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Effects of stripe rust on the wheat plant

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Abstract

Stripe rust of wheat caused by *Puccinia striiformis* f. sp. *tritici* reduced kernel mass and the number of kernels per head in field epidemics from 1984 to 1987 in southern New South Wales. These epidemics began at the stem elongation stage of growth in 1984 and at booting to heading stages in the other years. The effects were greatest in very susceptible cultivars when the epidemic began before the booting stage of growth and affected more leaf area by the early milk stage of growth. Grain yield was reduced by up to 84%, kernel mass by up to 43% and kernel number by up to 72%. Stripe rust did not affect plant height, tiller number or stem dry matter at booting and anthesis. In some cases, stem dry matter was reduced at maturity. The dates of booting, heading and anthesis were not affected. The possible implications of the effect of stripe rust on grain quality arising from reduced kernel size are discussed.

Introduction

Stripe rust caused by *Puccinia striiformis* Westend. f. sp. *tritici* Eriks. is a foliar pathogen of wheat (*Triticum aestivum* L.) that can cause extensive losses in grain yield (Weise 1987) due to reduced size of kernels and a reduction in the number of kernels, through both number per head and number of heads. In glasshouse experiments, the extent of reduction of these yield components depended on the earliness of onset and the total amount of disease that developed (Bever 1937; Doodson *et al.* 1964).

Most stripe rust epidemics in eastern Australia begin in early to mid-spring (Ash *et al.* 1991) when wheat crops are at the booting to heading stage of development. Between 1979 and 1990, only two epidemics (1983 and 1984) began in winter at the tillering stage of growth (Ash *et al.* 1991). Ellison and Murray (1992) studied epidemics that began at different times over 4 years in southern New South Wales. In these epidemics, grain yield loss was associated with the proportion of leaf area affected by stripe rust at the early milk stage of growth, the length of the epidemic and temperatures during grain filling (Murray *et al.* 1994).

This paper examines how epidemics of different duration and severity have affected the wheat plant under field conditions in southern New South Wales, and the implications of these effects for grain quantity and quality.

Methods

Experimental design Experimental plots of wheat were sown at the Agricultural Institute, Yanco, and at the Agricultural Research Institute, Wagga Wagga, in southern New South Wales, Australia, from 1984 to 1987. They were designed to provide a range of sites, sowing dates, cultivars (including differences in dates of maturity and reactions to stripe rust), fungicide treatments and seasons that would affect the development of stripe rust.

The cultivars had adult plant reactions (APR) to stripe rust that ranged from very susceptible (VS) to resistant (R) (Table 1). Sowing was in May in all years, with a second sowing in June in 1986 and July in 1987. Grain harvest was at maturity in December in each year. Full details of establishment, management, rainfall and temperature measurement, fungicide treatments, disease assessment, grain harvest and experimental design are in Ellison and Murray (1992) and Murray *et al.* (1994).

The design in all experiments was a split plot with four replications, except at Wagga Wagga in 1987 when three replications were used. In 1984 and 1985, main plots were split for fungicide treatment and cultivars placed randomly within main plots. In 1986 and 1987, cultivars were assigned to main plots and fungicide treatments were randomly allocated within main plots. Treatment plots were 7–10 m long by 6 m wide. The wheat was sown as three groups of eight rows (18 cm row spacing) with a 0.5 m walkway between each group to allow access for assessment and sampling. A barley plot 2 m wide separated the treatment plots at Wagga Wagga in all years and at Yanco in 1986 and 1987.

There were two standard treatments: unsprayed and sprayed, where either triadimefon or propiconazole applied at 125 g a.i./ha in 150 L water was sprayed at 4-week intervals throughout the growing season.

Disease assessments All plots were assessed for foliar and other diseases at regular intervals throughout the growing seasons, following methods reported in Ellison and Murray (1992).

Plot harvest The central eight rows of treatment plots were harvested at maturity with a small plot header. The grain was cleaned, dried at 105°C and weighed to find plot yield. Average kernel mass was found by weighing 300 whole kernels randomly selected from the harvest of each plot. The average number of kernels per 0.01 m^2 was calculated from the plot yield and plot kernel mass data.

Quadrat harvest The outer eight rows on either side of the plot harvest were used for quadrat harvests. Plants were cut at three stages of growth: booting (GS 45, Tottman and Makepeace 1979), anthesis to mid-milk (GS 65–) and physiological maturity (GS > 90). These cuts were from two cultivars in each field experiment: Zenith (VS) and Condor (MR) in 1984, Avocet (VS) and Egret (S) in 1985 and 1986, and Avocet (VS) and Bindawarra (S) in 1987. All tillers were cut at ground level from six x 1 m lengths of row (1 m^2). The row lengths were selected at random, except that areas of poor emergence and the outermost two rows were avoided. As each plot was cut, the fresh weight and number of tillers in the quadrat harvest were determined.

A sub-sample of the quadrat harvest was placed in a plastic bag to prevent moisture loss and the remainder discarded. This sub-sample consisted of 50 tillers at harvest 3 in all years and the other harvests in 1984, and of 20 tillers in the other harvests from 1985–1987. Fresh weight of the sub-sample was determined within one day of cutting.

Components of the wheat plant Grain yield is the product of the number of kernels harvested and the mass of each kernel. Number of kernels is the product of the number of tillers and the number of kernels per tiller. The photosynthetic parts of the plant (green leaf, stem and vegetative parts of the head) produce the sugars and other materials for filling of the kernels.

At booting, the tillers were divided into stem (true stem plus leaf sheaths), green leaf lamina and dead leaf lamina. At anthesis–early milk, they were separated into stem, green leaf, dead leaf and head. At maturity, the components were stem, dead leaf lamina, chaff (rachis, glumes, awns, lemmas and paleas), and grain.

All components were dried at 105°C to constant weight. Dry weight of each plant component was calculated on an area basis (g/m^2). The number and mass of kernels from the sub-sample were found: number of kernels was calculated per tiller and mass expressed per kernel.

Analysis Data were analysed by analysis of variance (GENSTAT 5, Payne *et al.* 1988).

Results

Leaf disease epidemics Stripe rust was the main foliar disease present in all experiments except at Wagga Wagga in 1985 and in the first sowing in 1986. In these experiments, Septoria tritici blotch, caused by *Mycosphaerella graminicola* (Fuckel) Schroeter, was the major disease. The spray treatment delayed the onset of disease and reduced stripe rust levels to virtually nil in all years except 1984. In that year the disease affected up to 15% of leaf area at GS 73 in sprayed Zenith at Yanco.

In 1984, the epidemics began in August when the wheat was at stem elongation (GS 31–37). They began later in the other years (in September at Yanco and October at Wagga Wagga) when the plants were at booting to heading (GS 45–55). Full details of stripe rust epidemiology in these experiments are reported in Ellison and Murray (1992).

Effect of stripe rust on plot yield The yield of unsprayed plots ranged up to 84% less than that of the sprayed plots, e.g. cv. Avocet in 1984 (Table 1). The yield loss was greater in cultivars with greater susceptibility to stripe rust in all experiments where stripe rust was the major foliar disease. Yield loss associated with stripe rust in cultivars with MR and R reactions to the disease occurred only in 1984 when stripe rust epidemics were longest and among the most severe.

Where Septoria tritici blotch was the major disease at Wagga Wagga in 1985 and the first sowing of 1986, it was associated with losses of up to 23%. The yield of cv. Banks, which is resistant to both Septoria tritici blotch and stripe rust, was not affected in those experiments (Table 1).

The yield loss associated with either stripe rust or Septoria tritici blotch was reflected in reduced number and mass of kernels in most experiments (Table 1).

This paper reports the response of plant components to infection with stripe rust for all experiments except where Septoria tritici blotch developed (Wagga Wagga in 1985 and the first sowing of 1986).

Effect of stripe rust at booting Stripe rust epidemics developed only by booting in 1984, with the disease at Wagga Wagga more severe than at Yanco (Table 2). Mass of dead leaves was greater in the unsprayed plots than the sprayed plots of cv. Zenith (VS) and cv. Condor (MR) at Wagga Wagga and cv. Zenith at Yanco. The mass of green leaf was significantly less in the unsprayed plots than the sprayed plots of cv. Zenith at Wagga Wagga. Stem dry matter and the number of tillers were also not significantly affected by the spray treatment in 1984 (Table 2). The height and total leaf mass were not significantly different between fungicide treatments (unpublished results).

At booting from 1985–1987, there was no stripe rust and no significant differences occurred in plant components between the unsprayed and sprayed plots.

Effect of stripe rust at anthesis–early milk stage Stripe rust had developed on unsprayed, susceptible cultivars in all experiments at the second quadrat harvest. The disease affected up to 97% of leaf area in very susceptible cultivars, exceeding 10% of leaf area at GS 73 in 28 of the 54 cultivar × site × year treatments (Table 1). Stripe rust exceeded 10% of leaf area in 12 of the 16 cases reported in Table 3.

The number of tillers did not differ significantly between sprayed and unsprayed treatments for each cultivar in each experiment, while the mass of stems and heads was also generally unaffected (Table 3). Green leaf mass was significantly reduced in 8 of the 12 times when stripe rust exceeded 10% of leaf area, while mass of dead leaves was significantly increased nine times (Table 3). The dead leaves were dry and brittle, which led to considerable loss and a probable underestimate of the dead leaf material at this harvest. Plant height did not differ significantly between unsprayed and sprayed treatments in any experiment (unpublished data).

Effect of stripe rust at physiological maturity The quadrat harvest at physiological maturity found no differences in numbers of tillers per m^2 in 15 of the 16 treatments; the exception was in cv. Zenith at Yanco in 1984 (Table 4) where there was a long and severe epidemic (Table 1). Kernels per head were reduced in four treatments, stem dry matter in five, leaf in two, and chaff in three, but there were no relationships between epidemic severity and these factors. Kernel mass was reduced in eight treatments and grain yield in ten, as estimated by quadrat harvest. Where kernel mass was significantly reduced, grain yield was also reduced (Table 4).

Kernels per 0.01 m^2, as estimated from the plot harvest, were reduced in nine treatments, kernel mass in 12 and grain in 13 (Table 4).

The estimates of kernel mass from the quadrat and plot harvests were highly correlated and similar, with the relationship: $y = 0.97x$ ($r = 0.78$, $d.f. = 31$), where y = plot kernel mass and x = quadrat kernel mass. However the *s.e.d.s* of the quadrat harvests were higher than those of

Table 1 Severity of stripe rust on unsprayed plots (per cent of leaf area affected at GS 73), duration of epidemic (days from 1% of leaf area affected to GS 73), and per cent reduction in yield, numbers of kernels and kernel mass in unsprayed compared with sprayed plots, as determined by plot harvest, of wheat cultivars with differing levels of adult plant reactions (APR) to stripe rust at Yanco and Wagga Wagga, 1984–1987

Cultivar	APR	Yanco					Wagga Wagga				
		Stripe rust		% reduction			Stripe rust		% reduction		
		Leaf area (%)	Duration (days)	Yield	Kernels No.	Kernels Mass	Leaf area (%)	Duration (days)	Yield	Kernels No.	Kernels Mass
1984											
Avocet	VS	73	39	84**[A]	72**	43**	82	57	75**	66**	27**
Zenith	VS	54	48	35**	19*	20**	73	62	51**	48**	22**
Egret	S	19	33	21**	11	12**	30	51	28**	21**	9**
Olympic	MS	7	24	–5	–4	–1	17	56	15*	14*	5
Condor	MR	18	35	11*	9	2	25	51	21**	16**	8
Banks	R	11	23	–2	–6	3	17	36	9*	5	4
1985											
Avocet	VS	27	11	53**	32**	32**	4	2	17**	–[B]	–
Egret	S	8	5	12*	4	9**	0	0	6	–	–
Harrier	MS	4	1	13**	11*	2	0	0	–3	–	–
Osprey	MR	0	0	6	–2	7*	0	0	–6	–	–
Banks	R	0	0	3	0	3	0	0	–3	–	–
1986–1											
Avocet	VS	50	16	39**	23**	21**	1	0	23**	–2	24**
Bindawarra	S	47	10	34**	17	20**	8	3	9	8	9**
Egret	S	20	15	18*	22**	–2	0	0	14**	–2	12**
Osprey	MR	0	0	–4	–6	2	0	0	13*	17**	3
Banks	R	0	0	6	3	3	0	0	5	–1	9**
1986–2											
Avocet	VS	97	37	70**	57**	36**	70	13	60**	28**	44**
Bindawarra	S	75	24	48**	36**	18**	–	–	–	–	–
Egret	S	59	22	32**	20**	14**	52	9	26**	5	21**
1987–1											
Avocet	VS	49	12	11	–10	19**	1	3	12	–7	18
Bindawarra	S	69	21	23**	11	14**	4	11	–10	–4	–2
Millewa	MS	27	14	21**	16*	6	1	2	–4	–22	14
Corella	R	0	0	5	4	1	0	0	10	11	–3
1987–2											
Avocet	VS	84	24	21*	5	17**	18	8	7	–4	10
Bindawarra	S	11	14	6	7	–1	6	6	–4	–15	10
Millewa	MS	17	13	5	9	–6	0	0	8	–2	12
Corella	R	0	0	10	4	7	0	0	17	17	–2

[A]*, ** Reduction compared with sprayed is significant at the 5 or 1% level, respectively.
[B]– not determined.

Table 2 Stripe rust (% of leaf area affected) and yield parameters at the booting stage of growth (GS 45) of wheat cultivars unsprayed (U) and sprayed (S) with fungicides at Wagga Wagga and Yanco in 1984

Cultivar	Treatment	Stripe rust (%)	Tillers (per m²)	Stem (g/m²)	Green leaf (g/m²)	Dead leaf (g/m²)
Wagga Wagga						
Zenith (VS)[A]	U	19	582	321	109*[B]	131*
	S	1	492	444	229	19
Condor (MR)	U	11	608	608	189	67*
	S	1	573	571	203	30
	s.e.d.[C]	–	46	95	33	16
Yanco						
Zenith (VS)	U	3	608	392	241	26*
	S	0	586	405	258	8
Condor (MR)	U	5	590	412	217	19
	S	0	574	450	238	12
	s.e.d.	–	65	38	33	9

[A]The adult plant reaction to stripe rust is in parentheses after the cultivar.
[B]* = sprayed treatment differs significantly ($P<0.05$) from unsprayed.
[C](s.e.d.) standard error of difference within cultivars.

Table 3 Yield parameters at the anthesis–early milk stage of wheat cultivars unsprayed (U) and sprayed (S) with fungicides at Yanco and Wagga Wagga from 1984–1986

Cultivar	Treatment	Tillers (per m²)	Stem (g/m²)	Green leaf (g/m²)	Dead leaf (g/m²)	Head (g/m²)
Wagga Wagga 1984						
Zenith (VS)[A]	U	480	378	13*[B]	141*	112*
	S	407	577	93	58	264
Condor (MR)	U	487	835	105	127	228
	S	547	1041	162	95	291
	s.e.d.[C]	47	139	17	29	58
Yanco 1984						
Zenith (VS)	U	540	1198[D]	37*	249*	–[D]
	S	539	1238	138	149	–
Condor (MR)	U	590	751	133	97*	–
	S	591	802	157	9	–
	s.e.d.	45	123	39	35	–
Yanco 1985						
Avocet (VS)	U	747	807	107*	113*	355
	S	808	892	193	69	332
Egret (S)	U	658	689	148	73	325
	S	598	660	160	50	269
	s.e.d.	94	87	26	19	37

Table 3 continued

Wagga Wagga 1986, second sowing						
Avocet (VS)	U	340	363	81	39*	148
	S	360	388	112	3	148
Egret (S)	U	347	399	103*	15	136
	S	360	534	162	6	180
	s.e.d.	42	76	20	6	28
Yanco 1986, first sowing						
Avocet (VS)	U	402	707	97*	59*	197
	S	427	777	153	18	211
Egret (S)	U	479	743	102	68*	204
	S	451	738	138	20	190
	s.e.d.	32	59	25	14	23
Yanco 1986, second sowing						
Avocet (VS)	U	415	463*	1*	121*	227
	S	461	683	143	3	264
Egret (S)	U	506	673	76*	68*	253
	S	460	644	127	10	246
	s.e.d.	30	54	9	12	18
Yanco 1987, first sowing						
Avocet (VS)	U	283	632	132*	31	175
	S	331	743	163	26	206
Bindawarra (S)	U	389	636*	140*	49	166
	S	436	747	201	32	194
	s.e.d.	48	50	14	19	33
Yanco 1987, second sowing						
Avocet (VS)	U	352	506	14*	84*	253
	S	356	545	94	13	269
Bindawarra (S)	U	363	474	94	18	235
	S	386	556	107	17	302
	s.e.d.	40	90	23	24	35

[A]The adult plant reaction to stripe rust is in parentheses after the cultivar name.
[B]* = sprayed treatment differs significantly ($P<0.05$) from unsprayed.
[C]s.e.d. = standard error of difference within cultivars.
[D]Stem component is stem plus head.

the plot harvests (Table 4). Where kernel mass was significantly reduced in the quadrat harvest, it was also significantly reduced in the plot harvest.

The estimates of grain yield from the quadrat and plot harvests were also highly correlated, but the values from the quadrat harvest were consistently higher than those of the plot harvest. The relationship between the two was: y = 0.63x (r = 0.84, *d.f.* = 31), where y = plot yield and x = quadrat yield. The *s.e.d.s* of yield, as determined by quadrat harvest, were consistently higher than those of the plot harvest. However, where quadrat harvest grain yield was significantly reduced in the unsprayed plots, the plot harvest yield was also reduced (Table 4).

Discussion

These experiments show that the losses in grain yield associated with stripe rust resulted from losses in kernel mass and the numbers of kernels. Once stripe rust was established, diseased plants had more dead leaf and less green leaf than sprayed plants. The numbers of tillers were only

Table 4 Plant components at physiological maturity of wheat cultivars unsprayed (U) and sprayed (S) with fungicides, determined by quadrat harvest and plot harvest at Yanco and Wagga Wagga from 1984–1986

Cultivar	Treatment	Quadrat harvest							Plot harvest		
		Tillers (per m²)	Kernels (per head)	Stem (g/m²)	Leaf (g/m²)	Chaff (g/m²)	Kernel mass (mg)	Grain (g/m²)	Kernels (per 0.01 m²)	Kernel mass (mg)	Grain (g/m²)
Wagga Wagga 1984											
Zenith (VS)[A]	U	560	26*[B]	591*	156	105*	29*	426*	51**	30**	184**
	S	523	35	797	178	162	36	653	98	38	377
Condor (MR)	U	578	38	560	135	153*	31	675*	119**	32	380**
	S	609	41	694	140	202	33	834	141	34	482
	s.e.d.[C]	51	3.2	53	17	13	1.1	54	7	1.0	21
Yanco 1984											
Zenith (VS)	U	517*	28	637*	165*	155	28*	400*	73*	35**	255**
	S	609	32	845	208	187	43	832	90	44	394
Condor (MR)	U	503	36	547	129	219	36	637	125	36	449*
	S	512	37	577	129	200	39	726	138	37	506
	s.e.d.	46	3.0	69	20	22	1.6	82	9	1.2	32
Yanco 1985											
Avocet (VS)	U	696	26*	620	153	333	32*	573*	91**	28**	290**
	S	683	34	753	171	397	46	1047	134	42	616
Egret (S)	U	655	30*	682*	165	270	40	784*	120	38*	501**
	S	604	39	844	203	293	45	1036	125	42	571
	s.e.d.	55	3.9	77	27	63	3.1	87	8	1.3	30
Wagga Wagga 1986, second sowing											
Avocet (VS)	U	408	37	416*	67	223	29	486	82**	17**	206**
	S	416	37	549	84	224	32	524	114	31	510
Egret (S)	U	356	38	390*	57*	238	41	598	106	30**	349**
	S	388	39	548	81	238	44	636	112	38	469
	s.e.d.	35	–	33	9	–	–	–	8	2.4	27
Yanco 1986, first sowing											
Avocet (VS)	U	376	31	555	81	207	40*	556*	93**	36**	370**
	S	464	35	695	119	246	47	771	121	45	605
Egret (S)	U	444	35	573	118	317*	41	676	104**	39	448*
	S	387	36	595	70	165	44	690	134	39	544
	s.e.d.	63	3.5	81	45	61	2.7	113	11	1.2	44
Yanco 1986, second sowing											
Avocet (VS)	U	346	27*	377	50	191	26*	288*	38**	28**	133**
	S	385	37	498	56	176	42	669	89	44	435
Egret (S)	U	389	33	451	66	166	37*	491*	80**	36**	312**
	S	395	38	545	104	198	43	716	100	42	457
	s.e.d.	23	2.4	72	31	31	2.0	91	7	1.1	28

Table 4 continued

Yanco 1987, first sowing											
Avocet (VS)	U	286	41	446	113	172	33*	498*	90	33**	326
	S	303	48	530	121	195	42	587	83	40	364
Bindawarra (S)	U	441	33	417	129	179	33	483*	103	1**	357**
	S	394	42	589	168	239	35	790	115	36	463
	s.e.d.	47	4.1	85	26	39	2.1	45	9	1.4	31
Yanco 1987, second sowing											
Avocet (VS)	U	364	28	298	69	143	32*	357	63	36**	252*
	S	363	30	376	68	193	41	512	67	44	320
Bindawarra (S)	U	361	27	312	63	156	41	460	71	43	333
	S	396	31	343	73	189	42	556	77	42	353
	s.e.d.	43	3.0	61	23	36	2.2	79	7	1.5	28

[A]The adult plant reaction to stripe rust is in parentheses after the cultivar name.
[B]*, ** = sprayed treatment differs significantly ($P<0.05$, 0.01) from unsprayed.
[C]s.e.d. = standard error of difference within cultivars.

significantly less in one of 16 comparisons and may have been a Type II error (Steel and Torrie 1960). Thus we conclude that the reduced number of kernels arose from fewer kernels per head. Other parts of the plant and plant height were generally not affected. Dates of booting, heading and anthesis did not differ between the sprayed and unsprayed plots within cultivars. The earliest epidemics in these experiments were in 1984 and began when plants were at the tillering stage. In the other years, epidemics began when plants were at the booting to heading stage.

Several other researchers have reported the effects of stripe rust epidemics on components of the wheat plant under field conditions in Australia. In Queensland, stripe rust epidemics that began by early tillering reduced grain yield and kernel mass, but not the numbers of tillers or kernels per head (Park *et al.* 1988). Ash and Brown (1990) in northern New South Wales found the effects of stripe rust varied between years. The disease reduced yield in each year, whether it began at early tillering or after flag leaf emergence; however, there was no consistent effect on the yield components of the plant. Also in northern New South Wales, Eskdale (1991) found in epidemics starting at early tillering or at booting, plant height, kernel mass and grain yield were reduced while the number of tillers was unaffected. In Victoria, yield loss caused by stripe rust was usually associated with reductions in kernel mass (O'Brien *et al.* 1990).

Controlled experiments have shown that the effects of stripe rust on plant growth depend on the time of onset of the disease relative to stage of growth of the plant. Bever (1937) inoculated wheat and barley beginning at different stages from seedling to anthesis. Early infections (starting at seedling, 3-leaf and jointing) reduced the number of heads, plant height, straw mass and number of kernels, and delayed development of the plants, while these factors were not affected when infections began at booting or later. Kernel mass and grain yield were reduced by all inoculation treatments (Bever 1937, Table 1). Doodson *et al.* (1964) also showed under glasshouse conditions that the extent of effects depended on when plants were inoculated.

Grain yield in wheat has four basic components: the number of heads or tillers per m^2, the number of spikelets per head, the kernels per spikelet, and the mass of individual kernels. The numbers of tillers and spikelets per tiller are determined before booting, the kernels per spikelet from stem elongation to early milk, and the kernel mass after anthesis. Stresses on the plant at different stages affect the yield components that are developing at that time (Teng and Gaunt 1980). In our studies, the earliest epidemics of stripe rust began at stem elongation, while most began at booting to heading. These affected kernel mass and kernel number but not the number of tillers, which is consistent with the predictions of Teng and Gaunt (1980).

Australian studies, including our experiments, show that stripe rust reduces yield by reducing kernel mass, and may affect other components of plant development. These agree with reports from other countries, e.g. New Zealand (Gaunt and Cole 1991), the United States of America (Schultz and Line 1992), England (King 1976), Germany (Schuler 1987), Israel (Shtienberg *et al.* 1990) and China (Yang and Zeng 1989). O'Brien *et al.* (1990) found that reduced kernel mass caused by stripe rust results in grain of lower quality, including reduced test weight, flour milling yield and altered dough properties.

In our experiments, the quadrat harvest consistently overestimated the plot yield by about 1.6 times. This difference could arise from errors in the estimate of the area of the plot or the quadrat, and from selection of more uniform lengths of row for the quadrat harvests. However, both plot and quadrat harvests gave similar estimates of the effect of stripe rust on yield and kernel mass. The error in the estimates was consistently higher for the quadrat harvests than for the plot harvests. Further, the labour and time required for the quadrat harvests were greater than for the plot harvests. Under the conditions of these experiments, plot harvests provide a rapid estimate of the effect of stripe rust on yield through reduced kernel mass and number of kernels.

Most stripe rust epidemics have begun at the jointing to booting or later stages of growth in Australia (Ash *et al.* 1991). Such epidemics will affect grain yield through reduced kernel mass and number of kernels per head, and potentially reduce grain quality. Thus, the total value of loss from stripe rust may include the reduced value of the affected grain.

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