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Yield reduction in wheat in relation to leaf disease from yellow (tan) spot and septoria nodorum blotch

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Abstract

Yellow or tan spot (caused by *Pyrenophora tritici-repentis*) and septoria nodorum blotch (caused by *Phaeosphaeria nodorum*) occur together and are a constraint to wheat yields in Australia. Recently, higher crop yields and lower fungicide costs have made fungicides an attractive management tool against these diseases. Yield-loss under different rates of progress of yellow spot and septoria nodorum blotch was examined in four experiments over three years to define the relationship between disease severity and yield. In these experiments, differences in disease were first promoted by inoculations either with *P. tritici-repentis*-infected stubble or aqueous spore suspensions of *P. nodorum*. Disease progress was further manipulated with foliar application of fungicide. The pattern of disease development varied in each year under the influence of different rainfall patterns. The inoculation and fungicide treatments produced differences in disease levels after flag leaf emergence. The infection of yellow spot or septoria nodorum blotch caused similar losses in grain yield, ranging from 18% to 31%. The infection by either disease on the flag or penultimate leaf provided a good indication of yield-loss. Disease severity on flag leaves during the milk stage of the crop or an integration of disease as area under the disease progress curve on the flag leaves based on thermal time explained more than 80% variance in yield in a simple regression model. The data provided information towards the development of disease management strategies for the control of septoria nodorum blotch and yellow spot.

Abbreviations: AUDPC – area under the disease progress curve; AUD – Australian Dollar.

Introduction

Yellow or tan spot caused by *Pyrenophora tritici-repentis* (anamorph of *Drechslera tritici-repentis*) and septoria nodorum blotch caused by *Phaeosphaeria nodorum* (anamorph of *Stagonospora nodorum*) are a constraint on yields of wheat in Australia and other wheat-growing areas of the world (Shipton, 1971; Wiese, 1987). *P. tritici-repentis* survives on infested stubble and under moist conditions produces pseudothecia. Ascospores produced by pseudothecia initiate the disease (yellow spot) on wheat leaves after rain, with most dispersal occurring within metres of the infested stubble (Rees and Platz, 1980; Rees, 1987). The fungus produces wind-borne asexual conidia on dead leaf tissue, which spread to new crop foliage. Conidia can spread the pathogen to other wheat paddocks (Francl, 1997). *P. nodorum* also survives on infested stubble and produces ascospores from pseudothecia under moist conditions (von Wechmar, 1966); these establish the disease (septoria nodorum blotch) on wheat plants. Ascospores of *P. nodorum* are readily trapped in air currents (Bathgate and Loughman, 2001). On diseased plants, the fungus asexually produces pycnidiospores within minute brown pycnidia in the dead leaf tissue. Pycnidiospores spread to new crop foliage through rain splashes (Faulkner and Colhoun, 1976).

Despite these differences in biology, the two diseases frequently occur together in Western Australia. Disease symptoms caused by both fungi are very similar and sometimes difficult to distinguish. The initial symptoms are yellow flecks on the lower leaves of the plant. These flecks eventually develop into lesions. Under suitable conditions, these pathogens cause dramatic symptoms and can result in substantial losses in both yield and quality through the production of undersized grains, which are shrivelled and have poor colour. In Australia, Shipton (1968) and Rees et al. (1982) attributed 30–50% losses in grain yield of spring wheat to these diseases.

The widespread use of stubble retention and early sowing, as a result of efficient chemical weed control, has favoured these leaf diseases in high rainfall areas of Western Australia (Loughman and Thomas, 1992). Management of these diseases consists of a combination of cultural, agronomic and plant resistance factors. More recently, fungicide use has become an additional management tool. Greater disease pressures, higher crop yields and lower fungicide costs are making fungicides an attractive option for management of these diseases in the low-input production system of Western Australia. Precise identification of crops and conditions likely to provide yield response to fungicide application requires an estimate of the yield-loss resulting from each disease.

This paper describes four experiments conducted in the northern wheat-belt of Western Australia examining yield-loss under different rates of progress of yellow spot and septoria nodorum blotch in wheat. The aim was to study yield-losses resulting from yellow spot and septoria nodorum blotch epidemics and define the relationship between disease severity and yield.

Materials and methods

Four field experiments were conducted over three years. Experiments with yellow spot were conducted in 1997 at Mingenew (50 343894E, 6759400N) and 1999 at Ogilvie (50 287153E, 6882505N). Experiments with septoria nodorum blotch were conducted in 1998 and 1999 at Mingenew. A uniform area free of wheat stubble was selected for the experiments. The previous crop had been grain lupins. In all experiments wheat (cv. Amery, susceptible to both diseases) was planted in eight-row plots ($20 \times 1.8\,m^2$) separated by same-sized barley buffer plots. Each experiment was a randomised block design with six replicates of six treatments.

Different levels of yellow spot were promoted by spreading different rates ($150\,g\,m^{-2}$, $50\,g\,m^{-2}$ or no stubble) of stubble from a crop of wheat (cv. Amery) severely infected by *P. tritici-repentis* during the previous year. Barley stubble was used to bring the total stubble applied to $150\,g\,m^{-2}$, including 'no stubble' plots (i.e. no wheat stubble). Disease progress was further manipulated with foliar application of tebuconazole fungicide (Folicur® 430SC) applied with flat fan nozzles spraying from 50 cm above the crop canopy using $100\,l\,ha^{-1}$ water. Table 1 gives the details of the treatments in 1997 and 1999.

To promote different levels of septoria nodorum blotch among treatments, some plots were inoculated with 10^6 spores ml^{-1} aqueous spore suspensions after crop establishment. Spores were produced on autoclaved wheat grain cultures, then dried and milled for storage at 4 °C prior to use (Fried, 1989). Spore suspensions were amended with 0.5% gelatin as a sticking agent and applied with a motorised backpack mister at a rate of $1\,l\,plot^{-1}$ ($0.03\,l\,m^{-2}$). Inoculation was undertaken in the evening shortly preceding rain. Disease progress was further manipulated with foliar application of fungicide (Folicur® 430SC) applied with flat fan nozzles spraying from 50 cm above the crop canopy using $100\,l\,ha^{-1}$ water. Table 2 gives the details of the treatments in 1998 and 1999.

Disease severity was assessed on five, six and seven occasions at 12–23, 9–13 and 6–14 day interval, respectively, during 1997, 1998, 1999, beginning at the time of the growth stage (GS) 31 (Zadoks et al., 1974). The percentage of the leaf surface covered by lesions of either septoria nodorum blotch or yellow spot, including associated senescence and chlorosis, was estimated on the top three fully expanded leaves (or four where present) on 15 randomly selected main tillers per plot. The disease was assessed from all six replications during 1997, from four replications in 1998 and from three replications in 1999. Only traces of any other diseases occurred in the experiments. Machine-harvested grain yield and components of grain quality (screenings, density and thousand grain weight) were assessed.

The area under the disease progress curves (AUDPC) was calculated using thermal time (degree-days above 0 °C) intended to encompass the natural lifetime of a leaf layer in the lowest diseased treatments. The starting point for this calculation was when approximately 50% of leaves of the represented leaf layer were

Table 1. Treatments applied to wheat (cv. Amery) to manipulate epidemics of yellow spot in experiments at Mingenew in 1997 and Ogilvie in 1999

Year	Treatments	Wheat straw[1]		Fungicide[2]	
		Rate ($g\,m^{-2}$)	Growth stage[3] (GS)	Rate ($ml\,ha^{-2}$)	Growth stage[3] (GS)
1997	High inoculum	150	15	Nil	
	High inoculum + fungicide	150	15	145	39
	Low inoculum	50	15	Nil	
	Low inoculum + fungicide	50	15	145	39
	Natural disease	Nil		Nil	
	Lowest disease	Nil		290	39; 65
1999	High inoculum	150	15	Nil	
	High inoculum + fungicide	150	15	145	39
	Low inoculum	50	15	Nil	
	Low inoculum + fungicide	50	15	145	31
	Natural disease	Nil		Nil	
	Lowest disease	Nil		290	31; 39; 57

[1]In plots receiving $<150\,g\,m^{-2}$ wheat straw, barley straw was applied to make up total mass to $150\,g\,m^{-2}$.
[2]Folicur® 430SC applied with flat fan nozzles spraying from 50 cm above the crop canopy using $100\,l\,ha^{-1}$ water.
[3]Growth stage (GS) of wheat when treatment applied.

Table 2. Treatments applied to wheat (cv. Amery) to manipulate epidemics of septoria nodorum blotch in experiments at Mingenew in 1998 and 1999

Year	Treatments	Inoculation[1]		Fungicide[2]	
		Rate ($l\,m^{-2}$)	Growth stage[3] (GS)	Rate ($ml\,ha^{-2}$)	Growth stage[3] (GS)
1998	High inoculum	0.03	15; 31	Nil	
	Inoculum + half fungicide	0.03	15; 31	72	31
	Inoculum + fungicide	0.03	15; 31	145	39
	Natural disease	Nil		Nil	
	Natural disease + fungicide	Nil		145	31
	Lowest disease	Nil		145	31; 39; 55
1999	High inoculum	0.03	31	Nil	
	Inoculum + half fungicide	0.03	31	72	32
	Inoculum + fungicide	0.03	31	145	39
	Natural disease	Nil		Nil	
	Natural disease + fungicide	Nil		145	32
	Lowest disease	Nil		290	32; 39; 55

[1]Inoculated with 10^6 spores ml^{-1} aqueous spore suspensions.
[2]Folicur® 430SC applied with flat fan nozzles spraying from 50 cm above the crop canopy using $100\,l\,ha^{-1}$ water.
[3]Growth stage (GS) of wheat when treatment applied.

fully extended. The AUDPC was calculated by trapezoidal integration (Campbell and Madden, 1990) over n observations as:

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{X_i + X_{i-1}}{2} \right) (t_{i+1} - t_i)$$

where X is the disease severity (in percentage) and t is the thermal time on which the disease severity observation was taken; $t = 0$ on day when 50% of the leaves of a particular leaf layer were fully expanded. Analysis of variance was used to examine the effects of inoculation and fungicide on disease and yield. Simple regression or multiple linear regression was used to examine the relationships between yield and disease severity at critical growth stages of the crop and AUDPC. Data from individual plots were used in the regression analysis.

Results

Relation of disease to inoculation and fungicide application

In experiments with yellow spot, treatment effects on disease were observed after flag leaf emergence (GS39) during 1997 and during jointing (GS31) during 1999 (Table 3). In experiments with septoria nodorum blotch, treatment effects on disease were observed during jointing (GS31) in 1998 and after flag leaf emergence (GS39) during 1999. The effects persisted during grain filling.

Patterns of disease and yield effects

Disease development on different leaf layers varied greatly between seasons (Figure 1). Yield loss relative to the lowest disease treatment was calculated (Table 4). In 1997, very little yellow spot developed on the upper three leaves until after flag leaf emergence. Wet weather, approximately 2 weeks after flag emergence, promoted the yellow spot development on these leaves during the grain filling period and 19% yield-loss was recorded (Table 4). In 1998, severe septoria nodorum blotch developed on the third and fourth topmost leaves because of frequent rains during stem elongation. However, after flag leaf emergence, septoria nodorum blotch development was subsequently reduced because of dry conditions and 18% yield-loss was recorded. In 1999, disease development was favoured by frequent rainfall and both yellow spot and septoria nodorum blotch development continued to high levels in respective experiments where 29–31% yield-losses were recorded (Table 4). Infection with either yellow spot or septoria nodorum blotch affected grain quality by increasing the screenings and reducing the grain density and grain weight (Table 4).

Relation of yield to disease

Disease on the top two leaves was consistently related to the yield in these experiments. In a simple linear regression model of disease severity on either the flag or penultimate leaf with yield, disease severity at milk stage (GS73–77) of the crop accounted for the larger variance in yield than disease severity at any other occasion in all the experiments (Table 5). A multiple regression model using various combinations of disease severity at different growth stages either on the same or different leaf layers did not significantly improve the relationship. The disease on the top two leaves at the same stage of growth is not independent and in

Table 3. Effect of inoculation and fungicide treatments on average disease severity (% leaf area diseased) on top leaves of wheat (cv. Amery) at different growth stages, in experiments with yellow spot (YS) in 1997 and 1999 and septoria nodorum blotch (SNB) in 1998 and 1999

Treatments[1]	Leaf area diseased (%)									
	1997 (YS)					1999 (YS)				
Growth stage (GS)	31[2]	39[2]	59[3]	69[3]	77[4]	31[2]	39[2]	69[2]	73[3]	77[4]
High inoculum	2	21	31	41	76	14	38	68	83	92
Low inoculum	4	16	26	43	72	14	24	58	79	90
Low inoculum + fungicide	6	18	18	33	62	9	24	53	71	87
Natural disease	3	15	22	35	69	8	21	58	75	90
High inoculum + fungicide	5	18	19	33	63	15	33	55	73	80
Lowest disease	4	17	16	24	48	9	17	44	47	40
$LSD_{0.05}$	ns	3.7	5.0	5.3	8.0	4.2	8.9	7.9	7.3	11.5
	1998 (SNB)					1999 (SNB)				
	31[2]	39[3]	65[3]	71[3]	83[4]	31[2]	39[2]	65[2]	71[3]	77[3]
High inoculum	26	38	61	81	73	11	32	54	63	100
Inoculum + half fungicide	22	43	61	80	72	8	18	35	38	83
Inoculum + fungicide	23	44	56	70	52	7	34	47	47	72
Natural disease	8	26	46	68	69	8	29	49	45	80
Natural disease + fungicide	5	23	36	61	64	10	27	46	57	98
Lowest disease	14	20	29	55	53	7	15	33	24	44
$LSD_{0.05}$	7.1	11.8	8.8	7.6	9.5	ns	5.7	8.0	6.3	8.5

[1]See Tables 1 and 2 for treatment details.
Average severity on top [2]four, [3]three or [4]two leaves.

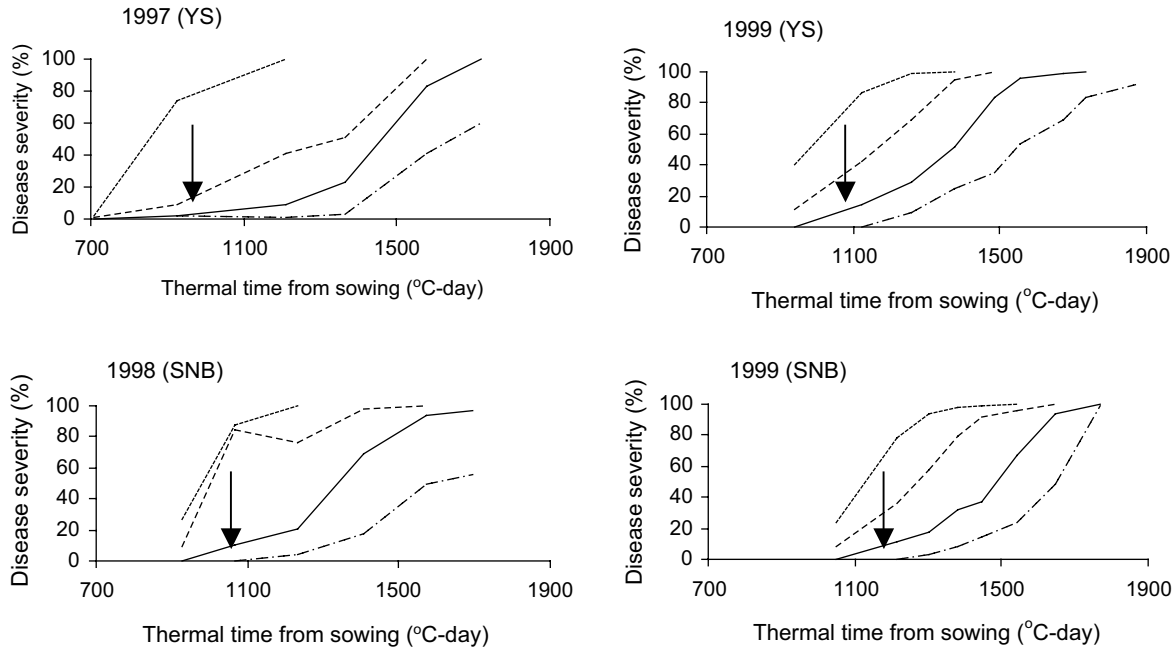

Figure 1. Disease progress curves showing % diseased area on leaves in high inoculum treatment of yellow spot (YS) in 1997 and 1999 and septoria nodorum blotch (SNB) in 1998 and 1999. Arrows indicate the time when 50% flag (F) leaves were fully expanded. –·–·– Flag leaf; —— F-1; – – – F-2; - - - - F-3.

Table 4. Effect of different levels of disease as a result of inoculation and fungicide treatments on grain yield and quality components of wheat (cv. Amery) in four experiments, two each for yellow spot (YS) and septoria nodorum blotch (SNB)

Treatments[1]	1997 (YS)					1999 (YS)			
	Yield ($t\,ha^{-1}$)	Yield loss (%)	S^2	TW[2]	TGW[2]	Yield ($t\,ha^{-1}$)	Yield loss (%)	S^2	TW[2]
High inoculum	2.36	19	3.2	70.9	34.8	1.80	29	2.0	79.8
High inoculum + fungicide	2.74	7	2.6	73.1	38.4	2.07	19	1.2	79.5
Low inoculum	2.46	16	3.1	70.5	34.6	2.11	17	1.9	79.2
Low inoculum + fungicide	2.72	6	2.3	73.3	40.0	2.12	17	1.6	79.9
Natural disease	2.66	9	2.9	72.2	36.3	1.98	22	2.0	78.9
Lowest disease	2.93	—	2.0	74.3	41.1	2.55	—	0.5	82.1
$LSD_{0.05}$	0.20		0.4	0.6	2.3	0.10		0.5	0.1
	1998 (SNB)					1999 (SNB)			
High inoculum	3.40	18	2.0	76.7	36.1	2.46	31	2.5	78.1
Inoculum + half fungicide	3.43	17	1.5	77.3	39.3	3.09	13	1.1	81.7
Inoculum + fungicide	3.74	10	1.0	79.2	42.2	2.95	17	1.3	80.8
Natural disease	3.73	10	1.3	78.0	40.0	2.63	26	1.9	80.3
Natural disease + fungicide	3.94	5	1.2	79.0	43.1	3.03	14	1.3	81.5
Lowest disease	4.14	—	0.9	79.6	45.1	3.54	—	0.7	83.4
$LSD_{0.05}$	0.30		0.4	0.7	1.9	0.23		0.2	0.8

[1]See Tables 1 and 2 for treatment details.
[2]S denotes screenings (%) through 2.5 mm sieve; TW denotes test weight ($kg\,hl^{-1}$) and TGW denotes thousand grain weight (g).

our studies was highly correlated ($R^2 = 0.65$–0.90). Therefore, in further analysis, disease on flag leaf on its own was used to define the relation between disease and yield.

Linear regression of yield *versus* disease severity on flag leaf at milk stage of the crop using pooled data from all four experiments accounted for 84.7% variance in yield when different intercept and slopes

Table 5. Parameters of simple linear regression between grain yield and disease severity on top two leaves at critical crop growth stages of wheat (cv. Amery), infected with yellow spot (YS) in 1997 and 1999 or septoria nodorum blotch (SNB) in 1998 and 1999

Year	Leaf layer	At milk stage		At other occasions	
		Variance accounted for	*F* probability	Variance accounted for	*F* probability
1997 (YS)	Flag (F)	58.0	<0.001	10.4–37.0	<0.001–0.033
	F-1	38.0	<0.001	34.0–34.8	<0.001
1999 (YS)	Flag (F)	74.2	<0.001	20.5–70.5	<0.001–0.034
	F-1	84.9	<0.001	45.8–56.3	<0.001
1998 (SNB)	Flag (F)	36.6	0.001	6.5–33.6	0.002–0.121
	F-1	56.4	<0.001	13.9–48.4	<0.001–0.041
1999 (SNB)	Flag (F)	71.4	<0.001	41.0–62.2	<0.001–0.003
	F-1	66.6	<0.001	42.1–60.4	<0.001–0.002

Table 6. Parameters of simple linear regression of pooled data on grain yield and disease severity on flag leaf at milk stage of crop growth of wheat (cv. Amery), infected with yellow spot (YS) in 1997 and 1999 or septoria nodorum blotch (SNB) in 1998 and 1999

Experiment	Intercept		Slope	
	Estimate	Standard error	Estimate	Standard error
1997 (YS)	3.171	0.075	−0.015	0.002
1999 (YS)	2.289	0.155	−0.008	0.003
1998 (SNB)	3.019	0.124	−0.011	0.002
1999 (SNB)	3.008	0.125	−0.011	0.003

*df = 88.

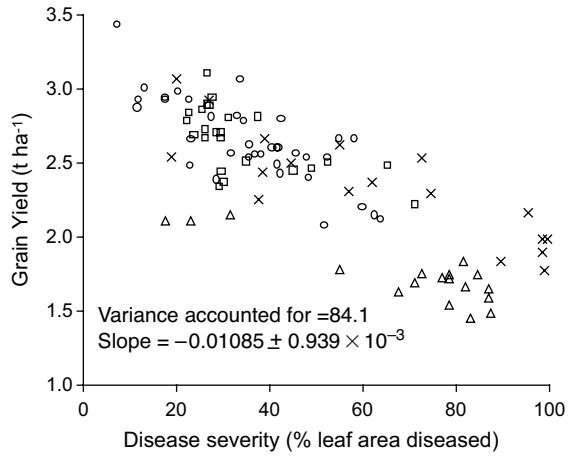

Figure 2. Relationship between grain yield and disease severity on flag leaf at milk stage of crop growth of wheat, infected with yellow spot (YS) in 1997 and 1999 and septoria nodorum blotch (SNB) in 1998 and 1999. ○ 1997(YS); □ 1998(SNB); △ 1999(YS); × 1999(SNB).

(separate lines) for each experiment were allowed in the model (Table 6). The slopes were not significantly different for the four experiments ($P = 0.109$) but there was a significant difference between intercepts ($P < 0.001$). Regression with different intercepts for each site and a common slope (-0.0108 ± 0.0009) accounted for 84.1% of the variance in yield (Figure 2).

Integral model

A linear regression of yield *versus* AUDPC on the flag leaf using pooled data from all four experiments accounted for 85.6% variance in yield when different intercepts and slopes (separate lines) for each experiment were allowed in the model (Table 7). The slopes and intercepts were significantly different ($P < 0.001$). When regression with common slope ($-0.436 \times 10^{-4} \pm 0.04 \times 10^{-4}$) but different intercepts was used, AUDPC on flag leaf still accounted for 82.9% variance in yield (Figure 3).

Discussion

Slight or no significant differences in disease were observed between plots until the jointing stage during all three years. It is therefore not possible to infer the effect of early season infection on disease development. In Western Australian farming systems, wheat is mostly rotated with non-cereal crops or pastures. In this environment, crop rotations as short as one year can contribute greatly to control of yellow spot and septoria nodorum blotch by greatly reducing early infection from local carry-over (Bhathal and Loughman, 2001). Furthermore, in yield-loss experiments, Thomas et al. (1989) showed that infection

Table 7. Parameters of simple linear regression of pooled data on grain yield and area under disease progress curve (AUDPC) for flag leaf of wheat (cv. Amery), infected with yellow spot (YS) in 1997 and 1999 or septoria nodorum blotch (SNB) in 1998 and 1999

Experiment	Intercept		Slope	
	Estimate	Standard error	Estimate	Standard error
1997 (YS)	3.758	0.143	-0.808×10^{-4}	0.102×10^{-4}
1999 (YS)	2.551	0.234	-0.281×10^{-4}	0.120×10^{-4}
1999 (SNB)	3.648	0.227	-0.425×10^{-4}	0.116×10^{-4}
1998 (SNB)	3.765	0.290	-0.530×10^{-4}	0.157×10^{-4}

*df = 88.

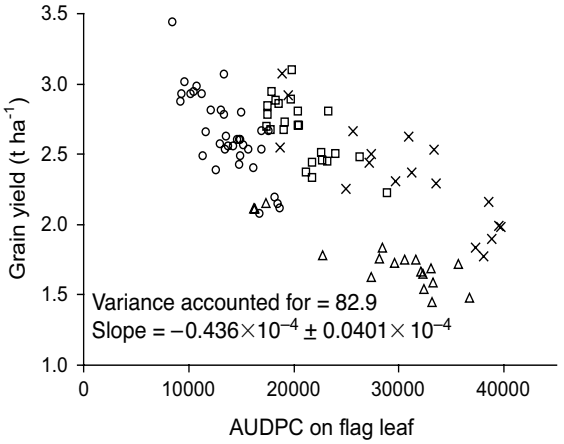

Figure 3. Relationship between grain yield and area under disease progress curve (AUDPC) on flag leaf of wheat, infected with yellow spot (YS) in 1997 and 1999 and septoria nodorum blotch (SNB) in 1998 and 1999. ○ 1997(YS); □ 1998(SNB); △ 1999(YS); × 1999(SNB).

of septoria throughout the period from seedling emergence until GS31 had no detrimental effect on yield. Disease development later in the crop's life was most relevant for this study.

The pattern of disease development in the four field experiments varied in each year under the influence of different rainfall patterns. In 1997, very little disease developed until flag leaf emergence after which disease developed rapidly. In contrast, disease developed rapidly before flag leaf emergence and thereafter developed very gradually during 1998. The disease development was continuous during 1999. These disease patterns represent a broad range of seasonal conditions. This makes the results of practical value to the economics of disease-induced yield-loss.

The inoculation and fungicide treatments successfully achieved differences in disease levels after flag leaf emergence in all the experiments. Under these differences, yellow spot and septoria nodorum blotch caused similar losses in grain yield. In 1999, when the disease development was continuous due to favourable conditions, both diseases caused around 30% loss in grain yield. In situations when conditions were favourable for disease development in only part of the growing season, either before or after flag leaf emergence, yellow spot in 1997 and septoria nodorum blotch in 1998 caused around 20% loss in grain yield of wheat. The losses were similar to those reported from septoria diseases in field experiments in Australia (Shipton 1968; Loughman and Thomas, 1992). Considerably higher losses (49%) in grain yield due to yellow spot infection are reported under conditions very favourable (sprinkler irrigation) for development of both crop and disease (Rees et al., 1982).

A single application of triazole-based fungicide (tebuconazole, flutriafol or propiconazole) applied at 62 g ha^{-1} of active ingredient during flag leaf emergence stage of the crop is a commercial practice to control septoria nodorum blotch and yellow spot in Western Australia. The effect of a single application of Folicur® 430SC applied at GS39 at the rate of 145 ml ha^{-1} (representing commercial practice) on disease control and grain yield can be measured in these experiments by comparing the high disease treatment with that of inoculum plus fungicide treatment in each experiment. This fungicide treatment provided partial control of both diseases and resulted in 0.3–0.5 t ha^{-1} yield increase and provided an estimated profit of AUD22-60 ha^{-1} considering current farm gate price of wheat as AUD175 t^{-1} and cost of fungicide treatment as AUD25 ha^{-1}.

Madden (1983) summarized the concepts in measuring, modelling and predicting losses caused by plant diseases. He categorized regression models for crop loss as those using single or multiple independent

variables. Models with a single predictor (one independent variable) relate yield to either disease intensity at a particular time or time at which a certain level of disease is reached, or AUDPC which integrates the level of disease for a time period of the epidemic. Multiple predictors in crop loss models include levels of disease intensity at several times, other epidemic characteristics such as time of epidemic onset and rate of increase and disease levels in combination with other crop characteristics. Shaw and Royle (1989) used a new method of analysis to predict yield from the integral of disease severity over the normal lifetime of each leaf, measured in thermal time.

In this work, regression analysis was used to quantify the relationship between disease and yield. The results indicate that the infection of yellow spot and septoria nodorum blotch on the flag or penultimate leaf are good indicators of yield-loss. King et al. (1983) also indicated that yield-loss by septoria diseases is explained by infection of the flag or second leaf.

Disease severity on the flag leaf during milk stage of the crop or an integration of disease as AUDPC on the flag leaf based on thermal time best explained the relationship. Either measurement accounted for more than 80% of the variance in yield. Teng (1985) suggests that a problem with models which rely solely on the quantification of visible disease symptoms is that they do not take account of variations in growing conditions which occur between sites and seasons, and these can affect yield potential as well as disease progress. However, in the regression between yield and disease on the flag leaf at milk stage from our experiments there is no significant difference in slopes between sites, suggesting that yield response to disease is independent of disease type (yellow spot and septoria nodorum blotch), sites and years. Additionally, the regression between yield and AUDPC for the flag leaf using a model with a common slope still accounts for more than 80% of variance in yield. The fact that the use of a common slope in either model resulted in very little reduction of yield variance is an important finding from this work. To accommodate differences in yield potential we allowed different intercepts in the regression models. Also, here we are more interested in the slope of the regression line than the intercept as the slope can be used to derive yield-loss.

Using the relationship between disease severity and yield, the gain in yield as a result of fungicide treatment can be estimated as:

$$Y_t - Y_u = b(D_t - D_u)$$

where Y_t is the yield from a fungicide-treated area and Y_u is yield from an untreated area; D_t is the disease severity on the flag leaf at milk stage of the crop or the disease indices (AUDPC over the normal lifetime of the leaf, measured in thermal time) in a fungicide-treated area and D_u is from an untreated area; 'b' is constant (slope of the regression line and its value is $-0.01085 \pm 0.939 \times 10^{-3}$ for the disease severity model and $-0.436 \times 10^{-4} \pm 0.0401 \times 10^{-4}$ for the AUDPC model.

These relationships provide the information required to make an optimal fungicide control decision for the management of septoria nodorum blotch and yellow spot in wheat.

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