Session 5

Strategies for Managing Resistance

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FUNGICIDE RESISTANCE MANAGEMENT: NEEDS AND SUCCESS FACTORS

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ABSTRACT

The result of 20 years of fungicide resistance management is encouraging. Modern fungicides continue to add to a high level of disease control despite the fact that many of these are prone to resistance. The strategies implemented did not prevent resistance in all cases but definitely contributed to delay the onset of resistance or to safeguard the high level of field activity. FRAC (Fungicide Resistance Action Committee) played a leading role in this sector.

The analysis of actual operations and organization of resistance management shows weaknesses and suboptimal use of resources which became more scarce in recent years. The squeeze on resources will continue with the ongoing restructuring process and changing priorities in the plant protection industry.

In this paper, ideas are proposed on how to revitalize fungicide resistance management in order to preserve the usefulness of modern fungicides. All of these ideas circle around more intense and constructive cooperation, coordination and communication. Harmonization in methods and information exchange is also an objective. The re-orientation must be done within industry, but should also include the relationship of industry with the public sector including academia. FRAC can and should again take the initiative, with efforts primarily being based in the countries. More regulation is not desired. Cooperation must evolve voluntarily and include all groups involved in plant protection.

INTRODUCTION

Ever since modern fungicides have been developed and marketed, field resistance has been either a reality or a continued, latent threat. As a result, fungicide resistance management became a standard product stewardship procedure in the industry, the main objective being to preserve the usefulness of these products. Resources were made available in many but not all research based companies for these tasks. The plant protection industry, which was so innovative during the last 20 years now faces strong economic head winds. With significant resources bound to safety and environmental challenges, the new situation requires a re-evaluation and a re-orientation in industry, including re-allocation of resources. The aim of this paper is to analyze the achievements and the present environment of fungicide resistance management and to propose new ways whereby this important task could be carried out more efficiently.

ANALYSIS OF PAST ACHIEVEMENTS AND STATUS OF FUNGICIDE RESISTANCE MANAGEMENT

It seems worthwhile to look at the following three sectors in order to clarify the actual situation of fungicide resistance management:

- Achievements
- Operational and organizational aspects
- Economic environment

20 years of fungicide resistance management: A success story?

In the 1970's widespread resistance to fungicides coupled with severe yield losses occurred for the first time. This was the moment when awareness in industry evolved that fungicide resistance management was to be an extraordinary and important task. Individuals with clear vision in industry, public services and academia were the driving forces. As a result of this, fungicide resistance management became a scientific and operational discipline with clear objectives, approaches and tasks allocated (Urech, 1984, 1990) as shown in Table 1.

TABLE 1: Job assignment in fungicide resistance management (according to Urech, 1984)

Active group	Action: Determination of inherent resistance risk	Risk evaluation and design of resistance strategy	Coordination between manufacturers	Implementation: communication, education	Monitoring	Adaption, new design of strategy
Industry	•••	•••	•••	•••	•••	•••
Academia Official Services	•			•••	••	•
Farmers				•••	•	
	Development stage	Development stage	Marketing stage	Marketing stage	Marketing stage	Marketing stage

FRAC (Fungicide Resistance Action Committee), which was founded in 1981, was a breakthrough in industry cooperation and helped to shape the fungicide resistance landscape with big impact and authority not only by support of conceptual efforts including strategies, but also by training and education (Highwood, 1989). The results of these efforts confirm that the resources were well invested and that fungicide resistance management practices can be regarded as a success. In particular:

• Phenylamides remain a very valuable tool to control oomycetes despite resistance in foliar pathogens since 1980.

• Dicarboximides are still widely used despite the discovery of less sensitive or resistant strains.

• Even benzimidazoles have not disappeared from the market despite the fact that widespread resistance occurred more than 20 years ago.

• DMI fungicides are growing in importance despite the occurrence of less sensitive strains in some target pathogens.

Public and industrial research supported and accompanied practical management efforts. Although not all the phenomena observed in practice have been clarified (major gaps are present in our knowledge of the epidemology of resistant or less sensitive strains, in the resistance mechanisms and their genetic background) these efforts were of vital importance for risk assessments, modelling, cross resistance studies, synergism studies, etc. As a whole, for us there is no doubt that our joint efforts in fungicide resistance management (and by this we mean not only industry, but at the same time also official services and farmers) have preserved the usefulness of the modern fungicides. Some probably would have disappeared, others would have decreased in use. Winners are all social groups engaged in disease control, including farmers. Fungicide resistance was not prevented but mastered.

The way we operate in fungicide resistance management

Chemical plant protection is a highly regulated industry. Registration requirements and the FAO code of conduct for instance impose stringent regulations and guidelines on manufacturers and users of chemicals. With the exception of the still to be completed EU registration requirements, regulations have not yet covered fungicide resistance, and it is hoped that this complex matter will not undergo more regulation in future. However, with the exception of product related resistance management strategies, little agreed standards, procedures and approaches have been implemented so far. This makes life difficult for all those who are actively engaged in this field.

A few examples should highlight this point and consequently stress the need for action:

• Monitoring of field efficacy and sensitivity is often done using various methods and by only a few companies or institutions. All others take profit from this knowledge free of charge.

• Industry has little or no cooperative monitoring or resistance research programmes implemented.

• Advertisements using resistance arguments often damage the image of the industry because they are too obviously aimed at gaining commercial advantage.

• Resistance strategies are too often unilaterally proposed and promoted, be it from the official or industrial side.

• Resistance definition often remains a matter of view point, rather than an agreed state of the art, e.g. for triazoles.

• In many countries, developing an own view on fungicide resistance with consequently own studies is more important than cooperative investigation of resistance situations.

• In some countries, officials use legal means in a doubtful manner to regulate the use of fungicides which are prone to resistance, e.g. indexing in Switzerland.

• The registration of mixtures is not or only reluctantly allowed, e.g. India.

The changing economic climate in the plant protection industry

The heavy research and support efforts (search for new products, new formulations and packaging, product stewardship, safety, IPM and others) could be easily financed in many companies when economic growth and healthy productivity were the rule in the industry. Over the last 3 years, however, the economic situation has undergone a significant change and external as well as internal factors have contributed to a gloomy economic outlook in the industry:

• Shrinking fungicide markets in Western Europe due to CAP and in Eastern Europe due to economic difficulties.

• Increased competition leading to lower prices.

• Higher cost of doing business, including discovery, design and registration costs.

• Generic producers entering the market.

The plant protection industry is therefore going through a restructuring process worldwide. As a consequence of decreasing profits, resources for all activities become smaller and managers are asked to focus on the most promising projects. In such a climate, technical programmes aiming at managing fungicide resistance have to compete with many other high priority research and maintenance projects. There is, and will be, less money available for fungicide resistance management. Whether the same is true in official services is open, but we could imagine that the shrinking agronomic sector in Western Europe certainly will have an influence on fungicide resistance research and monitoring programmes. That is where we are today: Successful in fungicide resistance management in the past. But what will the future bring us?

FUNGICIDE RESISTANCE MANAGEMENT IN THE LIGHT OF THE CHANGING ECONOMIC ENVIRONMENT

There is no doubt that effective fungicide resistance management must remain an essential part of product stewardship. It must remain a clear and agreed objective for the industry as well as for all official bodies involved in plant protection. The analysis in the previous section shows us that:

• Success stories in fungicide resistance management prove that the conceptual working procedures are sound.

• Resources available for resistance management will shrink.

• Productivity improvements on the operational and organizational level are absolutely possible. This now gives us the basis to propose ideas for a re-orientation in fungicide resistance management.

The framework could be the following: Continued successful fungicide resistance management will only happen if a closer cooperation between industry members and the industry and public services will be realized. Cooperative and integrated work programmes must be considered combined with a free flow of information and better understanding of research methods and resistance strategies.

These general ideas can be clarified by describing the needs and success factors.

Needs

Needs are defined as those factors which are absolutely necessary for highly effective, but also very efficient fungicide resistance management.

The following is a list primarily seen by an industry member.

1. Resources: Sufficient resources must remain available within industry and public services/academia. All industry members selling products which are prone to resistance must contribute. There is no free ride. Funding of projects or doing own scientific work are possible contributions. Best use of resources can be achieved by focusing, priority setting and high quality work.

2. Cooperation: Project related, national or transnational cooperation must be intensified. "Who does what" agreements must lead to a wise use of available resources. Cooperation must improve among industry and between industry and the public sector. Basic research and field monitoring are the main targets.

3. Strategies: Enforceable resistance strategies based on scientific risk assessments for all fungicides at risk are obligatory. There can be no unilateral ruling in resistance strategies either from industry or from the public sector. There is no veto right and no command. Mutual agreement must be the goal in decision making on strategies. Implementation in practice needs understanding and support in all social groups involved in plant protection. Strategies must be seen as changeable if new data justify this. Communication with one voice increases credibility towards the farmers who are to follow the strategies.

4. Field monitoring: This is a product stewardship task and a must. The originators are in the drivers seat, but should also include licencees. Monitoring methods should become more harmonized in order to save resources, facilitate and improve the quality of interpretation of results. See also under point 1 and 2.

5. Residual fungicides: Must remain in the market in order to be included in the design of resistance strategies.

6. Resistance definition: There must be agreement on how to define field resistance for product groups or for individual products. In a much more responsible way, experts have to clarify what is and what is not applicable. There is an obvious and urgent need to do this for the DMI's.

Success factors

They determine whether and to which degree we will be successful in fungicide resistance management.

1. Information exchange: Honest and open exchange of e.g. monitoring data within project groups, and in a consolidated form to the outside is vital if efficiency in resistance management is to be realized.

2. Role of FRAC: It must continue to support efficiently all efforts in fungicide resistance management. Within industry, it must more than ever encourage cooperation. Outside of industry, it must become more open and willing to cooperate.

3. Generic producers: Must stick to FRAC guidelines and accept their share of costs, e.g. monitoring. Officials could and should become more demanding in this respect.

4. Research: Additional research programmes are needed to better understand some of the open questions, e.g. epidemiology of resistant or less sensitive strains, survival of such strains, genetic and biochemical background of resistance.

5. Farmer support: So far, resistance was not so often an issue to them because new products kept emerging to solve occuring problems. Better explanation at users level as to why resistance management efforts are needed and take place is necessary.

6. EU resistance regulations: Have to be finalized soon. We do not want more regulation but support what is written in the directive. All companies must stick to it.

7. Advertisements: Advertising fungicides using the resistance argument must be done in an objective way and must have the aim to inform users correctly and not to discredit competitors. A lot of credibility is at stake for industry.

8. Marketing and resistance management: Everybody must understand that resistance management is only one element in the use strategy of a product.

Marketing has a vital interest in the performance of a product and its longevity. What marketing people do not want is prohibitive regulation and use.

CONCLUSIONS

Modern fungicides represent a controversial, fragile technology. While their technical potential could present a revolution in disease control e.g. curative use and season long use, resistance, aspects pose severe restrictions on such an unlimited wide application. During the 1980's many new products were developed to the market, but most were DMI's and not many new modes of action were discovered. Some older products disappeared from the market.

Fungicide resistance management is therefore important not only to industry but for all social groups involved in plant protection. As far as industry is concerned one has to accept the fact that R & D resources must be directed to many projects and that some of them have also high priority. Among them are: research for new technologies to control plant diseases, biologicals, chemicals with novel mode of action, diagnostics etc.

The ideas presented in this paper should therefore contribute to improve three aspects of fungicide resistance management:

- Enforcement that fungicide resistance management is important.
- More efficient utilization of available resources, doing work more professionally and with better organization.
- More cooperative understanding within all social groups involved.

How to reach these goals?

FRAC groups must become more active and take the initiative, primarily within industry. Industry should define projects for research and monitoring which would then be carried out as joint programmes or farmed out to public services with corresponding funding.

FRAC groups should communicate more actively with the public sector, being from Steering Committee or being by the working groups. Decisions have not been made, but the need for such action seems obvious. At the country level, industry, advisory services and academia could engage in more cooperative programmes for monitoring, with clear objectives for this work, good definition of methods and more intense data exchange. The dialogue on resistance strategies must lead to agreeable positions, in a partnership like attitude and understanding. There is no place for unilateral actions, because resistance strategies must be supported by all influencers. Clearly, the final use strategy of a fungicide including resistance aspects is within the responsibility of the industry, however, the more agreement that can be reached about the best way to manage fungicide resistance, the better for the products. Fungicide resistance management has to stay: The way we do it has to change and become more professional.

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STRATEGIES FOR MANAGEMENT OF FUNGICIDE RESISTANCE: CEREALS

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ABSTRACT

Fungicides were used on over 95% of winter wheat and over 90% of winter barley crops in England and Wales in 1993. Over 90% of all applications included a DMI fungicide, and over 50% included a morpholine. Most farmers applied between one and three fungicides to winter wheat (mean 2.10) and one or two to winter barley (mean 1.35). A large proportion of applications include a mixture of two or more fungicides. Current ADAS and Fungicide Resistance Action Committee (FRAC) guidelines for reducing the risk of fungicide resistance are discussed. It is concluded that, in relation to fungicide mixture or alternation, current farming practice corresponds reasonably with the guidelines, although there will need to be a greater emphasis on the use of mixtures if threats such as morpholine resistance in *Erysiphe graminis* or DMI resistance in *Septoria tritici* become widespread. The area of greatest concern is the use of DMI seed treatments, used on almost 25% of winter wheat and winter barley crops in 1993. In many cases, alternative treatments from different fungicide groups would be appropriate.

INTRODUCTION

Fungicide resistance has been recognised for many years as an important consideration in the effective use of fungicides in UK cereal crops. A list of resistance problems is given in Table 1 (Fletcher & Locke, 1993). The current status of resistance for many of these pathogen/fungicide combinations, and the risk of resistance for others, is covered elsewhere in this volume and will not be detailed here. The objectives of this paper are to review how and why fungicides are used on cereals, to what extent this corresponds with current guidelines for avoidance or management of resistance, and whether these strategies are appropriate.

FUNGICIDES ON CEREALS

The main pathogens of wheat and barley for which fungicides are available, and the most effective fungicide groups for their control, are listed in Table 2. This list is not exhaustive, and takes no account of differences in efficacy between members of a group, but indicates which fungicides are most likely to be used for control of a particular pathogen. The current dependence on DMI (demethylation inhibitor) fungicides and on morpholines is shown clearly. These two groups constitute the SBI (sterol biosynthesis inhibitor) fungicides. Protectant fungicides are used, mostly in mixture with a DMI fungicide, for control of *Septoria* spp., but for all the other pathogens except *Rhynchosporium secalis* there is virtually complete dependence on DMI and morpholine fungicides.

TABLE 1. Fungicide resistance on cereals in the UK.

Crop	Pathogen	Disease	Fungicide or group name	Frequency
Wheat	*Pseudocercosporella herpotrichoides*	Eyespot	MBC	common
	Septoria tritici	Leaf spot	MBC	common
	Erysiphe graminis	Powdery mildew	DMI (some)	common
	Fusarium nivale	Brown foot rot	MBC	common
	Fusarium culmorum	Ear blight/foot rot	MBC	infrequent
Barley	*Pseudocercosporella herpotrichoides*	Eyespot	MBC	common
	Erysiphe graminis	Powdery mildew	DMI (some)	common
			ethirimol	common
	Rhynchosporium secalis	Leaf blotch	DMI (some)	common
			MBC	common
	Ustilago nuda	Loose smut	carboxin	infrequent
	Pyrenophora graminea	Leaf stripe	organomercury	infrequent
Oats	*Pyrenophora avenae*	Leaf spot	organomercury	common

TABLE 2. Summary of fungicide efficacy against pathogens of wheat and barley in the UK.

Pathogen	Disease	Most effective fungicide group(s)
Septoria tritici	Leaf spot	DMI ± chlorothalonil
Septoria nodorum	Glume blotch	DMI, MBC + protectant
Erysiphe graminis	Powdery mildew	Morpholine
Puccinia spp.	Rusts	DMI, morpholine
Pyrenophora teres	Net blotch	DMI
Rhynchosporium secalis	Leaf blotch	DMI + morpholine or MBC
Pseudocercosporella herpotrichoides	Eyespot	DMI

Data on foliar fungicide use on winter cereals in England and Wales are given in Table 3, and data on seed treatments are in Table 4 (R.W. Polley, pers. comm.). There are no comparable data for spring cereals, which generally receive fewer fungicide applications than winter cereals. On winter cereals, the most commonly used fungicides were the DMIs, followed by morpholines, both at GS30-33 and GS37-69 (Tottman, 1987) (Table 3). In most cases, morpholines were applied in mixture with another fungicide, and only 12.4% of winter wheat and 2.8% of winter barley crops received a morpholine fungicide alone. A substantial number of crops received an MBC fungicide but, in every instance except one, the MBC was in a mixture with another fungicide. The other fungicides used were mostly protectants, such as chlorothalonil or dithiocarbamates. The proportions of winter wheat and winter barley crops which were treated with fungicides were 95.7% and 91.0% respectively, and the mean number of fungicide applications per crop was 2.10 for winter wheat (unchanged from the two previous years) and 1.35 for winter barley (compared with 1.43 in 1992 and 1.51 in 1991).

TABLE 3. Foliar fungicide usage on winter wheat and winter barley in England and Wales, 1993.

Fungicide group	Percentage of treated crops which received fungicides from each group			
	Winter wheat		Winter barley	
	GS30-33	GS37-69	GS30-33	GS37-69
DMI	91.0	93.4	87.9	93.6
Morpholine	48.7	63.4	68.2	63.8
MBC	14.4	28.8	43.6	32.6
Total % crops treated	75.0	86.4	74.6	39.0

Data from MAFF winter wheat and winter barley disease surveys (R.W. Polley, pers. comm.). Total number of crops in surveys: winter wheat 370; winter barley, 354.

TABLE 4. Fungicide seed treatments on winter wheat and winter barley in England and Wales, 1991 and 1993.

Fungicide	Percentage of crops treated			
	Winter wheat		Winter barley	
	1991	1993	1991	1993
Organomercury	79.7	0	72.6	0
Carboxin + thiabendazole [+ imazalil][a]	0	26.4	0	29.7
Guazatine [+ imazalil][a]	0	17.7	0	9.3
Triadimenol + fuberidazole	17.5	22.9	6.6	10.2
Flutriafol + ethirimol + thiabendazole	0	0	15.4	15.6
Treated but product unknown	0	28.1	0	31.5
Untreated	2.8	4.9	5.4	3.6

Data from MAFF winter wheat and winter barley disease surveys (R.W. Polley, pers. comm.). Data from 354 and 345 wheat and 354 and 332 barley crops in 1991 and 1993 respectively.
[a]Imazalil included in barley treatments only.

The seed treatment data show the effect of the withdrawal in 1992 of organomercury seed treatments, which had previously been the standard treatment for over 50 years (Table 4). The 1991 data are for the final year in which organomercury was widely available, and 1993 was the first year in which it was unavailable. On both wheat and barley, the main trend was for treatments based on carboxin or guazatine to be used in 1993 in place of organomercury. There was a small increase in the use of the DMI fungicide triadimenol, but no change in the use of the other DMI, flutriafol, on barley. There was a substantial number of farmers in 1993 who had used treated seed, but did not know which treatment had been applied.

HOW DOES THE FARMER USE FUNGICIDES?

Although most cereal farmers have a general appreciation of when and why fungicides should be applied, few farmers feel confident to make all their fungicide decisions without assistance. In addition, fungicide selection is only one of many agronomic decisions that each farmer must make. Most farmers, therefore, rely substantially on a consultant, who may be concerned to avoid risk of serious disease or other mishaps, and therefore may be inclined to recommend insurance treatments. Farmers themselves are generally risk-averse, and may favour this approach. The large proportion of farmers in 1993 who did not know which seed treatment had been applied (Table 4) is an extreme illustration of the extent to which farmers delegate the decision-making!

Few farmers have the time available to monitor crops frequently for disease, and few consultants are able to visit crops sufficiently often to be confident of early detection of all diseases. In consequence, most farmers/consultants have a basic strategy, which is planned before any fungicides are applied. This strategy is then adjusted according to the perception of disease risk, based either on knowledge of diseases in the crop or the vicinity, or on weather conditions in relation to disease. On winter wheat, many farmers apply a fungicide in the period GS30-33, usually at GS31 or GS32 (Table 3). In some instances eyespot is the main target disease, and on some cultivars there is a clear risk of yellow rust, mildew or *Septoria tritici*, but in many cases there is not a clearly identified disease threat and the spray is intended as an insurance against foliar diseases. Almost all crops receive one or two fungicides in the period from GS37-GS69, often with *S. tritici* as the main target, but also with the aim of preventing other foliar diseases from becoming severe. On winter barley, over 50% of crops received just one fungicide in 1993, in most cases at GS31 or GS32. Further sprays are applied as routine for insurance by some farmers, but only on an "as necessary" basis by the majority. Fungicide treatment of other winter cereals (oats, rye) and of spring cereals is more usually in response to specific disease risks rather than to a pre-determined plan.

Although many farmers and consultants have a structured approach to fungicide timing, they are increasingly flexible in relation to application rates. Reduced rates of fungicides have been used by some farmers for many years, but there is increasing interest in reduced rates as more data become available on their efficacy. On winter wheat, Paveley & Lockley (1993) showed that a single application of propiconazole plus fenpropimorph at one quarter of the recommended rates was as effective against yellow rust as a full rate treatment, provided the sprays were applied in the week that yellow rust was first detected in the crop. When the same treatments were applied one week earlier or later, the low rate treatment was less effective than full rate. Similarly on spring barley, Wale (1993) found that one quarter rate, or even one eighth rate, of propiconazole plus tridemorph was effective against mildew provided that it was timed accurately. If treatment was delayed until mildew was well established, a higher rate was required. It is widely understood among farmers and consultants that low rates of application can be very effective, if timed correctly. It is also appreciated that the appropriate rate of application depends not only on disease severity, but also on crop development, host resistance and other factors. Due to economic pressures, reduced rates are here to stay. It is important that they are used appropriately.

STRATEGIES FOR AVOIDANCE OR MANAGEMENT OF RESISTANCE

In the short term, there are unlikely to be any new fungicides with different modes of action available to the UK cereal grower, so strategies will need to concentrate on maximising the effectiveness of DMI and morpholine fungicides. Current ADAS guidelines for reducing the risk to cereal fungicides are in Table 5 (Jones, 1993), and the recommendations of the Fungicide Resistance Action Committee (FRAC) SBI Working Group are in Table 6.

TABLE 5. ADAS recommendations for reducing the risk of fungicide resistance on cereals.

Reduce disease severity by non-chemical means, like good husbandry, growing resistant varieties, and by varietal diversification.
Ensure that fungicides are applied at the optimum times, to give maximum effectiveness.
Avoid the frequent application to a crop either of the same fungicide or of different fungicides which act in the same way. Whenever possible, a fungicide with a different mode of action should be used for the next application.
Make full use of multi-site fungicides. They are less prone to resistance problems.
Make full use of any appropriate formulated fungicide mixtures or label-recommended tank mixtures. To minimise the risk of resistance, both fungicides in the mixture should be effective against the disease or diseases concerned.
Avoid applying fungicide sprays at times when they are not cost-effective or when they are likely to be only marginally cost-effective - for instance, on cereals in the autumn or after flowering.
On winter cereals, minimise the use of seed treatments containing active ingredients which act in the same way as fungicides likely to be used later to control leaf disease.

APPLICATION OF RESISTANCE MANAGEMENT STRATEGIES TO CEREALS

Several of the strategies listed in the ADAS and FRAC guidelines (Tables 5 and 6) relate to fungicide mixtures or alternation of fungicide groups, and avoiding repeated use of one group alone. Where mixture and alternation strategies have been compared, mixture strategies have proved more effective (Staub, 1991). In practice, there are few problems in fitting these strategies to current farming practice. Most winter wheat and barley crops receive only one or two foliar fungicides; in the 1993 surveys 32.5% of wheat and 6.2% of barley crops received more than two foliar fungicides (R.W. Polley, pers. comm.). A large proportion of these treatments include a mixture of two fungicides from different groups, with mixtures generally selected to increase efficacy, allow lower application rates or broaden the spectrum of activity, rather than specifically as an anti-resistance strategy.

TABLE 6. FRAC general recommendations for reducing the risk of resistance to SBI fungicides.

Repeated application of SBI fungicides alone should not be used on the same crop in one season against a high risk pathogen in areas of high disease pressure for that particular pathogen.

For crop/pathogen situations where repeated spray applications (e.g. orchard crops/powdery mildew) are made during the season, alternation (block sprays or in sequence) or mixtures with a non cross-resistant fungicide are recommended.

Where alternation or use of mixtures is not feasible because of lack of an effective or compatible non cross-resistant partner fungicide, then input of SBIs should be reserved for critical parts of the season or crop growth stage.

Where DMI or morpholine performance is declining generally and sensitivity testing has confirmed the presence of less sensitive forms, SBIs should only be used in mixture or alternation with non cross-resistant partner fungicides. For control of cereal powdery mildews, mixtures or alternation of a DMI with a morpholine fungicide represent the best currently available non cross-resistant combination. Consideration should also be given to restricting DMI use to critical parts of the season or crop growth stage.

Users must adhere to the label recommendations.

Fungicide input is only one part of crop management. Fungicide use does not replace the need for resistant crop varieties, good agronomic practice, or plant hygiene/sanitation.

Farmers would normally use a morpholine rather than a DMI where there is a risk of severe mildew, but since most morpholine applications are made in mixture with a DMI, farmers are, perhaps without realising, taking an anti-resistance measure for mildew, and also rusts. If morpholine sensitivity in the mildew fungi declines such that there is resistance in practice, then greater emphasis will need to be placed on using morpholines in mixture with a DMI, and more attention paid to the differences between DMI fungicides in mildew activity. Since DMI resistance was found in *Rhynchosporium secalis* (Kendall *et al*., 1993), farmers have readily accepted that a DMI plus morpholine or DMI plus MBC mixture should be used. With MBC resistance also found recently to be widespread in *R. secalis* (Phillips & Locke, 1994), there may need to be increased reliance on DMI/morpholine mixtures. For control of *Septoria tritici*, farmers often use a DMI plus chlorothalonil mixture, but a significant proportion of crops receive a DMI alone. To date, there is little evidence of a significant reduction in sensitivity of *S. tritici* to DMI fungicides, but if such a reduction is detected, the importance of the mixture with a protectant fungicide will be increased, and may need to become a standard recommendation. At present, farmers do not have an alternative to DMIs for eyespot control, but the recent introduction of cyprodinil in France provides farmers there with an alternative mode of action, which may become available in the UK in the future.

The fact that farmers often use application rates lower than label recommendations has been discussed above. In the past, it was believed that the use of low rates could enhance the risk of resistance, but it is now considered that the duration of exposure to fungicide is more important than application rate in determining resistance risk (Heitefuss, 1989). Although general observance of label recommendations must be encouraged, farmers are allowed to apply any rate they wish below the stated application rate, and will continue to do so.

The recommendations on preventing disease by non-chemical means should be encouraged, but options are limited for the cereal grower. The main methods by which the grower can manipulate disease are rotation, cultivar selection, sowing date and nitrogen application rate. However, for those diseases which can be controlled by fungicides, it is often more profitable for the farmer to accept the cost of fungicides rather than introduce other changes which may reduce the yield or quality, and hence profitability of the crop or of the farming system. Cultivars with good resistance to disease have only found wide acceptability if they can produce the same gross margins as more susceptible cultivars. In practice, the only disease which farmers routinely manipulate by crop rotation and delayed sowing is take-all (*Gaeumannomyces graminis*), for which there is no reliable commercially available fungicide treatment. If the cost:benefit ratio for fungicides changes markedly (which may happen as grain prices fall during the next few years), or if a resistance problem develops which makes control of a particular disease difficult to achieve, then farmers will re-examine non-chemical methods of disease control.

The final consideration is that because cereal growers are very dependent on DMI and morpholine fungicides in the spring and summer, there is a strong case for not using them at other times, in order to avoid unnecessary risk of resistance development. This is consistent with both ADAS and FRAC guidelines. Foliar treatment of winter barley for mildew control is sometimes thought necessary in the autumn or winter, although the proportion of crops where it is worthwhile is small (M.J. Hims, pers. comm.). Treatment of wheat before GS30 is very rarely required.

The main area of concern is the use of DMI fungicides in seed treatments. There are instances where a DMI seed treatment is clearly justified, for example in controlling bunt (*Tilletia caries*) of wheat or loose smut (*Ustilago nuda*) of wheat or barley in the early stages of seed multiplication, but there are alternative fungicides effective against bunt for commercial crops, and loose smut in both wheat and barley should not require control on commercial seed stocks if the diseases were controlled earlier in multiplication. There are other circumstances where a DMI seed treatment may be justified, for example on wheat cultivars which are very susceptible to yellow rust, but these represented only a small proportion of the total area of wheat in 1993 (less than 5%). Also, triadimenol plus fuberidazole seed treatment can give useful early suppression of take-all, although it cannot be relied upon, so may be justified for early sowings in fields known to have a high risk of take-all. The resistance risk from use of a DMI seed treatment is probably greatest for

Septoria tritici, which infects most winter wheat crops during the autumn, when some of the active ingredient from the seed treatment will still be in the leaf tissues. There is also a risk with the rusts and, possibly, other diseases. On winter barley, the use of flutriafol plus ethirimol plus thiabendazole is preferable to triadimenol plus fuberidazole in relation to DMI resistance in mildew, but ADAS experiments in the 1980s showed that neither treatment was justified in most situations (M.J. Hims, pers. comm.).

It is encouraging that, following the withdrawal of organomercury seed treatments, there has been only a small increase in the proportion of crops receiving a DMI seed treatment. In view of the relatively good correspondence between current practice with foliar fungicides and what would be recommended to combat resistance (even though strategies are rarely designed specifically for resistance management), it would be unfortunate if these beneficial effects were negated by injudicious use of DMI seed treatments.

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