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**CEREAL SEED HEALTH AND
SEED TREATMENT
STRATEGIES**

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CEREAL SEED HEALTH AND SEED TREATMENT STRATEGIES

by

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SUMMARY

The objectives of the Review were to:

- Summarise the mechanisms by which cereal seed health is maintained through the use of fungicide seed treatments, seed certification and health testing
- Examine how efficiently current seed health practice meets the needs of the industry
- Summarise current understanding of the epidemiology and importance of seed-borne diseases of cereals
- Review seed health and seed treatment practices in other countries and consider how they might be applied under UK conditions
- Consider how existing knowledge, and future seed testing technologies and research information, might be used to improve the efficiency of cereal production
- Identify alternative future strategies for the maintenance or improvement of cereal seed health, and the costs and risks associated with them

The current practice of routine cereal seed treatment developed during a period when organomercury treatments were available at negligible cost, and seed health testing was in most cases impractical as a guide for treatment and in the seed certification process. Routine seed treatment continues to maintain a stable supply of healthy seed, but a number of economic and technical circumstances, listed below, have changed, making it appropriate to carry out a review.

- Seed treatments now represent a significant cost
- A recent survey of the health status of UK cereal seed stocks has allowed the proportion of seed stocks free of seed-borne disease to be quantified
- New research has shown the risk of soil-borne fusarium seedling blight to be small

- The relationships between seed health test results and field expression of disease have been better defined for some key pathogens
- DNA and immunoassay technologies are now being used routinely for the detection of pathogens in medicine, and are beginning to be applied in plant health

Approximately 95% of all cereal crops are grown from treated seed, at a cost to UK growers of approximately £23 million per annum. Fungicide seed treatments are used predominantly for the control of seed-borne diseases, although some also control certain foliar diseases.

The most important seed-borne diseases of cereals in the UK are bunt and fusarium seedling blight on wheat, and loose smut and leaf stripe on barley. Some of these diseases have the potential to increase very rapidly if suppression is not maintained, and other currently rare diseases, which were common in the past, could recur should agronomic circumstances change. A recent seed health survey (HGCA Project Report No. 124, funded by the HGCA and Zeneca Crop Protection) has shown how the incidence of the main diseases varies with season and seed source. There is little difference in the incidence of bunt, leaf stripe and fusarium on certified and farm-saved seed, but loose smut is less common on certified seed compared with farm-saved seed. Depending on the source of seed and season, 13% to 84% of winter wheat and 62% to 97% of winter barley seed stocks carry nil or sub-threshold levels of the main seed-borne diseases. Seasons with poor wheat seed health are associated with high levels of seed-borne fusarium, following conditions conducive to ear blight prior to harvest.

Unless infected stocks can be readily differentiated from those that are free of pathogens, a high level of disease suppression can only be maintained by treating all stocks. Current tests for seed-borne diseases take several days and are labour intensive. This limits their usefulness, particularly for winter cereals where seed must be processed during a short period in the autumn. DNA and immunoassay based techniques offer the potential for highly sensitive tests, without the delays inherent in current methods. On-farm seed

health test kits are technically feasible in the longer term. However, significant research investment would be needed to realise this potential.

There is now strong evidence that where seed is substantially free of seed-borne pathogens, and the crop is not grown for seed, sowing seed untreated is the most cost-effective option. The risk of seedling losses due to soil-borne disease has been shown to be low. If accurate information on seed health status was quickly and readily available, growers might therefore question the value of treating healthy seed. Current advisory treatment thresholds have been shown to be robust, but only against a background of routine seed treatment. Accurate threshold definition would be required to ensure consistent downward pressure on pathogen populations, and to allow the results of novel health tests to be interpreted into appropriate treatment decisions. The process of threshold definition would need to take account of the risks posed by spread of pathogens to neighbouring and subsequent crops, and non-compliance with seed health procedures by a proportion of cereal producers.

The Review proposes four possible future strategies for the maintenance of cereal seed health. It discusses their advantages and disadvantages and the research required to implement them:

1. Minimal change to current practice

Maintaining the current practice of routine treatment will mean that a substantial amount of seed will continue to be treated unnecessarily, and that growers will continue to bear the cost. However, this may be justifiable in the short to medium term, because:

- Routine treatment has maintained a high level of seed health and ensured minimal losses from seed-borne diseases
- Existing technology imposes logistical constraints on testing of winter cereals
- The income generated from seed treatments is important to seed and agrochemical companies and, if reduced, may jeopardise the development of new products

2. Limited strategy of treatment according to need

Seed could be treated only when health tests have identified a need. For spring cereals this strategy could be encouraged with existing testing techniques and advisory thresholds, and could be implemented in the short term. The Scandinavian countries, where spring cereals predominate, are already adopting this approach.

3. Long-term change to a wider strategy of treatment according to need

A significant long-term decrease in seed treatment costs on all cereals could begin to take effect in about five years time, if the potential of new, rapid, seed testing technologies is exploited. This strategy would require significant investment in the development of testing techniques, research to define relationships between test results and disease expression, and the definition of treatment thresholds

4. Treatment based on compulsory testing of all seed

This would require the same technical developments as Strategy 3 above, and could ensure exceptionally high standards of seed health, as compliance would be assured. However, the industry may consider the constraints imposed by new legislation too restrictive.

CHAPTER 1

INTRODUCTION

Cereal production is dependent on a reliable supply of healthy seed. The suppression of seed-borne diseases, from epidemic levels in the early part of this century, to the point where damage to a commercial crop is a noteworthy event, is one of the most striking achievements of crop protection.

It would be wrong, however, to think that absence of visible symptoms implies eradication. Recent survey work, funded by the HGCA and Zeneca Crop Protection (Cockerell & Rennie, 1995), shows that diseases such as bunt and loose smut are present at low levels in a high proportion of seed lots. The situation might, at best, be described as being in dynamic equilibrium. Only the combined effects of the certification process and the use of fungicide seed treatments, maintain seed-borne diseases at acceptable levels.

The costs of maintaining disease suppression are substantial. It is estimated that cereal growers in the UK pay £23 million per annum for fungicide seed treatments.

In most industries, commercial practice and government regulations reflect the economic pressures, technical possibilities and public concerns experienced during their development. When circumstances change, a review of current practice may be beneficial.

Current commercial practice in the use of seed treatments, and the procedures of seed certification, evolved during a period when organomercury seed treatments were available at negligible cost, and routine use of pesticides was seldom questioned. The main weakness of organomercury was its inability to control the deep seated infections of loose smut. In response, voluntary and later statutory seed certification schemes set defined thresholds for loose smut - above which seed lots were either rejected, or 'retrieved' by the application of more expensive systemic treatments.

Concerns about the use of mercury-based pesticides led to the withdrawal of organomercury seed treatments in the UK in 1992. It is widely accepted that if the withdrawal had led to a general increase in cereal crops being sown untreated, significant seed-borne disease problems would have resulted. Fortunately, stimulated by a substantial new market opportunity, the agrochemical industry introduced a range of novel seed treatment products. As a result, approximately 95% of cereal crops are still grown from treated seed.

This review brings together information on seed treatment and seed production practice, and relates it to our understanding of disease epidemiology, to address the question: is current practice the most effective way to manage seed-borne diseases in the post-organomercury era?

Control of seed-borne diseases has a social aspect. For most foliar diseases, the actions of one grower in controlling or failing to control disease have little effect on others. For the seed-borne diseases, all growers and seed producers share a national responsibility for maintaining suppression.

It could be argued that the continuation of routine seed treatment use after the withdrawal of organomercury has provided a stable base from which to evaluate the technical possibilities. The logical extension of current research in diagnostic techniques would be the development of highly sensitive seed health tests, which with appropriate sampling techniques could provide instant results 'off the back of the combine'. Beyond the current grain price buoyancy, the competitive nature of the world cereal market will demand reductions in the unit cost of production. In addition, the need to reduce political pressure for regulatory restraint on pesticide use will focus attention on ways in which the industry can be seen to be putting its own house in order - through the implementation of treatment according to need strategies.

In future, if accurate information on seed health status was quickly and readily available, growers might reasonably ask whether the treatment of seed known to be free of disease aids the suppression of seed-borne diseases. And if not, is the significant cost of the

'organomercury replacement' products justified by other potential benefits? If the health status of farm-saved seed could be so readily measured, growers may also re-evaluate their use of certified seed.

There is a risk that new techniques will be developed before the industry understands how to convert test results into appropriate decisions. This review aims to help the seed health debate run ahead of and guide the technology, and to consider future seed treatment strategies. The main aims of any strategy to maintain cereal seed health are to:

- Ensure long term security of production against the deleterious effects of seed-borne diseases on output (yield and grain quality)
- Minimise input costs
- Maximise any additional benefits of seed treatment against soil-borne or foliar diseases
- Minimise the risk of fungicide resistance
- Ensure adequate returns to agrochemical companies, to stimulate development of improved seed treatments
- Ensure adequate returns to plant breeders, to allow development of improved varieties
- Minimise risks to operators, consumers and the environment

The first of these aims cannot be compromised, and the high multiplication potential of seed-borne diseases does not allow the current level of suppression to be relaxed. However, it is reasonable to ask if seed treatments can be targeted more effectively, while achieving a balance between the other needs. The cereal industry has a collective responsibility for seed health, and must consider how to maintain this as economic, political and technical factors change.

CHAPTER 2

HISTORICAL PERSPECTIVE

2.1 HISTORICAL USE OF SEED TREATMENTS

Cereal seed treatment is one of the oldest practices in crop protection, carried out in one form or other for over 300 years. The first recorded use of seed treatment was for the control of stinking smut or bunt, the scourge of the European wheat grower in the 18th century. This disease converts developing grains into balls of foul-smelling black powder, reducing yield and rendering the remaining grains blackened and unfit for bread production. In the 18th century bunted flour was used to make ginger-bread; the grey colour and fishy taste of the flour being masked by black treacle and ginger.

Brine steeps were the first method for the prevention of bunt. In 1637, Richard Remnant wrote of their use, but gave no details of the method or its efficacy. In 1725, Prof. R. Bradley of Cambridge University, and later Jethro Tull in 1733, reported that wheat salvaged from a ship wreck in about 1650 and dried out over lime, produced a crop with very little bunt. Bradley also recorded that a certain Col. Plummer of Hertfordshire had developed a brine steep which gave good control of bunt. The seed-borne nature of the disease was finally demonstrated in France by Mathieu Tillet in 1751-52. Later, 'brine strong enough to float a fresh egg' was used to condition the seed. In France, stale urine was used as an alternative steep, although drying over lime was an important part of the treatment.

Copper sulphate was first advocated as a seed treatment for the control of bunt by Schulthness (1761). Prevost (1807) clearly demonstrated the beneficial effects of copper sulphate, which led to the development of soaks which were used for over one hundred years. A further development was the use of dry copper carbonate or sulphate dust (Reynolds, 1913) removing the need to dry seed after treatment. The first recorded use of copper in the UK was in 1846 (Taylor, 1846).

Formaldehyde was first recommended for the control of smuts and bunt in the late 19th century (Geuther, 1895), although there had been earlier experimental work in the USA (Bolley, 1897). Formaldehyde was reported to be in common use in Australia by 1905 (Farrer & Sutton, 1905), and was widely used in Germany during the First World War due to a shortage of copper.

Organomercury seed treatments were developed commercially in Germany, with the first product, 'Uspulun' available by 1914 (Remy & Vasters, 1914). Earlier experimental work had been done in the USA (Bolley, 1897), Australia (Farrer & Sutton, 1905) and Germany (Hiltner, 1910; Richun, 1913). This material dominated the industry for over 50 years.

The organomercury compounds controlled not only the covered smuts but also seedling blight caused by *Fusarium* spp., leaf stripe of barley and leaf spot of oats. So effective and affordable were the organomercury compounds that they were widely adopted by growers throughout northern Europe. This widespread use had two major effects on the industry. Firstly, the seed-borne cereal pathogens that had previously been so damaging became very rare. Secondly, because of the low cost and widespread use there was little incentive for agrochemical companies to invest money in developing alternative products.

The only major diseases not controlled by organomercury were the loose smuts of wheat and barley. The fungi causing these diseases grow into the developing embryo of the seed and are thus protected from surface acting chemicals. In the 1880's Jensen, in Denmark, discovered that soaking the seed in hot water could kill the fungus without harming the seed. Hot water soaking was the only practical treatment until the 1960's when the introduction of the systemic fungicide carboxin made it possible to control the disease by chemical seed treatment. In the late 1960's ethirimol was developed as a seed treatment for the early control of mildew on barley.

The use of carboxin and organomercury allowed almost complete control of the major seed-borne diseases of cereals for a number of years. Organomercury, because of its low

cost, became almost routine on bought-in and farm-saved seed. From 1982, organomercury fungicides were progressively withdrawn from use within Europe and North America, although a derogation allowed their continued use in the UK until 1992. From 1992, UK farmers were faced with seed treatment costs as a significant part of their variable costs. The limited range of organomercury replacements in 1992 was quickly extended during the early 1990's, during which time over a dozen materials became available for cereal seed treatment.

2.2 THE DEVELOPMENT OF SEED CERTIFICATION SCHEMES

2.2.1 Voluntary schemes

Cereal seed certification schemes were developed to meet several objectives. These included maintaining varietal identity and purity over successive generations, and ensuring that seed met acceptable standards for various other quality attributes, such as weed seed contamination, germination and seed health.

The first attempts at cereal seed certification in the UK were the voluntary post-war Cereal Field Approval Schemes introduced and operated by NIAB (Kelly & Bowring, 1990). No mention was made of standards for disease in these schemes.

Following the Plant Varieties and Seeds Act 1964, which rationalised variety registration and introduced a system of Plant Breeders' Rights, seed certification remained voluntary in the UK. The British Cereal Seed Scheme (BCSS), introduced in 1969 (Anon., 1969) was more comprehensive than the old Field Approval Scheme and, in addition to seed crop inspections, included laboratory tests on seed harvested from inspected crops.

'Smuts' were the only seed-borne diseases for which standards were set in the BCSS, principally because they were not controlled by the organomercury seed treatments which were applied to virtually all traded cereal seed at that time. The BCSS field standard for loose smut (*Ustilago nuda*) allowed a maximum of 0.04% infection in the lowest grade of seed and 0.02% in early generation crops. There was also a requirement that 'other smuts' should not exceed 0.001%. The BCSS required all barley seed

destined for further seed production to be tested for loose smut, unless treated with an appropriate fungicide. The standards were not more than 0.1% of seeds infected for the grade equivalent to Basic seed and not more than 0.2% for the equivalent of C1 seed. There were no standards for ergot or seed germination.

In 1969, loose smut was a major problem in wheat and 34% of seed lots failed the 0.2% BCSS standard. However, the introduction of carboxin and new winter wheat varieties with resistance to the prevalent 'C4' race of loose smut led to a significant reduction in infection over the next few years. These methods of control were integrated in the BCSS in 1972 when it became obligatory to treat early generation seed of susceptible varieties.

2.2.2 Statutory seed certification schemes

In 1972 approximately 70% of UK cereal seed was supplied by the seed trade; divided almost equally between certified seed and uncertified 'commercial' seed. The remaining 30% was farm-saved. In 1973, the UK joined the European Community, and it became illegal to sell uncertified seed. The voluntary BCSS seed standards for loose smut in barley and wheat were carried forward to the new statutory regime, although treatment or seed testing of early generation seed was no longer required. Seed testing standards for ergot and germination were introduced and C1 and C2 seed had to have a germination capacity, as defined by international rules for seed testing (Anon., 1993a), of at least 85%.

To meet the standards for loose smut it became common practice in the UK to treat Pre-basic and Basic seed stocks of barley (and formerly wheat) with effective fungicides. Some merchants also applied an appropriate systemic fungicide to first generation certified seed (C1) to ensure that it consistently met the loose smut standards whilst others drew samples from seed stocks and systemic fungicides were applied in response to infection.

There has never been any requirement to test for *Microdochium (Fusarium) nivale* in wheat. However, there is some correlation between the incidence of *M. nivale* and germination capacity (Reeves & Wray, 1994).

CHAPTER 3

EPIDEMIOLOGY AND DAMAGE POTENTIAL OF THE MAIN SEED-BORNE DISEASES OF CEREALS

3.1 SEED-BORNE DISEASES OF WHEAT

3.1.1 Loose smut

Loose smut, caused by *Ustilago tritici*, has been rare in wheat since the 1970's. Symptoms and life history are the same as for loose smut of barley, described in Section 3.2.1.

The decline in loose smut of wheat appears to have been related to the introduction of more resistant varieties, and possibly to the widespread use of *Rht1* and *Rht2* dwarfing genes in wheat. It has been suggested (Jones *et al.*, 1995) that infected plants of *Rht* wheat varieties head later and are shorter than uninfected plants, reducing the pathogen's ability to infect the grain sites of healthy plants.

3.1.2 Bunt or stinking smut

Symptoms

Bunt, caused by *Tilletia caries*, is difficult to see in the standing crop. Affected plants are often slightly stunted and have 'squat', dark grey-green ears with slightly gaping glumes. If infected ears are broken open they are found to contain, in place of true seeds, seed-like 'bunt balls' each containing millions of greasy, black, foul-smelling spores. In severe cases, the whole field may smell of rotting fish. In wet weather conditions the ears may appear to be covered in a black ink-like substance as the spores are released and run out of the protective glumes onto the ear and stem.

Many of the bunt balls within the ear are broken open during combining. Spores are released and contaminate grain in the combine, and during subsequent movement, storage, and handling of contaminated seed. In severe cases, the grain can be so heavily contaminated that it is rendered unusable. The spores remain on the surface of contaminated seed, being concentrated in the brush hairs at the end of the grain. In

severe cases the grain assumes a dark appearance, often with a foul smell. Grain which has been stored for some time may lose the obvious smell but is still dark in appearance.

Life history

The spores on the seed surface germinate along with the seed. Each produces a short fungal thread terminating in a cluster of elongated cells. These, after a process of conjugation, produce secondary spores which infect the coleoptiles of the young seedlings before the emergence of the first true leaves. The mycelium grows up with the shoot eventually to infect the developing ear. Affected plants develop apparently normally until the ear emerges when it can be seen that grain sites have been replaced by bunt balls. Each bunt ball contains millions of spores and the capacity for contamination of healthy grain in the same field is enormous. Thus, if contaminated seed is continually saved and re-sown without treatment the disease can build up very rapidly.

Dry spores can survive for several years. Harvesting or handling equipment contaminated by spores from an infected crop can thus serve to introduce the pathogen into healthy seed lots harvested in the same or following season.

In damp soil spores usually germinate and then, in the absence of the host plant, die. In dry seasons, however, they may survive in the soil from the harvesting of one crop to the sowing of the next, especially if they are protected by the glumes of shed ears. Wind-blown spores, particularly from late-harvested crops, can occasionally contaminate neighbouring fields which have been cultivated for the next crop (Yarham & McKeown, 1989).

Johnsson (1990) for the first time reported long-term survival of bunt spores in soil in Sweden. However, this report conflicts with other results from many workers (Bonne, 1931; Foster & Henry, 1937; Vandervalle & Detroux, 1954; Parlak, 1986) who generally agree that the viability of bunt spores in soil is very short, particularly if the soil is moist. Recently there have been reports from Denmark (Cordsen Nielsen, personal communication) of bunt spores surviving overwinter to affect subsequent crops in moist soil. Similar reports have been received from ITCF in France (Maumene, personal

communication), and from ADAS in the UK (Yarham, personal communication). These reports suggest that overwintering of bunt spores, probably as intact bunt balls encased in glumes on intact ears, is possible.

Control

Since bunt spores lie on the surface of contaminated grain, disinfection is relatively easy. This explains the success of copper compounds, in use from the 19th century until the 1940's, and organomercury. Widespread use of organomercury seed treatments from the 1930's onwards greatly reduced the incidence of bunt, illustrated by data from the Official Seed Testing Station (OSTS), Cambridge (Table 3.1).

Table 3.1 Incidence of bunt in wheat seed

Year	1920	1921	1923	1935	1945	1955	1957
No. samples received	1926	2312	2340	5991	5000	14350	9170
Samples with bunt balls (%)	8.0	33.0	16.0	2.4	1.6	0.2	0.2

It should be noted, however, that even the best fungicides may not afford a complete control of the disease. If inoculum levels are high and conditions are favourable for infection (late drilling, cold soils) then disease control is often reduced.

Surface acting fungicides traditionally did not control infection caused by spores in the soil. For this a systemic material such as Baytan was required (active ingredients of seed treatments are given in Table 4.7). However, some of the newer materials such as Sibutol and Beret Gold, although not systemic, do give control of soil-borne infections. Early sowing (before spores have germinated as a result of autumn rain) favours infection from soil-borne inoculum. Late sown crops, on the other hand, are likely to suffer more severely from seed-borne infection, since at lower temperatures they grow less rapidly through the susceptible seedling stage and are less able to 'grow away' from the infection.

Potential losses

It is the potential for spread between seed stocks and the rapid rate of multiplication of this disease through seed generations that made it so important before the advent of effective seed treatments. The rate at which, under conditions favourable to the development of the disease, the pathogen can build up in an untreated stock was calculated by Dillon Weston & Engledow (1930):

Year 1	1 plant in	8,500 infected
Year 2	1 plant in	450 infected
Year 3	1 plant in	4 infected

Infection of 1 plant in 8,500 in the first year would, in the absence of seed testing go unnoticed on farm, and probably by any merchant buying the grain. However, the resulting infection from growing on that seed untreated (one plant in 450) would constitute a crop failure as all of the grain from that crop would be so heavily contaminated that it would be unsaleable.

3.1.3 Fusarium diseases of wheat

For convenience, and because of the similarity in its pathology, *Microdochium nivale* (previously *Fusarium nivale*) is included with the fusarium diseases. Of the 14 or so species of *Fusarium* which have been isolated from wheat crops in the UK, only *F. culmorum*, *F. avenaceum* and *F. graminearum* can be regarded as aggressive pathogens. *F. culmorum*, together with *M. nivale*, are by far the most common. *F. poae*, though it seldom causes more than small lesions on the glumes, is potentially serious as a producer of mycotoxins.

Symptoms

The most common symptom of a serious attack of fusarium is poor plant establishment. This occurs because of pre-emergence and post-emergence seedling blight, the most important phase of the disease.

Root rotting, brown foot rot and leaf blotching, usually following some other form of damage, glume discolouration and ear blights can all be caused by these fungi. Severe foot rot, usually affecting plants under stress, especially moisture stress, can result in premature ripening and 'whiteheads'. Under prolonged snow cover *M. nivale* can develop rapidly causing 'snow mould'.

Life history

Fusarium spp. and *M. nivale* are normal inhabitants of agricultural soils but all five species mentioned above can also be seed-borne.

Soil-borne *Fusarium* spp. and *M. nivale* invade roots and stem bases. Though some species have a limited ability to grow up inside the stem, infection of the upper leaves and ears usually results from rain-splashed spores produced on the lower leaves and stem.

Seedling blight is almost invariably caused by fungi carried on the seed. If the level of seed infection is high and untreated seed is sown into poor seedbeds, particularly if late, then seedling losses can be high. Warm soils favour infection by *F. culmorum*, cool soils infection by *M. nivale*. *M. nivale* is the pathogen most often responsible for seedling losses in wheat in the UK.

Control

Because *Fusarium* spp. and *M. nivale* are carried within the seed coat, rather than superficially on the seed surface, they are less easily controlled by surface acting fungicides. Despite this, organomercury gave good control. All of the current fungicides are effective although some less effective ones still rely on MBC components of the seed treatment.

Potential losses

In seasons where high levels of seed-borne infection occur the risk of poor crop establishment is high, particularly if seed has to be sown into poor seedbeds. Millar & Colhoun (1969) showed that the severity of disease symptoms increased with the number

of *M. nivale* spores on the seed, up to 50,000 spores per seed. Linear correlations have been shown between percentage seed infected with *M. nivale* and seedling establishment (Humphreys *et al.*, 1995; Rennie, personal communication).

Hare *et al.* (1995) used controlled environment facilities to test the effect of soil temperature and moisture, post-drilling, on seedling establishment of *M. nivale* contaminated seed. With a highly contaminated seed lot, 90% establishment was achieved in soil at 12°C, compared to 32% at 6°C. Effects of soil moisture were less marked, but emergence was reduced at -1.08 bar compared to soil at -0.05 bar, confirming that expression of seedling blight is most likely under cold conditions and may be somewhat more severe if the soil is dry. In contrast, the percentage emergence of healthy seed was only slightly affected by temperature and soil water potential, although cold and moisture stress decreased the rate of emergence.

In seasons when weather during flowering is wet, high levels of seed-borne fusarium can result. The two harvest years of 1992 and 1993 in the UK were high risk seasons when, on average over 90% of samples tested by the Official Seed Testing Station (OSTS) at Cambridge were infected by *M. nivale*. In 1993, over 90% of the samples tested not only carried infection, but also failed the OSTS advisory limit of 5% seed infection (Reeves & Wray, 1994). The level of seed-borne infection is almost entirely dependent on weather conditions following ear emergence and subsequent flowering and is probably not influenced by the seed treatment applied in the previous year.

Ear blights caused by fusarium usually arise from inoculum within the crop, and although seed-borne infection may lead to stem-base and nodal infections it is not thought to be a major factor in ear blight epidemiology (Jenkins *et al.*, 1988).

3.1.4 Septoria seedling blight

Symptoms

Although more usually associated with necrotic blotching of leaves and glumes, *Septoria nodorum*, now *Stagonospora nodorum*, can cause pre- or post-emergence seedling blight in cool soils.

Life history

S. nodorum can survive between crops either on seed or on plant debris. While trash-borne inoculum is usually more important in initiating leaf spot and glume blotch, seed-borne inoculum is more likely to be responsible for seedling blight.

Control

Seed treatment reduces the risk of septoria seedling blight. As with fusarium, organomercury gave only partial control but better protection is provided by some of the current seed treatments.

Potential losses

Losses due to seedling blight have been recorded as 'severe' (Gair *et al.*, 1972). However, the incidence of *S. nodorum* declined in UK wheat crops during the 1980's. In parts of south-west England and Scotland high levels of the disease occurred in the early 1990's. Hence, although typically of minor importance, the threat of septoria seedling blight cannot be disregarded. Since *S. nodorum* can survive on wheat stubble, control of seed-borne infection is unlikely to reduce the development of the disease on leaves and ears.

3.1.5 Ergot

Ergot, caused by *Claviceps purpurea*, is a common disease of grasses and cereal crops. All cereal species can become infected but rye is most susceptible. Although not truly a seed-borne disease, since it is spread as ergots with the seed, it is included here. It is also one of only two diseases for which there are standards in the UK Seed Certification Scheme for Cereals, the other being loose smut.

Symptoms

The causal fungus only attacks the ear, replacing the grain in a few spikelets by a hard, purple-black fungal mass (sclerotium), known as an ergot. Such ergots can be up to 2 cm in length, and are obvious in the standing crop and in grain samples from affected crops.

Life History

At or near to harvest, some ergots fall to the ground where they remain until the following summer when they germinate to produce small club-shaped spore bearing structures. These spores are spread by the wind to nearby open flowers of grasses and cereals. The spores germinate in the flower, infecting the ovaries. This infection leads to the production of more spores which are encased in a sticky secretion commonly referred to as 'honeydew'. This attracts insects which carry the spores to other flowers where further infection occurs and the process is repeated. Short distance spread can also occur by rainsplash or direct contact with infected ears. There are a number of strains of the fungus, some of which can infect grasses and cereals, and others which are restricted to specific hosts (Yarham, 1993a). Wheat and other cereals are less commonly affected than rye, although occasionally open-flowered varieties can be affected.

Control

Attempts to control ergot using fungicides applied to the ear are rarely successful, although they can reduce infection. The disease is favoured by cool, wet conditions during flowering which facilitate spore production, prolong flowering, and make infection more likely. Ploughing will bury the ergots, which cannot germinate from depth, and any which are ploughed up the following season will not be viable. Control of grass weeds, particularly black-grass in and around crops is important in preventing spread into cereal crops.

Potential losses

The disease has virtually no effect on yield, but the ergots contain very poisonous alkaloids which, if they contaminate feedstuffs or flour, can be very dangerous to livestock or humans. Poisoning in humans due to ergot consumption is very rare though there are reported cases on continental Europe, usually associated with the consumption of rye flour. Livestock poisoning is more common, involving a range of symptoms from poor weight gain to gangrene. Most livestock cases are usually associated with stock grazing pasture which has grasses affected by ergot, rather than from contaminated feed grain.

3.1.6 Dwarf bunt

Dwarf bunt, caused by *Tilletia controversa*, is not known in the UK, but has become of interest in recent years because of reports of long-term survival of common bunt (*T. caries*) in soil. Dwarf bunt can survive for long periods in soil and recent reports of long-term survival of *T. caries* raised debate about the existence of hybrids between *T. controversa* and *T. caries*. Dwarf bunt can be found in most areas where winter wheat is subject to prolonged snow cover, including Canada, North and South America, and many parts of Europe and Asia. Unlike common bunt, it can affect rye and winter barley as well as a range of grass species.

Tilletia spp. can be distinguished using morphological characteristics of the teliospores, but most species show a wide range of variation making positive identification difficult. Russell & Mills (1993) have suggested that the inability to differentiate between *T. caries* and *T. controversa* using either morphological features, electrophoresis, or DNA probes, and the lack of evidence for exchange of genetic material between them, does not support their classification as separate species.

Symptoms

The symptoms of dwarf bunt are similar to common bunt except that affected plants are stunted, to between half and quarter their normal height. The ears of affected plants tend to have a more ragged appearance than with common bunt, and leaves are occasionally chlorotic and flecked.

Life History

The life history of *T. controversa* matches that of *T. caries* very closely in many respects. When the ears emerge the seeds are seen to have been replaced by bunt balls which break open during harvest, contaminating healthy grain. When contaminated grain is sown the spores on the outside of the grain germinate, eventually reaching the growing point of the plant. It is at this stage that *T. controversa* differs from *T. caries*. With common bunt, the fungus normally infects the plant via the coleoptile as the seedling is emerging. Rapidly germinating seedlings can develop so quickly that they can effectively avoid

infection. With *T. controversa*, there is a long incubation period and a requirement for cool temperatures before the spores will germinate. Thus, the fungus frequently infects plants much later in development. The site of penetration of the host plant is presumed to be the tiller initials (Hoffman, 1982).

At harvest, bunt balls contaminate the soil, as well as healthy seed, but with dwarf bunt this is very significant as the fungus can survive in soil for many years. Free spores are reported to remain viable in soil for at least three years and bunt balls can survive for up to ten years.

Control

Dwarf bunt infects the host plant at a later stage than common bunt, and consequently seed treatment is less effective. Few treatments are effective against soil-borne infection. Systemic seed treatments such as Baytan have been shown to give some control but the long period between sowing and infection (3-4 months) makes control variable.

In the USA, host resistance has been employed against dwarf bunt in many varieties. Many are still, however, susceptible to one or more races of the fungus.

Spring-sown cereals are not affected. This can be used as a control strategy, but most areas where dwarf bunt is common are unsuited to early sowing of spring cereals.

Potential losses

Seed-borne infection is very important with this pathogen, which can cause similar losses to that of common bunt (Section 3.1.2). However, the potential rate of multiplication in seed stocks is likely to be less than with common bunt. The soil-borne phase of the disease adds a further dimension to the problems of control.

3.2 SEED-BORNE DISEASES OF BARLEY

3.2.1 Loose smut

Symptoms

Loose smut, caused by *Ustilago nuda*, is easily recognised at ear emergence as the ear is usually completely replaced by a mass of black fungal spores. Partly affected ears are sometimes seen. The spores are released as soon as the ear emerges, leaving only the bare remains of the ear rachis.

Life history

The spores, which are released from smutted ears, are carried by the wind to the open flowers of surrounding healthy plants. There they germinate and the fungus grows into the developing grain sites. Weather conditions during flowering affect the length of time that the florets remain open and hence the time that the plant is susceptible to infection. Thus, the likely level of infection varies considerably from season to season. The fungus lies dormant within the embryo of the seed until the seeds are sown and germinate. When the infected seed germinates the fungus grows within the developing shoot, eventually reaching the ear primordia. The fungus develops within the young ear, eventually replacing spikelets with masses of fungal spores.

Control

The UK Seed Certification Scheme is successful in ensuring that loose smut remains at low levels in the UK. Control of loose smut through certification is described in Section 5.1.3.

Because the fungus invades the embryo of the seed the fungus is protected from the effects of surface acting seed treatments. Steeping in hot water (53-58°C) was the only method of treating infected stocks until the systemic fungicide carboxin was developed in the 1960's. Some strains of *U. nuda* occurring on barley are now resistant to carboxin but other, triazole-based, materials active against loose smut (e.g. Baytan, Ferrax and

Raxil S, see Table 4.7) are now available. The use of treatments specifically aimed at loose smut is generally confined to seed crops.

Varieties differ in their susceptibility to loose smut. There are, however, several different races of the fungus and the longer a variety is grown the greater the likelihood of its resistance being eroded by selection of races to which it is susceptible.

Potential losses

Seeds infected by loose smut produce normal looking tillers up until the time of ear emergence. Thus, the affected plants compete for light, water and nutrients alongside healthy plants. Affected plants produce no grain so there is a clear relationship between percentage seed infection and yield loss. A 2% seed infection will give a corresponding 2% loss of yield. The disease is very obvious in the growing crop and very low levels of infection can easily be seen. An infection of 0.1% in the field (one in a thousand ears affected) can appear dramatic, even though the yield loss would be negligible.

The level of ear symptoms in a crop is, however, not a good indication of the level of disease which may be present in seed taken from that crop. Thus, saving seed from a crop which appears to have low levels of ear symptoms can result in high levels of seed infection. The disease spreads from affected ears to healthy ears in the same crop, and also to adjacent crops. Reeves & Wray (1994) describe examples of re-infection rates of between two and six-fold in certification control plots of barley (Table 3.2).

Table 3.2 Example of re-infection rate of loose smut in winter barley

Initial seed infection (%)	Subsequent disease levels in untreated crops (%)		
	1st year	2nd year	3rd year
0.05 (Possible level in certified seed)	0.3	1.8	10.8

Thus, loose smut can build up rapidly if infected seed is re-sown without seed treatment. Although yield losses in the first year would be negligible, the field infection would pose a threat to adjacent crops.

3.2.2 Leaf stripe

Leaf stripe of barley is caused by *Pyrenophora graminea*. *Pyrenophora* is the name given to the sexual stage of fungi in this genus. The asexual name *Drechslera*, previously *Helminthosporium*, is sometimes still used.

Symptoms

As leaves emerge from the leaf sheath they have long stripes, pale green to yellow at first but eventually becoming brown and often splitting lengthways to give the leaves a shredded appearance. Most leaves are affected and diseased plants senesce prematurely. Ears are often bleached or brown in part, are often 'rat-tailed' or may remain partially enclosed within the sheath. Affected plants produce thin and shrivelled grains.

Life history

When contaminated seeds are sown the coleoptile becomes infected as it emerges from the seed. The first leaf picks up the infection as it emerges and subsequent leaves are infected in a similar way, resulting in the long stripes on the leaves. Spores produced on affected leaves are carried by the wind to developing grains on healthy plants within the field or in adjacent fields. There they germinate to produce resting mycelium on the glumes and seed coat. Diseased plants result only from infected seeds: there is no spread of symptoms within the crop during the growing season

Control

Organomercury resistant strains were first encountered in Scotland in the 1980's and became increasingly common in England prior to the withdrawal of organomercury.

Leaf stripe can be more difficult to control in winter barley than in spring barley. The inclusion of imazalil or triazoxide in formulations of some of the more recent seed treatments improves their activity against the disease.

Potential losses

An example of the tiller infections found from a range of seed infection levels in 1990 is given in Table 3.3 (Rennie, personal communication). If seedbed conditions are good and seeds germinate quickly then the tiller infection can often be well below the seed infection levels. However, if seedbed conditions are poor then resulting tiller infection is likely to be high.

Table 3.3 Relationship between seed infection with *Pyrenophora graminea* and infection in the field

Seed infection (%)	Tillers infected in field (%)
2	0.1
7	0.4
25	1.4
39	3.7
53	21.6
84	39.1

Similarly, there is a poor relationship between the level of tiller infection and the resulting infection in seed taken from that crop (Table 3.4).

Thus, a very low level of tiller infection (0.7%) can result in very high levels of seed infection (35%) if conditions favour the disease. An example of the rate of multiplication of the disease is shown in Table 3.5 (Rennie, personal communication). It can be seen that although the risk of serious multiplication in the first generation is very low, if subsequent generations are grown without treatment, the risk of a severe disease outbreak increases.

Table 3.4 Relationship infection with *Pyrenophora graminea* in the field and infection of resulting seed

Tillers infected in field (%)	Seed infection (%)
<0.1	0
0.7	35
0.8	26
1.1	10
1.9	14
3.3	44
4.6	26
21.6	76

Table 3.5 Multiplication potential of *Pyrenophora graminea*

	Disease levels (%) in subsequent generations of seed			
	1st year	2nd year	3rd year	4th year
Initial certified seed	0	0.01	0.6	36

3.2.3 Net blotch

Symptoms

Infection of young seedlings with net blotch, caused by *Pyrenophora teres*, can look very similar to leaf stripe, with a single brown stripe extending the whole length of the first leaf. However, later leaves do not necessarily show striping symptoms, but typically show short brown stripes or blotches with a network of darker lines at random on the leaves. The glumes and awns can be affected, producing dark brown flecking and striping.

Life history

Seed-borne mycelium infects the coleoptile and the first leaf becomes infected as it emerges. Spores produced on this first leaf serve to spread the disease to other leaves and to surrounding plants. Seed-borne inoculum is relatively unimportant compared with trash-borne inoculum, and does not often lead to loss of yield.

Control

Seed treatments give effective control of seed-borne inoculum.

3.2.4 Covered smut

Symptoms

Covered smut is caused by *Ustilago hordei*. At ear-emergence the grains appear to be covered in a thin membrane but if this is broken open it can be seen that the grains have been replaced by masses of black spores held in place by the transparent membrane. The membrane is relatively easily ruptured and as spores are released the symptoms are then similar to loose smut.

Life history

Some spores may be released during flowering of the rest of the crop and be carried by the wind to neighbouring plants, as are those of *U. avenae*. Many, however, are retained within their membranous envelope until the crop is combined when, during the threshing process, they are released to contaminate the surrounding seeds. In either case, the spores remain dormant until the seed is sown when they germinate and infect the developing seedling. Thereafter the life history parallels that of *U. avenae*.

Control

Since the spores lie unprotected on the surface of the seeds, covered smut is readily controlled by seed treatment.

Potential losses

Covered smut is very rare in the UK but has a life cycle similar to bunt of wheat, in that the bulk of the spread occurs during harvesting. Multiplication potential similar to bunt (Section 3.1.2), might be assumed, but there are no practical data to support this.

3.2.5 Fusarium seedling blight

Fusarium spp. and *M. nivale* are common contaminants of barley seed, but in practice do not pose the important threat that they do on wheat. Seedling blight is rarely recorded in barley crops. This may be partly due to the fact that barley tends to be grown on lighter soils and drilled earlier than wheat. However, there is also evidence, for example from germination tests, that barley is inherently less susceptible to fusarium seedling blight. A fuller account of the disease is given in Section 3.1.3.

3.2.6 Leaf blotch

Leaf blotch, caused by *Rhynchosporium secalis*, can be carried on barley seeds but this source of the fungus is of much less epidemiological importance than trash-borne inoculum.

3.2.7 Foot rot

Foot rot due to *Cochliobolus sativus* is usually thought of as a disease of hotter climates than that of the UK. However, the pathogen does appear to be present in a small proportion of UK seed stocks (Cockerell & Rennie, 1995).

Symptoms

Symptoms of the disease are similar to fusarium. Seed-borne infection can result in seedling death but more usually infected plants grow to maturity. Affected plants show brown spotting on the lower leaves and in severe cases, can show stem-base rotting and poorly filled ears. This severe symptom is very rare in the UK.

Life history

The fungus behaves very much like *Fusarium* spp. and *M. nivale* in its survival and life history. It is both soil and seed-borne. It infects seedlings as they emerge, occasionally producing a seedling blight. More usually it infects roots of seedlings, allowing the plant to survive. Leaf spotting and stem-base infections produce air and splash-borne spores which can be carried to emerged ears resulting in seed infection.

Control

The disease is still relatively uncommon and does not pose a serious threat to crops in the UK. Seed contamination is largely superficial and is readily controlled by seed treatments.

3.3 SEED-BORNE DISEASES OF OATS

3.3.1 Loose smut (*Ustilago avenae*)

Symptoms

Loose smut of oats is caused by *Ustilago avenae*. Symptoms are similar to those of loose smut on wheat and barley.

Life history

Like those of *U. nuda*, the spores of *U. avenae* are carried by the wind to the open flowers of surrounding plants. Unlike loose smut of wheat and barley, the spores do not penetrate the embryo of the seed but either remain in the outer husks covering the grain or they germinate, producing a resting mycelium on the inner surfaces of the glumes or on the seed itself. When affected seed is sown the spores germinate to produce mycelium or the existing dormant mycelium is activated. The resulting mycelium penetrates the germinating seedling and grows up with the shoot eventually to infect the developing ear.

Control

Since the spores of the fungus or the resting mycelium are not protected within the seed, the disease can be readily controlled by seed treatment.

Potential losses

The way in which loose smut of oats spreads is comparable with that of loose smut in wheat and barley. Thus, it may be reasonable to assume that similar disease progress and yield losses could occur in oats as in barley (Section 3.2.1).

3.3.2 Covered smut

Symptoms

The symptoms of covered smut of oats, caused by *Ustilago hordei*, are virtually indistinguishable from those of loose smut. At ear-emergence the grains are covered in a thin membrane, but in oats this membrane is easily ruptured, releasing the masses of black spores.

Life history

In oats, because of the delicate nature of the outer membrane retaining the spores, most of the spores are released during flowering of the rest of the crop and are carried by the wind to neighbouring plants as with *U. avenae*. The spores remain dormant on the outside of the affected grain until the seed is sown when they germinate and infect the developing seedling. Thereafter the life history parallels that of *U. avenae*.

Control

Since the spores lie unprotected on the surface of the seeds, covered smut is readily controlled by seed treatments.

3.3.3 Leaf spot and seedling blight

Symptoms

Leaf spot and seedling blight of oats is caused by *Pyrenophora avenae*. The coleoptile becomes infected as it emerges from the seed. The first 3 or 4 leaves have short brown stripes, often with purple margins. Subsequent leaves are healthy as they emerge but can become infected later, producing brown spots with purple margins.

Life history

The disease can survive as spores carried on the seed or as dormant mycelium in the husk. The spores germinate, or the dormant mycelium becomes active, and infection of the coleoptile occurs as it emerges from the seed. The first 3 or 4 leaves become infected as they emerge (hence the stripes on them) and young seedlings may be killed completely. Later emerging leaves are infected by spores produced on the primary stripes. Spores produced on these secondary spots then contaminate grain.

Control

The disease can be readily controlled by seed treatment. Organomercury resistant strains of *P. avenae* have been known since the 1960's and became common before the withdrawal of organomercury.

Potential losses

Before the widespread use of organomercury seed treatments, leaf spot and seedling blight was regarded as an important disease of oats. However, even when resistance to organomercury was common, no serious outbreaks of the disease occurred. The reason for this is not understood. Early work on the disease showed that the most serious losses occurred with the primary phase of the disease, effectively a seedling blight. Severely affected seedlings could be killed pre-emergence or soon afterwards. Surviving tillers produced poorly filled or 'blasted' spikelets.

The multiplication potential of this disease is thought to be similar to leaf stripe of barley (Section 3.2.2), although seedling blight could result in greater yield loss. Losses due to seedling blight are exacerbated by poor, cold seedbeds, as with seed-borne fusarium on wheat.

3.3.4 Fusarium seedling blight and foot rot

Oats can be severely affected by fusarium seedling blight, much like wheat. The foot rot phase can also be severe. The same ranges of pathogens affect all of the cereals and details of the symptoms, life cycle and control are given in Section 3.1.3.

3.4 SEED-BORNE DISEASES OF RYE

3.4.1 Ergot

Ergot is described in Section 3.1.5.

3.4.2 Stripe smut

Symptoms

This disease, caused by *Urocystis occulta*, is specific to rye. It differs from the other smuts of small grain cereals in that it affects stems and leaves as well as ears. It produces long dark blisters in stripes parallel to the veins which eventually rupture to expose the spores.

Life history

The disease is both soil-borne and seed-borne. The developing grains in ears are contaminated by wind blown spores but the spores remain on the seed surface. Infection of the seed occurs at germination as with bunt. Soil-borne inoculum is more important with this disease than with the smuts affecting other cereals in the UK.

Control

Most seed treatments will control seed-borne infection. Baytan should control the soil-borne phase. Stripe smut has always been an uncommon disease despite the fact that, until very recently, rye seed was seldom treated with a fungicide seed treatment.

Potential losses

Since stripe smut is specific to rye, this disease is unlikely to become a serious risk unless the area of rye was to rise dramatically. However, isolated severe attacks have occurred, demonstrating potentially large losses (Gair *et al.*, 1972). Since spores of stripe smut spread during the growth of the crop and can survive on seed and in soil, the potential for multiplication may be similar to loose smut, with the added risk of soil-borne infection.

3.4.3 Bunt

Rye can be affected by bunt although the strains attacking the crop are specific to rye, and cross infection from wheat to rye does not occur. The disease is very rare.

3.4.4 Fusarium seedling blight and foot rot

Rye can be severely affected by fusarium seedling blight, much like wheat. Fusarium foot rot can also be severe. The same range of species affects all cereals and details of the symptoms, life cycle and control are given in Section 3.1.3.

3.5 SUMMARY OF POTENTIAL LOSSES DUE TO SEED-BORNE DISEASES

The risk of in-crop losses is summarised for two scenarios (Table 3.6). Firstly, saving seed once from a crop grown from certified, treated seed (a). Secondly, saving repeatedly without treatment (b). The very high, high, moderate and low risk values represent both the multiplication potential of the disease and the severity of its effect on yield and/or marketability. Risk of spread to adjacent crops, indicates both the likelihood of spread and the severity of effect of that spread.

Table 3.6 Summary of the risk of losses due to seed-borne diseases

Disease	Risk of in-crop losses		Risk to adjacent crops
	(a)	(b)	
Loose smut-of-wheat and-barley	Low	High	Moderate ¹
Loose smut of oats	Low	High	Moderate ¹
Covered smut of barley and oats	Low	Moderate	Moderate ¹
Bunt (stinking smut) of wheat	Low	Very high	Low ²
Stripe smut of rye	Low	Moderate	Moderate ¹
Leaf spot and seedling blight of oats	Low	Moderate	Moderate ¹
Leaf stripe of barley	Low	Very high	Moderate ¹
Fusarium seedling blight	- ³	- ³	Very low ³
Septoria seedling blight of wheat	- ³	- ³	Very low ³
Net blotch of barley	Very low	Low	Very low ⁴

(a) Seed saved from a crop grown from certified treated seed.

(b) Seed saved repeatedly without treatment.

¹ No threat is posed to adjacent growing crops, unless seed is taken from them which may then carry infection.

² May pose a threat to adjacent fields by wind blown spores released during harvesting contaminating the soil, leading to soil-borne infection of a subsequent wheat crop. Such cases are very rare.

³ The incidence of the disease in a growing crop is related to weather conditions during the season. This affects the level of seed-borne disease present on seed saved from the crop. Thus, multiplication of the disease in a season is weather dependent and is not related to disease levels on the seed sown.

⁴ Net blotch is a foliar disease, capable of long distance air-borne spread. However, the disease is endemic and the likelihood of an adjacent crop being put at additional risk because of spores arising from seed-borne infection in is small.

CHAPTER 4

CURRENT UK PRACTICE IN CEREAL SEED HEALTH AND SEED TREATMENT USE

4.1 SEED PRODUCTION

4.1.1 Seeds legislation

Certification is a system of checking aspects of seed quality which, as far as possible, aims to ensure that seed has the following attributes:

1. Correct variety
2. High level of varietal purity
3. Low level of contamination with weed or other crop seeds
4. Low level of inert matter, e.g. chaff
5. High germination
6. Low level of some important diseases

There are precise standards for these attributes, which are laid down in the legislation controlling certification.

In the European Union (EU) the certification of cereal seed is regulated by the Cereal Seeds Marketing Directives (66/402/EEC) (Anon., 1966). These Directives prescribe minimum quality standards, and rule that only certified seed may be marketed. This means in effect that the sale of uncertified seed is illegal. Each Member State must implement the Directives in its national legislation and in the UK this is done via The Cereal Seeds Regulations 1993 (Anon., 1993b). The seeds legislation in the EU protects growers, by laying down the standards that must be met by certified seed. It also provides a basis for intra-community trade and ensures that seeds are of high enough quality to meet the needs of agriculture.

Member States are allowed to prescribe stricter standards than those in the Directives, and most do, but for differing aspects of seed quality. In the UK, the most notable example of this is the 'Higher Voluntary Standard' (HVS), which is part of the Cereal

Seeds Regulations. HVS seed is certified to higher standards of varietal and species purity, and of loose smut infection, than the minimum grade of seed specified in the European Directives. In the Cereal Seeds Regulations, this grade of seed is called 'Minimum Standard' (MS). Wheat, barley and oats, but not rye or triticale, can be certified to HVS standard.

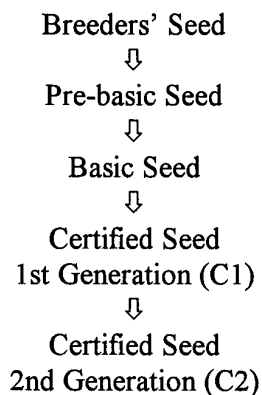
The legislation requires that certification is under the control of independent official bodies, giving consumers greater confidence in the quality of the seed. In England and Wales, the Certifying Authority is the Ministry of Agriculture, Fisheries and Food (MAFF), and the National Institute of Agricultural Botany (NIAB) is contracted by MAFF to carry out the technical work. In Scotland, the Certifying Authority is the Scottish Agricultural Science Agency (SASA), who also carry out the technical work. Similarly, in Northern Ireland, the Department of Agriculture for Northern Ireland (DANI) carries out all of these duties. It is the task of these official bodies to advise on standards, design procedures and operate the certification schemes.

4.1.2 Seed certification

Seed multiplication

Several years of multiplication are needed to provide enough seed for commercial crop production. The generations of seed multiplication are controlled in the certification scheme, starting with small quantities of 'Breeders' Seed' and ending with 'Certified Seed' (rye and triticale) or 'Certified Seed 2nd Generation' (wheat, barley and oats).

The generation system for wheat, barley and oats is illustrated below:



Most growers sow seed of the final generation for commercial crops. In the system illustrated above this would be Certified Seed 2nd Generation (C2).

Basic, C1 and C2 seed can be certified at HVS or MS, but there is no HVS for Breeders or Pre-basic seed. In recent years between 70% and 75% of C2 seed bought by farmers has been HVS.

Sampling

The objective of sampling, as defined in the International Rules for Seed Testing (Anon., 1993a), is to obtain a sample suitable for tests, in which the probability of a constituent being present is determined only by its level of occurrence in the seed lot (Anon., 1993a). A seed lot is a specified quantity of seed and the maximum weight for a cereal seed lot (except maize) is 25 t (Anon., 1993b). A seed lot must be packaged in sealed containers and each container must be labelled with the unique seed lot reference number authorised by the Certifying Authority. The seed lot should be homogeneous and at the time of sampling the lot should have been subject to appropriate mixing and blending and processing techniques so that it is as uniform as possible.

The Cereal Seeds Regulations (Anon., 1993b) Schedule 5 Part II specify that the minimum weight of a sample to be taken from a seed lot and submitted for certification quality tests is 1 kg. The sampling of seed lots is also governed by these regulations and samples must be taken by someone authorised and licensed by the Certifying Authority; that is a person who has passed an official examination and shown competence in seed sampling and who has been officially licensed by the appropriate government department, MAFF in England and Wales, SOAEFD (Scottish Office Agriculture Environment and Fisheries Department) in Scotland and DANI in Northern Ireland. The sample of seed taken by the authorised sampler should provide a representative sample of the seed lot for quality testing.

Quality assurance

The certification procedure involves a number of tests on seed to ensure that the standards set in the Cereal Seeds Regulations are met. These regulations also include

various preventative measures, aimed at maintaining seed quality, by stipulating for example, compulsory isolation of seed crops from sources of foreign pollen and previous cropping restrictions.

The quality tests on seed lots and seed crops are:

1) Seed Testing

Every seed lot must be tested for analytical purity, germination capacity, and the presence of other seeds (species purity). The test must be carried out at an Official Seed Testing Station (OSTS) or an officially Licensed Seed Testing Station (LSTS). In practice almost all tests are carried out by LSTSs. Analytical and species purity can be tested in less than one hour, but a germination test takes several days. An important difference between HVS and MS is that the sample searched for species purity is twice as large for HVS (1 kg) as for MS (500 g).

2) Sample Examination

Samples of all seed lots which will be used to produce more certified seed (i.e. Breeders, Pre-basic, Basic and C1 seed lots) are assessed by NIAB, SASA and DANI for varietal identity and varietal purity. Barley grain characters are checked in the laboratory, allowing very detailed examinations that may prevent contaminated seed from being used further. In addition 10% of C2 seed lots are checked to see that the standards for varietal purity are met.

3) Control Plots

The same samples as in 2) are used to sow control plots. Thus, for every crop grown to produce more seed, there is a plot representing the sown seed. These plots can be examined more closely and more frequently than seed crops. Plots are assessed for:

- varietal identity
- varietal purity
- species purity
- loose smut infection.

Seed crops may be downgraded or rejected if the control plots indicate a varietal admixture or loose smut infection in excess of the standards.

4) Crop Inspections

Inspections of seed crops in the field are complementary to control plot work. Whereas control plots are used to detect seed stock contaminations, field inspections are needed to check for:

- admixtures of other varieties from various sources e.g. volunteer
- contamination from weeds or other crops
- isolation from adjacent cereal crops
- crop condition

5) Documentation

All seed lots and seed crops are registered with NIAB, SASA or DANI. The results of tests and checks are collated with applications for certification, to ensure that certification is allowed only when all standards have been met in the growing seed crop and resulting seed lot. An important aspect of this work is pedigree checks, ensuring that every seed crop was sown with an eligible parent stock and that every seed lot produced comes from an approved seed crop.

4.1.3 Control of seed-borne diseases by certification

Two seed-borne diseases are specifically mentioned in the European Directives; ergot and loose smut. The Directives specify maximum levels of ergot allowed in seed samples. There is also a more general requirement for seed health in Annex I, 4, which states:

"Harmful organisms which reduce the usefulness of the seed, in particular *Ustilagineae*, shall be at the lowest possible level."

This refers to seed crops and there is a similar statement relating to seed lots. With the exception of ergot, European Directives do not lay down standards for any seed-borne disease.

Work on seed-borne diseases is only a small part of the certification process, and it is difficult to estimate its cost. However, the total cost of certifying and testing C2 seed of cereals is about £2.7 million per annum, of which about £50,000 to £100,000 can be attributed to work on seed-borne diseases.

Ergot

The UK Cereal Seed Regulations (Anon., 1993b) adopt the standard from the European Directives (Table 4.1) for the presence of ergot sclerotia in MS seed samples. There is also a HVS for ergot. Assessments for ergot are made at the same time as the species purity test in the seed testing laboratory.

Table 4.1. UK standards for ergot and loose smut (Cereal Seed Regulations, Anon., 1993b)

	Minimum Standard (MS)	Higher Voluntary Standard (HVS)
	Infection with loose smut (%)	Infection with loose smut (%)
Basic seed	0.5	0.1
C1	0.5	0.2
C2	0.5	0.2
	Maximum pieces of ergot in 500g	Maximum pieces of ergot in 1 kg
Basic seed	1	0
C1 and C2	3	1

Loose smut

For loose smut infection in seed of barley, wheat, durum wheat and spelt wheat the UK Regulations go further than European Directives, in that maximum levels of infection are prescribed (Table 4.1). The same standards also apply to seed crops. The Regulations do not prescribe loose smut standards for oats, rye or triticale, presumably because historically the disease has not been important in these crops.

Although there are standards applicable to loose smut infection in cereal seed, the certification procedure does not require routine testing of every seed lot. This is presumably because testing would add to the cost of seed, and loose smut is assessed during control plot examinations. Nevertheless, seed producers have a legal obligation to ensure that all marketed seed complies with the certification standards.

Loose smut is assessed in the control plots of seed being multiplied to indicate which seed crops will have excessive infection. In addition, plots are grown of 10 % of all C2 seed lots to check that standards are met. Assessment of loose smut in plots is more reliable than during crop inspections, where variation in time of ear emergence, and spores being dislodged by rain and wind, can lead to an underestimate of infection. Infected ears are counted in control plots at regular intervals over a four week period beginning at ear emergence. On each occasion infected ears are counted and removed from the plot.

Standards are not applied as a strict percentage but instead 'reject values' are used. A statistical formula is applied, taking into account plot population, which ensures that the probability of improperly rejecting a sample which just meets the standard is only 1%. In the event that a seed stock has excessive infection, all seed crops sown with it are rejected at the category or level where the standard has not been met. However, seed can be 'retrieved' from rejection. The Regulations permit rejected crops to be used for seed if either of the two following conditions is met:

1. if the seed is "adequately treated by any method approved by the Minister [based on advice from the Certifying Authorities and NIAB] for the control of loose smut, or
2. if an embryo test carried out by an official seed testing station, on the sample submitted for official examination shows that the seeds meet those standards."

Where a seed treatment is used it must be a product with a proven high level of efficacy. A new product must be as least as effective as currently approved treatments before it will be accepted for retrieval.

Other seed-borne pathogens

There are no standards applied for seedling diseases (e.g. fusarium and septoria), bunt of wheat or leaf stripe of barley although the UK Cereal Seeds Regulations (Anon., 1993b) do have the general requirement that:

"The seeds shall be of a satisfactory state of health in so far as seed-borne diseases and organisms affecting the seeds are concerned." (Schedule 4, Part II)

This statement may lead growers to believe that they are protected from seed-borne pathogens. However, such a requirement is difficult to enforce and, in practice, most seed-borne pathogens are controlled through the application of seed treatment. At the time the Regulations were established, organomercury seed treatments controlled most cereal seed-borne pathogens, with the exception of loose smut, and this perhaps explains why there has previously been no need to have specific seed certification standards for them.

4.1.4 The UK cereal seed industry

Seed companies

There are a number of different types of company involved in certified seed production, and marketing seed:

Plant breeders maintain varieties and often produce only the very early generation material - Breeders, Pre-basic and Basic seed. They supply Basic seed to retailing seed companies who use it to produce C1 and C2. Some breeders also produce C1.

Agents for foreign breeders import Pre-basic and Basic seed and usually supply other companies with Basic seed for further multiplication. A UK breeder might also act as an agent for a foreign breeder. There are about 20 breeders and agents involved in Pre-basic and Basic seed production in the UK.

Wholesalers produce seed for selling on to other seed companies, as well as, or instead of, retailing to farmers.

Processors are companies who take in seed from approved crops after harvest, clean it, sample it, bag and label it, and have it certified.

Merchants are companies who register seed crops with the certifying authority but get another company to process and certify the seed. There are also companies who sell seed to farmers, but are not involved in the seed production process.

There are currently about 200 companies producing cereal seed in the UK. In recent years, the number of companies has declined in England and Wales, but has stayed fairly constant in Scotland. The companies vary in size and nature, from small local firms processing a few hundred tonnes, to national or multinational companies producing tens of thousands of tonnes each year.

The UK cereal seed market

The UK production of certified seed peaked in the mid 1980's at about 600,000 tonnes. It has since dropped as a result of a decrease in cereal cropping, and since the introduction of set-aside, which took about 12% of cereal land out of production, the annual production of certified seed has been around 440,000 tonnes. The amounts of seed certified in the UK in 1994/5 and 1995/96 are given in Table 4.2. The majority of seed used in the UK is home produced and is normally processed near the main markets.

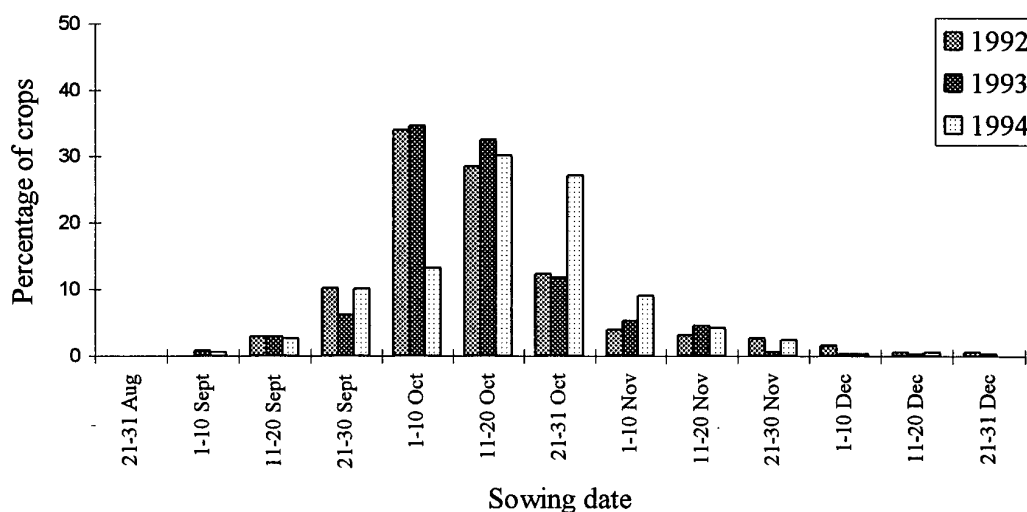
In 1995/6, 87% of UK certified seed was produced in England and Wales, 12% in Scotland and slightly less than 1% in Northern Ireland. Winter cereals made up 81% of the total and spring cereals 19%. In Scotland the emphasis is on spring barley production where 60% of cereal production in 1994/95 was spring barley (Anon., 1995). These figures are typical of the situation in the last few years.

Table 4.2 Weights of seed certified in the United Kingdom in 1994/5 and 1995/96

	1994/95 (tonnes)	1995/96 (tonnes)
Winter wheat	245,000	262,000
Spring wheat	5,400	4,900
Winter barley	93,500	105,500
Spring barley	75,700	79,300
Winter and spring oats	16,600	13,700
Rye and triticale	2,900	3,400

The current preference for autumn sowing in England and Wales has created a large demand for seed in late September and early October. Figures 4.1 and 4.2 show annual drilling date frequency distributions for over 350 randomly selected winter wheat and winter barley crops from England and Wales during the years 1992 to 1994 (Polley & Slough, 1992a *et seq.*; 1992b *et seq.*)

Figure 4.1 Winter wheat sowing dates in England and Wales, 1992-1994



Farmers are reluctant to take early delivery of seed and merchants have limited storage, so the majority of seed has to be processed in the autumn. Data for England and Wales showed that in autumn 1994 an average of 1,000 seed lots per week were processed during September and October (Figure 4.3), and that during a three week period in

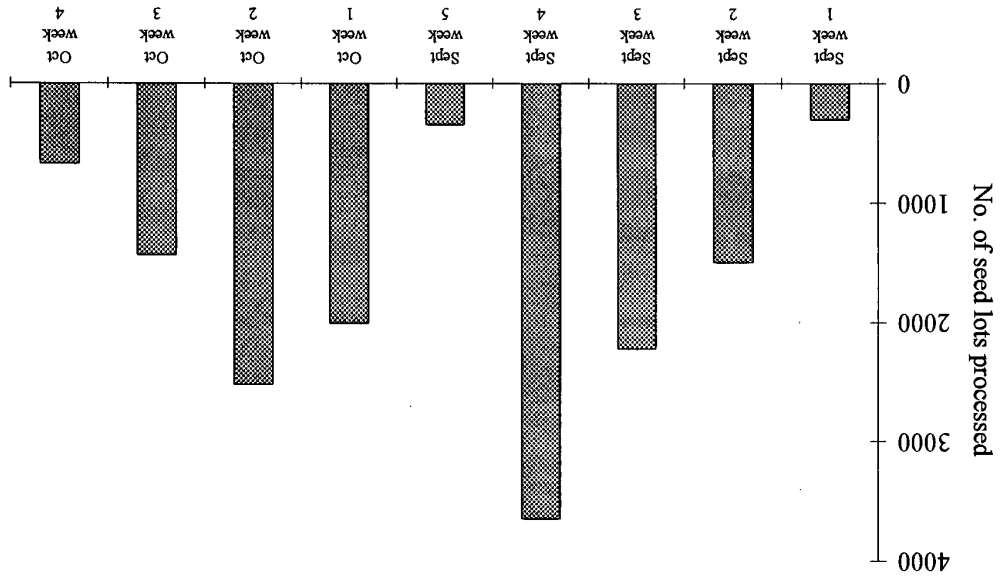


Figure 4.3 Number of seed lots processed per week in England and Wales, autumn 1994

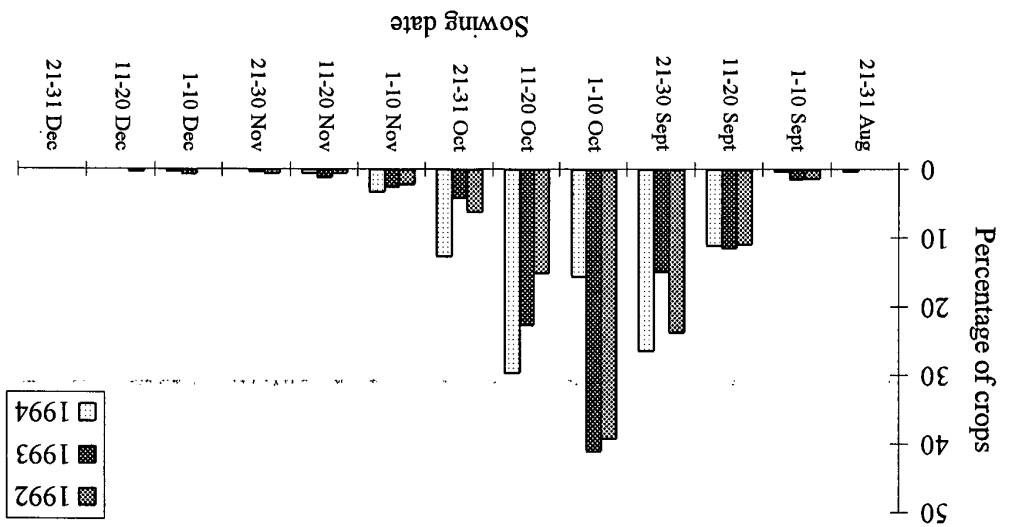


Figure 4.2 Winter barley sowing dates in England and Wales, 1992-1994

September, over 7,000 lots were processed. These 7,000 seed lots represent an estimated 42% of the total year's supply of cereal seed for the UK.

This large autumn peak demands quality assurance systems that can cope with a very high throughput, without delaying the supply of seed. Any strategy for seed health which is based on seed testing needs to take this into account.

Value of the certified seed market

Seed costs vary according to variety, tonnage ordered, availability and category.

With all these variables it is difficult to quantify the value of the cereal seed market. However, assuming £1000/tonne for Basic, £450/tonne for C1, £220/tonne for C2 winter varieties and £300/tonne for C2 spring varieties, this puts the value of UK certified seed at around £110-130 million each year. Seed treatment adds an estimated £23 million.

Breeders royalties

Almost all currently grown cereal varieties have Plant Breeders' Rights, which entitle the breeder to collect royalties on sales of seed. In 1995, European Plant Breeders' Rights were introduced, which extended this right to farm-saved seed.

The royalty is included in the price of certified seed and is passed on to the British Society of Plant Breeders (BSPB) by the seed processor. BSPB redirects it to the breeder. Royalties on C2 seed are normally between £25 and £50 per tonne, with older varieties at the lower end of the range and most new varieties at the upper end of the range.

Recent legislation will allow breeders to collect royalties on farm-saved seed, and a mechanism for collecting them has been agreed between the BSPB and the National Farmers Union (NFU) and other organisations representing farmers. Royalties on farm-saved seed will be lower than on certified seed.

4.1.5 Current practice for treatment and disease testing of certified seed

Seed treatment fungicides are applied to certified cereal seed in the UK on a routine basis, although effective seed treatment is not a requirement of certification. The seed trade views routine seed treatment as a good insurance against the effects of seed-borne disease and potential claims by growers. In some seasons the use of seed treatments to help seed reach the 85% germination standard is important. Some companies believe that routine treatment is 'best practice' since it prevents the build-up of inoculum. In addition, seed treatments provide an economic return to seed merchants and are important to their financial viability.

Very little disease testing is done on certified seed, although some seed producers routinely test seed of susceptible barley varieties for loose smut prior to the application of seed treatments.

4.1.6 Use of certified and farm-saved seed

Certification agencies publish information on the quantity of certified seed, and BSPB is aware of the volume of seed sales, but there is little data on the tonnage of farm-saved seed. Estimates of the use of farm-saved seed, based on the national cereal area, assumed seed rates and the weight of certified seed, have been calculated at 20-30% of crops being sown with farm-saved seed. Figures from the 1995 Central Science Laboratory (CSL)/ADAS cereal survey (Polley *et al.*, 1995a,b) (Table 4.3) agree with this estimate. The proportion of farm-saved seed varies slightly from year to year depending on perceptions of likely seed quality and variety choices. It is smallest when new varieties with perceived benefits are introduced to the market place, and largest when a few varieties dominate the market and/or when harvest is early. A survey of 682 farmers commissioned by Farmers Weekly in 1994 showed that 70% of farmers saved some of their own seed for re-sowing.

The proportion of crops sown with farm-saved seed in other European countries varies. Estimates quoted in the farming press range from around 15% in Denmark, 50% in

France and Germany, and up to 85% in Spain. Similar figures for Denmark and France were given by Rennie & Cockerell (1994).

Table 4.3 Use of certified and farm-saved seed, CSL/ADAS Cereal Disease Survey 1995

	Per cent crops grown from:		No. of crops surveyed
	Certified seed	Farm-saved seed	
Winter wheat	71	29	360
Winter barley	79	21	351

UK cereal growers have benefited enormously from improved varieties (Silvey, 1986, 1994) and the breeding effort which has enabled this has been funded by royalties collected on the sales of certified seed. Since royalties collected on farm-saved seed will be at a lower rate, income for breeding will continue to rely primarily on a successful seed supply trade.

The seed trade is concerned that the usage of farm-saved seed has increased in the last few years, but there is little clear evidence to confirm this. However there is no doubt that farm-saving is an option considered by many growers to reduce the cost of inputs. In a 1985 survey carried out by 'Produce Studies Ltd', 95% of farmers who were saving their own seed gave cost as a reason for doing so. The introduction of royalties on farm-saved seed will reduce the cost margin between it and certified seed, so cost could become a less important factor.

Quality assurance measures for farm-saved seed are very variable, from procedures similar to certified seed production and in some respects even more rigorous, to nothing at all. The 1985 survey by 'Produce Studies Ltd' suggested that certified seed, often C1, was used in the majority of cases to sow the crop used for farm-saved seed. Very few seed tests were done, except for germination and moisture content. Testing for seed-borne diseases was unusual and 87% of farmers applied a seed treatment routinely.

CSL/ADAS Cereal Disease Surveys (Polley & Slough, 1992a,b, 1993a,b, Polley *et al.*, 1994a,b, 1995a,b) of recent years show that on average about 5% of cereals are grown from seed without a fungicide seed treatment. The most recent survey (Table 4.4), suggests that most of the untreated seed is farm-saved.

Table 4.4 Treatment of certified and farm-saved seed, Cereal Disease Survey 1995 (Polley *et al.*, 1995a, 1995b)

	Certified seed		Farm-saved seed		No. of crops
	Treated (%)	Untreated (%)	Treated (%)	Untreated (%)	
Winter wheat	99	1	92	9	360
Winter barley	98	2	81	19	351

If it is assumed that 5% of the 10,672 cereal growers in England and Wales growing more than 50 ha of wheat, sow some of their seed without seed treatment, then about 500 growers are sowing seed untreated. Table 4.5 shows the number of seed health tests carried out for England and Wales by the Official Seed Testing Station in Cambridge.

These figures show the number of tests performed by the OSTS, Cambridge, not the number of seed lots tested or the number of growers that have their seed tested. For example, based on the assumption that one test is performed per sample and that each sample is received from an individual grower, the data suggest that between 200 and 300 farmers had their wheat seed tested for fusarium between 1993 and 1995. This is however not the case, since growers that have their seed tested often send two or three samples, with each having more than one test performed on it. These data therefore overestimate the number of growers who have seed tested, possibly by a factor of two or three, suggesting that a large proportion of growers saving their own seed do so without any knowledge of its health status.

Table 4.5 The number of seed health tests requested at the OSTS, Cambridge, on wheat and barley 1993 - 1995

Crop	Disease	Number of tests requested		
		1993	1994	1995
Barley	Loose smut	120	84	105
	Leaf stripe/net blotch	126	121	108
Wheat	Bunt	191	168	255
	Fusarium	304	203	271
	Septoria	13	9	11

4.2 SEED TESTING

4.2.1 Introduction

Seed health tests have been developed which determine the incidence of specific disease-causing organisms in cereal seed. More than one type of test may be required to determine the full health status of a seed sample. The different methods of testing vary in sensitivity, reproducibility, and in the amount of training and equipment required to carry them out. The appropriate method depends on the pathogen to be investigated, the species of seed and the purpose of the test. The number of seeds tested to ensure a worthwhile quantitative result is critical. The International Seed Testing Association (ISTA) recommends that at least 400 seeds should be used, but where low levels of infection are important, a large number of seeds must be tested (Anon., 1993a), e.g. in certification tests for loose smut 2000 seeds (embryos) are examined.

Seed health tests have a number of general requirements which were reviewed by Reeves (1995). These include speed, particularly where high throughput is needed, and simple procedures with as few steps as possible to minimise handling and errors. Seed health tests should be accurate and repeatable within limits of variation and should be as easy as possible for the operator to record without subjectivity. The cost of the test should not be too high.

The establishment of the relationship between laboratory test results and the incidence of disease in the growing crop is crucial and is covered in Section 4.2.4.

4.2.2 Current seed testing methods

The seed-borne pathogens of most concern in cereals are fungi, and current test methods have been in use for many years. Tests for leaf stripe, seedling diseases and net blotch involve plating the seeds onto agar. After incubation, the seeds are examined for mycelial growth characteristics, or by microscope for spore morphology, or both. Alternatively, seeds are placed on moist paper blotters, subjected to various treatments including an incubation stage, and examined by microscope (de Tempe & Binnerts, 1979; Hewett, 1965; Rennie & Tomlin, 1984). The incubation step in these methods allows growth of the pathogen for identification and may last a week or more. This type of incubation test is best suited to those pathogens occurring as dormant mycelium or spores in the outer layers of cells, usually the pericarp.

The test for loose smut, where the fungal mycelium is deep-seated within the embryo, involves extraction of the embryos and examination under the microscope for *U. nuda* mycelium (Rennie, 1984). The test for bunt, where spores are carried on the seed surface, involves washing the seeds and examining centrifuged or filtered washings under the microscope (Keitrieber, 1984). These two tests are quicker than those requiring incubation and fungal growth, and can be completed within 24 hours. They are, however, labour intensive, particularly that for *U. nuda*.

The technology used in these seed tests is not modern, and although it can be extremely effective and appropriate in some contexts it has a number of disadvantages. Firstly, incubation tests are slow, typically taking a week or more. Secondly, the identification of a particular pathogen requires skill and experience. Some pathogens are especially difficult to identify, e.g. *Pyrenophora* spp., but even where identification is easy in pure culture, the presence of pathogens may be obscured by other fungi and bacteria growing on the seed. Where the level of infection is low the difficulty is greater and the sensitivity of the seed test may be compromised.

The advantages are that these tests usually do not require complex and expensive equipment, and give an indication of pathogen viability. They also give an estimate of the number of seeds infected.

The disadvantages of existing methods mean that seed health tests are relatively expensive (currently £40 to £50 per test at OSTs, Cambridge). Large-scale testing with high throughput requires significant investment to provide sufficient capacity and trained personnel. This problem is exacerbated by the short time between harvest and sowing of winter cereals. These disadvantages have led to much interest in the use of new techniques in seed health testing, to improve the speed, accuracy and sensitivity of diagnosis (Reeves, 1995).

4.2.3 New test methods

Most improvements in seed health testing have concentrated on the development of semi-selective media for isolating the pathogen (mainly bacteria) and, more recently, on immunodetection techniques. The first immunodetection methods used polyclonal antibodies, but monoclonal antisera are increasingly being used to improve accuracy and overcome unwanted cross reactions. This has led to considerable advances in the development of immunoassays, particularly for fungal pathogens, but problems associated with extraction of suitable fungal antigens and the efficiency of isolating suitable monoclonal antibodies remain. These problems vary in extent for different host/pathogen complexes.

Recent developments in the raising of monoclonal antibodies *in vitro*, using genetically modified bacteria expressing antibody genes, hold great promise for the development of immunoassays. It is probable that further developments will allow these kinds of assays to be used in the field, as 'dipstick' type tests, as well as in the laboratory.

Antibody-based tests have been developed for the detection of cereal pathogens (Dewey & Priestley, 1994), and some of these have targeted seed-borne pathogens with varying degrees of success (Burns *et al.*, 1994). None is yet being used as part of routine high throughput seed health testing.

Another recent development is the use of conductance measurement for the detection of plant pathogenic bacteria and fungi (Fraaije *et al.*, 1994). This technique has been used for the detection of human pathogens in food, and although it shows some promise for plant pathogens the technique has not been developed for cereal pathogens or in routine seed testing.

DNA probes

The most powerful new technology available for the improvement of seed health testing is based on the molecular biochemistry of nucleic acids. These techniques have progressed rapidly over the last decade. They have a great power of discrimination between organisms and can detect them at very low concentrations. Such attributes are valuable for seed health testing and have the potential to overcome some of the disadvantages of conventional methods.

The use of nucleic acid methods for detection of bacteria dates back to the early 1980's when DNA probes were used to detect strains of *Escherichia coli* pathogenic to humans. Probes are short pieces of single-stranded DNA with a sequence homologous to some specific portion of the genome of the target organism. Under appropriate conditions the probe can be made to hybridise with the homologous target DNA and if the probe contains a label, or reporter molecule, the presence of the hybrid molecule can be detected. This process forms the basis of an extremely accurate method of identification, providing that the probe is specific, and the target sequence is unique to the pathogen. The first tests of this type used radioactive labels, making it expensive to carry them out safely, but their potential was clearly demonstrated (Rasmussen & Reeves, 1992; Reeves, 1995). Radioactive labels have now been largely replaced by safer techniques, simplifying any large scale use of probes.

Polymerase chain reaction (PCR)

Although DNA probes are highly specific to a particular pathogen, problems were encountered with their sensitivity and the presence of contaminating DNA. In the mid 1980's, the polymerase chain reaction (PCR) was developed (Saiki *et al.*, 1985). This

was quickly recognised as a powerful technique with the potential to combine the specificity of DNA probes with a high level of sensitivity. The development of PCR for a number of applications in diagnostics has grown rapidly, and it is now the method of choice for new tests to detect pathogens in medical, food, plant and increasingly seed pathology.

PCR allows a specific DNA sequence of the target pathogen to be amplified to a very high concentration in the reaction mixture, making it easy to detect and identify by gel electrophoresis or other methods. The amplification step is mediated by a DNA polymerase enzyme, which reproduces copies of the target DNA sequence, delineated by two short single-stranded sections of DNA known as primers. The technique involves successive cycles each of which theoretically doubles the concentration of the target DNA. The first step in the cycle is to denature the target DNA to two single strands, followed by annealing the primers to the complementary sequences in the target DNA, which are then extended to give two double stranded copies. These copies serve as templates for the next cycle, and so on.

This amplification process takes about two hours depending on experimental conditions and is very sensitive, typically detecting picogram (10^{-12} g) quantities of target DNA. Its specificity depends on an appropriate choice of primers, and prior knowledge of DNA sequences is required to facilitate primer design.

The speed and specificity of PCR make it very attractive as a diagnostic tool for many purposes, leading to much interest in plant and seed pathology. There is a growing number of examples of its diagnostic use in plant pathology (Schots *et al.*, 1994), and although there are fewer examples in seed pathology (Reeves, 1995) its use is increasing.

There are however some disadvantages to PCR. Whilst it is reliable when amplifying from pure DNA, the reaction may be inhibited by other materials. Problems have been encountered with some seed material (Reeves, 1995), although PCR has been made to work in the presence of biological matrices such as milk, saliva, cerebrospinal fluids and sewage sludge. This problem is not insuperable but adds to development costs.

In summary, the advantages and disadvantages of PCR-based techniques in seed health testing are:

Advantages

- The testing system can be substantially automated (e. g. by the use of plate readers and bar code labelled samples), greatly increasing test capacity
- Subjectivity in reading test results is largely removed
- Tests can be completed within 48 hours
- Pathogen detection can be made exceptionally sensitive

Disadvantages

- Substantially different skills are needed compared to traditional techniques. This could impede implementation unless carefully managed
- Development and capital costs are high, requiring high throughput to achieve low unit cost
- Quantitative results can be difficult to achieve
- Relationships between test output and field expression would need to be established

Many of the same considerations apply to immunoassay-based techniques.

The difficulty of obtaining a quantitative result from new testing methods might be overcome by the use of most probable number techniques. Alternatively, the rapidity of the test might be exploited as an initial screen to separate infected from uninfected seed.

The power of these techniques and their impact on allied diagnostic applications makes it likely that they will be beneficial in seed health testing. Rapid, accurate and sensitive tests could make a contribution to the management of seed-borne disease, giving more information about the health status of seed in time for appropriate action to be taken before drilling. The time between harvesting and drilling is very short for winter cereals, and it is unlikely that traditional techniques could meet the demand arising from any significant increase in seed health testing of winter cereals.

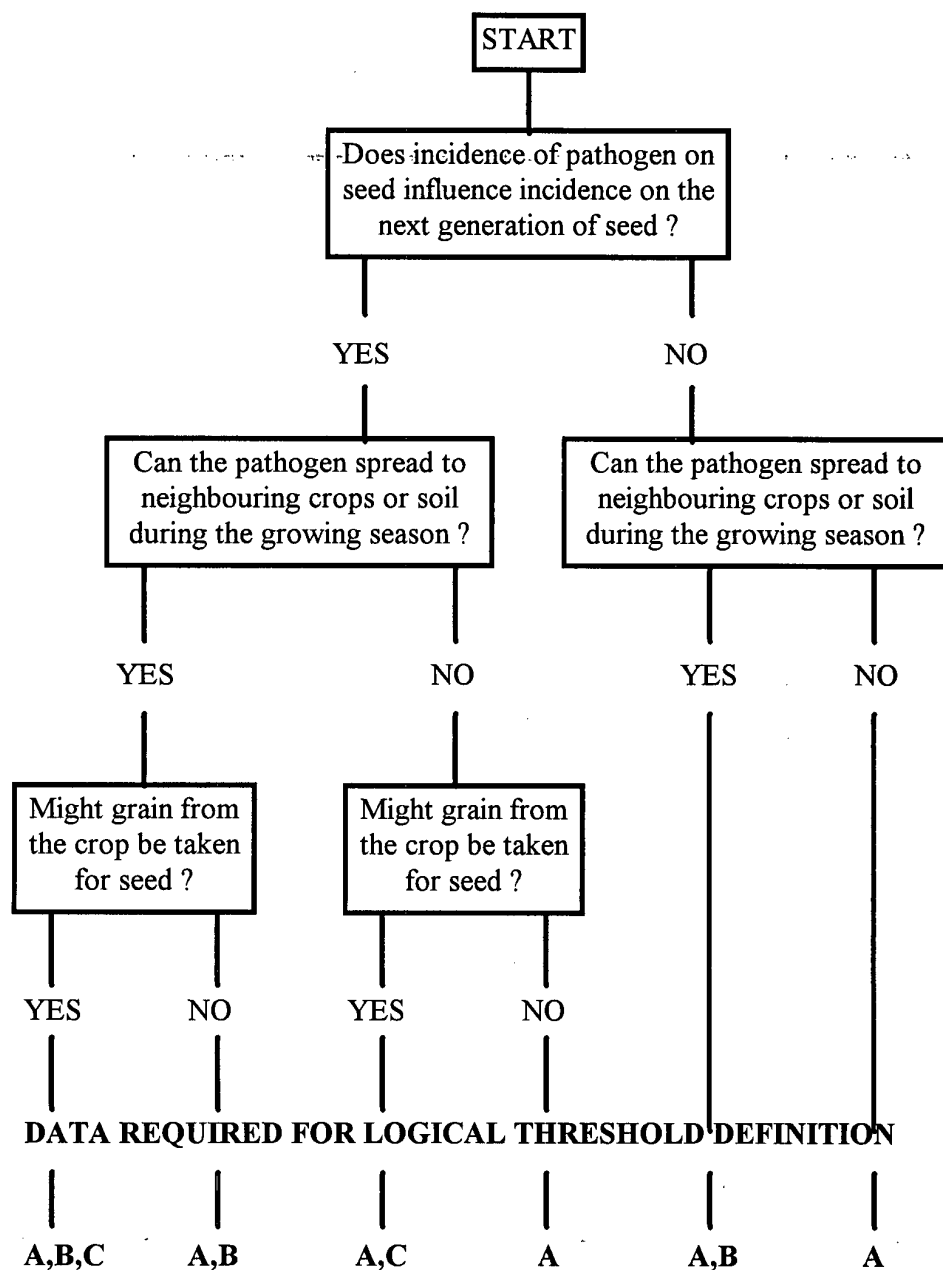
4.2.4 Interpretation of seed test results and threshold definition

The value of seed health testing lies in its ability to support decisions about suitability for seed and the need for treatment. Two test result thresholds may be set, the lower, below which seed can be sown untreated, and the higher above which treatment cannot provide robust control at an economic cost.

The information required to set thresholds depends primarily on the epidemiology of the pathogen and the use to which the seed will be put (Figure 4.4). The aim should be to set thresholds at levels which, on average, maximise profit (in this context, profit can be considered as crop yield minus seed treatment cost), minimise the risk of occasional severe loss in an individual crop, and place the whole pathogen population under consistent downward pressure over a run of seasons. The latter is particularly important, as it protects against a gradual deterioration in the health status of the national seed supply.

For most seed-borne diseases, factors A, B and C (Figure 4.4) interact with agronomic and environmental conditions. For example, the expression of seed-borne fusarium seedling blight is influenced by drilling date and seedbed conditions. Hence, from a given test result, interactions cause a spread of possible outcomes, which should be quantified if thresholds are to be suitably robust, but not over-cautious. In most cases, the efficacy of seed treatments in preventing yield loss will be closely related to their ability to reduce spread to neighbouring crops and suppress generational increases in seed infection. In practice, many of the thresholds used to convert test results into decisions have been developed empirically in the absence of key experimental data. The notes following Figure 4.4 describe the interpretation of seed test results and the definition of thresholds that have proven robust in practice, albeit against a background of routine use of seed treatments.

Figure 4.4 Information to derive thresholds for use of seed treatments



- A = Relationship of test result to disease expression, potential yield loss and the cost and efficacy of seed treatments in preventing loss
- B = Risk of spread to neighbouring crops, the outcome of that spread and the efficacy of seed treatments in preventing spread
- C = The rate of generation on generation increase in seed infection and the efficacy seed treatments in reducing generational increase in seed infection

Loose smut

Loose smut tests are requested mainly by seed processors and merchants prior to the processing of C2 seed to ensure that standards for certification can be met. Seed treatment decisions may be influenced by test results. If infection exceeds the level permitted in the Cereal Seeds Regulations, a systemic fungicide effective against *U. nuda* will be applied, or the seed may be discarded. Interpretation of seed test results on farm-saved seed is based on certification standards; a test result of over 0.5 % seed infection would mean either the farmer treating with a seed treatment that controls loose smut or not using the infected seed. There is good agreement between seed test results for barley loose smut and field expression of the disease (Marshall, 1959; Rennie & Seaton, 1975) and a 1 : 1 relationship between plant infection and yield loss is generally accepted.

Leaf stripe

Resistance of *P. graminea* (leaf stripe) to organomercury seed treatments led to a number of Scottish spring barley crops being infected at unacceptable levels during 1990 (Cockerell *et al.*, 1995) (Section 4.3.2). The introduction of a Voluntary Code of Practice to contain the disease led to a high demand for leaf stripe testing. The code required seed producers to test seed stocks for leaf stripe infection before making seed treatment decisions. Seed with up to 4% infection (reduced to 2% in 1992) could be treated with an organomercury fungicide, or sold untreated. Stocks with greater than 4% infection were required to be treated with a non-mercurial fungicide effective against the disease, or discarded for seed. The Code of Practice was aimed primarily at seed producers but many farmers saving their own seed also requested tests. In Scotland more than 1000 seed samples intended for certification and more than 900 farm-saved seed samples were tested in 1990/91 (Cockerell *et al.*, 1995). Fewer samples from England and Wales were tested. There are probably two reasons for this, spring barley is not such a widely grown crop in England and Wales and leaf stripe was not a serious problem in winter barley.

Assessments of leaf stripe in commercial spring barley crops during 1990 and 1991 showed a strong correlation between seed infection, as determined in the laboratory, and

diseased tillers ($r = 0.890$, $p < 0.001$). The percentage tiller infection was consistently lower than the percentage seed infection, and in the 27 crops examined, a mean seed infection of 21% gave a mean tiller infection of 6% (Cockerell *et al.*, 1995). Similar results were reported in Denmark, but the regression between laboratory and field test results varied from year to year, due to climatic differences during germination in the field. There was also some evidence that varietal resistance in Danish varieties influenced the regression (Jorgensen, 1983). In the UK yield loss due to leaf stripe was measured at 100 % for every barley plant infected (Richardson *et al.*, 1976). Therefore, if 1% of plants are infected in the field a 1% yield loss might be expected. Several studies in Denmark showed that yield loss was about 0.8% for each 1% of diseased plants in the field (Jorgensen, 1983).

Some seed processors still request leaf stripe tests on a few stocks of barley, but most requests come from farmers saving their own seed. The test result is generally used to determine whether a seed treatment is required, based on whether the sample exceeds the maximum infection level in the Voluntary Code of Practice.

M. nivale (fusarium seedling blight)

In total, approximately 500 seedling disease tests were requested at both the OSTs, Cambridge and the OSTs, Edinburgh during 1994-95. The majority of requests were for tests on wheat seed for *M. nivale* infection but a few growers specifically requested a test for *S. nodorum*. Growers used the test results to determine whether the seed was suitable to sow untreated or to aid seed treatment decisions. Differences in the efficacy of the commercially available seed treatments against *M. nivale* played an important role in the choice of seed treatment where seed test results showed high infection. The relationship between the percentage of seeds infected with *M. nivale* as determined in the seed health test and seedling emergence from untreated seed is well established. Hewett (1983) noted that low emergence of winter wheat seedlings was associated with high levels of *M. nivale*. More recently Humphreys *et al.* (1995) and Cockerell (1995) confirmed that the percentage infection by *M. nivale* on seed and plant establishment in the field were significantly correlated. The higher the seed infection the lower the plant

establishment. Humphreys *et al.* (1995) went on to show that low yields were also correlated with low establishments due to *M. nivale*. In both studies trials were sown either in late October or late November. The same trials sown earlier or at a different site may have produced different results if seedbed temperatures were warmer. The effect of seed infection on disease development will depend on conditions during and after sowing

Bunt

Approximately 300 bunt tests were requested from the OSTs, Cambridge and the OSTs, Edinburgh in 1994 and the majority of samples represented farm-saved seed. It is more difficult to interpret the results of tests for bunt because there is relatively little information on the relationship between spore contamination on the seed and disease development in the field. The advice given up to now has been based on thresholds used in other European countries, and the need for caution. At present if one spore per seed (20 spores per g) or more is recorded the general advice is to use a seed treatment. Spore contamination of around 100 spores per seed is considered high and the advice may be to discard the seed.

Many growers will not interpret seed test results themselves, but act on advice given by a consultant. Any interpretation of seed test results is based on the assumption that a good representative sample of seed has been taken from a seed lot. Samples submitted to the OSTs in Edinburgh for leaf stripe testing in 1990 represented seed lots of between 10 and 180 tonnes (Cockerell *et al.*, 1995). To ensure that the sample drawn for seed testing is representative of the seed lot, The Cereal Seeds Regulations limit lots of certified seed to 25 tonnes, but samples drawn from unprocessed cereal seed may represent a bulk much greater than this. Unprocessed seed may occasionally be the produce of more than one field or more than one farm and if samples are taken prior to processing there may be no mixing and therefore no homogeneity within the seed bulk.

Inadequate sampling could give misleading results when the bulk seed is divided into individual seed lots. One seed lot tested at the OSTs, Edinburgh for leaf stripe in 1990 gave a higher plant infection than was predicted by seed testing, and this discrepancy was associated with variation of infection within the seed lot and with inadequate sampling

(Rennie *et al.*, 1993). The predictive value of laboratory seed tests may be affected if samples are not fully representative of their bulks.

4.3 SEED TREATMENT USE

4.3.1 The seed treatment industry

Value of the seed treatment industry in the UK

Table 4.6 shows the areas of the major cereal crops grown in the UK (from the Agricultural Census 1995) and the cost to the farmer of the seed treatments applied to those crops. This assumes an average seed rate of 180 kg per hectare, that all seed is treated (in practice only a small percentage of crops do not receive treatment) and an average seed treatment cost of £40 per tonne.

Table 4.6. Cost of cereal seed treatment to UK farmers

Crops	Area of production in 1995 (ha)	Seed treatment cost to growers (£)
Wheat	1,858,600	13,381,920
Winter barley	688,400	4,956,480
Spring barley	503,200	3,623,040
Oats	111,800	804,960
Total	3,180,000	22,896,000

The value of the seed treatment market is considerable, with UK farmers paying approximately £23 million per annum for their cereal seed treatments. The British Crop Protection Council have produced a guide to seed treatments (Soper, 1995), and the current range of cereal seed treatments is given in Table 4.7.

Table 4.7 Cereal seed treatments available in the UK

Product Name	Active ingredients	Crop use *
Anchor	carboxin + thiram	W & B
Baytan	triadimenol + fuberidazole	W & B
Beret Gold	fludioxonil	W & B
Ferrax	flutriafol + ethirimol + thiabendazole	B
Ferrax IM	flutriafol + ethirimol + thiabendazole + imazalil	B
Panoctine	guazatine	W
Panoctine Plus	guazatine + imazalil	B
Raxil S	tebuconazole + triazoxide	B
Sibutol	bitertanol + fuberidazole	W
Vitaflo	carboxin + thiabendazole	W
Vitaflo Extra	carboxin + thiabendazole + imazalil	B

* Crop use: W= Wheat B= Barley

4.3.2 Development of resistance to seed treatments

Ustilago nuda (loose smut) - tolerance to carboxin

Throughout the 1970's, the incidence of loose smut infection declined in certified wheat seed stocks and had virtually disappeared by the mid 1980's (Anon., 1969-1985). By contrast, a small proportion of barley stocks continued to fail in certification and the health of winter barley deteriorated markedly in the early 1980's (Anon., 1984). In England and Wales, 13% of C1 winter barley seed lots failed the 0.2% standard in 1984. Almost a half of these also failed the 0.5% EC minimum standard, as both the incidence and severity of infection reached a peak. In Scotland, 36% of winter barley samples and 20% of spring barley samples intended for certification were infected above the 0.2% level during the period 1980-85 (Rennie, 1987). It was also noted that many infected lots were treated with carboxin, leading to the discovery of carboxin tolerant strains of *U. nuda* in winter barley.

Following this, the treatment of winter barley Basic and C1 seed shifted to triadimenol plus fuberidazole (Baytan) or flutriafol, ethirimol and thiabendazole (Ferrax). These

proved to be so effective that in 1987, less than 0.1% of C1 barley stocks failed a certification standard in England and Wales.

Pyrenophora graminea (leaf stripe) - resistance to organomercury seed treatments

In practice, seed-borne pathogens other than *Claviceps purpurea* (ergot) and *U. nuda* (loose smut) have been controlled by the routine use of seed treatments, rather than through seed certification. This approach worked well until the late 1980's when barley crops treated with organomercury compounds began to show occasional symptoms of leaf stripe. In 1990 leaf stripe was widespread in spring barley crops in Scotland, (although much less so in England and Wales), and occasional fields carried high numbers of diseased plants and suffered significant yield losses (Cockerell *et al.*, 1995). These unexpected occurrences of leaf stripe were due to a strain of *P. graminea* that had developed resistance to organomercury fungicides (Jones *et al.*, 1989) and which had multiplied and spread through seed stocks during the 1980's. In 1990 leaf stripe infection in Scotland was equally common in spring barley crops grown from both certified and farm-saved seed (Section 6.1.3).

In 1991, a Voluntary Code of Practice, which required spring barley seed to be tested, was agreed between the seed trade and growers in Scotland. The Code was extended to England and Wales in 1992. Samples were drawn from seed stocks intended for certification and tested for *P. graminea*. If more than 4% of seeds were infected (reduced to 2% in 1992) the seed could not be treated with an organomercury fungicide.

In March 1992, organomercury seed treatments were taken off the market and, to date, there is no evidence of resistance to the replacement products in seed-borne pathogens.

4.3.3 Reasons for seed treatment use

Control of seed-borne diseases

The primary reason for fungicide treatment of cereal seed is to control seed-borne diseases. Historically, diseases such as bunt were widespread and very damaging, and occasional crop failures reinforced concerns about seed-borne diseases. Thus, when

effective and low cost seed treatments became available they were taken up almost universally by the farming industry. The use of organomercury seed treatment, the introduction of the voluntary British Cereal Seed Scheme in 1969 and implementation of the Cereal Seeds Marketing Directives on joining the European Community in 1973 led to healthier stocks of certified seed. Seed testing methods were also developed, allowing seed lots to be examined for all the major seed-borne pathogens.

Perhaps on account of the complexity described in this Review, few cereal producers have a good understanding of the reasons for applying seed treatments, and a large proportion take little interest in which treatment is applied to their seed. Many are happy to devolve the responsibility for that decision to the seed merchant. This was understandable when organomercury was available and seed treatments costs were low, typically £6-8 per tonne in 1992. However, there is now a wide range of seed treatments available costing from £38-85 per tonne, and it is perhaps surprising that many farmers continue to take little interest in seed treatment decisions.

Control of soil-borne diseases

Take-all

An earlier HGCA Review on take-all disease of cereals (Hornby & Bateman, 1991), discussed chemical and biological control of take-all, caused by *Gaeumannomyces graminis* var. *tritici*, in some detail. In summary, Hornby and Bateman reported that, in the US, triadimenol (Baytan) applied as a seed treatment had provided early protection of the seminal root system in early sown winter wheat. Under UK conditions, prolonged protection from infection of the nodal root system, until late spring at least, is likely to be more important. Experiments at Rothamsted identified conditions in which triadimenol plus fuberidazole (Baytan) seed treatment can be beneficial: namely, when a winter wheat crop is sown very early and severe take-all subsequently develops and causes premature ripening. Results from a number of ADAS experiments confirmed a positive association between response to Baytan seed treatment and severity of take-all in untreated plots. There was some evidence of yield responses despite poor disease control, suggesting that the treatment may induce physiological changes which allow the crop to better tolerate

root infection. However, the development of severe take-all remains unpredictable at the time of drilling, and control of the disease on the nodal roots inconsistent.

More recently, a novel mode of action benzamide fungicide, MON 41100 (Barker, 1995), being developed by Monsanto, has been shown to have high activity against take-all (as well as *Fusarium* spp. and leaf stripe), and may offer reliable, persistent control. The availability of such a treatment, used alone or in mixture with more conventional active ingredients, may offer a degree of freedom from the rotational limitations currently imposed by take-all.

Considerable public and commercial sector resource has been applied to biological control of take-all, particularly in the USA and Australia. Seed treatment has been a favoured route for field scale delivery of potential bacterial or fungal biocontrol agents, as it offers convenience of use and introduces the organism in a position that allows colonisation of the rhizosphere. Despite early reports of success with fluorescent pseudomonads (Weller, 1985; Weller & Cook, 1983), soil amoebae (Old & Patrick, 1979), and fungal biocontrol agents (Deacon, 1973; Wong & Southwell, 1979; Simon, 1989), reliable and commercially viable take-all biocontrol has so far proved elusive, particularly in the biologically complex, fertile soils of the UK.

Bunt

Soil-borne bunt has been, until very recently, of little concern in the UK. Free bunt spores in soil germinate in the presence of moisture and if no host crop is present they die. Thus, under normal UK autumn conditions, spores shed to the soil of the harvested or adjacent fields would germinate long before a following wheat crop was sown into that field. Bunt spores can survive under dry conditions for 2-3 years (Mercer, 1916). Occasionally bunt outbreaks, due to soil-borne infection, have been confirmed when soil conditions between harvest and sowing have been very dry (Yarham, 1993b). Survival of bunt in dry soils is now well established as a UK phenomenon in dry harvest years. Yarham (1993b) also raised the question of variation in the survival ability of different races of *Tilletia caries*. Kendrick & Roh de Metzger (1964) described the occurrence of a strain of bunt (T-18) in Oregon which appeared to be able to survive for long periods

in soil. More recently, Johnsson (1990) described long term survival of common bunt; reports from Denmark (Cordsen Nielsen, personal communication) and ITCF in France (Maumene, personal communication) also confirm season-long survival of bunt in soils.

It is possible that the banning of straw burning in England and Wales may be implicated in the long-term survival of bunt in soil. Survival of free spores in moist soils is generally regarded as very short term. However, whole bunt balls (where the bunt spores are encased in a thin, but robust membrane) are very hydrophobic and are likely to survive for much longer than free spores. Equally, bunt balls encased in the glumes within the ear are more likely to survive for longer periods. Straw burning would probably destroy these sources of infection, but without it whole bunt balls or ears containing bunt balls may well survive in the soil for much longer.

Soil-borne bunt does appear to be an increasing problem in the UK, although the number of reported cases each year is still very small. Those farmers, and their neighbours, who have had soil-borne bunt, or severe bunt outbreaks which lead to soil contamination, must rely on seed treatments which are active against the soil-borne phase of the disease (Baytan, Sibutol and Beret Gold).

Fusarium seedling blight

Experimental work by Bateman (1977), using artificial inoculation, suggested that soil-borne fusarium could act as a source of seedling blight. Prior to the ADAS work, performed between 1992 and 1994, described later in this section, the importance of natural soil-borne inoculum had not been quantified in isolation from seed-borne inoculum. As a result of this uncertainty, even when seed had been tested and found to be within acceptable tolerances, the risk of soil-borne fusarium seedling blight made it: "...advisable to treat where there is a risk of winter crops being sown late, or where seed may be sown in unusually cold or wet seedbeds that may delay seedling emergence" (Rennie & Cockerell, 1993). As seedbed conditions cannot be predicted at the time of the treatment decision, most cereal growers err on the side of caution.

Stripe smut of rye

This disease is rare in the UK but soil-borne inoculum is more important with this disease than with any of the other smuts affecting UK cereals. Baytan should control the soil-borne phase of this disease.

Net blotch of barley

Although this disease can be seed-borne, the main source of inoculum is plant debris. The disease can be controlled with foliar applied fungicides. Control of seed-borne inoculum, although achieved by some seed treatments, is therefore of little significance.

Septoria seedling blight

Septoria nodorum can survive between crops either on plant debris or on the seed. With a minor resurgence of the foliar disease caused by *S. nodorum*, together with the straw burning ban, the soil-borne phase of this disease may become more important. Large amounts of infected straw chopped and incorporated into the soil may provide a significant source of *S. nodorum* inoculum in modern wheat crops. This could result in either seedling losses or a general increase in the incidence of the foliar disease, although the former is unlikely. Seed treatments which have some systemic properties and are effective against seed-borne *S. nodorum* are thought likely to give control of the soil-borne pathogen, but little work has been done on this aspect of the disease.

Control of foliar diseases with seed treatments

Control of foliar diseases by application of a seed treatment has often been the goal of agrochemical manufacturers. When first introduced, Milstem (ethirimol) gave excellent control of barley powdery mildew. Subsequently, Ferrax gave good foliar disease control. Ferrax is still used on some barley crops where early mildew control is required.

In wheat, the use of seed treatments for the control of foliar diseases is almost totally confined to the control of yellow rust. In the mid 1980's, several key wheat varieties including Norman, Longbow, Slejpner and Hornet succumbed to a new race of yellow rust. Where Baytan was used on these crops it was found that the seed treatment prevented autumn infection of the crops and gave long term protection. This use of

Baytan is still common. Recent changes in the yellow rust population have led to the use of this product on current wheat varieties, such as Brigadier, which are susceptible to the new races.

Another azole seed treatment, similar to Baytan, has been developed by Rhône Poulenc in France. This product, based on triticonazole, and sold under the trade name Real, gives control of mildew, brown rust and yellow rust of wheat, and mildew and rhynchosporium of barley. This is possibly because the active ingredient is not phytotoxic and thus high seed loadings are possible, extending the period of control. Lower seed loadings can be used to give control of seed-borne diseases alone. It is not clear whether this approach will be used in the UK.

There is concern that the use of systemic azole fungicides as seed treatments might encourage the development of fungicide resistance in the foliar pathogens; jeopardising control, which currently depends primarily on the use of azole based sprays. Debate centres on the extent of the risk. One view suggests that the risk is low, since the period for which pathogens are exposed to fungicides translocated to the leaves (autumn and winter) coincides with low temperatures, and a slow rate of reproduction in the pathogens. An alternative view suggests that the effect of exposure over a period of several months when pathogen populations would otherwise receive little selective pressure from fungicides, must have significant effect. The authors are not aware of any evidence from experiments or mathematical models to quantify the risk.

To assess the benefit of foliar disease control from seed treatment, it is necessary to quantify the level and consistency of the control achieved, and the probability of this control either producing a yield benefit or replacing a foliar fungicide application. A series of winter barley experiments in 1989 (ADAS unpublished) produced unusually severe mildew epidemics on a disease susceptible variety during the winter and early spring, and provide some indication of the value of seed treatment derived foliar disease control (Table 4.8). In these experiments, Ferrax generally provided good control of mildew during the winter and early spring. There was no significant ($p < 0.05$) yield

benefit from the mildew active seed treatment compared to the organomercury product, or indication of mildew activity allowing a reduced spray programme.

Table 4.8 Effect of seed treatments and foliar sprays on yield of winter barley variety Magie

Seed treatment	Grain yield (t ha ⁻¹ at 85% dry matter) *			
	Number of sprays in foliar fungicide programme			
	None	One	Two	Three
Organomercury	5.11	6.12	6.63	6.92
Ferrax	5.11	6.33	6.77	6.94

* Mean of three sites where mildew affected 6-40% of leaf 2 or 3 during the autumn, winter or early spring in plots grown from seed treated with phenyl mercuric acetate

Work in Scotland to quantify the benefits of broad-spectrum seed treatment to control foliar diseases (Sutherland *et al.*, 1994), suggested that: 'Although early seed treatment trials on spring barley showed good disease control and yield responses, more recent work has shown that their use solely for the control of foliar diseases is not cost effective'. They concluded that the use of broad-spectrum seed treatments on winter or spring barley might be justified in situations of high disease pressure, or where the grower, because of other on-farm commitments, wanted to delay the time of spraying.

Work on the epidemiology of wheat diseases (Paveley *et al.*, in press) has shown that the rapid expansion of the canopy after GS 31, combined with senescence of the lower leaves and the overriding effect of other factors (principally weather) on the relative growth rate of disease epidemics, cause early season inoculum to have little effect on subsequent disease severity; suggesting that application of broad-spectrum seed treatments may have little benefit for foliar disease control. Field experience and epidemiological theory suggest that similar processes apply to winter barley. One exception may be yellow rust on wheat, where suppression of early inoculum to very low levels (less than 0.01% mean severity) by broad-spectrum seed treatment may usefully delay the onset of epidemic development in the spring.

Other effects of seed treatments

When applied as seed treatments many of the azole fungicides show some degree of direct effect on growth. For example, Baytan slows plant emergence, but not germination, and also reduces tillering, resulting in plants with fewer, but consequently stronger tillers. This may be a positive effect, producing plants which are less prone to lodging. These plants also tend to have more vigorous root systems, reducing susceptibility to damage from frost-lift. Deleterious effects of seed treatments on crop establishment and yield, whilst noted from practical experience when severe, have seldom been quantified (Skou, 1989). As few field crops have the benefit of an untreated control for comparison, such positive or negative effects as may occur are not widely appreciated. Registration (Slawson & Gillespie, 1994) requires evidence that cereal yields are not adversely affected by seed treatment in the 'absence' of disease.

Seed treatment in the absence of seed-borne diseases

There is a clear distinction between use of seed treatments to control seed-borne diseases and their use on seed that is known to be healthy. Richardson (1986), using 77 seed stocks of spring barley and winter wheat intended for certification, made over 220 comparisons between organomercury treated seed versus untreated and concluded that: '...there were no significant differences in overall mean yield associated with the absence of treatment for either wheat or barley'. However, Richardson's scatter diagrams of treated on untreated yield showed considerable variation. It was not clear whether the variation in yield attained was attributable to treatment effects, site and seasonal variation or was simply error variation arising from the unreplicated nature of the work.

A series of ADAS experiments between 1992 and 1994 aimed to answer the question: if seed has been tested and found to be within acceptable tolerances for seed-borne pathogens, do the potential benefits from control of soil-borne fusarium seedling blight, take-all and foliar diseases, and non-disease effects, such as control of lodging, justify treatment ?

The experiments were completed at 23 sites, which were selected to give a range of soil types, weather conditions, rotational positions, seedbed conditions and sowing dates, representative of cereal growing in England and Wales. Certified seed was obtained centrally, randomly sub-divided, and treated with the seed treatments listed in Table 4.9. After treatment the sub-samples were further divided and dispatched to the sites.

Table 4.9 Treatments, active ingredients and doses applied

	Commercial product	Active ingredients	Rate (litres/tonne of seed)
1	Untreated control	--	
2	Baytan	triadimenol + fuberidazole	2.0
3	Panoctine	guazatine	2.0
4	Cerevax	thiabendazole + carboxin	2.5
5	Panogen M	2-methoxyethylmercury acetate	1.0

In 1992 and 1993, seed was selected which carried only low levels of seed-borne pathogens. In 1994, a seed lot with *M. nivale* infection was selected. The results of the seed tests for germination and seed-borne pathogens are given in Table 4.10. Bunt was absent from all seed lots. All the sites were sown as a randomised block design with four replicates. No foliar fungicides were applied earlier than GS 31, after which normal commercial spray regimes were applied.

Cross-site analysis of each season's data showed small, inconsistent and generally non-significant plant establishment and yield differences between products. The treated values in Figures 4.5, 4.6 and 4.7 are the means of treatments 2 to 5 in Table 4.9.

Figure 4.5 shows the relationship between treated and untreated plant establishment for all 23 experiments. The diagonal lines in Figures 4.5, 4.6 and 4.7 have a slope of unity, i.e. represent the line along which treated = untreated.

Table 4.10 Varieties, germination test results and seed-borne contamination with *M. nivale* or *Fusarium* spp.

Year	Variety	Germination (%)	<i>M. nivale</i> (%)	<i>Fusarium</i> spp. (%)
1992	Riband	98	1	-
1993	Haven	89	3	-
1994	Haven	94	12	19

There is considerable site and seasonal variation in establishment, ranging from approximately 100 to 400 plants m⁻². The effects of seed treatment were small. Regression analysis showed that untreated establishment explained 87% of the variation in treated establishment and there was a small overall benefit from treatment. However, if the 1994 data, when seed-borne *M. nivale* was present, are removed (Figure 4.6) the overall benefit of treatment is lost.

Similar analysis of yield data from the 23 sites (Figure 4.7) showed little evidence of consistent yield response to treatment. Untreated yield explained 98% of variation in treated yield, across all treatments and experiments, and there was no significant yield benefit from treatment. There was no association between yield response and rotational position, suggesting no benefit from take-all control by Baytan, within the range of take-all severities experienced. In the absence of yellow rust, no significant control of foliar disease was detected by disease assessments at GS 31.

These results support earlier work, suggesting that the risk to crop establishment from natural soil-borne fusarium is negligible. In the absence of seed-borne contamination, the effect of treatment is as likely to be deleterious as positive, even in poor seedbed conditions. The notion that improvements in establishment due to control of seedling blight will be consistently reflected in yield is challenged by the data in Figure 4.8, where the numbers of plants established are plotted against yield, for each treatment in each of the 23 experiments. Clearly there is a lot of variability in the relationship. The data suggest that a consistent yield response to treatment may only be obtained where establishment would be very low (less than 150 plants m⁻² (Sylvester-Bradley & Scott,

Figure 4.5 Effect of seed treatment on plant establishment in 23 experiments, 1992-94

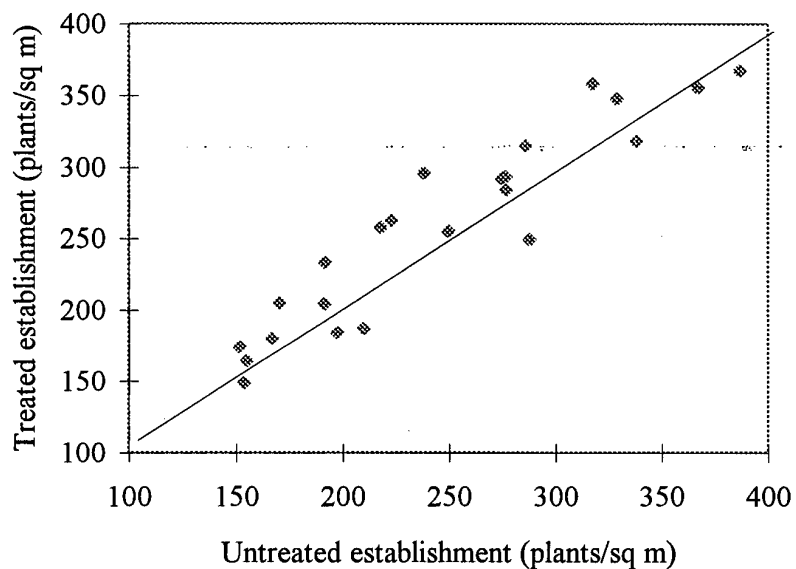


Figure 4.6 Effect of seed treatment on plant establishment in 14 experiments, uncontaminated seed, 1992 and 1993

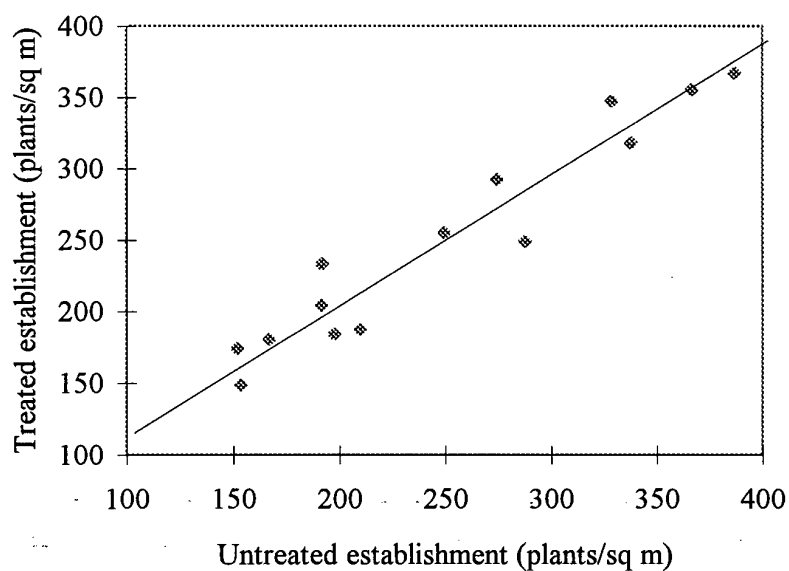


Figure 4.7 Effect of seed treatment on yield in 23 experiments, 1992-94

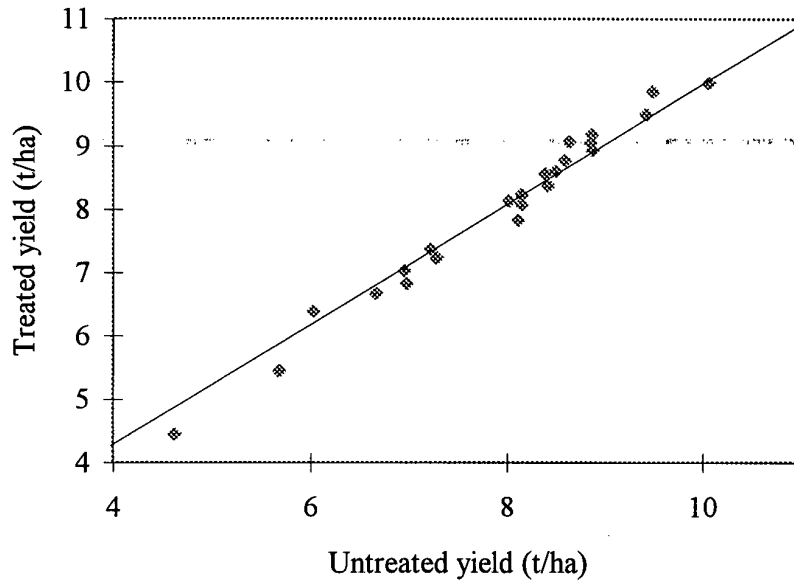
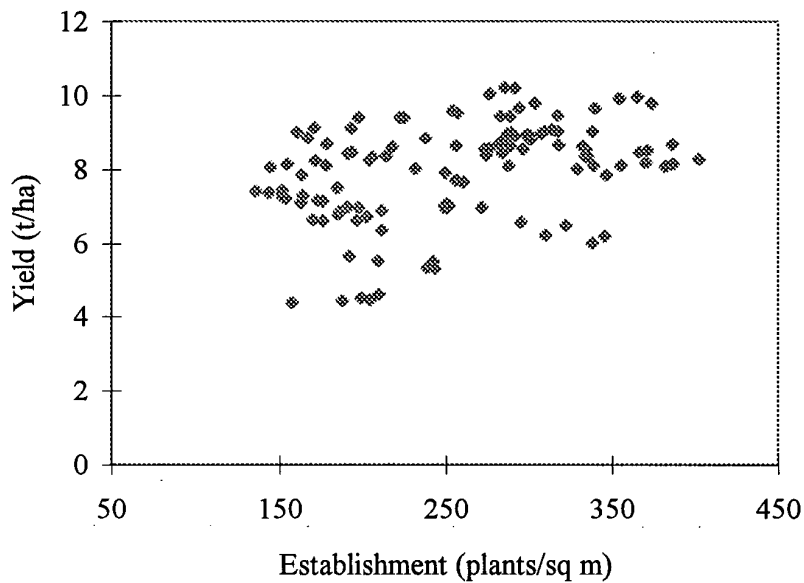


Figure 4.8 Relationship between plant establishment and yield in all treatments, 23 experiments, 1992-94



1990)) in the absence of treatment; a circumstance most likely where a seed stock with high *M. nivale* contamination is sown into a cold seedbed. In such situations, despite compensatory tillering, shortage of tillers may limit canopy expansion (and hence the carbohydrate 'source') or cause carbohydrate 'sink' capacity to become limiting. There is

some evidence that modern wheat varieties are less dependent on high tiller populations to achieve adequate 'sink' capacity, and may therefore be better able to withstand plant loss without yield loss.

4.3.4 Current use of seed treatments

The seed treatment market has changed rapidly since the removal of organomercury stimulated the introduction of new products. Table 4.11 gives an indication of the changes which have occurred. The information comes from manufacturers' claims and MAFF-funded CSL/ADAS cereal disease surveys. The data for 1995/96 are estimates based on information from a number of sources.

Table 4.11 Market shares of cereal seed treatments, 1993/94-1995/96

Product Group	Market share (%)		
	1993/94	1994/95	1995/96
Baytan / Ferrax	26	20	20
Beret / Beret Gold	4	15	20
Cerevax / Vitaflo group	40	30	15
Panoctine / Rappor	30	30	35
Sibutol / Raxil S	-	5	10

4.4 CONTROL OF SEED-BORNE DISEASES BY VARIETAL RESISTANCE

Some degree of varietal resistance is available for many important major seed-borne diseases of cereals. In the case of smuts and bunt, the level of resistance can be very high, but since it is usually single gene resistance it has the disadvantage of breaking down to new races of the pathogen. Plant breeders have had little incentive to use varietal resistance in their breeding programmes because of the cheap and effective control given by routine use of organomercury seed treatments or seed certification. This is understandable given the number of characters which a breeder is looking for, most

importantly yield, quality, standing power, resistance to foliar diseases, and the length of time taken to develop a new cereal variety, typically ten years.

In the UK, there is almost no information on the resistance genes to seed-borne pathogens in current cereal varieties, or frequencies of virulences in the pathogen populations. Knowledge is limited to work carried out up to the 1960's or more recently in other countries. The following sections summarise the information for the main seed-borne diseases.

4.4.1 Loose smut

Breeding for resistance to loose smut was considered important (Poehlman, 1964) until carboxin became widely used in the 1960's. Loose smut was still a major problem in wheat in the late 1960's, but was brought under control by carboxin and varieties with resistance to the common race of the pathogen. Resistance to loose smut is also influenced by flowering habit. Open flowered varieties, which expose their florets to airborne spores, are more susceptible.

NIAB produced resistance ratings for loose smut of wheat and loose smut of barley until 1991. The ratings for wheat were based on inoculated tests, and ratings for barley on flowering habit.

4.4.2 Bunt of wheat

Varietal resistance has not been used to a significant extent in the control of bunt in the UK. However, varietal resistance has been used in the USA where soil-borne inoculum, which is not controlled by organomercury seed treatments, is an important source of infection (Wiese, 1987). Work on resistance and pathogen virulence has been carried out in the USA (Hoffman & Metzger, 1976), although resistance is generally short-lived because of the development of new races.

4.4.3 Fusarium of wheat

Wheat varieties differ in their resistance to fusarium ear blight, and resistance ratings are produced by NIAB. There is also some evidence that varieties differ in their susceptibility

to fusarium seedling blight (Jackson & Parry, 1992). However, the level of resistance is relatively low, and environmental factors have considerable influence on the development of infection.

4.4.4 Ergot

As with loose smut, varieties with an open flowering habit are more likely to become infected. This also explains why rye, a cross-pollinating species, is more susceptible. For the reason, ergot may be a problem in the production of seed of hybrid varieties of cereals.

4.4.5 Leaf stripe of barley

Resistant varieties have been used to control leaf stripe in the USA (Kline, 1972), and varieties have been assessed for resistance in other countries (Knudsen, 1980). Different races are known to occur, but the genetics of resistance are not clearly understood. Varietal resistance has not been used in the UK.

CHAPTER 5

HOW WELL DOES UK PRACTICE MEET INDUSTRY NEEDS?

5.1 INCIDENCE OF SEED-BORNE CEREAL PATHOGENS

Since the maintenance of seed health is a key aim of seed treatment use, national assessment of the incidence and severity of seed-borne pathogens forms a valuable guide to the success of current strategies in meeting the industry needs set out in Chapter 2. Such measures can also act as a baseline from which longer term deterioration or improvement can be monitored, and form the starting point for simulations of the potential long term effect of changes in strategy.

5.1.1 Bunt

Marshall (1960) recorded the occurrence of bunt balls in winter wheat seed samples tested at the Official Seed Testing Station (OSTS) for England and Wales between 1918 and 1957. Throughout the 1920's and 1930's bunt balls were present in more than 5% of samples tested. 33% of samples contained bunt balls in 1921. In 1924 12% of samples had bunt balls but only 18% of samples tested in a random survey were found to be free from spore contamination. Marshall correctly concluded that recording contamination with bunt balls underestimated the extent of the bunt problem at that time. From the 1930's there was a steady decline in the proportion of samples containing bunt balls and by 1957 only 0.2% of samples tested in the OSTS for England and Wales were contaminated with bunt balls and no spores were found when 1% of samples were tested for spore contamination.

With the extensive use of organomercury seed treatments bunt was rare in the UK wheat crop during the 1960's and 1970's. No bunt balls were recorded in any wheat seed sample tested in the OSTS for Scotland during this period and Richardson (1986) found no evidence of bunt in a three year study of 36 winter wheat crops in Scotland. Bunt was very occasionally recorded in winter wheat crops in England during the late 1980's. Infection was initially associated with untreated farm-saved seed but later circumstantial

evidence suggested that some crops had become infected from soil contamination associated with a preceding infected crop (Yarham, 1993b).

These occasional reports of bunt, and the replacement of organomercury seed treatments with alternative products that differed or appeared to differ in efficacy, stimulated interest in the disease. This led to occasional requests for tests for bunt, mainly on samples of farm-saved seed. Reeves & Wray (1994) reported that more than 60% of samples received by the OSTS in Cambridge for advisory bunt testing in 1991 and 1992 were contaminated with spores of *T. caries*. However, only 3% of samples in 1991 and 12% of samples in 1992 failed to meet NIAB's advisory limit of 20 spores per gram of seed (equivalent to one spore per seed), the level at which seed treatment was recommended. A high proportion of the samples tested probably represented farm-saved seed and some may have been specifically selected because of concerns over contamination with bunt.

Cockerell & Rennie (1995) tested over 200 samples of winter wheat seed in each of the years 1992-1994, as part of a survey funded by HGCA and Zeneca Crop Protection that aimed to record the occurrence of seed-borne pathogens on UK cereal seed. They recorded one broken bunt ball in a single sample of English produced certified seed in 1992. This was the only record of bunt balls during the three years of the survey.

Figure 5.1 shows the percentage of winter wheat seed samples in Cockerell and Rennie's survey that were contaminated with *T. caries* spores. Figure 5.2 shows the percentage of samples that were contaminated at a rate of more than one spore per seed.

Spores of *T. caries* were recorded in between 20% and 60% of certified and farm-saved seed samples over the three years of the survey. However, a relatively small proportion of samples was contaminated at the level of more than one spore per seed. The maximum contamination recorded during the three years of the survey was 121 spores per seed in a sample of farm-saved seed in 1993. These data suggest that there is fairly widespread, low level contamination of UK winter wheat seed with *T. caries* spores.

They contrast with the report of Marshall (1960) who found no sample contaminated with spores of *T. caries* in 1957.

Figure 5.1 Percentage of winter wheat seed samples contaminated with *Tilletia caries* spores (bunt) 1992-94 (Cockerell & Rennie, 1995)

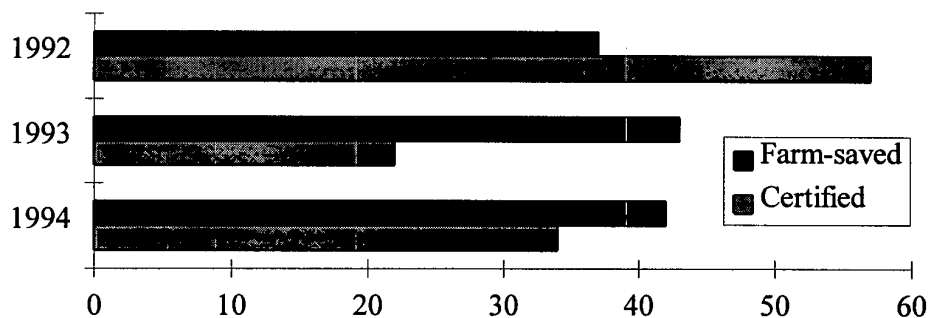
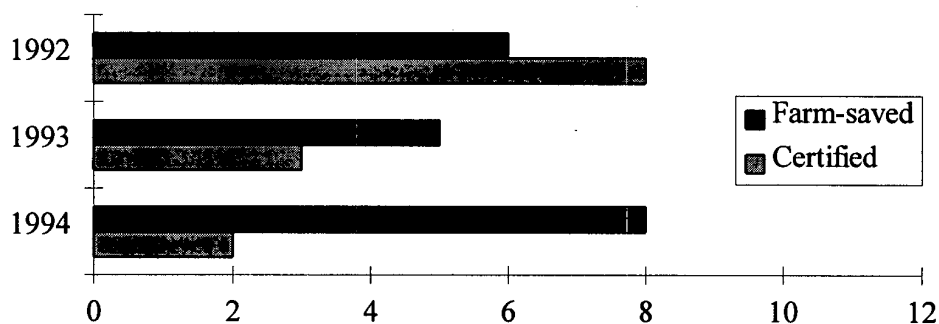


Figure 5.2 Percentage of winter wheat seed samples with more than one spore of *Tilletia caries* (bunt) per seed 1992-94 (Cockerell & Rennie, 1995)



5.1.2 Loose smut on barley and loose smut on wheat

Loose smut infection in UK winter wheat was relatively common during the 1960's and 1970's, but declined during the 1980's. This decline was due to widespread use of systemic fungicides on seed stocks for multiplication, and the introduction of new varieties which were less susceptible to re-infection (Reeves & Wray, 1994), partly as a result of an interaction with dwarfing genes (Jones *et al.*, 1995). Loose smut is now very rare in UK winter wheat.

Infection in spring and winter barley is influenced by varietal susceptibility, seasonal climatic patterns and the effectiveness of chemical seed treatments. Gray (1954)

reported that it was usual to find between 2 and 15% of plants infected with loose smut in crops of susceptible varieties in the north of Scotland during the 1940's and early 1950's. Between 1954 and 1957, the OSTs for England and Wales recorded loose smut in 84% of stocks of Scandinavian bred barley varieties, with a maximum infection of 19%. During the same period, UK bred varieties were less susceptible to infection, with only 10% of samples infected and with a maximum of 4% infection (Marshall, 1959). Rennie & Seaton (1975) reported a mean annual incidence of 1% or less in spring barley seed tested at the OSTs for Scotland between 1959 and 1973.

Rennie (1987) found that loose smut was more prevalent in samples of Scottish farm-saved seed than in samples intended for certification from 1980 to 1985, although 36% of winter barley samples and 20% of spring barley samples drawn from seed stocks intended for certification had more than 0.2% infection. These relatively high levels of infection in winter barley were confirmed in England by Wray & Pickett (1985) and were associated with strains of the fungus resistant to carboxin. More recently Reeves & Wray (1994) showed an increase from approximately 10% in 1990 to approximately 30% in 1993 in the percentage of barley seed samples that failed to meet the 0.2% standard for C1 and C2 HVS seed in tests in the OSTs for England and Wales.

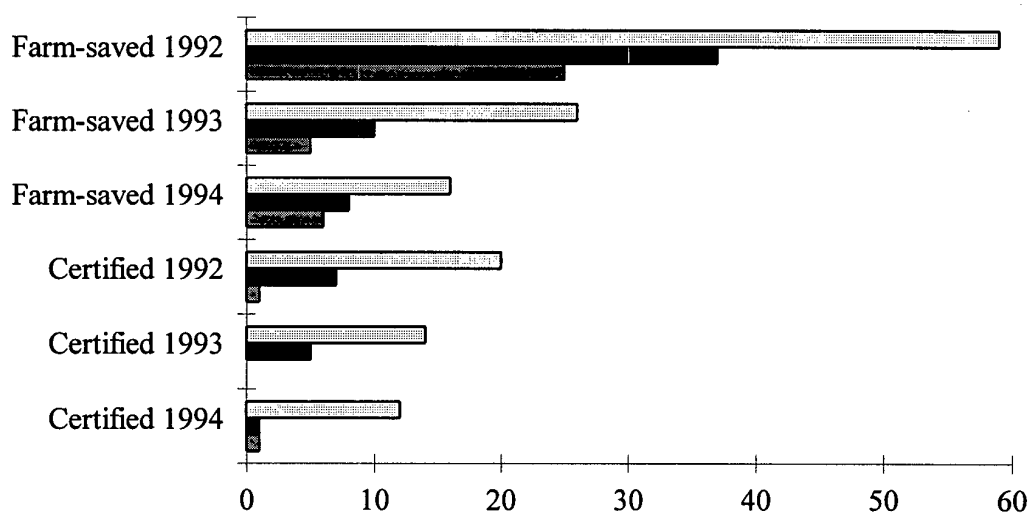
In the HGCA/Zeneca survey (Cockerell & Rennie, 1995) farm-saved seed was more frequently infected with *U. nuda* and at higher levels than certified seed. Winter barley was more often and more heavily infected than spring barley reflecting the greater susceptibility of winter varieties.

Figure 5.3 shows the percentage of winter and spring barley seed samples that were infected and shows the proportion within the total where infection exceeded 0.2% and 0.5%, the standards for C1 and C2 HVS and EC Minimum Standard respectively. In 1992, 7% of certified winter barley samples failed to meet the 0.2% standard, whereas 36% of farm-saved samples were infected at this level. In 1992 and 1993, 1% of certified winter barley seed samples had more than 0.5% infection but in 1992, 25% of farm-saved samples had this level of infection. The maximum infection recorded in winter barley seed was 10.5% in a sample of Scottish farm-saved seed in 1994.

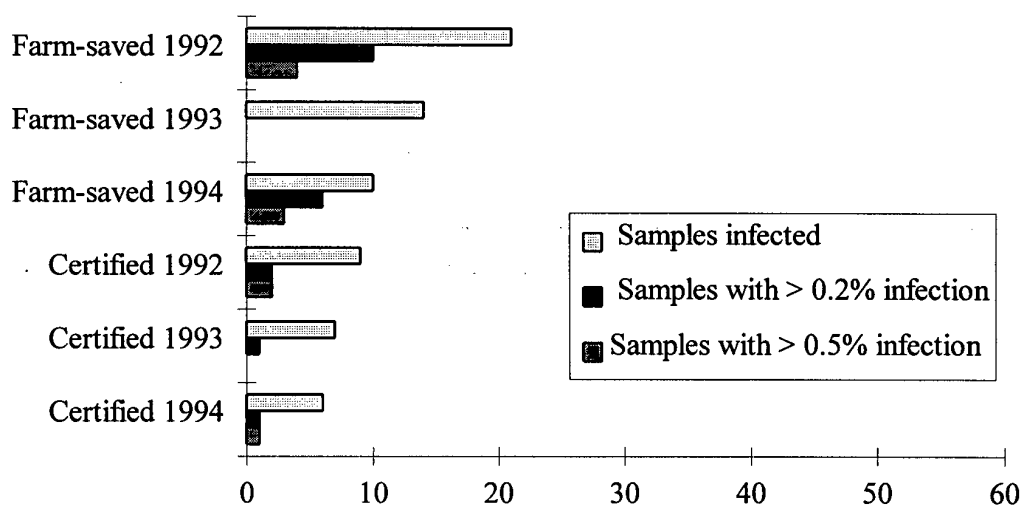
Infection levels were lower in spring barley and seed samples were less frequently infected. However, 2% of certified spring barley samples failed to meet the 0.5% Minimum Standard in 1992, and 1% of certified samples were infected at this level in 1994.

Figure 5.3 Percentage of winter and spring barley seed samples infected with *Ustilago nuda* and percentage of samples with more than 0.2% and 0.5% infection 1992-94 (Cockerell & Rennie, 1995).

Winter barley



Spring barley



These data are supported by data from certification control plots in England and Wales. Over the last five years loose smut has been present in around 14% of untreated winter barley control plots and 4% of spring barley plots (Table 5.1). Infection has been generally at a low level and only 0.3% and 0.8% of seed lots of winter and spring barley respectively failed the HVS certification standard.

These data do not relate directly to the incidence of loose smut in C2 certified seed produced from these C1 lots since much is treated before being sold. Most Basic seed, from which C1 is produced, is treated to control loose smut, and consequently the incidence in C1 seed, albeit with low levels of infection, does indicate that healthy crops can quickly become infected.

Table 5.1 Percentage of untreated C1 seed samples with some loose smut infection in certification control plots, England and Wales 1990-1994

	Untreated C1 seed samples with loose smut (%)	
	Winter barley	Spring barley
1990	10.1	0.2
1991	4.0	4.2
1992	16.7	9.2
1993	25.7	2.8
1994	19.4	2.7
Mean	14.2	3.5

5.1.3 Barley leaf stripe

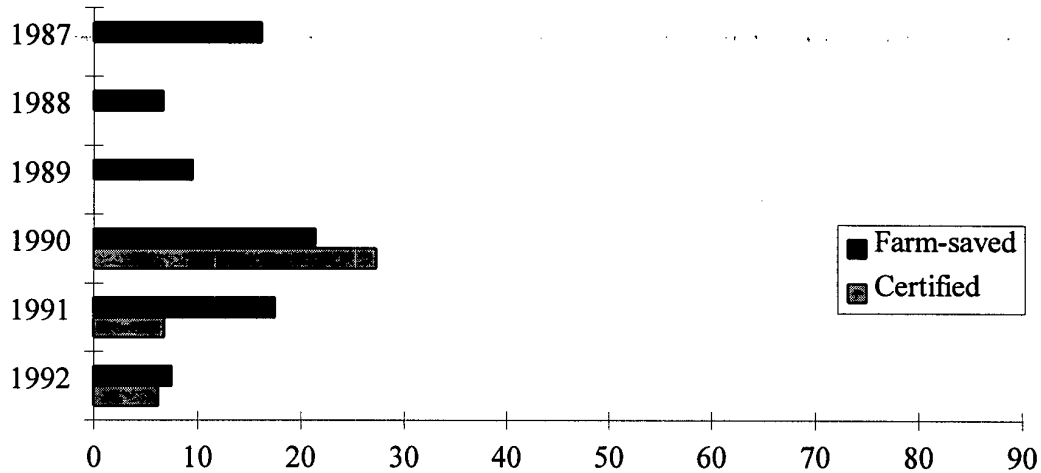
Barley leaf stripe (*Pyrenophora graminea*) was recorded at damaging levels in the UK spring barley crop during the 1930's (Foister, 1961). The introduction of organomercury fungicides to control the related species *Pyrenophora avenae* on oat seed led to the widespread use of organomercury seed treatment on barley. No *P. graminea* infection was recorded during seed health surveys at the OSTs, Edinburgh during the years 1953-54 and 1954-55 (Noble, 1956). Noble (1956) commented that although the disease was

rare in Scotland it was still common in Scandinavia and England. In 1970 a survey of barley and oat seed samples in Northern Ireland by Malone & Lorimer (1975) gave similar results to those reported in Scotland by Noble. No *P. graminea* was recorded on the barley samples tested. Contrary to this, Hewett (1975) reported an overall seed infection of 1% in 1972 in a survey of spring barley seed in the OSTs for England and Wales and only a trace of infection found in 1973 after what he describes as renewed attention to seed treatment. Hewett also noted that *P. graminea* mostly occurred as occasional high infections. In his survey one sample of Mazurka barley had 42% seed infection. Richardson (1974) reported a low incidence of leaf stripe during surveys of Scottish spring barley crops between 1970 and 1973; leaf stripe was recorded in 2% of the 504 spring barley crops studied, but the mean infection was less than 0.05%.

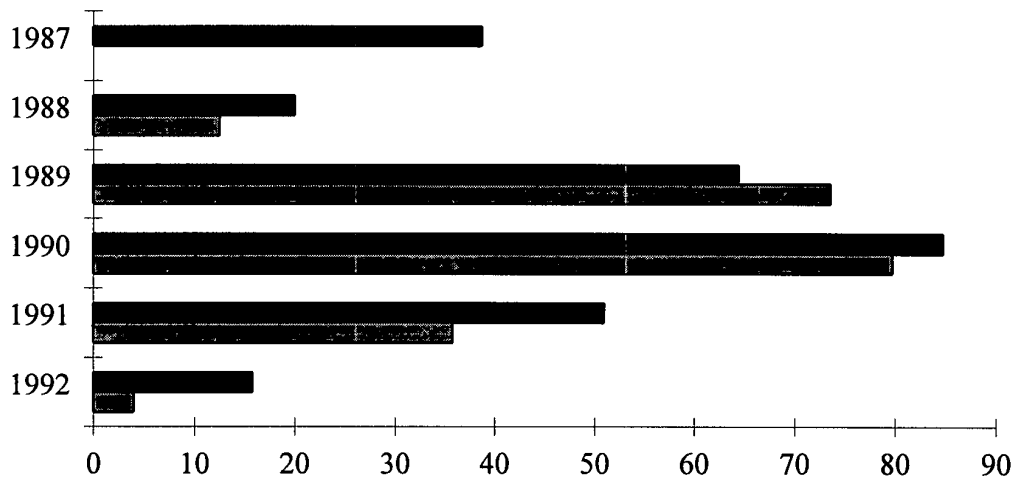
During the mid 1980's there were occasional reports of leaf stripe in UK spring barley crops grown from organomercury treated seed. Jones *et al.* (1989) later confirmed that some isolates of *P. graminea* were resistant to organomercury. Cockerell *et al.* (1995) reported the incidence of organomercury resistant *P. graminea* in Scottish winter and spring barley from 1987 - 1992. *P. graminea* infection was highest in spring barley seed harvested in 1989 and 1990, with 69% of samples infected in 1989 and 82% infected in 1990 (Figure 5.4). Mean infection was similar in certified (5.9%) and farm-saved seed (6.3%) in 1989. Infection decreased between 1990 and 1992 following the introduction of a voluntary Code of Practice (Anon., 1991) and a move from organomercury based fungicides to effective alternative seed treatments. Cockerell *et al.* (1995) found that *P. graminea* levels in winter barley were consistently lower than in spring barley (Figure 5.4) over the 6 year period. As with spring barley the incidence of *P. graminea* was highest in 1990; in that year there was little difference in infection between certified and farm-saved seed, with infection recorded in 27% of certified seed and 21% of farm-saved seed samples. They also noted that the mean annual infection did not exceed 1.0% in any year.

Figure 5.4 Incidence of *P. graminea* in samples of winter and spring barley from Scotland 1987-1992 (Cockerell *et al.*, 1995)

Winter barley



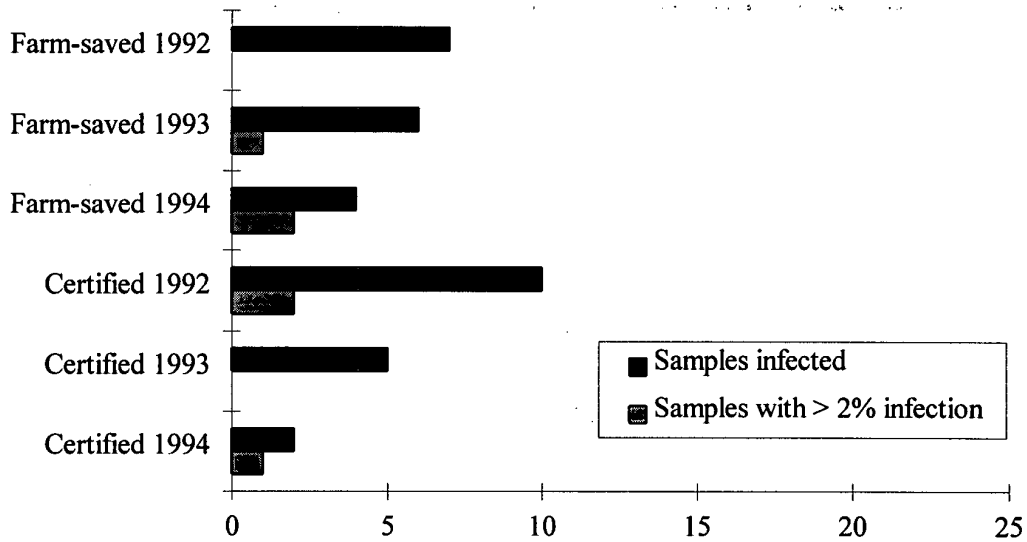
Spring barley



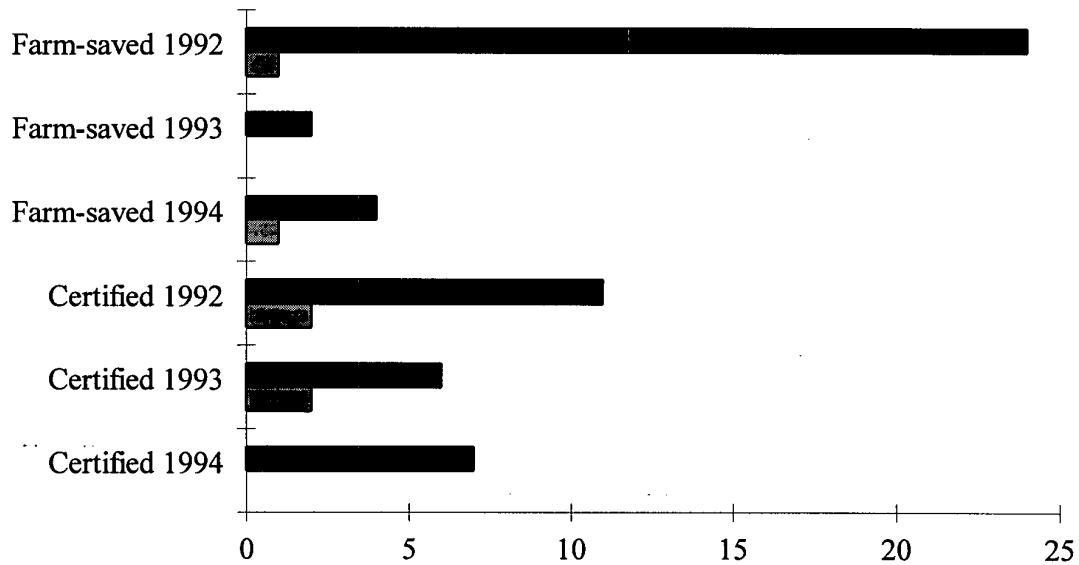
Reeves & Wray (1994) recorded the incidence of *P. graminea* in barley seed samples (winter and spring barley were not differentiated) submitted to the OSTs for England and Wales in 1992 and 1993. Approximately 20% of samples were infected in 1992 with approximately 15% having more than 2% infection; in 1993 approximately 35% of samples were infected and around 12% had more than 2% infection.

Figure 5.5 Percentage of winter and spring barley seed samples infected with *P. graminea* and percentage of samples with more than 2% infection 1992-94 (Cockerell & Rennie, 1995)

Winter barley



Spring barley



The HGCA/Zeneca survey of seed-borne pathogens in UK certified and farm-saved cereal seed confirmed the decline of *P. graminea* in spring barley. Infection was recorded in 7% of certified seed and 5% of farm-saved seed in 1994 (Figure 5.5).

Although the proportion of spring barley samples infected between 1992 and 1994 was lower than in 1990 the data suggest that *P. graminea* infection was higher than in the 1970's when surveys were made by Hewett (1975), Malone & Lorimer (1975) and Richardson (1986).

P. graminea was recorded at low levels of 2% to 10% of winter barley seed samples during the HGCA/Zeneca survey (Figure 5.5). There was no difference in infection of farm-saved seed and certified seed in any year. Both recent surveys suggest that *P. graminea* levels in winter barley have not changed significantly since 1991. There were very few samples certified or farm-saved winter or spring barley that failed to meet the voluntary 2% seed standard in the Code of Practice (Anon., 1991).

5.1.4 Seedling diseases (*Microdochium nivale*, *Stagonospora (Septoria) nodorum* and *Cochliobolus sativus*)

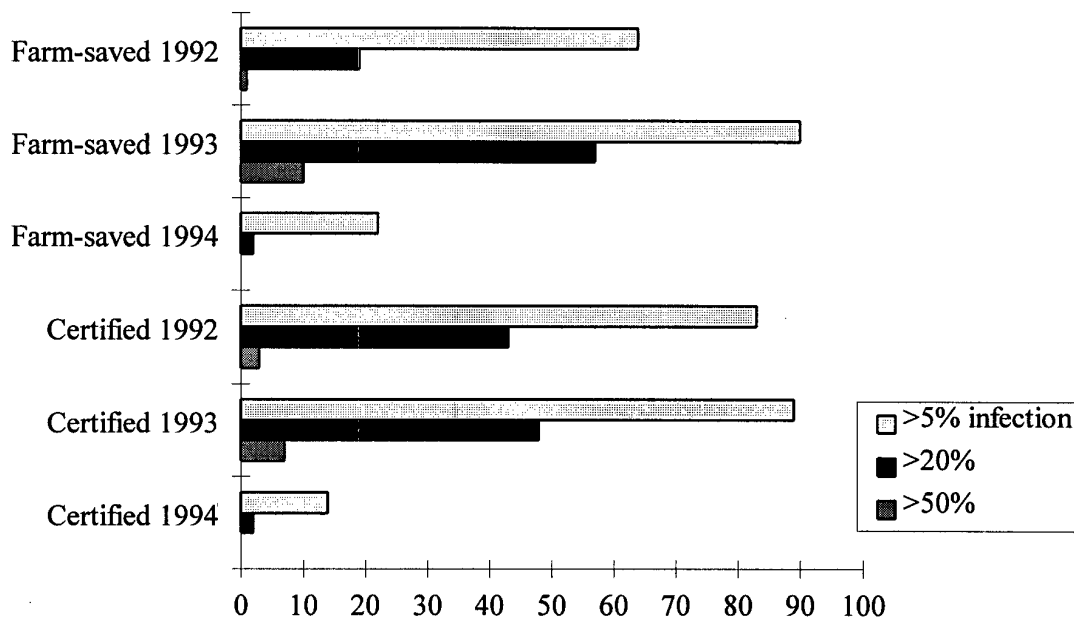
During the period when organomercury seed treatments were widely used, seed-borne pathogens that could affect seed germination and seedling establishment were of little interest and there are relatively few data on their occurrence.

Hewett (1965) recorded *M. nivale* and *S. nodorum* in winter wheat seed produced in England between 1959 and 1964. Throughout the first four years of his survey infection remained at a stable level. Approximately one in seven samples showed infection, mostly of only 1 or 2% and this resulted in mean infection levels of approximately 0.3%. In 1963-64 most samples were infected and mean infection in Cappelle-Desprez rose to 5%. Infection tended to be lowest in samples from the eastern part of the country. Richardson (1986) conducted field trials on 36 stocks of certified winter wheat over the 5 years 1979-1983. Mean annual infection reached 6% in 1981 and the highest infection recorded was 14% on a sample of Armada in 1981. In contrast, Reeves & Wray (1994) reported between 75% and 95% of samples with more than 5% infection in 1992 and 1993.

In the HGCA/Zeneca survey 99% of winter wheat seed samples were infected with *M. nivale* in 1992 and 1993 compared with 68% of samples in 1994. These high values

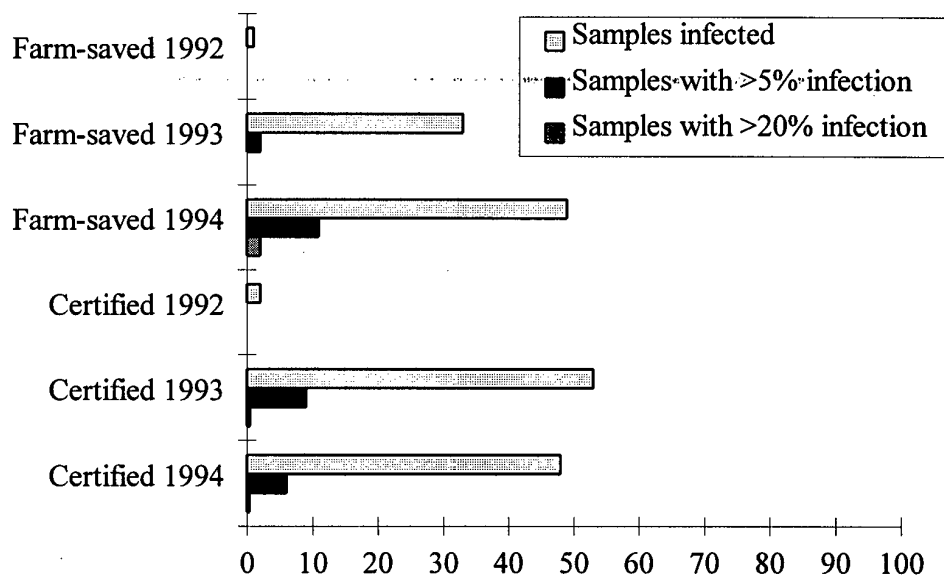
probably reflect conducive weather conditions for infection of ears during flowering and grain filling, rather than a long term deterioration in seed health. Infection above 20% was recorded in more than 40% of certified seed samples in 1992 and 1993 but only 2% of samples had this level of infection in 1994. Figure 5.6 shows the percentage of certified and farm-saved seed with more than 5, 20 and 50% *M. nivale*.

Figure 5.6 Percentage of winter wheat seed samples with more than 5, 20 and 50% *M. nivale* infection. (Cockerell & Rennie, 1995)



Both Noble (1956) and Hewett (1965) reported that *S. nodorum* was common in winter wheat seed but it declined in importance as a pathogen of UK wheat, and throughout the 1980's it was rarely recorded on wheat seed (Cockerell, unpublished observations). Infection of winter wheat seed with *S. nodorum* was low during the three years of the HGCA/Zeneca survey (Figure 5.7). In 1992 infection was rare and no sample had more than 5% infection. In 1993 33% of farmed-saved seed and 54% of certified seed samples were infected. About 9% of certified seed samples had more than 5% infection and 1% of samples had more than 20% of seeds infected. A similar pattern of infection was seen in 1994.

Figure 5.7 Percentage of winter wheat seed samples with *S. nodorum* infection and percentage of samples with more than 5 and 20% infection 1992-94. (Cockerell & Rennie, 1995)



Hewett (1975) reported *C. sativus* infection at low levels in a high proportion of spring barley seed samples in 1972 and 1973. In the susceptible variety Clermont 81% of samples tested were infected with an average infection of 24%. In 1991 13% of spring barley samples tested at the OSTs for Scotland were infected and samples of the susceptible variety Atem had up to 44% of seed infected (Cockerell, unpublished observations). The proportion of winter barley seed samples infected with *C. sativus* in the HGCA/Zeneca survey was low (Figure 5.8). The annual mean percentage infection did not exceed 1.5% in any year. There was no significant difference in infection between certified and farm-saved seed.

The proportion of samples of certified and farm-saved spring barley seed infected with *C. sativus* is shown in Figure 5.9. Also given is the proportion with greater than 5% infection.

Figure 5.8 Percentage of winter barley seed samples infected with *Cochliobolus sativus* 1992-94 (Cockerell & Rennie, 1995)

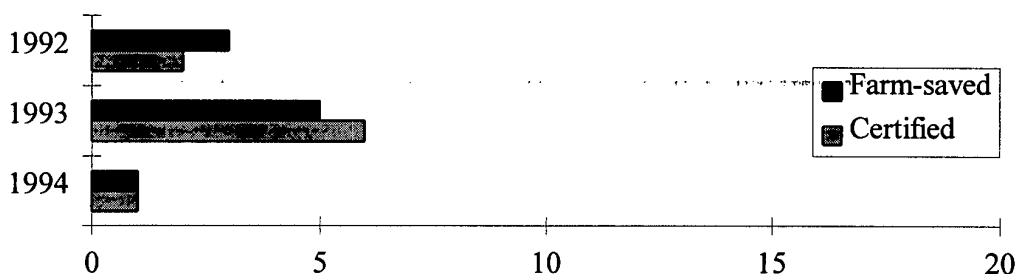
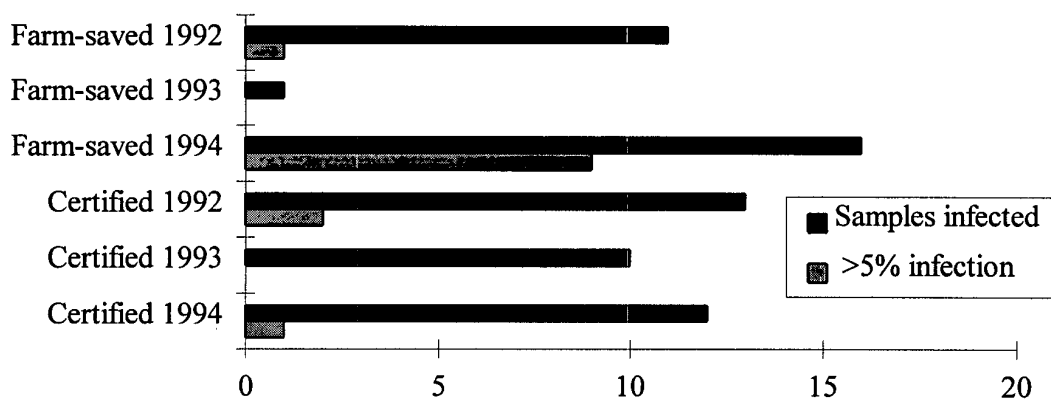


Figure 5.9 Percentage of spring barley seed samples infected with *Cochliobolus sativus* and proportion with more than 5% infection 1992-94 (Cockerell & Rennie, 1995).



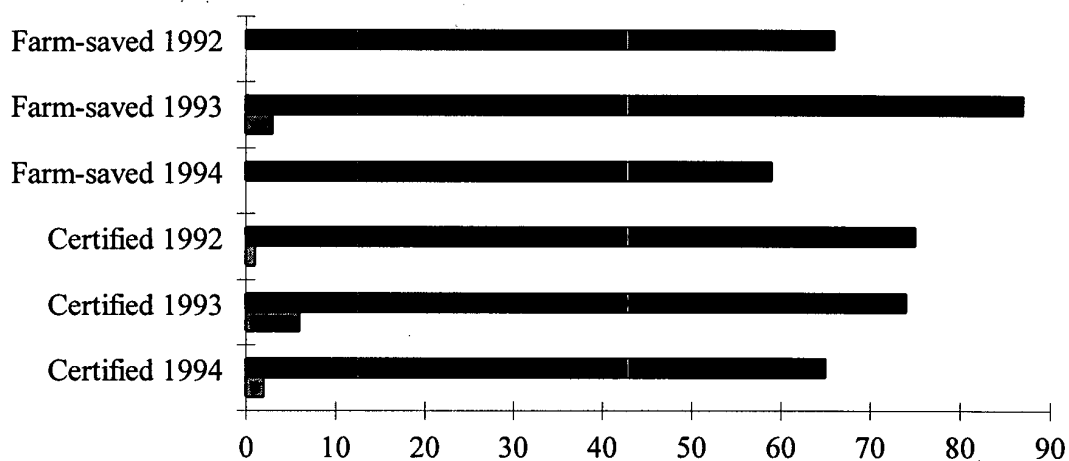
M. nivale can also infect oats and barley. Noble (1956) reported a mean infection of 14 and 16% in oat seed harvested in Scotland in 1951 and 1952, and found a mean infection of 20% in Scottish barley seed in 1954. In contrast, Malone & Lorimer (1975) recorded low levels of *M. nivale* on approximately 15% of samples of both barley and oats in Northern Ireland, with a mean infection of 0.3% in oats and 0.4% in barley.

Oat seed was not included in the HGCA/Zeneca survey but *M. nivale* was frequently recorded on barley seed. More than 50% of winter barley samples were infected with *M. nivale* each year, but infection was relatively low (Figure 5.10). 6% of certified winter barley seed samples had more than 20% infection in 1993. In spring barley, more than 60% of seed samples were infected with *M. nivale* in each of the three years but

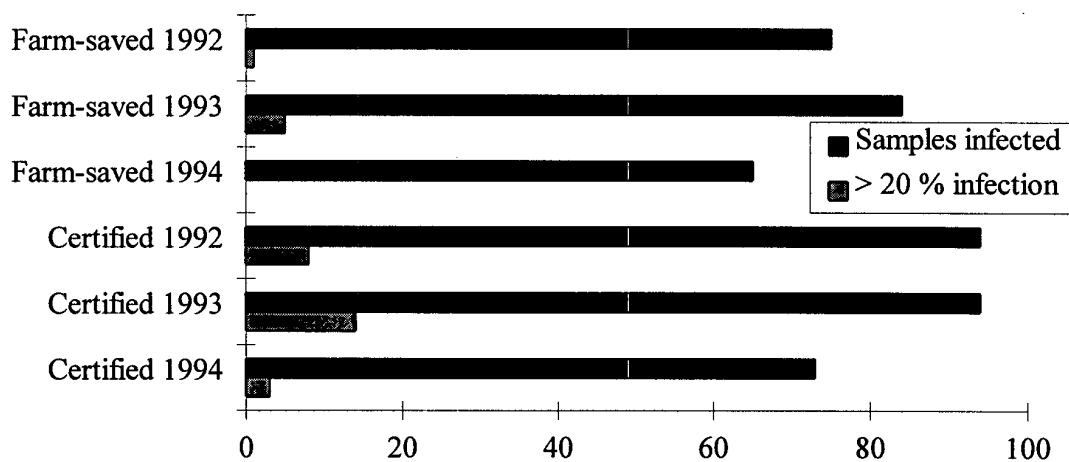
infection was at low levels (Figure 5.10). Approximately 15% of certified seed samples had more than 20% infection in 1993 and the proportion infected at this level in 1992 and 1994 was 8% and 4% respectively.

Figure 5.10 Percentage of winter and barley samples infected with *M. nivale* and percentage of samples with more than 20% infection 1992-94 (Cockerell & Rennie, 1995)

Winter barley



Spring barley



5.1.5 Incidence of ergot in certified seed in England and Wales

Cereal species vary in their susceptibility to ergot and this is reflected in the incidence of sclerotia in certified seed. The occurrence of ergot in official samples between 1990 and 1994 is given in Table 5.2.

There was considerable variation in occurrence of ergot between species and years. For most cereal species the incidence of ergot was very low and for the major species well over 99% of seed samples were free of ergot in each of the last five years. Rye, triticale and spring wheat had the highest incidence of ergot over this period. The highest figure for rye (30%) was due to adverse weather at flowering in 1994 and a recent trend towards hybrid varieties, which are more susceptible.

Table 5.2 Mean percentage of certified seed samples with ergot, England and Wales 1990-1994

	No. of samples	Mean % of certified seed samples with ergot		
		Lowest year	Highest year	Overall mean
Winter wheat	60,200	0.3	0.6	0.4
Winter barley	23,700	0.1	0.5	0.2
Winter oats	2,500	0	0.6	0.3
Rye	540	7.6	30.0	16.2
Triticale	420	0	4.0	2.5
Spring wheat	2,800	0.4	1.6	1.0
Spring barley	11,060	0.1	0.5	0.2
Spring oats	690	0	0.9	0.4

5.2 CONSUMER, OPERATOR AND ENVIRONMENTAL SAFETY CONSIDERATIONS IN THE USE OF SEED TREATMENTS

5.2.1 Approval of seed treatments

All pesticides in the UK require approval before they can legally be sold.

Before an approval is given for a new seed treatment, the Pesticides Safety Directorate (PSD) of MAFF considers data on a wide range of areas to ensure that the product is both safe and effective. Existing products are subject to periodic review to ensure that they continue to meet modern standards.

Data are provided by the manufacturer on the toxicology of the active ingredient, and in addition residues data are provided. Levels of pesticides in food are controlled by the Pesticides (Maximum Residue Levels (MRL) in Crops, Food and Feeding Stuff (Amendment) Regulations 1995. MRLs are intended primarily as a check that good agricultural practice is being followed and to assist international trade in produce treated with pesticides. MRLs are not safety limits, and exposure to residues in excess of an MRL does not automatically imply a hazard to health.

During the approvals process for pesticides, the potential exposure of consumers to residues in food is carefully assessed and compared to the Acceptable Daily Intake (ADI). Pesticides can only be approved if any such exposure results in intakes which are within the ADI. The ADI of a pesticide is a calculated figure, which indicates what quantity of a pesticide can be consumed every day for an individual's entire lifetime in the practical certainty, on the basis of all known facts, that no harm will result. Where statutory MRLs have been set the potential consumer intake from residues at that level is assessed and compared to the ADI.

Data are also examined on the fate and behaviour of the active ingredient in soil and water. The mobility and persistence of the active ingredients and its metabolites are considered. Also effects on wildlife such as mammals and birds, honeybees, soil organisms, aquatic life etc. are examined. In general the low dose of active ingredient applied, and its placement on the seed may reduce some risk, for example to honeybees,

compared to foliar sprays. The exposure of the person using the product is also examined to see if the risk is acceptable. In the case of a seed treatment, this exposure may occur during the treatment process and during the subsequent handling of the seed. It is also necessary to demonstrate that the product is effective against the diseases which it claims to control. After examining data in all these areas PSD decide whether or not it is acceptable for the product to be given approval for use within the UK.

Guidance on these requirements is given in the recently issued Registration Handbook (Anon., 1996). Information on the efficacy and physical/mechanical requirements for seed treatments is given in this handbook and by Slawson & Gillespie (1994).

5.2.2 Rationalising seed treatment use

The notion that pesticides should be used on a rational, 'according to need' basis has been widely accepted by the agricultural industry. In the case of foliar sprays, the substantial cost benefits of moving from routine prophylactic treatment to treatment based, for example, on varietal resistance and disease risk, have encouraged the uptake of new techniques. Regardless of the debate about the real or perceived environmental risks of pesticide use, a reduction in foliar spray applications can reduce the visible impact of pesticide use to the public. Such evidence that the industry is 'putting its own house in order', may reduce pressure for regulatory restriction.

The government set out its position on minimising the risks associated with pesticide use in the 1990 White Paper 'This Common Inheritance'. PSD assists MAFF in implementing these aims through the pesticide approvals process, by setting statutory maximum residue levels, surveillance monitoring and by its codes of practice; as well as providing advice on government funded research and development on the minimisation on pesticide use. Much of this research work is concerned with ensuring that pesticides are used rationally according to need.

In the case of seed treatments, the benefits of more rational use should not be dismissed, since no pesticide use is entirely free of risk. Operator exposure during seed handling

and drilling, poisoning of farm and domestic livestock from the accidental consumption of treated seed, and intake of treated seed by wild birds, are perhaps the most obvious sources of public and user concern, and require consideration in any debate on future strategies for seed treatment use.

5.3 BEST CURRENT ADVICE FOR CEREAL GROWERS

5.3.1 Risk assessment

The majority of growers use some farm-saved seed each year. Most buy in certified seed, grow the crop from that seed, and retain some of the grain produced to use as seed the following year. The majority have the seed cleaned and treated with a fungicide. A small, but increasing, minority follow the same procedure, but having saved seed from once-grown certified seed, do not apply a seed treatment. Some have the seed tested for diseases, particularly wheat seed in wet seasons when fusarium levels may be high, but many sow the seed with no direct knowledge of its health status. This may, at first sight, appear to be a high risk strategy but, in fact, the risks associated with such a strategy are actually small - provided that some assessment has been made of the likely risk of fusarium from the weather conditions during flowering. In dry seasons such as 1995, the risk from fusarium can be assumed to be very low. The only other serious disease to consider for wheat would be bunt and if the seed has been produced from certified, treated seed the likely levels of bunt in the subsequent seed produced are very small indeed.

Growers who choose to grow on seed saved from once-grown certified seed tend to do so from experience, rather than from an understanding of the biology of the pathogens involved in seed-borne diseases. However, the widespread belief that saving once from certified seed is safe, but saving more than once carries a high risk, is generally sound. The development of seed-testing methods which allow the farmer to make some judgement of the need for seed treatment, has removed some of the guesswork and quantified the risks associated with farm-saving of seed, particularly when no seed treatment is used. Technological advances have allowed us to detect a wide range of

pathogens which may be present on seeds, but relating the results of tests to the likely disease levels in the subsequent growing crop remains less well understood. Although seed testing stations give some guidance on the significance of the disease levels found in seed, they necessarily have to be very conservative and take account of all the possible factors affecting disease development. These include time of sowing, seedbed conditions, soil type, depth of sowing, soil temperature and seed vigour. Giving general advice cannot possibly take all of these factors into account. However, with a knowledge of these factors on an individual farm, a more informed decision can be made. Indeed, ADAS and the Scottish Agricultural College (SAC) in conjunction with NIAB and SASA do offer advice on the need for, and the choice of, cereal seed treatment. This advice is based on knowledge of pathogen epidemiology and data from field experiments on seed treatment efficacy. There are, however, some areas where critical levels of seed-borne disease have not yet been adequately determined, which means that advice may still be excessively cautious.

5.3.2 Seed treatment choice

Most seed merchants and mobile seed-treatment companies offer a limited range of treatments because of the practical difficulties in changing products, recalibrating and cleaning machines between batches, maintaining stocks of several products etc. This may restrict the choice available to farm-savers and purchasers of certified seed. Tables 5.3, 5.4 and 5.5 give the activity of seed treatments currently available in the UK for wheat, barley and oats respectively.

Table 5.3 Activity of seed treatments for wheat

	Baytan	Panoctine	Sibutol	Vitaflo	Beret Gold	Anchor
Bunt	+	+	+	+	+	+
Loose smut	+	-	+	+	-	+
Fusarium	+	+	+	+	+	+
<i>S. nodorum</i>	+	+	+	+	+	+

Table 5.4 Activity of seed treatments for barley

	Baytan	Ferrax	Raxil S	Panoctine Plus	Vitaflo Extra	Beret Gold	Anchor
Leaf stripe	+	+	+	+	+	+	+
Fusarium	+	+	+	+	+	+	+
Loose smut	+	+	+	-	+	-	+
Covered smut	+	+	+	+	+	+	+
Net blotch (seedling)	+	+	+	+	+	+	+

Table 5.5 Activity of seed treatments for oats

	Baytan	Panoctine Plus	Vitaflo Extra	Anchor
Fusarium	+	+	+	+
Loose smut	+	+	+	+
Covered smut	+	+	+	+
Leaf spot	+	+	+	+

Seed-borne diseases are not the only diseases which are taken into account when deciding on seed treatment options. There are some situations where the use of a seed treatment is dictated by risk of other diseases. An example is the use of Baytan on yellow rust susceptible varieties in high risk parts of the country, where treatment can provide protection from early infection. Ferrax is often used in susceptible spring barley crops to prevent early infection by mildew. In the latter case, seed treatment may be considered more as a management tool, to reduce the need for early season fungicide sprays, when farm resources may be over-stretched on other spring operations.

Most seed treatments do not protect against soil-borne bunt, but substantiated cases of soil-borne carry over of the disease remain rare. Where growers suspect soil contamination with bunt, either from problems in previous seasons, or from

observations of bunt at harvest, treatment with Baytan, Beret Gold or Sibutol may be justified. However, the situation is complex and advice should be sought.

5.3.3 Summary of current best advice

Wheat

Buy certified seed which has been treated with a fungicide seed treatment.

If retaining seed from this crop:

- In seasons when the weather is dry during flowering, seed saved from a crop grown from certified, treated seed poses little risk in terms of seed-borne disease. Have the seed cleaned and tested for germination, bunt and fusarium. An assessment of the risk from fusarium can be made based on weather during the flowering period. In dry seasons the risk of fusarium will be low and the test for fusarium may be omitted. Apply a suitable seed treatment if disease levels warrant.
- Soil-borne bunt, arising from a bunt infection within the field, or from wind-blown spores from an adjacent field should be considered when deciding on seed treatment. This is particularly relevant in years when conditions between harvest and sowing are dry, allowing bunt spores to survive between crops.

If retaining seed for a second or subsequent season:

- Do not sow the seed without testing for seed-borne diseases.
- Have the seed cleaned and tested for germination, bunt and fusarium. In dry seasons the risk of fusarium will be low and hence the test for fusarium may be omitted.
- Apply a suitable seed treatment if disease levels warrant.
- Never retain seed from a crop grown from certified seed and sow without seed treatment more than once. Bunt in particular can build up rapidly in seed stocks if an effective seed treatment is not applied.

Barley

Buy certified seed which has been treated with a fungicide seed treatment.

If retaining seed from this crop:

- Have the seed cleaned and tested for germination, leaf stripe and loose smut. Even in wet seasons fusarium is not a major seed-borne pathogen on barley and seed should not need to be tested for this pathogen. Apply a suitable seed treatment if disease levels warrant.
- Both leaf stripe and loose smut can be seen in the growing crop but the observed level of disease is not a good indicator of the likely level that could occur in a crop grown from seed taken from the crop. Both diseases can also spread from adjacent crops, although the risk of this is low. Thus, saving seed, even from crops grown from certified treated seed, and sowing it without a fungicide seed treatment is not advisable unless the seed has been tested and shown to have low levels of loose smut and leaf stripe.

If retaining seed for a second or subsequent time:

- Do not sow the seed without testing for seed-borne diseases.
- Have the seed cleaned and tested for germination, leaf stripe and loose smut.
- Apply a suitable seed treatment if disease levels warrant.

Oats

Buy certified seed which has been treated with a fungicide seed treatment.

If retaining seed from this crop:

- Have the seed cleaned and tested for germination, loose smut, seedling blight (*Pyrenophora avenae*) and fusarium. Apply a suitable seed treatment if disease levels warrant.

- Saving seed, even from crops grown from certified treated seed, and sowing it without a fungicide seed treatment is not advisable unless the seed has been tested and shown to have low levels of loose smut, *P. avenae*, and fusarium.

If retaining seed for a second or subsequent time:

- Do not sow the seed without testing for seed-borne diseases.
- Have the seed cleaned and tested for germination, loose smut, seedling blight (*P. avenae*) and fusarium. Apply a suitable seed treatment if disease levels warrant.

Rye

Buy certified seed which has been treated with a fungicide seed treatment.

If retaining seed from this crop:

- Have the seed cleaned and tested for germination and fusarium. (An assessment of the risk from fusarium can be made based on weather during the flowering period. In dry seasons the risk of fusarium will be low and the test for fusarium may be omitted.) Apply a suitable seed treatment if disease levels warrant.
- In seasons when the weather is dry during flowering, seed saved from a crop grown from certified, treated seed poses little risk in terms of seed-borne disease and can be sown untreated.

If retaining seed for a second or subsequent time:

- Do not sow the seed without testing for seed-borne diseases
- Have the seed cleaned and tested for germination and fusarium. Apply a suitable seed treatment if disease levels warrant.

CHAPTER 6

SEED HEALTH AND SEED TREATMENT STRATEGIES IN OTHER COUNTRIES

6.1 DENMARK

Denmark takes seed quality very seriously and like the UK has a mature seed certification system. As a result about 90% of the cereal area is sown with certified seed, about 80% of which is routinely treated with products approved by the Danish Ministry of Agriculture and Fisheries, resulting in a low incidence of seed-borne pathogens. There are no general requirements for seed treatment within the certification schemes, but the routine use of fungicides during the first three generations of seed production keeps infection and inoculum levels low.

Information from Denmark suggests a pattern of *T. caries* contamination of winter wheat seed similar to the UK, except that in Denmark there was a temporary increase in bunt from the early 1970's when a proportion of wheat seed was sown untreated. In recent years *T. caries* has been recorded in a high proportion of Danish winter wheat seed samples but contamination has, as in the UK, been at a low level. Table 6.1 compares contamination with bunt in Danish and UK seed in 1992 and 1993.

Table 6.1 Percentage of Danish and UK winter wheat seed lots contaminated with *T. caries* spores in 1992 & 1993 (Nielsen, 1994; Cockerell & Rennie, 1995)

Harvest year	% samples with:					
	No bunt		1-5 spores per seed		>5 spores per seed	
	Denmark	UK	Denmark	UK	Denmark	UK
<u>Farm-saved/requested analysis</u>						
1992	77	63	18	35	5	2
1993	64	57	27	42	9	1
<u>Certified seed</u>						
1992	80	43	20	55	0	2
1993	88	78	12	21	0	1

It is considered that treatment of C2 seed would not normally be necessary but that testing for seed-borne diseases should be a part of the strategy determining the need for seed treatment (Nielsen & Scheel, 1995). Thresholds have been adopted for a number of important seed-borne cereal diseases to facilitate decisions on seed treatment.

Although this is the situation at present, the Danish Government has instituted a policy of reducing the use of pesticides by 50% before 1997. Seed treatments are not yet part of this policy, but the feasibility of including them is being discussed. The view is emerging that this would be possible for spring barley, but that a decision to treat should be taken on the basis of a seed health test, modelled on the voluntary system adopted by Norway (Section 6.2). Treatment of winter cereal seed is expected to continue with little change, due to the importance of the diseases and the practical difficulties of testing between harvest and sowing. A decision on this position is awaited from the Ministries of Agriculture and Environment.

6.2 NORWAY

To prevent unnecessary use of fungicide seed treatments in Norway it was decided in 1990 that cereal seed should only be treated when the results of a seed-borne disease test indicate the presence of infection at, or exceeding, a given threshold level (Brodal, 1993). Introduction of this policy appears to have been successful because of the low price attached to disease testing, arising from an element of state subsidy. However, there are moves to institute greater or full cost recovery which will inevitably lead to price increases. Nevertheless prices will still be low in comparison with those in the UK, partly because of economies of scale with more than 5000 barley samples tested per annum, and partly because of circumstances in Norway which allow cheaper testing methods to be used. Spring cereals dominate in Norway and there is sufficient time between harvest and sowing for seed testing to be done using conventional methods.

The policy of treatment according to need is essentially voluntary, but is actively encouraged and supported by state authorities. The majority of farmers submit samples for disease testing and seed cleaning, and treatment companies apply treatments in

accordance with the results of that test. As in Denmark, seed treatment is recommended if seed-borne pathogens exceed certain thresholds (Table 6.2).

Table 6.2 Thresholds for seed treatment in Norway

Crop	Pathogen	Threshold (% seeds infected)
Spring Barley	<i>P. graminea</i> / <i>P. teres</i> in 6 row barley	5
	<i>P. teres</i> in 2 row barley	10
	<i>Fusarium</i> spp.	25
	<i>C. sativus</i>	10
Spring Oats	<i>P. avenae</i>	25
	<i>S. nodorum</i>	5

The policy is most widely applied to barley, but it is planned to extend it to wheat and oats in the future. However, it is recognised that, for wheat at least, it may be necessary to treat all seed without a prior disease test.

There is general acceptance of the approach throughout the agricultural industry, without major opposition from the agrochemical companies who could be expected to suffer most from the loss of sales (about 5m Nkr, £500,000, per annum). This probably results from the relative cheapness of seed testing compared with the cost of seed treatment and the small size of the Norwegian market for agrochemicals.

6.3 SWEDEN

The Swedish policy for seed treatments was initiated in 1966. There are well defined thresholds for common seed-borne diseases of cereals within the certification scheme, which together with the results of seed health tests are used to advise that treatment is unnecessary, recommended or required. Seed companies may treat seed even if the result of a seed health test indicates that this is unnecessary, but they must treat with an appropriate chemical if, based on the results of seed health testing, the testing authority

demands it (Sperlingsson, personal communication). Details of tolerances for cereal seed-borne pathogens in Sweden are given by Brodal (1993).

6.4 AUSTRIA

There has been a well organised and developed seed certification system in Austria for the past 30 to 40 years, including standards for many of the major seed-borne diseases of cereals. Unlike Norway, there are no regulations for the application of seed treatments on the basis of seed health testing, but there is a voluntary system of seed health quality. Nevertheless, there is increasing interest in organic production and as a result there is pressure to reduce the use of all agrochemicals. There is also price-driven pressure to reduce the use of expensive fungicide seed treatments in both conventional and organic agriculture. This is leading to sustained interest in seed health testing and in the establishment of appropriate thresholds for seed-borne pathogens. Research is being carried out in this area (Girsch, personal communication).

6.5 FRANCE AND GERMANY

A feature of the cereal seed market in both France and Germany is that up to half the wheat and barley sown is farm-saved, reflecting the relatively favourable conditions for seed production in both countries. Certified and farm-saved seed are treated on a routine basis with a wide range of seed treatment products: less than 5% of certified seed is sown untreated. Official authorities in some German states may monitor certain seed-borne pathogens, for example *Tilletia* spp. in Basic seed stocks, but seed health tests are not usually made before seed is treated and there is currently no move reduce seed treatment usage.

CHAPTER 7

SUMMARY POINTS AND CONCLUSIONS

This chapter takes the form of summary points (•) from each section and the main conclusions (**in bold**) drawn from them.

7.1 HISTORY

- Cereal seed treatments to control fungal diseases have formed an important part of crop production since the use of brine steeps to control bunt in the 17th century.
- The widespread use of cheap organomercury seed treatment over the past 50 years, and the development of systemic treatments, consigned previously important seed-borne diseases to obscurity.
- Voluntary post-war cereal seed 'certification' schemes incorporated limited seed health standards from the 1960's and became statutory in 1973.

During the period when certification schemes were being developed, organomercury seed treatments were cheap and routinely used. As a result, the only specific standards defined for seed-borne diseases were for the 'smuts' and ergot, which organomercury did not control.

Fifty years of organomercury availability at negligible cost has created a culture of routine seed treatment use.

7.2 EPIDEMIOLOGY

- The most important seed-borne diseases of cereals in the UK are currently bunt (*Tilletia caries*) and fusarium seedling blight (mainly *Microdochium nivale*) on wheat, and loose smut (*Ustilago nuda*) and leaf stripe (*Pyrenophora graminea*) on barley.
- Historically, the relative importance of different seed-borne diseases has fluctuated depending on varieties grown, the use of seed treatments and crop husbandry.

Diseases such as bunt have high potential for large generational increase and to cause significant economic loss.

Diseases which were once common, but are now rare (e.g. loose smut of wheat) should not be discounted, as they may have the potential to recur.

Recent cases of bunt persisting in the soil between harvest and emergence of the following wheat crop are a cause for concern - particularly in the light of the recently reported similarities between the non-indigenous, soil-borne dwarf bunt and the bunt species common in the UK.

7.3 SEED HEALTH THROUGH SEED CERTIFICATION

- Seed certification aims to achieve high standards of varietal purity and germination potential, and low levels of contamination and disease. The sale of uncertified seed is prohibited.
- The quality of certified seed is checked by seed testing, sample examination, the sowing of an inspected 'control plot' from each seed lot used to produce more certified seed and by crop inspections.
- The presence of ergot sclerotia in seed of wheat, barley, oats, rye and triticale is checked in a sample of each seed lot at the same time as the species purity test, and seed lots are rejected if they do not meet the standard.
- Wheat and barley control plots of Breeders', Pre-basic, Basic and C1 seed lots are inspected for loose smut. Seed produced from crops sown with seed lots which fail to meet the standard can only be certified and sold if: 'retrieved' by treatment with a product effective against loose smut, or an embryo test shows that the seed meets the standard. 10% of C2 seed lots are examined retrospectively in control plots to check that they meet the standard for loose smut.

There is a general misconception that certification guarantees an intrinsically high health status. Apart from a general requirement to ensure that 'The seeds shall be of a satisfactory state of health in so far as seed-borne diseases and organisms

affecting the seeds are concerned', only those diseases which can be readily observed in control plots (loose smut) or during visual inspection of the seed (ergot) are subjected to defined standards. No standards are set for other seed-borne diseases.

The certification procedure does not require routine seed testing for seed-borne diseases.

Health is primarily maintained by 98% of certified seed receiving a seed treatment. An average of 1,000 cereal seed lots per week are processed for certification during September and October in England and Wales. The quality assurance systems in seed certification need to cope with this high throughput without delaying the seed supply.

7.4 FARM-MADE SEED

- Approximately 30% and 20% of winter wheat and barley crops, respectively, are grown from farm-made seed. Only a small proportion of farm-made seed lots are tested for seed-borne diseases.
- Approximately 10% and 20% of winter wheat and barley crops, respectively, grown from farm-made seed, are sown without treatment.

Farm-made seed accounts for virtually all of the cereal seed sown without treatment.

There are some risks, both to the individual crop and neighbouring crops, associated with the use of untreated, untested seed. These risks would be increased if sowing untreated, untested seed became widespread. Guidelines to minimise these risks are dealt with in Section 5.3.

7.5 SEED HEALTH TESTING

- Current test techniques for leaf stripe, seedling diseases and net blotch involve plating onto agar, incubation for several days and identification under the microscope. Tests for bunt and loose smut are quicker, but labour intensive, adding to the cost.
- The development of seed health tests based on immunodetection (such as ELISA) is likely to run in parallel with laboratory techniques based on the molecular biology of nucleic acids (DNA).
- Highly specific DNA probes (portions of DNA which can combine only with the genetic material of the target pathogen) can be used to 'label' pathogens in such a way that they can be detected. When combined with polymerase chain reaction (PCR) techniques, high levels of specificity and sensitivity can be obtained.

Tests for seed-borne pathogens should be rapid, accurate, sensitive to low levels of disease, repeatable, inexpensive and easy to interpret. Simplicity, to minimise handling errors, and a lack of subjectivity in assessing the results are desirable features. Few of the current techniques meet all these criteria.

As a result of the technical limitations described above, it is unlikely that current methods of seed testing could cope, cost effectively, with a substantial increase in reliance on seed health testing to aid certification or treatment decisions.

A combination of high speed, high sensitivity and low unit cost are technically achievable with DNA based techniques. However, development costs and capital investment are likely to be high. Speed and low unit cost depend on high throughput, to adequately utilise automated plate readers, bar code labelling of samples etc.

In the long term, the new generation of immunoassay based techniques have the potential to provide immediate, 'in the field' tests for seed health.

7.6 SETTING THRESHOLDS FOR TREATMENT OR REJECTION OF SEED

- The results of seed health tests are of little value unless they can be interpreted to support management decisions. The conversion of test result to decision guidance is usually achieved by setting thresholds for treatment and/or rejection.
- Many of the current advisory and statutory thresholds were empirically derived, and appear to function adequately against a general background of routine seed treatment use.
- Differences in the life histories of the seed-borne pathogens affect both their susceptibility to seed treatment, optimal strategies for their control and the factors that need to be considered when defining thresholds.

Seed-borne disease thresholds for treatment or rejection of seed should maximise profit (in this context profit = marketable grain yield minus treatment costs), minimise the risk of occasional severe losses to individual crops and place the national pathogen population under consistent downward pressure.

The derivation of logical thresholds requires data defining: (i) the relationship between test result and disease expression, (ii) the risk of spread to neighbouring crops, and (iii) the rate of generational increase in seed infection. Some of these data are already available for the major pathogens.

Given the data above, potential thresholds could be mathematically tested to simulate a run of seasons, in order to set thresholds at robust, but not over-cautious, levels. The effects of non-compliance by varying proportions of the industry could be quantified.

7.7 SEED TREATMENT USE

- UK growers pay approximately £23 million per annum for cereal seed treatments.
- Seed treatments are used to control seed-borne, soil-borne and foliar diseases. Physiological characteristics, such as plant emergence, tillering, root development and lodging may also be beneficially or deleteriously affected by treatment.
- The withdrawal of organomercury seed treatments has not changed the proportion of crops grown from untreated seed.
- Seed treatment product choice is limited by the practicalities of seed treatment plant operation and commercial considerations.

The benefits of seed-borne disease control are clear and can hardly be overstated.

Treatment of seed that does not carry seed-borne disease cannot improve its intrinsic health status.

A number of studies have quantified the other potential benefits from treatment of healthy seed. These studies have concluded that, except in certain circumstances, the potential benefits of treatment - arising from control of soil-borne and foliar diseases, and physiological effects - are negligible.

The exceptions being: (i) control of yellow rust and powdery mildew on susceptible varieties of winter wheat and spring barley, respectively, by broad-spectrum seed treatments, (ii) control of soil-borne bunt by broad spectrum and phenylpyrrole based materials, (iii) partial control of take-all by broad spectrum treatments when wheat is sown early and severe take-all subsequently develops.

If seed is known to be healthy, the progeny are not to be taken for seed and the circumstances described above do not apply, sowing untreated seed is likely to be the most cost effective option.

7.8 FUNGICIDE RESISTANCE

- Resistance in *Ustilago nuda* (loose smut) to carboxin and *Pyrenophora graminea* (leaf stripe) to organomercury developed during the 1980's.
- The development of resistance to organomercury was particularly surprising, given its wide mode of action, and emphasises the extreme selective pressure exerted when virtually the whole of the pathogen population is exposed to the same active ingredient over many seasons.

In future, resistance to currently effective products is likely. Profits flowing back to the agrochemical companies will need to be sufficient to stimulate the development of new products, if control is to be sustained.

7.9 INCIDENCE OF SEED-BORNE DISEASES

- The incidence of seed-borne diseases provides a key measure of the success of current control measures, and a baseline from which to monitor long term trends.
- Spores of *Tilletia caries* (bunt) were found in 20% to 60% of certified and farm-saved wheat seed samples between 1992 and 1994. A small proportion of bunt contaminated samples exceeded the advisory limit of one spore per seed. On average, certified and farm-saved seed suffered a similar incidence of infection but, in some seasons, farm-saved samples were the more severely contaminated.
- In the worst season surveyed (1992) approximately 60% of farm-saved winter barley seed stocks were infected by loose smut, with 36% of stocks failing the 0.2% HVS standard for C1 and C2 seed, compared to 20% of certified seed stocks infected and 7% failing the 0.2% standard.
- Leaf stripe infected between 2% and 10% of winter barley samples, with approximately one quarter of these samples exceeding the 2% advisory limit. Both incidence and severity of infection were similar in farm-saved and certified seed.
- Fusarium contamination of wheat seed showed substantial seasonal fluctuation depending on weather conditions between flowering and harvest. In the worst season

(1993) 90% of samples showed some infection, with over 50% of samples showing greater than 20% of seed affected. Only 2% of samples were affected to that extent in 1994. Both incidence and severity of infection were similar in farm-saved and certified seed.

The certification process aids control of loose smut, for which specific standards are set and effective control plot inspections are possible. With the exception of loose smut, comparisons of certified seed against farm-saved samples suggest that the certification process does not provide seed of intrinsically higher health status.

The use of effective seed treatments on 98% of certified seed lots ensures that seed is fit for the purpose for which sold.

There is some unsubstantiated concern that one contributory factor to the widespread low level of infection seen with pathogens, such as bunt, that contaminate the surface of the seed, may be the spread of spores from an infected seed lot to other lots through contamination of seed handling equipment.

7.10 SAFETY CONSIDERATIONS IN SEED TREATMENT USE

- All pesticides in the UK require approval before they can legally be sold. Existing products are subject to periodic review to ensure that they continue to meet modern standards.
- During the approval process, potential exposure of consumers to residues in food, fate and behaviour of active ingredients in water, and effects on wildlife, soil organisms and aquatic life, are assessed. Risks associated with exposure of operators and users of treated seed are also assessed.

It is difficult to quantify the safety, environmental and public perception benefits of rationalising seed treatment use. The approvals process is rigorous in ensuring that the risks of use are properly weighed against the benefits. However, it would be simplistic to consider that approval implies that use is entirely without risk.

Operator exposure during seed handling, poisoning of farm and domestic livestock from the accidental consumption of treated seed, and intake of treated seed by wild birds, are perhaps the most obvious sources of public and user concern. Such sources of concern deserve proper consideration when debating the relative merits of alternative strategies to maintain seed health.

7.11 CURRENT PRACTICE IN OTHER COUNTRIES

- Denmark is broadly representative of the approach to seed health taken in Scandinavian countries. The routine use of seed treatments during the first three generations of certified seed production keeps seed-borne diseases at a low level. It is considered that treatment of C2 seed would not normally be necessary, but that seed health testing and defined treatment thresholds should be part of the strategy determining the need for treatment in that generation.
- The Danish government is currently considering inclusion of seed treatments in their policy to reduce pesticide use by 50% before 1997. The logistical difficulties associated with testing arrangements between harvest and sowing may make such a policy difficult to implement for winter cereals, but feasible for spring cereals.
- In France and Germany, certified and farm-saved seed continues to be treated on a routine basis, and there is no move to reduce usage.

The emphasis placed on ‘treatment according to need’ by different countries appears to depend mainly on the extent of public and governmental pressure to reduce pesticide use, and logistical considerations relating to seed testing. The latter being related to investment in seed testing facilities and the relative proportions of spring and winter cropping.

CHAPTER 8

POSSIBLE FUTURE STRATEGIES FOR UK SEED HEALTH AND SEED TREATMENT USE - IMPLICATIONS AND RESEARCH NEEDS

Four possible strategies for the future maintenance of seed health are outlined in the following sections, together with a brief summary of their implications. The research and technical development work associated with the implementation of each strategy is indicated.

8.1 MINIMAL CHANGE TO CURRENT PRACTICE

A case can be made, on technical and commercial grounds, to continue the current practice of applying fungicide seed treatments to approximately 98% of certified seed and 80-90% of farm-saved seed, and to maintain the certification standards for loose smut and ergot.

- It can be argued that current practice has achieved and maintained a high level of seed health and ensured minimal losses from seed-borne diseases. Although a small increase in the amount of untreated seed would probably make little difference to this position, significant changes may have unforeseen consequences on the incidence and severity of seed-borne diseases. A substantial reduction in the use of seed treatments may therefore be unacceptably risky.
- The short time available for cleaning, testing and treating seed of winter cereals would make it difficult to change current practice with the logistical constraints imposed by existing seed testing technology. Seed processors would need to carry out at least 2000 tests a week during September and October.
- The profit generated from sale of fungicide seed treatments for seed merchants, agrochemical companies and mobile seed processors is of sufficient importance for there to be commercial resistance to change. Reducing the market for seed treatments may make the development of new products unprofitable, and jeopardise the control

of seed-borne diseases in the future - particularly if the development of resistance renders some existing active ingredients ineffective.

Disadvantages

- Growers continue to bear the costs of routine seed treatment use and, indirectly, certification controls for loose smut and ergot.
- A substantial proportion of cereal seed lots, that carry nil or sub-threshold levels of seed-borne disease, continue to be treated unnecessarily.
- A gradual shift may occur to more crops being grown from untreated seed without appropriate tests, as growers respond to falling margins by farm-saving a higher proportion of their seed and leaving it untreated to cut input costs.

8.2 LIMITED 'TREATMENT ACCORDING TO NEED' STRATEGY

A change to a limited 'treatment according to need' approach to the use of fungicide seed treatment to spring cereals, both certified and farm-saved seed, would be feasible with existing seed testing techniques, and could be implemented in the short term. There may be some opportunity for uptake of similar principles for winter cereals.

- Encourage testing of farm-saved and C2 seed of spring cereals for seed-borne diseases. Use test results, together with other information, to define the need for treatment and product choice. In the short term, treatment decisions could be based on current advisory thresholds.
- Routine treatment of seed during multiplication would remain essential.
- Seed lots with disease levels in excess of those which can reliably be controlled by seed treatment would be detected and could be removed from the seed supply.
- Growers would benefit from savings in seed treatment costs, and the use of pesticides could be shown to be rational.

- There may be scope for the cereal seed industry to develop ‘premium’ seed products which have been tested and shown to carry nil or sub-threshold levels of the major pathogens.

This strategy might be particularly appropriate in Scotland, where spring barley occupies 60% of the cereal area.

Disadvantages

- The costs of seed testing would need to be taken into account in assessing any economic advantage. These costs have to be borne even when a seed lot is found to require treatment. Hence, the cost of the tests, the proportion of seed lots requiring treatment, the cost of the treatment and the size of the seed lot all affect the economic balance. In the best case, with adequate sampling techniques, a 25 tonne seed lot may require one set of tests to save £1000 of treatment costs. For one tonne seed lots, testing would not be economic.
- The delays involved in current seed testing methods would substantially limit uptake on winter crops, so the disadvantages described in Section 8.1 remain.

Constraints on implementation

- For spring crops, uptake would depend on the scale of the financial advantages, the effectiveness of the advisory message and flexibility in the seed and seed treatment supply trade in responding to customer demands.
- If demand for testing increased substantially, existing test facilities and techniques may not be able to cope effectively.

8.3 LONG-TERM CHANGE TOWARDS A WIDER STRATEGY OF ‘TREATMENT ACCORDING TO NEED’

Better targeting of seed treatments, both in avoiding treatment of healthy seed and in applying the products most appropriate to the range of pathogens present, could be achieved through advances in seed testing technology and an increase in understanding

of the major seed-borne diseases. A significant long-term decrease in the use of fungicide seed treatments in cereals should be achievable, together with maintenance or improvement of seed health. Given the necessary advances, outlined below, such a strategy could begin to take practical effect in approximately five years.

- Rapid, sensitive and reliable tests for seed-borne diseases would be necessary to meet the demand for processing of winter cereals in September and October. DNA based tests could meet these requirements, and their development is feasible with current knowledge.
- Automation in testing procedures could reduce unit costs and allow testing organisations to cope with high sample throughputs.
- It is possible that any delay to the processing of winter cereals in the autumn would be unacceptable to seed merchants and growers. An alternative to sampling and testing during processing would be testing on farm, prior to delivery to the processor. New generation immunoassay based tests may be the most appropriate technology for such tests.
- Quantitative information would be needed to allow the results of seed health tests to be accurately related to the risk of seed-borne diseases. For example, to define thresholds and to quantify the importance of environmental conditions in disease expression and spread. Mathematical projections of pathogen populations could be used to set thresholds to ensure a long term reduction in the national level of seed-borne diseases.
- Seed testing in the certification process could replace visual inspections for disease in control plots, and broaden the range of diseases for which logical thresholds for treatment or rejection could be set.
- The 'premium' seed products described in Section 8.2 could be developed to a high standard for winter and spring cereals.

Disadvantages

- The commercial viability of developing new fungicide seed treatments may be prejudiced by the reduced market, and the cost of certified seed may increase if seed merchants compensated for the loss of income from seed treatments.

Constraints on implementation

- Significant investment would be needed to develop new seed tests and to define relationships between test output and disease expression in the field.

8.4 TREATMENT BASED ON COMPULSORY TESTING OF ALL SEED

Given the social aspects of seed-borne disease control, some might argue that, in the long term, adequate levels of compliance with rational control strategies could only be ensured by regulatory controls. Such controls might make health testing of all certified and, possibly, farm-saved seed compulsory, and treatment dependent on the results of the tests.

- The technical and research developments described in Section 8.3 above could make such a scheme logistically feasible.
- The guaranteed compliance should enable exceptionally high levels of seed health to be achieved over a period of several seasons. Seed lots with excessive infections could be removed from the seed supply and the most effective treatments could be specifically targeted at the seed lots that most require them.

Disadvantages

- The disadvantages of Section 8.3 would apply.

Constraints on implementation

- Given the current emphasis on deregulation, it is unlikely that the legislation required to fully implement this strategy would obtain political support or be commercially

acceptable. However, some elements could be cost effectively introduced into the certification process.

8.5 KEY RESEARCH NEEDS

The key areas of research required to implement the proposed future strategies are outlined in this section. Table 8.1 summarises which areas of research are beneficial or a prerequisite for each strategy. Future research within the majority of topics listed in Table 8.1 should be focused on specific diseases for which knowledge is incomplete.

8.5.1 Quantifying multiplication potential

Current estimates of the rate of generation on generation increase in incidence and severity of seed-borne disease infection are based on limited data.

Epidemiological knowledge suggests that there should be substantial variability in the rate, dependent on combinations of genotype and environment. This variability makes interpretation of limited data risky, as it is not known where in the expected population distribution of rates, the available measures fall (i.e. do they represent extreme or typical cases?).

The rate of increase from generation to generation of seed is a key component of risk assessment. Objective thresholds for seed treatment or rejection should be set to take account of the worst case. For a few key diseases, worst cases might be artificially generated to enable direct measurement of the potential growth rate.

8.5.2 Quantifying risk of spread to neighbouring crops

The extent of the risk to neighbouring crops is at the heart of many growers' concerns on the seed treatment issue. Loose smut and leaf stripe pose a risk to neighbouring crops if they are to be taken for seed. Bunt may pose a threat to crops grown for seed or ware, via persistence in the soil. There are significant gaps in our quantitative knowledge of these risks, that could be filled by experimentation.

8.5.3 Development of rapid seed health tests

The limitations of current seed health testing techniques, particularly the time taken to carry out the tests, are preventing more effective targeting of seed treatments. Rapid, sensitive, high throughput, cost effective techniques are technically feasible and should be developed.

8.5.4 Establishing relationships between test results and disease expression

The conversion of test results to treatment or rejection decisions depends on knowledge of the relationships between test output and disease expression in the field (e.g. what does a reading of 216 from an immunoassay plate reader mean in terms of percentage plants affected?).

The shape of these relationships will vary according to genotype and environment and could be quantified experimentally.

8.5.5 Detecting long term changes in pathogen populations

The recent HGCA/Zeneca survey of seed-borne diseases has set a base-line against which long-term changes in seed health could be measured. Samples submitted for testing can be used as a crude measure by which to detect improvement or deterioration. However, such samples provide a skewed picture. Occasional stratified surveys may be helpful to detect negative changes in time for remedial action to be taken via awareness campaigns and tightening of treatment thresholds. Limited monitoring for currently rare diseases may also be of value.

8.5.6 Establishing confidence limits for seed test samples

Health tests are carried out on a small sample from each seed lot. Little is known about the distribution of infection within seed lots, and the effects of sampling on variation in the relationship between the test result and the actual level of infection in the seed lot. Confidence limits for sample results should be quantified, so that interpretation of test results can take account of sampling error.

8.5.7 Relative seed treatment efficacy against expression, spread and multiplication

Periodic assessments of new seed treatments (and of existing products where resistance is suspected) may be required to quantify relative efficacy against disease expression, risk of spread to neighbouring crops and generational increase.

8.5.8 Setting treatment and rejection thresholds through modelling

A trial and error approach to seed health is inappropriate. Any long term deterioration in the health of the seed supply could render the industry uncompetitive. The short and long term effects of changes in thresholds, certification standards and seed treatment use could be described mathematically. This would allow the implications of proposed changes to be evaluated prior to implementation. The predictive accuracy of such models would be dependent on data from work outlined above, particularly on the epidemiology of seed-borne diseases and the efficacy of seed treatments.

Table 8.1 Summary of research priorities for proposed future strategies

	Strategy 1	Strategy 2	Strategy 3	Strategy 4
	Minimal change	Treatment according to need: Limited	Wider	Compulsory testing
Research ¹				
Multiplication potential		Beneficial	Required	Required
Risk to other crops	Beneficial	Beneficial	Required	Required
Rapid health tests		Beneficial	Required	Required
Relationship between test results & disease expression		Beneficial	Required	Required
Long term changes			Beneficial ²	Beneficial ²
Confidence limits for sampling	Beneficial	Beneficial	Required	Required
Seed treatment efficacy	Beneficial ²	Beneficial ²	Required ²	Required ²
Theshold setting			Required	Required

¹ Details are given in the preceding sections, 8.5.1 to 8.5.8

² Priority for future research, current information probably adequate

CHAPTER 9

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APPENDIX
LATIN AND COMMON NAMES OF DISEASES

Common name	Pathogen
Seed-borne diseases of wheat	
Bunt or stinking smut	<i>Tilletia caries</i>
Dwarf bunt	<i>Tilletia controversa</i>
Ergot	<i>Claviceps purpurea</i>
Foot rot	<i>Cochliobolus sativus</i>
Fusarium diseases	<i>Fusarium avenaceum</i> <i>Fusarium culmorum</i> <i>Fusarium graminearum</i> <i>Fusarium poae</i> <i>Microdochium (Fusarium) nivale</i>
Loose smut	<i>Ustilago tritici</i>
Septoria seedling blight	<i>Stagonospora (Septoria) nodorum</i>
Seed-borne diseases of barley	
Covered smut	<i>Ustilago hordei</i>
Ergot	<i>Claviceps purpurea</i>
Foot rot	<i>Cochliobolus sativus</i>
Fusarium diseases	As wheat
Leaf blotch	<i>Rhynchosporium secalis</i>
Leaf stripe	<i>Pyrenophora graminea</i>
Loose smut	<i>Ustilago muda</i>
Net blotch	<i>Pyrenophora teres</i> (<i>Drechslera</i> or <i>Helminthosporium teres</i>)
Seed-borne diseases of oats	
Covered smut	<i>Ustilago hordei</i>
Ergot	<i>Claviceps purpurea</i>
Fusarium diseases	As wheat
Leaf spot and seedling blight	<i>Pyrenophora avenae</i>
Loose smut	<i>Ustilago avenae</i>
Seed-borne diseases of rye	
Bunt or stinking smut	<i>Tilletia caries</i>
Ergot	<i>Claviceps purpurea</i>
Fusarium diseases	As wheat
Stripe smut	<i>Urocystis occulta</i>

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