ENDURE

European Network for Durable Exploitation of crop protection strategies
Project number: 031499

Network of Excellence
Sixth Framework Programme

Thematic Priority 5
FOOD and Quality and Safety

Deliverable DR1.2

Best control practices of diseases in winter wheat

Due date of deliverable: M18

Actual submission date: June 2008

Start date of the project: January 1st, 2007 **Duration**: 18 months

Organisation name of lead contractor: University of Aarhus; Lise Nistrup Jørgensen

Revision: V3

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)	
Dissemination Level	
PU Public	
PP Restricted to other programme participants (including the Commission Services)	
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

Endure – wheat case study

2008

Report on Best control practices of diseases in winter wheat in 8 countries in the EU

Lise Nistrup Jørgensen, AU-Denmark
Marga Jahn, Julius Kühn Institute (BBA)-Germany
Bill Clark, Rothamsted-United Kingdom
Daniele Antichi, SSSUP, Pisa-Italy
Tomasz Góral, IHAR-Poland
Huub Schepers, Wageningen-the Netherlands
Philippe Lucas, Bernard Rolland; INRA-France
David Gouache, Arvalis-France
Laszlo Hornok, Szie-Hungary

endure
diversifying crop protection

Content

Glossary

For a glossary of terms related to plant pathology we refer to an excellent glossary available at http://www.inra.fr/hyp3/glossary.htm

Partners in wheat case

- WUR: Wageningen Universiteit & Researchcentrum (NL)
- INRA: Institut National de la Recherche Agronomique (F)
- ACTA: Association de Coordination Technique Agricole (F)
- AU: University of Aarhus (DK)
- IHAR: Plant Breeding and Acclimatization Institute (PL)
- Szie: Scent Istvan University (HUN)
- RRES: Rothamsted Research (UK)
- JKI (=Julius Kühn Institute) previous BBA (D)
- SSSUP: Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna (I)

DSS: Decision Support System
IPM: Integrated Pest Management
EPPO: European Organisation of Plant Protection
IOBC: International Organisation of Biological Control

Foreword

This report summarises the information on wheat disease management in Europe gathered by a working team of 10 people representing 8 different countries. The group has been doing work under ENDURE (network of excellence). The activity is one of several case studies which aim at collecting information on best pest control management using a minimum of dependency on pesticides.

The intention is that the collected information should be spread between countries and made available to advisers and farmers with the overall hope to achieve less dependency on pesticides. The working group consisted of the following members:

Lise Nistrup Jørgensen, AU-Denmark
Bill Clark, Rothamsted-United Kingdom
Marga Jahn, JKI -Germany;
Daniele Antichi, SSSUP, Pisa-Italy
Tomasz Góral, IHAR-Poland
Huub Schepers, Wageningen-the Netherlands
Philippe Lucas, Bernard Rolland; INRA-France
David Gouache, Arvalis-France
Laszlo Hornok, Szie-Hungary

The information gathered together in this report is if nothing else is stated provided by the country representative in the group.

Experimental work: The trial activities carried out by the project were supported by the following persons:

INRA:

Al Rifaï Mehdi, INRA, UE Amélioration des plantes Domaine des Verrines, 86600 Lusignan
Gardet Olivier, INRA /AO, UEMFV1094 Ferme du Moulon, 91190 Gif-sur-Yvette
Heumez Emmanuel, INRA UMR1281 SADVC domaine de Brunehaut, 80200 Estrées-Mons
Rolland Bernard, UMR INRA Agrocampus Rennes APBV BP35327, 35653 Le Rheu

University of Aarhus:

Lise Nistrup Jørgensen, Karen Henriksen, Henrik Jørgensen, Helene Saltoft, Ole Mygind, Rikke Heinfelt. Research Centre Flakkebjerg, Institute of Integrated Pest Management, 4200 Slagelse

Summary

ENDURE is an EU-funded network of excellence in the area of development and implementation of sustainable crop protection strategies. Advances in crop protection have greatly contributed to high yields and consistency in production, but major concerns about human health and the environment and increased consumer awareness of pesticide use have led to calls for the development of lower input farming systems that are less reliant on pesticide use.

This report summarizes information on disease control strategies in winter wheat gathered from 8 countries in the EU. The main focus of the work has been to share existing knowledge with respect to obtaining sustainable disease control systems.

Wheat is the most important cereal crop grown in EU. The yield levels and cropping conditions vary considerably between the different EU countries. In the countries most suitable for wheat production (Germany, the UK, France, Belgium, the Netherlands, Ireland, Denmark) average yields vary between 7 and 8 tonnes/ha, whereas in countries with more restricted cropping conditions (Hungary, Italy, Spain, Poland, Greece) yields vary between 2 and 4 tonnes/ha.

Yield losses from specific diseases in the 8 countries involved in the activity were estimated. Based on these estimates septoria leaf blotch, brown rust, take-all and fusarium head blight are considered as the most important diseases in the main wheat growing countries with respect to yield loss and quality of grain. Yield losses between 5 and 15 dt/ha are common in many regions. Yellow rust, powdery mildew, tan spot and eyespot are also regarded as important diseases; however, their distribution is much more regional.

Use of cultivars with effective resistance genes is well known as an important measure to reduce the risk of disease development and yield losses. The genetic resources used across Europe vary to a great extent as very few cultivars are grown in more than one country. All countries have an extensive cultivar testing system but the way of ranking resistance characteristics was found to be very different across countries. The exploitation of resistance genes in different countries was also found to take place to a different extent. Data from cultivar testing has shown that even the most resistant cultivars often give profitable yield responses from fungicide treatment, indicating that the resistance genes rarely cover all potential diseases that can attack the crop.

Several cultural measures are known to support a reduction of disease pressure. This includes factors like delayed sowing, ploughing rather than non-inversion tillage, crop rotations avoiding wheat and maize as previous crops, reduced nitrogen input and reduced seed rates. Several of these factors have, however, significant impact on the potential yield and are therefore only incorporated to some extent.

The approach for chemical control of diseases varies significantly between countries. In Poland, Hungary and Italy fungicides are used to a lesser extent compared with France, the UK, Germany, the Netherlands and Denmark. The frequency of chemical control varies from 0 to 5 treatments per season, depending on the region and problems. Only relatively few groups of fungicides are available for chemical disease control of the main diseases (triazoles, strobilurins, morpholines, boscalid and chlorothalonil). This makes it difficult to implement anti-resistance strategies, which can prolong the life of the fungicides and help to avoid erosion of the effectiveness. As few active groups of fungicides are available for chemical disease control in wheat it is important to use cultural methods and resistant cultivars along with fungicide treatments in order to minimise selection pressure.

The group has collected examples of strategies which can help to reduce the dependency on fungicides. These include:

- Constant focus on growing disease-resistant, high-yielding cultivars. Although these might still benefit from fungicide use, they will always minimise the risk from major yield losses due to severe disease attack.
- Adjustments of cultural factors should be included, in particular with respect to crop rotations and minimal tillage. Minimum tillage should be avoided in combination with wheat and maize as previous crops.
- Delayed sowing and significant reductions in nitrogen applications can both reduce the risk from several diseases, but will have a clear negative influence on the yield.
- Encouraging the farmers (or advisers) to do field scouting before deciding whether or not treatments are needed. This scouting can be supported by regional monitoring data updated at weekly intervals.
- Use of control thresholds in combination with field scouting can be a great help when the need for control is decided. Decision support systems are available in many countries but are rarely used by farmers as they are considered to be difficult and too time-consuming to use. The potential for reduction in fungicide use if applied at the right time is, however, considered to be significant.
- For both eyespot and fusarium good risk assessment systems have been developed, which can be used both as a strategy tool and as a tactical tool for risk assessment during the season. The main elements in the risk assessments are believed to be adoptable in most wheat growing regions in Europe.
- Good experiences from using reduced and appropriate doses have been found in many countries. The focus in these strategies has been to optimise net yield rather than gross yield. The actual input of fungicides can in many situations be minimised by optimising choice of product and timing.
- Results from analysis of historical trial data can be used to make general risk assessments and evaluation of expectations for achieving profit from fungicide applications. Again, calculations of net profit rather than gross yield are an important element in these calculations. In all wheat growing regions analysis should be carried out in order to get the best possible estimate of the risk and actual need for control. As the disease risk has been found to vary significantly in the different agro-ecological regions data cannot in all cases be generalised.
- Experiences from the Pesticide Action plans, which aim at reducing pesticide input, have shown that it is important to support farmers' decisions with trial data and monitoring data to convince them that they are making the right decisions. This is particularly important if the recommendation is not to spray. Often, the economic motivation for reducing fungicide input is limited since dose-response curves have been found to be rather flat in several wheat regions.

Several dilemmas are clear when one tries to implement lower input of fungicides. Some of these are related to the following points.

- The risk factors associated with not spraying are high, particularly with the high price of wheat. Most farmers and advisers are very risk-averse, aiming to protect potentially very valuable crops. This can in many cases lead to supra-optimal doses being used.
- The overestimation of risk coupled with high wheat prices tends to lead to overuse of pesticides. To reduce this, decision-support systems have to be very effective and low-risk – not easily achievable in all countries, particularly those in high disease pressure areas.
- Success stories cannot be directly transferred from one region to the other. Many tools and principles can easily be transferred but the actual optimal input is expected to vary considerable across the wheat growing countries.

In order to achieve a broader acceptability of sustainable strategies, policy makers, stakeholders and extension services should encourage the implementation of IPM strategies. The group generally agreed that at present farmers lack motivation and incentives to change their present disease control behaviour. Limitations in the availability of pesticides for example could change the way farmers behave. So to a great extent it became clear that any major changes in the way things are done today would require major changes in policy.

Field trials were carried out in 2007 as part of the activity in Denmark and France. The overall aim was to support control strategies with data from field trials.

The trials carried out in 4 regions in France aimed at testing the best combinations between cultivar type (21) and crop management (2 or 3). Cultivar types offered a range of resistance to major diseases, crop management was based on different levels of input (seeds, nitrogen, growth regulator, fungicides). The results indicated for the whole range of cultivars an average yield decrease of 1.5 t/ha to 2.8 t/ha, depending on the region, when nitrogen fertilisation was reduced by 60 kg/ha (thus reducing the yield target by 2 t/ha), no fungicide or growth regulator was applied and sowing density was reduced from 250 to 150 grains/m2. Cutting nitrogen only by 30 kg/ha, with the same reduction in sowing density, only one fungicide was applied and no growth regulator, gave similar (8 t/ha) or slightly reduced (-0.5 t/ha) yield compared to the conventional system. Among the 21 cultivars tested, some like Attlass maintained a good yield in low input crop managements, while others like Dinosor showed an important yield reduction. This illustrates the importance of the variety in designing crop management strategies aiming at reducing fungicide use (as well as other inputs) while maintaining good yield.

The two trials carried out in Denmark testing different fungicide input and the use of threshold based systems in 6 different cultivars showed a clear variation in the need for input depending on the disease resistance profile of the cultivar. The optimal TFI (fungicide input) varied from 0.7 for the most resistant cultivar to 1.4 for the most susceptible cultivar. The difference between high and low input was generally moderate in the resistant cultivars, but did in the susceptible cultivars exceed 130 € per ha. The threshold-based system (Crop Protection Online) recommended input varying from 0.4 to 0.7 TFI depending on cultivar. The results confirm the French results that the variety is very important, when one chooses the crop management strategies aiming at reducing fungicide use while maintaining good yield.

Fungicide trials have also been carried out by ARVALIS which support possibilities for optimization of input. Fungicide response can be considered a proxy for disease pressure in a given field. The stronger the disease pressure (due to the year's climatic conditions, but also cultivar choice and other crop management strategies), the higher the optimum fungicide use will be. The optimum fungicide use, from a microeconomic point of view, is also strongly influenced by wheat prices: fungicide use becomes more profitable as wheat prices increase. This has a number of consequences. First of all, if commodity prices are maintained at higher levels than in past years, this means that adjusting fungicide use by reasoning on net yield gains instead of gross yield gains will not allow as strong a reduction in fungicide use than it could be foreseen under low wheat price regimes. Secondly, if commodity prices become more unstable in coming years, it will be very difficult for growers and advisers to correctly react to both varying disease pressure and varying wheat prices from year to year. If emphasis on net yield is to be used as a major means of reducing fungicide input, stability of wheat prices needs to be addressed. Finally, if uncertainty on prices increases, it may be imagined that reducing variation in overall disease pressure could be a solution. This can only be achieved by using a reasoned combination of cropping techniques, adapted to local conditions, including overall pest (diseases, insects, weeds, etc.) pressure.

1. Background

Introduction to ENDURE

ENDURE is an EU funded network of excellence in the area of development and implementation of sustainable crop protection strategies. Advances in crop protection have greatly contributed to high yields and consistency in production, but major concerns about human health and the environment and increased consumer awareness of pesticides use have led to calls for the development of lower input farming systems that are less reliant on pesticide use.

Introduction to wheat case study

One area of ENDURE's activities has been to improve crop protection in the short term by demonstrating the feasibility of changing end-user practices towards more integrated strategies. Case studies will be used to assess how existing practices, tools and evaluation methods can be strengthened, transferred to new agro-ecosystems and adopted by growers. The case studies have been selected within the following range of systems: major crops, perennial crops, greenhouse crops, vegetable crops, and tropical crops.

Wheat has been identified as representing a major crop grown over large areas, thus contributing significantly to the overall use of pesticides in Europe. The case studies were initiated within the first 18 months of ENDURE to summarise existing knowledge and ongoing activities of existing networks identifying bottlenecks and good examples of elements which could be promoted in crop protection strategies.

1.1.1 Identification and configuration of the case studies

The following overall approach for designing case studies was applied:
- Survey available results and ongoing research and facilities
- Survey the state of the art of control strategies (toolboxes)
- Analysis of integrated control strategies

The research initiated by this activity will provide the theoretical base for implementing crop protection practices throughout Europe with a more optimum use of pesticides than is the case at present. The case studies were expected to draw on support from other activities in the ENDURE network, but also to create the foundation for new relevant activities.

1.1.2 Wheat case study

It was decided initially to focus the wheat case study only on disease management, as it was regarded as covering a very broad element in the crop protection activities in wheat. Fungal diseases can cause significant yield losses in wheat and fungicides are used routinely in wheat in major parts of the wheat growing regions in Europe. By combining information on 1) cultivar resistance, e.g. adopting cultivars developed for low-input systems, 2) disease thresholds and 3) innovative fungicide application strategies and applying a best margin-over-cost approach it has been possible to reduce fungicide use markedly in some regions.

As part of case study trial activities studying innovative fungal disease control strategies was performed in 2 different agro-ecological regions. The aim was to investigate the economic optimum and to evaluate the potential of innovative fungicide application strategies under different climatic conditions and cropping systems. In the trials conventional and low-input fungicide control strategies were compared using a number of cultivars representing various genetic resources. Yields were assessed and at each location the margin over fungicide cost was calculated for each strategy and cultivar.

The major outcome of the wheat case study is that innovative integrated control strategies against major diseases in wheat based on the best available technologies and knowledge were assessed systematically for the first time ever in different agro-ecological contexts. The case study will provide valuable understanding of the extent to which control strategies performing well in one country or one region of Europe can be extrapolated to other regions with different climatic conditions and/or cropping systems. Furthermore, the case studies will feed information of crop protection methods and cropping systems to other parts and activities of ENDURE.

If, in a given region, it transpires that it is not possible to adopt integrated control strategies developed under other agro-ecological conditions, it may still be possible that certain parts of integrated crop protection strategies can be implemented, providing valuable input to the design of innovative cropping systems.

Description of other IPM initiatives in wheat

IOBC

International Organisation of Biological Control (IOBC) concepts and guidelines established since the early 1990s define the general crop specific criteria of advanced sustainable production systems. The main elements in IPM, as described by IOBC, are summarised as follows:

Preventive measures and observations in the field on pest disease and weed status must be considered before intervention with direct plant protection measures takes place.

Specific IOBC guidelines describe in general elements of Good Agricultural Practice including the use of preventive measures to suppress diseases, pests and weeds. This includes the use of crop rotation for arable crops, elements to preserve and improve soil fertility, cropping of cultivars with good pest and disease resistance, and the use of cultivation elements which can minimise the risk of disease development, e.g. sowing date and tillage methods.

When indirect measures are included in the control of pests, weeds and diseases, the aim should be to choose the least harmful pesticides with respect to health and environment.

IOBC has not developed any crop specific guidelines for wheat production.

EPPO

Since the mid 1980s the European Plant Protection Organisation (EPPO) has developed a concept of Good Plant Protection Practice (GPPP) under the conditions of the EPPO region. The aim was to prepare a specific set of recommendations on GPPP, which took account of the registered products available, the spectrum of major pests and the growing conditions of the crop. The specific crop guidelines include specific information on using prevention measures, assessments of treatment need, control thresholds, possible choice of active substances, dosage and number of applications. The aim of the standards was among

others to 1) recommend optimal practice, 2) to consider the use of individual products in relation to an overall plant protection programme and 3) to make recommendations which could serve as a practical standard for assessing a given practice by the evaluators of efficacy data.

Specific guidelines exist for GPPP in winter wheat, describing all crop protection elements with respect to the control of pests, diseases and weeds. These guidelines describe all relevant diseases in winter wheat and give a basic strategy for control including use of both preventive measures and fungicides.

General importance of crop protection in wheat

Agricultural systems are not “natural” undisturbed ecosystems, and the inherent control mechanisms are often not sufficient to safeguard high crop productivity. In order to promote crop growth and yield farmers generally have to protect plants against pests, diseases and weeds. The ultimate goal of crop protection is not the elimination of pests, but the minimisation of crop losses to an economically acceptable level. Crop losses in wheat estimated by Oerke (1994) show that weeds are the most important contributor to wheat yield loss but in Western Europe diseases are nearly as important. The importance of insect pests is generally slight and more variable and so is the impact from virus.

Assessed worldwide, fungicides in European cereal crops, and wheat in particular, are the most widely treated segment (Kuck & Gisi, 2006).

2. General information on wheat production

Wheat area grown in the EU

Wheat is one of the most widely grown crops in Europe. Alone in the 8 participating countries more than 15 million ha is grown (Table 2.1). Most of the area is grown as conventional wheat – only a small proportion (<1%) is grown as organic wheat. The areas listed as organic are best estimates as no statistical information is available in several countries. Some EU stats are available.
See link: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-07-069/EN/KS-SF-07-069-EN.PDF

Table 2.1: Winter wheat area grown in the 8 participating countries

Country	Area in 2006	Organic area
France	4.785.240	75000
Hungary	1.077.000	-
Italy durum + hard	2.050.000	80000
Germany	3.067.000	38500
UK	1.833.000	15000
Netherlands	120.733	750
Poland	2.178.350	25000
Denmark	682080	2900
Total	**15.793.403**	

If we include the wheat area in the 27 EU countries altogether, the statistical data summarise the total area to 25 million ha. The countries represented in the Endure wheat case represent the majority of wheat grown in EU.
See: Eurostat file:
http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-07-086/EN/KS-SF-07-086-EN.PDF

In 2006 EU-27 was the world leader in wheat production, accounting for nearly 21% of the world output (604 million tons). Historically, wheat has been the main cultivated crop in EU, presenting nearly 14% of the total EU-27 utilised agricultural area and 43 % of the total cereal area (Source: FAO).

Yield level for wheat production in the EU

The general yield levels in Europe vary significantly. Figure 2.1 shows the level of yield since 1961 until today. All countries have experienced a significant increase in yield during this period. The highest level of yield is obtained in Ireland, the Netherlands, Germany, the UK, Denmark and Belgium. In the Mediterranean countries the level of yield is significantly lower which is also the case for the former Eastern European countries. Major reasons for the experienced yield differences are differences in water availability and soil types but the level of nitrogen applied also is a major influence.

The yield level is important with regard to how intensively the control measures against diseases can afford to be applied. It is generally recognised that the highest yield responses

to fungicides are achieved in high yielding crops. The average yield in EU-27 is 5.3 t/ha (FAO-data).

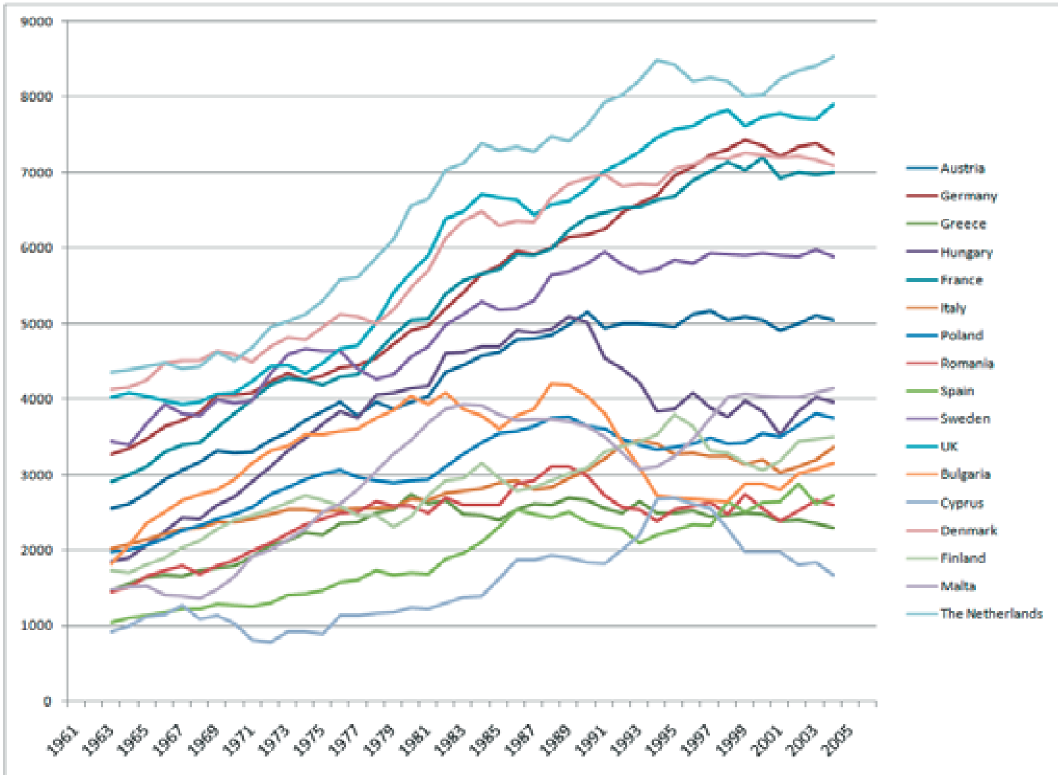

Figure 2.1: Yield development in wheat production in Europe (Source: FAO).

Role of organic wheat production

Organic wheat production is very small in Europe. When one observes the differences, in terms of yields of conventional wheat compared to organic wheat, the available bibliography shows that cereal crop yields under organic management in Europe typically are 60-70% of those under conventional managements (Nomisma, 2008).

Wheat growing conditions in different countries

UK

Wheat is grown intensively in the UK. Although soil and climate differ significantly across the country the conditions are generally favourable. The UK has approximately 1.8 million hectares of wheat, mostly winter wheat. Sowing of winter wheat takes place very early (over half of the crop is drilled in September) with the majority of the rest sown in early October. The better growers would expect yields of >10t/ha (<12t/ha on the best soils). The average UK yield is 8.2 t/ha.

Nitrogen is normally applied in line with guidance given in the government publication RB209. For a 'normal' wheat crop this is approximately 230kg N/ha applied mainly as ammonium nitrate. For milling wheat additional nitrogen may be applied late in the season (<30 kg/ha).

France

The winter wheat area in France is approximately 4,800,000 ha, grown in zones spanning all latitudes and longitudes of the country. Hence, soil and climatic conditions differ greatly, and both cultivation techniques and disease pressure differ accordingly. In general, it can be said that wheat is cultivated intensively in France, using high yielding cultivars, sown densely and early, using high levels of nitrogen fertilisation and pesticide inputs. A few figures can nonetheless highlight the strong variation behind this statement: approximately one third of wheat fields are sown before mid-October, but from one region to the next this proportion can vary from over 50% to almost 0%. In the same way, total mineral nitrogen applied on wheat fields can vary from 0 to over 250 kg N/ha, with a majority between 120 and 200. Levels of intensification vary strongly within a given region, but it can also be said that on a national level, intensification is strongest in areas with the highest attainable yield, i.e. with minimal limiting abiotic factors.

Germany

Wheat is also grown intensively in Germany and although soil and climate differ significantly across the country the conditions are generally favourable.

In Germany, the winter wheat area is about 3 million hectares, i.e. 45% of the total cereal-grown area. Only 40000 ha (up to 1.5%) are organically grown. The average yield level of conventionally grown winter wheat in Germany is 7.5 t/ha (in the range of 6 to 12 t/ha). A yield of 12 t/ha can only be reached in favourable years at good sites in parts of the North and the West of Germany.

The level of nitrogen input in Germany varies between 150 and 220 kg N/ha depending on measured N_{min} content in the soil and the level of the expected yield. According to the German Fertilizer Ordinance the N_{min} supply of the soil must be determined annually and respected in the decision-making on the N-value.

Sowing of the majority of winter wheat takes place between the end of September and the beginning of November. In northern parts of Germany sowing is to be earlier. It begins in early September.

The Netherlands

Compared to other European countries winter wheat is only a small crop in the Netherlands. In 2006 winter wheat was grown on 120,733 ha. Organic winter wheat production is very limited (750 ha). The yield level is generally high being on average 7-8 tonnes/ha.

The level of nitrogen applied in the Netherlands varies between 180 and 220 kg N/ha. The use is restricted to prevent leaching of nitrogen to groundwater and surface water. The highest amounts are used for milling wheat.

Italy

The durum wheat (*Triticum durum*) cultivated area is about 1.350.000 ha in 2006; this area is mainly located in Central and Southern Italy. The wheat (*Triticum aestivum*)-cultivated area is about 700,000 ha mainly located in Northern Italy. Considering the two crops on the whole, wheat is the most cultivated crop in Italy among the other arable crops. About 80,000 ha were organically cultivated according to EU 2092/91 reg. in 2006.

Wheat, and in particular durum wheat, is very important in Italy from the economic and the agronomic point of view because of its adaptability to suboptimal growth conditions such as low rainfall (or water availability) and high temperature. These conditions characterise many areas of Central Italy, the South and the Islands (Sicily and Sardinia); by contrast, in the North climatic conditions are more favourable to crop production. As a consequence, cropping systems including wheat are more intensive in the North where wheat grain yields range from 6 to 8 t/ha on average using high quantity of external input.

Wheat grain yields vary from 4 to 7 t/ha in Central Italy, while it is often lower than 4 t/ha in the South and in the Isles. In these areas the use of external input is not profitable due to the poor yield level.

Poland

Poland has approximately 2.2 million hectares of wheat, mostly winter wheat (83%). As climatic conditions in Poland are very varied, the country is divided into four regions depending on recommended optimal sowing dates. These dates are ranging from September 15-25 in the North-East and East regions to September 25-October 10 in the South-Western region.

The average yield in Poland is approximately 4.0 t/ha. Last year's yield is very variable because of widespread drought. Large regional differences exist - from below 3.0 to above 6.0 t/ha (Figure 2.2). Available recommendations for nitrogen use depend on cultivar, soil quality and expected yield. The dose range is 50-160 kg N/ha. Nitrogen is commonly applied in two doses. Average nitrogen input in all cereals in Poland is 62 kg N/ha.

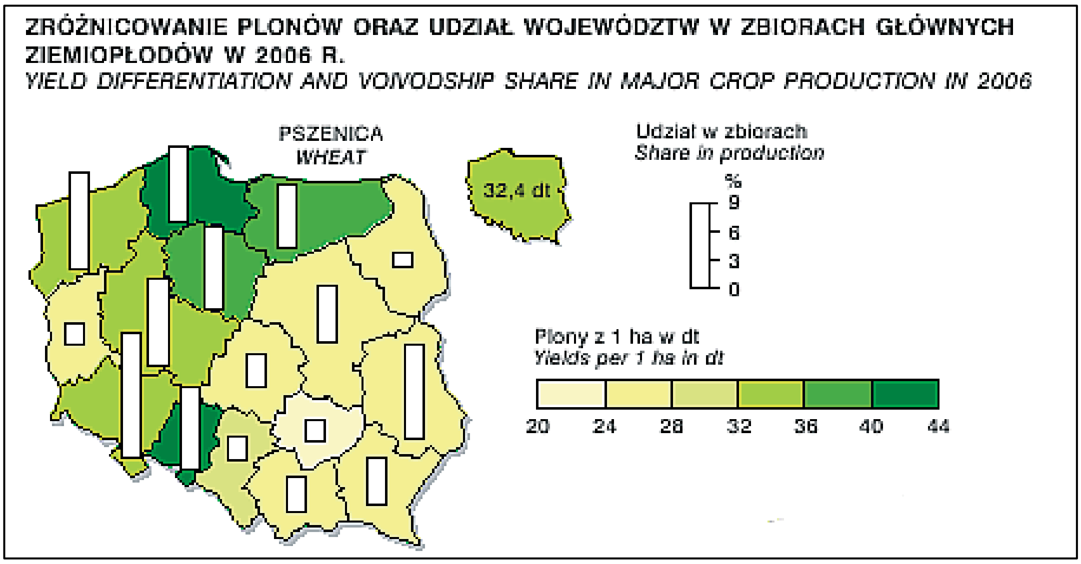

Figure 2.2: Yield variation in wheat crops in different regions of Poland in 2006 (Source: Statistical yearbook from Poland 2007).

Hungary

Hungary has approximately 1.1 million ha with winter wheat. The average yield various between 2.5 and 5.0 tonnes per ha. Organic ('ecological') wheat production is restricted to 1% of the total wheat growing area. The average input of nitrogen in Hungary is 150-200 kg/ha.

The major yield limiting factor in Hungary is water; the average yearly precipitation is 500-600 mm with great uncertainties, and severe drought may occur during April-June (in case of foreseen low yields fungicide sprays are not cost efficient). When we lost the Soviet market, the growers had to face sales problems, and therefore tried to use a low input technology. Due to the improving world market position of wheat this point will be less relevant in the next few years, and therefore we expect an intensification.

Denmark

Denmark has approximately 650.000 hectares of wheat, mostly winter wheat. There is very early sowing of winter wheat (over half of the crop is drilled in September) with the majority of the rest sown in early to mid October. The better growers would expect yields of >9-10t/ha. The average DK yield is 7.1 t/ha.

Half of the wheat grown is second or third year wheat. On the more sandy soils second year wheat is risky because of a relatively high likelihood of take-all development.

Nitrogen is very restricted in Danish agriculture and a nitrogen budget including the N-content from manure is obligatorily calculated for each farm. The 'normal' wheat crop is applied with approximately 160-180 kg N/ha applied mainly as ammonium nitrate. For milling wheat additional nitrogen may be applied late in the season (<30 kg/ha). The nitrogen level used is calculated yearly and is based on being 10% suboptimal. The aim is to minimise the nitrogen leaching to the sea.

3. Main disease problems in 8 EU countries

The group has at a national basis tried to identify the importance of different diseases with respect to wheat production in EU. This information is only available to a certain degree in the different countries so the data rely to a great extent on expert judgements and estimates. When the group estimated the importance of different diseases, experiences from historical trial data as well as experiences from plant pathologists were used.

For large countries like the UK, France, Poland and Germany a very large variation in disease occurrences and disease pressure also exists within the countries.

Table 3.1: Average yield losses (dt/ha) from different diseases in wheat including the range. The data are based on estimates from experts supported by trial data

Country	Septoria leaf blotch	Brown rust	Yellow rust	Powdery mildew	Tanspot	Stago no-pora
France	15 (3-50)	10 (0-40)	0 (0-60)	1 (0-15)	0,5 (0-20)	0 (0-5)
Hungary	5 %(0-40%)	5%(0-40)	-	10% (0-30)		-
Italy	11% (4-23)	11% (4-23)	-			-
Germany[1)]	3,2 (0-12)	2,7 (0-13)	2,5 (0-8)	1,7 (0-16)	1 (0-10)	2,8 (0-10)
UK	10 (0-30)	1 (0-40)	1 (0-40)	1 (0-8)	0 (0-2)	0.2 (0-50)
Netherlands	5 (2-20)	1 (0.5)	1 (0-5)	1 (0-5)	2 (0-5)	1 (0-2)
Poland	4 (0.8)	10 (0-16)	1 (0-19)	2 (0-6)	2 (0-11)	9 (0-16)
Denmark	8 (3-25)	1 (0-8)	1 (0-50)	2 (0-15)	1 (0-15)	0.5 (0-5)

Country	Eyespot	Take-all	Rhizoc-tonia	Fusarium
France	3 (0-25)	0-20	0 (0-5)	2 (0-20)
Hungary	-	-		5% (0.30)
Italy	-	-		28 % (8-60)
Germany	No data	No data	No data	0,4 (0-3)
UK	2 (0-20)	8 (0-50)	0 (0-1)	0.5 (0-10)
Netherlands	1 (0-10)	1 (0-2)	1(0-2)	2 (0-59
Poland	5 (0-10)	12 (0-19)	1 (0-2)	1 (0-19)
Denmark	1 (0-15)	5 (0-30)	0 (0-2)	0.5 (0-10)

1) Evaluation of data from 5 years (2003-2007) from 10 Fedral Lands.

As it can be seen from Table 3.1 Septoria leaf blotch is the most significant problem in most countries, but brown rust, take-all and Fusarium head blight also play a major role in several countries.

Fusarium ear blight *(Fusarium* spp.)

Powdery mildew (*Blumeria graminis*)

Brown rust (*Puccinia triticina*)

Septoria leaf blotch (*Septoria tritici*)

Pictures of the most serious diseases in winter wheat

The participants agreed that the following diseases are of major concern in all countries.

- Take-all (*Gauemannomyces graminis*). This disease is seen as a serious problem in all countries. The disease can be very yield reducing and no means of using cultivar resistance is known. It always exists as a potential risk, which, however, does not require use of fungicides. Although seed treatments are known to reduce the disease risk the effect is, however only moderate. Applications of good agricultural practices with good crop rotations are known to significantly reduce the disease risk.
- Septoria leaf blotch (*Septoria tritici*) was regarded as the major leaf disease in most countries. The disease can be very yield reducing and many fungicide applications are used in order to keep the disease under control. Since the start of the 1980s the disease has been of major importance in all countries. Recently Poland also sees septoria leaf blotch as a new problem. Although some degree of cultivar resistance exists in many cultivars, genetic resistance alone is not able to control the disease. Factors like early sowing and high nitrogen levels are known to significantly increase the risk of septoria leaf blotch.
- Brown rust (*Puccinia triticina*) was regarded as the 2nd most important leaf disease in the main wheat producing countries. The disease is well known in the warmer parts of Europe but has recently also been seen in more marine areas like the UK and Denmark. Brown rust is seen as a disease which is likely to increase due to climatic changes. Cultivars with good resistance exist and have proved very effective but

many current cultivars are very susceptible to the disease. Most fungicides that effectively control septoria will also effectively control rust.

- Powdery mildew (*Blumeria graminis)* is seen to be of major importance in certain regions throughout Europe (Italy, Poland, France, Denmark). It is a disease where it traditionally has been possible to apply thresholds for treatment. Many genetic resources have been adopted, but they are rarely long lasting. Effective control requires use of specific mildew fungicides. Cropping factors like late sowing and high levels of nitrogen are known to be favourable for disease development.
- Fusarium ear blight (*Fusarium* spp.) is seen as an increasing problem in many parts of Europe, including Germany, France, Denmark, Italy and Hungary. The disease is of major concern due to the production of mycotoxins by the fungi involved. It is a disease which is highly linked to crop rotation and minimal tillage. The risk is particularly high in regions where maize is a widely grown crop in the rotation. Genetic resistance is available with effective levels of control in some cultivars. Application of good agricultural practices can help significantly to keep the disease and toxin levels down. In high risk situations specific fungicide programmes need to be applied.
- Tan spot (*Drechslera tritici-repentis*) is found to be of major importance in certain regions through out Europe (Germany, France, Denmark). It is a disease which is very much linked to minimal tillage and previous crop being wheat. Little genetic resistance is available. Application of good agricultural practices can in most situations keep the disease level down. If significant attacks develop, specific fungicide programmes need to be applied.
- Yellow rust (*Puccinia striiformis*) is also seen as a disease which in certain years tend to play a major role. In cases of early attack the yield losses from this disease can be very high. The level of attack depends to a large extent on the susceptibility of the cultivars and the presence of inoculum during the winter and spring. The disease is favoured by cooler and humid conditions and often does not develop further if the weather turns dry and hot.
- Eyespot (*Tapesia yallundae, T. acuformis*) generally only causes minor problems in certain specific regions of Europe. Although present in most wheat fields the attacks rarely turns out to be too yield reducing. Some cultivars contain significant levels of genetic resistance, but also use of growth regulators has been found to prevent the crop from lodging in cases with clear symptoms of eyespot attack.

Short description of main disease problems in the participating countries

UK

The main seed-borne diseases are Bunt (*Tilletia tritici*) and Fusarium seedling blight (*Microdochium nivale*). The majority of seed (95%) is treated with fungicides active against these diseases. Approximately a third of seed sown is farm-saved. The main foliar disease of wheat in the UK is *Septoria tritici.* As can be seen from Figure 3.1 the disease pressure is greatest in the western part of the country. Yellow and brown rust can also be serious in seasons with favourable weather and susceptible cultivars. Powdery mildew is of lesser importance but can be severe on organic soils. Fusarium ear blight can be locally severe but is not a significant disease in terms of yield loss. Information on how to reduce the risk from mycotoxins in grain is widely available. Few cases of high levels of mycotoxins in grain are reported each year.

For maps showing distribution of disease see: :
http://www.hgca.com/cms_publications.output/2/2/Publications/Publication/Wheat%20Disease%20Management%20Guide%20-%20March%202008.mspx?fn=show&pubcon=4406

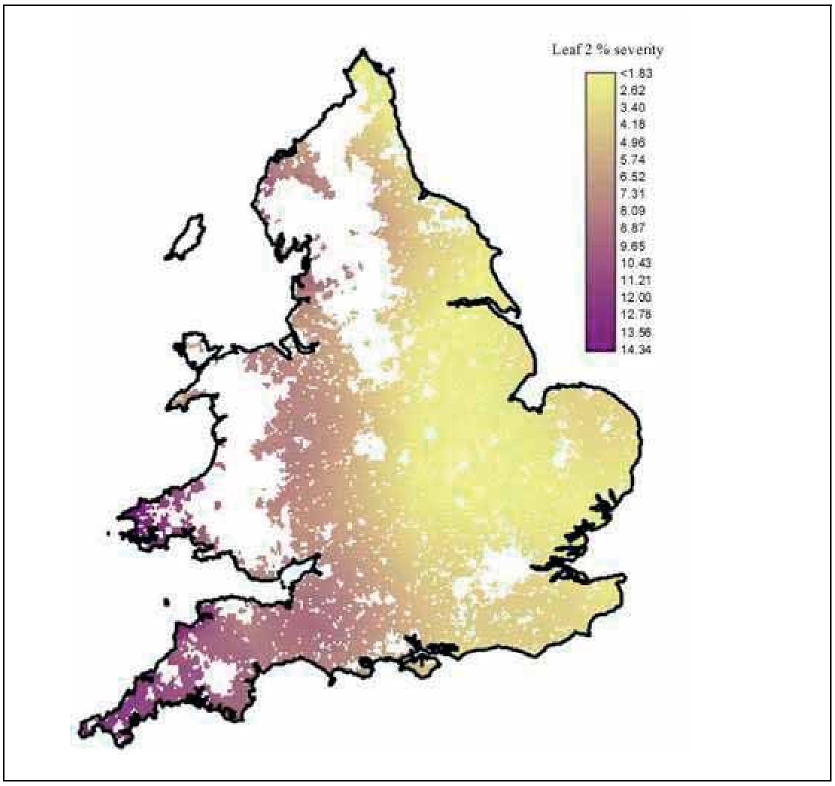

Figure 3.1: Attack of Septoria tritici on leaf 2 in the UK.

Take-all (*Gaeumannomyces graminis*) is a problem in second and subsequent wheat crops and does limit yields markedly. It is probably the most important disease of wheat in the UK. Eyespot (*Tapesia* spp.) is also significant in second and subsequent wheats. These two diseases reduce yields of second wheat by about 10%.

France

Main winter wheat diseases in France are illustrated in Figure 3.2, which also shows that there are strong regional variations. The main problems are considered to be, in order of importance: Septoria tritici, brown rust, fusarium head blight, eyespot and powdery mildew.

The yield responses from fungicides vary greatly between regions being highest in the coastal region of the country. The responses correlate with the severity of diseases in the region. Additionally, there is also a strong yearly variation of disease pressure: in 2003, yield loss to disease in trials was under 20 dt/ha in all trials, whereas in 2007 it was above that mark in 65% of the trials.

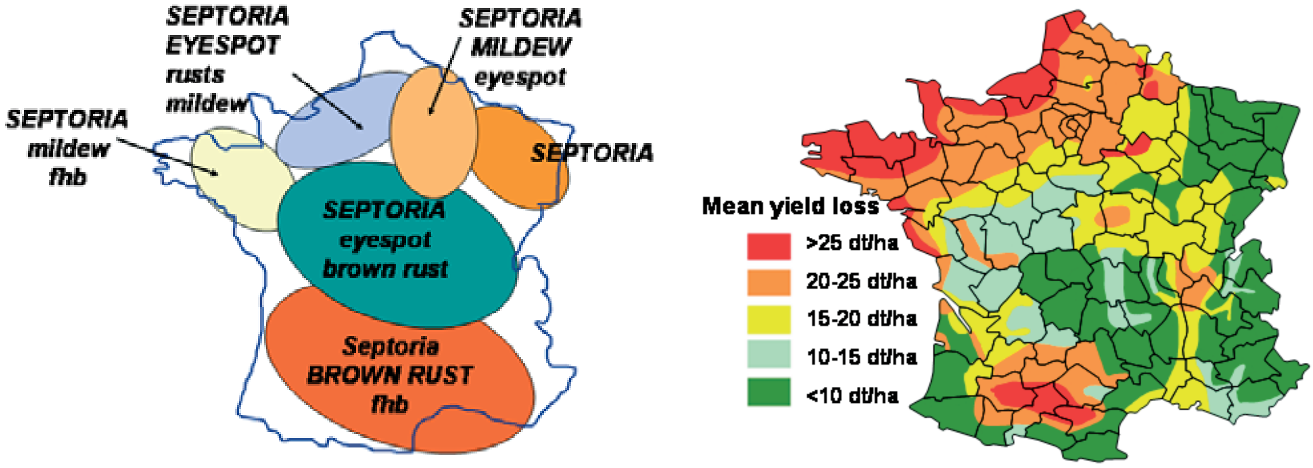

Figure 3.2: Qualitative and quantitative variations of disease pressure in France.

Germany

There is a very large variation in the need for control measures over the whole country and between years. The regional situations as well as the cultural measures result in very different disease pressures. The possible situations are demonstrated in Figure 3.3. A high disease risk could develop, e.g. following preceding crop wheat, without ploughing, early sowing, growing a susceptible cultivar, high regional and/or year-dependent disease pressure. A low disease risk could arise from dryness in early summer, late sowing, less susceptible cultivar, low regional and/or year-dependent disease pressure.

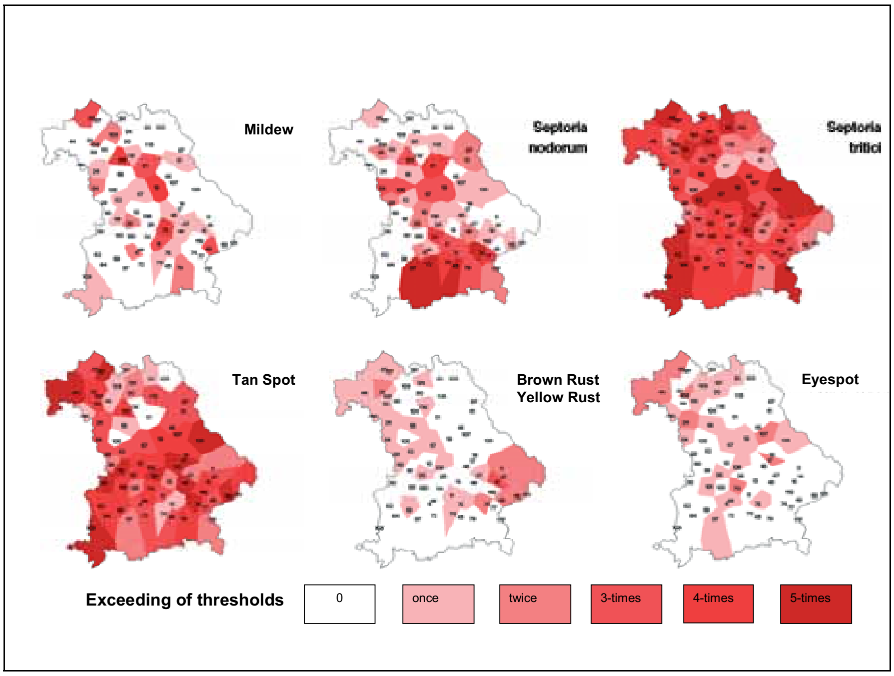

Figure 3.3: Importance of different diseases in Germany in the period 2001-2005 (Tischner *et al.*, 2006).

As a consequence of different climatic conditions, the importance of the diseases can be very different in the different parts of the country over the years. Nevertheless, there were distinct changes all over the country in the 1990s and a general statement can be given on the major diseases. Over the last 15 years the wheat cropping system has been changed at several positions. Earlier sowing, restricted crop rotation and reduced tillage have led to an

increase in the infection pressure of some diseases. The main foliar disease is now *Septoria tritici*. Tan spot (*Drechslera tritici-repentis*), brown rust as well as powdery mildew can also be serious. The actual disease pressure depends on the region, the yearly disease pressure and the resistance of the cultivated cultivar. Due to a good basis of resistance in newer cultivars, the importance of mildew has decreased.

The occurrence of stem base diseases like take-all or eyespot is very different. Generally, they were of lower importance in the last few years. Fusarium ear blight is very important in most (perhaps three of four) years. High levels of mycotoxins are a problem, and farmers in high-risk areas pay great attention to that.

Netherlands
In recent years, Septoria leaf blotch is the most important disease for causing yield losses. But depending on the weather conditions also Fusarium Head Blight and tan spot can lead to important losses. Wheat is rarely grown intensively in the crop rotation, which helps to minimise the risk of diseases like take-all.

Italy
In Italy the highest disease pressure generally concerns only the northern part of the country, where fungi can determine even consistent yield losses (up to 40%). In the last few years, some fungal diseases, like *Fusarium* ear blight and *Septoria tritici*, have become quite widespread also in the Centre and in the South of Italy.

Poland
The main seed-borne diseases are bunt (*Tilletia tritic*i) and Fusarium seedling blight and snow mould (*Microdochium nivale*). The main foliar diseases of wheat in Poland are powdery mildew (*Blumeria graminis*), brown rust (*Puccinia triticina*) and Septoria glume blotch (*Stagonospora nodorum*). Ranking of these three diseases depends on weather conditions in that particular year. Septoria leaf blotch (*Septoria tritic*i) is less widespread than in Western Europe. However, the importance of this disease has been growing in the last years. Yellow rust appears only in seasons with favourable weather in spring. Fusarium head blight can be severe only in some years on susceptible cultivars and does not reduce yield significantly.

Take-all (*Gaeumannomyces graminis)* is a very important disease. It can reduce yield by up to 60%, particularly in second and subsequent wheat crops and under favourable weather conditions, e.g. year 2007. Eyespot (*Tapesia* spp.) is also significant in late sown wheats during moist and mild autumn and winter.

Table 3.2: Main diseases in wheat described in Poland during 4 years. * in 2003 disease levels were low in all crops

	1	2	3	4	5
2003*	powdery mildew	brown rust	Tapesia eyespot		
2004	powdery mildew**	take-all	yellow rust		
2005	powdery mildew	brown rust	septoria glume blotch		
2006	septoria glume blotch	Tapesia eyespot	take-all	brown rust	powdery mildew

Hungary

The most important fungal wheat diseases in Hungary are Fusarium head blight (FHB) (*Fusarium* head blight), leaf rust (*Puccinia triticina*), powdery mildew (*Blumeria graminis* f.sp *tritici*) and leaf spot diseases (*Drechslera tritici-repentis, Septoria* spp.) Under epidemic conditions and without treatments they may cause 30-40% yield losses.

Denmark

The main seed-borne diseases are Bunt (*Tilletia tritici*) and Fusarium seedling blight (*Microdochium nivale*). The majority of seed (95%) is treated with fungicides active against these diseases. Approximately 25-33% of seed sown is farm-saved.

The main foliar disease of wheat in Denmark is *Septoria tritici*. Yellow and brown rust can be serious in seasons with favourable weather conditions and susceptible cultivars. Rust diseases are, however, only known to cause serious problems in 1-2 years out of 10. Powdery mildew is quite common, but severe and yield reducing attacks are mainly found on sandy soils in combination with particularly late sowing. Fusarium ear blight can be locally severe but is not a significant disease in terms of yield loss. This disease is mainly seen as a problem in situations with minimal tillage and maize or wheat as previous crop. Information on how to reduce the risk from mycotoxins in grain is widely available. Only few cases of high levels of mycotoxins in grain are reported each year. Tan spot (*Drechslera tritici repentis*) can be severe in some fields, but are mainly know from fields following minimal tillage and wheat after wheat.

Take-all (*Gaeumannomyces graminis*) is seen as a major problem in second and subsequent wheat crops and does limit yields markedly. Take-all can under significant attack reduce yields of second wheat by 20-30%, as it was seen in the 2007 season.

Eyespot (*Tapesia* spp.) can give significant attacks in second and subsequent wheat crops, it is, however, rarely found to be reducing yields significantly and as a consequence fungicides are rarely used as a control measure against this disease.

4. Disease control strategies

The approach for control of diseases varies significantly between countries but also within countries. Traditionally diseases have been controlled by means of crop rotation and use of resistant cultivars. Modern effective fungicides have been available for disease control for approximately 30 years. Fungicides are today widely used and regarded as a common practice for controlling diseases in wheat. Both seed treatments and foliar applications are widely used. In Poland, Hungary and Italy fungicides are used to less extent compared with France, the UK, Germany, the Netherlands and Denmark.

The current use of fungicides in the different countries varies significantly due to various reasons. Major differences in disease pressure exist in Europa and also the potential yield responses from chemical control measures vary to a great extent. Table 4.1 summarises the input measured in terms of fungicide input (TFI) and money spent on disease control. The sources of information on fungicide use in specific crops do not exist in some countries, which is particularly the case for Hungary, Italy and Poland.

Table 4.1: Used amounts of fungicides measured in no. of treatments and cost of fungicides. 2003-2004

	Number of treatments	Total input of dosages (TFI)	% area treated	Money spent on fungicides €
UK	2.7	1.7-2.4	>95	66-80
France	2.1	1.3-2.0	>95	69 (40-88)
Germany	2.7	1.3-1.5	>95	80-100
Denmark	2.1	0.6-0.8	>95	33-47
Netherlands	2	1.6	>95	80-100
Hungary	0.7 (0-2)	0.5-0.7	60	20-30
Italy	0.25 (0-2)	0-1.5	15	0-60
Polen	0.75 (0-2)	0.7	60	20-55

Control strategies in individual countries

UK

Winter wheat crops receive on average 2.7 sprays per season. This does not vary much year on year (range was 2.6-2.8 in last 4 years) despite a wide range of disease pressure over years (Figure 4.1). The main timings are at GS31-32 (T1), GS39 (T2) and GS65 (T3) (See Figure 4.3). In high pressure situations for Septoria tritici or rust an earlier spray (T0) would be applied. This would normally be chlorothalonil for Septoria control and a triazole for rust control. Farmers will normally spend £50-60/ha on foliar applied fungicides. The groups of fungicides most commonly used are shown in Figure 4.2.

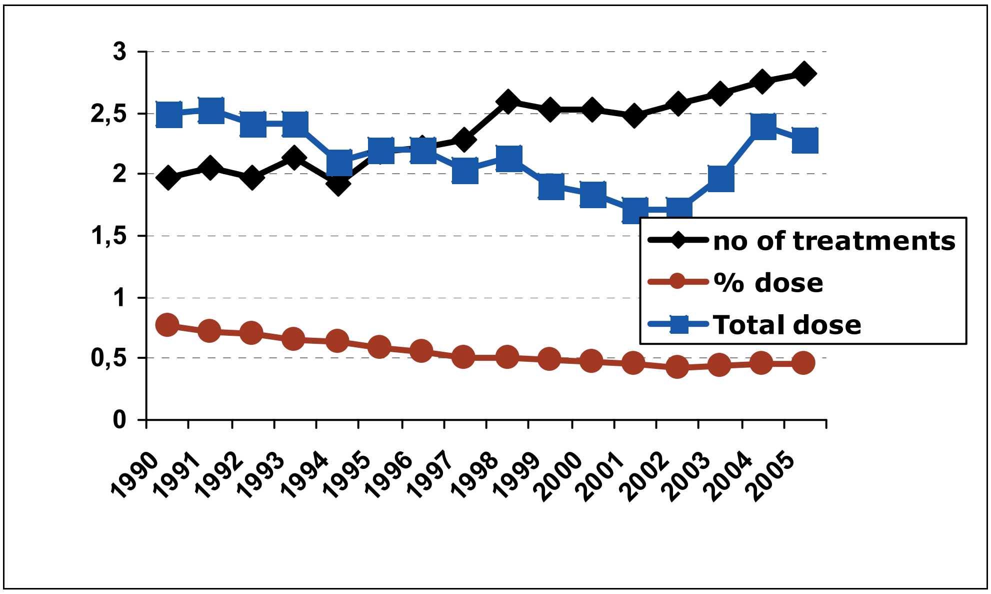

Figure 4.1: Pattern of fungicide use in winter wheat in the UK from 1980-2005.

Most large farms would employ an independent adviser to advise on fungicide use in wheat. These advisers have to undergo special training and pass an exam (BASIS) before they can advise farmers. Some large farms have farm managers who have been specially trained and have passed the BASIS exam. Agrochemical distributors and manufacturers also give technical advice as part of the sales of fungicides.

Many control thresholds and decision support systems have been developed for disease control, the most sophisticated of which is the 'Wheat Disease Manager' (DESSAC), a model-based system (Brooks, 1998). However, very few decision support systems are actually used today by advisers or farmers.

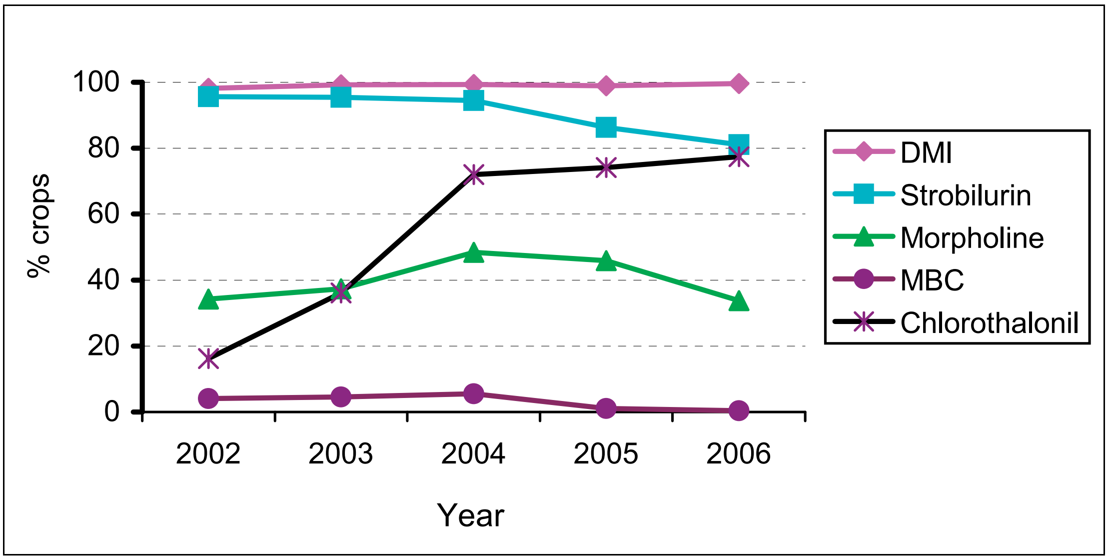

Figure 4.2: The main fungicide groups used wheat production in the UK.

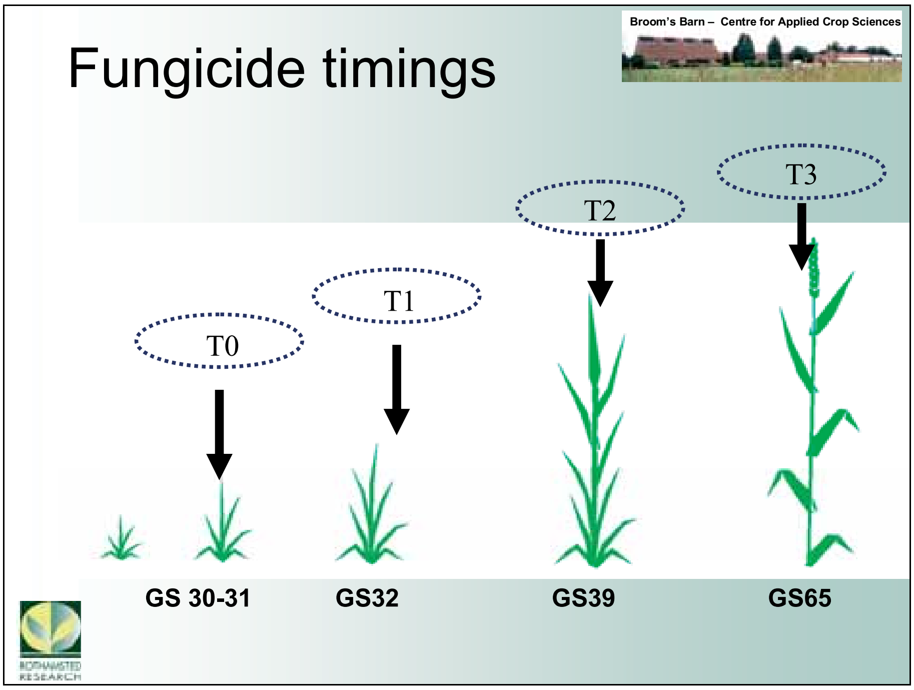

Figure 4.3: Main timings of fungicides applied in the UK.

France

On average in France in 2006, fungicide spending was 69 €/ha. In regions with low disease pressure where only one treatment was needed, this figure was only 37 €/ha, whereas in regions necessitating 3 treatments on average, fungicide investment was as much as 88 €/ha. On average 40-50 €/ha of this expenditure goes to protection against foliar diseases, mainly septoria and brown rust.

Fungicide use in France, calculated using the treatment frequency index for product (see Champeaux, 2005 & Delavaux, 2007 for methodology) has diminished in France over the past 10 years, in line with wider use of reduced doses per application (Table 4.2).

Table 4.2: Treatment frequency index and dose per treatment in 5 French departments from 1995-2004 [1]

Year	TFI	Dose/treatment
1995	2.3	0.7
1996	2.2	0.7
1997	2.3	0.7
1998	2.4	0.7
1999	2.2	0.7
2000	2.2	0.6
2001	2.2	0.6
2002	2	0.6
2003	1.3	0.5
2004	1.6	0.5

[1] Source : Delavaux 2007

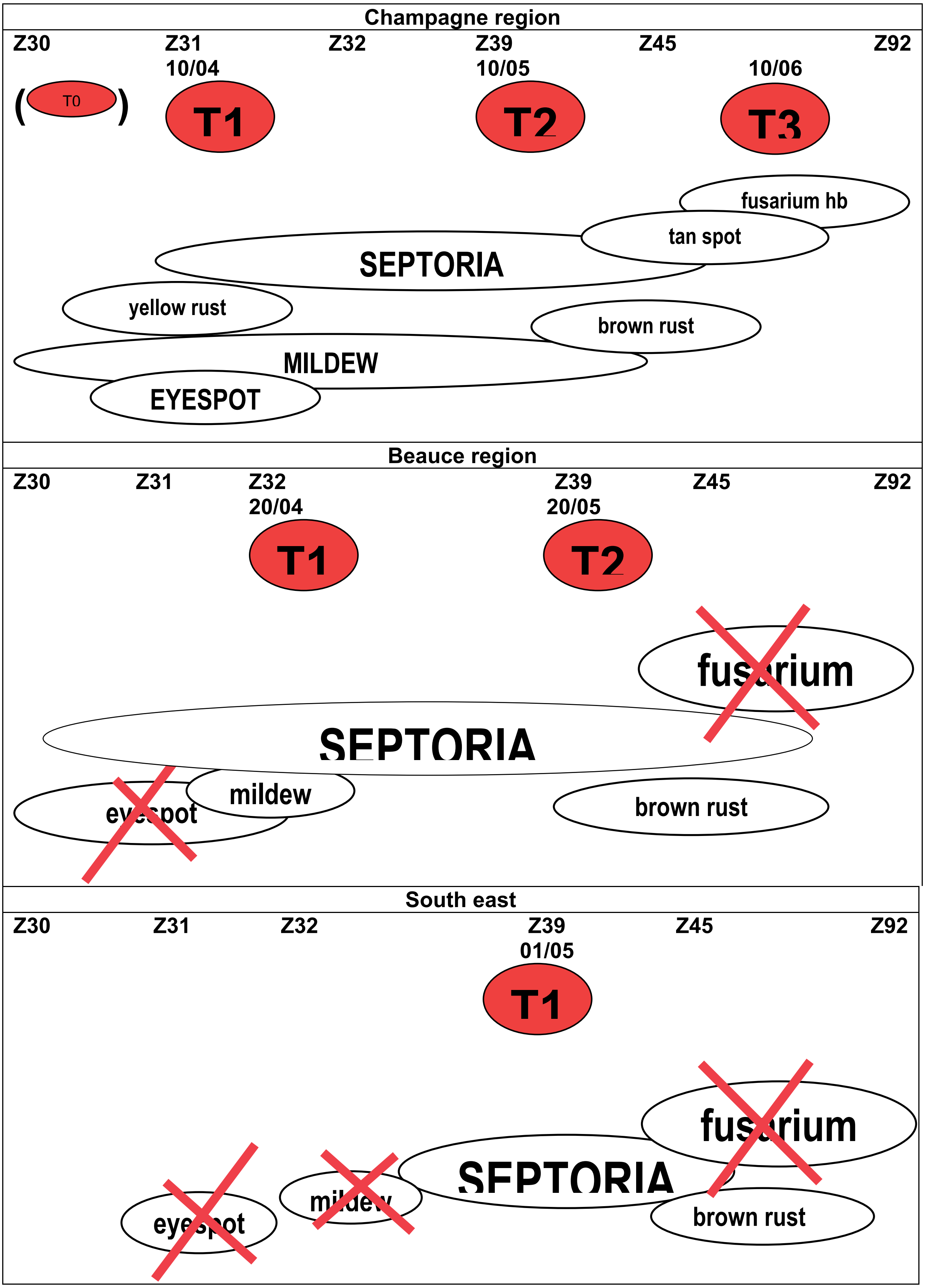

Figure 4.4: Timing of fungicide application and associated disease risk in 3 regions; TX = treatment n° X.

The detail over these 5 departments shows that TFI for fungicides has diminished more strongly than TFI for other products, and that reduction in TFI also varies regionally (Table 4.3). This variation can be explained by the original situation for fungicide use in each department, as well as the disease pressure in these departments.

Table 4.3: Reduction of fungicide and overall pesticide (plus growth regulator) use in 5 French departments from 1995 to 2004[1]

	77	80	89	51	28
TFI all products	-20.1%	-24.2%	-12.5%	-18.5%	-19.2%
TFI fungicides	-30.5%	-39.0%	-30.0%	-34.7%	-35.3%
Number of treatments (all products)	-13.8%	-17.0%	6.7%	-3.8%	-0.7%
Number of treatments (fungicides only)	-12.0%	-1.3%	2.1%	-4.0%	-22.1%
Fungicide spending	-16.1%	-11.3%	-14.6%	-19.3%	-17.6%

As stated above, fungicide strategies in France generally vary from one to three treatments, depending on disease pressure. Typical timing of these different strategies is illustrated in Figure 4.4.

Germany
An average of 2.7 treatments per season could be calculated for the last 4 years. However, these values are only based on 6 reference farms (with 3 fields each) in 5 climatic regions. It does not vary much from year to year (range was 2.5-2.9) despite a wide range of disease pressure in the years. An example with a broader data base is available from 2000. From that year on, a network for identification of use of plant protection products (the so-called NEPTUN survey) was launched to collect detailed data on the actual use of chemicals in agriculture. As arable crops were involved only in 2000, such extensive data (from 790 farms) are available only for that year. Resulting from a very dry season in many parts of the country, the number of treatments in 2000 was 1.6. This was distinctly lower than the average. The NEPTUN surveys showed remarkable differences in the intensity of pesticide use between crops, landscapes and farms in different German regions. The TI for fungicides used in wheat in different regions of Germany was found to be highly variable covering a span of 0.5-2.0 indicating major differences in infection pressure. Examples of the Treatment Index are demonstrated in Table 4.4 in relation to regions with high (first part) and low (second part) infection pressure.

Table 4.4: Treatment Index (TI) for fungicides in wheat in different German regions in 2000 (NEPTUN survey)

Region	TI
Ostholsteiner-Mecklenburger Küstenland	2.00
Oberbayerisches Hügelland	1.98
Detmolder-Waldecker Hügelland	1.88
Münsterland	1.78
Ostbrandenburger Platten	0.79
Westbrandenburgische Ebenen	0.59
Südbrandenburgische Niederungen	0.46

From the last year on, a network of (>70) reference farms all over the country has been established. Thus more relevant data will be available soon.

The average dose per ha ranged in the years between 0.48 and 0.71. A slight tendency to an increase seems to be connected with the fungicide resistance situation and the change in the use of active ingredients (broader use of chlorthalonil with much higher amount than systemic fungicides).

The relevant timings are described in Figure 4.5 for 3 different scenarios, with different need for treatments. The main fungicides used in Germany for disease control in wheat belong to the triazoles and strobilurins.

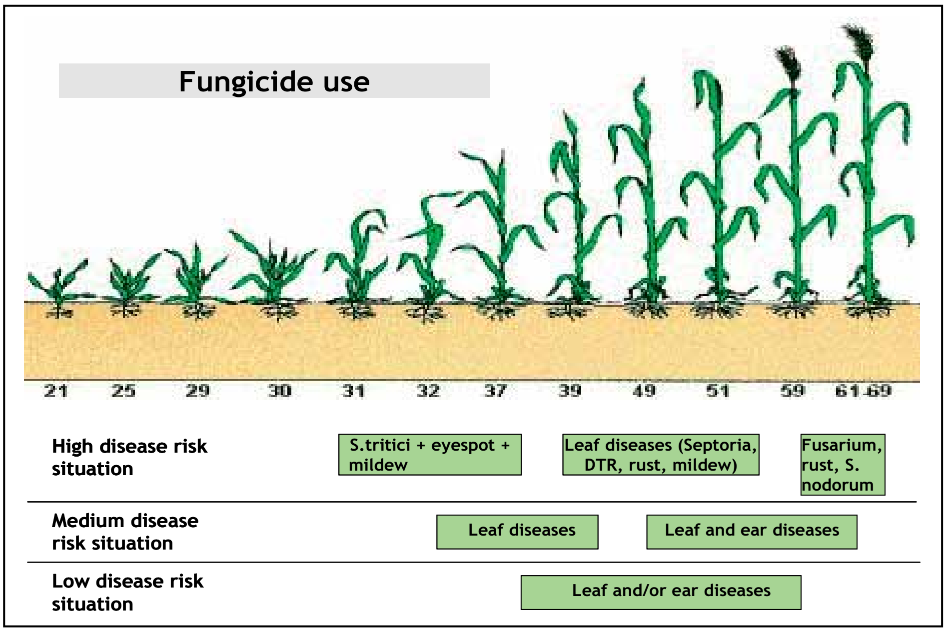

Figure 4.5: General demonstration of fungicide use (1, 2, or 3 treatments in the field) depending on the disease risk in Germany.

The Netherlands

The advisers of agrochemical distributors have a large influence on the control strategy in winter wheat. Depending on the resistance of the cultivar to Septoria and brown (and yellow) rust, one or two sprays are applied. When the weather conditions during flowering are high risk for the infection of Fusarium head blight (FHB) one more spray is applied during flowering to control FHB. Although work has been carried out to look into the possibilities of applying reduce doses (Schepers *et al.*, 1996, 1997) the occurrence of strobilurin-resistant Septoria, which is now widespread in the Netherlands, resulted in a limited use of lower doses. Doses below 75% are rarely used.

Under high risk conditions two sprays are applied: the first at T1 with 75-100% dose and the second spray at T2 with a 90-100% dose. Under medium risk conditions also two sprays are applied: the first at T1 with 50-75% dose and the second spray at T2 with 90-100% dose.

Under low risk conditions one or two sprays are applied. When one spray is applied it is timed at T2 with 90-100% dose. When two sprays are applied, the first is at T1 with 50-75% dose and the second is at T2 with 90-100% dose.

Normally, the last spray is applied at T2 but in years with wet weather conditions during flowering (T3) it can be profitable to spray to control FHB to guarantee both yield and quality (mycotoxins). A prediction tool is developed for deoxynivalenol content in winter wheat

(Schepers *et al.*, 2006). This tool will support growers to decide whether it is necessary to spray a fungicide during flowering.

Italy
Overall, only a relatively small proportion of the wheat grown in Italy is treated with fungicides. Crops which are treated receive on average only one fungicide spray per season with an average dose of about 0.35 kg of active ingredient per ha. Generally speaking, Durum wheat often requires a larger input because of its higher susceptibility to *Fusarium* ear blight, controlled by high-dose fungicide. The number of sprays does not vary on a yearly basis but mainly in relation to latitude and intensiveness of agricultural practices. In the North, where wheat is cultivated with a high amount of chemical inputs, the number of treatments is up to 2.0 sprays per season, while in the more extensive cultivations in the South farmers often do not spray.

Even if the total amount of fungicides sprayed is not as high as in other European countries, there is still believed to be a high potential for reducing the use. The main reduction potential is seen from cutting down spills due to inefficient machinery and techniques of distribution, and to the non-observance of economic risk thresholds. Italian farmers in fact usually do not change type and dose of fungicide as a function of weather conditions, incidence of diseases and the resistance of the cultivar; moreover, chemical companies offer to farmers very few active ingredients to control several foliar diseases. This means that often less effective products are used and dosages are not optimised.

Poland
Less than 30% of the cereal crops area is treated with fungicides and it is estimated that approximately 60% of the wheat area is treated. The input is on average 0.7 TFI. Treated winter wheat crops receive on average 1.5 sprays per season. Treatments are relatively rare at growth stages 30-32 (eyespot, Fusarium crown and root rot and early stages of leaf diseases) and mainly at growth stage 49-61 (control of leaf diseases on flag leaf). Under high pressure of leaf diseases a full dose before heading is recommended, at low disease incidence half-dose after heading is recommended. Last year an additional treatment against Fusarium head blight at growth stage 61-71 was recommended under high disease pressure.

The most used active ingredients are triazoles and strobilurins, despite recent reports on strobilurin resistance of some pathogenic fungi. The proportion of the cereal area sown with treated seeds is about 60%. Approximately 88% of wheat seed sown is farm-saved.

Most farmers are making decisions on fungicide use based on their own knowledge and experience. They can also get advice from the State Agricultural Advisory Service. Advisory centres are affiliated in the majority of rural districts in Poland. Plant Protection Recommendations as support to the advisers are published every year by the State Institute of Plant Protection. This institute is also developing thresholds for the main wheat diseases.

Also distributors of agrochemicals give technical advice as part of the sales of fungicides. They organise trainings and presentations of IPM systems so-called "field days" for farmers. In recent years a decision support system has been developed. However, up to now, very few advisers or farmers are using it.

Hungary
In addition to fungicide seed dressing, two technologies are generally used for disease control in winter wheat in Hungary:
In intensive technology crops are sprayed twice, once around GS 31-32 in the spring in combination with herbicide (e.g. with strobilurin as active agent) and once prior to flowering (e.g. with triazole as active agent). In non-intensive technology a single treatment is carried out prior to flowering with a triazole or a combination of fungicides to protect the spike.

60% of the total wheat growing area is treated with fungicides, 50% are treated once, 10% are treated twice. 40% have no fungicide treatment, but this cannot be regarded as an ‘organic’ production technology, since these crops are treated with chemical fertilisers. Organic (‘ecological’) wheat production is restricted to 1% of the total wheat growing area.

The main reasons for this reduced fungicide usage are (i) ecological and (ii) economic ones: (i) the major yield limiting factor is water in Hungary, the average yearly precipitation is 500-600 mm with great uncertainties, and severe drought may occur during April-June (in case of foreseen low yields fungicide sprays are not cost efficient); (ii) when we lost the Soviet market, the growers had to face to sales problems and therefore tried to use a low input technology. Due to the improving word market positions of wheat reason (ii) will have less influence in the next few years, and therefore we expect an increasing fungicide usage in wheat.

Denmark

Winter wheat crops receive on average 2.1 sprays per season. This does not vary much from year to year despite considerable variation of disease pressure over years. The main timings are at GS31-32 (T1), GS39 (T2) and GS65 (T3) (See Figure 4.6). The benefit from early treatments is generally low and account for less than 20% of the total yield response. Chemical disease control relies mainly on triazoles and strobilurins are only used to minor extent since development of resistance has taken place. Chlorothalonil and prochloraz are not registered. Farmers will normally spend 40-55 €/ha on foliar applied fungicides. The total dose applied per season varies between 0.5 and 0.75. This is typically split between using ¼ rate at an early timing and ½ rate around heading.

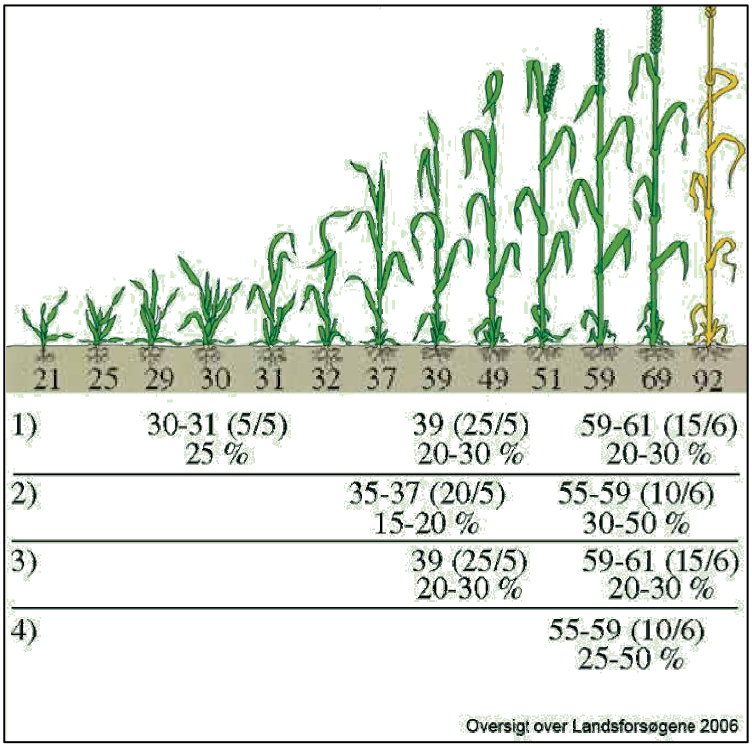

Figure 4.6: Examples of control strategies recommended by the advisory services in Denmark. The recommended dosages of the fungicides are given as % of normal rate under the growth stage/date.

1) High disease risk situation. Early recommendations are only relevant if mildew or rust develop early. This recommendation will also handle moderate to severe attack of Septoria.
2) No early attack of mildew or rust, but early risk of septoria which encourages an earlier control for septoria.
3) Standard recommendation in situation with only septoria as the major problem
4) Input in a low disease risk situation often with a resistance cultivar.

Most Danish farmers will employ an independent adviser to advise them on fungicide use in wheat. More than 70% of all advice on fungicide usage in wheat comes from independent advisers. Few rely on information from agrochemical distributors and manufacturers when decisions have to be made on the use of fungicides.

The dose-response curves for fungicides with respect to control of diseases and yield gains from ear treatment are generally very flat (Jørgensen *et al.*, 2003). In the most resistant cultivars, a fungicide input of 0.25-0.5 TFI applied as an ear application gives normally the best economic result. In more susceptible cultivars, a fungicide input of 0.5 TFI has been optimal under moderate attack, while 0.5-0.75 TFI has been optimal under more severe attacks. Control of yellow rust generally required 2-3 treatments depending on when the epidemic starts. For control of this disease timing is more important than the dose. The increasing grain prices from 10 to 20 Euro per dt have generally been increasing the optimal dose by approximately 50%.

Use of decision support systems like Crop Protection Online (CPO) provides the possibility of adjusting input depending on disease pressure and susceptibility of the cultivars.

A major reduction in fungicide use has taken place since the 1980s mainly due to successful use of appropriate and reduced dosages (Figure 4.7). The development was supported by field trial data which showed that a reliable economic output could be obtained also from the use of reduced rates.

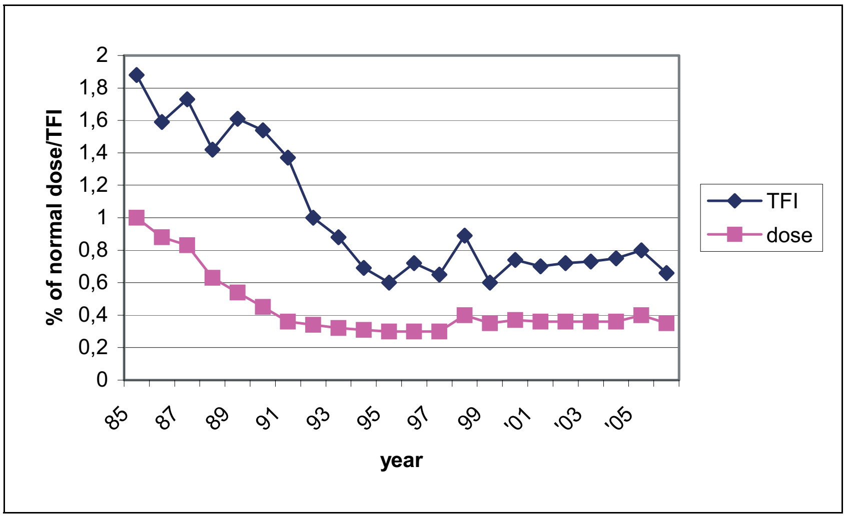

Figure 4.7: Development of fungicide input in Denmark from 1985 to 2005.

Fungicide resistance

Intensive use of fungicides for control of major diseases in wheat like septoria leaf blotch, mildew, rust and eyespot has over the years been found to give rise to development of fungicide resistance in several populations of diseases.

There are issues of fungicide resistance in the majority of the modern fungicide groups currently available. Consequently, manufacturers take the issue of fungicide resistance development very seriously as a threat to their long-term profits. FRAC (Fungicide Resistance Action Committee) is very active in trying to devise and promote strategies to avoid resistance development but its efforts have not always been successful.

There is an on-going debate as to whether there is such a thing as a successful anti-resistance strategy. However, there are few examples where a planned or reactive strategy has been successful in slowing or preventing the further development of resistance. Where such a strategy has 'worked' it is often unclear why – and so the industry continues to apply the general principles promoted by FRAC. These principles are primarily:

- Limiting the exposure of the pathogen population to the fungicide, mainly by reducing the number of applications per season.
- Avoiding the use of fungicides in an eradicant situation, where the target pathogen is already well established in the crop.
- Mixing or alternating fungicides with different modes of action.
- Manipulating dose (generally described as avoiding multiple low doses and promoting the use of high doses).

Some of these principles are based on general assumptions, some are impracticable, and others contradicted by experimental evidence. The issue of dose is contentious and there is no general agreement as to the effect of dose on selection. Experimental work with strobilurin fungicides and *Septoria tritici* (Fraaije *et al.,* 2003) clearly showed that high doses posed a greater selection pressure. The argument that low doses pose a greater selection pressure is not very convincing and yet is often repeated. It has been argued that low doses can delay the selection of single-site resistance by reducing the overall effectiveness of the treatment (and hence increasing the number of sensitive surviving isolates) but this is not a practical proposition. The one principle that cannot be argued against is that of limiting the exposure of the pathogen population. This can only be achieved by reducing disease pressure by whatever means possible including genetic resistance, cultural controls, etc.

The development of resistance to any new fungicide active ingredient is inevitable as selection increases as soon as any dose is applied. Because of increased standards in safety to operators, consumers and the environment, new active ingredients are likely to have single-site modes of action. Development costs will continue to rise, limiting the number of new active ingredients with novel modes of action that come to the market. Inevitably we will have to manage disease with fewer active ingredients than we currently have available.

Figure 4.8 illustrates an example of the variation in the septoria population's sensitivity to triazoles ranked according to mutations in the CYP51 gen. WT= Wildtypes are almost not existing any longer. The changes have happened in response to 25 years' intensive use of triazoles.

In terms of sustainable disease control, we have a medium-term set of problems:

- No anti-resistance strategy that can prevent resistance development.
- Inevitable resistance development to remaining single-site active ingredients.
- Increasing development costs leading to a falling number of active ingredients, most of which have single-site modes of action.
- Cultivars lacking durable resistance to the major pathogens.

Consequently, fungicides continue to be used to support failing resistance genes in the wheat crop, putting increasing pressure on fungicides. Durable disease resistance may only be possible using GM technology but European consumers might still be far from ready to accept genetically modified crop plants. In the meantime, reduction in disease pressure by whatever means possible is likely to prolong the life of fungicides in the marketplace and allow them to be used at lower doses, reducing the likely selection of fungicide resistance.

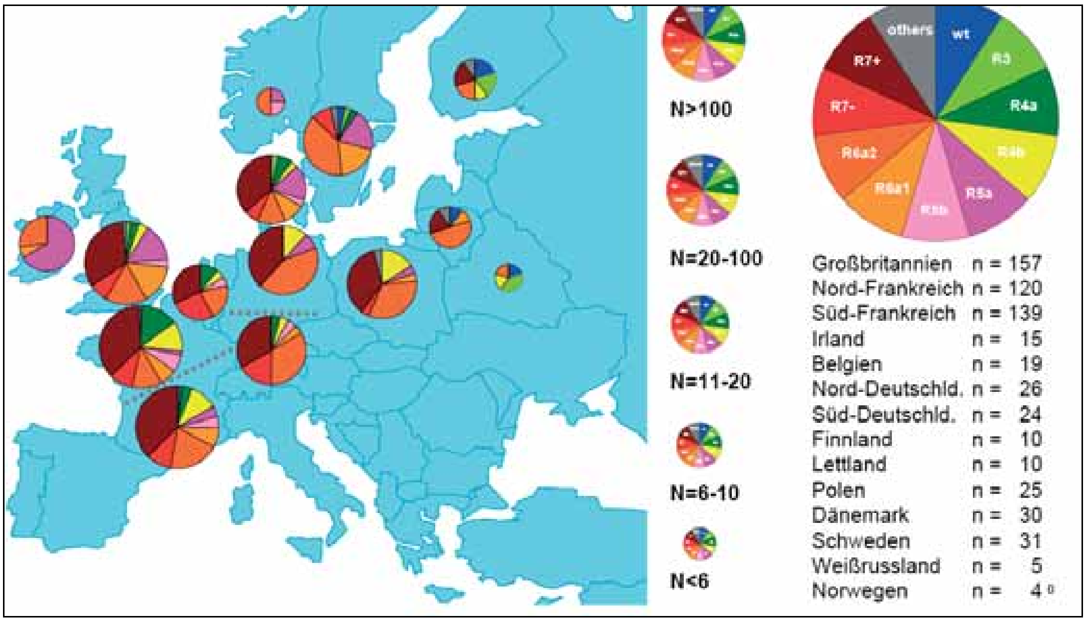

Figure 4.8: Distribution of triazole resistant subpopulations of *septoria tritici* Europe (source:BASF).

5. Use of genetic resources

The use of resistant cultivars presents a high potential for reducing disease pressure and the need for fungicide treatment. The exploitation of genetic resources is used to a different extent in different countries, partly due to tradition but also due to pressure from government pesticide action plans. Generally speaking, yields are ranked as the most important factor when farmers choose cultivars. Quality parameters and disease resistance are often ranked second or third.

Comparing the most commonly grown cultivars in the wheat growing countries there appear to be very few cultivars which are common and being grown widely in several countries. Table 5.1 gives the names of the most commonly grown cultivars in 2006 or 2007.

All countries carry out trials in order to rank the susceptibility to the most common diseases. The screening methods for the determination of resistance ratings are different in each country. The ranking is often done using a 0-9 scale. In some countries 9 = fully resistant whereas in others 9 = most susceptible. The scale is typically logarithmic in its way of scaling susceptibility. In other countries like Denmark percentage of attack is used as basis for assessments. This scale is then used to separate the cultivars into 4 groups of susceptibility, which are subsequently used when control measures are recommended.

Table 5.1: 10 most commonly grown cultivars in 2006 or 2007 in the countries participating in the project

	Name of cultivar	% area cultivated
UK Cultivar ranking on a 0-9 scale; 9= fully resistant.	Robigus	15
	Alchemy	13
	Eistein	12
	Solstice	8
	Claire	6
	Gladiator	4
	Brompton	3
	Hereward	3
	Cordiale	3
	Consort	3
France Cultivar ranking on a 0-9 scale; 9= fully resistant.	Caphorn	14
	Apach	11
	Sankara	8
	Soissons	4
	Mendel	4
	Isengrain	4
	Aubusson	3
	Rosario	3
	Orvantis	3
	Charger	2
Germany Cultivar ranking on a 1-9 scale; 9= most susceptible	Dekan	10
	Tommi	9
	Cubus	6
	Herman	6
	Turkis	5
	Akteur	4
	Brilliant	4
	Raroli	3
	Anthus	3
	Schamane	3
Poland Cultivar ranking on	Bogatka	7
	Tonacja	6

a 0-9 scale; 9= fully resistant	Zyta Finezja Rywalka Legenda Mewa Muza Ludwig Sukces	5 4 4 4 4 4 4 3
<u>Hungary</u> Cultivar ranking on a 0-9 scale; 9=fully resistance	Mv Csardas Mv Magdalena Lupus GK Kalasz Mv Verbunkos Mv Suba GK Petur Mv Palotas Mv Marsall Mv Ködmön	8 8 7 7 5 4 4 4 3 3
<u>Italy</u> Cultivar ranking on a 1-4 scale 1 = resistant	<u>Soft grain wheat</u> Isengrain Serio Bolero Eridano Genio Provinciale Tremie Victo Abusson Craklin	<u>Durum wheat</u> Sancarlo Duilio Svevo Grazia Simeto Ciccio Cirillo Claudio Creso Iride
<u>Netherlands</u> Cultivar ranking on a 0-9 scale; 9= most resistant	Drifter SW Tataros Residence Illias Bristol Limes Globus Anthus Robigus Tulsa Patrel	1 (most grown area) 2 2 2 5 6 6 8 9 10 11 (least grown area)
<u>Denmark</u> Cultivar ranking on a 0-3 scale 0 = resistant	Smuggler Skalmeje Cultivar mix Samyl Opus Robigus Abika Ambition	34 11 11 7 7 7 3 2

It can easily be observed that the difference in fungicide response can vary significantly between cultivars relating to their level of resistance. However, even the most resistant cultivars tend to respond positively to fungicide treatment. In the following section examples from different countries showing variations in responses to fungicides are given.

The use of resistant cultivars is generally of more interest in the case of foliar disease control, since the sources of inoculum for these diseases are less strongly linked to field

history, and thus less easily controlled through other agricultural practices such as crop rotation and tillage.

French experience with genetic resources

Use of cultivars resistant to foliar diseases can lead to a strong reduction in yield loss between fully treated and untreated plots, as illustrated below (Figure 5.1). It can also be observed that the difference in fungicide response can vary greatly between trials, essentially due to differences in disease pressure between locations.

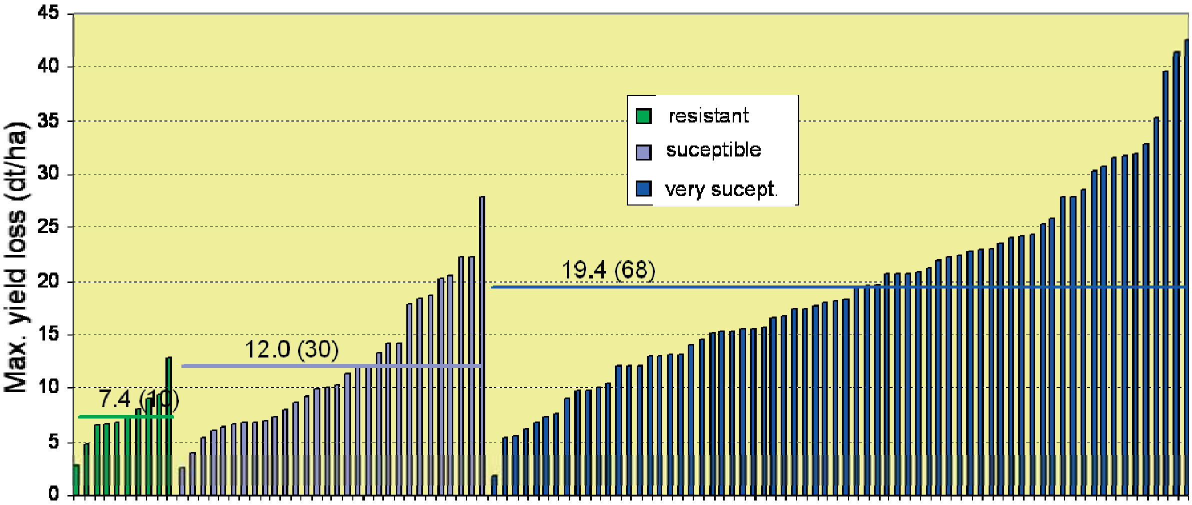

Figure 5.1: Distribution of yield loss in 108 trials in 2005 for 3 classes of resistance to foliar diseases. Horizontal bars represent mean values. The first number above the bar is the mean value, the second (in brackets) is the number of trials used to establish the mean.

Improved disease resistance in cultivars gives a reduction in the yield loss due to disease. This results in a reduction in the optimum fungicide expense (calculated by focusing on net yield), as illustrated in the following Figure 5.2. In those trials, the use of a resistant cultivar allowed for an average decrease of optimum fungicide expense of 20 €/ha[2].

Cultivar resistance to eyespot also exists. For example, using solely the resistance rating of a cultivar as the criterion for whether to treat or not against eyespot led to the “right” decision being taken in 75% of the cases in 44 field trials from 2000 to 2002[3] (the “right” decision = decision to treat & treating brought about a net yield gain or decision not to treat & treating brought about a net yield loss).

[2] Couleaud, 2004
[3] Couleaud, 2003

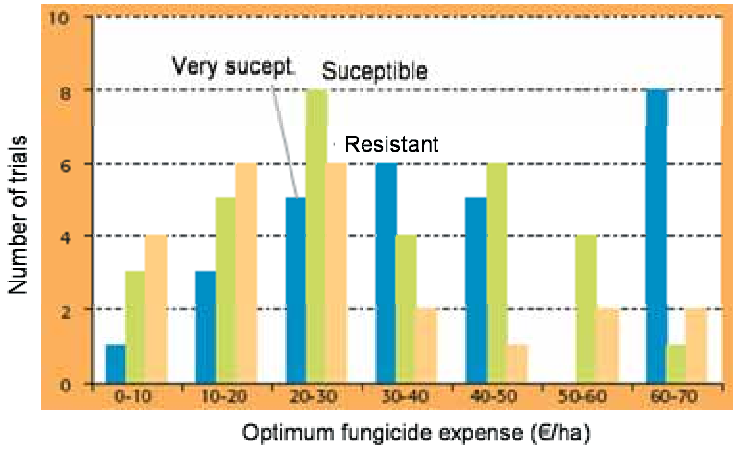

Figure 5.2: Distribution of optimum fungicide expense for 3 classes of resistance to foliar diseases in 82 trials from 2000 to 2003[5].

Finally, it is interesting to observe that use of resistant cultivars can not only reduce fungicide use, but can also stabilise it. Indeed, in trials conducted over 3 years (2001-2003) in Northern France (Vraignes, 80) with 2 cultivars, one resistant and one susceptible, yield loss to disease and optimum fungicide expense varied less for the resistant cultivar[5] (Table 5.2).

Table 5.2: Variation of yield loss and optimum fungicide expense over 3 years (2001-2003) between susceptible and resistant cultivars in Vraignes, France (80)

	Susceptible	Resistant
Variation in yield loss to disease	35 dt/ha	14 dt/ha
Variation in optimum fungicide expense	62 €/ha	28 €/ha

Limitations in use of resistant cultivars

One of the first limitations for the use of resistant cultivars often cited is the fact that potential yield of these cultivars is limited. In France, this difficulty has been countered through a joint effort, over the past 15 years, of public and private breeders who have developed high yielding cultivars with good levels of resistance, and technical institutes and extension services who have strongly communicated on disease resistance. This is illustrated by the fact that when asked what their principal criterion for cultivar choice is, growers place agronomic criteria, among which disease resistance holds a strong place, above yield[4]. As a consequence, there has been a strong renewal of cultivated cultivars in France in the past years, with some recent cultivars that display good resistance levels entering the top 10.

Another difficulty of use of resistant cultivars is that no available cultivars display resistance to all diseases. For example, Sankara is often chosen as a more resistant cultivar in Northern France, due to its good performances against Septoria. For example, in 2006, it showed a mean yield loss of only 8.5 dt/ha over 24 trials, but in 2007, a year with unprecedented levels of brown rust attacks in Northern France, mean yield loss over 30 trials rose to 27.1 dt/ha.

Also, the use of resistant cultivars can be ineffective under certain cropping practices. For example, concerning fusarium risk (DON risk) after a maize crop without tillage, the use of a resistant cultivar cannot guarantee a low level of DON: there is a greater than 20% chance that levels will be above the 1250 µg/kg threshold.

[4] ONIGC, 2007

Finally, a strong limitation to the use of resistant cultivars is the durability of resistance. Indeed, there are many examples of cultivars whose initial good resistance to a disease has fallen over the years, sometimes very rapidly, other times more slowly. For example, when cultivars Caphorn and Orvantis were first tested, they ranked among the 25% best cultivars in all trials. In 2004, while Orvantis ranked in the top 25% in only one trial out of 6, Caphorm was still placed in the top 25% 2 out of 3 times. In fact it is not the cultivars that change – it is the selection of pathogen races that are able to overcome the resistance factors of the cultivar. This is particularly a problem with the rust diseases.

This development of new pathogen races is clearly a problem, as it can lead to the situation whereby a cultivar that is perceived as resistant can actually become susceptible. This is all the more problematic in that changes in disease resistance differ greatly among cultivars, depending on their specific resistance factors. Some cultivars' resistance ratings change more slowly than others, and even sometimes increase, as illustrated below: Charger's level of resistance seems to have remained stable over the years, while Soissons, a cultivar which was ranked as resistant when introduced in 1987 but rapidly became very susceptible, seems to be regaining resistance.

The diversity of situations in the four examples above illustrates the fact that predicting the changes in cultivar resistance levels is very difficult, as it depends on the combination of specific resistance genes and underlying partial resistance of cultivars, but also of the intensity with which these cultivars are cultivated in the landscape, as well as use of other cropping practices that contribute to reducing disease. Furthermore, the situation varies from one disease to the next, depending notably on its mode of reproduction and dissemination. For example, brown rust shows a strong diversity of populations, with pathotypes varying between cultivars[5]. This can be linked to the diversity of situations illustrated above. On the other hand, yellow rust populations in France are composed almost exclusively of one dominant race. When this dominant race changes, the resistance of a large number of cultivars may shift dramatically. For example, in 2007, a new race of yellow rust appeared which has circumvented a resistance gene present in a number of cultivars (Yr32)[6]. Thus, many cultivars that used to have a good rating against yellow rust performed very poorly this year. On the other hand, this population is not virulent to Yr6, a resistance that had been circumvented some years ago. Hence, certain cultivars that were considered susceptible in the past years performed well this year.

Experiences from the UK

In the UK there is a national testing of cultivars, carried out by the Home-Grown Cereals Authority (a levy-funded organisation) which aims to choose high yielding cultivars with good disease resistance. Despite efforts to breed more resistant cultivars and the introduction of minimum standards for disease resistance in the recommended list, yield responses to fungicide use remain very large (Figure 5.3). On average, cultivars give approximately a 20% yield response to fungicide treatment. There is also an emphasis on yield performance of treated cultivars, inadvertently leading to the selection of high yielding cultivars that respond well to fungicide use. This can lead to cultivars that are very susceptible to some diseases becoming recommended and being widely grown. This situation makes the demand for fungicide use high but also leads to very high selection pressure for pathogen resistance to fungicides.

5 Source : H. Goyeau, INRA
6 Source : C. Pope, INRA

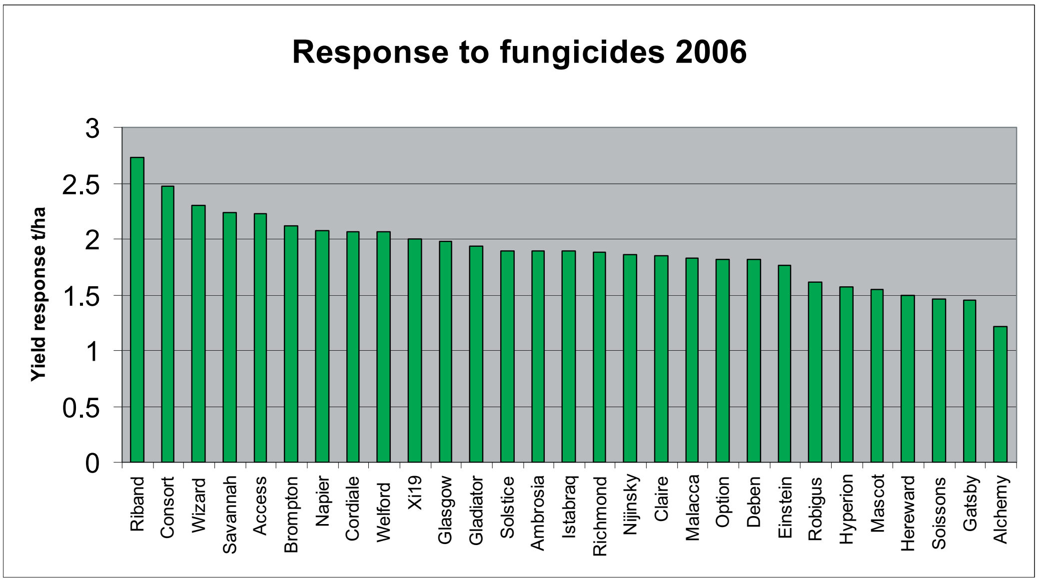

Figure 5.3: Yield responses from fungicide treatments in cultivar trials in the UK. The response varies from around 1.2 to 2.7 tonnes/ha. Even cultivars with generally good resistance give relative large responses (Table 5.3).

Table 5.3: Resistance ratings of top 10 UK cultivars. 9= fully resistant

% of Crop Area					
2007		Septoria	Y. Rust	B.rust	Mildew
Robigus	**15.3**	6	3	9	7
Alchemy	**12.8**	7	9	4	7
Einstein	**11.7**	5	6	6	6
Solstice	**8.2**	5	9	4	6
Claire	**6.2**	6	9	5	4
Gladiator	**4.3**	5	8	8	6
Brompton	**3.4**	5	8	7	4
Hereward	**3.1**	6	5	5	6
Cordiale	**3.0**	5	6	3	6
Consort	**2.9**	4	6	3	6

Experiences from other countries

The Netherlands

Winter wheat cultivars are tested for their agronomic characteristics and disease resistances. Results are published in the Dutch Cultivar list. Resistances to yellow and brown rust, mildew, Septoria and Fusarium Head Blight (FHB) are presented with an index ranging from 1=very susceptible to 9=very resistant. The most important cultivars were Drifter, Ilias and Residence.

Germany

Cultivar resistance as a major impact and is very important for disease development in Germany. In Germany, the ranking of the susceptibility is made by the Bundessortenamt based on cultivar trials at 13 trial sites for cultivar testing throughout Germany, with about 700 ha of agricultural land in the various cultivation and climatic regions. Further tests managed by the Federal States are carried out at 450 trial sites. Ratings for the cultivar resistances are given on a 1-9 scale where 1 is fully resistant (Table 5.4). Analysing the values altogether it can be concluded that good levels of resistance are only available for mildew. For all other diseases, in most cases cultivars have a medium to high level of susceptibility.

Table 5.4: Commonly grown cultivars in 2007 and ranking of their susceptibility to the main diseases

Cultivar	**Per cent of wheat area 2007**	Septoria, particularly S. tritici (1-9*)	Fusarium head blight (1-9*)	DTR (1-9*)	Mildew (1-9*)	Brown rust (1-9*)
1) Dekan	9.8	4	4	5	1	8
2) Tommi	9.0	4	4	5	2	5
3) Cubus	5.9	6	4	5	2	7
4) Hermann	5.8	4	3	5	2	2
5) Türkis	5.0	4	4	6	1	4
6) Akteur	4.4	6	4	5	2	4
7) Brilliant	4.0	5	4	5	2	3
8) Paroli	3.2	6	6	5	3	6
9) Anthus	2.9	4	4	6	2	4
10) Schamane	2.5	4	5	5	3	6

* 9 = most susceptible

France

France also has an extensive variety testing which characterises the resistance level to relevant diseases. The list is updated yearly.

Table 5.5: Commonly grown cultivars in France in 2007 and ranking of their susceptibility to the main diseases. France rank the varieties on a 0-9 scale; 9= fully resistant

Variety	% crop area	Eyespot	Septoria leaf blotch	Powdery mildew	Brown rust	Leaf rust
Caphorn	14	3	5	6	7	8
Apache	11	2	5	5	4	8
Sankara	8	5	6	8	3	6
Soissons	4	2	5	7	2	6
Mendel	4	3	6	5	4	7
Isengrain	4	1	4	6	3	5
Aubusson	3	6	4	8	3	5
Rosario	3	3	5	6	5	8
Orvantis	3	2	4	5	2	5
Charger	2	2	5	8	6	9

Italy

In Italy there is a national research network led by the Experimental Institute on Cereals (C.R.A.-I.S.C.) of the Ministry of Agriculture, aimed at the annual characterisation of the most important cultivars of common and durum wheat available. One of the criteria selected is the incidence of the major fungal diseases, by means of which a rating for cultivar resistance (on a 1-4 scale, where 4 is highly susceptible) is given. Many cultivars with high levels of resistance to foliar diseases are characterised by a very early earing date that prevents fungal spread to upper leaves, especially the flag leaf.

Although this information is quite accessible by farmers, the use of highly resistant cultivars is still constrained by agronomic and economic factors, such as unsatisfactory yield and poor grain quality, high prices and shortage of certified seeds and poor perception by farmers of fungal diseases as an important yield loss factor. Moreover, this kind of experimentation is carried out not from an “IPM” point of view, but following the standard management for conventional farming (there is another network based on organic farming wheat management, but it involves only few cultivars); in this way, there is a great lack of knowledge about the real resistance of cultivars, because they could be still very responsive to the fungicide use.

There is little information regarding the suitability of cultivar mixtures in terms of yield increase and resistance to fungal diseases. Only few trials have been made in recent years, mainly highlighting the constraints of this technique, related to the low market acceptability of products characterised by high heterogeneity.

Poland

Wheat cultivars are tested by the Research Centre for Cultivar Testing (COBORU) and added to the Polish National List. Testing activity at COBORU is done by 51 Experimental Stations for Cultivar Testing. These stations are distributed all over the country. Cultivars are tested based on the system of a value for cultivation and use research. The basic factor is yield, although resistance to the main diseases is also estimated. Ratings for the cultivar resistance to diseases are given on a 0-9 scale where 9 is fully resistant. Generally, the cultivars have quite high scores for resistance. The average score for the 10 most commonly grown cultivars have been around 7-8 on a 1-9 scale.

Hungary

There are two major R & D institutes in Hungary, the Cereal Research Institute, Szeged and the Agricultural Research Institute, Hungarian Academy of Sciences, Martonvásár, where internationally recognized, efficient wheat breeding programmes are run. 90% of the total national wheat growing area is covered by cultivars produced by these two institutions. Furthermore, cultivars developed at Szeged and Martonvásár are grown in Slovakia, Ukraine, Romania, Turkey and Croatia.

Denmark

There is a national experimental testing of cultivars which aims to choose high yielding cultivars with good disease resistance. Cultivars in Denmark are normally tested by the Danish cultivar testing station as well as by the advisory services. Cultivars are frequently changed by farmers and consequently they rarely last for more than 2-4 years. Ratings for the cultivar resistance to diseases are given on a percentage scale based on yearly observations made at 10-15 localities. The cultivars are then divided into 4 groups, which are further used when categorising cultivars as susceptible or resistant (Table 5.6). Minimum standards for disease resistance are not specified. There has been a major effort to breed for more resistant cultivars, and the cultivars have generally become more resistant in particular to septoria and rust diseases.

The need for fungicide input is dependent on the degree of cultivar resistance. A higher yield gain has generally been obtained from fungicide applications in susceptible cultivars than in

resistant cultivars. The differences between resistant and susceptible cultivars amounted to 3.2 dt/ha on average (Figure 5.4) (Jørgensen *et al.*, 2007). The data showed considerable variations between seasons. In seasons with significant disease attacks, the difference was approximately 6 dt/ha, whereas it was only about 1.5 dt/ha in seasons with low attack (data not shown).

In the last 2 years cultivar mixtures have been sown on approximately 10% of the wheat area. This has been supported by breeders and grain merchants.

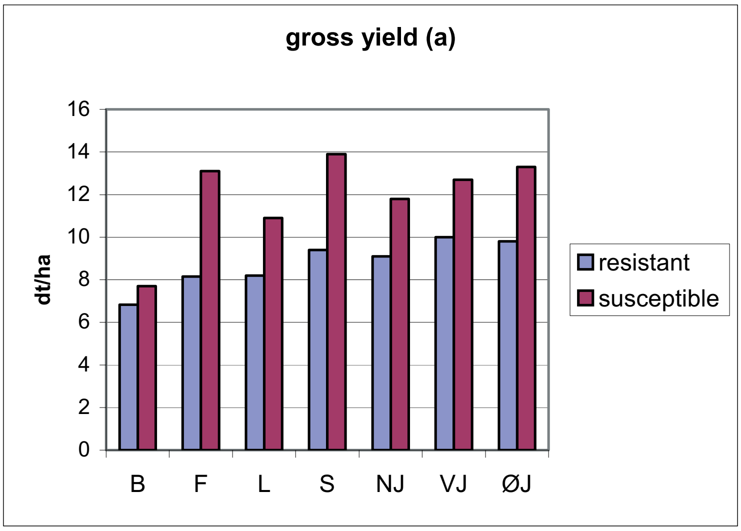

Figure 5.4: Gross yield (dt/ha) obtained with resistant and susceptible cultivars at TFI between 0.5 and 0.75 in different regions in Denmark. Labels on x-axes represent regions: B=Bornholm, L=Lolland/Falster; F=Fyn; S=Sjælland; NJ=Nordjylland; VJ=Vestjylland; ØJ= Østjylland.

Table 5.6: Commonly grown cultivars in 2007 and ranking of their susceptibility towards the mean diseases 0-3; 3= high susceptibility

Culltivar	Part of wheat area 2007, pct.	Septoria (0-3)•	Mildew (0-3)•	Yellow rust (0-3)•
1) Smuggler	34,1	2	1	1
2) Skalmeje	11,3	2	1	1
3) mixture.	11,1	-	-	-
4) Samyl	7,3	3	3	1
5) Opus	7,2	2	2	1
6) Robigus	6,6	2	0	1
7) Abika	2,7	2	0	1
12) Ambition	1,9	1	0	0

• 3 = very susceptibel

6. Use of thresholds and DSS

Decision support systems and thresholds systems have been developed in many European countries. Table 6.1 gives examples of systems available in the different countries.

For most systems it is generally found that they have very minor use among farmers. Most systems are used by advisers and as support during the more strategic planning of crop protection strategies.

Dissemination of information from research to advisers and farmers is of major importance for successful disease management. This issue is handled very differently depending to the country involved. Little focus has previously been given to the more sociological aspect of spreading information to farmers. A Danish project found that there generally is a much greater need for involving farmers and advisers before developing DSS in order to make sure that the systems will successfully reach the end-users' demand (Jørgensen *et al.*, 2008).

Table 6.1: Decision support systems and available information on the web

	Name of system
UK	www.Cropmonitor.uk
France	Monitoring system (Service de la protection des vegetaux)
Germany	Isip (Crop protection services of the federal states) ProPlant (Private company) Ips-weizen/ips-raps (Schleswig Holstein only) Getreide actuell (Syngenta) www.progosesystem.com (BASF) www.pflanzenschutzberater (Bayer crop science)
Poland	Few systems available but of little use
Hungary	Nothing mentioned.
Italy	Nothing mentioned
Netherland	Epipre (old dss used as basis for other DSS) www.Milieumeeetlat.nl (Enviromental index of pesticides. CerDis developed by Opticrop (www.opticrop.nl).
Denmark	Crop protection online www.pvo.planteinfo.dk Cultivar database www.sortinfo.dk General information www.Planteinfo.dk

Experiences from individual countries

UK
Most large farms employ an independent adviser to give recommendations on fungicide use in wheat. These advisers have to undergo special training and pass an exam (BASIS)

before they can advise farmers. Some large farms have farm managers who have been specially trained and have passed the BASIS exam. Agrochemical distributors and manufacturers also give technical advice as part of the sales of fungicides.

Many thresholds and decision support systems have been developed for disease control, the most sophisticated of which is the 'Wheat Disease Manager' (DESSAC), a model-based system. In these decision support systems the 'support' ranges from simple weather data, used to indicate high disease-risk periods, through to complex model-based systems that aim to advice on possible spray programmes on the basis of economic outcome. Simple risk warnings can be used to adjust the start date or number of sprays in multiple spray programmes. In cereal spray programmes, where the number of treatments is small and optimal timing is largely determined by the emergence of the final three leaves, the main value of risk assessment is to determine the appropriate dose. Even when supported by risk information, extension workers tend to give advice that is risk-averse. The outcome of their advice is difficult to quantify in economic terms, so it tends to be judged on disease levels in the treated crop. However, crop appearance is not a good basis for judging economic success of a treatment programme. Consequently there is considerable uncertainty in the feedback mechanism which the adviser uses to judge whether the decisions were near optimal. Model-based systems, which account for the crop suggest more optimal spray programmes, but users' perceptions of the success of such systems may still be based on crop appearance or comparisons with arbitrary user-suggested programmes. Without training in understanding the basis of such systems, to build confidence, extension workers are likely to remain overly risk-averse and growers will not achieve the economic or environmental benefits that could arise from their use.

Consequently, very few decision support systems are actually used by advisers or farmers.

The Netherlands
The first decision support system developed in winter wheat was EPIPRE system (Rijsdijk, 1983). The original aim of EPIPRE was to implement a yellow rust disease management system. In 1979 it broadened into a management system of diseases and pests of wheat.

The relative small acreage of winter wheat and the limited possibilities to save input and costs are the main reason that only one DSS has been developed for diseases in winter wheat. The system is called CerDis and is developed by Opticrop (www.opticrop.nl). The number of users of CerDis is limited to a small group of intensive winter wheat growers in the North East of the Netherlands.

The advisers of agrochemical distributors have a large influence on the control strategy in winter wheat. Depending on the resistance of the cultivar to Septoria and brown (and yellow) rust, one or two sprays are applied. When the weather conditions during flowering are risky for the infection of FHB one more spray is applied during flowering to control FHB. Although work has been carried out to look into the possibilities to reduce dose rates (Schepers *et al.*, 1996, 1997) the occurrence of strobilurin-resistant Septoria, which is now widespread in the Netherlands, resulted in a limited use of lower dose rates. Doses below 75% are hardly used.

Poland
Most farmers make decisions on fungicide use based on their own knowledge and experience. They can also get advice from the State Agricultural Advisory Service. Advisory Centres are affiliated in the majority of rural districts in Poland. Support for the advisers is Plant Protection Recommendations published every year by the State Institute of Plant Protection. This Institute is also developing thresholds for the main wheat diseases.

Also distributors of agrochemicals give technical advice as part of the sales of fungicides. They organise training and presentations of IPM systems; so-called "field days" for farmers.

Recently a decision support system was developed: Internet based Decision Support System for Integrated Pest Management. However, up to now very few advisers or farmers are using it.

Germany
From the 1970s to date threshold systems were developed on the basis of experiments conducted to find disease-loss-relationships. In several Federal Lands of Germany as well as in the former GDR such systems were developed for important cereal diseases. In the nineties, a harmonisation took place between the Federal States. Nowadays, similar thresholds are used in Germany. Most common examples are given in Table 6.2.

Table 6.2: Most common treatment thresholds in Germany

Mildew	60% disease incidence at the scope of the upper three leaves (in BBCH 35 to 61)
Septoria tritici	30% disease incidence at the scope of the upper four leaves in BBCH 32 to 37 or 10% in BBCH 39 to 61
Septoria nodorum	10% disease incidence at the scope of the upper three leaves in BBCH 39 to 61
Brown rust	30% disease incidence at the scope of the upper three leaves in BBCH 37 to 61
DTR	5 … 10% disease incidence at the scope of the upper three leaves in BBCH 35 to 65; preceding crop winter wheat without ploughing: at the beginning of disease development

Decision support systems for crop protection via computer are a clear advance in giving advice for targeted fungicide use. They include forecast systems based on thresholds and weather conditions. These tools have been promoted in many countries. In Germany, there are two "standard providers": ISIP **(ZEPP)** and **ProPlant**. In ISIP, more than 20 met-based predictive models for pests and diseases have been successfully developed and introduced for practical use by means of governmental crop protection services within the last years. The occurrence of diseases and periods of incubation can be calculated with high accuracy. The ProPlant system is similar. In addition, considerable free information is available on the Internet (see Table 6.1).

Thus, it is possible to reduce the intensity of chemical control in combination with a high effectiveness. The forecast and decision-support systems are widely used especially by advisers but also by active farmers. In Germany, around 1200 advisors (sum of advisors of Plant Protection Services, independent advisors, and advisors of pesticide manufacturers and retailers) deliver information to the farmers. The majority of the advisers is highly qualified, e.g. one third with a MSc degree. (All professional pesticide users, retailers, advisors and trainers must have professional knowledge and skills in the field of plant protection.)

Furthermore, each Federal Land publishes each year a guide entitled "Plant Protection Recommendations – Agriculture and Pasture –" which contains the regional recommendations for use of plant protection products and the actual application strategies.

France
The overall approach of disease control can be broken down into 3 steps:

1. Determining overall fungicide budget: fungicide expense should be planned according to expected yield loss due to disease, focusing on net economic gain. In France, it has been found that optimum fungicide expense, i.e. fungicide expense that maximises net gain, is approximately 2€ for each dt of yield lost to disease, for a wheat price of 90 €/t. This figure is however, strongly dependent upon wheat prices. Hence, for an average loss of 18 dt/ha, if wheat prices increase from 90 to 130 €/t, optimum fungicide expense rises 28%.

Allocating this expense to control the different risk periods of different diseases is the challenge: to aid in this, Arvalis publishes each year for each region a guide entitled "*Choisir 2®*". The decision tree guiding to different fungicide programmes is illustrated below (Figure 6.1):

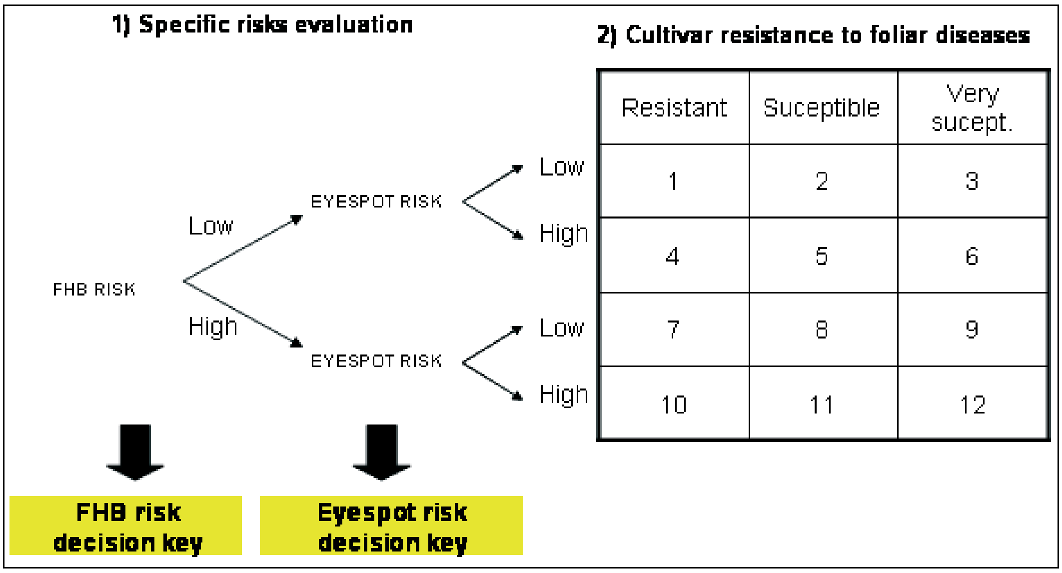

Figure 6.1: Decision tree for construction of fungicide programmes in France.

2. Adjusting fungicide strategy with in season information using visual thresholds or decision support systems: Detailed observation thresholds can be found in the Arvalis document "*Fongiscope®*". They are briefly summarized below:

Table 6.3: Summary of thresholds for in season adjustment of disease control (N.B. : F1 is the topmost fully developed leaf, F2 the one below that, etc.)Ingen teksthenvisning

Disease	Growth stage for observation	Threshold
Eyespot	Z31-Z32	> 35% stems
Mildew	Z31-Z39	20% F1 or F2
Septoria	Z32-Z45	20-50% F3
Brown rust	Z39-Z45	Presence F1 or F2
Fusarium head blight	Z55	Persistent humidity

Use of all these thresholds for adapting fungicide strategy was tested in 57 trials from 2000 to 2003. Detailed results are presented below. On average in 2003, a year with low disease pressure, adjustment resulted in a 20 €/ha gain of net margin as well as reduction of fungicide use of 0.4 l/ha[7].

[7] Couleaud, 2004

Table 6.4: Results of use of observation thresholds for in season adjustment of fungicide strategy[2] Ingen teksthenvisning

	2000-2002 (33 trials)	2003 (24 trials)
Improved net gain	46%	59%
Same net gain	36%	33%
Worsened net gain	18%	8%

3. Decision Support Systems: Finally, different decision support systems exist, many relying in part on field observation. These different systems are mainly proposed by government plant protection services (Service de la Protection des Végétaux), Arvalis or agrochemical companies. These systems simulate disease dynamics using weather data and use certain model variables as a basis for decision thresholds, thus replacing in-field observation. Another important characteristic of these decision support systems is that they are not constructed to deliver information directly to growers, but to their advisers, who in general belong either to the local cooperative/input distributor or Chambre d'Agriculture. Indeed, in a survey of 801 cereal growers by BVA Instititute[8] for Arvalis, these 2 types of player are recognised by more than 50% of growers, whereas all others involved in agricultural advising obtained less than 11% recognition by farmers.

Denmark

Use of a decision support system like Crop Protection Online (CPO) provides the possibility of adjusting input depending on disease pressure and susceptibility of the cultivars. The disease and pest module of the Danish decision support system PC-Plant Protection was introduced to Danish farmers in 1993. The system has been validated in several trials (Secher *et al.*, 1995; Henriksen *et al.*, 2000b, Jørgensen *et al.*, 2008). Since 1996, the models have been adjusted according to the results of the validating trials and the information on new cultivars. In 2002, the system was introduced as a web-based DSS (Rydahl *et al.*, 2002).

CPO includes models for mildew, rusts, septoria diseases and eyespot and is based on empirical data on (i) the specific effect of each pesticide, (ii) control thresholds, (iii) importance of diseases and pests according to growth stage, (iv) susceptibility to diseases of the grown cultivar and (v) influence of the weather on the development of diseases. The system requires input of disease levels and weather data in order to run. For disease data frequency of attacked plants are used (Jørgensen, 1996). Today the CPO is widely used by advisers (>75%) and 3% of the farmers have the system. Indirectly the thresholds are widely used when advisers disseminated information to farmers during the season through news letters, etc. Examples of the used control thresholds are given in Table 6.5.

Table 6.5: List of some of the control thresholds used by the decision support system Crop Protection Online (CPO) for control of diseases in winter wheat

Eyespot More than 35% plants attacked at growth stage (GS) 30-32. Only main shoots are assessed. The attack must have spread to the next-to-the-outermost leaf sheath to be included.
Powdery mildew Susceptible cultivars: GS 29-31: More than 10% plants attacked. GS 32-40: More than 25% plants attacked. Non-susceptible and partly susceptible cultivars: GS 29-31: More than 25% plants attacked. GS 32-40: More than 50% plants attacked.
Brown rust

[8] BVA, Institut d'études de marché & d'opinion. http://www.bva.fr

Susceptible cultivars: GS 30-31: More than 25% plants attacked. GS 32-50: More than 10% plants attacked. GS 51-71: More than 25% plants attacked. None susceptible and partly susceptible cultivars: GS 32-71: More than 75% plants attacked
Yellow rust Susceptible cultivars: GS 29-60: More than 1% plants attacked. GS 61-71: More than 10% plants attacked. Non-susceptible cultivars: GS 29-60: More than 10% plants attacked. GS 61-71: More than 75% plants attacked.
Septoria tritici Susceptible cultivars: At least 4 days with precipitation (> 1 mm) from GS 32. If the crop was sprayed before GS 52, the counting of days with precipitation begins after 10 days. If the crop is sprayed from GS 52 onwards, the counting of days with precipitation begins after 20 days. A maximum of 30 days are counted back in time. A spray is also triggered at GS 45-59 if more than 10% of the plants show attack on the 3rd leaf from the top. Control of septoria can be considered until GS 71. Partly susceptible cultivars: At least 5 days with precipitation (> 1 mm) from GS 37. Control at GS 39 at the earliest. Otherwise as in susceptible cultivars.
Tan spot Control is only considered if the previous crop was wheat and reduced tillage is practiced. Susceptible cultivars: GS 31-32: More than 75% plants attacked. GS 33-60: More than 25% plants attacked. GS 61-71: More than 50% plants attacked. Less susceptible cultivars: GS 37-60: More than 50% plants attacked. GS 61-71: More than 75% plants attacked.

The monitoring system on cereal diseases, which is run by the advisory services also relies on the assessments methods and thresholds incorporated in Crop Protection Online. The system is updated weekly and provides broad information on disease development and risk separated into susceptibility groups.

Hungary
Due to the increased demand for wheat, increased fungicide usage is expected.
There are four sources supporting plant protection decision making in Hungary,

1. In the communist era Hungary had large cooperative agricultural farms with well-organised plant protection systems. All these large cooperatives (some 3000 throughout the country) hired plant protection engineers with a MSc degree who were responsible for decision making. Remnants of this system still exist, as 60-70% of wheat production is made in large scale farms (former cooperatives, now joint stock companies or public limited companies owned by previous leaders of the cooperatives). In such companies the plant protection skill is still excellent. Furthermore, only such plant protection engineers can use the so-called category I. pesticides (with high health or environmental risks), therefore the plant protection MSc courses are very popular even among the small- and medium-scale owners.

2. There are 20 Plant Health and Soil Protection Stations in the country with a staff of 20-30 people. This network is coordinated by a central station and is supervised by the Ministry of Agricultural and Rural Development. The plant protection network acts as the official authority of plant protection (e.g. have the right to impose a penalty if an obligatory plant protection treatment is neglected by the land owner) and provides consultation upon request by the farmers. An 'on duty system' works in every region: they give advice on special/actual plant protection problems.

3. The plant protection network (20 stations + the central one) runs a website, a so-called Plant Protection Information System filled up and regularly refreshed with actual warnings and plant protection advices. These actual warnings are based on reports from the regional plant protection stations. The web site is: www.ontsz.hu/nir .

4. Hungary has various practical journals, published monthly that regularly provide plant protection consultation. They are Növényvédelem (Plant Protection, ISSN 0133-0829, established in 1964) and Agrofórum (Forum on Agriculture, ISSN 1788-5884, established in 1990, internet: www.agroforum.hu).

Problems with thresholds and DSS

Generally speaking DSS systems are not widely used directly by farmers. The actual potential for optimizing fungicide input according to a given need in a field has been investigated but has so far been seen to suffer from major barriers. Some of these are:

- ✓ Threshold systems: farmers have larger and larger farms and are having less time for observation in individual fields.
- ✓ The system does not fit into the individual farms management plan. In order to optimise the spraying capacity the farmer might need to combine fungicide sprays with other agrochemical inputs. This will result in moving away from a complete optimisation of the input.
- ✓ Not all DSS combine information on different pests and diseases, which makes it difficult for the farmers to practically adopt it, as the farmer typically will have to consider all relevant pest and diseases when planning his strategy.
- ✓ Some information in DSS is more suitable for advisers and will need further adjustments before delivering the information to farmers.
- ✓ The farmers in many cases lack a direct motivation factor for using DSS, as pesticides are generally still found to be cheap compared to the benefits which they provide.
- ✓ Many decision support systems rely on the user inputting considerable amounts of information. The more information that is required for the system to work (e.g. field observations), the less likely a potential user is to use the system.

Environmental payments for 'green' pesticides

There are few examples of countries which score their pesticides in terms of environmental impact. Holland has had some success in this area and their example may be a useful model to follow. In such a scenario farmers are encouraged to use fungicides which have a lesser impact on the environment. Financial incentives or penalties may have to be imposed to encourage modifications in fungicide use.

7. Examples of Good Agricultural Practice

A major task for the wheat case study has been to give examples of how the dependency on the use of fungicides in wheat could be minimised. The group has identified several good cases or examples of knowledge which could be further exploited.

The good examples which will be described in this chapter cover:

- Use of cultural measures
- Use of measures against fusarium
- Use of reduced nitrogen levels
- Use of genetic resources including cultivar mixtures
- Use of thresholds
- Use of optimised and reduced doses

Many diseases are affected by cultural measures such as rotation, sowing date, tillage methods, cultivar choice, nitrogen use etc. Among general aspects, which should be considered in relation to adopting an IPM approach to help to minimise disease pressure, the following points can be mentioned.

1. Growing more resistant cultivars
2. Modulating dose and kind of fungicides according to economic thresholds, target disease and cultivar resistance
3. Introducing wheat in longer and more diversified rotations
4. Avoiding early sowing and high seed rates
5. Reducing N levels (according to low input systems)
6. Determining tillage from a "rotational" point of view

Several of these points might not always provide the most economic option and might easily be overruled by management strategies or market mechanisms driven by economic aspects rather than agronomic aspects.

Cultural measures

Sowing date has a marked impact on disease susceptibility. Early sowing favours many diseases such as take-all, eyespot, septoria leaf blotch and the rust diseases. Late sowing has, however, been found to increase the risk of powdery mildew in spring. Delaying sowing, although good in terms of reducing fungicide requirement for some diseases, is highly detrimental to yield per se. Farmers are therefore unlikely to take the risk of reducing their yield potential by deliberately delaying sowing until very late. The trend in the direction of very large farms with few staff also pushes the trend towards earlier sowing simply from a practical point of view. Delaying sowing also means running the risk that late sown crops may not establish well or may not be able to be sown at all, due to winter weather conditions. A move to spring sowing would certainly reduce disease risk for many diseases, but the economic penalties from lower yields would be high and many soil types would not allow spring sowing.

Cultivations/tillage can have a marked effect on disease pressure.
Minimum or no tillage could increase disease pressure by conserving fungal propagules on crop residues left on the soil surface. As a consequence, deep tillage, especially ploughing,

can be very useful for reducing diseases like tan spot and *Fusarium* ear blight, when wheat is cultivated in monoculture or in a short cereal-based rotation (Figure 7.1).

However, ploughing is not always positive as eyespot (*Tapesia* spp.) can be made more severe following ploughing (possibly due to nitrogen release during ploughing). Similarly take-all can sometimes be seen to be less of a problem following direct sowing or minimal tillage, which is believed to partly be due to a positive build-up of antagonists in the soil, which help to keep the level of take-all down.

Direct sowing and minimal tillage also increase the risk of particularly developing large populations of grass weeds and increase the dependency on chemical weed control.

Applying minimal tillage methods do not necessarily always result in problems, such as if crop rotation is adjusted in a sensible way avoiding for example monoculture with wheat. On the other hand, tillage methods may also be constrained by other factors for example in certain regions of Italy farmers have to plough in early autumn, i.e. the rainiest season, and it is often difficult to till soils in optimum conditions, especially in hilly and clayey soils. Ploughing also has high economic and energy costs, in addition to environmental ones (e.g. erosion, nitrogen leaching and loss of soil organic matter by mineralisation), so that in an IPM context farmers should take decisions by balancing all these aspects.

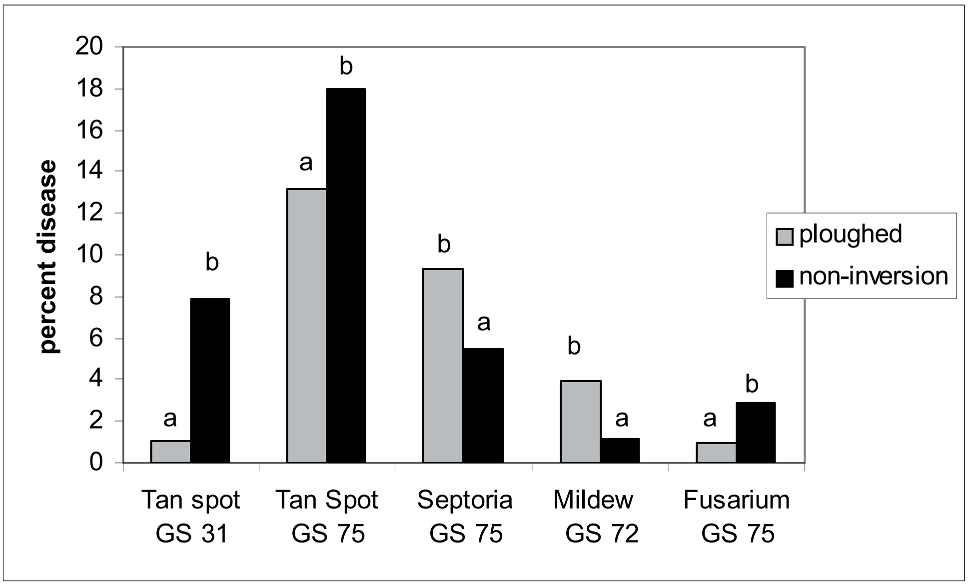

Figure 7.1. Per cent attack of diseases in winter wheat comparing the impact from the two tillage systems, ploughed and reduced tillage in a situation with wheat as previous crop. Average from two trials in 2003/2004. Bars within a disease having the same letter were not significantly different.

Rotation has a marked effect on disease pressure. Rotations can play an essential role in reducing many fungal diseases of wheat, first by avoiding wheat monoculture or cereal-based short rotations, and then by introducing trap crops or non-host crops and by enhancing the biodiversity and the resilience of the agro-ecosystems.

Crop rotation is particularly known to have an impact on root and stem-base diseases such as take-all (*Gaeumannomyces graminis*) and eyespot (*Tapesia* spp.). However, many leaf diseases such as Septoria are not affected by crop rotation.

Economic pressures often force farmers into very close rotations, which tend to increased disease pressure and fungicide demand. Incentives to widen rotations would be needed to influence current rotations.

Nitrogen restrictions – High amounts of nitrogen in the soil are generally known to increase the severity of fungal diseases like powdery mildew, rust and septoria leaf blotch (Olesen *et al.*, 2003). These increases are due to several factors, this includes among other things increasing the nitrogen content of leaf tissue, increasing growth in general, improving the microclimate in the crop and reducing resistance to penetration of cell walls.

However, reducing the total amount of N applied as fertilizer would not be the best solution, especially from an economic point of view. Scope for reducing the nitrogen to input to the economic optimum as well as using a split strategy can sometimes give fewer problems than applying single treatments with large amounts of nitrogen. To have a marked effect on disease susceptibility it is likely that nitrogen use would need to be reduced significantly – which would have a detrimental effect on profitability.

In some situations it might be a better strategy to include the distribution of organic fertilisers instead of mineral ones, because they would be able to provide N to wheat in a more gradual way, fitting well the crop needs and avoiding at the same time excess releases in the soil. Nitrogen inputs of wheat should also be tailored to the expected yield to avoid risk from leaching of N.

Sowing rate and spatial arrangement – In high disease pressure conditions, like in many regions of Northern Italy, also the sowing rate of wheat could play an important role in terms of reduction of fungicide use. A smaller spatial density of seeds (and plants) could avoid high relative humidity levels and reduce the spread of fungal spores within the canopy.

An example from Germany regarding the sowing rate on sandy soils is shown in Figure 7.2. In untreated plots of three susceptible varieties the yield in small-seed-fields was about 6 dt/ha higher than in normal-seed-fields. In fields which were treated due to *Septoria tritici* attack the surplus in the normal-seed-fields was about 5 dt/ha higher than in the small-seed-fields. This means that the yield potential can better be exhausted with the use of fungicides. Otherwise, the optimum yield on sandy soils can be achieved also with lower seed rates if the seed costs are taken into account. Apart from this advantage the better plant stability and leaf health has to be considered. Especially for earlier sowing the reduction of seed density has been recommended.

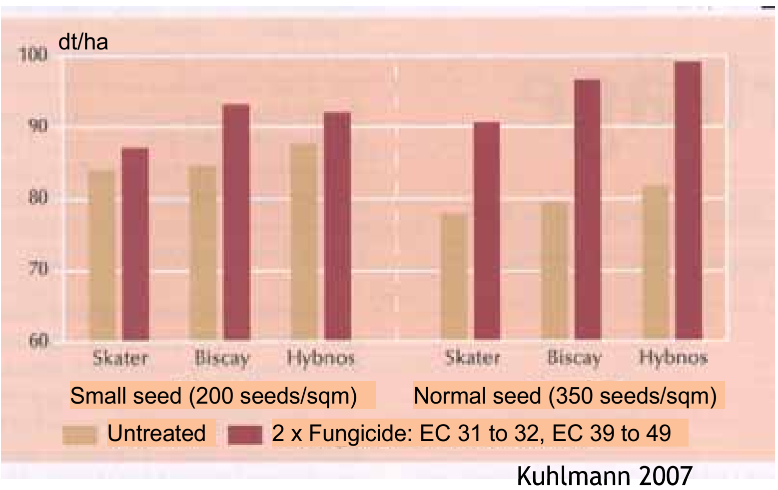

Figure 7.2: Effect of sowing rate and fungicide treatment on yield of winter wheat grown on a sandy soil (average of three years)

Factors influencing Eyespot

Several cultural factors have a significant effect on eyespot. This is a very well documented case, which have been exploited in several regions of Europe. The impact from sowing dates is given in both Figure 7.3 and Figure 7.4 representing trial data and survey data respectively.

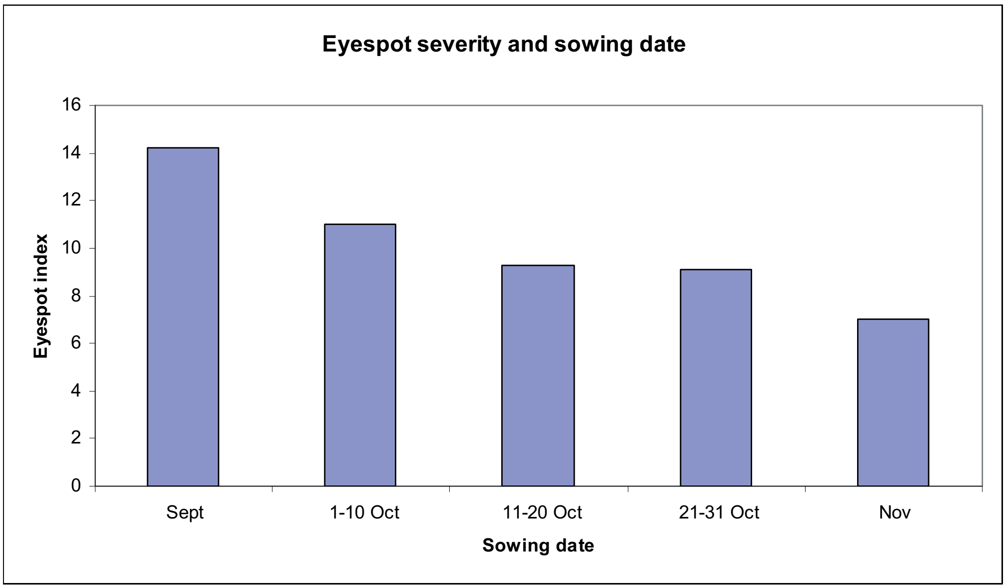

Figure 7.3: Effect of sowing date on subsequent levels of eyespot for wheat following a cereal crop.

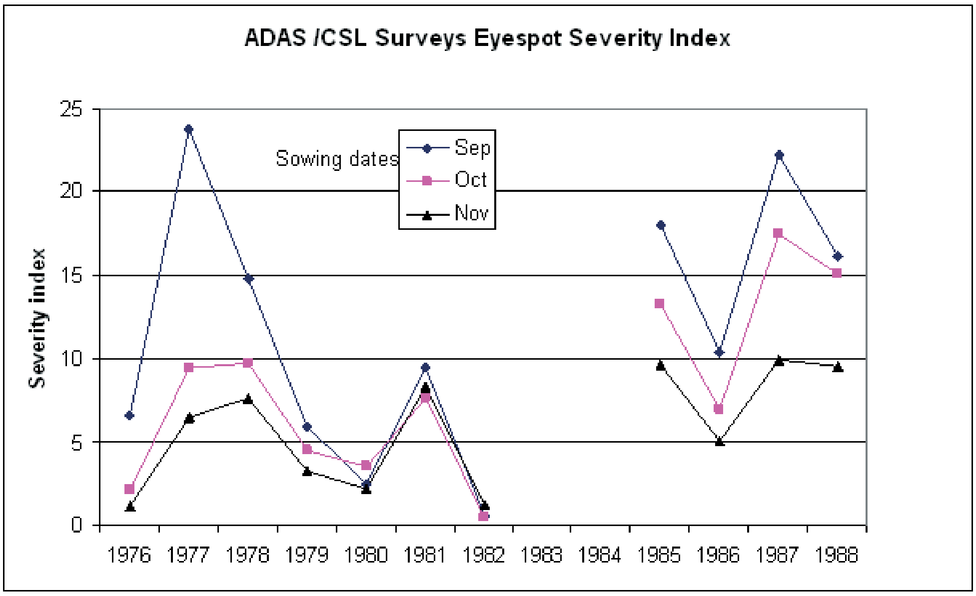

Figure 7.4: Results from ADAS/CSL survey on eyespot severity depending on sowing date (1976-1988)[10].

French trial data has also shown that the combination of previous crop and tillage methods can reduce the impact of eyespot (Figure 7.5). What can be seen here is that a preceding crop of maize controls eyespot much more efficiently than a fungicide application.

An important conclusion to be drawn when one compares results for fusarium and eyespot is that the preceding crop most favorable to a reduction of disease pressure for one disease may be least favorable for the other. This implies that there is no unique solution for controlling all diseases and that a global, systematic approach should be taken at the

cropping system level to reduce risk on the whole. This also implies that for certain situations growers need to be given the tools to evaluate with confidence whether or not they need to spray. This can be illustrated by an example of the eyespot risk assessment key (see Figure 7.6).

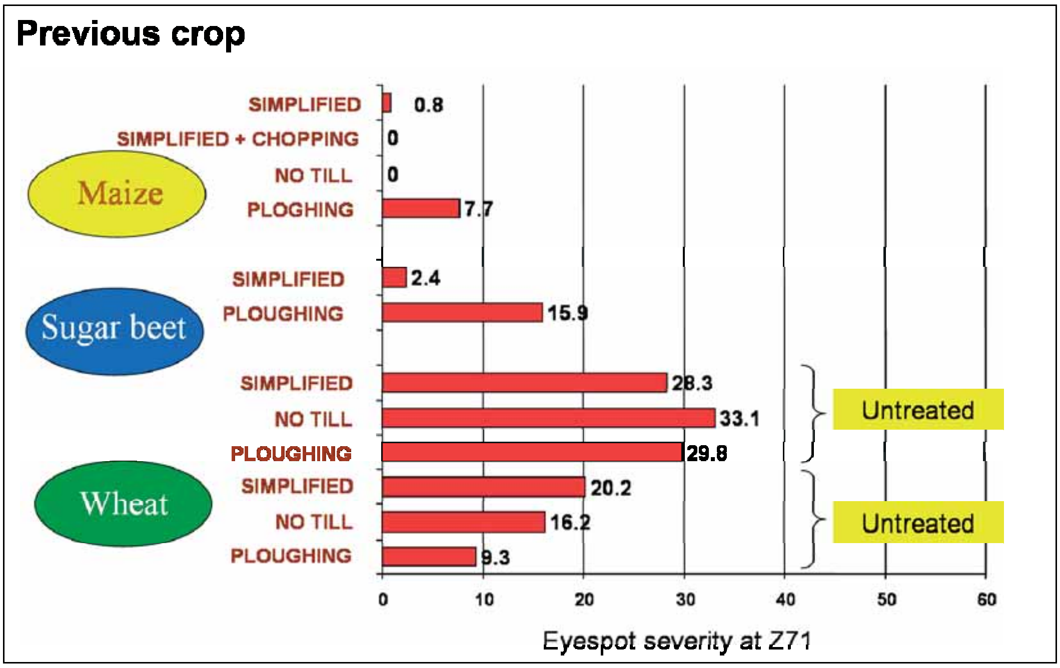

Figure 7.5: Eyespot severity depending on preceding crop and residue management at Boigneville in 2005.

Crop rotation and residue management

Tillage	Previous crop	Ante-previous crop	
All	Wheat	Wheat	4
No ploughing	Wheat	Other	4
Ploughing	Wheat	Other	3
Ploughing	Other	Wheat	3
No Ploughing	Other	Wheat	2
All	Other	Other	1

Soil type

Chalky	2
Loam	1
Others	0

Sowing date

Early *	2
Late *	1

* exact cutoff dates vary regionally

Cultivar resistance

1-2	2
3-4	1
5	-1
>6	-2

OVERALL SCORE

10, 9, 8 – **HIGH RISK :** Specific anti-eyespot spraying required

7, 6 – **MEDIUM RISK :** Field observation strongly advised

5, 4, 3, 2, 1, 0 – **LOW RISK :** No spraying required

Figure 7.6: Eyespot risk assessment key (SOURCE: Arvalis).

Factors influencing Fusarium head blight (French case)

Fusarium head blight has become a major concern in the past few years, as it is related to mycotoxin production, and European legislation has regulated the maximum allowed mycotoxin (DON) levels. It has been shown that combinations of agricultural practices can contribute to strongly reducing this risk, without use of fungicides.

Among these practices are those concerning management of inoculum at field level. This involves crop rotation and residue management, i.e. tillage practices. The figure below (Fig. 7.7) illustrates the fact that maize as the preceding crop strongly increases the risk of DON-contamination in the following wheat crop and that ploughing can contribute to reducing that risk.

Cultivar resistance to DON accumulation is also a key factor to reducing risk without fungicides: DON levels from the most susceptible to the most resistant cultivar can be reduced by a factor of 3 (Figure 7.8). These results are confirmed by a survey in 56 growers' fields in which risk levels (due to preceding crop and tillage) for DON were low, conducted from 2001 to 2003: mean DON levels between the best and worst cultivars varied by a factor of 8.

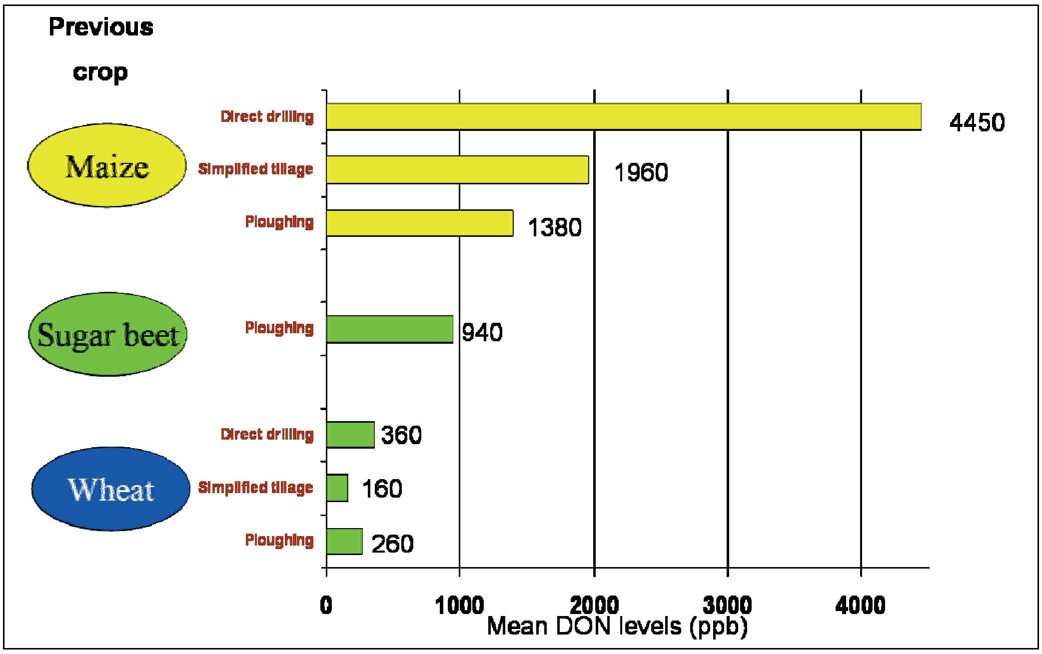

Figure 7.7: Mean DON levels for different preceding crops and tillage practices in Boigneville, France from 1999-2004.

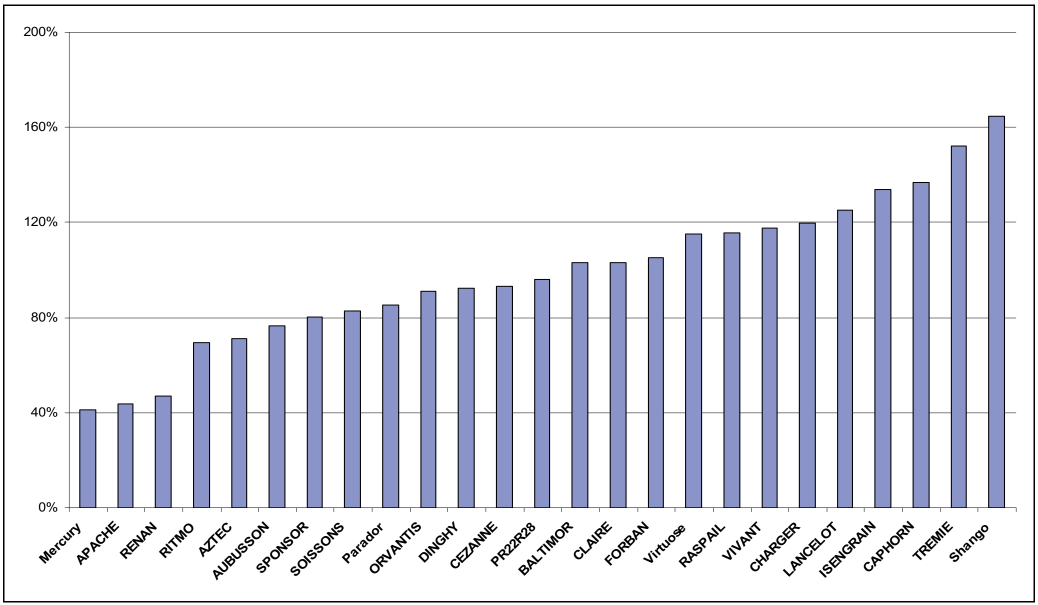

Figure 7.8: Mean levels (over 6 trials, 2001-2004, conducted with “facilitated infection”, i.e. spreading of maize residues, or artificial inoculation) of DON accumulation in cultivars as % of the median value.

The combination of these different results has led to the establishment of a decision key to aid in evaluating the risk level for DON in a given field (Figure 7.9). Through this we can see that a combination of agricultural practices can drastically reduce DON risk without use of fungicides. The quantification of these risk levels is represented in Figure 7.10.

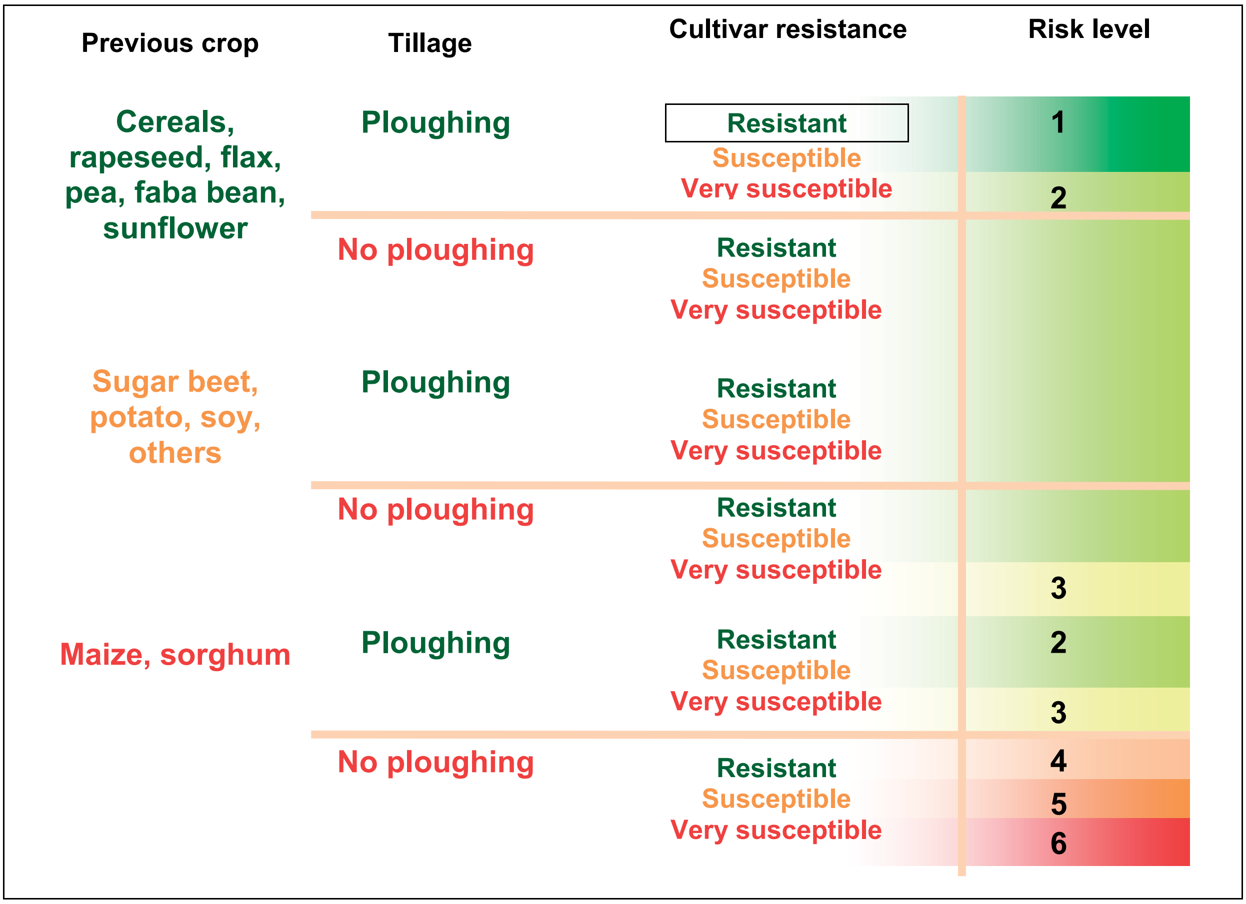

Figure 7.9: Decision key for DON risk.

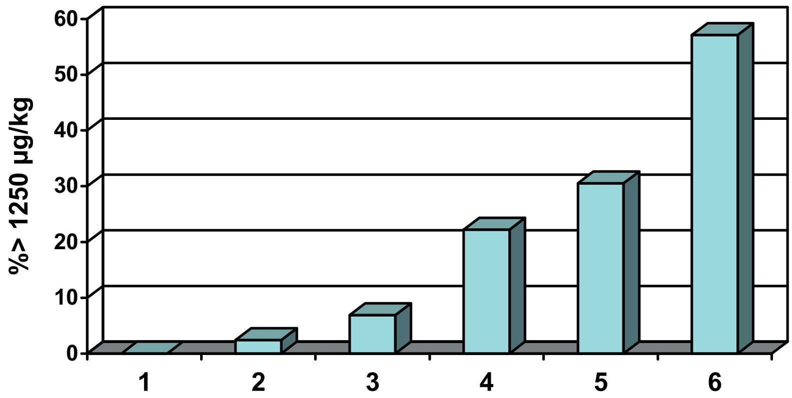

Figure 7.10: Probability of DON accumulation greater than 1250 ppb threshold depending on risk level (1292 fields surveyed from 2001 to 2004).

Factors influencing Septoria leaf blotch

Septoria leaf blotch is regarded as the most important disease in several of the major wheat producing countries in the EU. The disease is widespread and gives rise to significant attacks in most seasons. The severity depends to a great extent on the sowing date and the resistance level of the cultivar. The need for control is very closely linked to rain events and the level will typically increase if rain events are common during stem elongation and heading. The possibilities to reduce attack and fungicide input rely on regional severity factors. The best strategy to minimise fungicide dependency involves:

- Delayed sowing
- Choosing a resistant cultivar.
- Applying fungicides when control thresholds have been exceeded

The impact from use of resistant cultivars is described in Chapter 5 and the use of thresholds is given in more detail in Chapter 6.

Use of reduced fungicide rates

Whenever a fungicide is chosen it is of major importance to choose the most effective products as these in many cases have a great potential for being used at reduced or appropriate rates.

During the last 20 years, more than a 50% reduction in fungicide input in winter wheat has taken place in Denmark, mainly due to the use of appropriate and reduced dosages. Experiences from the Danish Pesticide Action plans, which aim at reducing pesticide input, have shown that it is important to support farmers' decisions with trial data and monitoring data and to convince them that they are making the right decisions. This is particularly important if the recommendation is not to spray. Often, the economic motivation for reducing fungicide input is rather limited, since dose-response curves have been found to be rather flat (Jørgensen *et al.,* 2003).

In order to predict the right fungicide input in a given field in a given cultivar and in a given season, prediction of yield responses to the treatments is required (Paveley, 1999). Although many studies of the *Septoria tritici* pathosystem have been carried out, there is still a need to improve the prediction of epidemic development. Paveley (1999) suggested that this should take place by integrating inoculum, host resistance and weather variables. Because all of

these factors are not yet fully elucidated, farmers and advisers will very often rely on experiences from field trials in previous seasons and “rules of thumb” when evaluating the need for input. Although this may not provide the most optimal answer, the robustness of dosages and strategies will usually protect the farmers against major economic losses (Jørgensen *et al*., 2003).

Trials in UK with different doses of fungicides have similarly shown that the preventive and curative effects of most fungicides vary significantly again indicating that it is very important to choose effective fungicides which have a higher potential for reducing the dose (Paveley & Clark, 2000; Clark, 2003).

Monitoring of diseases

The Danish Monitoring Network is an important tool when recommendations have to be adjusted and made during the season. Advisers report typically once a week about the disease incidence of powdery mildew and rust diseases in local fields. The method used for assessments are based on frequency of plants attacked in the fields. The data are separated for susceptible and more resistant cultivars to obtain as detailed a picture of the disease risk as possible. These data are summarised as a map of Denmark indicating the locations that currently need treatment and those that do not because disease levels do not exceed treatment thresholds for treatment (Jørgensen *et al*., 1996). The same thresholds and methods for assessments that are used in Crop Protection Online are applied in the monitoring system. The data are available on the Internet as well as in the farming press. An example of the map is shown in Figure 7.11.

Experience has shown that early fungicide treatments are often not cost-effective, and the monitoring network helps farmers and advisers in making decisions about such treatments. The data also make it possible to adjust recommendations quickly; for instance, if a new virulent strain of rust has been seen to be attacking new cultivars that previously have been found to be resistant. This was the case for yellow rust in the cultivar Robigus, which developed rust attack for the first time in 2007.

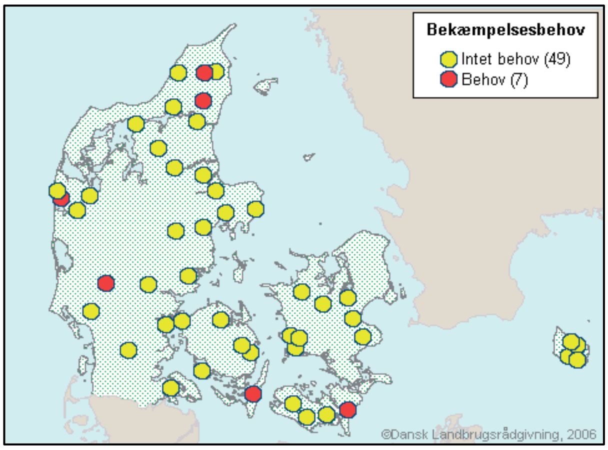

Figure 7.11: An example from the Danish Monitoring Network where assessments of the risk for powdery mildew in wheat are being assessed at weekly intervals. Frequency of plants with attack is assessed. The data are separated for susceptible and more resistant cultivars in order to get as broad a picture of the risk as possible. When the thresholds are exceeded in a field, the colour changes from yellow to red, which indicates that the farmers should be alert.

Optimising margin over fungicide cost

In recent years an increased focus has been given to calculate net yield (= margin over fungicide cost) rather than gross yield, when one analyses the benefit from using fungicides. As fungicide treatments are relatively expensive, it is important to deduct the cost of application when one calculats what is appropriate to apply. This is very important when one gives advice on optimal solutions.

In order to get a general picture of the benefit from applying fungicides in a region it is important to analyse historical trial data screening traditional control strategies. In Denmark the benefit from fungicide treatment is represented in yield terms, having deducted the equivalent yield necessary to cover the cost of fungicide and its application costs. Recent changes in the wheat price from 10 €/dt to 20€/dt has a major impact on the actual benefit. Included in the cost is also the cost of application of 10 €/ha.

The results shown in Figure 7.11 give examples from trial data in Denmark based on data from 1999-2003. In order to get the full benefit of such calculations data were subdivided into resistant and susceptible cultivars. Based on the data a model was developed which handles dose-response functions for fungicides control strategies with respect to timing, active ingredients and doses. A control profile was addressed including five different timings of application, A-E, defined by the winter wheat growth stages (GS) (Zadoks *et al.*, 1974); A: GS 25-31, B: GS 32-36, C: GS 37-50, D: GS 51-64 and E: GS 65-70. In this way, a split strategy with applications in GS 37-39 and 51-54 is called CD.

Benefit from different timings and strategies

In the analysis of the data, it was possible to extract the benefit from single treatments applied at different timings (Figure 7.11). In both susceptible and resistant cultivars, treatments C and D, covering the period from GS 37 to 65, were the most beneficial with a small advantage to treatments at GS 37-51. The very early treatment (GS 25-31) was the least economic giving negative net returns in resistant cultivars and very low returns in susceptible cultivars. The treatments during stem elongation (GS 31-37) or very late (GS 65-71) were similarly beneficial. The optimum net yield gain at a grain price of 10 € per dt was approximately 6 dt/ha in resistant cultivars and 9.5 dt/ha in susceptible cultivars.

When we compared different control strategies in Denmark, it was found that most of the strategies gave very similar benefits. In the most susceptible cultivars the strategy CD with two sprayings was found to be the most efficient strategy. The highest average net yield gain, close to 10 dt/ha, was obtained by using half a standard dose of fungicides, equivalent to a treatment frequency index (TFI) of 0.5. The net yield gain was almost unaffected by the dose in the interval between 0.4 and 0.75 TFI. A single treatment C or a split strategy BCD was almost as efficient as the two-spray strategy. In the resistant cultivars, strategies D or CD proved most economic with a TFI optimum around 0.4 TFI (Figure 7.13). For this group it was seen that the net yield did not vary significantly in the interval between 0.30 and 0.65 TFI.

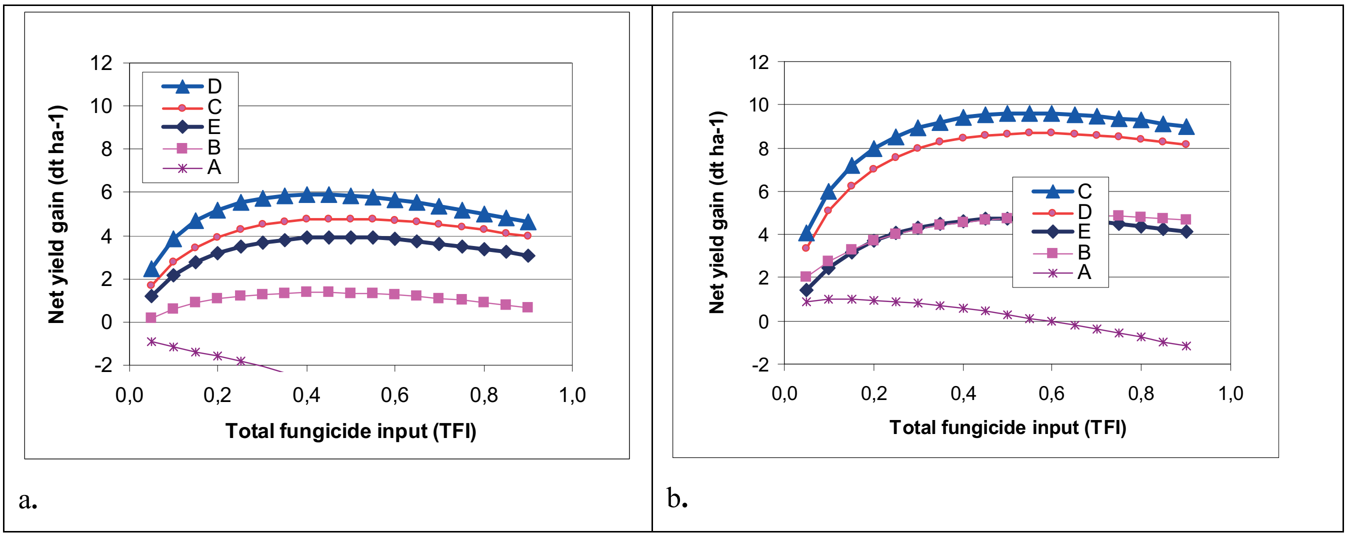

Figure 7.12: Average estimated net yield increase (dt/ha) from different timings and input of fungicides in resistant cultivars (a) and susceptible cultivars (b). Calculated for the Sjælland region in the period 1999-2003. The legends are ranked according to the most beneficial solutions.

Impact of grain price on fungicide optimum

The grain price is known to fluctuate between seasons and recently the grain price has increased significantly. In 2007 the grain price is about double the price level of 2003-2006. An increased wheat price has a significant effect on optimal fungicide strategies and input. In the case of a higher wheat price (20 € per dt), the BCD strategy becomes slightly more efficient than the CD strategy in the most susceptible wheat cultivars (Figure 7.13), and the most efficient total fungicide input is increased by 50% from 0.5 TFI to 0.75 TFI.
At higher wheat prices the relative fungicide costs decrease, and even in case of no strategy or dose adjustment the net yield gain increases by more than 2 dt/ha.

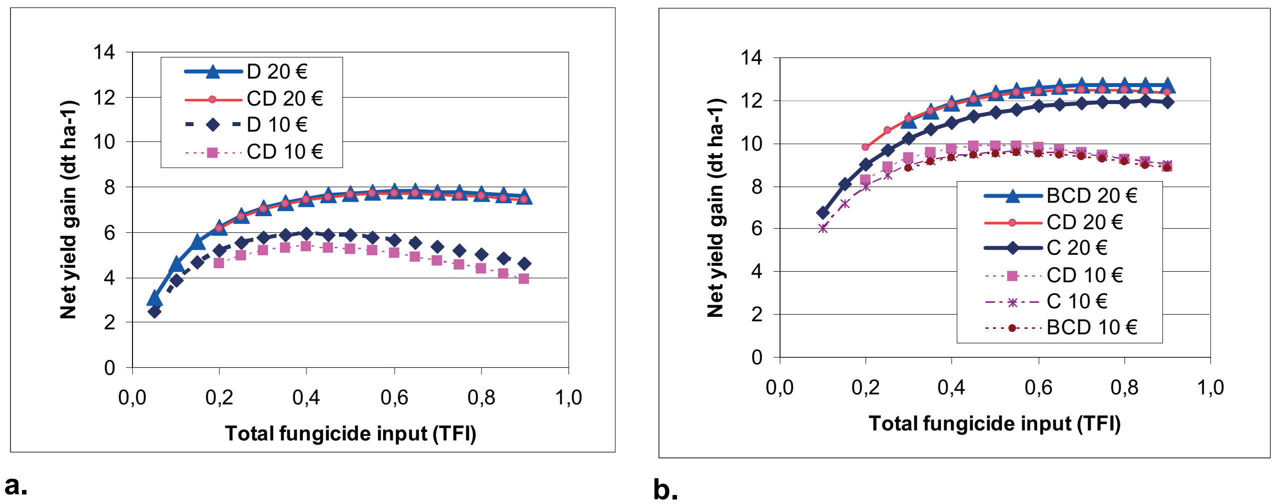

Figure 7.13: Calculated net yield gain in winter wheat in resistant (a) and susceptible cultivars (b) for selected strategies using two prices for grain. Based on data from the Sjælland region 1999-2003. The legends are ranked according to the most beneficial solutions.

In the case of higher wheat price (20 € per dt) the D strategy is still the most efficient strategy in the most resistant wheat cultivars (Figure 7.12), but also here the most efficient fungicide

dose is increased by 50% from 0.45 TFI to 0.65 TFI. And the CD split strategy becomes almost as efficient as the D strategy.

Unfortunately the wheat price is often not known at the time of application but farmers will act according to given expectations. The fluctuation in price is partly accounted for by the fact that most farmers act conservatively and choose a dose slightly higher than the optimal dose.

Optimising input from the UK and France

In a similar way a calculation of the optimal fungicide input based on historical data was done in the UK and France. In the example from the UK calculations were separated depending on cultivar resistance. The optimal input in susceptible cultivars was about the double amount compared to using a resistant cultivar (Figure 7.14).

A B

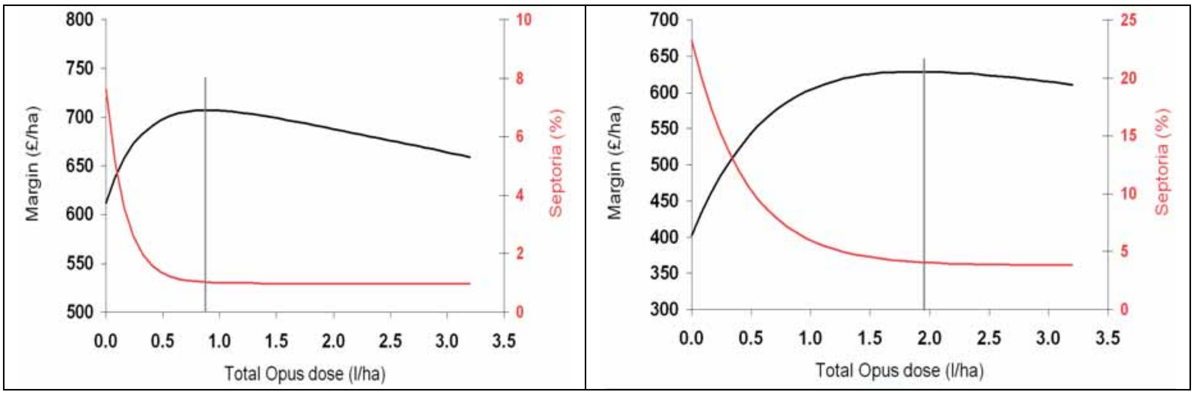

Figure 7.14: Fungicide requirement at economic optima for disease resistant (A) and disease susceptible (B) cultivars. Examples from the UK.

In France the optimal economic input of fungicides from fungicide strategies were calculated and ranked according to the expected yield loss from diseases and the expected grain price (Figure 7.15). Similar to the Danish case the input increases significantly once the grain price increases.

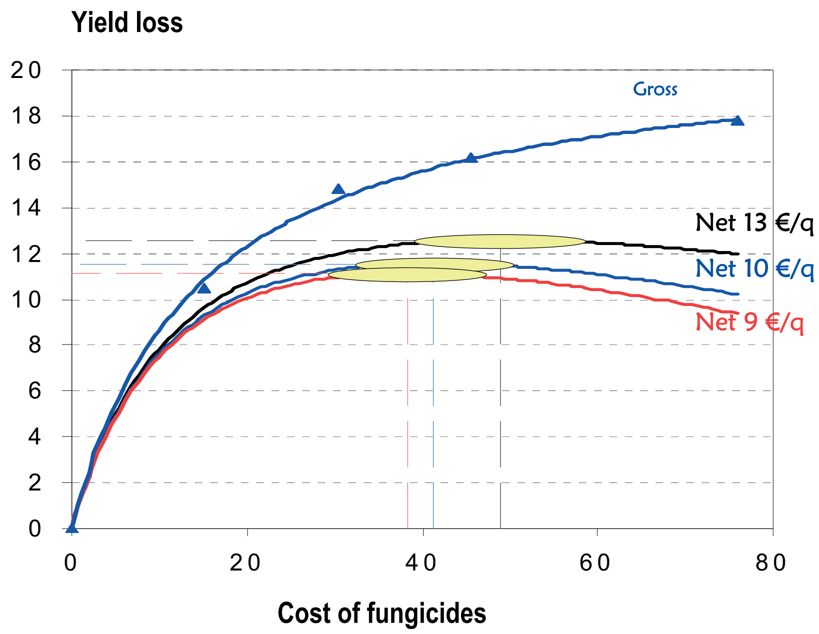

Figure 7.15: French example of optimising fungicide input using 3 different grain prices.

Use of genetic resistance

The benefits from using resistant cultivars have generally been described in chapter 5. So a major scope for better exploitation of genetic resources should be focused on. Resistant cultivars will, however, not solve all problems, as the stability of resistant genes are gradually changed over time

Particularly in relation to occurrences of yellow and brown rust diseases, it is well known that resistant cultivars can completely eliminate the risk from these diseases. This is not seen to the same extent with diseases like powdery mildew, septoria leaf blotch, tan spot and Fusarium head blight, where often only moderate levels of resistance are seen.

Use of cultivar mixtures

Use of cultivar mixtures has been quite common in barley production but less so in wheat. Cultivar mixtures can limit the spread of pathogens that have an airborne dispersal phase and cause polycyclic epidemics (powdery mildew, rusts, septoria leaf blotch). In the case of rusts and powdery mildew, most resistance is complete for a given race of fungi, and mixtures can reduce diseases severity by 40 to 90% compared to the mean of the pure stands (de Vallavieille-Pope, 2004). In the case of septoria leaf blotch, most cultivar resistance is partial, and there is a great degree of genetic diversity in the pathogen population. Mixtures are therefore less efficient at reducing disease severity.

In France an experiment was therefore set up to test whether this cultural practice could be useful for bread wheat. A series of on-farm experiments, totalling 28 environments on 260 ha, tested four different four-cultivar bread wheat mixtures and the associated pure stands over a three-year period. The integrated crop management system aimed at using 30% less input than the system generally practiced in the region. Only one foliar fungicide spray was applied in most of the environments. On average, 6% septoria leaf blotch severity was

observed in the mixtures compared to the mean of the pure stands; yield was increased by 0.32t/ha and protein content by 0.54%. Baking quality of the mixtures was equal to that of the means of the pure stands (de Vallavieille-Pope, 2004).

In general, yield stability is higher in cultivar mixtures than in pure stands, but the practical use of cultivar mixtures is still limited. In France, cultivar mixtures are not yet accepted but in Denmark the area grown with variety mixtures was 11% in 2007 and 8% in 2008. In Denmark most of the wheat is used for feeding pigs and there the farmers have not seen any obstacles when either selling or feeding the crops directly to the pigs.

In the UK there is great reluctance to the use of cultivar mixtures, largely driven by market demand which has very specific quality requirements, even for feed wheat.

Dissemination

A tradition for strong collaboration between agricultural scientists and people in the Agricultural Advisory Service, enabling swift communication of research results to end users is very important when optimising inputs. The yearly updates need to include factors like: ranking of cultivar resistance, adjustments of thresholds, adjustment of optimal input and recommendations of the most effective fungicides.

Disease risks and recommendation for control measures should be sent out to the farmers in newsletters or in other media during the growing season. Several countries run monitoring systems during the season making sure to update new information on disease risk at weekly interval via the Internet or in the farming press.

Recent studies have focused on the major problems related to reaching the farmers and getting them to adopt the existing methods and information made available by scientists and advisers (Jørgensen *et al*., 2008). The problems seem to be closely related to lack of time for detailed assessments and difficulties in overcoming the management-related barriers which can be linked to the problems of handling very big farms with little time for each field or main interest from the farmers in for example animal production.

8. Results from field trials

During the wheat case study trials were carried out in Denmark and in France. In both countries the trials were part of a longer series of trials investigating the possibility to optimise and minimise the dependency on fungicides.

Due to the short life of the case study France and Denmark combined their trial activities with already ongoing activities, as it was not possible to sow new trials at the time when the project was initiated. The advantage of this process is that results both in France and Denmark can benefit from previous years' experiences with the same kind of trial objectives.

Trials will be represented from 3 major trials series. One carried out by INRA, one by Arvalis and one by the University of Aarhus.

Results from Arvalis trials

Effects of wheat price on economic optimum for fungicide use
Emphasis on net yield instead of gross yield is often considered a way to achieve reduction in fungicide use while maintaining or increasing farmer revenue. In past years, relative stability of wheat prices allowed for relatively stable recommendations to farmers. However, 2007 saw a large increase in wheat prices, which went from 150 $/t to over 350 $/t[9] from July 2006 to July 2007. The impact of wheat prices on the economic optimum for fungicide input needs to be assessed to renew recommendations to farmers and also to evaluate how potential reductions in fungicide use can be affected by the economic context.

Materials and methods
45 fungicide trials over 3 years (2005, 2006 and 2007) were analysed for this study. Their locations are summarised below.

Table 8.1: Number and location of trials (2T = trials conducted with 2 sprayings; 3T = trials conducted with 3 sprayings)

Year	Number of trials	Average fungicide response (dt/ha)	Location (department numbers)
2005	20	19.6	2T : 24-47-3-21-22-56-41-77-27-69-39-52-54-55 3T : 51-10-80-76-14-77
2006	16	18.9	2T : 3-41-45-18-1-21-22-55-56 3T : 51-51-80-77-76-27-27
2007	9	28.4	2T : 52-55-55 3T : 51-51-80-76-14-77

Trials were conducted according to local agricultural practice with 3 replicates. Depending upon the region, 2 or 3 fungicide treatments were applied, according to recommended practice in the region. 5 fungicide treatments were applied. In all 3 years, the best technico-

[9] Euronext

economic reference for foliar treatments was used: in 2005 and 2006, epoxiconazole[10] (no fungicide, epoxiconazole 0.2 l/ha/spraying, epoxiconazole 0.4 l/ha/spraying, epoxiconazole 0.6 l/ha/spraying, epoxiconazole 1 l/ha/spraying) and in 2007 epoxiconazole[2] + prochloraz[11] (no fungicide, epoxiconazole 0.2 l/ha + prochloraz 0.7l/ha/spraying, epoxiconazole 0.4 l/ha + prochloraz 0.7 l/ha/spraying, epoxiconazole 0.6 l/ha + prochloraz 0.7 l/ha /spraying, epoxiconazole 1 l/ha + prochloraz 0.7 l/ha /spraying)[12]. Different cultivars were used, so as to be adapted to local conditions. This also allowed for a wide range of fungicide responses to be explored. Net yield was calculated using the following prices for fungicide inputs: 38 €/l for epoxiconazole and 11 €/l for prochloraz. A dose-response curve to fungicide input was fitted to net yield against fungicide input using Monod's model[13] for each trial under different wheat price hypotheses. Optimum fungicide input was then calculated as dose maximising the fitted curve multiplied by fungicide prices above. Regression lines were fitted for optimum fungicide input against fungicide response (difference between gross yield at full dose and gross yield without fungicide) for the 45 trials was fitted, under 3 of the different wheat price hypotheses, and the significance of differences between these regression lines was tested through covariance analysis using R language and environment for statistical computing[14].

Results

Figure 8.1 illustrates optimum fungicide input against fungicide response for 3 wheat price hypotheses (10, 17 and 20 €/dt) for the 45 trials, as well as the regression lines.

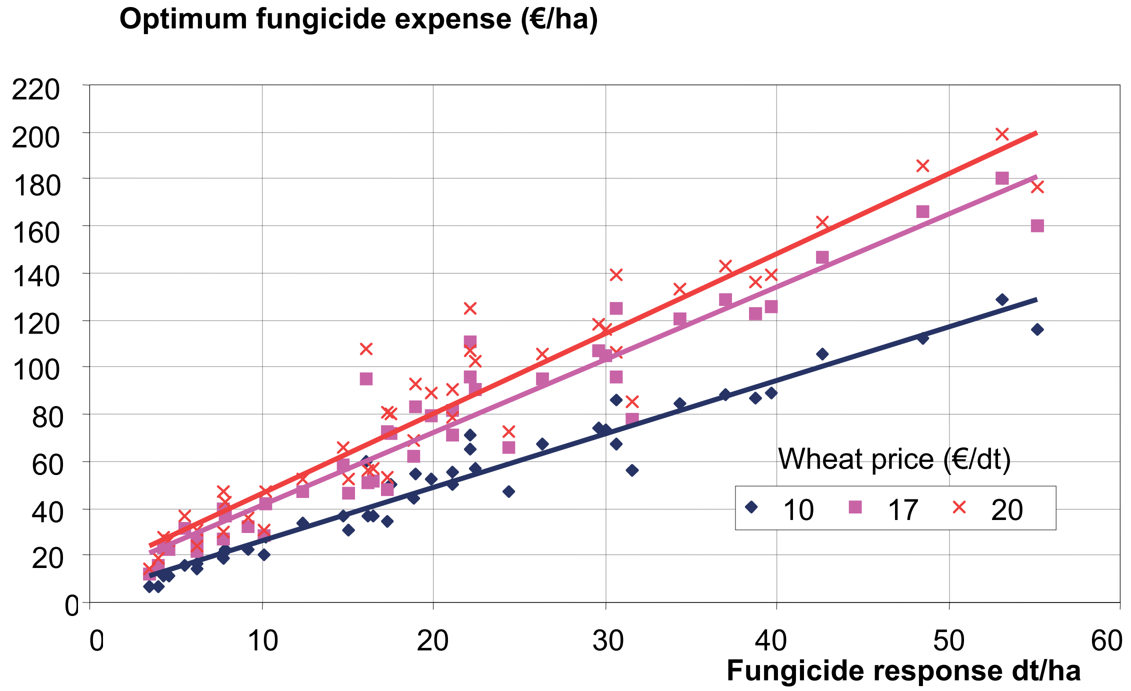

Figure 8.1: Optimum fungicide expense as a function of fungicide response in 45 trials conducted in 2005, 2006, and 2007 in France, using 3 different hypotheses for wheat price.

Figure 8.1 shows that optimum fungicide expense varies strongly depending upon wheat price. For a foliar disease pressure amounting to a fungicide response of 20 dt/ha, optimum

[10] Opus, BASF
[11] Pyros, BASF
[12] For trials with 3 sprayings, 3rd spraying was done with epoxiconazole alone
[13] Henriot F. (2001) « Modélisation des risques de maladies sur blé tendre en vue de l'élaboration d'un outil d'aide à la décision » , Master's thesis; ITCF, INA P-G
[14] R Development Core Team (2007). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

fungicide expense goes from 50 to 70 to 80 €/ha as wheat prices increase from 10 to 17 to 20 €/dt.
Covariance analysis reveals that interaction between fungicide response and wheat price is significant with a p-value of $3.35*10^{8}$. The following table summarises for a range of wheat prices the slope between fungicide response and optimum fungicide expense.

Table 8.2. For a range of wheat prices, the slope between fungicide response and optimum fungicide expense was calculated

Wheat price	Slope
9 €/dt	2.1289
10 €/dt	2.2687
11 €/dt	2.4017
12 €/dt	2.5288
13 €/dt	2.6506
14 €/dt	2.7679
15 €/dt	2.8811
16 €/dt	2.9905
17 €/dt	3.0966
18 €/dt	3.1996
19 €/dt	3.2998
20 €/dt	3.3973
21 €/dt	3.4925
22 €/dt	3.5854

Conclusion from Arvalis trials
Fungicide response can be considered a proxy for disease pressure in a given field. The stronger the disease pressure (due to the year's climatic conditions, but also cultivar choice and other crop management strategies), the higher the optimum fungicide use will be. What can be seen in this study is that optimum fungicide use, from a microeconomic point of view, is also strongly influenced by wheat prices: fungicide use becomes more profitable as wheat prices increase.

This has a number of consequences. First of all, if commodity prices are maintained at higher levels than in past years, this means that adjusting fungicide use by reasoning on net yield gains instead of gross yield gains will not allow as strong a reduction in fungicide use than it could be foreseen under low wheat price regimes. Secondly, if commodity prices become more unstable in coming years, it will be very difficult for growers and advisers to correctly react to both varying disease pressure and varying wheat prices from year to year. If emphasis on net yield is to be used as a major means of reducing fungicide input, stability of wheat prices needs to be addressed. Finally, if uncertainty on prices increases, it may be imagined that reducing variation in overall disease pressure could be a solution. This can only be achieved by using a reasoned combination of cropping techniques, adapted to local conditions, including overall pest (diseases, insects, weeds, etc.) pressure.

Results from INRA - cultivars performance in different cropping systems

Background
In France, breeding winter wheat for resistance to major diseases has received higher priority within the past fifteen years. Based on the winter wheat cultivars coming from these programmes, integrated low-input strategies have been developed. Previous INRA and Arvalis Institut du Végétal studies (2000-2006) showed it is relevant from an economic point

of view to grow cultivars totally or partially resistant to diseases and lodging under low input strategies, although yield might be reduced due to lower level of inputs.

The level of reduced cost crop management is entirely in the hands of the user: choice of cultivar, lower sowing density and zero nitrogen fertilisation at the tillering stage make it possible to reduce fungicide applications and to reduce the use of growth regulators. If density and nitrogen fertilisation are not reduced, then the farmer cannot afford to reduce growth regulator use.

Therefore, choosing the right cultivar is a strategic choice which must be made ahead of the sowing season.
The key to success lies in a judicious combination of input reductions: lower sowing density means less biomass to feed at the tillering stage. As a result, nitrogen fertilisation can be cut out without too much damage at that stage. The combination of those two decisions leads to less competition between the plants and an environment which does not stimulate disease development. As a result the growth regulator is not needed and the pressure from disease is reduced: in all cases, from the North to the South of France, all that is required is a fungicide application at the flag leaf stage. The nitrogen saved at the tillering stage is not transferred to later stages but truly saved: nitrogen fertilisation consists of one single dose, around thirty units lower than the normal dose (dose X-30, X being the amount calculated using the nitrogen balance method), spread from the beginning of the stem elongation period to the boot swelling stage. Provided the above nitrogen split is respected, protein content is stable or drops very slightly compared to when traditional crop management methods are implemented. The choice of cultivar remains far more crucial than the choice of crop management style.

Material and methods
The aim of the 2006-2007 INRA study was to examine adaptation of a large range of new cultivars, different for resistance to diseases and lodging, within the context of integrated crop management.
We carried out a multi-environment experimental network to test cultivars within three rule-based crop management plans (Tables 8.3a and 8.3b). Rule-based crop management plans (ITK) were defined, with a decrease in input level from ITK2 (regional advice on high input management of wheat), ITK3 (integrated low input crop management plan) to ITK4 (extremely low input system with no fungicide protection, no plant growth regulator applications, as well as a decrease in N fertiliser quantity by 60 kg/ha as compared to ITK2). The multi-environment experimental network comprised two or three combinations of cultivars and crop management systems (Figure 8.2).
21 cultivars were grown under each crop management plan with two replications (table 8.4). Plots were assessed for earliness, diseases, lodging, ear density, yield and grain quality traits as protein content and hectolitre weight (Table 8.5).

Table 8.3a: Expected crop management systems

CM	*sowing density* [a]	*expected yield*	*Nitrogen*	*N* [d]	*growth regulator* [d]	*fungicide* [d]	*herbicide* [d]
ITK2	250	median potential yield[b]	balance-sheet [c]	3	1	2	1
ITK3	150	ITK2-1t.ha-1	ITK2 - 30	2	0	1	1
ITK4	150	ITK2-2t.ha-1	ITK2 - 60	2	0	0	1

[a] sowing density (grains.m^{-2}) [b] median of the distribution of regional potential yields over a set of prior years
[c] total quantity N fertilizer adjusted according to the balance-sheet method (Rémy and Viaux, 1982)
[d] number of applications between sowing date and harvesting time

Table 8.3b: Effective crop management systems

location	*crop system*	*previous crop*	*sowing rate* [a]			*mineral N in soil* [b]	*N fertilisation*			*fungicide* [d]		
			ITK2	*ITK3*	*ITK4*		*ITK2*	*ITK3*	*ITK4*	*ITK2*	*ITK3*	*ITK4*
Estrees-Mons	cash crops	peas	250	150	150	100[c]	170	110	110	3	1	0
Le Moulon	cash crops	oats	220		130	70	150		100	4		0
Lusignan	cash crops	maize (silage)	240		150	45	200		150	2		0
Rennes	cash crops	faba bean	150-250			70	100	70	40	3	1	0

[a] seeds/m² [b] residual mineral N in the soil after winter
[c] N kg/ha [d] number of applications

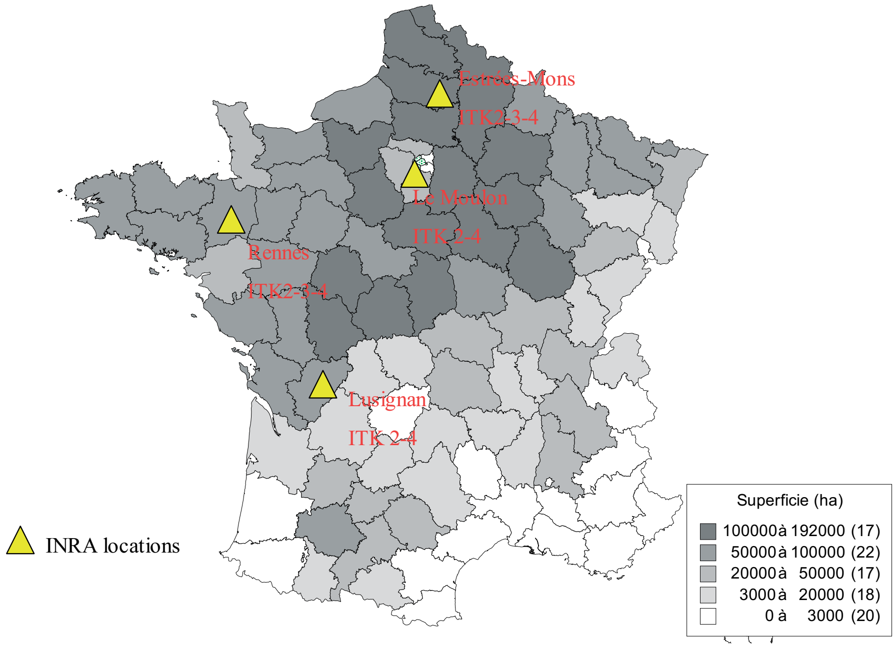

Figure 8.2: INRA trial network 2006-2007.

Table 8.4: Cultivars 2006-2007

Table 8.5: Traits analysed in experiments

			EM	LM	LU	RE
symbol	Trait	zadoks scale	Estrées-Mons	Le Moulon	Lusignan	Rennes
yield	yield dt/ha 15%H2O		+	+	+	+
%H2O	% water in kernel		+	+	+	+
TKGW	thousand kernel weight 15%H2O			+	+	+
HLGW	hectolitre weight (kg/hl)		+	+	+	+
PROT	protein content %		+	+	+	+
EPIA	ear emergence	55	+	+	+	+
Yrust[a]	stripe rust (*Puccinia striiformis*)	71	+	+		+
Brust[a]	leaf rust (*Puccinia recondita*)	71	+	+	+	+
SEPB[a]	septoria leaf blotch (*Septoria tritici*)	71		+		+
lodg[a]	lodging	77		+	+	+
ears/m²	numbers of ears per m²	77		+	+	
haut	plant height cm	77		+	+	+

[a] 1=none, 9=totally diseased or lodged

Results
Climatic conditions for the North of France in 2006-2007 were characterised by a mild winter, warm and dry beginning of spring (March, April), followed by rain and cold (for the season) temperatures until harvest.
For the first time, since 2000, disease pressure (*Septoria tritici*, brown rust, yellow rust, fusarium head blight, eyespot) was very high in 2007. According to Arvalis analytic trials, which were managed in high input conditions, yield loss comparing cultivars in treated and untreated (i.e. without fungicide) was 25 dt/ha while the average national yield was 64 dt/ha.

Table 8.6: Mean values for all analysed traits related to yield

Estrées-Mons	*CM*	*yield* [a]	*S.D.* [a]	*protein* [b]	HLGW[c]	TKGW[d]
	ITK2	78,7	3,08	11,7	75,4	
	ITK3	73,6	2,93	12,0	76,1	
	ITK4	56,2	2,56	12,5	70,5	

[a] dt/ha [b] protein content % [c] kg/hl [d] g

Le Moulon	*CM*	*yield* [a]	*S.D.* [a]	*protein* [b]	HLGW[c]	TKGW[d]
	ITK2	106,9	2,38		65,3	51,5
	ITK4	82,0	3,64		63,9	48

Lusignan	*CM*	*yield* [a]	*S.D.* [a]	*protein* [b]	HLGW[c]	TKGW[d]
	ITK2	79,2	2,75	11,6	75,8	49,8
	ITK4	50,8	2,32	10,8	70,8	40

Rennes	*CM*	*yield* [a]	*S.D.* [a]	*protein* [b]	HLGW[c]	TKGW[d]
	ITK2	79,4	5.9	12,4	73,7	41,0
	ITK3	80,9	3,7	13,1	72,8	38,4
	ITK4	64,3	2.8	13,3	69,7	33,2

The data sets comprise results from experiments performed according to two or three crop management plans over four sites (Table 8.6). The analysis is based on disease development throughout the season, yield and grain protein content at harvest for each management strategy.

Compared to results obtained with recommended (ITK2) fungicide protection combined with non-disease resistant cultivars, diseases such as brown rust (*Puccinia triticina*) or Septoria leaf blotch (*S. tritici*) were partially controlled when disease resistant cultivars were associated with low-input crop management plans (Figures 8.3 and 8.4). For instance, in Lusignan, yield loss varied from 15 dt/ha with resistant genotypes (Attlass and Toisondor) to 45 dt with susceptible one (Dinosor, Royssac and Orvantis). Diseases were among the most yield influencing characters. In Rennes we observed a relatively close relationship between susceptibility to *Septoria tritici*, brown rust and yield (Table 8.6). As expected, the effect of crop management is far more important for susceptible cultivars than for resistant cultivars. Consequently, growing a cultivar with a resistance rating of 8 under a low input management (ITK4) resulted in Septoria and brown rust severities similar to a sensitive cultivar (resistance rating of 3) under a high input management (ITK2).

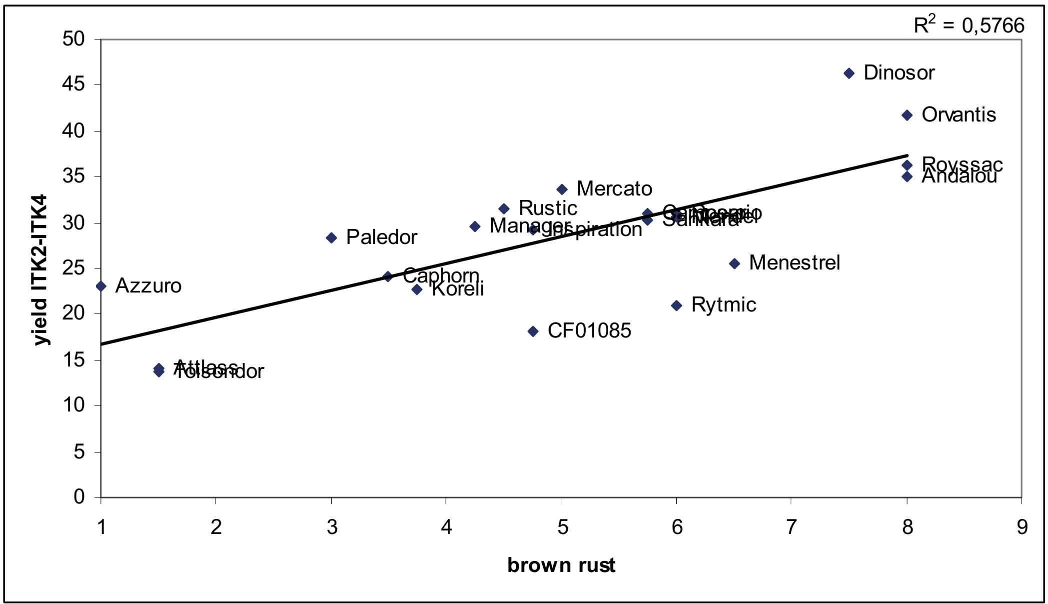

Figure 8.3: Yield loss (dt/ha) due to brown rust in Lusignan.

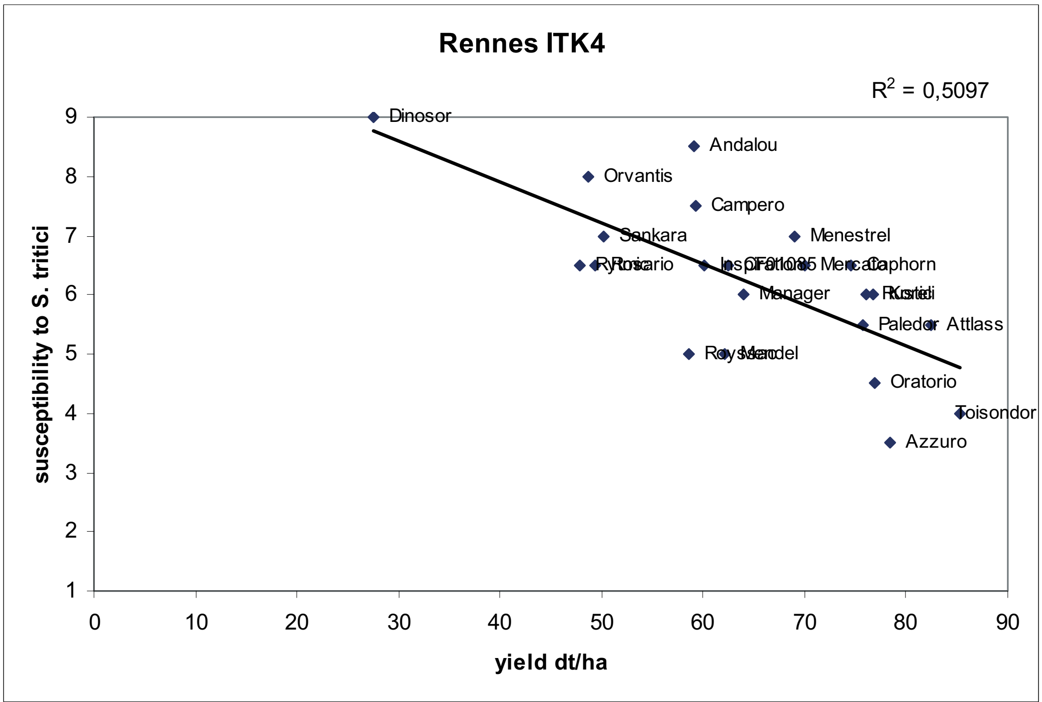

Figure 8.4: *Septoria tritici* severity (1-9 scale) without fungicide in ITK4 in Rennes. Ingen teksthenvisning

Table 8.7: Correlation coefficient between traits analysed in Rennes

	yield	*H2O*	*proteins*	*HLGW*	*TKGW*	*heading date*	*yellow rust*	*brown rust*	*S.tritici*	*lodging*	*height*
yield	1										
H2O	0,490	1									
proteins	**-0,585**	-0,439	1								
HLGW kg/hl	0,706	0,683	**-0,470**	1							
TKGW	0,686	0,582	-0,567	**0,576**	1						
heading date	-0,288	0,022	0,240	-0,103	-0,142	1					
yellow rust	-0,006	-0,170	-0,180	-0,153	-0,110	-0,235	1				
brown rust	**-0,510**	-0,573	0,452	-0,504	**-0,615**	-0,121	-0,003	1			
S. tritici	**-0,634**	-0,667	0,574	-0,693	**-0,730**	-0,163	0,041	0,728	1		
lodging	0,032	0,029	0,067	-0,089	0,082	-0,498	0,021	0,005	0,237	1	
height	-0,173	0,236	0,216	0,215	-0,032	0,633	-0,290	-0,077	-0,093	-0,285	1

Combined effects of crop management and cultivar type impact on disease severity: The damage caused by Septoria leaf blotch increased with decreasing resistance ratings and when cultivars are grown under low input crop management (ITK4). Stronger Genotype x Management interaction was observed for brown rust. However, average yield losses were higher for ITK4 with the cultivar type susceptible to diseases than for ITK3 and ITKT2. Disease intensities increased when the level of inputs was lowered. As a result, the fungicide protection appeared to be more effective than the decrease in both sowing densities and N fertilisation to control diseases. However, we can assume that reductions in sowing density and fertilisation rate contributed to lowering the yield loss due to the suppression of fungicide application in ITK4. Effect of foliar diseases on yield components is shown by the observed difference in thousand kernel weight when comparing ITK3 and ITK4 in the Rennes situation (Figure 8.4).

As input levels were lower, average yield obtained under ITK3 or ITK4 systems were significantly reduced, from 20 to 40% according to locations compared with those obtained under ITK2 crop management plan.
As shown in the Estrées-Mons results (Figure 8,5) interactions between cultivar and crop management were observed for septoria leaf blotch, brown rust and yellow rust intensities. Cultivars ranked differently in high inputs (ITK2) compared to low inputs management without any fungicide (ITK4).

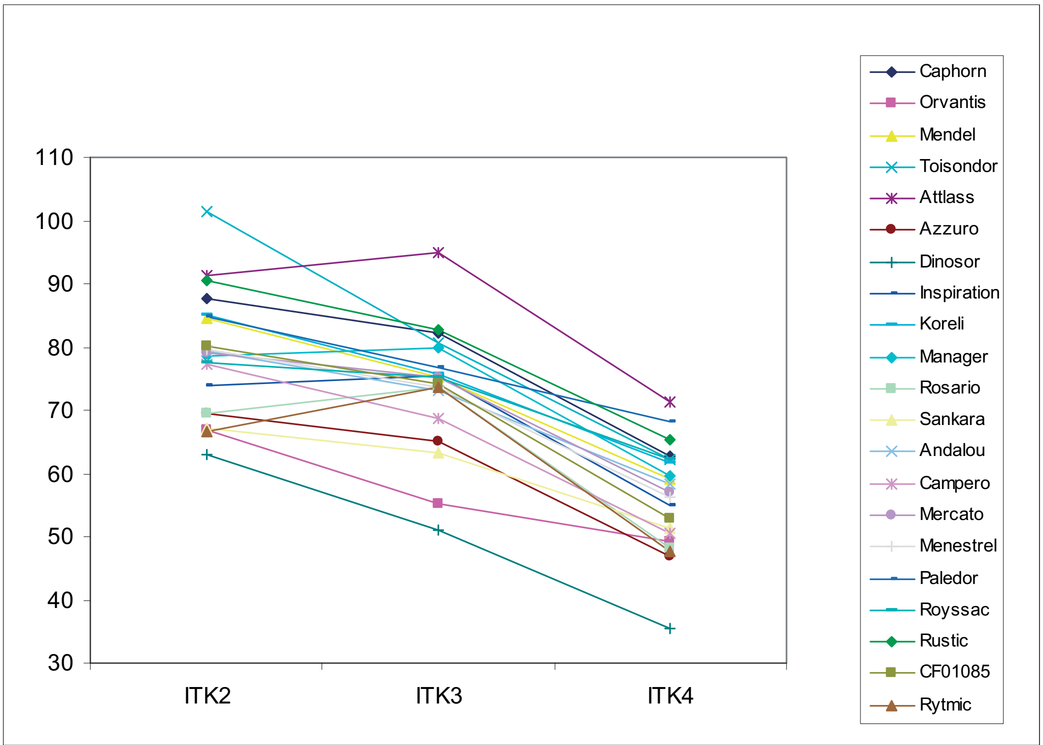

Figure 8.5: Cultivars ranking for yield in Estrées-Mons.

The mean yield results of 21 genotypes are highly correlated between locations in very low inputs (ITK4 and also ITK3) due to the fact that the most important annual limiting factor, disease pressure, is common in all sites (Table 8.8).

The yield reduction from ITK2 to ITK4 resulted from the decrease of inputs, especially in ITK4 (susceptible to diseases). Interaction between cultivar and crop management were identified for lodging, septoria leaf blotch, brown rust and yellow rust intensities.

Table 8.8: Correlation coefficient between yield in 3 crop management plans

ITK2	*Estrées-Mons*	*Le Moulon*	*Lusignan*	*Rennes*
Estrées-Mons	1			
Le Moulon	0,180	1		
Lusignan	0,391	0,373	1	
Rennes	0,212	0,013	0,139	1

ITK4	*Estrées-Mons*	*Le Moulon*	*Lusignan*	*Rennes*
Estrées-Mons	1			
Le Moulon	0,724	1		
Lusignan	0,732	0,885	1	
Rennes	0,786	0,860	0,917	1

ITK3	*Estrées-Mons*	*Rennes*
Estrées-Mons	1	
Rennes	0,583	1

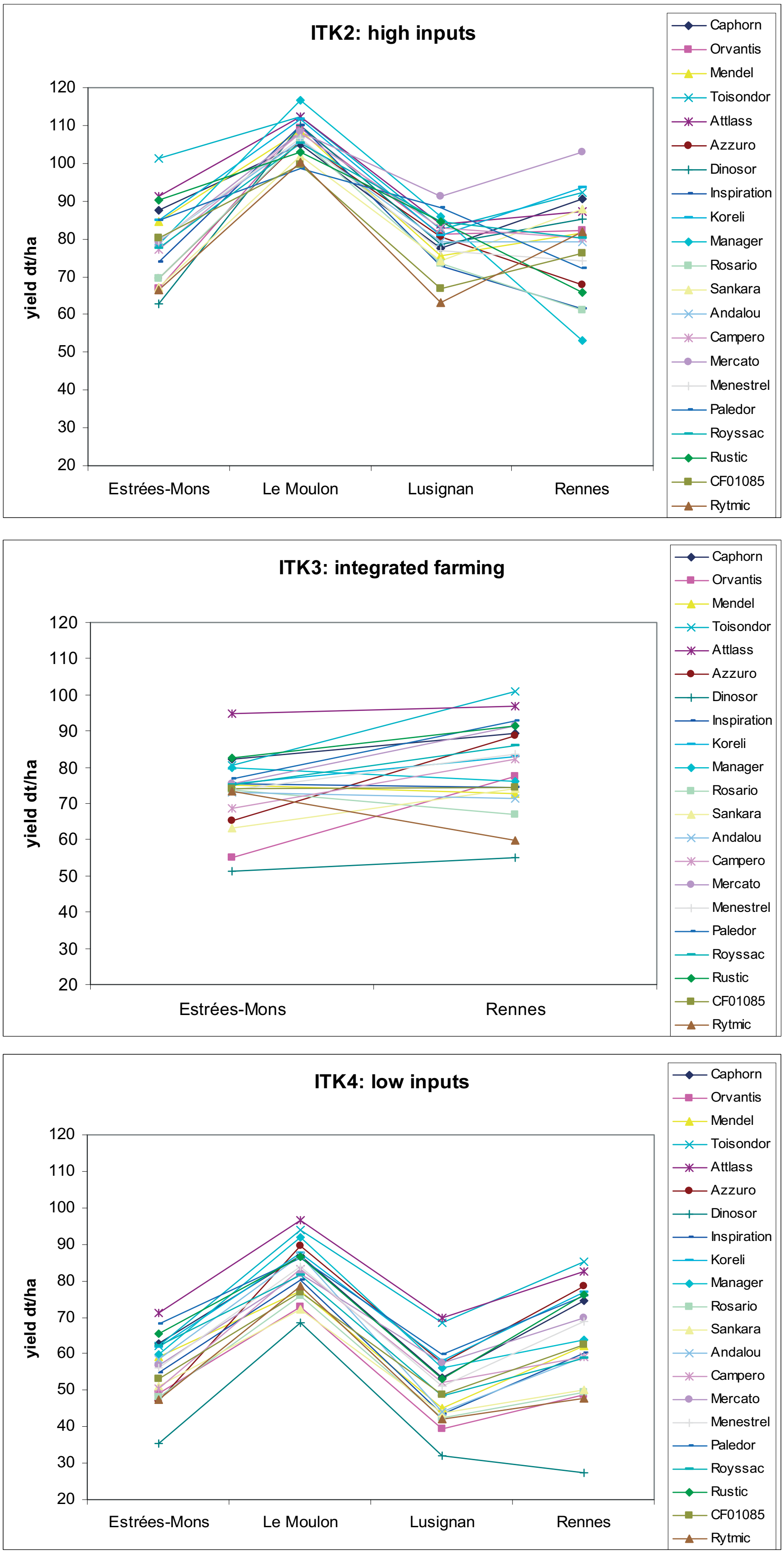

Figure 8.6: Cultivars ranking for yield in 3 crop management plans. Ingen teksthenvisning

Conclusion

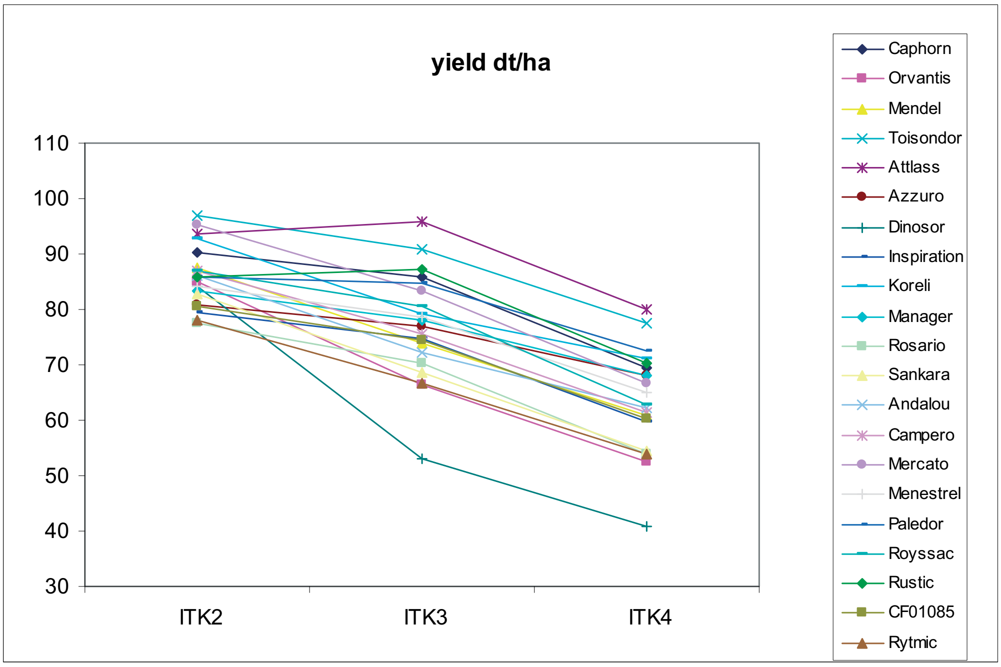

Figure 8.7: Cultivars crop management plans (average 4 locations).

Genotypes ranked differently for grain yield when grown under low or high input levels. Our results showed 4 cultivar groups, useful for farmers advice (Figure 8.7):

- susceptible high yielding: Andalou, Campero Mendel
- susceptible low yielding: Rosario, Rytmic, Dinosor, Orvantis, Sankara
- medium susceptible adapted to integrated farming: Caphorn, Mercato, Koreli, Rustic
- hardy lines: Attlass, Paledor, Toisondor.

Even if high yielding cultivars with low resistances to diseases still have a dominant position in the seed market, new multiresistant cultivars such as Attlass and Toisondor have good prospects for productivity under reduced levels of input crop management. This ability gave benefits in integrated pest management especially in a high disease pressure year. According to significant differences observed between cultivars, the future effort in breeding programmes should contribute to the specific needs of integrated farming for productivity and environmental friendly agriculture. The next study aims at investigating the genotype / management interactions for disease and lodging intensities, and analysing their subsequent effects on yield and profitability within a context of integrated crop management.

Danish trials with cultivars and low and adjusted input of fungicides

Background

In Denmark rules for assessing a need for pesticide application have been formalised in the decision support system, Crop Protection Online (Secher, 1991). This system can be used by the farmers themselves, but the rules and principles are also generally used in newsletters and local recommendations given by the advisory service. Overall, the system aims at organising complex information in a user-friendly way. The models underlying the system have been adjusted according to the results of validating trials (Henriksen *et al.*, 2000), and in 2002 the system was introduced as a web-based DSS (Rydahl *et al.*, 2003).

The system needs yearly updating to evaluate the results in different cultivars. The trials included here are part of this validation comparing control and yield responses from CPO with given strategies often recommended by advisers.

Material and methods

In 2007 two trials, each with 6 different winter wheat cultivars, were carried out comparing the input recommended by CPO in the individual cultivar with standard treatment using 1, 2 or 3 treatments and different doses. The trials were carried out at two locations (Flakkebjerg and Horsens) using three replicates and a split plot design. These trials were assessed weekly in order to release treatments as soon as recommendations were suggested by the DSS programmes.

Results

The level of disease varied to a significant degree between different cultivars. *Septoria tritici* was the dominant disease, but also brown rust appeared widely in the trials. Disease assessments were carried out at 10-day intervals. Main results are shown in table 8.9.
Net yield is calculated in dt/ha as the yield response in treated plots compared with untreated plots with costs of fungicides and application subtracted. The cost of grain price were calculated for both 10€ and 20€ per decitonne (fig. 8.8)

The following treatments were compared in the cultivars:
Untreated

1. 0.75 Bell (GS 37) & 0.4 Proline at GS 65
2. 1 x 0.5 l Bell GS 39-45
3. 0.375 Opus Team (GS 31); 0.375 l Bell GS 37-39 and 0.25 l Opus GS 65
4. 0.375 l Bell GS 37-39 and 0.25 l Opus GS 65
5. Crop Protection Online

Ambition and Frument were the two most resistant cultivars to septoria and Biscay and Samyl developed the most severe attack. The attack of septoria caused the crop to senesce in untreated plots before the treated plots.
The different strategies gave rise to only minor variations in control and yield responses.

- Best control and yield response in all cultivars was obtained from 2 applications using a half rate of Bell/Proline. The poorest control was found following a single treatment with 1/3 rate of Bell. This was too low in all cultivars.

- With respect to net yield benefit the variation between the treatments was very small and could not be separated significantly from each other for cultivars with good resistance.
- The optimal TFI (fungicide input) varied from 0.7 for the most resistant cultivar to 1.4 for the most susceptible cultivar. The difference between high and low input was generally moderate in the resistant cultivars, but did in the susceptible cultivars exceed 130 € per ha.
- Crop Protection Online recommended 1-2 treatments depending on cultivars and locality. TFI varied in the CPO plots between 0.3 and 0.7 with the highest input being used in Biscay. The obtained results were slightly suboptimal, which was most pronounced on the cultivar Smuggler and Frument.
- The yield increases were relatively moderate for all treatments. The level of response did, however, to some extent reflect the level of resistance in the cultivars. Ambition and Skalmeje gave rise to the lower yield increases.

Crop Protection Online has previously been tested in validation trials and given disease control and yield responses in line with relevant references (see table 8.10). The system has not shown a big potential for reduction compared to actual use. The system does however offer an option to optimise timing in relation to disease development and particularly the system offers a chance to evaluate the need for the early season treatments which often have been seen to give low net yields.

Table 8.10: Hvad med henvisning I tekst? Der er kun henvisning til den rigtige tabel 8.8. Results on disease control, yields, cost of control and fungicide input (TFI) from validation of Crop Protection Online (CPO) in field trials in winter wheat

Crop	***Treatment***	***No. of trials***	***% septoria***	***% mildew***	***Yield increase (dt ha^{-1})***	***Net yield (dt ha^{-1})***	***Costs of fungicide+ application (DKK/ha)***	***TFI***
Winter wheat 45 trials[3)]	*Reference [1)]*	*45*	*12*	*2*	*12.3*	*6.6*	*362*	*0.79*
	CPO	*45*	*10*	*1*	*13.4*	*7.7*	*360*	*0.70*
LSD_{95}					*ns*			

[1)] Reference treatments have been chosen based on present standards and varies across the trials.
[2)] LSD_{95} values refer to comparison between actual version of Crop Protection Online and actual reference treatments.
[3)] 50 trials originate from DAAS and 33 trials from DJF.

Table 8.9: Control of septoria and mildew in 2 trials with 6 cultivars of winter wheat and yield responses from different fungicide treatments; CPO = Crop Protection Online

Cultivars	% septoria (2. leaf) GS 75						% septoria (1. leaf) GS 75					
	control	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO	Control	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO
Samyl	66.7	13	32.5	24.2	25.8	32.5	35.8	5.5	13.3	10.8	10.2	13.8
Skalmeje	65.8	5.7	14.3	7.8	9.2	15.8	17.2	3.3	4.4	4.3	4.3	8.3
Smuggler	60.8	13.2	15.2	11.5	11.7	20.5	19.7	4.8	5.9	5.4	6.0	8.7
Biscay	64.2	16.7	29.2	20.8	33.3	34.2	31.7	8.5	11.3	10.8	11.8	13.0
Ambition	10.0	2.8	4.7	5.9	4.8	6.0	3.8	1.4	1.5	1.8	1.8	1.5
Frument	25.8	4.7	6.5	6.3	9.0	9.8	10.2	2.6	3.1	3.5	3.7	4.0
Average	48.9	9.4	17.1	12.8	15.6	19.8	18.0	4.4	6.6	6.1	6.3	8.2

Cultivars	% septoria (1. leaf) GS 77						% mildew (2. leaf) GS 71-73 (1 trial: 350-2)					
	Control.	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO	Control	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO
Samyl	80.0	14.0	18.3	10.7	11.7	28.3	28.3	7.0	20.0	16.7	25.0	23.3
Skalmeje	43.3	9.8	13.7	12.3	12.7	14.5	0.2	0	0.1	0	0	0
Smuggler	38.3	15.8	21.3	21.2	22.2	27.8	0	0	0.1	0	0	0
Biscay	66.7	6.7	15.0	7.7	9.3	16.7	2.8	0.5	6.2	3.8	4.4	4.4
Ambition	13.3	2.5	3.5	3.2	3.7	3.8	0.4	0	0.1	0.1	0	0.1
Frument	22.5	7.3	8.3	8.7	9.3	10.3	1.1	0.1	0.5	0.2	0.2	0.5
Average	44.0	8.5	13.4	10.6	11.5	16.9	5.5	1.3	4.5	3.5	4.9	4.7

……….Continuation of Table 8.9

Cultivars	% brown rust GS 73-75						TGW g/1000 grain					
	Control	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO	Control .	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO
Samyl	2.8	0	0.1	0.2	0.1	0.3	34.2	38.5	36.6	37.5	37.3	37.0
Skalmeje	1.0	0	0	0	0	0	37.3	41.5	40.9	41.3	40.9	39.7
Smuggler	0.1	0	0	0	0	0	33.4	40.7	40.1	40.4	40.2	38.4
Biscay	0	0	0	0	0	0	32.9	40.9	39.5	41.8	40.9	39.8
Ambition	0.7	0	0.1	0	0	0	38.5	40.6	40.4	40.6	33.8	40.2
Frument	0.8	0	0	0	0	0	39.7	40.8	41.7	42.1	40.9	40.0
Average	0.9	0	0	0	0	0.1	36.0	40.5	39.9	40.6	39.0	39.2

Cultivars	Yield and yield increases dt/ha						Net yield dt/ha					
	Control	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO	TFI In CPO	0.75 Bell/ 0.4 Proline	0.5 Bell	Opus Team/ 0.375 Bell /0.25 Opus	0.375 Bell /0.25 Opus	CPO
Samyl	71.3	13.9	8.4	10.6	10.2	9.6	0.64	9.1	6.6	7.9	7.4	6.0
Skalmeje	78.9	7.6	5.5	7.8	8.2	6.9	0.6	2.8	3.7	5.1	5.4	4.0
Smuggler	72.4	9.3	5.9	7.5	7.0	4.7	0.6	4.5	4.1	4.8	4.2	1.8
Biscay	69.2	14.5	7.5	12.6	10.8	7.0	0.7	9.7	5.7	9.9	8.0	3.8
Ambition	82.0	7.1	3.7	5.6	6.5	4.6	0.42	2.3	1.9	2.9	3.7	2.5
Frument	79.6	8.8	4.8	8.4	7.0	2.5	0.42	4.0	3.0	5.7	4.2	0.4
Average	75.6	10.2	6.0	8.8	8.3	5.9	0.56	5.4	4.2	6.1	5.5	3.1

0.75 Bell GS 37 and 0.4 Proline GS 55-65; 0.5 Bell GS.39-45; 0.375 Opus Team GS 31 + 0.375 Bell GS 39 + 0.25 Opus GS 59-61; 0.375 Bell GS 37 and 0.25 Opus GS. 55-65; CPO = Crop Protection Online.

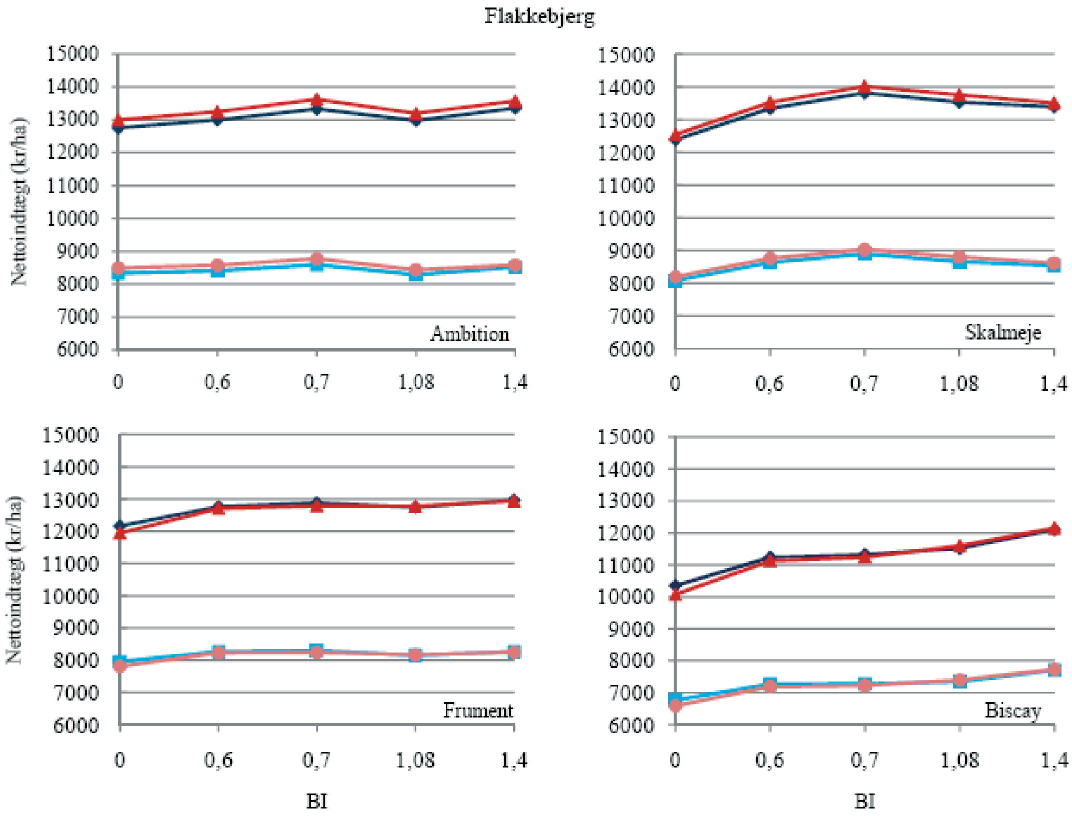

Figure 8.8: Net yield (kr/ha) calculated for 4 varieties with different levels of resistance at 2 grain prices 85 DKK/ha and 140 DKK/ha grain also taking in to account the feeding value of the grain as measured in the grain. The optimum TFI (BI) varies for the different cultivars.

References

Brooks, D.H. 1998. Decision Support System for Arable Crops (DESSAC): an integrated approach to decision support. *The 1998 BCPC Conference – Pests & Diseases*, 239-246.

Champeaux, C. 2005. Recours a l'utilisation de pesticides en grandes cultures : evolution de l'indicateur de frequence de traitements au travers des enquetes ' pratiques culturales ' du scees entre 1994 et 2001. INRA, Ministère de l'Agriculture et de la Pèche.

Clark, W.S. 2003. Wheat Disease Management - 2003 Update. Home-Grown Cereals Authority, London, UK.

Couleaud, G. 2003. La variété, base du raisonnement fongicide. *Perspectives Agricoles,* **287** (Feb. 2003), 65.

Couleaud, G. 2004. Des programmes à repenser en 2004. *Perspectives Agricoles,* **298** (Feb. 2004), 62.

De Vallavieille-Pope, C. 2004. Management of disease resistance diversity of cultivars of a species in single fields: controlling epidemics. *C.R. Biologies*, **327**, 611-620.

Delavaut,M. 2007. Blé tendre d'hiver : analyse d'un indicateur de fréquence de traitement pesticide et de ses variations. Master's thesis ; Arvalis – Institut du Végétal, Université Bordeaux IV – Institut d'Administration des Entreprises.

Fraaije, B.A., Lucas, J.A., Clark, W.S. & Burnett, F.J. 2003. QoI resistance development in populations of cereal pathogens in the UK. *Proceedings British Crop Protection International Congress***, 2**, 689-694.

Henriksen, K.E., Jørgensen, L.N. & Nielsen, G.C. 2000. PC-Plant Protection – a tool to reduce fungicide input in winter wheat, winter barley and spring barley in Denmark. Brighton Crop Protection Conference. Pest and Diseases, 835-840.

Jørgensen, L.N. & Kudsk, P. 2006, Twenty years' experience with reduced agrochemical inputs. *HGCA R&D conference. Lincolnshire, UK. Arable Crop Protection in the Balance Profit and the Environment*, 25-26 Jan. 2006, 16.1-16.10.

Jørgensen, L.N., Hagelskjær, L. & Nielsen, G.C. 2003. Adjusting the fungicide input in winter wheat depending on variety resistance. *BCPC conference on Crop Science and Technology, Glasgow.* 1115-1120.

Jørgensen, L.N., Nielsen, G.C. & Henriksen, K.E. 2000. Margin over cost in disease management in winter wheat and spring barley in Denmark. *Proceedings of the Brighton Crop Protection Conference - Pest and Diseases*, 655-662.

Jørgensen, L.N., Secher, B.J. & Nielsen, G.C. 1996. Monitoring diseases of winter wheat on both a field and a national level. *Crop Protection*, **13**, 383-390.

Jørgensen, L.N., Noe, E., Nielsen, G.C., Jensen, J.E., Ørum, J.E. & Pinnschmidt, H. 2008. Problems with disseminating information on disease control in cereals to farmers. *European Journal of Plant Pathology,***121**, 303-312.

Jørgensen, L.N., Ørum, J.E. & Pinnschmidt, H. 2007. Integrating disease control in winter wheat – optimizing fungicide input. In: *Modern Fungicides and Antifungal Compounds V.*15th International Reinhardsbrunn Symposium. Er året korrekt? I PURE som 2008.

Kuck, K.H. & Gisi, U. 2006. FRAC mode of Action Classificantion and Resistance Risk of Fungicides. In: Krämer & Schirmer (eds.), *Modern Crop Protection Compounds*. Wiley-VCH Verlag, 415-432.

Kuhlmann, J. (2007). Wie intensiv auf leichten Böden? DLG-Mitteilungen, 2, 50-53.

Nomisma. 2008. http://www.nomisma.it/uploads/media/Executive_summary-20080124_01.pdf

Oerke E.C., Dehne, H.W., Schonbeck, F. & Weber, A. 1994. Crop protection and crop prodiction. Amsterdam: Elsevier.

Olesen, J.E., Jørgensen, L.N., Petersen, J. & Mortensen, J. 2003. Effects of rate and timing of nitrogen fertilizer on disease control by fungicides in winter wheat 1. Grain yield and foliar disease control. *Journal of Agricultural Sciences*, **140,** 1-13.

ONIGC (Office national interprofessionnel des grandes cultures (Enquête céréalière par sondage)) (2007). Variétés de blé tendre - Récolte 2007.

Paveley, N.D. 1999. Integrating Septoria risk variables. In: Lucas, J.A., Bowyer, P. & Anderson, H.M. (eds.), *Septoria on Cereals: a study of Pathosystems*. Cap Publishing, 230-250.

Paveley, N.D. & W. Clark, S. 2000. The Wheat Disease Management Guide. Home-Grown Cereals Authority, London, UK.

Paveley, N.D., Thomas J.M.,Vaughan, T.B. Havis, N.D. & Jones, D.R. 2003, Predicting effective doses for the joint action of two fungicide applications. *Plant Pathology,* **52**, 638-647.

Reus, J.A.W.A. de & Leendertse, P.C. 2000. The environmental yardstick for pesticides: a practical indicator used in The Netherlands. *Crop Protection*, **19**, 637-641.

Rijsdijk, F. 1983. The EPIPRE system. In: Austin, R.B. (ed.), *Decision making in the practice of crop protection*. Monograph No. 25. BCPC, Croydon, 65-76.

Rydahl, P., Hagelskjær, L., Pedersen, L. & Bøjer, O.Q. 2003. User interfaces and system architecture of a web-based decision support system for integrated pest management. *EPPO Bulletin*, **33**, 473-482.

Schepers, H.T.A.M., Bouma, E., Frahm, J., Volk, T. & Secher, B.J.M. 1996. Control of fungal diseases in winter wheat with appropriate dose rates and weather-based decision support systems. *EPPO Bulletin*, **26**, 623-630.

Schepers, H.T.A.M., Bouma, E. & Secher, B.J.M. 1997. Appropriate dose rates of fungicides to control diseases in winter wheat. *Proceedings of conference on Protection of cereal crops against harmful organisms. 1-4 July 1997*, Kromeriz Czech Republic, 145-149.

Schepers, H.T.A.M., Spits, H.G. & Jansen, D.M. 2006. Development of a prediction tool for deoxynivalenol content in winter wheat in the Netherlands. Book of Abstracts, *9th European*

Fusarium Seminar, Wageningen, 19-22 September 2006, sidetal?.

Secher, B.J.M., Jørgensen, L.N., Murali, N.S. & Boll, P.S. 1995. Field validation of a decision support system for the control of pests and diseases in cereals in Denmark. *Pesticide Science*, **45**, 195-199.

Tischner, H., B. Schenkel & P. Eiblmeier (2006). Monitoring für Getreidekrankheiten in Bayern – mehrjährige Auswertungen über die Bedeutung der einzelnen Schaderreger. Gesunde Pflanzen 58:34-44.

Zadoks, J.C. 1983. An Integrated Disease and Pest-Management Scheme, Epipre, for Wheat. *Ciba Foundation Symposia,* **97**, 116-129.