Effects of diseases and pests on yield and quality of wheat.

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Introduction

Wheat crops are subject to a wide range of diseases and pests; with 43 diseases so far recorded on wheat in New Zealand (Pennycook, 1989). Some of these can cause substantial losses in grain yield and quality. When new diseases are detected, such as stripe rust in 1980, changes to growing practices and breeding priorities may be necessary.

The disease and pest spectrum in a specific paddock is influenced by physical environment, cultivar susceptibility, and crop management (Cromey and Beresford, 1990). A fundamental understanding of these factors and how they interact is necessary for appropriate disease and pest control strategies.

This paper focuses on wheat diseases and pests in New Zealand, how they affect the yield and quality of wheat, and how they may be controlled.

Disease and Pest Problems

Important diseases and pests

It is generally agreed that, world-wide, the rusts - stripe rust, leaf rust and stem rust (caused by *Puccinia striiformis, P. recondita* and *P. graminis*) - are the most important diseases of wheat. They are characterised by the orange or brown pustules produced on leaves, sheaths, stems, or even glumes. Stripe rust of wheat was first detected in New Zealand as recently as 1980 (Harvey and Beresford, 1982). It is now potentially the most devastating disease of wheat, being found in all New Zealand wheat growing areas, although most important in South Island crops. Control of stripe rust was integrated rapidly into the wheat management programme without a marked reduction in national yield. Leaf and stem rusts have been present in New Zealand for many years. Leaf rust is also found on the leaf sheath but stem rust differs in that its elongate reddish-brown pustules are formed on the stems and leaf sheaths of wheat. Both diseases become established late in the season and can be important in spring-sown crops, especially in the North Island.

Wheat crops in New Zealand are subject to several other leaf and stem diseases which can cause economic losses. Leaf diseases such as powdery mildew (caused by *Erysiphe graminis*), speckled leaf blotch (caused by *Mycosphaerella tritici*), and glume blotch (caused by *Leptosphaeria nodorum*) are each favoured by different environmental conditions, and are most prevalent at different times during the season. Speckled leaf blotch is usually detected early in the season, and can cause yield losses in autumn-sown crops, especially in cool wet weather. Powdery mildew is common in crops of susceptible wheat cultivars in Canterbury throughout the season and is the most significant disease in currently grown durum wheat cultivars. Glume blotch affects both leaves and glumes, and is usually seen late in the season sometimes causing appreciable losses in susceptible cultivars during wet weather. Didymella scorch (caused by *Didymella exitalis* and *Ascochyta* spp.) can be common in wheat crops near harvest and may play a part in early senescence of leaves.

Several diseases can affect the wheat stem. Eyespot (caused by *Pseudocercosporella herpotrichoides*) and sharp eyespot (caused by *Thanatephorus cucumeris*) are found near the base of the stem. Eyespot can cause economic losses in Southland, Otago, and occasionally Canterbury. Basal glume rot, caused by the bacterial plant pathogen *Pseudomonas atrofaciens*, is characterised by dark brown blotches on glumes and stems below the head and about nodes. Symptoms appear after flowering, but the disease is uncommon on most cultivars and appears to cause little yield loss.

Take-all (caused by *Gaeumanomyces graminis*) and foot rot (caused by *Fusarium* spp.) are widespread and considered the two most important soil-borne diseases affecting wheat crops grown in New Zealand (Anon., 1991). Take-all is most destructive on autumn sown crops, although severe damage can also occur in plantings of spring wheat (Zillinsky, 1983). Wet, cool soil conditions favour infection and disease development. Plants can withstand mild infections of take-all, however severely infected plants show symptoms soon after heading. Such plants are pale, stunted and spiky in appearance, have bleached heads and shrivelled grain (Wiese, 1987). The roots and base of the plants have a dark-brown to black coloration. Commonly the heads of infected plants have a blackened appearance following the invasion of secondary mould such as *Alternaria* and *Cladosporium* species. Where disease levels within a paddock are very high young seedlings can show early symptoms of infection. This can occur when close cereal rotations are practised or heavy infestations of infected alternative hosts (such as twitch) occur in the paddock.

The complex of *Fusarium* species which cause foot rot can also cause a range of other symptoms on wheat including; leaf spots, stem lesions and head blights. The typical foot rot symptoms however consist of a brown rot of the stem base and roots. Plants can also be severely weakened with poor grain fill. Intensive cropping and wet followed by dry conditions favour disease development. Alternative grass hosts can also be an important source of infection.

The most familiar head or ear diseases are the smuts. Wheat smuts are caused by six highly specialized fungi of which only loose smut (*Ustilago tritici*) and covered smut or bunt (caused by *Tilletia caries*) occur in New Zealand. Smuts are seed-borne but some (such as covered smut) can also be soil-borne where spores of the fungus can infest soils. The disease symptoms are most apparent at the time of heading when kernels are replaced by masses of spores. Although smut diseases have become less important with the availability of good control by seed treatment they are not uncommon. However, without regular control measures, they will cause significant losses.

Ergot (caused by *Claviceps purpurea*) is an uncommon disease in wheat because of the closed nature of the florets (it is primarily a flower disease), seed cleaning techniques (which remove the sclerotia or resting structures of the fungus) and crop rotations.

Scab or head blights (caused by *Fusarium* spp.) and black or sooty mould (*Cladosporium* spp. are a group of head diseases frequently occurring where humid or wet climatic conditions are associated with crop maturation. Scab is best recognized by the premature death of spikelets, which later become covered with pink masses of the fungus. The causal fungus also affects other plant parts, e.g., root and stem base and in turn is a source of scab inoculum.

Black heads are striking manifestation of colonisation of wheat heads by saprophytic or weakly parasitic fungi. Heads that are small, weak, or sized or prematurely ripe are prone to attack by these fungi. Plants that are nutritionally deficient, in water-logged soil, or damaged by disease tend to be colonised by these fungi.

Three aphid species are found on wheat in NZ, but cause little direct feeding damage. The rose grain aphid is unimportant as wheat is relatively resistant to this species (Farrell and Stufkens, 1988). The "grain aphid" (actually the blackberry-cereal aphid) is only rarely found infesting heads. The cereal aphid (known as the birdcherry-oat aphid overseas) occurs on wheat in low numbers, but is the main vector of barley yellow dwarf virus (BYDV). During the last decade, patches of severe BYDV infection were found in only 2-3 wheat paddocks, in the years 1985, 1987 and 1990, during annual surveys of ca. 90 Canterbury cereal crops (Farrell and Stufkens, unpublished). Yield loss due to BYDV is therefore of minor importance.

Hessian fly causes stem-break in wheat, particularly in 2nd or 3rd year crops on the same land, but is often blamed for similar damage caused by the Argentine stem weevil. Where present, the grass grub may destroy seedling wheat. The incidence and extent of damage to wheat by these pests is unknown.

Effects of diseases on yield

While heavy yield losses due to diseases and pests are rare in New Zealand wheat, those that do occur demonstrate the need to maintain effective control strategies. Yield losses due to diseases and pests in wheat are usually minimised through successful control strategies, but a relaxation or failure of these control strategies would soon result in damaging levels of diseases and pests.

Yield losses due to stripe rust of up to 60% have been recorded in susceptible cultivars (Beresford, 1982). As well as infecting leaves, stripe rust infection of wheat spikes is also common in susceptible cultivars, where grains in infected florets weigh up to 77% less than grains in uninfected florets (Cromey, 1989).

Stem rust reduces yield in a wheat crop in two ways: through shrivelled, lightweight grain (thus greatly reducing yield) and by causing the straw to become brittle, leading to heads breaking off or crops lodging. The disease can be important in North Island wheat growing areas where individual crops have been so severely attacked that they could not be harvested (Allen, 1961). Neill (1931) showed that at Palmerston North, control of leaf and stem rust resulted in yield increases of up to 96%, the increase in yield being directly correlated with the severity of the rusts. More recently, Burnett and McEwan (1983) reported yield losses of 60% in crops of Karamu wheat in the Manawatu due to a severe stem rust epidemic.

Leaf rust is less important in New Zealand than stripe and stem rusts, although it causes yield losses in some seasons. For instance, a yield reduction of 6% was recorded in the cultivar Takahe in field trials in Gore, Southland, where there was a low incidence of leaf rust (Burnett and McEwan, 1983). Greater yield losses are likely where outbreaks of the disease are more severe.

Smith and Wright (1974) reported a yield reduction of 11% due to powdery mildew on the cultivar Aotea and 35% on the highly susceptible cultivar Hilgendorf 61, grown in an area where mildew is frequently severe. More recently, powdery mildew has been implicated in yield losses in the mildew-susceptible cultivar Kotare (Cromey and Hanson, 1992) and possibly also in crops of Durum wheats in South Canterbury.

Take-all can result in large yield losses in individual crops. Little data is available, but Blair (1953) attributed the widespread failure of wheat crops in Canterbury in 1952 to the disease. Severely infected crops are sometimes not worth harvesting.

Sanderson (1978) attributed yield losses of up to 40% in autumn-sown wheat crops in Canterbury to speckled leaf blotch, while Thomson *et al.* (1981) suggested losses of 10-20% were common. Differences in cultivar susceptibility are probably responsible for variation in yield loss. Infection occurred over two periods of crop growth (Sanderson, 1978): early infection of seedlings, which caused loss in grain number, and infection of the flag leaf, which caused loss in kernel weight.

Effects of diseases and pests on wheat quality

Wheat pathogens have two types of effect on grain quality- direct and indirect effect:

1. Direct effect. These pathogens are found on the grain and have a direct influence on quality or suitability of the grain for either milling or baking. Some have an influence on the suitability of the wheat lines for seed purposes. Grain affected by covered smut or bunt causes has a dark coloration, a fishy smell and can cause rejection for milling or seed. Grain infected by the loose smut pathogen is virtually indistinguishable from healthy grain. It has little or no effect on the quality of grain for processing purposes, but for sowing, the losses are almost proportional to the percentage of infection that is in the grain.

Ergot, while uncommon in wheat, is serious if it occurs, since contaminated flour and resulting products are highly toxic. The sclerotia contain large quantities of ergot alkaloids that cause illness and death in both animals and humans if incorporated into food produced from contaminated wheat.

Black point has no effect on yield but discolours flour and may reduce crumb size in bread (Lorenz, 1986). Seed germination is little affected (Cromey and Mulholland, 1988).

Mouldy grain caused by scab is of little value and is rejected for feed and milling since the fungi produce toxins that can induce a range of humans and animal diseases (Marasas *et al.*, 1985).

The wheat bug feeds on developing wheat grain, injecting salivary enzymes that selectively degrade high-molecular weight glutenins. As a result, flour milled from the grain is of poor baking quality (Every *et al.*, 1989). There have been five outbreaks of widespread "bug damage" in the last 30 years, following dry spring weather (Swallow and Cressey, 1987; Dr D. Every, pers. comm.). The detection and downgrading (to feed grain) of bug-damaged wheat is a major nuisance in outbreak years.

Storage conditions can affect grain quality. Grain that is harvested or dried to the correct moisture content of 12 to 15% (Poichotte, 1980) has few quality problem developing in storage. Under normal circumstances, wheat harbours a range of organisms on and in the testa or seed coat, and these are of no consequence under good storage conditions. However, as can be seen from Figure 1, deviation into certain regions of temperatures and moisture contents of the grain can lead first to germination and then to mould growth. The mould may

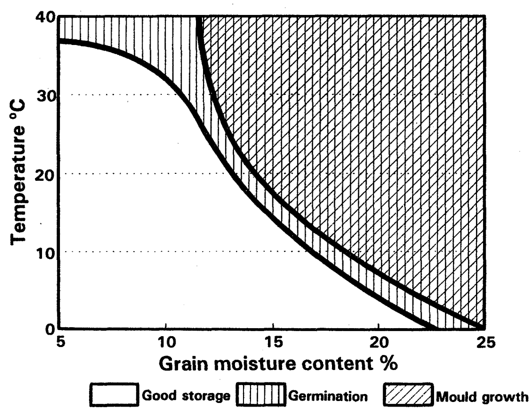

Figure 1. The interaction of temperature and grain moisture on mould growth and germination of stored wheat. (From Poichotte, 1980)

be pathogens to wheat, but may also be saprophytes or weak pathogens that develop mycotoxins under appropriate conditions and (Magan and Lacey, 1985).

2. Indirect effect. These pathogens affect the parent plant and can influence indirectly the quality of the resultant grain.

Most diseases which affect yield also affect kernel weight, which can influence the quality of wheat. Notes on these diseases and control measures can be located in other sections of this paper and in Anon. (1991).

In general, the baking score increases with increase in grain protein up to around 12.5%. Diseases such as stripe rust and root rots decrease the kernel weight but also increase the protein levels in the grain. However, there are other factors that influence this protein deposition, and these include the application of nitrogen and its timing, irrigation (Stephens *et al.*, 1989), and the cultivar. These factors thus influence the final quality of the grain and resultant baking score. There has thus been little agreement on the influence of kernel weight and final baking quality from the resultant flour.

Grain and end-product quality associated with higher kernel weights are increases in C:N ratio, flour extraction rate and seed vigour, and decreases in hectolitre (bushel) weight, flour protein and baking score. However, these trends may be modified by other factors other than kernel weight, such as inherent cultivar characteristics, available soil nitrogen and water availability (Stephens *et al.*, 1989). Some of the assumptions are thus questionable under certain conditions.

Most studies have shown no effect of grain weight on seedling emergence, plant height or grain yield (Shahbazahmad *et al.*, 1988). Lafond (1986) showed that small wheat seeds always germinated faster, with shorter coleoptiles, than large seed, but emergence of both was similar. However, Goodman and Scott (1985) showed that in New Zealand, small size grain (35.7g TGW) in the cultivar 'Rongotea' produced more 'failed' seedlings, especially when sown below 5cm depth than those of 52.6g TGW.

Control Strategies

Diseases and pests may have a major influence on yield and quality of wheat and must therefore influence many of the grower's decisions. Disease and pest management in wheat crops is a compromise whereby the costs of treatment must be set against the benefits (to yield and quality) of control. In producing disease and pest management guidelines, the risks associated with particular diseases and pests must be carefully considered, and the benefits expected from control calculated. Whilst there is some insurance value in routine application of control, the cost of such action must be taken into account: the unnecessary use of fungicides incurs a financial cost and increases the risk of fungicide insensitivity as well as residues in harvested grain, crop debris, and soil.

Control measures fall into three broad categories: host resistance, cultural methods, and chemicals. A fourth method, biological control, has promise in the future. While these will be discussed separately, it must be remembered that diseases and pests are managed by sensibly integrating all the available control measures.

Resistant cultivars

The development of disease resistant cultivars is a very effective method for the control of plant diseases since growers can reduce the need for costly chemical inputs, whilst still retaining yield. Trials have been carried out to determine the effects of disease resistance on yields of wheat cultivars (Elmer and Gaunt, 1984, Cromey and Hanson, 1992). Recorded yield losses due to diseases, in particular stripe rust, varied between 0% and 63% according to cultivar. Use of resistant cultivars reduces dependence on fungicides to realize the yield potential of a wheat crop.

Single gene resistance is attractive to plant breeders because it is relatively easy to manipulate in a breeding programme and usually confers a high degree of resistance to cultivars. This is particularly useful for important diseases such as stripe rust. Unfortunately, such resistance is often lost when new races of plant pathogens attack previously resistant cultivars. Rusts and powdery mildew, in particular, are frequently able to change and overcome genetically simple resistance. In New Zealand, new wheat rust races probably arise through mutation or importation. If a new race is able to attack a previously resistant cultivar, it will have a selective advantage over other races wherever that cultivar is grown. Surveys of wheat rusts in New Zealand are carried out annually in conjunction with the University of Sydney Plant Breeding Institute, to track changes and results are linked to the presence of resistance in local cultivars.

The emergence and spread of New Zealand's second race of stripe rust, 106E139A- (popularly known as the "Oroua race"), is a spectacular example of a rapid change in the pathogen population. This race was identified in 1982, two years after stripe rust was first detected in New Zealand. It spread rapidly during that season, helped by its selective advantage on the widely grown cultivar Oroua, which was resistant to the original race.

By the end of the season, the race was widespread in Canterbury, and later spread through remaining New Zealand wheat growing regions. Oroua was shown to rely on the resistance gene "Yr7" for its resistance to stripe rust. When race 106E139A- came to dominate the stripe rust population, the resistance of Oroua became ineffective, as did the resistance of all other cultivars relying on the same gene.

Many breeders opt to select for partial resistance to disease, which usually avoids the problem of dramatic swings from resistant to susceptible. Such resistance is usually more genetically complex and so is more likely to be durable.

In stripe rust, partial resistance is termed "adult plant resistance". Cultivars with adult plant resistance, although susceptible as seedlings, develop resistance at post-seedling growth stages in the field. Resistance develops progressively, usually on leaves 3, 4 and 5, with some infection possible even on the flag leaf (Cromey, 1990). Such cultivars may need fungicide protection early in the season.

For instance, the popular spring-sown cultivar Otane has a moderate degree of adult plant resistance to stripe rust, and is not highly susceptible to other diseases. The usual spring sowing of this cultivar, the application of a fungicide seed treatment, and development of adult plant resistance, means that an early fungicide spray will probably only be required if stripe rust becomes established early in the season. However, Otane has been shown to be susceptible to stripe rust in the spike (Cromey, 1989b), and if conditions (cool, damp weather) around the time of ear emergence are particularly suitable for disease development, then a late spray (between ear emergence and flowering) may be warranted.

The degree of resistance required differs. Partial resistance is often adequate in most situations. For instance a moderate degree of resistance to powdery mildew is sufficient in Canterbury, where only highly susceptible cultivars are severely affected. Selection for disease resistance is an important part of any wheat breeding programme, but resistant cultivars must also have desirable yield, agronomic and quality characteristics. Therefore, while it is hoped to get some resistance to all diseases, positive selection must be restricted to the most important ones. For other diseases, a form of negative selection, whereby highly susceptible lines are discarded, is carried out.

Cultural

Many factors influence a farmer's choice of crop rotation: diseases, pests, weeds, prices, and available machinery to name but a few. Cropping strategies cannot be adopted solely to reduce the impact of diseases and pests, but they must be taken into account when planning a cropping sequence.

Take-all is controlled primarily though effective crop rotation, at least one non-cereal crop free of graminaceous weeds being required. Little research has been done in New Zealand on the specific effects of crop rotation on take-all, but Blair (1972), suggested that, as well as building up under successive cereal cropping, the disease can also appear in cereal crops sown straight out of ploughed grass, where the period following cultivation has been too brief to ensure breakdown of grass root residues on which the fungus is maintained. Crop rotation is also important in control of the *Fusarium* complex of diseases (foot-rot, snow mould and head blight), where a rotation away from cereals for at least three years is desirable.

Choice of sowing date, in particular autumn-sown versus spring-sown, can also influence the likely disease spectrum of a wheat crop (Cromey and Beresford, 1990). For instance, speckled leaf blotch is spread via two types of spore. The first type is produced on infected stubble. These spores are air-borne and so can travel relatively long distances. The time of spore release means that the disease is a problem largely of autumn-sown wheat. Spring-sown wheat emerges after the bulk of these air-borne spores have been released. Further spread of disease is via splash dispersed spores which do not travel large distances.

Barley yellow dwarf virus is a problem mostly of early autumn-sown wheat, where crops have emerged when the aphid vectors are in flight, and cultural control by sowing after 1 June (Lowe, 1965) is still optimal for the avoidance of BYDV damage.

Spring-sown crops remain green later, and so diseases favoured by warm, dry climates are likely to be more important. Leaf rust develops slowly through the season, seldom becoming prevalent in Canterbury before ear emergence. This means that later sown crops are more likely to become infected.

Cultivation methods can have an influence on the likelihood of losses due to diseases and pests. For instance, Sanderson (1976) suggested that destruction of stubble is important to eliminate the source of speckled leaf blotch infection. Another example is the take-all fungus, which is a poor saprophyte and must survive on infected crop debris. Early cultivation after harvest can help the breakdown of infected stubble. The take-all problem can, however, be exacerbated by the use of the herbicide glyphosate to control the weed twitch (*Agropyron repens*) (Harvey *et al.*, 1982). Twitch, while resistant to take-all, can harbour the pathogen. When twitch is sprayed with glyphosate the herbicide kills the plant, including the rhizomes, but does not kill the pathogen. The fungus can colonise the dying rhizomes more readily, and soon blackens the infected tissue. In this way the level of disease inoculum is dramatically increased. The problem is worst where the crop is direct drilled, since cultivation hastens the breakdown of twitch rhizomes.

Use of fertiliser and irrigation alters the micro-environment of the crop and so influences the disease spectrum. High nitrogen usage coupled with irrigation result in a very different environment within the crop and this can influence the severity of disease (Cromey and Beresford, 1990). For instance, powdery mildew has been reported to be more severe under conditions of high nitrogen. Severity of take-all can be affected by the form of nitrogen applied: high nitrate nitrogen increases severity, and high ammonium nitrogen decreases severity (Harvey, 1985).

Fungicides: economic considerations

In practical terms the first decision relating to the use of any fungicide is whether it should be applied at all. When making the decision to use fungicides for disease control in wheat it is important to distinguish between the "damaging threshold" (the minimum level of disease that will affect yield) and the "economic threshold" (where there is an economic gain from applying the fungicide). In wheat, a moderate amount of disease infection may be required before there are any economic benefits from applying a fungicide treatment.

Predicting yield loss is extremely difficult and turning this loss into monetary values is even more difficult (James, 1974). It is most desirable to keep the treatment costs as low as possible. This can be achieved by:

- selecting the cheapest effective product;
- using the minimum necessary dosage;
- making the least number of treatments;
- using the most cost effective method of application.
- applying at the most effective time

Fungicides have traditionally been used on wheat as seed treatments to control serious seed-borne diseases such as smuts and bunts. There were additional benefits in these seed treatments with the control of soil-borne seedling diseases such as those caused by *Pythium* and *Fusarium* species.

The use of modern systemic fungicides for the control of wheat diseases has gained widespread acceptance in only a few years (Hoffmann, 1986). The main reasons for this is that the fungicides are highly efficacious and, because of the low dose rate, less hazardous. In Europe powdery mildew is one of the most important diseases on cereals (Cook and Yarham, 1985), however in New Zealand control of stripe rust on wheat necessitates widespread use of systemic fungicides. Seed treatment with an appropriate fungicide provides up to eight weeks protection from stripe rust for spring-sown wheat, and even longer for autumn-sown wheat. The length of protection is associated with a dilution effect as the plants grow (Führ, 1986). Control of stripe rust beyond this period is achieved with foliar sprays. There are a range of chemicals available which includes; cyproconazole, tebuconazole, propiconazole, fenpropimorph/propiconazole, and triadimenol. Up to a couple of years ago control of stripe rust was achieved by the regular application of one of these chemicals throughout the season, approximately every three to four weeks.

Resistance of plant pathogens to fungicides is an increasing problem around the world. The only case recorded on wheat in New Zealand to date is resistance to benomyl in the eyespot fungus *Pseudocercosporella herpotrichoides*, although resistance of powdery mildew (*Erysiphe graminis*) to fungicides is common in Europe.

Decreased returns for wheat and the high input costs have forced growers to look at and use other alternatives (Royle, 1985). There are now available cultivars with varying degrees of disease resistance, which may require only a single fungicide spray to give effective disease protection. There is the potential for reduced fungicide applications in New Zealand, with the development of new cultivars showing increased resistance to stripe rust. Monitoring for other diseases, especially late season diseases such as Didymella leaf scorch and glume blotch will be important, in order ensure fungicide applications are well timed. The application of a late fungicide spray near flowering may be useful in some seasons.

Biological

There has been increasing interest over recent years in the possibilities for using micro-organisms to control plant diseases.

Take-all of wheat, like some other soil-borne diseases, has proved difficult to control other than with cultural methods: there are problems in getting fungicides to the wheat roots, and resistant cultivars are not available. It has been known for some time that take-all increases in severity over the first few years of continuous wheat cropping, and then begins to decrease in severity, eventually reaching an equilibrium, where a low disease severity is maintained. This phenomenon is known as take-all decline and research in several countries has implicated a change in the soil microflora in this decline.

There is evidence that an increase in the numbers of fluorescent pseudomonad bacteria in the soil are responsible for antagonism to the take-all fungus.

Recent research on biological control of take-all has focused on isolating suitable bacterial strains and developing and assessing methods for their application to the soil. In thus doing, it is hoped to bring about "take-all decline" in a first year wheat crop. Several formulations have been produced, some of which involve coating bacteria onto the seed. Promising results have been achieved, and commercialisation of products is under way.

The rose grain aphid is under biological control by an introduced parasitic wasp (Farrell and Stufkens, 1990).

Prospects for the Future

Future trends in diseases and pests

Disease and pest problems have historically followed a cyclical pattern. The reasons for this are many: changes in cultivars, changes in pathogens, climatic differences between seasons, cropping practices. Stripe rust will probably remain important, but with serious outbreaks limited to situations where new races of the rust fungus change the resistance status of popular cultivars. Smuts and bunts, controlled by systemic fungicides, could again be important if the pathogens became resistant to the fungicide, or farmers ceased treating their seed. Global warming may have a direct effect on the importance of particular diseases or pests, or may necessitate changes in growing practices which, in turn, could cause a change.

Control

The introduction of new chemicals, possibly with better activity, will probably be counterbalanced by the withdrawal of chemicals due to insensitivity or possible detrimental effects on health or the environment. The move to lower chemical inputs will probably also continue, with biological control and disease and pest forecasting possibly assisting. The use of biotechnology may make it possible to engineer disease resistance where it does not currently exist. For instance, there is no genetic resistance to barley yellow dwarf virus or take-all known in wheat, but new techniques may allow transfer of resistance to wheat from other species.

Artificial intelligence and expert systems

Computer based intelligence systems can be used in cereal growing in problem diagnosis and/or decision making. An expert system for cereal growers has been developed in the UK by ICI (Jones, 1988) to guide growers and advisors in cost effectiveness of treating diagnosed diseases and pests. In New Zealand, a diagnostic and decision making cereal system was developed through to prototype stage by Victoria University and MAF in Canterbury (Turner, 1984). This system was never adopted because of user resistance to computer based systems at the time, and the fact that many diagnoses and decisions could more easily be made through other methods. Cole and Gaunt (1984) produced a sequential sampling plan to give more efficient control of stripe rust in a highly susceptible cultivar. However, such susceptible cultivars are no longer in use, and result are not directly applicable to more resistant cultivars. These points highlight the requirements of an expert system. They must be:

- Applied to a system or situation where other means of obtaining information and an answer are not readily available or are unavailable from other sources
- Carefully targeted to the end user.
- Attractive and easy to use with clear menus and options and even the use of high quality graphics.
- Regularly updated with new information
- Based on in-depth and sound scientific and extension knowledge

Diagnostic kits

The identification of causal organisms is fundamental to efficient crop protection and so diagnostic methods should be reliable, reproducible, and appropriate. Recent advances in immunology and nucleic acid technologies have provided new possibilities for the diagnosis of plant diseases and pests (Plumb and Ball, 1990). Serological methods, such as the enzyme-linked-immunosorbent assay (ELISA) have been used for several years to identify plant viruses such as barley yellow dwarf virus. More recently, the development of monoclonal antibodies has revolutionised this technique by allowing the production of large quantities of antibodies specific to individual organisms.

Increasing numbers of commercial kits based on monoclonal antibodies are being produced, and are likely to become widely used over the next few years. Diagnosis of many fungal pathogens can easily be done by eye, but it is where several fungi may cause similar symptoms, or where symptoms become apparent after a period of latent infection, that there is the greatest need for such kits. Two possibilities in New Zealand are for eyespot and glume blotch, where control should be applied before symptoms become obvious, but infection is not easily detected.

Threats for the future

The wheat growing industry needs to be alert for the introduction of new pest and diseases and the potential danger of existing ones. New diseases occur (stripe rust is a good example) and early detection is critical for evaluating their potential seriousness to industry. They may arrive in a number of ways such as seed-borne or wind-borne. Some diseases which are present overseas could cause serious harm to the cereal industry if they were to be introduced. Such diseases include smuts, bunts and viruses. To help in the detection of new diseases MAF Quality Management offers a free identification service for all pest, pathogen or weed species suspected to be new to New Zealand (Anon., 1991).

Changing wheat cultivars, fungicide resistance and variable climatic conditions can result in existing diseases of low significance gaining increased importance and possibly warranting additional control measures in the future. A disease which has become more common late season over the last few years is Didymella leaf scorch. This has probably occurred because of the reduced amount of fungicide sprays required for stripe rust control on some of the new cultivars now available. The importance of this disease and the effectiveness of the present range of registered fungicides on this disease is not known. New cultivars therefore need to be closely monitored for the presence of diseases so potentially damaging diseases can be identified early and control strategies adopted.

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