Effect of Soil pH on Cephalosporium Stripe in Wheat

CONNIE S. LOVE, Research Assistant, Crop Science Department, Oregon State University, Corvallis 97331, and G. W. BRUEHL, Professor Emeritus, Department of Plant Pathology, Washington State University, Pullman 99164-6430

ABSTRACT

Love, C. S., and Bruehl, G. W. 1987. Effect of soil pH on Cephalosporium stripe in wheat. Plant Disease 71:727-731.

Incidence of Cephalosporium stripe (*Cephalosporium gramineum*) in wheat (*Triticum aestivum*) increased with increased soil acidity down to pH 4.5, the lowest pH tested, in both greenhouse and outdoor trials. In greenhouse trials with high levels of inoculum, disease incidence was high in acid soil in the absence of known physical root injuries. Evidence is presented that the susceptibility of some cultivars may be affected more by soil pH than that of others. The susceptibility of winter wheats in the greenhouse was similar to field reactions of the cultivars.

Cephalosporium stripe, incited by *Cephalosporium gramineum* Nisikado & Ikata, was prevalent in Washington prior to about 1975 on soils that were very wet from November well into winter, usually on soils with restricted internal drainage (3,4,11). Fall-sown cereals are infected from late fall (G. W. Bruehl, *unpublished*) to early spring (10) through roots that have been predisposed by freeze stress (1) or damaged by frost-heaving of soil (3) or by insects (14). Brevor, a highly susceptible wheat, was popular in the high-rainfall areas of eastern Washington (6) between 1952 and 1962. Brevor was replaced by Gaines in 1963, and Gaines was replaced by Nugaines in 1966. Both Gaines and Nugaines are less susceptible than Brevor, and field observations indicated that disease was subsiding throughout the chronic area. About 1976, the disease became more severe in wheat growing on soils extending into drier areas and on soils without restricted drainage. No significant changes in tillage practices or rotations occurred. The extension of the geographic range is believed due in part to the introduction of three highly susceptible cultivars, beginning about 1976 (Hyslop, McDermid, and Stephens). A second factor, soil pH, was also changing.

Mahler et al (9) examined the results of soil-testing laboratories of Idaho and Washington over a 40-yr period and reported a steady decline in soil pH in northern Idaho and eastern Washington. Starting at near neutrality in the late 1940s, by 1984, more than 45% of the soils were below pH 5.6. They attributed the decline in pH to the continual use of ammonium-based fertilizers that accelerated after the development of high-yielding semidwarf wheats that benefit from heavy fertilization.

Bockus and Claassen (2), working in Kansas, used lime to raise the pH of a soil from 4.8 to 6.5. This in turn led to a decrease in incidence of Cephalosporium stripe. Bruehl and Lai (5) found that low soil pH favored survival as well as sporulation of *C. gramineum* in infested straw, but Bockus and Claassen (2) provided the first evidence of the importance of soil pH in epidemiology in the field and suggested that declining soil pH may be an important factor in increasing Cephalosporium stripe.

The present studies were undertaken to further explore the role of soil pH in the incidence of Cephalosporium stripe. A preliminary report has been published (8).

MATERIALS AND METHODS

One growth chamber trial, one trial in outdoor soil beds, and three greenhouse trials were used to investigate the effects of soil pH on disease incidence.

Soils. Moist Palouse silt loam, pH 5.4 as determined in 1:2, soil/0.01 M $CaCl_2$ (15), was collected each summer at the Plant Pathology Farm near Pullman, WA. The soil was screened and stored outdoors at ambient temperature until it was brought into the greenhouse and air-dried. After air-drying, portions were adjusted to various soil pHs with hydrochloric acid (HCl), reagent-grade calcium hydroxide, or calcium carbonate. The HCl was added in a tap water spray to the dry soil as it was being mixed in a cement mixer. The calcium sources were added dry during agitation in the cement mixer. To improve drainage, coarse pumice, 2:1, soil/pumice (v/v), was used in one greenhouse experiment, whereas perlite, 3:1, soil/perlite (v/v), was used in the growth chamber experiment. They had no effect on soil pH. All other experiments were in soil alone. In all but the first greenhouse experiment, the soils were stored moist for 8 wk after treatment for pH equilibration. Soils were placed in 15-cm-diameter standard unglazed clay pots in the greenhouse or in outdoor beds.

For the outdoor trial, wooden frames 0.25 × 1 × 4 m were placed on a layer of sand for drainage in a courtyard between two greenhouses. Each frame was divided into four 1-m^2 sections. The unamended soil (pH 5.4) served as the pH 5.5 treatment. Soil depth in the beds was 22.5 cm. Eight treatments were arranged in a randomized complete block split-plot design with five replicates. Main plots (the four pH levels: 4.5, 5.5, 6.5, 7.5) were split into inoculated and check subplots by placing a strip of lawn edging (0.1 m wide × 1 m long) into the soil in the center of each plot. To reduce splashing of conidia, a strip of corrugated plastic sheeting (0.4 × 1 m) was secured directly above the lawn edging between subplots and between main plots.

Soil pH determinations. All soil pH measurements were made on duplicate soil samples in 1:2, soil/0.01 M $CaCl_2$ (15). In all greenhouse trials except the cultivar trial, pH determinations were made on samples collected at the beginning of each trial, at growth stage 5 (7), beginning of stem extension, and after harvest. Only initial and final pH determinations were made in the remainder of the trials.

Growing the plants. The winter wheats in two greenhouse experiments were grown at 12–20 C until the two-leaf stage, then they were vernalized for 6–8 wk at 2 C. The seeds in the cultivar trial were germinated, arranged on moist paper towels, and vernalized in a controlled-environment chamber at 0.5–1 C for 6 wk. After vernalization, the seedlings, with plumules 1–3 mm long, were removed from the paper towels and planted, four per pot, at a depth of 2 cm. All other seed of spring and winter wheat was planted 2 cm deep directly into the soil, with four seeds per pot. Selection 101 (CI 13438) was seeded 3 cm deep by hand in rows 0.15 m apart in outdoor soil beds on 26 September 1984.

Plants in all greenhouse experiments, after vernalization in the case of the

Scientific Paper 7659, Project 0561, College of Agriculture and Home Economics, Washington State University, Pullman 99164. Portion of M.S. thesis by first author.

Accepted for publication 2 April 1987 (submitted for electronic processing).

winter wheats, were grown at 6–8 C. In experiments starting in October and November and extending into April to early May, daytime temperatures reached as high as 20 C for short periods (3–4 hr) on sunny days, but the mean temperature in all greenhouse experiments during early stages of plant development was in the range of 6–8 C. Plants in the controlled-environment chamber were maintained at 9 C with a 12-hr photoperiod (photon flux density of 315 $\mu E \cdot m^{-2} \cdot s^{-1}$). Greenhouse and outdoor bed studies were carried out with natural light.

Plants in the greenhouse and controlled-environment chamber were watered with tap water and fertilized with Peter's Professional Soluble Plant Food, 20-20-20 (W. R. Grace & Co., Fogelsville, PA), as needed to maintain good growth. The greenhouse cultivar trial and the outdoor bed experiment were fertilized with commercial ammonium nitrate (34-0-0). The plants in the pots were fertilized periodically with commercial ammonium nitrate dissolved in the tap water. The outdoor beds received 110 kg/ha on the soil surface after planting. In all experiments, fertilization maintained good growth and plant color.

Inoculum. Conidia were produced by isolates of *C. gramineum* that were recently isolated from naturally diseased wheat from several fields within 40 km of Pullman, WA. The cultures were incubated 4–5 wk on fresh Difco potato-dextrose agar (PDA) in petri dishes at 10 C in the dark. Conidia were washed from each dish and strained through four layers of cheesecloth to remove agar pieces. The numbers of colony-forming units (cfu) in the concentrated spore suspensions were determined by dilution plating on PDA. The concentrated conidial suspensions were diluted with tap water and used immediately after they were made. All spore suspensions were composites of conidia of all isolates.

To inoculate the outdoor beds, *C. gramineum* was grown on oat kernels, and the colonized oat kernels served as the source of conidia. Dried oat kernel inoculum was screened to mix isolates and stored at 25 C in paper bags until use.

Inoculation. All soils, except in the outdoor beds, were infested by drenching with conidial suspensions. The soil in the outdoor beds was infested by conidia washed from the oat kernel inoculum by rain. In all experiments receiving spore suspensions, an equal amount of water was applied to the controls.

Data collection. In the greenhouse and controlled-environment chamber studies, tillers were severed at the soil line and separated into two classes, diseased or healthy, based on visual symptoms of the disease including leaf striping and premature aging of heads. Disease incidence was recorded as percent diseased tillers. In all greenhouse experiments except the winter wheat cultivar trial, disease incidence scores were given an arc sine square root transformation to improve homogeneity of variance, and data were retransformed for presentation (16). Analysis of variance was performed on data from all experiments, and Fisher's least significant difference test ($P = 0.05$) was used to compare treatments (16).

In the outdoor bed study, disease incidence was assessed at growth stage 11.1, milky ripe. The number of tillers in each of the center rows of the inoculated subplots with characteristic longitudinal chlorotic stripes on the flag leaf was determined. Disease incidence was calculated by dividing the number of tillers with striped flag leaves by the total number of tillers in the row. Analysis of variance was performed, and Fisher's least significant difference test ($P = 0.05$) was used to compare treatments. The wheat was harvested at maturity by row. Air-dry bundle weight, plant height, grain weight, and thousand-kernel weight were recorded, and harvest index (the ratio of grain yield to biological yield) was calculated.

Table 1. Effect of soil pH on incidence of Cephalosporium stripe in two spring wheats (Dirkwin and Wampum) and two winter wheats (Stephens and BRL80112) in the greenhouse in 1984

Soil pH			Percent diseased tillers[x]			
			Dirkwin		Wampum	
Initial	Growth stage 5	Final	Control	Infested[y]	Control	Infested
4.5	4.6	5.3	0.0	37.2 a[z]	13.0	75.9 a
5.0	5.1	5.9	5.0	37.7 a	0.0	70.3 a
6.0	6.2	6.7	0.0	12.2 b	0.0	10.3 b
7.0	7.1	6.7	0.0	2.8 b	0.0	2.3 b
8.0	7.6	6.8	0.0	0.0 b	0.0	0.0 b
			Stephens		BRL80112	
4.5	4.6	5.3	10.7 a	60.4 a	0.0	6.7 a
5.0	5.1	5.9	2.9 b	11.3 b	0.0	0.0 a
6.0	6.2	6.7	0.0 b	7.5 bc	0.0	0.0 a
7.0	7.1	6.7	0.0 b	0.0 c	0.0	0.0 a
8.0	7.6	6.8	0.0 b	0.0 c	0.0	0.0 a

[x] Percentage of tillers with characteristic chlorotic stripes on leaves at growth stage 10.5 (7), heading complete. Growth stage 5 (under soil pH), stem elongation beginning.
[y] Each pot received 350 ml (4.1×10^6 cfu/ml) at two-leaf stage.
[z] Data were transformed using an arc sine square root transformation before analysis; nontransformed means are presented. Means (five replicates) within a column followed by a common letter do not differ significantly according to Fisher's protected least significant difference test ($P = 0.05$).

Table 2. Effect of soil pH on incidence of Cephalosporium stripe in two spring wheats (Dirkwin and Wampum) and in two winter wheats (Stephens and Nugaines) in the greenhouse in 1985

Soil pH			Percent diseased tillers[x]			
			Dirkwin		Wampum	
Initial	Growth stage 5	Final	Control	Infested[y]	Control	Infested
4.5	4.6	5.4	2.4 a[z]	52.3 a	19.6 a	97.5 a
5.5	5.5	5.6	0.0 a	71.1 a	18.0 a	86.8 a
6.5	6.3	6.5	3.6 a	11.7 b	0.0 b	48.7 b
7.5	7.2	6.9	0.0 a	6.9 b	0.0 b	21.3 c
			Stephens		Nugaines	
4.5	4.7	5.5	56.8 a	100.0 a	0.0 a	58.9 a
5.5	5.4	5.6	19.8 b	97.5 a	0.0 a	45.7 a
6.5	6.4	6.7	18.8 b	83.8 ab	5.3 a	22.1 b
7.5	7.2	6.8	10.5 b	70.6 b	0.0 a	33.2 a

[x] Percentage of tillers with characteristic chlorotic stripes on leaves at growth stage 10.5.4 to 11.1 (7), watery ripe to milky ripe.
[y] Spring wheats (top) received 300 ml (4.8×10^6 cfu/ml); winter wheats (bottom) received 300 ml (4.3×10^6 cfu/ml) per pot.
[z] Data were transformed using an arc sine square root transformation before analysis; nontransformed means are presented. Means (five replicates) within a column followed by a common letter do not differ significantly according to Fisher's protected least significant difference test ($P = 0.05$) treatments.

RESULTS

Greenhouse study, 1984. Low soil pH (4.5 and 5.0) increased disease incidence in the spring wheats Dirkwin and Wampum (Table 1). Fewer tillers were diseased at pH 6.0 and 7.0 in both cultivars, and no disease developed at pH 8.0. At pH 4.5 and 5.0, Wampum was more susceptible than Dirkwin. In the absence of mechanical root wounds, low

soil pH increased Cephalosporium stripe incidence in the highly susceptible winter wheat cultivar Stephens (Table 1), with most disease at pH 4.5. Disease incidence in line BRL80-112, relatively resistant in field trials, was not affected in this trial by soil pH.

Significant differences between Stephens and line BRL80-112 were found at pH 4.5, 5.0, and 6.0 in infested soil and at pH 4.5 in the controls. Disease incidence increased as soil pH decreased, but only in the more susceptible cultivar. The small percentage of diseased plants found in the controls of the pH 4.5 and 5.0 treatments probably resulted from a low level of natural inoculum present in the field soil, because the soil was collected from an area of a field that had supported a moderately diseased winter wheat crop the previous year.

Greenhouse study, 1985. Low soil pH increased disease incidence in Dirkwin and Wampum (Table 2). In Dirkwin, disease incidence was lower at pH 6.5 and 7.5 than at pH 4.5 or 5.5. In Wampum, the pH 6.5 and 7.5 treatments were significantly different but had less disease than the pH 4.5 and 5.5 treatments. There was no significant difference between pH 4.5 and 5.5 in the control treatments of Wampum.

With the winter wheats Stephens and Nugaines, the relationship between low soil pH and increased disease was weakly apparent (Table 2). Stephens had a higher percentage of diseased tillers than Nugaines at each pH level in the inoculated treatments. A significantly higher percentage of diseased tillers was found in Stephens in the controls at pH 4.5 than at pH 5.5 or higher, but not in Nugaines, probably reflecting the greater susceptibility of Stephens to low but unknown inoculum levels. The low level of disease reported in the control treatments probably resulted from an unknown level of natural inoculum, because the soil was collected from an area of a field infested with *C. gramineum*.

Controlled-environment chamber. Disease incidence was highest in the inoculated treatment at pH 4.5 and decreased as pH increased. Significant differences were found among pH levels, except between pH 6.5 and 7.5 (Table 3). No disease developed in the controls.

Outdoor beds, 1984–1985. The percentages of tillers with striped flag leaves in the inoculated treatments at pH 4.5, 5.5, 6.5, and 7.5 are presented in Table 4. There is no significant difference between pH 4.5 and 5.5 or between pH 5.5 and pH 6.5. A low level of disease developed in the controls at all pH levels, although the percentage of diseased tillers was not determined.

At maturity, plant height, thousand-kernel weight, and straw yield were similar in the controls and in infested soil at pH 7.5, but significant differences were found for grain yield and harvest index (Table 4). The differences between controls and infested soil treatments became more pronounced as soil pH decreased, with the greatest differences at pH 4.5. Plants were shorter and grain yield was lower in the controls at pH 4.5 than in the controls at the other pH levels, reflecting the deleterious effect of low soil pH on wheat. Grain yield, kernel size and weight (as reflected by thousand-kernel weight), straw weight, and harvest index were all lowest in the inoculated treatment at pH 4.5.

Cultivar trial. Stephens responded greatly to soil pH, with 100% diseased plants at pH 4.5 but only 13% diseased plants at pH 6.0 (Table 5). Brevor, in contrast, had 92% diseased plants at pH 4.5 and 52% diseased plants at pH 6.0. The percentages of diseased plants and tillers in each treatment were closely associated in most comparisons.

Data reflect incidence only, with no allowance for severity. In the cool greenhouse with ample water, the roots and crowns of the most severely diseased plants remained alive and small green shoots developed even when all main tillers were severely diseased or dead. Small, very late tillers of such plants were not included when collecting data.

The total number of tillers was greatest, averaging five per plant for each cultivar, at pH 4.5. The average number of tillers for the other soil acidities varied between 3.1 and 3.4 ($LSD_{0.05}$ = 0.33). Most main tillers of Winridge remained alive even though striped.

DISCUSSION

The most important result of the greenhouse and controlled-environment chamber experiments may be disease development in the absence of known physical injury to the roots. The roots were not frozen (1), and no frost-heaving of soil occurred (4,6,13). In Washington, the disease in the field was originally strongly associated with wet soils and seasons in which root injury in the winter was severe (4).

The initial inoculum levels of these experiments were very high, up to 5.5×10^6 cfu/g of air-dried soil in the cultivar trial. Wiese and Ravenscroft (17) reported up to 2×10^5 cfu/g in the field in Michigan, and Bruehl and Machtmes (*unpublished*) found 2×10^6 cfu/g in "microsites" in the top 5 cm of soil during the winter months in Washington; heavy inoculum levels may exist in spots in the field. Studies of local concentrations of inoculum in fields should be extended. Pool and Sharp (12) noted microsite

Table 3. Effect of soil pH on incidence of Cephalosporium stripe in spring wheat Wampum in a controlled-environment chamber

Soil pH		Percent diseased tillers[x]	
Initial	Final	Control	Infested[y]
4.5	5.4	0.0	64.9 a[z]
5.5	5.5	0.0	28.1 b
6.5	6.6	0.0	10.5 c
7.5	7.1	0.0	2.3 c

[x] Percentage of tillers with characteristic chlorotic stripes on leaves at late boot stage. Feekes stage 10.5.4–11.1 (7), watery ripe to milky ripe.
[y] Each pot received 300 ml (3.8×10^6 cfu/ml).
[z] Means (seven replicates) within a column followed by a common letter do not differ significantly according to Fisher's protected least significant difference test ($P = 0.05$).

Table 4. Disease incidence, plant height, thousand-kernel weight (TKW), grain yield, straw yield, and harvest index from Selection 101 winter wheat in soil beds inoculated or not inoculated with *Cephalosporium gramineum* at four soil pH levels at Pullman, WA

Soil pH			Disease incidence	Plant ht	TKW	Grain yield	Straw yield	Harvest
Initial	Final	Treatment[a]	(%)	(cm)	(g)	(kg/ha)	(kg/ha)	index
4.5	5.3	Control	···	76.1	36.8	2,739	5,164	0.346
		Infested	87.4	56.7	20.4	792	3,038	0.210
5.5	5.6	Control	···	81.7	38.4	3,327	5,493	0.380
		Infested	71.1	65.8	28.9	1,455	4,188	0.256
6.5	6.5	Control	···	80.7	37.6	2,940	4,681	0.386
		Infested	55.6	70.3	33.0	1,703	3,900	0.303
7.5	6.9	Control	···	84.3	37.9	3,300	5,064	0.394
		Infested	20.9	82.9	37.3	2,765	5,074	0.352
$LSD_{0.05}$[b]			17.4	5.3	2.3	457	727	0.030

[a] Infested = 2,195 kg of artificially infested oat kernel inoculum per hectare applied 12 November 1984.
[b] Fisher's least significant difference ($P = 0.05$) for comparing all means (five replicates) within a column. Disease incidence data collected at milky ripe, growth stage 11.1.

variations in disease distribution in Montana. Some plants could be infected in nature in acid soils even with a minimum of physical damage to the roots, which could aid survival of the pathogen in seasons unfavorable to disease development.

Disease incidence was increased in all experiments by soil pH of 5.5 or less, supporting the field experiment results of Bockus and Claassen (2). Not only did soil acidity increase disease incidence, but in the soil beds in which plants went to full maturity, the proportion of grain to straw (harvest index), thousand-kernel weight, plant height, and grain yield decreased as acidity increased, indicating that disease severity as well as incidence increased with increased acidity. Four times as many tillers showed symptoms at pH 4.5 than at pH 7.5. Although less straw was produced in the former treatment (Table 4), the total amount of infested straw returned to the soil was two and one-half times greater at pH 4.5 than at pH 7.5. Also, because soil acidity favors survival of the fungus in infested straw (5), it is probable that inoculum levels will steadily increase in acidic soils, resulting in increased disease in successive winter wheat crops.

Soil pH changed gradually in all of the trials, and in most cases, final pH levels were vastly different from initial levels. In the two greenhouse trials in which soil pH was measured midway through the study (Tables 1 and 2), however, the largest changes in soil pH occurred after tillering, as the growth rate of the plants began to increase. A similar pattern of soil pH change probably occurred in all of the trials. Presumably, infection occurred before the pH changed appreciably, because all other factors (temperatures, moisture, fertility) were constant, but significant differences in disease incidence and severity among pH treatments were found.

We do not know why acidity favors disease, but spore survival should not be a factor in these trials. The plants in all but the outdoor trial were in the two- to three-leaf stage of development at the time of inoculation. Although conidia free in soil survive in greater numbers at 9 C in soil at pH 4.5 than at pH 5.5, 6.5, or 7.5 (*unpublished*), the fungus was not eliminated at any pH level for at least 16 wk, a period that is adequate for infection in the greenhouse and controlled-environment chamber trials. Unless effective infections occur much later, differences in spore survival should not be significant. All eight replicates of the cultivar trial received three drenchings with spores, but replicate 6 received an additional drench, replicate 7, two additional drenches, and replicate 8, three additional drenches at weekly intervals. Analysis of variance revealed no differences among replicates. Therefore, the extra inoculations were superfluous, supporting the supposition that spore longevity was not the factor accounting for increased disease in acid soils in these experiments.

In nature, sporulation is heavy from November on into the winter during mild, rainy weather (4,17). Soil temperatures lower than those of our greenhouse experiments would prevail, and these low temperatures should further favor spore survival and accumulation in the upper levels of soil (17), leading to high natural inoculum levels. Further evidence that spore survival was not an important factor was provided by the outdoor bed trial. Spores produced on the oat kernels were introduced repeatedly into the soil with each significant rain, yet disease incidence reflected soil pH the same as in the greenhouse trials, where spores were added in a single drench at the two- to three-leaf stage.

The first evidence of the effect of elevated soil pH on reduced Cephalosporium stripe may have been presented by Wiese and Ravenscroft in 1978 (18). They recorded disease incidence and *C. gramineum* propagule numbers in soil in field plots maintained under continuous wheat for 8 yr. The soil had an initial pH of 4.7. After liming, the soil pH rose to 6.2 by the third year and remained between 6.0 and 6.6 thereafter. Each year, after harvest, the residue was incorporated into the soil. Propagule numbers in the soil were monitored monthly from October to December, beginning in the third year of the study. Incidence of tillers with stripe symptoms increased from 0% in year 1 of the study to a high of 53% in year 3. Thereafter, incidence gradually declined each year to 9% by year 8. About 5×10^4 *C. gramineum* propagules per gram of soil were detected during years 3–5, and populations decreased in subsequent years to about 1×10^4 cfu/g during years 6–8. These workers termed the gradual decrease in disease incidence "Cephalosporium stripe decline." Because the soil pH increased after liming and remained between 6.0 and 6.6 thereafter, it is possible that effects of soil pH on *C. gramineum* may have contributed to the decline.

The relationship between low soil pH and increased Cephalosporium stripe incidence is important for several reasons. Bruehl and Lai (5) suggested that acidic soils may affect the distribution of Cephalosporium stripe by increasing the ability of the fungus to survive saprophytically in infested residue. Our results indicate that soil pH has additional effects, although the mechanisms responsible for the increase in disease in acid soils are not known.

The steady decline in soil pH in this region (9) is significant, not only because high acidity itself is deleterious to wheat but because of its probable contribution to the increase of this disease. Liming, rotation, and avoidance of highly susceptible cultivars will be increasingly important.

Assuming that soil acidity was less pronounced 25 yr ago, when Cephalosporium stripe first became important in this region, the susceptible cultivar Brevor may have contributed to an increase in Cephalosporium stripe in this region. We have only one experiment in which Brevor was compared with other cultivars (Table 5), but Brevor appears to be susceptible over a wider range of soil pHs than most wheats. Experiments comparing cultivars should be repeated, especially with lower levels of inoculum.

These results, along with field trials (6), suggest that winter injury, soil pH, and cultivar susceptibility strongly affect disease incidence and severity. When

Table 5. Effects of soil pH and cultivar on the percentage of winter wheat plants and tillers with symptoms of Cephalosporium stripe in the greenhouse[a]

	Diseased plants (%)					Diseased tillers (%)				
Cultivar	**4.5**	**5.6**	**5.5**	**6.0**	**Av.**	**4.5**	**5.0**	**5.5**	**6.0**	**Av.**
Brevor	92	87	83	52	79	88	91	83	44	77
Stephens	100	75	63	13	63	97	75	53	17	61
Nugaines	71	83	54	21	57	66	60	49	12	47
Winridge	83	71	42	17	53	62	54	47	11	43
Lewjain	79	48	63	8	49	69	38	46	7	40
Daws	50	46	46	29	43	49	41	43	29	41
Sprague	33	29	39	0	25	18	32	32	0	21
Sel. 80-112	46	13	17	4	20	38	10	10	11	17
Av.[b]	69	57	51	18		61	50	45	16	
$LSD_{0.05}$[c]	30	28	28	25	28	27	26	24	23	17
Final pH	5.6	5.8	5.7	6.2						

[a] All pots in all replicates received three applications of 100 ml of a spore suspension totaling 5.5 $\times 10^6$ cfu/g of air-dried soil when the wheat was in the two- to three-leaf stage. Replicate 6 received a fourth inoculation 1 wk later, replicate 7, two additional inoculations, and replicate 8, three additional inoculations at weekly intervals.

[b] $LSD_{0.05}$ for averages of columns = 13 for percent diseased plants and 12 for percent diseased tillers.

[c] LSD for numbers within columns. Data taken 23–29 April 1985, when some heads in each cultivar were in anthesis.

winter injury is severe, differences in resistance among cultivars are minimized. When Mathre and Johnston (10) inoculated individual roots, differences in resistance were expressed in greenhouse trials, with a correlation of $r = 0.87$ between greenhouse and field results. When the crown was inoculated, differences in resistance were practically nonexistent. The latter may correspond to severe field conditions with much host injury. Increasing soil acidity probably reduces the significance of host wounds in epidemiology. Tests for resistance of winter wheats varying in tolerance to acidity in field plots adjusted to different soil pH levels may help clarify these relationships.

ACKNOWLEDGMENT

Support of the Vogel Research Foundation is gratefully acknowledged.

LITERATURE CITED

1. Bailey, J. E., Lockwood, J. L., and Wiese, M. V. 1982. Infections of wheat by *Cephalosporium gramineum* as influenced by freezing of roots. Phytopathology 72:1324-1328.
2. Bockus, W. W., and Claassen, M. M. 1985. Effect of lime and sulfur application to low-pH soil on incidence of Cephalosporium stripe in winter wheat. Plant Dis. 69:576-578.
3. Bruehl, G. W. 1957. Cephalosporium stripe disease of wheat. Phytopathology 47:641-649.
4. Bruehl, G. W. 1968. Ecology of Cephalosporium stripe disease of winter wheat in Washington. Plant Dis. Rep. 52:590-594.
5. Bruehl, G. W., and Lai, P. 1968. Influence of soil pH and humidity on survival of *Cephalosporium gramineum* in infested wheat straw. Can. J. Plant Sci. 48:245-252.
6. Bruehl, G. W., Murray, T. D., and Allan, R. E. 1986. Resistance of winter wheats to Cephalosporium stripe in the field. Plant Dis. 70:314-316.
7. Large, E. C. 1954. Growth stages in cereals, illustration of the Feekes scale. Plant Pathol. 3:128-129.
8. Love, C. S. 1985. Effect of soil pH on infection of wheat by *Cephalosporium gramineum*. (Abstr.) Phytopathology 75:1296.
9. Mahler, R. L., Halvorson, A. R., and Kochler, F. E. 1985. Long-term acidification of farmland in northern Idaho and eastern Washington. Comm. Soil Sci. Plant Anal. 16:83-89.
10. Mathre, D. E., and Johnston, R. H. 1975. Cephalosporium stripe of winter wheat: Infection processes and host response. Phytopathology 65:1244-1249.
11. Pool, R. A. F., and Sharp, E. L. 1967. Soil moisture as a factor affecting the incidence of Cephalosporium stripe disease of winter wheat. (Abstr.) Phytopathology 57:1008.
12. Pool, R. A. F., and Sharp, E. L. 1968. Distribution of Cephalosporium stripe disease of wheat in Montana. Plant Dis. Rep. 52:818-819.
13. Pool, R. A. F., and Sharp, E. L. 1969. Some environmental and cultural factors affecting Cephalosporium stripe of winter wheat. Plant Dis. Rep. 53:898-902.
14. Slope, D. B., and Bardner, R. 1965. Cephalosporium stripe of wheat and root damage by insects. Plant Pathol. 14:184-187.
15. Smiley, R. W., and Cook, R. J. 1972. Use and abuse of the soil pH measurement. Phytopathology 62:193-194.
16. Steel, R. G. D., and Torrie, J. H. 1980. Principles and Procedures of Statistics, a Biometric Approach. 2nd ed. McGraw-Hill, New York.
17. Wiese, M. V., and Ravenscroft, A. V. 1975. *Cephalosporium gramineum* populations in soil under winter wheat cultivation. Phytopathology 65:1129-1133.
18. Wiese, M. V., and Ravenscroft, A. V. 1978. Cephalosporium stripe decline in a wheat monoculture. Plant Dis. Rep. 62:721-723.