Impact of Diseases on Wheat Yields in Idaho's Kootenai Valley in 1981

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ABSTRACT

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About 10,000 A (4,050 ha) of winter wheat is grown annually in a disease-prone environment in Idaho's Kootenai River Valley. In the spring of 1981, fungicide sprays were applied to replicated plots within selected winter wheat fields spaced along the 20-mi. (32.2-km) valley floor. The objective was to selectively control portions of the anticipated disease syndrome, measure any resultant change in disease and yield levels, and quantify the wheat yield loss in the valley attributable to diseases individually and collectively. In 1981, foot rot, powdery mildew, leaf rust, tan spot, sharp eye spot, and stem rust developed in control plots. Preferential control of foot rot and tan spot with benomyl applied in early spring and selective control of leaf rust and powdery mildew (with butrizol and ethirimol, respectively) increased yields from 73 bu/A (4,906 kg/ha) to 84 (5,645), 78 (5,242), and 74 bu/A (4,973 kg/ha), respectively. A repeated benomyl and triadimefon spray treatment controlled foot rot, leaf rust, and tan spot and increased yield to 96 bu/A (6,451 kg/ha). Significant negative correlations between yield and foot rot, leaf rust, tan spot, and sharp eye spot were uncovered. The impact of diseases on yield also was investigated using stepwise multiple linear regression equations that described yield as a function of one or more diseases and disease levels. Total yield loss due to disease was 23 bu/A (1,546 kg/ha) when measured in the field and 38 bu/A (2,554 kg/ha) when estimated from multiple linear regression equations.

Additional key words: crop loss assessment, disease measurement, disease stress, yield loss assessment

The impact of diseases on crop yields across large production areas is difficult to assess (9). Survey and measurement of one or more diseases relative to crop yield over time and space is costly and infrequently done. Nevertheless, the impact of diseases as yield-determining variables in commercial crop settings remains a fundamental concern.

As a case in point, disease symptoms occur each year on winter wheat grown in the Kootenai Valley in northern Idaho. About 10,000 A (4,050 ha) of winter wheat are grown annually in this valley, which is about 3 mi. (4.8 km) wide by 20 mi (32.3 km) long. The valley, divided by the Kootenai River and bounded by mountains, is prone to late sunrises, early sunsets, high relative humidity, and cool night temperatures. Powdery mildew (*Erysiphe graminis* f. sp. *tritici*), leaf rust (*Puccinia recondita* f. sp. *tritici*), stem rust (*P. graminis* f. sp. *tritici*), and/or stripe rust (*P. striiformis*) (5) occur most frequently and, in recent years, tan spot (*Pyrenophora trichostoma*), foot rot (*Pseudocerosporella herpotrichoides*), and sharp eye spot (*Rhizoctonia solani*) (5–7) also have been identified in the valley.

This report describes an attempt to measure naturally occurring plant diseases relative to crop yields within a large production area. It describes an investigation of wheat diseases within Idaho's Kootenai Valley in 1981. It involves selection of sample sites within the production area and use of fungicides to reduce or eliminate different portions of a naturally occurring disease syndrome. Finally, it attempts to quantify the wheat yield losses imposed by diseases in the valley. Toward this end, the yield response associated with induced disease reduction at each sample site is measured. The individual and collective impacts of diseases on yield are calculated from field data and projected from multiple linear regression equations that describe yield as a function of the different disease levels present (3,6,7). The equations have the general form $y=b_0+b_1x_1+b_2x_2+\ldots b_nx_n$, where y is the predicted yield, b_0 is the intercept, and $x_1, x_2, \ldots x_n$ are diseases having partial coefficients $b_1, b_2, \ldots b_n$, respectively.

MATERIALS AND METHODS

Selection of sample sites. Sample sites for collection of disease and yield data were selected within existing winter wheat (*Triticum aestivum* L.) fields in Idaho's Kootenai Valley in March 1981. Because resources did not permit sample sites to be numerous, the valley was scouted and six representative winter wheat fields were selected on the basis of location and cultivar. The fields were spaced along the valley floor between Bonners Ferry, ID, and the Canadian border. In order to approximate the cultivar composition of the valley's winter wheat crop, three of the selected wheat fields were cultivar Stephens (CI 017596), two were cultivar Daws (CI 017419), and one was cultivar Weston (CI 017727).

In each selected field, an accessible site showing a uniform wheat stand was chosen in which 24 plots 4 ft (1.22 m) wide by 20 ft (6.1 m) long were delimited by 3-ft (0.91-m) alleys in a 6 × 4 configuration. Six fungicide treatments (Table 1) were applied as foliar sprays in 25 gal water per acre (234 L/ha). Treatments were replicated four times in the same randomized complete block design at each field site.

Disease and yield measurement. During visits to each field site in May, June, and July 1981, the spectrum of developing diseases was noted. After heading on 17–19 July at growth stage 85 (8), the predominant disease symptoms were identified (5) and rated (2).

Foot rot was evaluated by uprooting 50 culms at random from each plot, removing all leaf sheaths from the base of each culm, and recording the number of culms bearing foot rot lesions relative to the total number of culms examined. Superficial foot rot lesions (penetrating only leaf sheaths) were ignored and lesions on culms were not differentiated by size. When this process of culm examination revealed sharp eye spot lesions, the percentage of culms with sharp eye spot lesions was similarly recorded. Lodging of tillers, often a consequence of foot rot, did not occur. Whiteheads were visible, however, and their number per 12 ft (3.7 m) of row was recorded in each plot as a general indicator of disease stress.

Foliar diseases were evaluated visually and collectively on leaf blades comprising the upper half of the crop canopy (two or three uppermost leaves) in each plot. Viewing each entire plot, the percentage of the total surface area of these upper leaf blades that was occupied by disease symptoms was scored by two independent observers on a percentage scale ranging from 0 to 99 (2). This total percentage then was partitioned among the individual foliar diseases present. In all cases, an average of the independent percentage ratings of two observers was calculated,

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recorded, and used in analyses.

On 16 September, after the wheat at all sample sites had matured (growth stage >92), all plots were harvested with a Hage self-cleaning plot combine equipped with a 4-ft (1.22-m) cutting bar. The harvested seed from each plot was placed in coded paper bags, stored 10 days at 20 C and 20% RH in the laboratory, and weighed to the nearest gram. Test weights were determined as described previously (4).

Disease and yield data were summarized and analyzed using standard *t* tests and correlation and regression (general linear model) techniques (1).

RESULTS

Each of the chemical treatments applied increased both seed yield and test weight (Table 2). Only ethirimol failed to increase mean yield and test weight significantly; however, powdery mildew, its target disease (Table 1), was of minor consequence (Table 2).

The early-spring (14 May) application of benomyl increased yields by 11 bu/A (739 kg/ha) and reduced foot rot from 6 to 3% and tan spot from 50 to 41% (Table 2). Sharp eye spot levels were low and unaffected by any chemical treatment (Table 2).

The principal foliar diseases that developed in control plots in the Kootenai Valley in 1981 were leaf rust and tan spot (Table 2). Although stripe rust, stem rust, and powdery mildew were anticipated, stripe rust did not develop and stem rust and powdery mildew were confined to sparse colonies on the lower half of culms. Over all sites, leaf rust symptoms occupied nearly one-quarter of the surface of upper leaves. Leaf rust was reduced significantly by butrizol (Indar), triadimefon (Bayleton), and benomyl-triadimefon treatments (Table 2). Tan spot was marginally but significantly reduced by benomyl and/or triadimefon but unaltered by ethirimol and butrizol (Table 2).

Correlation analyses between all paired combinations of disease, yield, and test weight variables revealed that yield and test weight were positively correlated with each other and inversely related to disease ratings (Table 3). Over all treatments and sites, levels of foot rot and whiteheads were positively and significantly correlated with each other and with the severity of tan spot and leaf rust (Table 3). In control plots, however, where diseases were not manipulated, no significant correlations between disease levels were uncovered.

The yield increases realized by the various disease control treatments (Table 2, Fig. 1, measured) indicated that the inherently low level of powdery mildew provoked a nonsignificant yield loss of 1 bu/A (67 kg/ha). On the other hand, the selective reduction of leaf rust from 21 to 8% of leaf area caused a 5-bu/A (336-

Table 1. Disease control treatments applied as foliar sprays to replicated winter wheat plots at six locations in Idaho's Kootenai Valley in 1981

		Application[a]	
Chemical treatment	**Target diseases(s)**	**Rate**	**Date(s)[b]**
None (control)			
Benomyl	Food rot	0.5 lb/A (561 g/ha)	14 May
Ethirimol	Powdery mildew	0.3 lb/A (354 g/ha)	14 May 18 June 4 July
Butrizol	Leaf rust	4 fl oz/A (0.45 L/ha)	14 May 18 June 4 July
Triadimefon	Rusts	2 fl oz/A (0.23 L/ha)	14 May 18 June 4 July
Triadimefon + benomyl	Foot rot Foliar diseases	2 fl oz/A (0.23 L/ha) +0.5 lb/A (561 g/ha)	14 May 18 June 4 July

[a] All chemicals applied in water at 25 gal/A (234 L/ha).

[b] Growth stages (8) on 14 May, 18 June, and 4 July were 32–41, 59–68, and 73, respectively.

Table 2. Mean yield[a] and disease levels[b] resulting from differential disease control treatments within six winter wheat fields within Idaho's Kootenai Valley in 1981

	Chemical treatment					
	Control	**Benomyl**	**Ethirimol**	**Butrizol**	**Triadimefon**	**Triadimefon + benomyl**
Seed yield						
(bu/A)	73.0	84.0[c]	74.0	78.0[c]	86.0[c]	96.0[c]
(kg/ha)	4,906.0	5,645.0[c]	4,973.0	5,242.0[c]	5,779.0[c]	6,451.0[c]
Test weight						
(lb/bu)	54.3	55.8[c]	54.9	55.4[c]	56.5	57.6[c]
(g/L)	700.0	719.0[c]	707.0	714.0[c]	728.0	742.0[c]
Disease levels (%)						
Leaf rust	21.0	23.0	22.0	8.0[c]	7.0[c]	8.0[c]
Foot rot	6.0	3.0	5.0	7.0	5.0	2.0[d]
Sharp eye spot	5.0	4.0	5.0	5.0	3.0	6.0
Tan spot	50.0	41.0[d]	47.0	52.0	39.0[c]	28.0[c]
Powdery mildew	t	t	t	t	t	t
Stem rust	t	t	t	t	t	t
Whiteheads[e]	13.0	12.0	13.0	14.0	12.0	8.0

[a] Mean seed yield and test weight from four replicate plots (4 × 20-ft [1.22 × 6.09-m]) in each of six fields.

[b] Foot rot and sharp eye spot measured as percentage of culms with lesions. Leaf rust and tan spot measured as percentage of leaf surface occupied by each symptom. Powdery mildew and stem rust present only as trace (t) colonies and pustules, respectively, on the lower half of culms.

[c] Significantly differs from control at $P = 0.01$.

[d] Significantly differs from control at $P = 0.05$.

[e] Number per 12-ft (3.7-m) row.

Table 3. Significant relationships between disease and yield levels in winter wheat

	Yield	**Test weight**	**Foot rot**	**Whiteheads**
Test weight	0.3630[a] 0.0001[b] 144[c]			
Foot rot	−0.4651 0.0001 144	−0.2933 0.0004 144		
Whiteheads	−0.4530 0.0001 132	−0.5493 0.0001 132	0.3804 0.0001 132	
Leaf rust	−0.2312 0.0053 144	−0.5158 0.0001 144	0.3397 0.0001 144	0.3297 0.0001 132
Tan spot	−0.5453 0.0001 144		0.3436 0.0001 144	0.3270 0.0001 132
Sharp eye spot	−0.2403 0.0184 96			

[a] Correlation coefficient.

[b] Prob >!R! under HO:RHO = 0.

[c] Observations.

kg/ha) positive yield response (Table 2). The early-season benomyl spray aimed at foot rot (Table 1), but which also reduced tan spot (Table 2), increased yield by 11 bu/A (739 kg/ha). The combination benomyl-triadimefon treatment, applied three times during the growing season to provide comprehensive disease control, boosted yields by 23 bu/A (1,546 kg/ha) to a final yield of 96 bu/A (6,451 kg/ha).

Because the diseases comprising a natural disease complex probably influence yield in an interactive manner, their relative impact may be more accurately represented using multivariate techniques. In this light, a stepwise series of multiple linear regression equations was constructed. Using the entire data set, yield was expressed as a function of one or more diseases and disease levels (Table 4). Stepwise addition of diseases to such yield equations generally increased the coefficient of determination (R^2) and in most cases increased the significance of the included independent disease variables. Up to 71% of the variation in seed yield over all sample sites was explained when yield was expressed as a function of tan spot, foot rot, leaf rust, sharp eye spot, and whitehead levels (Table 4, equation 5). This exercise and the normalized Type IV sums of squares (1) consistently identified tan spot as the primary yield-determining disease (Table 4). Using equation 5 (Table 4) and disease data from control plots, tan spot, leaf rust, and foot rot accounted for yield reductions of 26, 6, and 3 bu/A, respectively (1,747, 403, and 202 kg/ha) (Fig. 1, modeled). Setting all diseases in equation 5 to zero (to create a hypothetical disease-free circumstance) projected a yield of 118 bu/A (7,930 kg/ha) (Fig. 1, modeled).

Table 4. Selected multiple linear regression equations[a] describing yield as a function of one or more diseases

Equation	Intercept (b_0)	Partial correlation coefficient (b_n)	Disease level[b] (x_n)	Significance (P)	SS[c]	R^2
1	103	−0.706	Tan spot	0.001	1.00	0.30
2	99	−0.474	Tan spot	0.001	1.00	
		−0.741	Foot rot	0.001	0.52	0.38
3	101	−0.472	Tan spot	0.001	1.00	
		−0.685	Foot rot	0.001	0.40	
		−0.114	Leaf rust	0.304	0.02	0.38
4	102	−0.415	Tan spot	0.002	1.00	
		−0.679	Foot rot	0.003	0.93	
		−0.547	Sharp eye spot	0.042	0.44	
		−0.145	Leaf rust	0.336	0.09	0.41
5	118	−0.580	Tan spot	0.001	1.00	
		−0.544	Foot rot	0.001	0.30	
		−0.296	Leaf rust	0.008	0.19	
		−0.369	Sharp eye spot	0.080	0.08	
		−0.180	Whiteheads	0.090	0.08	0.71

[a] Equations have the general form $Y = b_0 + b_1x_1, + b_2x_2 \ldots + b_nx_n$, where Y is the predicted yield (bu/A), b_0 is the intercept, and $x_1, x_2 \ldots x_n$ are disease levels with partial coefficients $b_1, b_2 \ldots b_n$, respectively.

[b] Foot rot and sharp eye spot expressed as percentage of tillers with lesions. Leaf rust and tan spot expressed as percentage of leaf surface affected. White heads expressed as number per 12-ft (3.7-m) row.

[c] Normalized Type IV sums of squares (1).

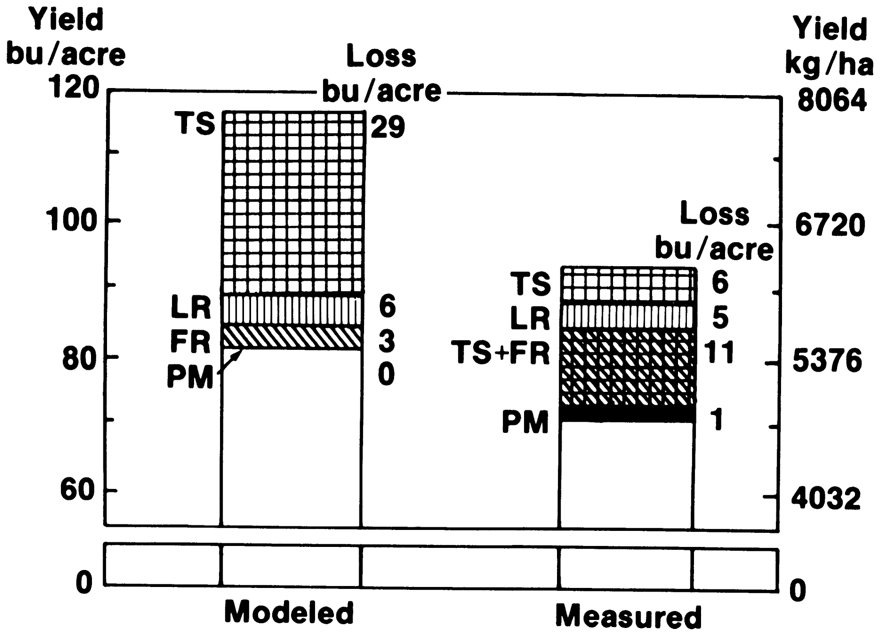

Fig. 1. Additive (measured) and interactive (modeled) representation of the yield losses in winter wheat imposed by a complex of four diseases: TS = tan spot, LR = leaf rust, FR = foot rot, and PM = powdery mildew.

DISCUSSION

This study attempted to quantify the yield losses imposed by diseases individually and collectively within a large crop production area. The study was successful in that differential disease control was achieved and measurable positive yield responses resulted (Table 2). Also, by replicating the disease control treatments within sample sites and replicating sample sites within the production area, sufficient yield and disease data were obtained for yield loss approximation (Table 3) and yield model generation (Table 4).

The data used to assess yield losses due to diseases over a 10,000-A (4,050-ha) crop production area were generated using uncomplicated techniques and at reasonable cost. The techniques, however, have limitations. First, it must be assumed that the selected field sites were representative of the 10,000-A (4,050-ha) winter wheat production area in question. Second, tools to selectively reduce or eliminate portions of natural disease complexes are not readily available. In this study, selective disease suppression was achieved only with leaf rust and powdery mildew and the yield of disease-free plants was not realized. The benomyl-triadimefon treatment, though relatively comprehensive, did not provide complete disease control (Table 2). Furthermore, the hormonal nature of benomyl and triadimefon, albeit modest, may have spurred yield increases apart from any disease control.

In spite of these limitations, the assessments herein of wheat yield losses attributable to the disease complex and to its components in the Kootenai Valley in 1981 (Table 2, Fig. 1) are not without value. The most comprehensive disease control treatment revealed that the 1981 disease syndrome in the valley reduced wheat yields by a minimum of 23 bu/A (1,546 kg/ha). Furthermore, because their symptoms were significantly and negatively correlated with yield (Table 3), it appears that all the measured diseases were yield-limiting.

Although the measured (additive) and modeled (interactive) values for maximum yield (Fig. 1) differ appreciably, the modeled and measured yield responses following selective control of powdery mildew and leaf rust show agreement. When disease control treatments are nonselective, interpretation of specific disease impact is difficult. The impact of foot rot, for example, may be exaggerated in studies that ignore the nonselective nature of benomyl treatments (Table 2). In equation 5 (Table 4), foot rot accounted for a 3-bu/A (202-kg/ha) reduction in yield (Fig. 1, modeled). A less comprehensive field study could erroneously conclude that reducing foot rot levels from 6 to 3% with a spring application of benomyl provoked an 11 bu/A (739 kg/ha) yield increase (Table 2).

The yield models (Table 4) and the sums-of-squares procedure consistently showed tan spot measurements to contain more yield information than any other disease data and assigned little yield value to whiteheads, a nonspecific and perhaps redundant stress symptom (Table 4).

The selective reduction or elimination of portions of a naturally occurring disease complex followed by measurement of resultant disease and yield levels appears to be a legitimate crop loss assessment technique. In this instance, it provided an approximation of the loss imposed by at least four diseases that developed within a large winter wheat production area.

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