

Effects of sharp eyespot on yield of wheat (*Triticum aestivum*) in New Zealand

M. G. CROMEY

R. C. BUTLER

H. J. BODDINGTON

A. R. MOORHEAD

New Zealand Institute for Crop & Food
Research Limited
Private Bag 4704
Christchurch, New Zealand
email: cromeym@crop.cri.nz

Abstract The incidence, severity, and effects on yield of sharp eyespot (caused by *Rhizoctonia cerealis* van der Hoeven) in New Zealand wheat (*Triticum aestivum*) crops were assessed over 4 years (1996–2000). In 1998/99, 37 crops were examined, and symptoms of sharp eyespot were recorded in 43% of them. The disease was particularly common in south Canterbury. Laboratory isolations confirmed that *R. cerealis* was the causal organism. Sharp eyespot was detected in 17 of 19 crops selected for detailed examination between 1996 and 2000. Incidence in individual crops ranged from 2 to 88% of tillers infected, and differed between years. Mean yield losses as a result of sharp eyespot in infected crops were estimated at 6, 1, 8, and 14% respectively over the 4 years. Yield loss was related to disease incidence and was considered to be negligible when the incidence was <10%. The maximum individual yield loss was estimated at 18%. Losses were the result of reductions in both grain number/ear and grain weight and were greatest in moderately to severely infected tillers. Although sharp eyespot is not a major yield-limiting disease of wheat in New Zealand, it can reduce yields considerably under conditions conducive to its establishment.

Keywords sharp eyespot; *Rhizoctonia cerealis*; wheat; incidence; yield loss

INTRODUCTION

Sharp eyespot of wheat (*Triticum aestivum*) (caused by *Rhizoctonia cerealis* van der Hoeven) is found throughout New Zealand and can cause problems in dense crops, especially under intensive cropping (Anon. 1991). It has, however, been little studied in New Zealand and has been suggested to cause no observable economic consequences (Blair & Morrison 1949). The disease can cause pre- and post-emergence damping off and shoot death in seedlings, but is more frequently observed as lesions on stem bases of plants. Severe infection of mature tillers may result in small, shrivelled grain, lodging and premature ripening (Clarkson & Cook 1983).

Infection by *R. cerealis* depends on cool, moist conditions. Thereafter, lesion development is favoured by light and well drained soils (Wiese 1987). Clarkson & Cook (1983) found that in England and Wales slight sharp eyespot infection had little effect on yield, but moderate infection reduced yields by an average of 5% and severe infection by 26%.

Although formal surveys of sharp eyespot incidence have not been carried out in New Zealand, the disease has been regularly observed in recent years (Cromeey unpubl. data), prompting an evaluation of its economic effects. In the present study we determined the incidence and severity of sharp eyespot in New Zealand wheat crops in the 1998/99 growing season, and examined the effects of the disease on yield over 4 years.

METHODS

Survey

Forty-three New Zealand wheat crops were examined in 1998/99 for symptoms of sharp eyespot. Most of the crops were in Canterbury because more wheat is grown in Canterbury than in other regions. About 10 plants were collected from each of 10 sites/crop between ear emergence and early grain-fill growth stages. Sharp eyespot severity was assessed

on each tiller according to the following key, based on that of Clarkson & Cook (1983)—0, Nil infection: no symptoms of sharp eyespot. 1, Trace infection: one or more lesions on the leaf sheath, not penetrating to stem. 2, Slight infection: one or more lesions girdling in total less than half the stem circumference. 3, Moderate infection: one or more lesions girdling in total at least half the stem circumference. 4, Severe infection: one or more lesions girdling in total at least half the stem circumference **and** stem weakened at lesions.

The presence of *R. cerealis* was confirmed by surface sterilising representative lesions in 1% sodium hypochlorite for 1 min, rinsing in sterile water, and isolating on potato dextrose agar.

Crop loss assessment

Nineteen wheat crops in areas of Canterbury where sharp eyespot is common were selected between 1996 and 2000 to assess the effects of sharp eyespot on yield. No site was sampled in more than one season. Within each crop, c. 50 stems were collected from each of four areas at the mid-dough growth stage and then left to dry. Each stem was assessed for sharp eyespot on the above scale. From each of the four area samples, subsamples (5, 10, and 10, and all stems in 1996/97, 1997/98, 1998/99, and 1999/2000 respectively) from each severity category were taken to determine the effects of disease incidence and severity on yield, grain size, and grain numbers. In the few instances when there were less than the desired numbers in a category, all available stems were used. Ears were threshed and the grain dried, weighed, and counted. Mean values of yield/ear and yield components (grain number/ear and grain weight) were determined.

Percent tillers infected in each severity category were analysed using a multinomial response model (McCullagh & Nelder 1989). Numbers of grains/ear were analysed with a log-linear model for count data (McCullagh & Nelder 1989). Mean ear weights,

grain weights, and predicted yields were examined with analysis of variance. Predicted means were calculated, along with 95% confidence intervals, for these means. For % tillers infected and grain numbers, the means and confidence intervals were made on the transformed scale (logit and log respectively), and then back-transformed.

Predicted yield losses were estimated for each sample. An estimate of yield for each sample was calculated by summing yields over the five disease categories. Similarly, an estimate of the potential yield for the sample (if no stems had been diseased) was calculated from the mean ear weight for the healthy stems. Percent yield loss was calculated from the difference between these two numbers.

All analyses were carried out with Genstat v 4.1 (Genstat 5 Committee 1997).

RESULTS

Survey

Symptoms of sharp eyespot were recorded in 23 (53%) of the 43 wheat crops surveyed in the 1998/99 growing season (Table 1). The disease was particularly common in Canterbury, especially in south Canterbury. Twelve (28%) of the crops, 11 of them in Canterbury, had over 10% of tillers infected. Crops with over 40% infected tillers were found only in Canterbury. Most of the crops sampled in Canterbury, Otago, and Southland were autumn sown, whereas all the North Island crops were spring sown. Laboratory isolations from lesions confirmed the presence of *R. cerealis*. The analysis of crops sampled for yield analysis indicated that there were significant ($P < 0.05$) differences in disease incidence and severity between years and between sites within each year (Table 2). There were also differences between disease severity categories and the two yield components measured (Table 2).

Table 1 Number of wheat (*Triticum aestivum*) crops in each sharp eyespot incidence category in different regions of New Zealand in 1998/99.

Region	% tillers infected				
	0	1–10	11–20	21–40	41–80
North Island	5	3	0	0	0
North/mid Canterbury	8	6	1	1	3
South Canterbury	3	1	0	3	3
South Otago/Southland	4	1	0	1	0

Effects of sharp eyespot on yield components

Sharp eyespot was detected in 17 of the 19 crops sampled for detailed examination between 1996 and 2000 (Table 2). Disease incidence in affected crops ranged from 2 to 88% of tillers infected, with a mean incidence across all crops of 35%. The range in incidence was greatest in the 1996/97 growing season where crops had from 18 to 88% tillers infected. Most crops in 1997/98 had a low incidence of disease (0–39% tillers infected), and in 1998/99 most were moderately to heavily infected (12–73%). Similarly, estimated crop losses were very low in 1997/98, but more variable in the 1996/97 and 1998/99. The crop examined in 1999/2000 had a high incidence (87%) of sharp eyespot, and the third highest estimated yield loss. In most cases, few moderately or severely infected tillers were recorded

where the overall incidence of sharp eyespot was <30% of tillers affected. Mean yield losses were 2, –1, 8, and 14% in the 4 years respectively. Data from two crops (Hilton A and Geraldine 2) were omitted from the yield loss analysis because disease was concentrated in one of the four samples.

Effects of sharp eyespot on grain number/ear differed between years (Table 3). Consistent reductions in grain numbers/ear with severe sharp eyespot infection occurred in 1998/99 and 1999/2000, with a mean reduction across years of 26%. On average, grain numbers were also reduced in the other severity categories, although there was considerable variability between sites. Stems with trace or slight infection had substantially less grains/ear than healthy stems in some crops, but similar levels to healthy stems in other crops. Grain numbers

Table 2 Percentage of tillers in each sharp eyespot severity category and estimated yield loss in 19 Canterbury, New Zealand, wheat (*Triticum aestivum*) crops between 1996 and 2000.

Year and location	No. tillers examined	% tillers					Estimated yield loss (%)
		Nil	Trace	Slight	Moderate	Severe	
1996/97							
Geraldine Flat 1	311	62.1	16.1	12.9	8.4	0.6	5
Geraldine Flat 2	294	82.3	9.9	7.8	0.0	0.0	5
Hilton A	275	11.6	5.5	25.1	22.5	35.3	–*
Hilton B	245	51.0	11.4	18.4	7.8	11.4	7
	Mean	51.8	10.7	16.0	9.7	11.8	2
1997/98							
Arowhenua	256	98.0	0.0	1.6	0.0	0.4	–3
Geraldine 1	407	60.9	1.5	13.5	11.3	12.8	6
Geraldine 2	206	71.8	0.0	12.1	7.3	8.7	–*
Geraldine 3	306	100.0	0.0	0.0	0.0	0.0	0
Geraldine 4	259	100.0	0.0	0.0	0.0	0.0	0
Hilton 1	393	98.0	0.5	1.0	0.3	0.3	–1
Hilton 2	379	91.3	0.3	6.1	1.3	1.1	1
Waitohi	408	97.5	1.7	0.7	0.0	0.0	0
	Mean	89.7	0.5	4.4	2.5	2.9	–1
1998/99							
Irwell	436	53.2	16.7	21.3	6.2	2.5	1
Geraldine 5	653	33.1	17.8	21.1	21.6	6.4	7
Geraldine 6	663	88.2	8.7	2.4	0.6	0.0	3
Hilton 3	588	27.4	5.8	22.4	22.6	21.8	18
Hilton 4	603	52.7	7.0	20.1	15.1	5.1	6
Methven	729	35.8	9.6	20.2	29.9	4.5	16
	Mean	48.4	10.9	17.9	16.0	6.7	8
1999/2000							
Morven	1354	12.7	21.2	10.9	14.8	40.4	14

*Data from these two crops were omitted from yield comparisons because disease was concentrated in one sample.

Table 3 Mean grain numbers/ear for stems in different sharp eyespot severity categories, and % reduction in number compared with healthy stems. (Figures in parentheses are derived from <5 stems, but are included in means.)

Year and location	Grain number/ear (95% CI)					% reduction compared to Nil				
	Nil	Trace	Slight	Moderate	Severe	Trace	Slight	Moderate	Severe	
1996/97										
Geraldine Flat 1	48 (41, 55)	41 (35, 48)	43 (37, 50)	41 (36, 47)	19 (9, 38)	14	9	14	(61)	
Geraldine Flat 2	46 (40, 53)	38 (33, 45)	40 (33, 47)	—	—	17	14	—	—	
Hilton B	37 (31, 43)	35 (29, 42)	36 (32, 42)	37 (32, 44)	33 (28, 39)	5	1	-1	9	
					Mean	12	8	7	35	
1997/98										
Arowhenua	37 (30, 46)	—	49 (36, 67)	—	48 (26, 90)	—	(-31)	—	(-29)	
Geraldine 1	29 (25, 34)	30 (17, 53)	28 (22, 34)	29 (24, 36)	24 (19, 30)	-3	5	0	18	
Hilton 1	31 (22, 42)	22 (11, 42)	35 (24, 50)	—	—	(28)	(-14)	—	—	
Hilton 2	43 (38, 49)	—	40 (32, 49)	41 (27, 60)	30 (20, 44)	—	8	5	(31)	
Waitohi	43 (39, 48)	44 (34, 57)	47 (33, 68)	—	—	-3	(-10)	—	—	
					Mean	7	-8	3	7	
1998/99										
Irwell	40 (36, 45)	39 (35, 43)	40 (36, 45)	35 (30, 41)	37 (30, 46)	4	0	13	8	
Geraldine 5	44 (40, 49)	43 (39, 48)	43 (39, 48)	40 (36, 45)	25 (22, 29)	2	2	9	43	
Geraldine 6	45 (41, 50)	38 (34, 43)	38 (32, 45)	46 (33, 63)	—	15	16	(-1)	—	
Hilton 3	48 (43, 53)	47 (42, 52)	45 (41, 50)	45 (40, 49)	28 (25, 32)	3	5	7	41	
Hilton 4	39 (35, 43)	34 (30, 38)	38 (34, 43)	35 (31, 39)	22 (18, 26)	13	2	10	44	
Methven	40 (36, 45)	34 (30, 38)	35 (31, 39)	31 (27, 35)	25 (21, 29)	16	13	23	38	
					Mean	9	6	10	35	
1999/2000										
Morven	43 (41, 46)	42 (41, 44)	43 (41, 46)	41 (40, 43)	33 (32, 35)	2	1	5	23	
					Mean of all crops	9	1	8	26	

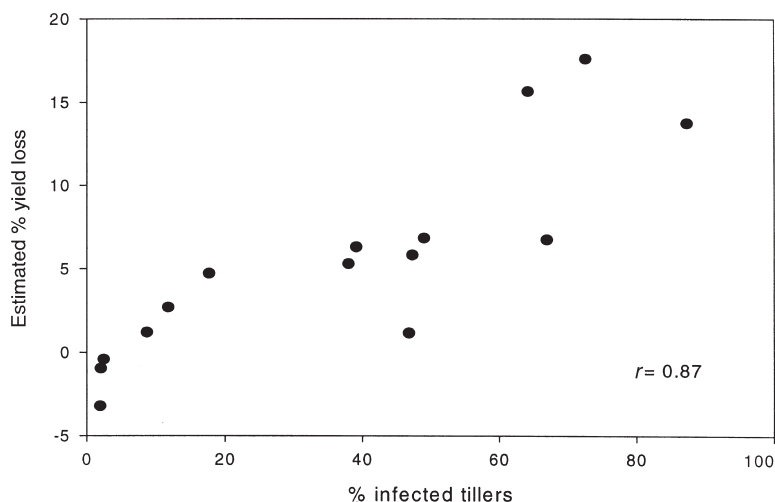
Table 4 Mean grain weight in stems in different sharp eyespot severity categories, and % reduction in number compared with healthy stems. (Figures in parentheses are derived from <5 stems, but are included in means.)

Year and location	Grain weight (mg) (95% CI)					% reduction compared to Nil				
	Nil	Trace	Slight	Moderate	Severe	Trace	Slight	Moderate	Severe	
1996/97										
Geraldine Flat 1	41 (37, 45)	40 (35, 44)	40 (36, 44)	40 (36, 44)	29 (9, 49)	2	1	2	(29)	
Geraldine Flat 2	45 (41, 49)	42 (37, 46)	42 (37, 47)	—	—	7	7	—	—	
Hilton B	39 (34, 43)	37 (32, 43)	37 (33, 41)	39 (34, 43)	32 (28, 37)	4	5	0	17	
				Mean		3	4	1	17	
1997/98										
Arowhenua	44 (38, 50)	—	46 (37, 54)	—	47 (30, 65)	—	(-5)	—	(-8)	
Geraldine 1	34 (30, 38)	44 (28, 59)	36 (29, 42)	35 (30, 41)	32 (25, 38)	-28	-5	-5	7	
Hilton 1	30 (21, 39)	29 (10, 47)	31 (20, 41)	—	—	(4)	(-3)	—	—	
Hilton 2	35 (31, 38)	—	34 (28, 40)	31 (20, 42)	32 (21, 44)	—	2	11	(7)	
Waitohi	41 (38, 44)	41 (34, 48)	42 (31, 52)	—	—	-2	(-2)	—	—	
				Mean		-9	-3	3	2	
1998/99										
Irwell	37 (34, 40)	36 (33, 39)	37 (34, 40)	38 (33, 42)	38 (31, 44)	2	-1	-2	-2	
Geraldine 5	40 (37, 43)	39 (36, 42)	40 (37, 43)	37 (34, 40)	31 (26, 35)	2	-1	6	23	
Geraldine 6	33 (30, 36)	30 (27, 34)	31 (26, 36)	14 (5, 23)	—	7	7	(57)	—	
Hilton 3	41 (38, 44)	38 (35, 41)	36 (34, 39)	38 (35, 41)	32 (28, 36)	6	11	7	21	
Hilton 4	41 (37, 44)	39 (35, 43)	41 (38, 44)	41 (38, 44)	39 (34, 44)	4	-1	-1	4	
Methven	46 (43, 49)	41 (38, 44)	44 (41, 48)	42 (38, 45)	42 (37, 46)	10	2	8	9	
				Mean		5	3	13	11	
1999/2000										
Morven	47 (46, 49)	47 (46, 48)	48 (46, 49)	47 (45, 48)	43 (42, 44)	1	0	2	9	
				Mean of all crops		2	1	8	11	

Table 5 Mean grain yield/ear for stems in different sharp eyespot severity categories, and % reduction in yield compared with healthy stems. (Figures in parenthesis are derived from <5 stems, but are included in means.)

Year and location	Yield/ear (g) (95% CI)					% reduction compared to Nil				
	Nil	Trace	Slight	Moderate	Severe	Trace	Slight	Moderate	Severe	
1996/97										
Geraldine Flat 1	1.9 (1.6,2.2)	1.6 (1.3,1.9)	1.7 (1.4,2.0)	1.6 (1.4,1.9)	0.5 (0.0,1.5)	15	10	15	(72)	
Geraldine Flat 2	2.1 (1.8,2.4)	1.6 (1.3,1.9)	1.7 (1.3,2.0)	—	—	22	20	—	—	
Hilton B	1.4 (1.1,1.7)	1.3 (1.0,1.6)	1.3 (1.1,1.6)	1.4 (1.1,1.7)	1.1 (0.8,1.4)	9	6	-1	24	
				Mean		7	7	-1	37	
1997/98										
Arowhenua	1.6 (1.2,2.0)	—	2.2 (1.6,2.9)	—	2.3 (1.0,3.6)	—	(-37)	—	(-40)	
Geraldine 1	1.0 (0.7,1.2)	1.3 (0.4,2.2)	1.0 (0.6,1.3)	1.0 (0.7,1.4)	0.8 (0.4,1.1)	-32	0	-5	24	
Hilton 1	0.9 (0.4,1.4)	0.6 (0.0,1.5)	1.1 (0.4,1.7)	—	—	31	(-18)	—	—	
Hilton 2	1.5 (1.2,1.7)	—	1.3 (0.9,1.8)	1.3 (0.5,2.0)	1.0 (0.3,1.6)	—	9	16	(35)	
Waitohi	1.7 (1.5,1.9)	1.8 (1.3,2.3)	2.0 (1.2,2.7)	—	—	-5	(-13)	—	—	
				Mean		-2	-15	6	-6	
1998/99										
Irwell	1.5 (1.3,1.7)	1.4 (1.2,1.6)	1.5 (1.3,1.7)	1.3 (1.1,1.6)	1.4 (1.0,1.8)	6	-1	11	7	
Geraldine 1	1.8 (1.5,2.0)	1.7 (1.5,1.9)	1.7 (1.5,1.9)	1.5 (1.3,1.7)	0.8 (0.5,1.0)	4	1	15	56	
Geraldine 2	1.5 (1.3,1.7)	1.2 (0.9,1.4)	1.2 (0.8,1.5)	0.6 (0.0,1.3)	—	22	21	(57)	—	
Hilton 1	2.0 (1.8,2.2)	1.8 (1.6,2.0)	1.7 (1.5,1.9)	1.7 (1.5,1.9)	0.9 (0.7,1.1)	9	15	14	54	
Hilton 2	1.6 (1.4,1.8)	1.3 (1.1,1.5)	1.6 (1.4,1.8)	1.4 (1.2,1.6)	0.8 (0.6,1.1)	17	0	9	46	
Methven	1.8 (1.6,2.0)	1.4 (1.2,1.6)	1.6 (1.3,1.8)	1.3 (1.1,1.5)	1.0 (0.8,1.3)	24	15	30	43	
				Mean		14	9	22	41	
1999/2000										
Morven	2.1 (2.0,2.2)	2.0 (1.9,2.1)	2.1 (1.9,2.2)	1.9 (1.8,2.0)	1.4 (1.4,1.5)	3	0	6	30	
				Mean of all crops		10	2	15	32	

Fig. 1 Relationship between sharp eyespot incidence and estimated yield loss in 15 wheat (*Triticum aestivum*) crops.



in infected categories in the 1997/98 crops were often based on few stems because of the low incidence experienced.

The effect of sharp eyespot infection on mean grain weight also varied between years (Table 4). The maximum grain weight reduction occurred in the severe category, which averaged 17, 2, 11, and 9% in 1996/97, 1997/98, 1998/99, and 1999/2000 respectively. Although there was little overall effect in 1997/98, low proportions of severely infected tillers make this result less meaningful. Grain weights were also reduced in the trace, slight, and moderate severity categories in 1996/97 and 1998/99.

Overall, grain yield/ear was affected by sharp eyespot in a similar manner to grain number and weight (Table 5). Yields were usually adversely affected by severe infection. In the 1998/99 growing season, yields averaged across crops were substantially lower in all severity categories compared to yield from healthy stems. However, there were variations between crops, and two of the six crops showed little effect of trace or slight infection levels. Reductions of 7% were recorded in the trace and slight category in 1996/97, and 6% in the moderate category in 1999/2000. Averaged across all trials in all years, grain yield/ear reductions were 10, 2, 15, and 32% for the trace, slight, moderate, and severe categories respectively.

The relationship between sharp eyespot incidence and yield loss (Fig. 1) was determined from the infected crops (excluding the two where disease was concentrated in one sample). There was a

relationship between incidence and yield loss ($r = 0.87$). Yield losses did not exceed 5% until at least 40% of tillers were infected, and did not exceed 10% until at least 60% of tillers were infected. There was a similar relationship ($r = 0.88$) between disease index (based on proportions of tillers in each severity category) and yield loss (graph not presented).

DISCUSSION

Sharp eyespot is common in New Zealand wheat crops, although its incidence is often low. Regional differences in incidence were evident in this survey, with the greatest proportion of heavily infected crops being located in south Canterbury. Similar regional differences have been reported in other countries. In Ontario, sharp eyespot tends to be more abundant in the cooler counties (Hall & Sutton 1998) and its incidence differs between regions in England and Wales (Polley & Thomas 1991). Early sowing of winter wheat is common in south Canterbury (Cromeley unpubl. data), which may also contribute to the high disease incidence in this region. Early sowing increased sharp eyespot severity in trials in France (Colbach et al. 1997) and in crops surveyed in England and Wales (Polley & Thomas 1991). A longer pre-winter period, during which conditions are favourable to infection, may contribute to higher disease levels (Colbach et al. 1997). The North Island wheat crops were all spring sown (no winter crops were detected during the survey), which may explain the low sharp eyespot incidence there.

Variation in disease incidence occurs between years as well as between regions. The 1997/98 growing season was marked by unusually warm and dry El Niño conditions (R. Hanson pers. comm.). The low disease levels in 1997/98 suggest that the incidence and severity of sharp eyespot can be affected by environmental variations between years. In England and Wales there was a sustained increase in sharp eyespot from 1980 onwards (probably not directly related to climate), although seasonal differences were observed within this trend (Polley & Thomas 1991). Cool, moist conditions are reported to encourage initial infection (Wiese 1987). The effects of soil moisture during later stages in disease development are not clearly defined, although stem girdling may restrict water movement up the stem, exacerbating the effects of dry soil conditions late in crop development.

Although estimates of the effects of sharp eyespot on yield vary, most studies suggest that only moderate or severe symptoms substantially reduce yield. Clarkson & Cook (1983) suggest that in the United Kingdom, moderate and severe infections cause average yield losses of 5 and 26% respectively. These figures are similar to those calculated in the present study in which, on average, moderate and severe infection reduced tiller yields by 15 and 32% respectively. Richardson et al. (1976) recorded an average yield loss of 8% in infected tillers, with 75% of the loss because of reductions in grain number and 25% to reductions in grain weight. In the present study, averaged across years, grain numbers were only slightly reduced in moderately infected tillers; the biggest effect of disease was evident in reductions in grain weight. The presence of moderate infection in tillers, therefore, is likely to restrict the flow of water and nutrients into developing grains. Conversely, about two-thirds of the yield loss in severely infected tillers was because of reductions in grain number, whereas the remaining one-third was because of reductions in grain weight. Infection in such tillers probably reaches a critical level earlier than in moderately infected tillers, affecting tillers between ear emergence and flowering as well as during grain fill.

Overall, both the incidence and severity of sharp eyespot affect yield. Croxall et al. (1964) suggested that losses can be as great as 20–25% when sharp eyespot incidence reaches 80% and c. 5% with 10–25% incidence. Pitt (1966) recorded yield losses of 19 and 44% respectively in heavily or severely infected plots that had been inoculated at early

tillering. Yield reductions were because of a decrease in grain weight rather than grain number. However, he estimated maximum yield loss in commercial crops at 12.5%. Maximum yield loss in the present study was estimated at 18% in a crop where 73% of tillers were infected, 44% of them in the moderate or severe categories. Despite the recorded effects of severe infection on yield, sharp eyespot incidence predicted yield loss almost as well as a disease index based on proportions of tillers in each severity category. It is also easier to measure. However, although there is a general relationship between sharp eyespot incidence and yield loss, there is much variation between individual crops. The relationship is, therefore, more useful for estimating overall losses due to the disease than losses in specific crops. Clearly, other factors influence the final effect of sharp eyespot on yield.

Although sharp eyespot can cause yield losses as high as 18%, losses are likely to be negligible where the incidence of the disease is <10%. Yield losses of over 5% were likely to occur in up to 20% of crops (mostly from Canterbury) in 1998/99. Although sharp eyespot is not a major yield-limiting disease of wheat in New Zealand, considerable crop losses are possible in environments conducive to the disease. In the absence of effective fungicide control (Colbach et al. 1997) or information on cultivar resistance (Wiese 1987), improved understanding of the factors affecting sharp eyespot incidence would be valuable in developing management practices that minimise the effects of the disease.

ACKNOWLEDGMENTS

Funding was provided by the New Zealand Foundation for Research, Science and Technology and the New Zealand Foundation for Arable Research. Pietre Allan provided technical assistance.

REFERENCES

- Anonymous 1991: Management of pests and diseases 1991–1992. Cereals. Lincoln, MAF Quality Management. 26 p.
- Blair, I. D.; Morrison, L. 1949: Wheat diseases and insect pests. *Information Series No. 3*. Wellington, DSIR. 59 p.
- Clarkson, J. D. S.; Cook, R. J. 1983: Effects of sharp eyespot on yield loss in winter wheat. *Plant Pathology* 32: 421–428.

- Colbach, H.; Lucas, P.; Cavelier, N.; Carvelier, A. 1997: Influence of cropping system on sharp eyespot in winter wheat. *Crop Protection* 16: 415–422.
- Croxall, H. E.; Dale, W. T.; Knight B. C. 1964: The incidence of soil-borne diseases of cereals in the West Midlands 1959–63. *Proceedings of the British Insecticide and Fungicide Conference, 1963*: 223–231.
- Genstat 5 Committee 1997: Genstat 5 Release 4.1 Reference Manual Supplement. Oxford, Numerical Algorithms Group.
- Hall, R.; Sutton, J. C. 1998: Relation of weather, crop, and soil variables to the prevalence, incidence, and severity of basal infections of winter wheat in Ontario. *Canadian Journal of Plant Pathology* 20: 69–80.
- McCullagh, P.; Nelder, J. A. 1989: Generalised linear models (2nd ed.). London, Chapman and Hall.
- Pitt, D. 1966: Studies on sharp eyespot disease of cereals. III. Effects of the disease on the wheat host and the incidence of disease in the field. *Annals of Applied Biology* 58: 299–308.
- Polley, R. W.; Thomas, M. R. 1991: Surveys of diseases of winter wheat in England and Wales, 1976–1988. *Annals of Applied Biology* 119: 1–20.
- Richardson, M. J.; Whittle, A. M.; Jacks, M. 1976: Yield-loss relationships in cereals. *Plant Pathology* 25: 21–30.
- Wiese, M. V. 1987: Compendium of wheat diseases. Second edition. St Paul, APS Press.