John E. E. Jenkins
Agricultural Development and Advisory Service, Leeds, LS16 5PY, England
Luc Lescar
Institut Technique des Céréales et des Fourrages, Boigneville, 91720 Maisse, France

Use of Foliar Fungicides on Cereals in Western Europe

Cereals are very important crops in Western Europe. In the countries listed in Table 1, 40–70% of the arable land is devoted to cereals. Culture varies greatly according to such factors as geographic location, climate, and size of farms and fields. Wheat is sown mainly in the autumn and barley sowings are evenly divided between autumn and spring. Oats and rye are also planted, but not as extensively as wheat and barley.

Use of foliar fungicides on cereals in Europe began in the early 1970s and gradually increased (Fig. 1) until in 1979 about 6.5 million ha received at least one treatment, with possibly a third of that area receiving two. Fungicides are used chiefly on wheat and barley and seldom on oats and rye.

The term "foliar fungicides" refers to fungicides applied to the foliage or seed of cereals to control fungal diseases affecting leaves, stems, or ears. Fungicides applied to seed to control seedborne diseases are not considered.

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Fungicides are used mainly in areas with known damaging diseases and production levels high enough to warrant the cost, ie, the northern parts of France and Germany, the Netherlands, Belgium, the United Kingdom, and Ireland and, to a lesser extent, the Scandinavian countries; use in northern Italy and Switzerland is limited. Yields of winter wheat and winter barley are about 5 t/ha and can reach 10 t/ha, and yields of spring barley are in the range of 4–6 t/ha. In the southern regions of France, Germany, and Italy and in Spain and

Table 1. Estimated areas (× 1,000 ha) with cereal crops in Western Europe and total areas treated with fungicides during 1979

Country	Wheat	Barley	Oats	Rye	Total	Treated with fungicides (%)	
Belgium	182	157	28	15	397	180	(45)
Denmark	124	1,571	62	80	1,837	417	(23)
France	3,965[a]	2,740	589	138	7,432	2,000	(27)
Ireland	52	342	26	...	410	205	(50)
Italy	3,500[a]	300	227	...	4,027	120	(3)
Netherlands	140	63	21	...	224	90	(40)
Norway	21	179	99	2	302	3	(1)
Sweden	342	633	490	106	1,644	262	(16)
Switzerland	...	...	...	...	180	9	(5)
United Kingdom	1,370	2,340	135	7	3,872	1,900	(50)
West Germany	1,598	1,811	793	702	4,904	1,500	(29)

[a] Totals in France and Italy include 85 and 1,700 durum wheat, respectively.

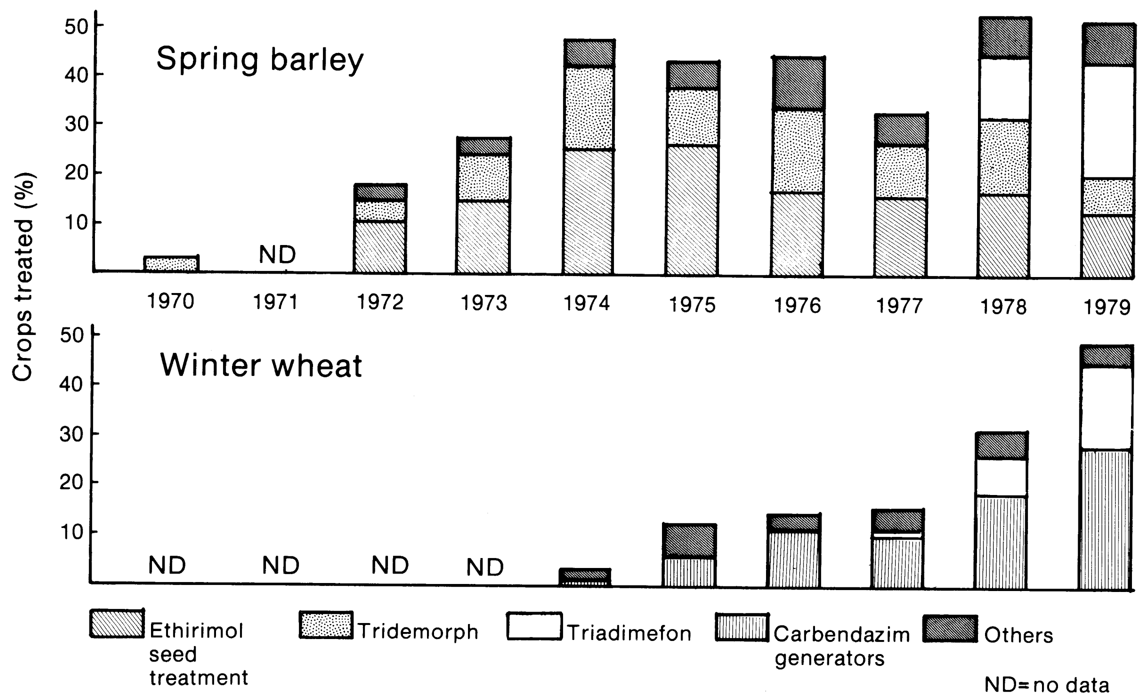


Fig. 1. Percentage of winter wheat and spring barley crops treated with fungicides in England and Wales, 1970–1979 (Agricultural Development and Advisory Service surveys).

Fig. 2. Wheelways or "tramlines" being made in wheat to facilitate application of chemicals. (Courtesy Chafer of Doncaster)

Portugal, factors other than disease are more important in limiting yield, and foliar fungicides are not used.

Fungicides are applied mainly by tractor-drawn or tractor-mounted sprayers. In France, Italy, and the United Kingdom, relatively small areas (0.5, 20, and 5% of treated areas, respectively) are sprayed by aircraft. For many crops, wheelways or "tramlines" (Fig. 2) are made by blocking appropriate single coulters at drilling. With such clear guidelines, application of pesticides, fertilizers, and other chemicals is easier and more accurate and wheel damage to the crop is limited to specific areas. When applications are at an early growth stage, compensatory growth along the wheelways results in very little overall loss in yield. When applications are made later, eg, at ear emergence, the amount of crop damage caused by tractor wheels varies according to equipment and soil conditions; with a spray boom 10 m wide the damage can cause overall yield losses of up to 4%.

The Damaging Diseases

Foot rots, especially eyespot (*Pseudocercosporella herpotrichoides*) (Fig. 3), are common and severe on winter wheat in France, Germany, Ireland, and Denmark, causing yield losses of 5–8%. The disease is also common in other countries but is less damaging. In the United Kingdom, most winter wheat cultivars are resistant to eyespot, and although even these are occasionally damaged by the disease, the average national loss is estimated at no more than 1%. Eyespot is also frequently seen on winter barley but is generally less damaging than on winter wheat. The disease is rarely damaging on spring-sown cereals.

In Sweden and West Germany, the snow molds caused by *Fusarium nivale* and *Typhula* spp. can cause severe damage during long winters with snow cover on frozen ground. In Sweden, about 6% of winter cereals have to be resown in the spring because of these diseases, and a 5–7% loss occurs in crops that survive.

Powdery mildew (*Erysiphe graminis*) (Fig. 4) is consistently the most important leaf disease in most countries. Grain losses in barley average about 10% in the United Kingdom, but severe attacks can cause much higher losses. In most other countries, losses are estimated at 5–10%.

Fig. 3. Eyespot (*Pseudocercosporella herpotrichoides*) on wheat. (UK Crown Copyright)

The disease tends to be less severe in wheat, about half the estimated losses occurring in barley. In France and Switzerland, the disease is less frequent and less severe. Powdery mildew in oats is seldom of economic importance.

Yellow or stripe rust (*Puccinia striiformis*) and the brown or leaf rusts (*P. hordei* and *P. triticina*) are common, but severe attacks occur erratically between seasons and regions. Severe yellow rust of wheat is usually associated with a breakdown in resistance of a widely grown cultivar. The disease is rarely serious in barley. Brown rust is more significant on barley, and severe epidemics have occurred in susceptible cultivars. Brown rust of wheat tends to occur too late in the season to be damaging.

Septoria diseases of wheat caused by *Leptosphaeria nodorum* (*Septoria nodorum*) and *Mycosphaerella graminicola* (*S. tritici*) affect the leaves, although *L. nodorum* occasionally affects the ears. *L. nodorum*, regarded as the more important pathogen and the one mainly associated with damaging attacks after ear emergence, causes fairly serious disease in Switzerland, Germany, Belgium, Ireland, and, in recent years Sweden. In other countries, the pathogen is important in areas subject to rain or mists (eg, coastal regions) but otherwise occurs erratically. In the United Kingdom, for example, Septoria diseases were widespread and severe only once during the last 10 years.

Rhynchosporium leaf scald (*Rhynchosporium secalis*) (Fig. 5) is a common disease of barley in most countries except Italy and Switzerland, but severity varies considerably.

Although one disease may dominate, in winter wheat and winter barley several may be present, and this can influence the choice of fungicides, ie, broad-spectrum fungicides may be preferred to specific ones. Mildew is the dominant disease in most crops of spring barley and is the major factor when considering the use of a fungicide.

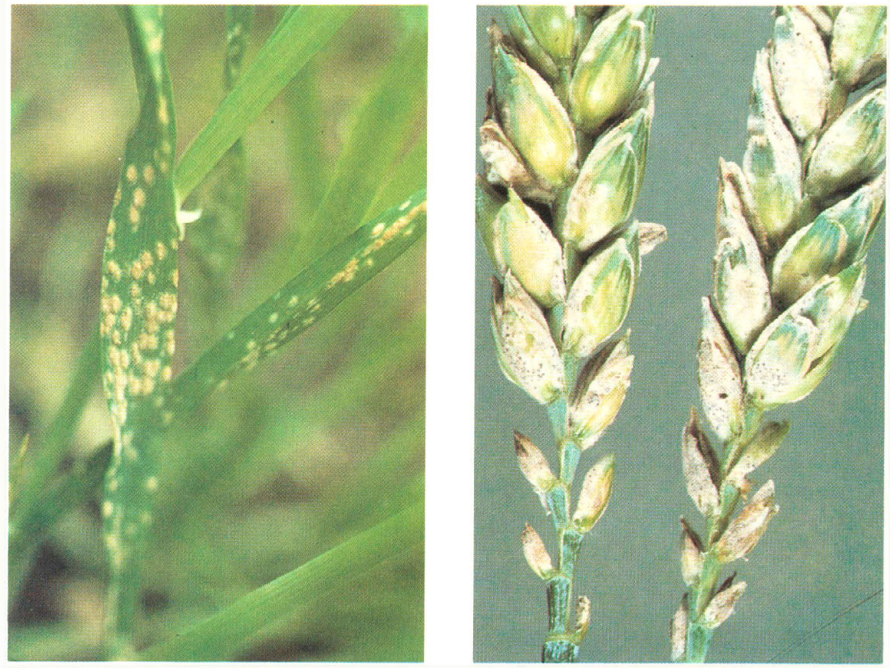


Fig. 4. Powdery mildew (*Erysiphe graminis*) on (left) barley and (right) wheat. (UK Crown Copyright)

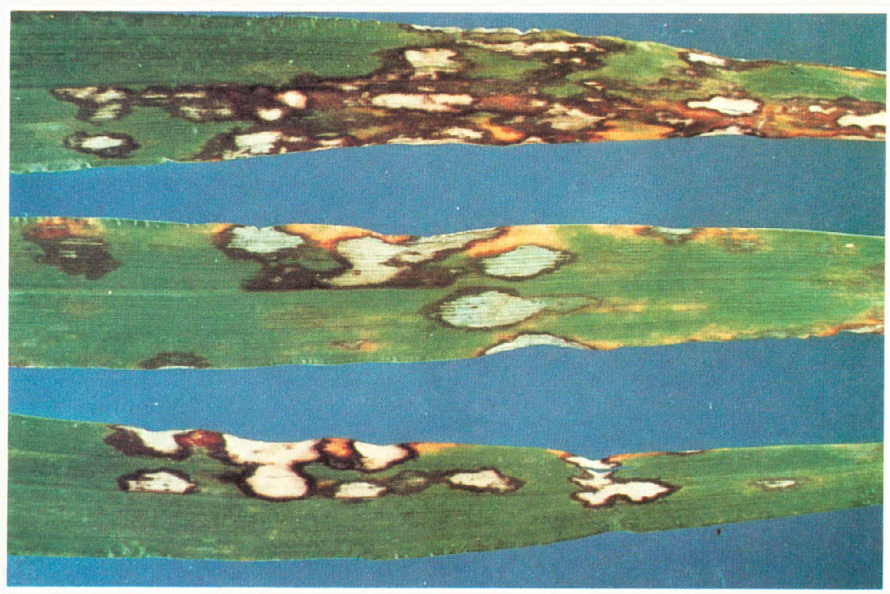


Fig. 5. Rhynchosporium leaf scald (*Rhynchosporium secalis*) on barley. (UK Crown Copyright)

The Fungicides in Use

The use of foliar fungicides for diseases of winter wheat and, to a lesser extent, winter barley started mainly in France and Germany, first to control eyespot and then to control leaf diseases developing just before or after ear emergence. The first fungicides marketed specifically to control cereal leaf diseases were tridemorph, applied as a spray, and ethirimol, applied chiefly to seed, and aimed at control of barley mildew. They were very effective and were rapidly adopted by farmers. Several other fungicides subsequently marketed to control mildew, including ditalimfos, triforine, and sulfur, were less effective. None of these fungicides gave good control of wheat mildew. A more recent introduction, triadimefon, has proved very effective against mildew of both barley and wheat as well as several other diseases. A number of related compounds, also very effective, will be available soon. Fungicides are less effective for leaf diseases other than powdery mildew, although control is often satisfactory.

The only fungicides satisfactory for control of eyespot are the related compounds carbendazim, benomyl, and thiophanate-methyl. For yellow rust, triadimefon is considered the best, although other fungicides, such as benodanil, oxycarboxin, and tridemorph-dithiocarbamate mixture, have also been used. The same fungicides are recommended for brown rust, but results are not as good. Several fungicides and mixtures are used against Rhynchosporium leaf scald on barley, including carbendazim and related compounds, triadimefon alone or combined with carbendazim, and tridemorph plus carbendazim. Least satisfactory are the fungicides for controlling Septoria diseases of wheat, including captafol, chlorothalonil, triadimefon plus captafol, and carbendazim combined with dithiocarbamate.

Effects on Yield

Yield response to the use of fungicides varies tremendously according to severity

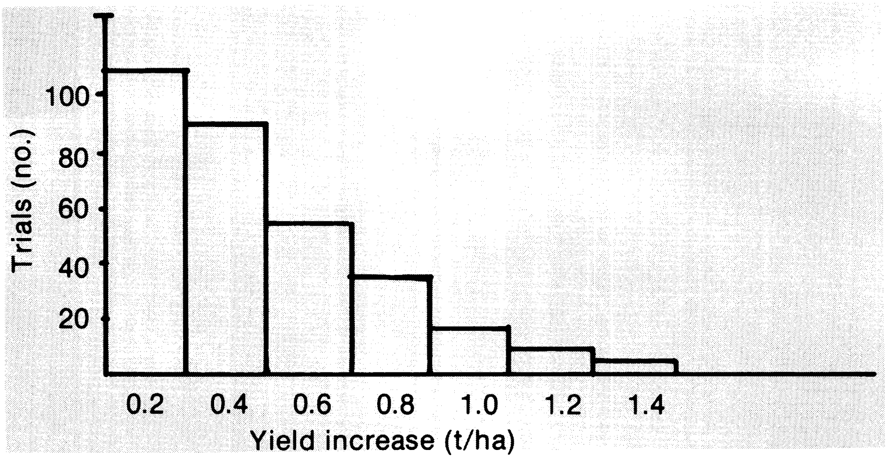


Fig. 6. Yield increases in winter wheat after fungicide treatments at the two-node and ear-emergence growth stages, compared with untreated controls; results of 279 trials, France 1975. (After Lescar [5]).

Table 2. Mean yield increases of winter wheat and winter barley in France after use of broad-spectrum fungicides[a]

	Winter wheat[b]		Winter barley[c]	
Year	Yield increase (%)	Frequency yield increase ⩾ 0.5 t/ha (%)	Yield increase (%)	Frequency yield increase ⩾ 0.5 t/ha (%)
1973	7.3	37	10.4	55
1974	8.2	40	7.6	35
1975	6.5	29	7.8	37
1976	2.0	4	5.1	9
1977	9.2	48	11.6	53
1978	10.8	60	11.9	61
1979	6.4	31	11.1	49

[a] After Lescar (5).
[b] Yield, 4.90–6.09 t/ha; number of trials, 67–310 per year.
[c] Yield, 5.07–6.04 t/ha; number of trials, 26–64 per year.

of disease, efficiency of the fungicide, and number of applications. When disease is severe, treatment may increase yield by 1 t/ha (20%) or more. Results from many trials in crops subjected to a range of diseases and disease severity, however, show responses of 5–12%. Responses tend to be highest in winter barley, lower in winter wheat, and lowest in spring barley. Results from trials on winter wheat and winter barley in France (Table 2) are fairly typical (5). The exception to this generalization is the response in spring barley when mildew is severe. In the United Kingdom, where this disease is common and often severe, yield increases of 30% (1.5 t/ha) have been obtained from a single well-timed spray, although average responses are 10%. When mildew is absent or at very low levels, however, yield responses in spring barley are small.

In addition to affecting yield, fungicide applications may improve the quality of grain, especially the specific weight (kg/hl) and grain size, important in selling grain, particularly durum wheat and barley for malting. Fungicide treatments do not seem to affect the quality of wheat for bread making.

Economic Considerations

The high value of cereals in Europe provides a strong incentive to produce good yields and to protect crops against losses from pests and diseases—a crop of 6 t/ha was worth $1,200–1,680/ha in 1979. Fungicide costs are relatively low. Two of the most effective used separately or in mixtures are carbendazim generators costing about $18/ha and

Table 3. A method of assessing the benefit of fungicide treatment for control of eyespot[a]

	Low risk[b]		Average risk[c]		High risk[d]	
Criteria	Conditions	Points	Conditions	Points	Conditions	Points
Previous crop	2 break crops:		1 break crop:		Susceptible cereals:	
	Row crop/clover/alfalfa	1	Row crop/clover	4	Rye	6
	Oats	2	Oats	5	Wheat, barley	7
	Forage grass	2				
Soil	Light to medium	1	Medium to heavy	3	Medium to very heavy	5
Weather	Long, hard winter	1	Average winter	2	Mild, wet winter	3–4
Cultivation[e]	No cultivation	1	Plowing or similar	2		
Sowing date[f]	After 25 October	1	5–15 October	3	Before 4 October	4
	15–25 October	2				
Density, vigor in spring	Poor	1	Fairly poor	2	Strong	4
			Average to fairly strong	3		
Cultivar	Flinor	1	Champlein	2	Probus	4
			Zenith Ardus and others	3	Svenno (autumn sown)	4

[a] Adapted from Vez and Gindrat (12).
[b] Up to 21 points, treatment not advised.
[c] 21–23 points, treatment depends on health of crop; threshold = 20% of plants attacked.
[d] 24 or more points, treatment recommended.
[e] Add 1 point for crops invaded by rhizomatous grassweeds.
[f] For high land, advance dates 5 days.

triadimefon, about $21/ha. The cost of application must be considered, however, and allowance should be made for damage from tractor wheels when sprays are applied at the flag leaf emergence stage or later; this latter cost may be shared by other practices, such as fertilizer application and pest control.

In some areas of Europe, notably northern Germany and northern France, some high input–high yield growing systems (8 t/ha and above) integrate one, two, or three fungicide treatments. When disease is consistently damaging, one or two treatments may be applied routinely. In Scotland, the cultivar Golden Promise is valued as a malting barley and occupies about 60% of the barley area. However, because it is very susceptible to mildew, virtually the whole crop is given routine fungicide treatment.

Under such special conditions, routine treatment may be justified. However, many crops are not very high yielding (about 5 t/ha) or are not at obvious risk to disease, and evidence from several countries shows that in more than half the crops such treatment cannot be justified on economic grounds. In a large number of experiments in France, yield responses have varied; this is well illustrated in the frequency of responses of 0.5 t and above in winter wheat and winter barley (Table 2) and in the more detailed analysis of responses in the winter wheat trials during 1975 (Fig. 6) (5).

In the United Kingdom, annual surveys in randomly selected crops of winter wheat and spring barley permit assessment of the proportion of crops in which fungicide treatment is likely to be economically worthwhile (1). Mildew control would have been worthwhile in most spring barley crops, but control of other diseases was worthwhile in less than 20% of crops.

The farmers' attitude toward fungicide use is largely influenced by management and economics. Many farmers are not inclined to inspect crops regularly for disease, and the need to spray large areas at short notice can cause management problems. Such factors tend to influence farmers to choose between no treatment and routine treatment. They will be dissuaded from this approach only when satisfactory methods have been devised for assessing the risk from disease and the benefit from fungicide treatment. Plant pathologists are attempting to do this.

Criteria for Treatment

The problem of providing satisfactory criteria has been approached in two ways: 1) by developing prediction methods to assess the risk of disease becoming severe enough to warrant use of fungicides and 2) by measuring effects of fungicide treatments on yield in a large number of trials, then identifying factors which are associated with economic yield responses.

In the United Kingdom, criteria for assessing risk from disease and benefit from fungicides have been defined largely in terms of disease thresholds. With spring barley mildew, a disease threshold was derived empirically from over 50 experiments in which single sprays of tridemorph were applied at weekly intervals. A relationship was established between the level of disease at the time of spray application and yield increase (Fig. 7). Single sprays applied as soon as 3–5% of the area of the oldest green leaves was affected by mildew gave the highest yield increases and about 75% of the increase given by a program of sprays that ensured complete control (4). We therefore suggest that farmers inspect crops regularly in the spring and early summer and treat with a fungicide as soon as 3% mildew is noticed. A similar threshold has been established for wheat mildew, but for this and other diseases that occur more erratically than barley mildew, disease threshold is linked with cultivar susceptibility. For example, fungicides are recommended as soon as yellow rust of wheat is noticed in very susceptible cultivars but only when 1% of the youngest leaves is affected in moderately susceptible cultivars. For all diseases, the latest growth stage for fungicide treatment is specified; control when the threshold occurs after this stage is unlikely to be economical.

With winter barley in England, additional factors must be taken into account when deciding to apply a fungicide. Crops sown early (September) are prone to mildew, and mildew-affected crops are more susceptible to winter damage. Crops on lighter soils are more susceptible to winter damage and benefit most from autumn control of mildew. In crops on heavy soils, however, control of mildew in the autumn, unless it is very severe, may not be economical. Yield response may not occur and yield or quality occasionally is depressed when mildew control leads to an excess of tillers that, in turn, result in a high proportion of small grain and an increased risk of lodging.

Although generally satisfactory for mildew and the rusts, disease thresholds have not been adequate on their own for eyespot and Septoria and Rhynchosporium diseases. The first attempt to forecast severe outbreaks of eyespot in winter wheat was based on a probability of infection calculated on meteorological data (10) in the spring when fungicides are applied. However, this method and others based on disease thresholds (percentage of plants infected in the spring) do not take into account environmental and cultural factors that significantly affect subsequent development of disease which determines whether yield losses occur. These factors have now been assessed in several countries to facilitate the decision on fungicide use. To make the assessment more tangible for advisers and farmers, some systems rate factors on a point basis (Table 3), with the decision to spray based on the accumulated points. Disease assessment is done only when additional information is required to make a decision (12).

Septoria diseases are most damaging when wet weather occurs soon after heading (6). Experiments in winter wheat have shown that fungicides applied soon after flag leaf emergence give the best disease control and yield response. Septoria diseases are at a low level at this time, however, and may be difficult to diagnose and assess for a threshold level. In the United Kingdom, a relationship has been shown (11) between the number of days with more than 1 mm rain during the second half of May and early June

Table 4. Example of risk assessment in a winter wheat crop in the Nord Picardie region of France[a]

Cultural factors	Points[b]
Previous crop	
Peas	+3
Potatoes	+3
Wheat	+2
Sugar beet	+1
Maize	0
Distance from sea	
< 50 km	+1
50–100 km	0
> 100 km	−1
Soil depth exploited by roots	
0–25 cm	+1
25–50 cm	0
> 50 cm	−1
Susceptibility of soil to drought	
High	+1
Medium	0
Low	−1
Clay content of soil	
< 12.5%	+1
12.5–25%	0
> 25%	−1
Lime content of soil	
> 20%	+2
10–20%	0
< 10%	−1
Cultivation	
Plow	+1
Tines or disks	0
Rotavator	−1
Sowing date	
Before 15 October	+2
15–31 October	+1
1–24 November	−1
After 25 November	−2
Cultivar	
Clement	+3
Rivoli	0
Maris Huntsman	−1
Roazon	−2
Add fixed score	+7

[a] After Lescar (5).
[b] 10 points or more = high risk and need for fungicide treatment. Below 10 points = low risk and benefit from fungicide treatment unlikely; crop must be monitored for disease, eg, mildew, yellow rust.

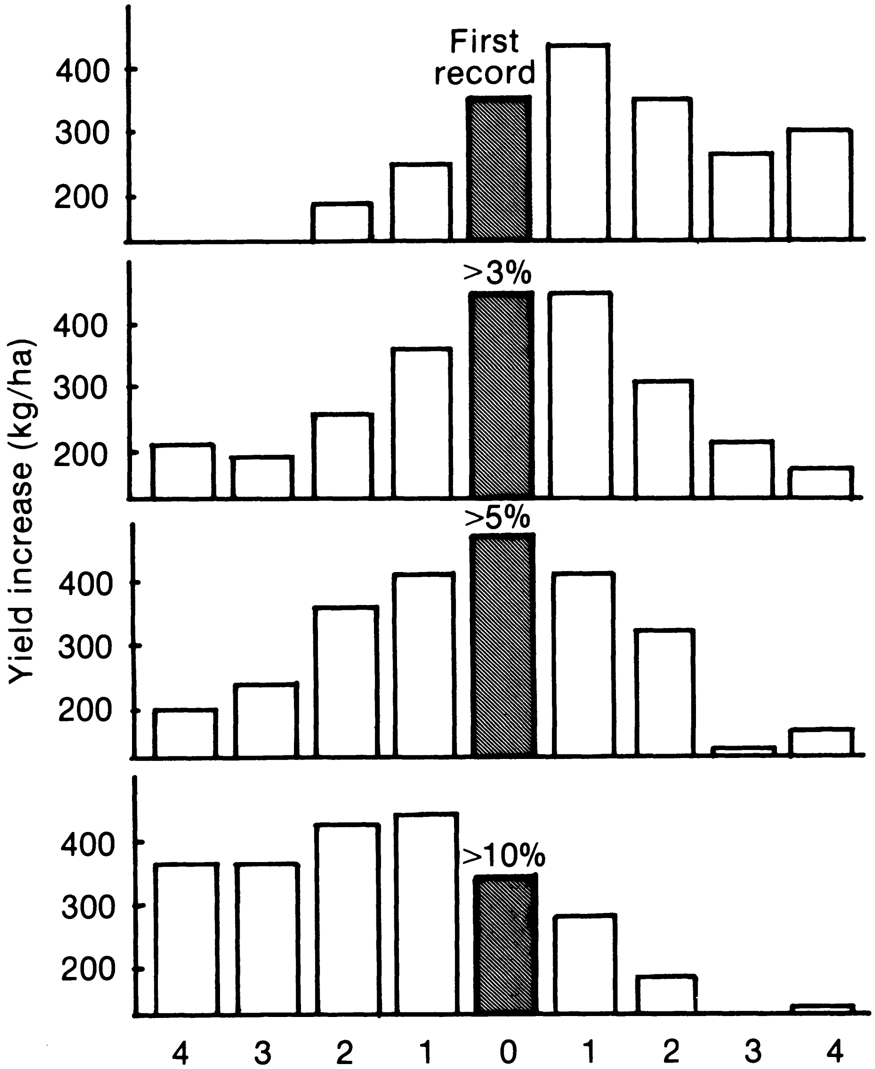
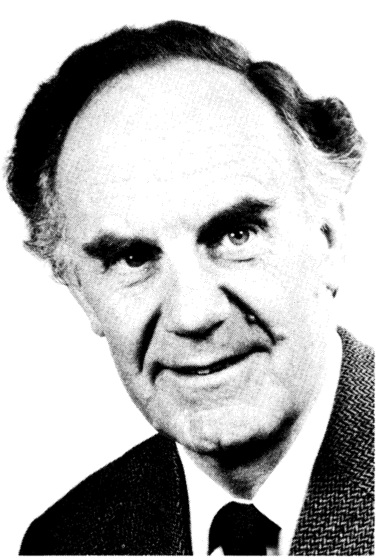
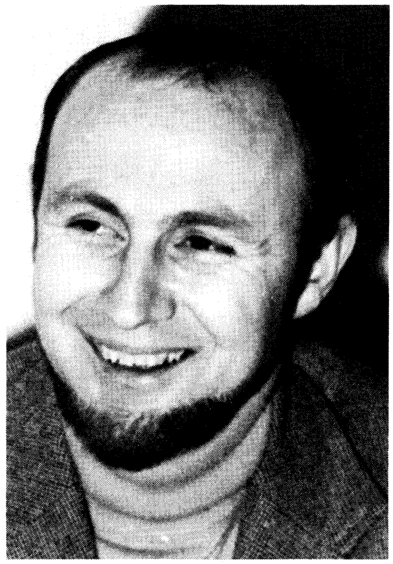


Fig. 7. Increase in yield of spring barley associated with single sprays of tridemorph applied at the first record of mildew in the crop and when 3, 5, and 10% mildew were first recorded on leaf 3 or 4, and increase in yield associated with single sprays applied up to 4 weeks before and after this. (After Jenkins and Storey [4])



John E. E. Jenkins

In 1948, after graduating from the University College of Wales, Aberystwyth, John Jenkins became an advisory plant pathologist in a branch of the Ministry of Agriculture, Fisheries and Food, now known as the Agricultural Development and Advisory Service. He worked in four different areas before becoming the regional plant pathologist at Leeds and has had a special interest in cereal diseases, especially control with fungicides, for nearly 20 years.



Luc Lescar

Luc Lescar qualified as an agronomist at L'Ecole Nationale Supérieure Agronomique de Rennes and is responsible for the Crop Protection Department at the Institut Technique des Céréales et des Fourrages. The department does applied research on cereals and forage crops in France. After working on weed control, he turned his attention to cereal diseases and since 1971 has coordinated studies on this subject throughout France under the auspices of his institute.

and the severity of Septoria disease after ear emergence. Because the spray to control Septoria disease is applied in the end of May and early June, weather data can aid in assessing the risk from disease and the need to spray. In general, however, meteorological data have not been used much in decisions on fungicide treatment.

In the Netherlands, a more sophisticated method for determining fungicide use is being developed in a cooperative project (EPIPRE) among farmers and plant pathologists. The aim is supervised control of some diseases and pests of winter wheat and minimal use of pesticides. Basic data from each field are entered in a data bank and supplemented with field observations by the farmer on disease incidence. These data are reviewed daily by simplified simulation models using weather records, and expected damage and loss are calculated. The system leads to one of three decisions: "treat," "do not treat," or "send new observations." Communication between the farmer and the computer center is by mail, but turnaround is rapid. The approach is different from that in most other countries; the use of more data and a computer means that decisions are made centrally and not on the farm.

Although the described methods can be satisfactory in selecting crops likely to benefit from fungicide treatment, fungicide trials in several countries have shown that some significant yield responses do not relate to recorded disease, especially when levels are low. Further, yield responses (usually relatively small) to broad-spectrum fungicides are evident even when levels of disease are not significant (1,2). Such findings have led to attempts, especially in France, at developing methods to assess the response of individual crops to fungicides.

In France, disease complexes generally occur. The mean responses of winter wheat to broad-spectrum fungicides applied at the two-node and ear-emergence growth stages are shown in Table 2 and Fig. 6. These data also illustrate the variability of responses, and usually relationships between yield responses and simple observations such as disease have not been consistent. Poussard et al (7) showed that treatments were economically beneficial in only 35–40% of the trials but by considering a number of cultural factors—preceding crop, type and depth of soil, sowing date, cultivar—crops could be selected that would benefit from treatment. In 1979 a risk assessment table (Table 4), compiled after analyses of 750 trials in the preceding 4 years, was tested in 28 fields and gave satisfactory results in 24. This result is excellent, considering more than 50% of routine applications in the area are not economical (5).

Both methods of assessing fungicide treatment are useful and are not mutually exclusive. For most crops, more than two treatments—necessary to ensure complete protection of winter cereals—is unlikely to be economical. Therefore, whether or not routine sprays are applied, it is necessary to monitor crops, especially for powdery mildew and the rusts, and to use disease risk assessment to determine the need to apply fungicides.

The Problem of Insensitivity

Large-scale use of fungicides raises the problem of insensitivity, or tolerance, in the pathogen. Only the carbendazim generators have been used for eyespot control, and so far insensitivity in the fungus has not been reported. Ethirimol has been used extensively for seed treatment in the United Kingdom, and a tendency has been noted for less sensitive isolates of the barley mildew fungus to dominate in populations examined at the early growth stages. By the end of the season, however, the more sensitive isolates dominate (3). Despite some circumstantial evidence for a decline in ethirimol's efficiency in controlling mildew, this has not been demonstrated experimentally nor has a reduced level of yield response been shown.

That no serious insensitivity problems have yet occurred may be related at least partly to infrequent (once or twice) applications of fungicides. Complete control is not the aim, so wild sensitive forms are able to build up again. However, because of reliance on a few fungicides and the introduction of some new ones with greater persistence, insensitivity and especially loss of effectiveness need to be monitored, and some strategy should be devised to prolong the usefulness of fungicides.

The Future

The development of effective fungicides during the past 10 years has provided farmers with a valuable tool for protecting cereal crops from foliar diseases. Now a strategy for using them effectively is needed. Economics will limit the frequency of application to some extent, but other factors, social and political, may be influential in determining their use on a crop occupying such a large proportion of the countryside. In all countries, fungicides and their use must be approved by government agencies, and future legislation is likely to be increasingly strict. A recent Royal Commission on Environmental Pollution in the United Kingdom expressed concern about the scale of pesticide use. The commission did not feel that the restraining effect of cost would ensure wise use and wished to see the approach changed to one of reduced use.

Present methods for determining

whether to use fungicides are unsophisticated, which may be an advantage, especially if application on farms is to be encouraged. Improved methods are needed, however. Further epidemiologic studies and development of models such as those for Septoria diseases and eyespot by Rapilly et al (8,9) may provide helpful information that could be incorporated into present or new schemes. The production of computers for farm use may promote more sophisticated methods.

Monitoring crops for disease is important, and in many countries disease intelligence schemes are being formulated to alert farmers to examine their crops before diseases become epidemic. The information is conveyed by such means as press, radio, television, and telephone.

Seed treatment is convenient and considered less damaging to the environment than the more generally applied sprays, even though it is always used as a routine preventative. Only ethirimol for the control of barley mildew has been widely used in this manner, but further developments may be expected, with more broad-spectrum fungicides, such as triadimenol (related to triadimefon), being introduced.

We have emphasized the established role of fungicides in cereal growing in Western Europe, but they form only one part of an integrated system, supplementing disease control still largely provided by cultural practices and cultivar resistance.

Acknowledgments

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