Crop Losses Caused by Xanthomonas Streak on Spring Wheat and Barley

W. W. SHANE, Department of Plant Pathology, Ohio State University, Columbus 43210-1087; J. S. BAUMER, Land O'Lakes Research Farm, R.R. 2, Webster City, IA 50595; and P. S. TENG, Department of Plant Pathology, University of Minnesota, St. Paul 55108

ABSTRACT

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The relationship between severity of Xanthomonas streak and yield components of spring wheat was evaluated for plots and modified single tillers (MST). In the MST approach, tillers with similar disease severities were harvested and processed in bulk lots of 10 tillers. In three seasons, a 50% disease severity on the flag leaf resulted in an 8–13% loss in kernel weight; a 100% disease severity on the flag leaf resulted in a 13–34% loss. Disease onset was too late to affect the number of kernels per head. Protein concentration in the grain was positively correlated with disease severity in most years. The MST approach was deemed more efficient than single-tiller or plot methods for determining severity/loss relationships for this disease.

Xanthomonas streak of wheat (*Triticum aestivum* L.) is a bacterial disease caused by *Xanthomonas campestris* pvs. *undulosa* (Jones, Johnson, & Reddy) Dye or *translucens* (Jones, Johnson, & Reddy) Dye (5). The disease has been recognized as a problem on wheat and barley since 1917, when the causal organisms were identified (8,9). Disease symptoms are dark green water-soaking or dark brown streaking of leaves, culms, glumes, and awns (1,8,9). Bacterial ooze is sometimes present on diseased tissues as small yellow droplets or, after drying, as scalelike flakes. Similar symptoms are caused by pathovars of *X. campestris* on rye and triticale (4,15).

Information concerning the effects of Xanthomonas streak or other bacterial foliar pathogens on the performance of grain crops is scanty and for the most part qualitative. Dwarfed heads, shriveled grains, and barren spikelets have been associated with severe symptoms of Xanthomonas streak (8,13). Waldron (14) reported a 10.5% reduction of 1,000-grain weight and a decrease in fertile tillers among F_3 hybrids for diseased wheat compared with less severely affected tillers.

Our objective was to determine the quantitative relationship between severity of Xanthomonas streak and yield components of wheat and barley.

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MATERIALS AND METHODS

Modified single-tiller (MST) studies. The relationships between severity of Xanthomonas streak disease and yield of wheat and barley were studied in naturally infected commercial fields and research plots in Minnesota (Table 1). Individual primary tillers were assessed once for bacterial streak severity at the early milk to soft dough growth stages (decimal codes [DC] 77–83) (16). Each assessed culm was tagged with water-resistant colored tape according to the disease severity on the flag leaf. The following severity classes were used: 0 (0–1.2), 2.5 (1.2–3.7), 5 (3.7–7.5), 10 (7.5–17.5), 25 (17.5–37.5), 50 (37.5–62.5), 75 (62.5–87.5), and 100% (87.5–100) with reference to standard area diagrams for Xanthomonas streak (= black chaff) (6). All plants sampled at one site were within an area 20 × 20 m. The predominant pathogen isolated from wheat and barley leaves with bacterial symptoms during 1981 through 1982 was *X. campestris* pv. *translucens*, whereas *Pseudomonas syringae* pv. *syringae* was encountered only occasionally (11).

At each site, each severity class was represented by about eight groups of 10 heads. At harvest, labeled heads were bulked, dried, and processed in groups of 10 within each severity class. This method will be referred to as an MST approach to distinguish it from the method in which tillers are processed individually (12). Ten heads provided the minimum amount of flour required per sample for protein analyses. Protein content was not measured in MST studies during 1982.

Plot studies. Four seed lots of spring wheat cultivar Angus with different levels of natural contamination by *X. campestris* were obtained. Lot A1 was produced on the West Central Experiment Station, Morris, MN, during 1980. Lot A2 was a certified seed lot from the Minnesota Crop Improvement Association. Lot A3 was obtained from a commercial field in western Minnesota. Lot A4 was a combination of subsamples from lots 1, 2, and 3. The seed lots were planted 16 April 1981 at two locations at West Central Experiment Station, Morris, and on 23 April 1981 at one location at the Rosemount Experiment Station, Rosemount, MN, with conventional grain drills at seeding rates of 118 and 90 kg/ha, respectively. Plots were 7.6 m long × 2.4 m wide, and treatments were replicated four times per location. Disease severity on 50 flag leaves selected at random in each plot was rated at the early to soft dough stage (DC 83–85). Plots were harvested with a plot combine at full grain maturity.

Yield components. All samples from plots and MST were dried at 32–38 C for 3–5 days. Plumpness was defined as the percentage of grain retained on a 2.83-mm screen sieve after 1 min of agitation by hand (2). Protein concentration was measured by infrared reflectance with a Technicon InfraAlyzer 300 (Technicon Industrial Systems, Tarrytown, NY), and values are expressed in terms of 14% moisture content.

Statistical analyses. Linear and polynomial regression analyses were used to determine the relationship of disease severity on flag leaves to 500-

Table 1. Descriptions of sites for study of severity/loss relationships of Xanthomonas streak on wheat and barley using modified single-tiller method in west central Minnesota

Year	Crop	Cultivar	Site	Location
1980	Spring wheat	Era	F80	Commercial field
		Olaf	K80	Commercial field
		Era	A80	Commercial field
	Spring barley	Morex	S80	Commercial field
1981	Spring wheat	Kitt	K81	Commercial field
		Angus	A81	Research plot
1982		Angus	A82	Research plot

grain weight, plumpness, protein content, or in the case of plot studies, grain weight per plot (expressed as kilograms per hectare). Graphic plots of residuals, significance levels of linear and quadratic regression coefficients, F tests, and coefficients of determination were examined to determine the appropriateness of each model. Heterogeneity of disease severities on flag leaves within each plot was estimated by calculating the standard deviation for the 50 leaves assessed per plot.

RESULTS

During 1980 and 1981, trace amounts of Xanthomonas streak were detected in mid-June in research and commercial fields at the four- to five-leaf stage (DC 14–15). In 1980, the disease was most severe by late milk stage (DC 77) in late June. In 1982 and 1983, initial disease symptoms occurred during late tillering to early boot (DC 22–24) in late June. The epidemics reached maximum severity at early to soft dough (DC 83–85) in 1981 through 1983. Disease was more severe on lower leaves than on flag leaves. Xanthomonas streak was usually distributed in foci with diameters of 2–5 m.

MST studies. No significant relationship between number of kernels per head and severity on flag leaves was detected on tagged single tillers. Grain weight (500-kernel weight) was inversely related to disease severity on the flag leaves of wheat and barley (Table 2). The 500-kernel weights for the tillers with 100% disease severity on the flag leaves ranged from about 13 to 34% less than those of healthy plants (Fig. 1). The functional relationship between disease severity on the flag leaves and 500-kernel weight was linear (sites A80, S80, A81, K81, A82) or sometimes curvilinear with a plateau at severities of 50–75% (sites K80 and F80, Fig. 1). Response curves for 1980 and 1982 contrasted with those for 1981 when a sharp decrease in grain weight was associated with 100% severities compared with the 75% severity category. The proportion of variance accounted for by the best simple linear or quadratic regression models ranged from 0.27 to 0.66 (Table 2).

Seed plumpness was inversely correlated with bacterial streak severities (Table 2, Fig. 2). Sharp reductions in grain plumpness often were associated with the low and high ends of the severity scale and a plateau of relatively constant plumpness for the midrange of severities.

Grain protein content (%) was positively correlated ($P < 0.05$) with disease severities for the three wheat sites but not for the barley site in 1980 (Table 2). In 1982, grain protein content in the one site studied was not significantly correlated with disease severity even though the full range of severities was present in the samples.

Plot studies. The range of severities observed for the four seed lots depended

Table 2. Linear or quadratic regression of yield components of wheat and barley on severity of Xanthomonas streak on flag leaf in groups of single tillers

Field site	Regression parameter[a] B_0	B_1	B_2	Model F	Adjusted R^2
		Weight of 500 kernels (g)			
K80	13.0	−0.0494	0.000334	17.3	0.303
F80	12.3	−0.0617	0.000347	34.3	0.552
A80	12.7	−0.0168	...[b]	25.1	0.270
S80	15.6	−0.0173	···	28.0	0.278
K81	15.3	−0.0448	···	57.9	0.640
A81	15.0	−0.0458	···	44.4	0.634
A82	15.4	−0.0182	···	10.8	0.204
		Kernel plumpness (%)			
K80	47.9	−0.737	0.00475	33.9	0.495
F80	33.4	−0.610	0.00353	38.8	0.607
A80	34.6	−0.242	···	32.6	0.369
S80	50.0	−0.294	···	117.0	0.623
K81	65.8	−0.386	···	62.5	0.658
A81	63.8	−0.432	···	41.3	0.636
A82	63.4	−0.234	···	20.6	0.341
		Grain protein content (%)			
K80	16.1	0.0480	−0.000349	34.2	0.497
F80	15.1	0.0646	−0.000363	56.9	0.695
A80	15.2	0.0196	···	25.0	0.308
S80	13.0	0.0037	···	6.08	0.067

[a] Regression models used are: $Y = B_0 + B_1X$ and $Y = B_0 + B_1X + B_2X^2$, where X = disease severity and Y = yield component.

[b] Dots indicate that the two-parameter linear model was more suitable than the three-parameter quadratic model.

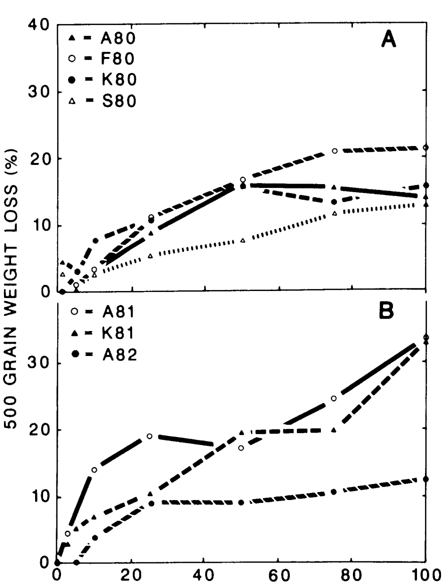

Fig. 1. Relationship between percent loss in weight of 500 kernels of wheat or barley and severity of Xanthomonas streak on the flag leaf as measured in groups of single tillers at sites in Minnesota in **(A)** 1980 and **(B)** 1981 and 1982.

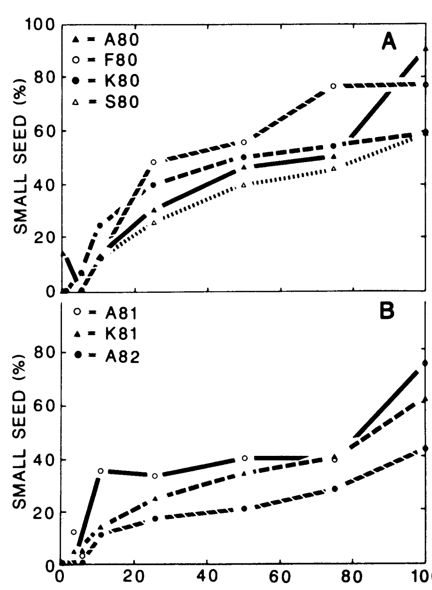

Fig. 2. Relationship between percent small seed (able to pass through 2.8-mm sieve) of wheat or barley as measured in groups of single tillers at sites in Minnesota in **(A)** 1980 and **(B)** 1981 and 1982.

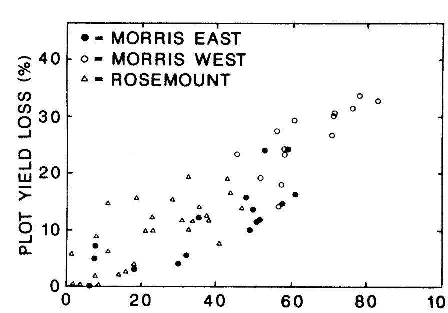

Fig. 3. Relationship between yield loss (%) of Angus wheat and average severity (%) of Xanthomonas streak on flag leaves in research plots at three Minnesota research sites in 1981.

on the environment in which the seed lots were grown (Fig. 3). Absolute yield decreases associated with each disease severity increment of 1% for the three sites were 10, 18, and 56 kg/ha (Table 3). The complete severity/loss relationship could not be closely defined with the data from one site because the full range of average plot severities was not achieved. Plot yields for healthy plants at the Morris east site was estimated from the computed regression line by extrapolation. Percent yield loss was used to obtain a composite summary (Fig. 3). Expressed in this fashion, leaf severity/grain weight loss relationships measured for plots were about equal to those determined for the MSTs in the same year (1981). Grain yield per plot for an average flag leaf severity of 50% was about 20% less than that estimated for healthy plots. Quadratic models were only slightly better than linear models as determined by coefficients of determination adjusted for the number of predictor variables. The proportion of variance explained by the simple linear models ranged from 0.57 to 0.64 (Table 3).

The standard deviation of disease severities calculated for the 50 flag leaves within each plot was roughly proportional to the mean plot severity. As a result, possible nonlinear relationships between severity and yield may have been obscured by heterogeneity of disease severities within plots.

Table 3. Linear regression of grain yield (kg/ha) of field plots of Angus wheat on severity (%) of Xanthomonas streak on flag leaves

Field site	Regression parameter[a] B_0	Regression parameter[a] B_1	Model F	Adjusted R^2
Morris east	3,550	−10.3	26.1	0.626
Morris west	4,511	−18.4	16.7	0.582
Rosemount	2,410	−56.4	41.9	0.569

[a] Regression model used was: $Y = B_0 + B_1 X$, where X = disease severity (%) and Y = plot yield in kilograms per hectare.

DISCUSSION

Xanthomonas streak has been the primary bacterial disease on wheat and barley in eastern North Dakota and western Minnesota in recent years (1980–1985). These studies provide the best current estimation as to the effects of *X. campestris* on yield of small grains, primarily spring wheat. Recent regional yield losses in wheat and barley associated with the disease are probably low because average field severities in Minnesota have generally been below 1% (W. W. Shane, *unpublished*).

Differences in the apparent severity/loss relationships, e.g., linear vs. quadratic, measured in the 3 yr on groups of single tillers, may have resulted because the models were based only on disease readings of the flag leaf. Inclusion of disease readings from other leaves in addition to the flag, of leaf area (10), and of environmental information may have helped to explain the apparent variation in the severity/loss relationships among years. The impact of the disease as measured on groups of single tillers was more pronounced in 1981 even though the onset and progress of Xanthomonas streak was earlier and more rapid in 1980. Thus, multiple-point models based on disease severity readings on the flag leaf at additional time periods could not, by itself, explain differences among years.

Elucidation of the relationship between severity of Xanthomonas streak and yield of small grain is hampered by difficulties in manipulating the disease. When seed lots with different levels of *X. campestris* contamination were mixed, a range of plot severities was obtained in 1981 for Angus but not for another cultivar (Era wheat). Maintenance of disease-free plots for reference yields was difficult, and efforts to manipulate disease epidemics in the field with spray applications of streptomycin were unsuccessful. If the distance between plots were increased, interplot interference caused by spread of bacteria among plots may be reduced.

The single-tiller approach provides a means to investigate severity/loss relationships in situations where manipulation of disease epidemics is difficult. Because treatments (disease severities) were not imposed by the researcher but were natural occurrences, it is possible that other factors may confound the system. For example, Boosalis (3) in Minnesota observed that root-rot fungi can predispose small grains to Xanthomonas streak. Also, the single-tiller approach would not reveal compensatory growth by healthy plants resulting from increased availability of water, light, and nutrients when located next to diseased plants (7). The opportunities for interplant or intertiller compensation are less in the *X. campestris*-cereal system, because the disease generally is not severe until all the yield components (tillers per area, spikelets per ear, florets per spikelet, and grains per spikelet) except grain filling have been established. Waldron (14) noted, however, that Xanthomonas streak can cause reduced numbers of grains per plant. Therefore, presumably, the disease has the potential to be more severe earlier in the season than we observed.

We employed the MST approach in our tests because tillers in groups of 10 allowed more rapid processing of samples than with individual tillers. Coefficients of determination (r^2) in the MST tests were intermediate to the lower and higher r^2 values generally associated with true single-tiller (12) and plot studies (7), respectively. With the MST approach, plant yield parameters are averaged within severity classes. As a result, the severity/loss curve can be more closely defined than with plot methods.

Estimations of the effects of disease on yield may be biased in plot studies if disease severity has a nonlinear effect on crop performance and within-plot severities are widely heterogeneous. High within-plot standard deviations for individual plant severities result from the tendency of the disease to develop in foci. Relatively healthy plants give a disproportionately high contribution to plot yield compared with their influence on the calculated average plot severity. This is not compensation but rather a consequence of a sometimes nonlinear relationship between severity and yield in addition to within-plot heterogeneity. For example, severity/loss models for plots constructed from the MST data for 1980 differed 5–10% from MST models in the higher severity ranges. Research is needed on ways to evaluate the appropriateness of linear or nonlinear models for describing severity/loss relationships in the *X. campestris*-cereal system. Until this is understood, the use of linear severity/loss models is recommended in view of their simplicity.

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