sowing time, winter and early spring weather can all influence disease development on the lower leaves of a wheat plant (Verreet, 1992), and consequently affect subsequent disease development on the upper leaves. The 'Bayer Cereal Diagnostic System' (Verreet & Hoffmann, 1990) is an integrated decision model for the control of wheat diseases based on infection threshold values in a crop. This system was developed in Southern Germany where the major yield loss in wheat crops is caused by *Septoria nodorum*. Field trials were carried out in the UK to gather data on the epidemic development of *Septoria tritici* and to establish infection threshold criteria. The aim of this paper is to illustrate the basic elements of a decision scheme which has been developed using results obtained during the last four years.

## METHODS AND MATERIALS

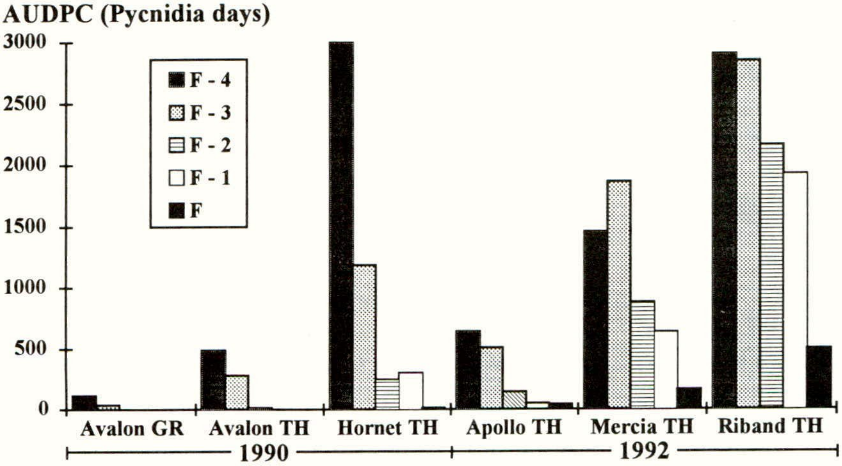
Between 1990 and 1993 a total of 14 field experiments, designed as randomised blocks with three replicates, were carried out at different sites in the UK. Winter wheat cultivars used were Riband, Beaver, Hornet, Avalon, Hereward, Mercia and Apollo. The fungicides tebuconazole (250g AI/l; Folicur, Bayer), tebuconazole + triadimenol (250g AI/l + 125g AI/l; Silvacur, Bayer), flusilazole (400g AI/l; Sanction, DuPont) and cyproconazole (100g AI/l; Alto, Sandoz) were applied according to a fixed series of growth stages as well as threshold criteria. Foliar diseases (*Septoria tritici, Septoria nodorum, Erysiphe graminis, Puccinia recondita*) were assessed, with the aid of a binocular microscope, on a weekly basis from the end of March (GS 25) to the beginning of July (GS 75/80). The leaf area affected or severity of infection, the incidence of infection and the necrotic leaf area were recorded as a percentage proportion for each leaf layer on 10 randomly sampled tillers per plot using standard keys. In addition, for Septoria species pycnidia numbers were counted (up to 200 per leaf) until total senescence. Weather records were taken from local stations close to the field experiments to measure min./max. temperature, humidity and rainfall. Glasshouse experiments to determine the protectant and curative properties of the fungicides were carried out at the Technical University of Munich using standard procedures (Eynard & Shephard, 1990).

## RESULTS

### Septoria development in untreated plots

Disease development in untreated plots was recorded and six epidemics of *Septoria tritici,* shown in Figure 1, are based on pycnidia counts on leaves 5 (F-4) to flagleaf (F) carried out during the growing period up to growth stage 75.

FIGURE 1. AUDPC's (area under disease progress curve) for Septoria epidemics based on pycnidia counts recorded at Grantham (GR) and Thurston (TH).

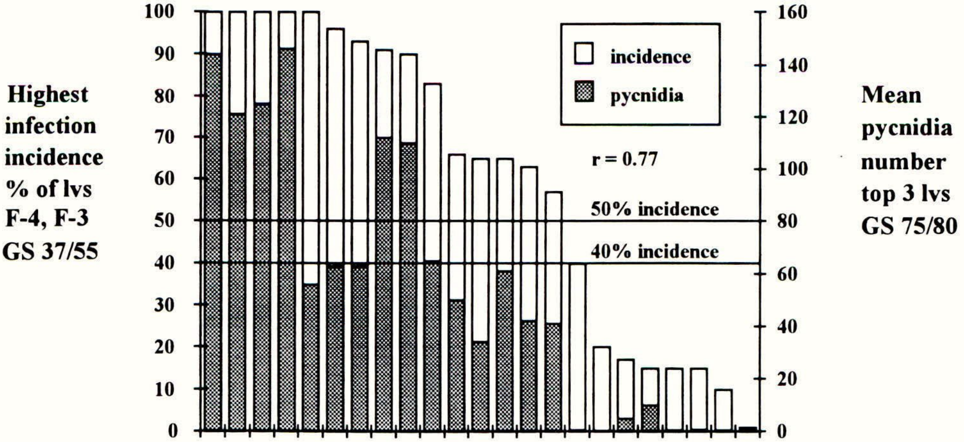


On the cultivar Avalon in 1990 low levels of *Septoria tritici* were present on the middle leaf layers F-4 and F-3 during stem elongation. Although the season was generally dry, infection events were given by rainfall at Grantham (GS 37: 5mm and 3mm; GS 55 to 65: 20mm) and Thurston (GS 37: 14mm and 3mm; GS 55 to 65: 22mm). Later disease progress on the top three leaves was not observed, although the time period after infection was 42 and 28 days respectively. In comparison, on cv. Hornet disease development on F-4 and F-3 was much stronger and due to the rainfall in May and June, higher levels of the disease appeared on the top three leaves.

In 1992, the weather conditions in May and June were suitable for disease progress. At Thurston rainfall at GS 32 (17mm rain in 3 days), GS 37 (21mm in 4 days) and GS 59 (35mm in 5 days) provided several infection events. Disease development on leaves F-4 and F-3 was relatively low on cv. Apollo whilst, in contrast, was much higher on cvs. Mercia and Riband and consequently resulted in severe infections of the upper three leaves.

The differences in the epidemic development of *Septoria tritici* indicated a possible relationship between the amount of inoculum found on the lower leaves and subsequent disease progress on the three upper leaves. A comparison of 23 examples of *Septoria tritici* epidemics indicated that the amount of inoculum, measured as the incidence of infection (the percent leaves with any infection), on the middle leaf layers correlated (r = 0.77) with the subsequent level of infection on the upper three leaves (Figure 2). It was also apparent that severe infections (100 pycnidia = c. 8% leaf area infected) only resulted if the incidence levels on F-4 and F-3 were greater than 50% (c. 30-40 pycnidia).

FIGURE 2. Illustration of the relationship between incidence values of *Septoria tritici* and the disease level on the top three leaves in the presence of rainfall during stem elongation and ear emergence from 23 epidemics.

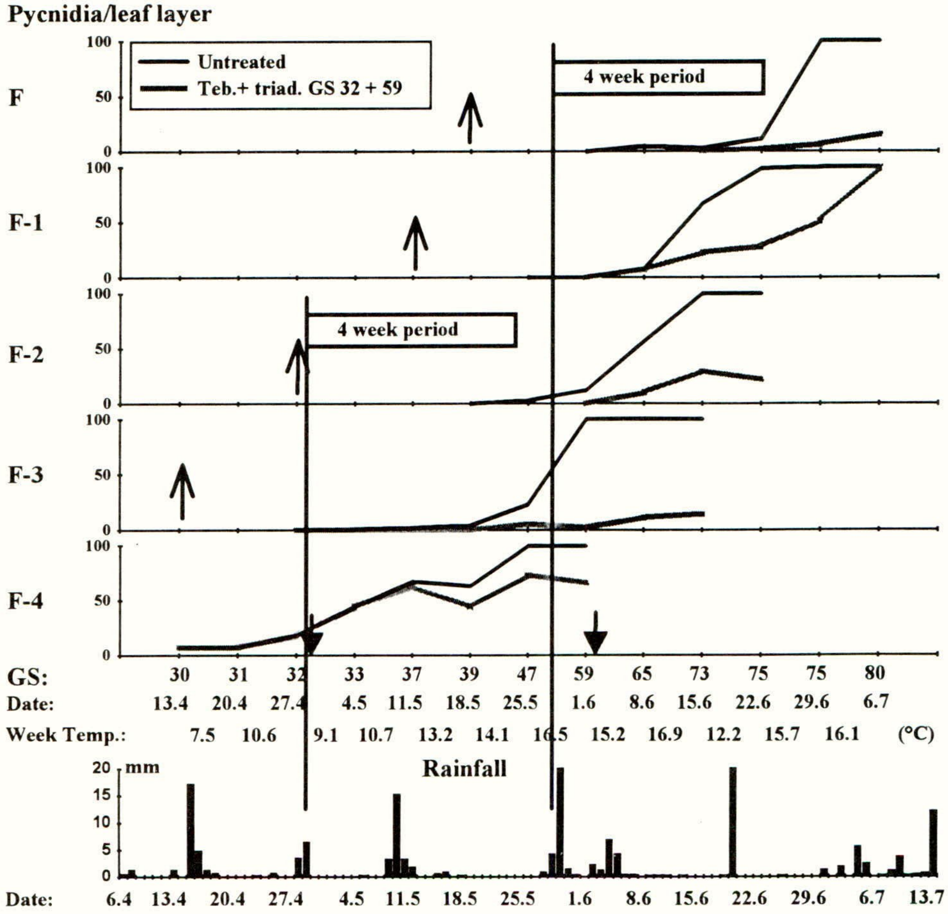


<u>Importance of rainfall for application timing</u>

Figure 3 represents the epidemic development of *Septoria tritici* in an untreated plot and the effect of two growth stage orientated applications of tebuconazole + triadimenol. At the bottom of the chart rainfall distribution and weekly mean temperature are included to illustrate the interaction between pathogen, weather and crop development. The disease progress was recorded on each leaf layer from leaf 8 (F-7) but only leaves 5 (F-4) to flagleaf (F) are illustrated.

High infection levels (up to 200 pycnidia) were recorded on leaves below F-4. The emergence of F-3, F-2 and F-1 coincided with rainfall and was followed by the appearance of symptoms four weeks later; see example for leaf F-2 shown in Figure 3. The flagleaf emerged during a dry period and was strongly infected by rainfall at the end of May. The low pycnidia numbers visible from the 8 June were the result of rainfall at GS 37 when only the tip of the flagleaf had emerged.

FIGURE 3. Thurston 1992: Progress of *Septoria tritici* on 5 upper leaves in an untreated plot and the effect of two applications of tebuconazole + triadimenol on cv. Riband. Leaf fully expanded indicated by '↑' and fungicide application denoted by '↓'

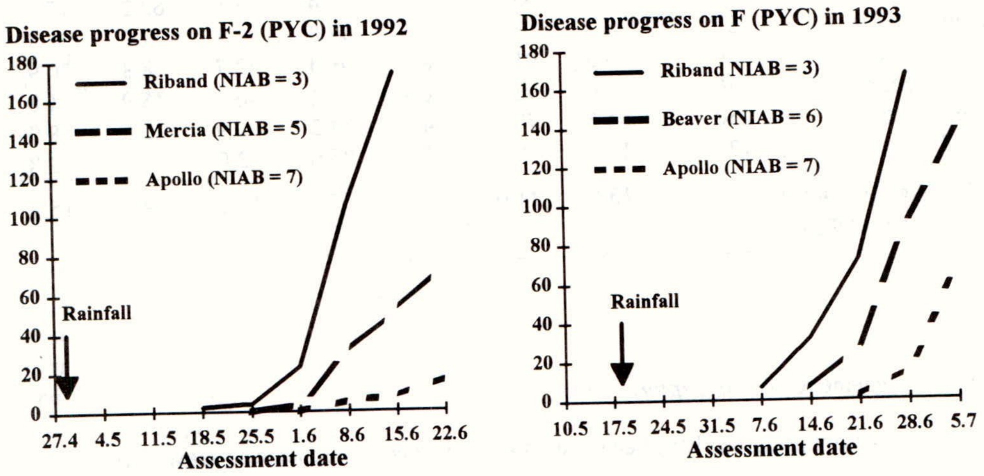


The first application of the fungicide at GS 32 provided a high curative activity on leaf F-3 (rainfall 16 and 3 days resp. before application) and F-2 (rainfall 3 days before application). Leaf F-1 was not emerged at the application date and rainfall at GS 37 caused infections which produced the first pynidia at GS 59/65. The second application at GS 59 only delayed disease establishment on F-1 but reduced infection on the flagleaf.

Influence of cultivar susceptibility

Within the experiments the host resistance affected the inoculum development on the lower leaves and the disease progress rate after an infection event (Figure 4).

FIGURE 4. Influence of wheat cultivars on the latent period of *Septoria tritici* based on pycnidia numbers (PYC).



**Disease progress on F-2 (PYC) in 1992**

**Disease progress on F (PYC) in 1993**

In 1992, a rain event of more than 18mm within four days at GS 32 (F-2 just emerged) apparently dispersed pycnidiospores upwards. The first pycnidia appeared on cv. Riband after three weeks, followed by Mercia and Apollo one week and two weeks later respectively. Similar results were found in 1993 with the development of infection on the flagleaf (F) after rainfall at GS 39 (9mm, 4.2mm, 7.3mm on 3 days). These differences were recorded on all leaf layers and influenced the curative activity of fungicides. An application of tebuconazole on cv. Riband at 40 day degrees after the infection of leaf F provided 94% disease control whereas 78% control was obtained by a spray at 120 day degrees. In contrast, on cv. Beaver tebuconazole reduced *Septoria tritici by* 93% when applied at 120 day degrees after infection and on cv. Apollo, an application as much as 250 day degrees after the infection event gave 94% disease control.

Fungicide activity

The result of a glasshouse experiment to test the effect of applied dose on the protectant and curative activity of three triazoles against *Septoria tritici* is shown in Table 1. High levels of Septoria infection were ensured by artificial inoculation, resulting in 76% to 100% necrotic leaf area on untreated plants.

The protectant activity of tebuconazole was excellent and more persistent than cyproconazole which gave reduced control when applied 170 day degrees before infection. Both fungicides showed good curative activity applied up to 135 day degrees after infection, with later applications being less effective and applied dose more critical. Flusilazole was a less active compound and needed to be used at full dose close to the time of infection.

differences in disease susceptibility of individual cultivars and the influence this has on the period between infection and symptom expression previously reported by Shaerer, (1978). This resulted in a longer period during which the fungicide could act curatively and a decreasing importance of infections later in the growing season, both of which can be used to optimise spray decisions.

Triazoles need to be applied within their period of curative activity against *Septoria tritici*; subsequent control measures depend on their protectant activity and the emergence of new leaves. It is possible to use lower rates without increasing application frequency when timing is close to an infection event or as a second application following a full dose. However, full doses are required for reliable disease control when several infection events have occurred before spraying, when the first treatment is after GS 39 or when there is more than one target disease, for example *Septoria nodorum*. The activity of tebuconazole-based treatments against *Septoria tritici* was high in comparison with other triazoles, supporting other work which describes its suitability as a tool for integrated disease control (Ceynova *et al.*, 1993).

The different factors which influence disease development of *Septoria tritici* have been integrated into one system which enables effective control by taking into account the particular circumstances of a wheat crop. The difference in disease development in individual crops is reflected in application timing and frequency in order to provide a more rational use of fungicides, with consequent economic benefit. The decision elements form part of the "Bayer Cereal Diagnostic System" to control different wheat pathogens.

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## REFERENCES

Ceynova, J.; Lindenberg, H.; Piening, G. (1993) Epidemilogie und infektionsbezogene Bekämpfung der Blattdürre (*Septoria tritici*) an Winter weizen. *Gesunde Pflanzen*, **45**, Jahrg. (4), 155-162.

Eynard, R.; Shephard, M.C.; (1990) Comparative activity of fungicides against *Septoria nodorum* and *S. tritici* on wheat. *Brighton Crop Protection Conference - Pests and Diseases 1990,* **2**, 861-866.

Polley, R.W.; Thomas, M.R. (1991) Surveys of diseases of winter wheat in England and Wales, 1976-1988. *Annals of Applied Biology,* **119**, 1-20.

Shaerer, B.L. (1978) Inoculum density - host response relationships of spring wheat cultivars to infection by *Septoria tritici*. *Netherlands Journal of Plant Pathology,* **84**, 1-12.

Thomas, M.R.; Cook, R.J.; King, J.E. (1989) Factors affecting development of *Septoria tritici* in winter wheat and its effect on yield. *Plant Pathology,* **38**, 246-257.

Verreet, J.A.; Hoffmann, G.M. (1990) Threshold based control of wheat diseases using the Bayer cereal diagnosis system after Verreet/Hoffmann. *Brighton Crop Protection Conference - Pests and Diseases 1990,* **2**, 745-750.

Verreet, J.A. (1992) Habilitationsschrift an der Fakultät für Landwirtschaft und Gartenbau der Technischen Universität München-Weihenstephan.