Proceedings 8th British Insecticide and Fungicide Conference (1975)

PRESENT SITUATION OF DISEASE CONTROL IN CEREALS IN NORTH WESTERN EUROPE (EXCLUDING GT. BRITAIN)

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Summary For the north-west of the European Continent, i.e. France, Belgium, Luxembourg, Netherlands, Denmark and West Germany, the disease situation in wheat, barley, rye and oats is described, and the economic significance of the most important diseases in each country indicated. The present role of fungicides for the control of the diseases is discussed in relation to other methods of control including genetic resistance and cultural practice. The basis on which growers are recommended to treat their crops with fungicides in the countries covered by the paper is summarised and an indication of the current level of fungicide usage is given.

Résumé Pour le nord-ouest du continent européen, c'est-à-dire la France, la Belgique, le Luxembourg, les Pays-Bas, le Danemark et l'Allemange, la situation phytopathologique dans le blé, l'orge, le seigle et l'avoine est décrite et l'importance économique des principaux maladies en chaques pays est indiquée. Le rôle actuel des fongicides contre ces maladies est discuté en comparaison d'autres méthodes de lutte la résistance génétique et les techniques de culture y comprises. La base, sur laquelle il est recommendé aux cultivateurs de traiter leurs céréales avec des fongicides dans les pays en discussion est resumée et enfin il est donné une indication de l'étendue présente de l'usage des fongicides.

The intensification of cereal growing increases the risk of infection by pathogenic fungi (quantitative aspect) and also the increasing use of production aids such as nitrogenous fertilizers, growth regulators and to a certain extent herbicides affects the development of cereal pathogens (technological aspect). As a result of these changes diseases are at present regarded as the major factor preventing the full exploitation of the yield potential in cereal crops.

It is the aim of this paper to describe the disease situation in cereal crops (wheat, barley, rye and oats) in those countries of Europe which in climatic conditions and agricultural practice and yield levels are similar to the United Kingdom; in particular France, the Benelux countries, Denmark and West Germany are discussed.

Information on each of the cereal crops is presented in three sections, namely: incidence and economic importance of the major diseases, disease control, and the basis on which growers are recommended to spray. In the territory which stretches from the Atlantic Ocean to the Baltic Sea and from the Alpine ranges to the North Sea, a great diversity of phytopathological situations exists and in this paper only the main aspects can be described. Selected references are cited here to serve as an introduction for further studies.

In the course of this paper the economic importance of diseases will be indicated by tabulated data. These estimates are given only with great reservation since the figures presented are based on the results of fungicidal treatments and the actual losses due to a disease may be greater than the increases of yield obtained. Sometimes the data published are not representative for the major cereal growing areas and conditions and experimental conditions may also differ. Differing climatic conditions again may result in different disease situations.

Initially the agronomic situation of the countries mentioned above may be clarified by quoting a few statistics.

Table 1 shows the extent of cereal production in the territory under consideration and it indicates the relative importance of cereal cultivation compared to the total arable land.

Table 2 presents the proportion of the different cereal crops to the total cereal acreage. The phytopathological influence of these data will be discussed later.

Table 1

Total national acreage and % arable land occupied by cereals

	Total acreage (1000 ha)	Cereals as % of arable land
France 1973	7 838	46
Belgium 1974	431	56
Luxembourg 1974	43	70
Netherlands 1973	290	43
Denmark 1973	1 762	67
W.Germany 1974	5 191	69

Table 2

Cereal crops in % of total cereals

	wheat		barley		rye		oats	mixed grain
	winter	spring	winter	spring	winter	spring		
France 1973	47	4	7	29	2		11	
Belgium 1974	41	5	24	11	3		14	2
Luxembourg 1974	8	17	4	35	2	trace	28	6
Netherlands 1973	40	8	4	27	11	trace	10	
Denmark 1973	5	2	0	82	2	trace	8	1
W.Germany 1974	27	4	13	19	13	1	16	7

WHEAT DISEASES

1. Incidence and economic importance of the major pathogens

Eyespot, *Cercosporella herpotrichoides*, is the major foot rot disease of winter wheat occurring especially in the western and northern regions, where infection mainly takes place during mild winters (VAN DER SPEK 1975). Additionally, depending on the weather conditions, infections may occur in spring also in other parts of the Continent, as happened for example in the south of Germany in 1972. In France, due to mild winters in the years 1973 and 1974, foot rot diseases were thought to be more damaging than leaf and ear pathogens. In Luxembourg, Denmark and W.Germany the high proportion of cereals (Table 1) considerably favours eyespot. In Belgium however according to preliminary results of FRASELLE (1974 a) eyespot is not regarded as a serious disease especially when wheat follows sugar beet or legumes. In the Netherlands a medium significance is attached to this pathogen.

Fusarium foot rots are only prevalent on dry soils, more in the south than in the north. Sharp eyespot, Rhizoctonia solani, is reported as a serious disease only on some sandy and peat-reclamation soils especially after dry and cool weather in spring, and take-all, Gaeumannomyces graminis is reported only sporadically. In Table 3 the average annual yield losses due to foot rots in wheat are given.

Table 3

Average national annual yield losses in winter wheat due to foot rot diseases (kg/ha)

France	Belgium	Luxembourg	Netherlands	Denmark	West Germany
250	50	200	200	300	300

Among the leaf pathogens yellow rust, Puccinia striiformis, has achieved major importance. From 1972 to 1974 the most severe epidemics have been recorded in Denmark (cv. Kranich, Cato) where chemical rust control often resulted in increases in yield up to 900 kg/ha. Heavy attacks have also occurred in the far north of West Germany and in the Netherlands (cv. Joss, Tadorna, Diplomat, Kormoran). In the north of France the disease has also been noticed. In 1975 yellow rust has mainly occurred in the Netherlands, the north of France, Luxembourg and the extreme north-west of Germany. The pathogen in particular has spread on the cultivar Clement, and in France also on Joss and Maris Huntsman.

The disease is of major commercial importance because of its ability to develop new races which are aggressive on previously resistant cultivars and because such races can spread very rapidly under suitable conditions. As a result the value of commercial wheat cultivars can change. The development of such races significantly effects the commercial choice of wheat cultivars and consequently the development of new races is carefully monitored (JOHNSON et al 1972).

Powdery mildew, Erysiphe graminis, as a significant leaf pathogen is confined mainly to areas of high humidity, i.e. to the north and west of the Continent (Denmark, coastal areas of Germany, Netherlands, Luxembourg, Belgium and the west coast of France). In other regions the pathogen is mainly found on susceptible cultivars (Hardi, Caribo). High nitrogen dressings also favour the disease. Unlike barley mildew heavy attacks of wheat mildew do not necessarily result in yield losses because wheat apparently reacts more tolerantly (LÖCHER and HAMPEL 1973).

Other fungi, especially Septoria nodorum (in districts with high precipitation) and S. tritici (in coastal regions), can be present on the leaves, but are only of importance when they attack the flag leaves and the ears. Locally brown rust, Puccinia recondita, is found; it is more frequent in the south-west of France.

On the ears powdery mildew is of greater importance. Septoria nodorum follows often as secondary pathogen. The wetter the weather before and shortly after heading the more glume blotch prevails and mildew diminishes. Thus in the locations with high precipitation, e.g. the Lower Alps and the uplands, S. nodorum as single ear pathogen causes considerable reductions of yield. In areas with warm summer conditions and moist spells Fusarium ear blights are observed in some years, the main infection centres being the Paris Basin and the central plains of France. According to FOCKE (1974) severe damage by this pathogen only occurs when at least 10 to 15% of the ears are attacked and in practice this disease level is rarely exceeded. Rust is also found on the ears under favourable conditions, while in the Netherlands and in Luxembourg some significance is attributed to the black moulds (Cladosporium, Alternaria and Epicoccum).

The ear disease complex is considered of great significance in Belgium, Denmark and the Netherlands and is a considerable problem in the north of France, Luxembourg and Germany. The economic importance of the pathogens under consideration is tentatively summarized in Table 4.

Table 4

Average national annual yield losses in winter wheat due to diseases of the ears and the flag leaves (kg/ha)

France	Belgium	Luxembourg	Netherlands	Denmark	West Germany
200	450	200	350	400	300

Before finishing the disease survey for winter wheat, dwarf bunt, Tilletia controversa should be mentioned. This pathogen is found only in the south of Germany in locations high above sea-level. Local losses up to 60% have been recorded in some years, the last being 1970.

2. Disease control

Cultural measures to prevent or to reduce the attacks of pathogenic fungi are still the basis of plant protection. In the modern system of integrated disease control chemical treatments should only be used complementarily. The choice of at least partially resistant or tolerant cultivars is one of the main features of disease control by cultural techniques, and it is interesting to note that because of their extreme susceptibility to yellow rust the Kranich and Cato cultivars have been replaced in Denmark since 1974 by the cultivars Solid and Starke. Similarly the cultivars Clement and Joss will also be replaced in future. 60% of the cultivars which in course of time were removed from the official Dutch recommended list, were rejected because of their susceptibility to yellow rust.

Cultivars with low levels of resistance often remain on the recommended lists because of other positive agronomic qualities. A knowledge of cultivar resistance properties should at least facilitate disease forecasting and also explain present disease situations. The resistance properties of the major winter wheat cultivars to the major diseases are outlined in Table 5.

Table 5

Resistance properties of the main wheat varieties in N.W.Continental Europe

	Resistance against	eyespot	yellow rust	powdery mildew	glume blotch
France:	Capitole	+	+++	++	++
	Hardi	++	+++	+	+++
	Champlein	+	++	++	+++
	Joss	+++	+	+	++
	Top	++	+++	++	++
	Talent	+	+	+++	+
Belgium:	Cama	+++	++	++	+
	Norda	+++	+++	+	+
Luxembourg:	Caribo	+++	+++	+	+++
	Kormoran	+	+	+++	++

Table 5 (continued)

	Resistance against	eyespot	yellow rust	powdery mildew	glume blotch
Netherlands:	Manella	+	+++	+	+
	Caribo	+++	+++	+	+++
	Clement	+	+	+++	+++
	Cyrano	+++	+++	+	+++
	Lely	+++	+++	+	+
Denmark:	Solid	+++	+++	+++	+
	Starke II	+++	+++	+++	+
	Holme	+++	++	+++	+
	Kranich	+++	+	+++	+
W.Germany:	Jubilar	+	+++	+	+
	Caribo	+++	+++	+	+++
	Diplomat	+	+	++	+

+++ moderately susceptible; ++ intermediate susceptibility; + highly susceptible.

As far as crop rotation for disease control is concerned, the effect of directly preceding crops is much higher than the influence of long-term crop rotation systems (VEZ 1969, FISCHBECK et al 1969). 75% wheat and barley within a crop rotation are practicable providing that under heavy infection pressure eyespot is controlled by fungicide. Higher proportions of cereals, however, may result in considerable losses of yield (DIERCKS 1975) although under favourable soil and climatic conditions wheat can be cultivated even for a succession of several years with good results. In practice, however, wheat mostly follows a leaf crop, monocultures at present still generally being uncommon. On French experimental sites a significant increase of the Fusarium inoculum has been observed where there is the succession maize/wheat or, more especially, maize/hard wheat (Triticum durum) (CASSINI 1975).

Phytopathological risks increase if the soil is cultivated only superficially after harvest or before sowing the next crop, and if the residues of the preceding crop remain on the soil surface. These techniques are popular particularly in France and, as a result, the survival of Fusarium graminearum or Septoria nodorum is favoured (CASSINI 1973).

At present no chemical treatment is recommended for control of dwarf bunt (Tilletia controversa) in Germany, prevention is solely by cultural techniques, i.e. late sowing of winter wheat and substitution of winter wheat by spring wheat.

Cultural measures generally only give limited disease control and therefore complementarily chemical treatments are often necessary. Chemical disease control is practised to its greatest extent in France, Belgium and the Netherlands where the farmer may choose between several groups of fungicides: 1. MBC group fungicides + dithiocarbamates with a broad spectrum of activity; 2. mildew fungicides (including sulphur) + dithiocarbamates or captafol which are somewhat cheaper but with little effect against foot rot diseases; 3. MBC group fungicides for eyespot only and 4. fungicides for mildew only.

In France it has been shown that the best practical protection of wheat can be achieved by one fungicide treatment against foot rot diseases between growth stages (LARGE 1954) 7 and 10 (at the two node stage until the appearance of the flag leaf) and a second application against ear and leaf diseases, when heading is completed. Generally broad spectrum fungicide combinations are used (LESCAR et al 1975). In Belgium several treatments are sometimes carried out, and whereas chemical foot rot control is regarded as uneconomic, up to three applications may take place at later growth stages (FRASELLE 1974 a). It is considered essential to protect the ears and flag leaves immediately after heading using polyvalent fungicide combinations. An extra spray with a specific mildew compound may be necessary before ear emergence occurs (mostly as a result of high levels of nitrogen in the soil e.g. preceding crops being legumes) and finally a second ear treatment after flowering may be applied under wet conditions.

The situation in the neighbouring Netherlands is similar. Only limited treatments are made to control foot rot diseases (in the first half of May, height of crop 25 cm) and for the control of ear diseases general recommendations are issued for a single application at the beginning of flowering with one of the systemic MBC group fungicides + maneb.

In Luxembourg, against eyespot, carbendazim fungicides are recommended at the beginning of stem extension. Powdery mildew is controlled by mildew fungicides applied before heading. Against glume blotch and Fusarium diseases the ears are sprayed shortly after emergence with benomyl + maneb; to improve the effect, this treatment is recommended to be resprayed after 14 days.

In Denmark benomyl is registered for eyespot control in winter wheat only. Mildew fungicides are often used, and maneb also, but maneb is not officially recommended.

Whereas in France, Belgium and the Netherlands the official approval of fungicides relates to complexes of cereal parasites, in Denmark and W.Germany, products are approved against single pathogens only. Thus in Germany MBC group fungicides are registered for application against eyespot in winter sown cereals only, the optimum time for the fungicide application being the beginning of stem extension to the appearance of the second node (GS 6-7) (EFFLAND 1973). Thiophanate-methyl is registered against mildew of the ears in wheat and recently captafol was approved against glume blotch. Captafol seems to be far more effective against Septoria than other available fungicides or combinations (OBST and KRUMREY 1975). In Germany dithiocarbamates are not currently registered for application in cereals, and for toxicological reasons it is doubtful whether they ever will be.

In all the countries discussed a similar range of chemical products is used, so no separate comments need be made on this point with one exception, that there are considerable differences in the recommended rates for the MBC group fungicides e.g. benomyl (a.i.) against eyespot; France 0.25 - 0.3 kg/ha; Belgium 0.2 kg/ha; Netherlands 0.25 kg/ha; Denmark 0.5 kg/ha; W.Germany 0.125 kg/ha. FEHRMANN (1973) has shown, that dosages higher than 0.12 kg/ha benomyl may result in a further reduction of visible eyespots but they do not bring any corresponding increase in yield. FRASELLE et al (1973) found an optimum of 150 to 175 g benomyl for the control of ear diseases.

In Table 6 some figures on the present usage of cereal fungicides are given, again with reservation.

Table 6

Percentage of winter wheat acreage treated with fungicides in 1975

	France	Belgium	Luxembourg	Netherlands	Denmark	W.Germany
Foot rot diseases	20	1	1	12	5-10	15
Leaf and ear pathogens	20	1x35, 2x15	2-3	55	50-60*)	15

*) up to three applications

It should also be added that the fertilizer calcium cyanamide shows some effect on eyespot; but against severe infections it is not sufficiently active. It is applied to a relatively small extent mainly in W.Germany. Here also chlormequat (CCC) is used on a large scale to prevent pathogenic and physiological lodging, roughly 50% of the wheat acreage being sprayed every year. In Luxembourg nearly the total Kormoran acreage is treated with chlormequat.

Unsolved up to now is the problem of chemical control of rust in Europe. Neither benodanil (Calirus) nor pyracarbolid (Sicarol) are at present available and oxycarboxin is in general too expensive. As a substitute in Denmark the combination tridemorph + maneb is used (LINDEGAARD and ELBEK PEDERSEN 1975). According to recent experience triadimefon reveals a good activity against yellow rust.

3. Conditions under which growers are recommended to spray

When diseases do not occur to the extent that direct control measures are necessary every year, appropriate methods are needed to decide whether or not chemical control is economically justified. This is a question of reliable disease forecasting. The official recommendations in the different countries may be outlined as follows:

1. In France two applications with polyvalent fungicide combinations are economic when an increase in yield of at least 500 kg is achieved. In 85% of all experiments investigated, these treatments were justified in cases where all the following conditions were satisfied:

   When the preceding crops were wheat or potatoes, when only a superficial cultivation of the soil had been carried out before sowing, when the wheat area was situated in the north of the Paris Basin and when the varieties Joss, Hardi or Capitol were cultivated.

   Only 7% of the trials rendered economic results when the preceding crops were maize or sugar beet and when the cultivars Champlein or Top were grown (other conditions the same). These data are just an extract from many results from a network of trials which were carried out in 1973 and 1974 in the whole country in order to assess conditions for a quantitative disease prognosis (LESCAR et al 1975).

2. In Belgium, Luxembourg and the Netherlands leaf sprays against mildew are recommended only when there is a significant mildew attack shortly before ear emergence (GS 10). A critical injury level from mildew is given by PARMENTIER (1972). A treatment is justified when a total of 25 pustules is found on both sides of the three upper leaves. Spraying against eyespot in the Netherlands is only regarded as essential when in the first week of May 15-20% infected culms are counted.

3. In W.Germany, with the help of the Meteorological Service, a prognosis for eyespot based on weather conditions has been developed. However, only those infections, which occur during stem extension in spring are forecasted meteorologically. Winter infections of autumn sown cereals can be detected in spring by a laboratory test developed by KLEWITZ (1973). The test was used for the first time on a large scale in 1975 but because of its cost in terms of work only a limited number of samples can be examined in practice. This only permits a general estimation of the eyespot situation. The decision on the necessity for ear sprays is derived from the experience of disease attack in preceding years when considered in conjunction with the essential climatic condition.

4. Finally in Denmark spraying against eyespot is justified, if in GS 5-6 more than 30% of the plants are infected. Disease surveys, too, are the bases for decision to control powdery mildew and rust fungi.

In all countries the decision concerning the use of fungicides against *Septoria nodorum* remains a problem, although several workers are developing prognosis models for this fungus.

In relation to Fusarium ear blights, recent investigations by FOCKE (1974) may prove useful for the development of a prognosis. The production of the infection potential, the infection itself, the spread of the pathogen in the tissue of the host and the development of symptoms are described in relation to weather conditions and plant growth.

No additional comment is given on the disease problems in spring wheat, as the acreage is far smaller than that of winter wheat and the disease situation is similar. The probability for eyespot infections is, of course, lower due to a quicker plant growth in the young stages. Foregoing statements for soft wheat are also in general valid for hard wheat, which is grown to a relatively small extent (6% of the total wheat acreage) in France. This wheat species is mainly susceptible to Fusarium and mildew.

BARLEY DISEASES

1. Incidence and economic importance of the major pathogens

Until quite recently little attention has been paid to the incidence of foot rots in barley, as this cereal was supposed to be more tolerant than wheat to attacks by these pathogens. The recent introduction of MBC group fungicides into barley crops has, however, revealed the economic importance of eyespot, at least in winter barley. Because of its early sowing in the autumn, winter barley is susceptible to infection for a long time and even in South Germany attacks during winter are obviously more important than those in spring. The regional incidence of eyespot in winter barley is nearly the same as in winter wheat. Chemical eyespot control achieves results equally as good as those in winter wheat (HAMPEL 1975). Spring barley is, of course, grown for a much shorter time at low temperatures and therefore the disease hazard is slighter and the probability of economic increases in yield after treatment generally is smaller.

Take-all, even in barley monocultures in Denmark, plays a surprisingly unimportant role (JENSEN 1975). Some significance is attributed to the Fusarium foot rots in France.

Without doubt the major barley disease is powdery mildew. The pathogen occurs mainly in the north and the north-west of the area under consideration. In the south of Germany (Bavaria) only a slight to medium attack is observed on average every two years (BAUMER and ULONSKA 1971). The significance of powdery mildew for spring barley increases with the increase of winter barley acreage. According to German results (HAMPEL and LANG 1972) and experiences in Luxembourg, winter barley, because of its longer growth period, in general suffers more from mildew attacks than spring barley. In France, however, spring barley is slightly more damaged than winter barley and in Belgium and in the Netherlands, too, spring barley is supposed to be more damaged than the winter crop, a fact attributed to the precocity of winter barley which often at least partially escapes severe mildew attacks (FRASELLE et al 1973). Probably in these countries mildew epidemics are starting later in the season. However, in considering these comparisons it should be remembered that, due to their resistance properties, the different cultivars of winter barley do not react equally. For France it is estimated that the losses due to mildew attacks are of the same rank as those caused by the sum of all other pathogens (RAPILLY et al 1975). The spectrum of powdery mildew races seems to change in barley far quicker than in wheat and whereas in one location in East Germany from 1968 to 1974 new races or biotypes could not be detected in wheat, in barley nine races and six subraces were recorded (MEYER 1974).

Other barley leaf pathogens in order of economic significance are brown rust (Puccinia hordei), Rhynchosporium secalis and Helminthosporium gramineum. Brown rust is found nearly everywhere, but in general the highest disease incidence is in the western region of France near the Atlantic Ocean. The spread of Rhynchosporium leaf blotch depends on moist weather conditions to a higher degree and in some years severe epidemics are recorded, particularly in Denmark (especially in the cultivar Term). In the south of France leaf blotch is of some significance during winter, since susceptible spring barley varieties are sown in autumn. In Northern France, Belgium, the Netherlands and the north of Germany attacks are in general relatively slight. Turning to barley leaf stripe (*Helminthosporium gramineum*) the significance of this disease is stressed in the Netherlands and Denmark where the use of mercury seed dressings is restricted. Finally referring to yellow rust, contrary to the situation in wheat, epidemics in barley have occurred only locally in recent years.

Ear diseases seem to be of minor significance with the exception of loose smut (*Ustilago nuda*) which is often reported and, unlike wheat cultivars, most of the barley varieties possess almost no resistance (CHERY 1973).

On the basis of experimental results available a tentative estimate is given of average yearly yield losses due to foot rot and leaf pathogens in barley (Table 7).

Table 7

Average national annual yield losses in barley due to foot rot and leaf diseases (kg/ha)

		France	Belgium	Luxembourg	Netherlands	Denmark	W.Germany
w.barley	foot rots	470	50	400	?	no cultivation	300
	leaf diseases		400		250		350
sp.barley	foot rots	400	-	-	-	-	100
	leaf diseases		?	300	300	300-500	300

2. Disease control

Among cultural techniques the choice of resistant cultivars is a dominant feature. Barley cultivars display a by far higher range in resistance properties than wheat cultivars. In Denmark the pattern of barley cultivars is changing quickly, particularly to overcome the risks of powdery mildew. In Belgium, the Netherlands and Germany also great efforts are being made in breeding barley cultivars resistant to mildew and rust fungi. However in France barley cultivars with multiple resistance are seldom grown because in the absence of pathogens they are less productive than traditional ones. Indeed, among the most wide-spread spring barley cultivars in France are Rika, Mamie and Ingrid, which do not possess any resistance genes at all against mildew (CHERY 1973).

A summary is given of the mildew resistance properties of the most cultivated spring barley varieties, the acreage of which is more extensive than that of winter barley (Table 8).

Table 8

Resistance to powdery mildew of the major spring barley varieties

France:	Delisa	++	Belgium and Luxembourg:	Hebe	+	Denmark:	Tern	++
	Rika	+		Volla	+		Lofa	+++
	Mamie	+		Aramir	+++		Emir	+++
	Julia	++		Betina	++		Nordal	++
	Ceres	++		Mazurka	++		Rupal	+++
	Ingrid	+						
			Netherlands:	Berac	+	Germany:	Carina	+
				Mazurka	+		Villa	+
							Ortolan	++
							Union	+

+++ moderately susceptible; ++ intermediate susceptibility; + highly susceptible.

To suppress the overwintering of obligate parasites the cultivation of winter barley in Denmark was considerably restricted in 1932, and completely forbidden in 1968. There are also regional limitations for winter barley cultivation in the Netherlands. Thus, despite the cultivation of partially susceptible varieties, yellow rust of barley has only rarely occurred in the last years.

As far as chemical disease control is concerned, the specific mildew products were the first fungicides to be applied on a large scale in cereal crops and that in barley. Tridemorph is used the most and in the majority of countries also chloraniformethan (the production of which recently has been stopped), ethirimol (as spray and seed dressing), triforine, and to a small extent, sulphur sprays are used. In barley not so much experience has been gained with the broad spectrum MBC group fungicides although against foot rot diseases in this crop they seem to display a higher efficacy than in wheat (HAMPEL 1975). Their effect against leaf mildew, however, is not sufficient and also it is considered necessary to improve the effectiveness against Rhynchosporium leaf blotch by the addition of dithiocarbamates. The latter also give some rust control.

In France, for winter barley, a spray programme is recommended which corresponds to that of wheat except that timing is somewhat earlier. The first spray is recommended with MBC group fungicides or a specific mildew fungicide, each in combination with dithiocarbamates at the one to two node stage (GS 6-7) A second spray with broad spectrum fungicide combinations follows at the in boot stage (GS 10). These sprays are apparently directed against a complex of diseases, in which powdery mildew is often not the prevalent fungus. For spring barley one treatment with a broad spectrum fungicide is recommended at the swelling of the ears. Specific mildew fungicides are recommended only when mildew is present (LESCAR 1975).

According to preliminary experiences in Belgium, the best results in winter barley are obtained by spraying once with a broad spectrum fungicide (threefold combination of an MBC group fungicide + a mildew specific product + a dithiocarbamate) immediately before heading. Two sprays have not rendered economic results, the cost for one fungicide application being equivalent to the returns for 280 kg barley (FRASELLE 1974 b). In spring barley the treatment, generally with a specific mildew fungicide, has to be carried out earlier (tillering to first node stage).

In the Netherlands MBC group fungicides are not officially approved against foot rot diseases of barley. However, it is recommended to control mildew with specific fungicides, when non-resistant varieties (e.g. barley for malting) are grown. In Denmark, too, specific mildew fungicides are the most commonly recommended and used, although benomyl is also approved.

Broad spectrum fungicides are registered in W.Germany against eyespot in winter barley only. Contrary to winter wheat this crop can be treated between the end of tillering until shortly before heading with equally good results (HAMPEL 1975). At present specific mildew fungicides are sprayed to a considerable extent, particularly in the northern regions in spring. Leaf sprays against mildew of winter barley in autumn have only rarely rendered positive results. When Cercosporella and powdery mildew occur together in winter barley, a combination eyespot and mildew treatment is possible, in this case carried out at the onset of the mildew epidemic.

Finally the control of fungal diseases of cereals by seed treatment deserves some comment. With regard to the control of Helminthosporium diseases, especially barley leaf stripe, appropriate substitutes for mercury seed treatments are not yet available, and mercury is still used in all countries. However, the application of mercury seed dressings is restricted in the Netherlands and Denmark to seed production only, in France to special mercury compositions and in W.Germany official approval of all mercury compounds is limited until 1979.

Some tabulated data are given to demonstrate the extent of the present usage of fungicides in barley (Table 9). Up to now at the most one single spray is carried out in barley and as mentioned before, different fungicides or fungicide combinations may be used.

Table 9

Percentage of barley acreage treated with fungicides in 1975

		France	Belgium + Luxembourg	Netherlands	Denmark	W.Germany
w.barley:	foot rots	5	1	-	no cultivation	10
	leaf diseases	12	30	49		15
sp.barley:	leaf diseases	5	30	28	10	20

3. Conditions under which growers are recommended to spray

The conditions under which broad spectrum fungicides can be recommended, are at present still under investigation. In France RAPILLY et al (1975) have pointed out the interactions between chemical treatment and cultivar resistance properties. They showed that the cultivars Delisa, Rika and Mamie gave better yield increases following fungicide treatment than Bérénice, Julia and Ceres. For the evaluation of the eyespot situation in winter barley in Germany the KLEWITZ test is again used.

For the justification of specific mildew treatments a better basis exists. In Germany seed treatments of spring barley are only considered necessary when there is a high probability of an early mildew attack. In all other cases foliar spraying is more appropriate and is recommended to be carried out in spring at the onset of a visible mildew epidemic. As the new systemic fungicides have a good curative effect their application can be delayed until the lower leaves, which loose their field resistance first, are 1 to 5% covered with mildew pustules (BENADA 1974). Recently a prognosis model was developed for spring barley mainly for those regions where mildew control is not necessary every year. Where spring barley remains free of mildew for 30 to 40 days after emergence of the seedlings, a chemical mildew control later on is not justified (KLOSE 1975).

In the Netherlands the economic threshold for a specific mildew spray is reached when the third upper leaf is 10 to 15% covered with mycelium, or earlier under dry conditions. For France the corresponding figure is 10 to 25%

of the leaf surface infected during stem elongation. Under certain circumstances two sprays may be necessary. Both in Belgium and in Denmark careful disease surveys are the basis for recommendations for a directed mildew control.

RYE DISEASES

The cultivation of rye, mainly autumn sown, is still of interest, especially in the Netherlands and in Germany. However little knowledge exists on the economic importance of its major diseases.

Eyespot in winter rye chiefly occurs on rich soils and, unlike wheat, the culms are less susceptible to lodging. Detailed estimates of losses due to eyespot in winter rye have been published for E.Germany revealing that, on average, at least 15% reduction in yield is common (GIEFFERS and POHLAN 1974). The application of MBC group fungicides appears useful, also in combination with chlormequat on rich soils. In an average of 29 experiments from 1972 to 1974 HAMPEL (1975) with 350 g/ha thiophanate-methyl (a.i.) sprayed at the beginning of stem extension until the appearance of the first node, achieved an increase in yield of approx. 300 kg/ha. On light soils sharp eyespot (Rhizoctonia solani) often prevails and fungicides at present available are not suitable for the control of this pathogen. Depending on weather conditions snow mould (Fusarium nivale) may also be harmful.

Among the leaf pathogens powdery mildew is often troublesome. In E.Germany yield losses from 10 to 18% due to this pathogen have been recorded for the cultivar Danae. The attacks can be reduced by chemical treatments, but some care has to be taken because of the high tendency of rye to react phytotoxically after treatment. Brown rust (Puccinia dispersa) is another significant leaf pathogen but Rhynchosporium leaf blotch only occurs occasionally. Urocystis occulta is observed in Denmark.

For all these diseases no distinct cultivar reactions are mentioned in the Dutch or German official recommendations. Chemical treatments are at present still of no significance.

OAT DISEASES

Oats appear to suffer comparatively little from attacks of detrimental pathogens. In the north of the continental area powdery mildew may occasionally cause considerable losses and stem rust (Puccinia graminis) is also observed. Crown rust (P. coronata) tends to be more widespread but little economic significance is ascribed to these rust fungi. In the Netherlands the infection of oat seedlings with Helminthosporium avenae has recently increased since new races of the pathogen have developed which are tolerant to mercury seed dressings and other seed dressings give incomplete control. In coastal regions Septoria avenae may cause severe leaf lesions under favourable conditions and stem break caused by this fungus has also been observed. At present plant protection measures are not carried out to any extent.

FINAL REMARKS

Many more or less serious diseases present a risk for cereal cultivation in North-western Europe and are considered to be a major factor limiting the achievement of the full yield potential of modern cereal cultivars. At present economic control measures for most of these pathogens are still being investigated but experience has shown that reliance on crop hygiene alone or on chemical treatments alone will not render satisfactory results. Initial steps have been taken towards an integrated disease control system which is specific for the crop and the location and takes into account the requirements for economic cereal cultivation. However, further research is needed to establish more precise correlation between disease levels and yield loss. It is also necessary to devise methods of forecasting disease attacks and providing a basis for justifying the economic use of fungicides.

Acknowledgements

Many colleagues of neighbouring countries have promoted this survey by giving useful information, their friendly help is gratefully acknowledged. In particular the author wishes to thank: Dr. R.Cassini, Versailles, France; Prof. Dr. J.Fraselle, Gembloux, Belgium; Mr. C.Conter, Luxembourg; Dr. J. van der Spek, Wageningen, Netherlands; Mr. A.Jensen, Lyngby, and Mr. H.Elbek Pedersen, Viby, Denmark; Dr. H.Effland, Kiel, Dr. Eva Fuchs, Braunschweig, and Dr. M.Hampel, Limburgerhof, Dr. Celia J. Baker, Limburgerhof, W.Germany who kindly corrected the English.

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Proceedings 8th British Insecticide and Fungicide Conference (1975)

CONTROL OF YELLOW RUST (PUCCINIA STRIIFORMIS) IN WHEAT WITH OXYCARBOXIN

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Summary This paper summarises trials work carried out in Denmark, France and Holland from 1972 to 1975. Comparison of a 20% emulsifiable concentrate and 75% wettable powder indicated that the former was more effective. Timing of spray application was found to be critical, and it was suggested that oxycarboxin be applied whenever rust infection was observed on the flag leaf or leaf 2.

Résumé Voici un résumé des travaux de recherches effectués au Danemark, en France et aux Pays Bas entre 1972 et 1975. La comparaison d'un concentré emulsifiable de 20% et d'une poudre humidifiante de 75% indique que le premier était plus efficace. Nous avons trouvé que le règlage l'application de pulvérisation était critique. On a donc suggéré l'application d'oxycarboxine lorsque des attaques de rouilles apparaissaient sur la première ou la deuxième feuille.

INTRODUCTION

The preliminary description of the fungicidal properties of carboxin and oxycarboxin was first given by von Schmeling and Kulka (1966).

Since then carboxin has become a major component in cereal and cotton seed dressing.

Like carboxin, oxycarboxin is a systemic fungicide, but its activity is limited principally to rust fungi.

Initially oxycarboxin was marketed as a 75% wettable powder and used to control rust in ornamentals. This rather small niche in the agricultural chemical market place was prescribed more by the economics of rust disease control than by lack of disease on other crops (e.g. cereals).

The development of an emulsifiable formulation containing 20% of the active ingredient, together with the rise in value of cereal grains over the last 5 years, combined to promote oxycarboxin to an important role in European crop protection.

This new formulation of oxycarboxin, known as Plantvax 20, has been registered and is commerically available in Denmark and the UK, while registrations are pending in Holland, France, West Germany and Spain.

The economic status of the various rust diseases in cereals (Puccinia striiformis. P.recondita, P.hordei, P.coronata etc.) on a national basis varies with year, country and cultivar. It is perhaps the inconsistency of development of these diseases that makes them so troublesome.

With major epidemics of P.striiformis occurring only every 3 to 4 years, Batts (1957) Doling and Doodson (1968) the execution of field trials programmes designed to furnish comprehensive information for commercial use in different European countries requires patience and perseverance.

The plant breeders also have their problems. Rapid appearance of new races, which overcome factors of resistance in new cultivars, is a characteristic of yellow rust.

However, within the last three years systemic rust fungicides have become available that offer realistic cost/benefit advantages to supplement the efforts of the plant breeder and the traditional rotational practices of the grower.

This paper summarises work carried out in Europe between 1972 and 1975 with the systemic rust fungicide oxycarboxin. In the light of this experience the aim is to suggest recommendations for its use in the control of yellow rust in wheat.

METHODS AND MATERIALS

Trials carried out in Denmark have been published elsewhere, and materials and methods described therein. Stapel (1972) Noddegard et al (1973) and Lindegaard et al (1974).

In Holland small plot sprayers ("Azo") pressured by propane gas were used to apply treatments in a volume equivalent to 400 litres/ha on plots 25 sq.m. in area. There were 4 replicates of each treatment arranged in a randomised block design.

In France small plot sprayers ("Van der Weij") pressured by propane gas or compressed air were used to apply treatments in a volume equivalent to 750 l/ha on plots 60-100 sq.m. in area. There were 4-5 replicates of each treatment arranged in a randomised block design.

RESULTS

All results in the following sections relate to yellow rust (P. striiformis) on winter wheat.

I Efficacy of emulsifiable concentrate and wettable powder formulations

Table 1

Comparison of yield increases of wheat treated with 75% wettable powder and 20% emulsifiable concentrate formulations of oxycarboxin

Formulation	Rate kg a.i./ha	Yield tonnes/ha	% increase over untreated
(Single application)			
20% EC	0.8	6.02	22.1
"	0.4	5.80	17.6
"	0.2	5.71	15.8
75% WP	1.88	5.85	18.7
"	0.94	5.53	12.2
Untreated	-	4.93	-
(Two applications)			
20% EC	0.4	4.46	18.6
75% WP	1.13	4.50	19.7
Untreated	-	3.76	-

Trials specifically designed to compare the efficacy of the emulsifiable concentrate and the wettable powder formulations were conducted in Denmark on wheat cv. Kranich Noddegaard et al, (1973) and the effects on yields of using one and two applications are shown in Table 1. Better control of the disease was also evidenced by foliar assessments and the authors concluded that the emulsifiable concentrate was about 3 times as effective as the wettable powder. This can be seen in Table 1 by comparing the rates of active ingredient employed and the % yield increases realised.

Further evidence of improved performance is presented in Table 2, where results from several trials have been accumulated.

Table 2

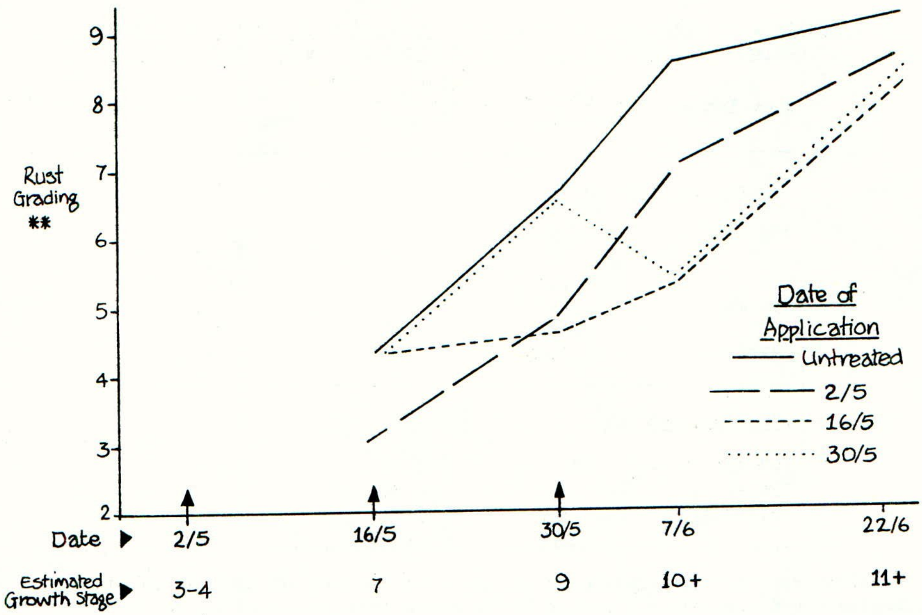
Percentage yield increases from wheat treated with emulsifiable and wettable powder formulations of oxycarboxin

Rate kg a.i./ha	% yield increases* 20% EC	75% WP	Number of trials
0.4	8.6	-	19
0.8-0.94	13.0	6.5	8
1.88	-	14.2	5

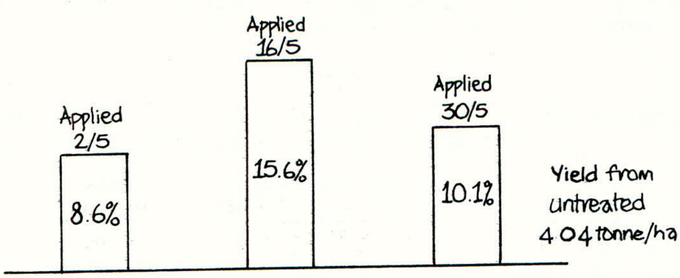
* Data given represent means from accumulated results of trials conducted in Denmark by Stapel (1972), Noddegaard et al (1973) and Lindegaard et al (1974), in France by La Quinoleine (1974, 1975) and in Holland by Ligtermoet (1975).

FIG. 1

Effects of different timings of application of Oxycarboxin on Yellow rust development and yield of wheat (cv. Kranich) from Noddegaard et al (1973)



% increase in yield over untreated



** Stapel 1972

II Yield responses from different countries

Table 3

Yield responses of wheat from trials conducted in various countries with oxycarboxin formulations

Formulation	Rate kg a.i./ha	No. of applications	No. of trials	Mean yield, tonnes/ha* Untreated	Treated	% increase
(Denmark)						
75% WP	0.94	1	4	4.76	5.05	6.1
"	"	2	3	4.70	5.04	7.2
"	1.88	1	5	4.49	5.06	12.9
"	"	2	4	4.37	5.11	16.9
20% EC	0.4	1	14	4.28	4.67	9.3
"	"	2	8	4.09	4.72	15.5
"	0.8	1	2	4.93	6.02	22.1
"	"	2	2	4.93	5.60	13.7
(France)						
20% EC	0.3	1	9	3.47	3.76	8.3
"	0.4	1	9	3.47	3.84	10.6
"	0.5	1	9	3.47	3.92	13.0
(Holland)						
20% EC	0.4	1	2	5.12	5.27	2.9
"	"	2	2	5.12	5.67	10.7

* See footnote, Table 2.

Results in Table 3 are only intended to give an indication of yield response. Trials were conducted on different cultivars, in different locations and with different levels of rust infection. These variables can lead to considerable fluctuations in results.

Cultivars used in these trials were as follows: in Denmark Kranich; in France Joss Cambier, Durtal (hard wheat), Etoile de Choisy and Agathe (hard wheat); in Holland Adamant and Clement.

III Timing of applications

Timing of spray application is a critical factor in rust control. Thus early control of the disease would seem to be of major importance, but protection of the flag leaf is also considered necessary. Results from a typical trial in Denmark Noddegaard et al, (1973) where oxycarboxin was applied on three dates are shown in Figure 1.

Foliar applications of the 20% emulsifiable concentrate formulation at a rate of 0.4 kg a.i./ha were made on 2/5, 16/5, 30/5 when plants were at estimated growth stages (Feeke's scale) 3-4, 7 and 9.

Rust infections were graded 0-10 , Stapel(1972).

0 – No infection
1 – 1 infected shoot/10 m row
2 – 1 infected shoot/1 m row
3 – 1 infected shoot/0.1 m row
4 – Each shoot infected, <1% of shoot infected
5 – >5% infection per shoot
6 – >10% infection per shoot
7 – >25% infection per shoot
8 – >50% infection per shoot
9 – >75% infection per shoot
10 – 100% infection per shoot

The first evaluations of rust infection were made on 16/5, and it is evident that rust development had been affected by the first treatment of oxycarboxin applied 14 days earlier. Subsequent assessments showed an increase in the amount of disease on plants in the first treatment; however, the level never reached that observed in untreated plots. Yield from this treatment was 8.6% greater than from untreated.

In the second treatment, oxycarboxin was applied on 16/5, when it was estimated that plants were at Growth Stage 7. By this time, rust grading in untreated plots was >4 (<1% of shoot infected). This application of oxycarboxin also retarded rust development, as seen when plants were assessed on 30/5. However, by the third (7/6) and fourth (22/6) assessments the disease was developing at a rate similar to that in the untreated plots. Yield from the second treatment was 15% higher than untreated plots.

The third treatment was applied on 30/5, when infection in untreated plots was graded at 6.5 (>10% of shoot infected), and when plants were at approximately GS 9. Yield advantage (10%) from this application was not as great as that from the second application.

Trials in France conducted in 1975 were also designed to evaluate different timings of application of oxycarboxin on rust control. The effects of these different timings of application were evaluated in terms of yield (Table 4).

Table 4

Effects of timing of oxycarboxin emulsifiable concentrate applications on yields of wheat infected with yellow rust (France, 1975)

Date of** Application	Growth stage	Yield tonnes/ha	% Increase
Trial No. 1	(cv. Joss Cambier)		
26/3	4-5	4.04	2.2
24/4	6-7	3.97	0.5
4/6	10	4.52	14.4
26/3 + 4/6	4-5 + 10	4.67	18.2
Untreated	-	3.95	-
Trial No. 2	(cv. Joss Cambier)		
10/6	10.1	4.95	12.2
21/6	10.5.1	4.49	1.8
10/6 + 21/6	10.1 + 10.5.1	5.02	13.8
Untreated	-	4.41	-

** Rate – 0.4 kg a.i./ha at each application.

In the first trial the level of rust infection at the first date of application (26/3) was 10% on the lower leaves, and by 24/4 the level on these leaves was 10-30%. There was no infection on the upper leaves at these dates. By 4/6, which was the third date of application, there was 0.2% infection on the first leaf, 20-30% on the second leaf and 10-20% on the third leaf.

In the second trial at the first date of application (10/6), the levels of rust infection observed were 0 on the first leaf, 5-10% on the second leaf, 5-15% on the third leaf and 40% on the fourth leaf. By the second date of application (21/6) there was 3% on the first leaf, and 10-15% on the second leaf.

Different timings of application resulted in different yields in both Danish and French trials. Timing of application for optimal results would seem to be rather critical. In Denmark in 1973 the best yields came when treatment was made in the middle of May (16/5), when the wheat plants were at GS 7, while in France in 1975 the best timing was the first week in June (4/6 in Trial No. 1 and 10/6 in Trial No. 2) when the plants were at GS 10-10.1.

DISCUSSION

Much of the evidence for yellow rust control presented in this paper is based on yield response. It could be argued that this is not a direct or valid method of assessment. However, it is on the basis of economic benefit to the grower that the product will be evaluated by the majority of delegates at this Conference. Also, indirect linear relationships have been shown to exist between incidence of rust on wheat flag leaf and yield (Mundy, 1973). Finally, it should be mentioned that foliar assessments of disease control can be misleading, unless they are conducted on a periodic basis, preferably at 10-14 day intervals during critical periods. It has been our experience that one or two foliar assessments can indicate lack of fungicidal activity, whereas comparison of yields at the end of the season contradicts these assessments.

As is the case with most pathogens, the timing of application of oxycarboxin for rust control is a critical factor in achieving the maximum yield benefit. Because of the complexity of the interaction of host plant growth stage and development of the pathogen it is difficult with the present data to make a precise recommendation for the timing of oxycarboxin application. Mundy (1973) suggested that "protection of the foliage during ear emergence and flowering is important and that action should be taken before the disease reaches very severe proportions, preferably before it exceeds 5 percent infection on the top two leaves (mean value)".

The best results were achieved in Denmark (Fig. 1) when oxycarboxin was applied at GS 7 and the infection was graded at 4 (<1% of shoot infected). However, this treatment also effectively restricted disease development up to GS 10.0+, so that the parameters of foliage protection relative to plant growth suggested by Mundy may have been met.

In the two timing trials conducted in France the best results came from applications made when the plant was at GS 10 and GS 10.1, the mean grading of infection on the top two leaves being 12% and 3.5% respectively for the two trials. In the first trial an application made a little earlier than 4/6 may have resulted in a greater yield advantage. Nevertheless these timings tend to confirm Mundy's hypothetical recommendation.

Data in Table 3 do indicate that higher rates of application give higher yields, with the exception of two applications of the 0.8 kg rate of the e.c. formulation.

To conclude, oxycarboxin is effective in controlling yellow rust of wheat, and maximum benefit is derived from careful timing of application with regard to development of pathogen and host. With regard to disease development, it is thought that rust infection should not be allowed to exceed a level of 5% on the flag leaf and leaf 2, these being the last leaves to emerge. The critical stages of plant development are GS 8-GS 10.1, which cover the period of expansion of these leaves and emergence of the ears Mundy, (1973) Because of the practical difficulties of observing very low levels of infection, it is recommended that oxycarboxin be applied as soon as rust is observed on the flag leaf or leaf 2.

Acknowledgements

The authors would like to thank the employees of the companies of Ligtermoet, La Quinoleine and Lindinger for their assistance in preparing this paper.

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Proceedings 8th British Insecticide and Fungicide Conference (1975)

SOME OBVIOUS AND NOT SO OBVIOUS SOURCES OF POST-HARVEST LOSS

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Summary A distinction is made between real losses of weight and quality which are often high in tropical countries and business losses which are important in temperate countries. Three reasons why our knowledge of the extent of national losses of produce in storage are so imprecise are discussed. The patchy distribution of insects, mites and fungi and consequently of the damage they cause makes it almost impossible to estimate losses accurately in single large stacks. We know that moisture is so seldom uniformly distributed in produce that we cannot easily use dry weight as a basis for estimates. In any event, temperature gradients cause the translocation of moisture around a stack and can raise an acceptable moisture content to a hazardous level. Feeding trials are difficult to perform because we cannot be sure that the diets are palatable and free from unwanted toxins, live or dead pests, or disease organisms.

Resumé On distingue entre les pertes de poids et de qualité qui sont souvent grandes dans les pays tropicaux et les pertes commerciales qui sont notables dans les pays tempérés. On donne trois explications pour l'inexactitude de notre connaissance du niveau des pertes de produits en stockage. Il est presque impossible d'estimer exactement les dommages dans un tas unique occasionnés par les insectes, les acariens et les moisissures parce que leur distribution est très irregulière. La teneur en eau est très rarement uniforme, en consequence on ne peut pas fonder l'estimation sur la base du poids sec. En tout cas il y a un mouvement de l'eau d'une partie d'une pile à l'autre à cause des variations de temperature et ce mouvement peut élever la teneur en eau d'un niveau acceptable à un niveau nuisible.

Il est difficile d'évaluer les resultats des expériences sur l'alimentation des animaux parce qu'on ne sait pas si les animaux ne trouvent pas la nourriture agréable ou si la nourriture contient des toxiques, des insectes vivants ou morts, ou des pathogènes.

INTRODUCTION

Crop losses must be as old as agriculture and storage losses nearly as old. The natural course for primitive man was to eat a crop immediately he had gathered or harvested it. However, in a seasonal climate, harvests are limited to certain periods, so man had the choice of going hungry between harvests or learning to store the crop from one harvest to the next, perhaps for a whole year. At first the harvest was kept for the community that gathered it and some deterioration of the food at any stage after gathering was accepted as normal and sometimes even desirable. This deterioration depended to a large extent on the ravages of pest species that also needed food and ate it when it was available. We can call the losses that man suffered at this stage of civilisation 'real losses'. These included the weight of food utilised by the pests, together with some degradation of quality such as loss of germination and of nutritive qualities and contamination by toxic metabolites and by disease organisms.

Later, as societies developed trade, stored food was passed to other communities and, presumably, the quality balanced against needs determined its "value". Thus, aesthetic and business judgements were then introduced and no doubt the standards accepted depended on the current abundance or scarcity of the product.

The three aspects that determine the extent of deterioration of a crop during storage are the environment, the period of storage and the presence of pests, the consequences of the last depending on the previous two. Theoretically the principles governing the influence of these two aspects are very simple: the good storage environment must be cool and dry and protected, especially against rain; and risks increase exponentially with time. Those of us who have been concerned with dry stored produce in temperate zones tend to regard pests, principally insects, mites and rodents, as organisms that can be excluded from stores and to visualise significant storage periods as lasting for weeks at least. But for stored products of higher moisture content, the pest micro-organisms may be readily airborne and capable of extremely rapid multiplication. Thus they cannot be readily excluded or contained without manipulating the storage environment, otherwise the moist stored product will have a very short maximum life.

Basically every protected storage environment is a box. It may be tiny or enormous, simple or complex, fixed or mobile, or even just a hole in the ground. Generally the temperature inside even simple boxes is higher than the surroundings and the atmosphere is drier, but most also house machinery which raises temperatures further. When temperatures are naturally low enough to discourage pests they are too uncomfortable for man to work in, so he puts in artificial heating. Clearly it is not universally possible to keep stores cool and dry and since storage periods of at least a year are often necessary, losses are inevitable unless something is done to prevent them.

What we do to improve the storage environment or to kill the pests must depend on the costs of these actions and on the value we place on the produce saved by their use.

Surprisingly, although so many people are hungry, and in the technically advanced countries a lot of money is spent on pest control, our ideas of the size of real losses of stored food are vague. The principles underlying their causes were stated briefly by PARKIN (1956) and discussed in some detail by HOWE (1965), but there are real difficulties in estimating loss even in fairly simple situations, and a large number of standards by which they can be judged. In technically backward tropical countries, real losses of food are considerable but until quite recently they were regarded as inevitable and no great amount of research was undertaken in any of them. Most research, indeed, was done in the technically advanced temperate countries, which, even when storage insect and rodent pests flourished during the first half of this century, seldom suffered from a scarcity of basic foods.

STIMULI FOR CONTROL

In the United Kingdom we have few native storage pests. Up to 1940 we continuously imported many tropical and sub-tropical species, distributed them by road and rail to mills, maltings, merchants and farms and had to rely on pyrethrum and fumigants for their control. Since then we have acquired more flexible insecticides and have greatly restricted the import of pests, but we have instead provided a more widespread sub-tropical environment, especially on farms, by introducing grain-drying on a large scale.

Except during war, the stimulus for action against pests has not so much been the damage they did as the costs arising from fruitless argument and litigation about who was responsible for the insect pests, and thus who should pay the bills for control measures and accept the losses when somebody in the chain of trade refused to accept a consignment containing insects. There were no consistent policies for prevention or control or for acceptance or refusal of goods and in any event the costs eventually passed to the consumer. The guidelines generally were the reputation of a firm for quality and a natural reluctance to be the scapegoat. To some extent the problem was an aesthetic one at what level of damage or contamination does the customer refuse to buy, use, or eat a product attacked by pests?

However, when in 1947 the FAO held a conference in London, every delegate to speak estimated his nation's annual losses by the rounded estimates of 5 or 10%. I think these were exaggerations even then. There is no doubt that farmers and merchants who stored small quantities of a commodity often lost 30% or even 50% by weight of certain lots, especially if they had kept them for a long time without inspection, but losses need to be integrated over the year and for a nation they must include all kinds of storage. Unfortunately the losses are worst among those who can least afford them and large scale merchants lose less in terms of percentage than do small ones. In general, weight losses are proportional to the surface area of a stack rather than to its volume so the percentage loss tends to be smaller in bigger stacks.

Since 1947, the insect problem in the United Kingdom and in exporting countries has gradually been diminished by the use of insecticides and by improved standards of hygiene and warehouse management. But as insects have become less dominant, the presence of mites and fungi has become noticeable and infestations that were overlooked in the past now often appear to be serious.

We must, therefore, try to estimate the extent of losses in store in order to justify the costs of control measures against all kinds of pests and those of research designed to improve these control measures. Here we must bear in mind that savings of real losses in the order of 0.01%, even of the cheap staple foods, ought to justify national research. For industrial concerns a single incident causing a loss of grade might cost in the order of a million pounds.

CATEGORIES OF LOSS

As already stated, losses can be catalogued under two main headings, the 'real' weight and quality losses and the indirect aesthetic and business losses. The latter may stimulate greater expenditure on control than the former.

The estimation of direct weight losses seems the more straightforward and for an individual consignment it might be, if the whole can be weighed before and after storage and moisture contents accurately estimated. If the estimate is based on random samples taken as the consignment goes into and comes out of storage it may well be poor. It will usually be an underestimate, but occasionally will be a gross overestimate, because insect pests tend to be distributed in clumps with foci of severe damage. It is not easy to arrange for samples to be divided between areas bearing the different levels of infestation and in any event representative in-situ samples of satisfactory size are impossible to get from points below the surface.

Thus a fair estimate of loss in a single stack is seldom feasible and even when one is obtained it represents just the one special instance. To obtain national estimates we need a series of these special instances covering the range of climates, standards of storage and periods of storage in balanced proportions - a formidable task.

Subject to the same sampling problems, some quality properties are easily assessed. Thus for seed or malting uses, the germination of samples can be measured straightforwardly and the loss of germination is an estimate of loss. For maltsters, uneven germination is also a business loss because it affects the quality of the malt. Similarly the chemical deterioration of oils, for which the free fatty acid content is a reasonable measure of loss of edible yield, is a direct loss that can influence quality and become a business loss. If seed grain is treated with a fungicide it cannot be used as food, so, poor germination of such seed represents a total loss.

DIRECT LOSSES

In view of these problems it is not surprising that few efforts have been made to measure direct losses until the last few years during which farm losses of maize have been examined in several African countries. I made one attempt in 1949 when I was in Nigeria where almost all the groundnut crop was stored in a small and convenient geographical area (HOWE, 1952). The conditions were very suitable for storage insects. The nuts were soft and nutritious, were stored for very long periods, some for more than 15 months, the climate was hot and good hygiene difficult. The only factors to favour those in charge of storage were the long dry seasons and the use of large stacks of 750-1000 tons of groundnuts. I was able to weigh selected bags as they were put into storage and again as they were removed and to decide what positions these occupied in stacks, but had no control over their period of commercial storage. My estimate of loss of dry weight in these very rigorous storage conditions was only 4.5%,lower than the FAO estimates for countries with much better storage facilities and climates. Even this figure did not represent commercial loss for the nuts gained 2% in weight by moisture uptake between stacking and export. Further I sieved off 2% by weight as frass and dust and counted this as loss whereas, in practice, not only was this powder left in the bags but dust and spillage from storage sites was bagged and exported. This weight loss was accompanied by a deterioration of oil quality as measured by free fatty acid and I have no doubt that this, and a considerable loss of bags damaged by insects, was the greater cause for concern. The weight loss caused by insects was accepted as inevitable in the tropics at the time.

THE INFLUENCE OF WATER AND TEMPERATURE ON THE APPRECIATION OF LOSS

The example just quoted highlights the difficulties that water introduces into any attempt to assess losses, even those based on dry weights. Obviously it is undesirable to buy and sell large quantities of water along with a dry food, 13 or 14 tons in every 100 tons of wheat, but it cannot easily be avoided. The solution of working with dry weight or some standard moisture content is not feasible unless the moisture content in large quantities can be guaranteed as uniform and it seldom can be, even where good grading standards have been introduced.

There is another facet to moisture content. Whilst cereals such as barley and wheat need to be dry for long term storage, they need to be damp for use. The farmer using feed barley for animals and the miller making flour thus face contradictory expensive operations of removing water for storage and replacing it for use. There is a real economic temptation to store feed damp and thus there is a market for a safe efficient fungicide that makes this possible, and an extra use for it when harvests are gathered quicker than they can be dried to an acceptable moisture level. But what is an acceptable moisture level?

Generally a moisture content in equilibrium with 60-70% R.H. is acceptable, but a lot of produce that is acceptable on receipt does not necessarily remain acceptable during storage. The surfaces of products absorb moisture from the atmosphere or give it up. This is important only in damp climates (or in very dry ones where this causes shrinkage) especially when small quantities of product are kept in relatively large buildings. If the product fills the building only about half the space is air and then the product controls the humidity. Here temperature gradients become important, because if the initial moisture content is reasonably uniform, a temperature gradient creates a vapour pressure gradient and moves the water vapour around. Even though this does not change the total amount of water vapour, it does change the moisture content of the product, which rises in the cooler parts. It renders moisture measurements of samples invalid, and worse it could generate zones of unacceptably damp produce in a consignment that was initially acceptable. Once again size of stack is a factor, a small stack will absorb a greater percentage of moisture from a damp atmosphere but a large stack is subject to greater translocation. These are especially serious if organisms generate heat and cause steep temperature gradients and these gradients are more serious in temperate areas than in the tropics because the external temperature is lower.

With moisture as with pests, average qualities are less important than the pockets of sub-standard quality wherein the problems develop. It is as well to remember that the product contains more moisture than the air. Let us consider containers that are increasingly being used to transport valuable commodities. In one containing 14 tons of cocoa beans at a wet weight moisture content of 6% we can calculate that the air holds about 0.3 kg of water whilst the cocoa holds 850 kg. If loaded in the tropics at 25°C (or more) and landed in Britain at 15°C (or less) there would probably be condensation on the inside of the container and on some of the cold beans. This can cause moulding on a cocoa bean if spores germinate where there is liquid water, but if the cocoa is unloaded quickly after landing few beans should be affected in that way. The temperature gradient will have a much greater tendency to raise the moisture content of the colder beans and to encourage the growth of fungi. Clearly the joint relationship of humidity and moisture content cannot be unravelled simply, but it is the latter that is really the major influence.

OTHER ASPECTS OF LOSS

Losses may be grouped under other headings such as quality, economic, health and legal. Some of these are, in part, direct and have already been mentioned. Thus the pest may selectively eat the most nutritious parts of the product and it might add toxic or disease-causing contaminants. Further, the presence of a pest often complicates the way the product is handled or it may introduce the extra costs of essential cleaning. To some extent these categories overlap the aesthetic losses which ensue when a housewife throws away a packet of dates because she sees one insect, even though she would cheerfully eat the insects in infested dates if she did not know they were there.

In this field we confront problems that are not easily quantified and it is often impossible to define the problems precisely. A farmer whose animals are sick may decide that this is because he fed them with a certain batch of feed, but have no idea what was wrong with it. We may know that it contained insects and mites and that it heated. Moisture was translocated and a zone of fungi developed. To kill the invertebrates the feed was fumigated and the surroundings were sprayed with insecticide. We still do not know if the farmer was right to blame the feed but neither, if he was, do we know what parts were played by chemical residues of the control treatments; by disease or parasites picked up with the food; by toxins from the fungi or the invertebrates; by scouring caused by chitin of the cuticles; by the depletion of some food constituent; or by a diminished intake of food caused by dislike of the taste of the food attributable to one of the previous items. We can only attempt to sort out this mixture by conducting careful feeding trials in which each cause is isolated. Once again this is easier said than done and, in the past, the results of feeding trials have been contradictory. It often happens that control animals give very variable results, so that real but small average differences are not easily detected. More often in field trials it is not possible to be certain that the experimental and control feeds differ only in the characteristic under investigation. Few of us have sufficient knowledge to supervise such trials unaided, so for good trials to be achieved, people from different disciplines must co-operate and they must all be able to appreciate the problems encountered by the others and the precautions required by them. All must agree on the measurements to be made. Whereas a farmer can rely on his experience to diagnose and form opinions about the causes of illness and lethargy, the experimenter must work with quantifiable variables, like the quantity of food eaten or change in live weight if he is to establish a valid conclusion that will be accepted by the farmer and by other investigators.

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