Aust. J. Agric. Res., 1983, **34**, 39–46

Effects of Yellow Spot on Wheat: Comparison of Epidemics at Different Stages of Crop Development

R. G. Rees and G. J. Platz

Queensland Wheat Research Institute, Queensland Department of Primary Industries, Toowoomba, Qld 4350.

Abstract

Effects of yellow spot (*Pyrenophora tritici-repentis*) on two cultivars (Banks and Olympic) of wheat have been examined in a field experiment where distinctly different epidemics were produced in various treatments. Severe yellow spot before jointing reduced production of both tillers and dry matter, and substantially lowered leaf area index at jointing. Severe disease after jointing reduced leaf area index at flowering, dry weight of plants at maturity and harvest index. Crop phenology was also modified, with flowering being delayed by early disease and crop maturity hastened by late disease. Where yellow spot was severe throughout, the grain-filling period was greatly reduced.

Grain yield of Banks was reduced by *c*. 13% by early disease, *c*. 35% by late disease, and *c*. 48% by disease throughout the crop season. Most of the loss was in reduced grain size. Although yield loss in Olympic was less than in Banks, the resistance of Olympic was shown to be inadequate.

Introduction

The wheat disease yellow spot (*Pyrenophora tritici-repentis* (Died.) Drechsler) has become an important problem in the prime-hard wheat areas of Queensland and northern New South Wales (Rees and Platz 1979; Klein and Ellison 1982). Grain yield of affected crops may be substantially reduced (Rees *et al.* 1981, 1982).

The severity of yellow spot varies greatly between years and can differ markedly within a crop season, depending largely on the occurrence of wet weather. If rain follows crop emergence, the disease may be severe in young plants. Should dry conditions then occur, further development of yellow spot is restricted. In other years, periods of wet weather later in the growing season may result in a small amount of disease developing into a damaging epidemic. Little is known on the effects of yellow spot at different stages of crop development.

The effects of severe yellow spot during early or late crop growth and over the whole season were examined in a field experiment in 1980.

Methods

The cultivars Banks and Olympic were planted in plots 8·5 by 1·7 m, in an area free of wheat stubble at Toowoomba, Qld, on 2 June 1980 in four replications of six treatments. Banks was used because of its high susceptibility to yellow spot, while Olympic possesses some resistance to the disease (R. G. Rees and G. J. Platz, unpublished data). Buffer areas of oats (cv. Stout) 6·5 m wide, planted 19 days earlier, separated the wheat plots.

Stubble infected with *P. tritici-repentis* was collected from three 1979 wheat crops and some was fumigated with methyl bromide. Before emergence of the crop, stubble was applied to the wheat plots at 326 g m^{-2} to provide the following treatments: A and C, cv. Banks with fumigated stubble;

0004–9409/83/010039$02.00

B and D, cv. Banks with infected stubble; E and F, cv. Olympic with fumigated and infected stubble respectively. About 960 pseudothecia per gram of infected stubble were present at crop emergence. Twelve sprays of triadimefon (250 g ha^{-1} active ingredient) or triadimefon plus mancozeb (1·76 kg ha^{-1} active ingredient) were applied every 1–2 weeks to treatments A and E to provide 'disease-free' references.

The stubbles on treatments B (infected) and C (fumigated) were exchanged on 8 August, when the crop was at pseudostem erection (growth stage (g.s.) 30 of Zadoks *et al.* (1974)), to provide early- and late-disease treatments. To enhance the epidemic in the late-disease treatment (C), these plots were inoculated with conidia of *P. tritici-repentis* collected in the field during the previous year and stored in liquid nitrogen. A suspension of 2·53 g of conidia, including those of various saprophytic fungi, was prepared in 2·5 l. water and contained *c.* $7 \cdot 53 \times 10^7$ conidia of *P. tritici-repentis* per litre. This suspension was misted onto the plots on 11 August. Following the exchange of stubbles, sprays of triadimefon plus mancozeb were commenced on the early-diseased (B) plots which were subsequently sprayed with fungicide at the same time as the reference (A, E) treatments.

All plots were sprayed with manganous sulfate and zinc sulfate (1·1 kg ha^{-1} of each) about 5 and 7 weeks after planting to reduce possible effects associated with enhanced zinc and manganese nutrition in plots sprayed with mancozeb. To promote epidemic development, sprinkler irrigation (*c.* 1·8 mm h^{-1}) was used for 2–3 h up to several evenings per week when the weather was dry and not excessively windy.

Yellow spot severity was assessed in each plot on 11 occasions using the key for Septoria leaf blotch developed by James (1971). On each occasion, 10 main tillers in each plot were assessed independently by two operators. The average number of tillers per plant was measured on five occasions, and flowering and harvest dates were recorded for each treatment.

Plant samples were taken from 0·48 m^2 of each plot at jointing (g.s. 31–32), flowering (g.s. 61), and at harvest (g.s. 92), with two quadrats being taken from each plot at the last sampling. Tiller numbers and dry weight were measured on the samples. A subsample of plants from each quadrat taken at jointing and flowering was dissected for determination of leaf area index (LAI). LAI is a measure of leaf area per unit area and is primarily used as an index of energy interception per unit area. At jointing, leaves were separated into categories based on leaf number from the top of the plant, the tip of the expanding leaf being included with the top leaf. At flowering, the categories were based on leaf number with the flag leaf as leaf 1. The plant samples taken at maturity were separated into 'main' and 'minor' tillers, where 'main' tillers were the main stem plus the two or three subtended primary tillers and the 'minor' category included the smaller late heads. These were used to provide measures of tiller height, peduncle diameter, spikelet number, grain yield, grain number, grain size and harvest index. Estimates of leaf area duration (LAD) (Thorne 1966) were obtained by integration of LAI at flowering and duration of grain-filling period, on assuming a linear decline in LAI. 'Main' and 'minor' tillers were analysed for concentrations of nitrogen and phosphorus in the straw.

At maturity, plots were machine harvested and the grain used for measurement of yield, proportion of screenings through a 2·26 mm triangular sieve, hectolitre weight, grain size, amount of pink grain, and concentrations of nitrogen and phosphorus.

Results

Disease Epidemics

Small but frequent amounts of sprinkler irrigation resulted in severe epidemics of yellow spot in inoculated plots. Distinctly different levels of disease developed with the various treatments up to jointing (g.s. 31–32) (Table 1). Subsequently, differences in disease severity were not quite as distinct, largely because of interplot interference and the incomplete control provided by the fungicides, especially late in the season. Transferring the infected stubble from the early-disease Banks (B) and inoculation with conidia resulted in severe yellow spot in the late-disease Banks (C). Throughout the crop season, less disease was present in Olympic than in Banks, and better disease control was achieved by the fungicides on Olympic.

Tillering

One of the earliest observed effects of severe early yellow spot was a delay or reduction in tillering; this is illustrated for Banks in Fig. 1*a*. Significant differences ($P < 0\cdot01$) between severely diseased (D, F) and reference treatments (A, E) occurred

Table 1. Average severity (%) of yellow spot during early-disease and late-disease periods and over the complete growing season

The arcsin transformation was applied to data for analysis and values given are equivalent means

Within columns, values with a common superscript do not differ at $P = 0\cdot05$

Treatment	Cultivar	Yellow spot	To jointing[A] (five dates)	After jointing (six dates)	Full season (11 dates)
A	Banks	'nil'	0^{d}	$5\cdot12^{c}$	$2\cdot78^{d}$
B	Banks	early	$52\cdot4^{a}$	$5\cdot75^{bc}$	$27\cdot1^{b}$
C	Banks	late	$0\cdot51^{c}$	$44\cdot6^{a}$	$24\cdot6^{b}$
D	Banks	'full'	$52\cdot9^{a}$	$35\cdot0^{a}$	$43\cdot2^{a}$
E	Olympic	'nil'	0^{d}	$1\cdot27^{d}$	$0\cdot69^{e}$
F	Olympic	'full'	$17\cdot8^{b}$	$11\cdot3^{b}$	$14\cdot3^{c}$

[A] Epidemics in early-disease and late-disease Banks treatments were respectively curtailed or initiated about 12 days earlier, i.e. at pseudostem erection (g.s. 30). Assessments are the average of the percentage leaf area affected on two leaves, usually the top two leaves.

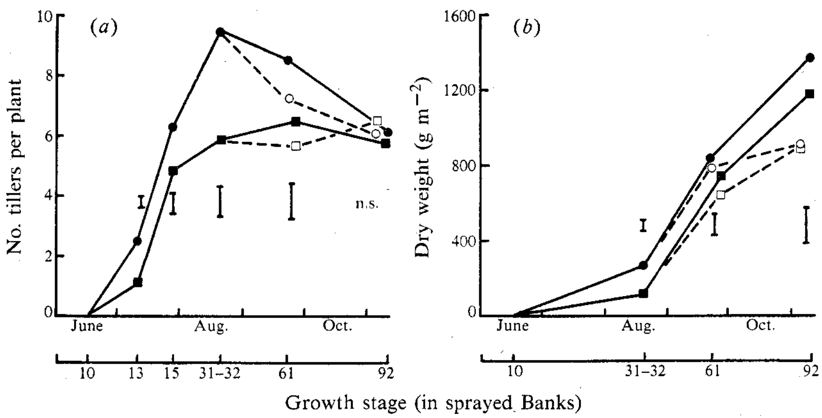

Fig. 1. (*a*) Changes in the number of tillers per plant with time or growth stage (in sprayed Banks) in four treatments of Banks. (*b*) Changes in dry weight per m^2 of plot with time or growth stage in four treatments of Banks. ● 'nil'-disease (A); ■ early-disease (B); ○ late-disease (C); □ 'full'-disease (D). Vertical bars indicate least significant differences ($P = 0\cdot05$). Tiller numbers and dry weights did not differ significantly ($P > 0\cdot05$) between the late-disease (C) and 'nil'-disease (A) or early-disease (B) and 'full' disease (D) treatments before separation of the respective treatments after g.s. 30.

in both cultivars at the three- and five-leaf stages (g.s. 13 and 15). These differences ($P < 0\cdot01$) remained for the Banks treatments at jointing (g.s. 31–32) and flowering (g.s. 61), but disappeared in cv. Olympic. By maturity, no significant differences ($P < 0\cdot05$) in tiller numbers were present within cultivars.

Tiller Height and Peduncle Diameter

A second effect of severe early yellow spot was on plant size, with the diseased plants being noticeably smaller. The dry matter yields for the four treatments involving Banks are shown in Fig. 1*b*. In the diseased Olympic (F) dry matter was 36% below that in the reference treatment (E) at jointing (g.s. 31–32), differences at flowering (g.s. 61) were not significant ($P > 0 \cdot 05$). At maturity, dry matter in the diseased Olympic was 18% less than in the sprayed treatment.

There were no significant differences ($P < 0 \cdot 05$) between treatments within cultivars in tiller height at maturity. Similarly, no significant differences in peduncle diameter of 'main' tillers were present between treatments. Significant differences ($P < 0 \cdot 05$), however, occurred in peduncle diameters of 'minor' tillers, with those in the late-disease Banks (C) reduced by 6·7% relative to the sprayed treatment and those in the diseased Olympic (F) reduced by 7·7%.

Table 2. Leaf area index (LAI) measurements derived from plant samples taken at jointing and flowering

Leaves are numbered from the top of the plant
Within columns, values with a common superscript do not differ at $P = 0 \cdot 05$

Treat-ment	Cultivar	Yellow spot	Jointing Leaves 1+2	Jointing Leaves 3+4	Jointing Leaves 1+2+3+4	Flowering Leaves 1+2	Flowering Leaves 3+4	Flowering Leaves 1+2+3+4
A	Banks	'nil'	$3 \cdot 58^{bc}$	$0 \cdot 820^{a}$	$4 \cdot 40^{b}$	$3 \cdot 36^{ab}$	$1 \cdot 81^{a}$	$5 \cdot 17^{a}$
B	Banks	early	$1 \cdot 62^{d}$	$0 \cdot 066^{b}$	$1 \cdot 69^{d}$	$2 \cdot 59^{bc}$	$1 \cdot 96^{a}$	$4 \cdot 54^{abc}$
C	Banks	late	$3 \cdot 03^{c}$	$0 \cdot 205^{b}$	$3 \cdot 23^{c}$	$2 \cdot 90^{abc}$	$0 \cdot 811^{b}$	$3 \cdot 71^{bc}$
D	Banks	'full'	$1 \cdot 18^{d}$	$0 \cdot 049^{b}$	$1 \cdot 23^{d}$	$2 \cdot 25^{c}$	$1 \cdot 07^{b}$	$3 \cdot 32^{c}$
E	Olympic	'nil'	$5 \cdot 93^{a}$	$0 \cdot 967^{a}$	$6 \cdot 89^{a}$	$3 \cdot 43^{ab}$	$1 \cdot 86^{a}$	$5 \cdot 29^{a}$
F	Olympic	'full'	$3 \cdot 98^{b}$	$0 \cdot 105^{b}$	$4 \cdot 08^{bc}$	$3 \cdot 61^{a}$	$1 \cdot 20^{b}$	$4 \cdot 81^{ab}$

Leaf Area Index

Severe yellow spot reduced LAI at jointing and flowering in both cultivars (Table 2). LAI for the 'full'-disease Banks (D) was 72% less at jointing and 36% less at flowering than the reference treatment.

Crop Phenology

Another conspicuous effect of severe yellow spot was on crop phenology. Crop development was retarded by early disease and flowering was delayed in both cultivars (Table 3). Maturity in Banks, however, was hastened by late disease. The overall effect was a reduction in grain-filling period by 22% in the 'full'-disease Banks, or by 11% in the diseased Olympic (Table 3).

Grain Yield and Quality

Machine harvest

Grain yield was substantially reduced by severe yellow spot, with a reduction of 48% in the 'full'-disease Banks and 39% in the diseased Olympic (Table 4). In Banks, the late disease resulted in 35% loss in yield while the early disease caused 12·5% loss. Most of the screenings would be lost during commercial harvesting and, if excluded, the yield loss in the 'full'-disease Banks would be 56%. Hectolitre weight was also reduced in the 'full'- and late-disease Banks (D and C) and in the diseased Olympic (F).

Table 3. Duration (days) of periods from planting to flowering and to crop maturity and duration of the grain-filling period

Treat-ment	Cultivar	Yellow spot	Planting to flowering	Planting to harvest	Grain filling
A	Banks	'nil'	112	161	49
B	Banks	early	116	161	45
C	Banks	late	112	154	42
D	Banks	'full'	117	155	38
E	Olympic	'nil'	118	164	46
F	Olympic	'full'	123	164	41

Table 4. Measurements of grain yield and some components from machine harvest, harvest index and concentrations of nitrogen and phosphorus in grain

Within columns, values with a common superscript do not differ at $P = 0\cdot 05$

Treat-ment	Cultivar	Yellow spot	Grain yield ($g\ m^{-2}$)	Screen-ings[A] ($g\ m^{-2}$)	Hectolitre weight ($kg\ hl^{-1}$)	1000-grain weight (g)	Harvest index (%)	Grain nitrogen (%)	Grain phosphorus (%)
A	Banks	'nil'	551^{b}	$8\cdot 66^{b}$	$80\cdot 3^{a}$	$35\cdot 9^{a}$	$46\cdot 8^{a}$	$2\cdot 34^{b}$	$0\cdot 338^{c}$
B	Banks	early	482^{c}	$15\cdot 0^{b}$	$78\cdot 3^{ab}$	$32\cdot 3^{b}$	$45\cdot 8^{ab}$	$2\cdot 38^{b}$	$0\cdot 340^{c}$
C	Banks	late	356^{e}	$44\cdot 7^{a}$	$72\cdot 1^{cd}$	$24\cdot 5^{d}$	$37\cdot 9^{c}$	$2\cdot 69^{a}$	$0\cdot 408^{b}$
D	Banks	'full'	287^{f}	$46\cdot 4^{a}$	$69\cdot 0^{d}$	$23\cdot 5^{d}$	$36\cdot 0^{c}$	$2\cdot 80^{a}$	$0\cdot 403^{b}$
E	Olympic	'nil'	675^{a}	$7\cdot 16^{b}$	$75\cdot 6^{bc}$	$37\cdot 7^{a}$	$43\cdot 1^{b}$	$2\cdot 35^{b}$	$0\cdot 395^{b}$
F	Olympic	'full'	409^{d}	$16\cdot 1^{b}$	$69\cdot 8^{d}$	$28\cdot 3^{c}$	$35\cdot 9^{c}$	$2\cdot 49^{b}$	$0\cdot 435^{a}$

[A] Screenings through a 2·26-mm triangular sieve. These are included in the grain yield data presented.

Table 5. Measurements of grain yield and its components from plant samples taken at crop maturity

Within columns, values with a common superscript do not differ at $P = 0\cdot 05$

Treat-ment	Cultivar	Yellow spot	Grain yield ($g\ m^{-2}$) 'Main' heads	'Minor' heads	All heads	Grains/head 'Main' heads	'Minor' heads	All heads	1000-grain weight (g) 'Main' heads	'Minor' heads	All heads
A	Banks	'nil'	366^{ab}	273^{a}	639^{a}	$50\cdot 4^{a}$	$32\cdot 9^{a}$	$40\cdot 7^{b}$	$36\cdot 7^{a}$	$32\cdot 7^{a}$	$34\cdot 4^{a}$
B	Banks	early	318^{b}	225^{b}	543^{b}	$52\cdot 5^{a}$	$36\cdot 1^{a}$	$43\cdot 4^{ab}$	$31\cdot 3^{b}$	$27\cdot 3^{b}$	$29\cdot 1^{b}$
C	Banks	late	211^{c}	135^{c}	346^{d}	$44\cdot 4^{b}$	$32\cdot 5^{a}$	$37\cdot 6^{c}$	$24\cdot 3^{c}$	$17\cdot 7^{c}$	$20\cdot 7^{d}$
D	Banks	'full'	202^{c}	125^{c}	327^{d}	$54\cdot 9^{a}$	$35\cdot 7^{a}$	$44\cdot 1^{a}$	$20\cdot 8^{d}$	$16\cdot 9^{c}$	$18\cdot 6^{d}$
E	Olympic	'nil'	370^{a}	274^{a}	644^{a}	$50\cdot 3^{a}$	$36\cdot 2^{a}$	$42\cdot 7^{ab}$	$38\cdot 0^{a}$	$34\cdot 6^{a}$	$36\cdot 2^{a}$
F	Olympic	'full'	241^{c}	199^{b}	440^{c}	$43\cdot 3^{b}$	$31\cdot 3^{a}$	$36\cdot 5^{c}$	$25\cdot 1^{c}$	$24\cdot 8^{b}$	$24\cdot 9^{c}$

Concentrations of nitrogen and phosphorus in the grain were higher in the late- and 'full'-disease Banks (C and D) than in the 'nil'- or early-disease treatments (A and B) (Table 4). However, total grain nitrogen and phosphorus per unit area were reduced by severe yellow spot. Nitrogen and phosphorus concentrations were significantly higher ($P < 0\cdot 05$) in stubble from late-disease plots (0·82 and 0·13% respectively) than from the other Banks treatments (av. 0·69 and 0·054% respectively).

Nitrogen and phosphorus concentrations were higher ($P < 0 \cdot 05$) in the diseased Olympic (0·72 and 0·068% respectively) than in the sprayed treatment (0·56 and 0·031% respectively).

Grain from each plot was examined for the presence of pink grain, but few grains showed distinctive discoloration; no significant differences were evident between treatments.

Plant samples

Grain yield data from the plant samples taken at crop maturity are summarized in Table 5. In Banks, the loss of grain yield due to disease was less for 'main' heads than 'minor' heads (45 and 54% respectively). However, in Olympic, the 'main' heads were more affected than the 'minor' heads (35 and 27% respectively).

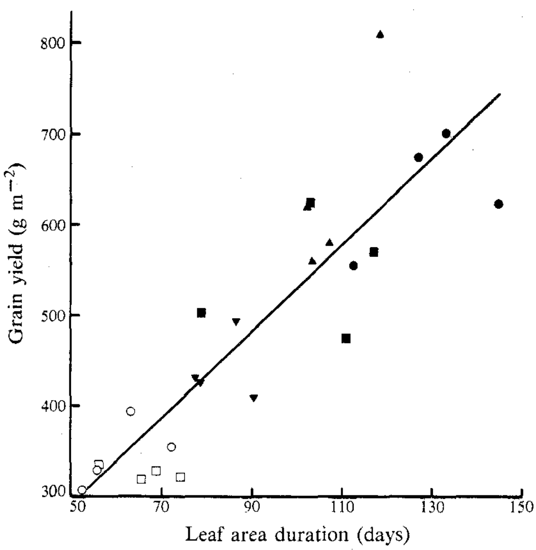

Fig. 2. Relationship between grain yield (from plant samples) and estimated LAD. ● 'nil'-disease Banks (A); ■ early-disease Banks (B); ○ late-disease Banks (C); □ 'full'-disease Banks (D); ▲ 'nil'-disease Olympic (E); ▼ 'full'-disease Olympic (F).

No significant differences ($P < 0 \cdot 05$) were found within cultivars in the number of fertile heads per plant and no distinct trends in spikelet numbers or in grain numbers were detected for Banks. A significant reduction of 4·3% in spikelet number of 'main' heads and 4·6% over all heads was recorded for the diseased Olympic relative to the sprayed treatment. A considerable reduction in grain size caused most of the loss in grain yield, especially from the occurrence of late disease (Table 5).

Relation Between LAD and Grain Yield

Leaf area duration (LAD) was estimated from the LAI at flowering and the duration of the grain-filling period, on assuming a linear decline in LAI. The regression of grain yield against estimated LAD was significant ($b = 4 \cdot 76 \pm 0 \cdot 556$, $r = 0 \cdot 877$, $P < 0 \cdot 001$) (Fig. 2).

Discussion

Severe yellow spot throughout the crop season had pronounced effects on crop development and resulted in a loss of 48% in grain yield in the cv. Banks (Table 4), similar to previous results under conditions favouring crop and disease development

(Rees *et al.* 1982). In this experiment, severe seedling disease resulted in a loss in grain yield of *c.* 13%, or about one-quarter of the total loss in yield. Accordingly, in years where wet conditions after planting promote development of yellow spot, but subsequent dry conditions curtail the disease, losses of up to *c.* 13% could be expected. However, the effect may be greater where tillering is constrained by more severe growing conditions than encountered in this experiment, and where additional reductions in tillering associated with the disease lead to reduced yield.

About three-quarters of the yield loss was a consequence of severe yellow spot after jointing (Table 4). Accordingly, losses from yellow spot are likely to be greater in years where frequent falls of rain occur after jointing rather than before jointing.

The major influence of yellow spot on grain yield was through a reduction of grain size rather than in grain number per unit area (Table 5). This was in spite of the large effect of early disease on tiller number per unit area. The irrigated conditions of this experiment, however, caused an excess production of tillers in the sprayed treatment; some of these later aborted so that final head numbers did not differ between treatments (Fig. 1*a*). The reduction in grain size determined from the machine harvest was slightly less than that derived from the plant samples, probably a result of the loss of small grains through the harvesting machine. No distinct trend in grain numbers was evident with disease timing.

In Banks, the loss in grain yield for 'main' heads was less than the loss for 'minor' heads (Table 5), supporting findings in a previous experiment (Rees *et al.* 1982). However, the loss for 'main' heads of Olympic appeared to be greater than the loss for 'minor' heads.

Severe yellow spot reduced dry weight per unit area by affecting tiller production, tiller size and LAI (Table 2, Fig. 1). As there was very little yellow spot on the top two leaves of Banks when sampled at both growth stages, the reduction in LAI was apparently an effect of earlier disease on lower leaves (Table 2). That is, severe yellow spot early in the crop reduced the subsequent production of leaf material.

The retardation of crop development up to flowering, due to an early severe epidemic of yellow spot (Table 3), has been observed previously (Rees *et al.* 1982), while the hastened maturity associated with severe late disease also occurs with other foliar diseases of wheat, such as rusts (e.g. Rees *et al.* 1979). The reduced grain-filling period resulting from delayed flowering and hastened maturity could reduce grain yield considerably. The effect of disease on leaf area and rate of senescence is integrated in LAD, with the estimated LAD explaining *c.* 77% of the variation in grain yield. While severe yellow spot can result in a substantial reduction in root development (R. G. Rees and G. J. Platz, unpublished data), the end effect of the disease on grain yield appears to be primarily through a reduced 1000-grain weight as a consequence of reduced LAD.

The reduction in hectolitre weight measured for some treatments would have considerable commercial effects, as grain samples below 74 kg hl^{-1} are usually downgraded by the marketing authority in Queensland. Thus the value of the grain from the 'full'-disease and late-disease Banks was reduced.

The cv. Olympic was included because preliminary examination had shown that *P. tritici-repentis* produced smaller lesions on it than on Banks. However, under wet conditions in the field, severe general leaf chlorosis occurred in Olympic. The rapid development of the chlorosis followed by collapse of the tissues suggested the possibility of a toxin being involved in the reaction. While the disease development and yield loss were less in Olympic than in Banks, they were still considerable and the degree of resistance in Olympic would be commercially inadequate. Fortunately, more effective sources of resistance have been identified (da Luz and Hosford 1980; R. G. Rees and G. J. Platz, unpublished data), and resistance is being incorporated into wheats suitable for the prime-hard wheat areas of Australia.

Acknowledgments

Concentrations of nitrogen and phosphorus in grain and stubble were determined by staff of the Agricultural Chemistry section of this Institute. We are also grateful to D. R. Woodruff and R. J. Mayer for helpful discussions and suggestions. This study was supported by the Australian Wheat Industry Research Council.

References

James, W. C. (1971). An illustrated series of assessment keys for plant diseases, their preparation and usage. *Can. Plant Dis. Surv.* **51**, 39–65.

Klein, T. A., and Ellison, F. W. (1982). The occurrence and significance of *Pyrenophora tritici-repentis* in the eastern wheat belt of Australia. In 'Proceedings of Tan Spot of Wheat and Related Diseases Workshop'. North Dakota State University, Fargo, U.S.A., July 1981. pp. 71–5.

da Luz, W. C., and Hosford, R. M. (1980). Twelve *Pyrenophora trichostoma* races for virulence to wheat in the Central Plains of North America. *Phytopathology* **70**, 1193–6.

Rees, R. G., Mayer, R. J., and Platz, G. J. (1981). Yield losses in wheat from yellow spot: a disease-loss relationship derived from single tillers. *Aust. J. Agric. Res.* **32**, 851–9.

Rees, R. G., and Platz, G. J. (1979). The occurrence and control of yellow spot of wheat in north-eastern Australia. *Aust. J. Exp. Agric. Anim. Husb.* **19**, 369–72.

Rees, R. G., Platz, G. J., and Mayer, R. J. (1982). Yield losses in wheat from yellow spot: comparison of estimates derived from single tillers and plots. *Aust. J. Agric. Res.* **33**, 899–908.

Rees, R. G., Thompson, J. P., and Mayer, R. J. (1979). Slow rusting and tolerance to rusts in wheat. I. The progress and effects of epidemics of *Puccinia graminis tritici* in selected wheat cultivars. *Aust. J. Agric. Res.* **30**, 403–19.

Thorne, G. N. (1966). Physiological aspects of grain yield in cereals. In 'The Growth of Cereals and Grasses'. (Eds F. L. Milthorpe and J. D. Ivins.) pp. 88–105. (Butterworths: London.)

Zadoks, J. C., Chang, T. T., and Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Res.* **14**, 415–21.

Manuscript received 16 July 1982, accepted 1 November 1982