Influence of Crop Management Practices on Physiologic Leaf Spot of Winter Wheat

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ABSTRACT

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The response of physiologic leaf spot to winter wheat management practices was examined in the semiarid Pacific Northwest. Winter wheat cultivars exhibited large differences in susceptibility. The dominant cultivar (Stephens) produced in the region was the most susceptible cultivar evaluated. The disease became less severe as the date of seeding was delayed and as the rate of nitrogen fertilization increased. Leaf spot severity was reduced and grain yield increased with foliar application of urea + calcium chloride, but not with application of urea + micronutrients. The disease was more severe in annual wheat than in rotations of wheat with fallow or peas. Leaf spot severity was not affected by the application of diclofop-methyl herbicide, the timing or source of soil-applied nitrogen, or the burning or leaving of stubble from previous wheat crops. The amounts of residue on the soil surface had inconsistent effects on leaf spot severity. We conclude that the severity of physiologic leaf spot can be reduced by the management of wheat cultivar selection, crop rotation, planting date, and plant nutrition.

A leaf spot of unknown etiology, named physiologic leaf spot (37), has occurred on winter and spring wheat (*Triticum aestivum* L. and *T. durum* Desf.) in semiarid regions of the inland Pacific Northwest for three or more decades. The disease is typically minor but has been moderate to severe since 1989. In many eastern Oregon and Washington fields, this necrotic and chlorotic leaf spot affected up to 60% of the flag leaf area and caused early death of lower leaves during an unusually severe epiphytotic in 1990. Smiley et al (37) reported that this leaf spot reduced grain production by 10% and was not affected by the application of several fungicides.

Disease incidence and severity on winter wheat appeared to differ among cultivars and crop-management practices in experimental plots. Observations on commercial fields also suggested that leaf spot was more severe in conservation tillage than in low-residue tillage systems, especially with early seeding and continuous wheat. Diseases of similar appearance are sometimes suppressed by urea (32), chloride (16,19), or micronutrients (27).

The objectives of this investigation were to characterize winter wheat cultivars for susceptibility to physiologic leaf spot and to determine the effects of tillage and fertilizer management systems on disease severity.

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MATERIALS AND METHODS

Evaluations of physiologic leaf spot incidence and/or severity were made on 19 experiments conducted in north central and northeastern Oregon from 1989 to 1992. Unless otherwise stated, all experiments were performed as 2-yr rotations of winter wheat with summer fallow.

The region has a warm-temperate climate with warm to hot summers, cool to cold winters, and winter and spring precipitation. Soils at the experimental sites were silt loams of the Walla Walla, Ritzville, and Palouse series (coarse-silty mesic Typic Haploxerolls) with about 1-2% organic matter, surface horizon pH (in 0.01 M $CaCl_2$) 5.0-6.5, and deep, well-drained profiles. Farm management systems in the region are governed by annual precipitation (230-700 mm), soil depth, and growing degree days (13). They include 2-yr rotations of winter wheat with fallow, peas (*Pisum sativum* L.), rape (*Brassica* spp.), spring wheat, or spring barley (*Hordeum vulgare* L.); or 3-yr rotations with a spring crop and summer fallow. Winter wheat is sometimes produced annually, especially under irrigation. Cultivation systems include primary tillage with a moldboard plow and subsequent management of low-residue fallow or dust mulch, tillage with a chisel plow and subsequent management of high-residue fallow, no tillage prior to planting, and many variants within this range of tillage intensities and frequencies.

Wheat cultivars. Leaf spot was evaluated in winter wheat nurseries in eastern Oregon during 1990 (two sites), 1991 (four sites), and 1992 (two sites). The nurseries each contained 28 wheat and two triticale (*Triticum* × *Secale* hybrid) cultivars or advanced selections. Wheat cultivars and their market class are listed in Table 1. Each wheat entry was planted in a 1.5 × 3 m plot replicated three times in a randomized complete block design. Nurseries were planted during October in commercial fields near Athena, Helix, Lexington, and Heppner, Oregon; and in Oregon State University research centers near Pendleton and Moro. Plants were evaluated for the incidence and severity of leaf spot after head emergence in early May.

Wheat leaves were designated as the flag (F) and the first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. During 1990, a rating scale of 0-10 was used to describe disease severity on the main stem: 0 = no symptoms, 1 = fewer than four spots on F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15-40% on F, and 10 = >40% on F. This scale assigns higher severity ratings to damage that occurs in the upper plant canopy, where leaf spots cause the greatest damage to the yield of small grains (11,22,24,28,41,42). Upper leaves did not necessarily exhibit symptoms at low ratings, but lower leaves were always damaged at high ratings. For instance, leaf spot was generally absent on F at ratings of 2 or less, F-4 leaves were typically killed at ratings of 5 or more, and F-3 leaves were typically killed at ratings of 8 or more. Unless otherwise stated, leaf spot in other experiments was quantified with this whole-plant scale.

In addition to the rating scale used during 1990, disease severity (percent necrosis) on each leaf of the oldest two tillers was determined for all cultivars during 1991. Analysis of variance was performed on data from individual plots and from grouped data for the six plot-years in which leaf spot occurred. Analysis of variance was also conducted separately for each leaf, cultivar, and plot location where leaf spot occurred during 1991.

Nitrogen rate. Malcolm wheat was planted near Pendleton in soil treated with nitrogen applied at 0, 56, 112, or

168 kg/ha of N. Plots were 2.5 × 30 m and replicated four times. Planting was on 9 September 1991. Nitrogen was applied as urea-ammonium nitrate 5 cm below the seed at planting. Wheat was seeded with a no-till drill with modified John Deere HZ openers spaced 25 cm apart. An autumn drought delayed substantial wheat emergence until early November. Physiologic leaf spot severity was evaluated on 1 April.

Foliar nutrients. Foliar nutrients were applied to Stephens wheat near Helix during 1991 and 1992 (Table 2). Nutrients included urea + calcium chloride (1.3 kg/L, with 15% nitrogen, 8% calcium, and 14% chlorine; formulated by Stoller as Stand Seedling Solution and

Table 1. Leaf spot ratings[a] on winter wheat cultivars at five eastern Oregon locations

Cultivar	Market class[b]	1990 Helix	1991 Helix	1991 Athena	1991 Heppner	1992 Moro	1992 Pendleton	Mean	Standard deviation
Buchanon	HR	...	1.0	1.7	0.3	1.7	2.0	1.3	0.6
Tres	CL	1.3	2.0	0.7	1.0	1.3	3.0	1.6	0.8
Dusty	SW	1.3	1.3	3.3	0.7	...	...	1.7	0.9
Moro	CL	1.0	...	...	...	2.3	2.3	1.9	0.5
Ute	HR	...	1.6	2.3	0.7	3.0	3.3	2.2	0.9
Hyak	CL	2.7	2.0	3.3	2.3	0.7	3.0	2.3	0.9
Cashup	SW	2.0	2.7	2.7	0.7	2.7	3.7	2.4	1.0
Andrews	HR	1.7	2.0	4.7	1.0	2.7	2.7	2.5	1.3
Rohde	CL	2.3	3.7	3.3	1.7	2.0	3.7	2.8	0.9
Wanser	HR	1.7	3.0	5.3	1.7	1.7	3.7	2.9	1.5
Daws	SW	3.3	3.7	3.3	3.0	2.0	2.7	3.0	0.6
Basin	SW	4.0	3.7	4.3	2.0	2.0	3.7	3.3	1.0
Hill 81	SW	3.7	4.0	2.0	2.3	3.3	5.0	3.4	1.1
Eltan	SW	...	4.3	3.0	3.3	3.0	3.7	3.5	0.5
Gene	SW	3.3	3.7	3.3	4.7	3.0	3.0	3.5	0.6
Oveson	SW	3.7	3.7	3.3	3.0	3.7	4.3	3.6	0.4
Yamhill	SW	...	5.0	3.3	3.7	2.7	3.7	3.7	0.8
Madsen	SW	4.3	4.0	5.7	3.3	2.0	4.0	3.9	1.2
Lewjain	SW	5.0	4.3	3.7	2.7	2.7	5.0	3.9	1.0
Malcolm	SW	3.3	4.0	4.7	3.3	3.3	5.0	3.9	0.8
Batum	HR	3.3	5.0	4.0	4.0	...	...	4.1	0.5
Kmor	SW	...	4.3	5.3	2.7	4.0	4.3	4.1	0.8
MacVicar	SW	4.0	3.7	3.3	3.0	4.7	6.0	4.1	1.1
Hoff	HR	4.0	4.7	4.0	3.0	3.3	5.7	4.1	1.0
Stephens	SW	5.7	5.0	5.3	3.7	5.3	6.7	5.3	1.0
LSD ($P = 0.05$)		1.4	1.6	1.5	1.4	1.9	1.4	0.9	...

[a] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.

[b] HR = hard red winter wheat, SW = soft white winter wheat (common head type), CL = soft white winter wheat (club head type).

Table 2. Incidence and severity of leaf spot on main stem leaves, and grain yield for plants treated one or more times with foliage-applied nutrients

Year Treatment	Application dates Dec.	Feb.	Mar.	Apr.	May	Necrotic area (%)[a] F[b]	F-1	F-2	F-3	Yield (kg/ha)
1991										
Control						0	2	12	26	4,769
UCC[c]	X	X	X	X	X	0	1	4	9	5,487
UCC	X	X				1	0	3	8	5,451
UCC					X	1	2	10	24	5,135
LSD ($P = 0.05$)						NS[d]	1	6	13	511
1992										
Control						10	19	S[e]	S	5,336
UCC		X		X		3	9	S	S	5,872
UCC			X			3	10	S	S	5,887
UCC + benomyl[f]		X		X		4	11	S	S	5,853
UCC + propiconazole[f]		X		X		3	9	S	S	5,898
UFG[g]	X	X				8	16	S	S	5,415
UFG		X		X		7	14	S	S	5,543
UFG + benomyl		X				10	21	S	S	5,423
UFG + benomyl		X		X		6	15	S	S	5,405
UFG + propiconazole		X				7	16	S	S	5,551
LSD ($P = 0.05$)						2	5	...	...	347

[a] Leaf spot severity ratings were on 15 May 1991 and 2 June 1992.

[b] Flag leaf (F) and first (F-1), second (F-2), and third (F-3) leaves below the flag leaf.

[c] Urea + calcium chloride; as Stoller's Stand Seedling Solution; applied at rates of 9.1, 4.9, and 8.5 kg/ha for nitrogen, calcium, and chloride, respectively.

[d] NS = Not significant.

[e] S = Premature senescence of leaves.

[f] Benomyl and propiconazole were applied at 1.1 and 0.1 kg/ha, respectively, as a tank mix with nutrients in February, but were not applied with the nutrients in April.

[g] UFG = Urea (9.1 kg/ha of N) + minor elements (0.5% magnesium, 1.0% manganese, 1.5% zinc, 1.0% iron, 0.25% copper, 0.025% boron, and 0.0025% molybdenum; as Wilbur-Ellis's Micro-Mix Foli-Gro, with 1.15 kg/L, applied at 3.6 kg/ha).

currently marketed as "Foliar 158" by Hill Brothers Chemical, Orange, CA) or urea + micronutrient mixture (1.15 kg/L, with 0.5% magnesium, 1.0% manganese, 1.5% zinc, 1.0% iron, 0.25% copper, 0.025% boron, and 0.0025% molybdenum; Micro-Mix Foli-Gro by Wilbur-Ellis). The fungicides benomyl (Benlate 50DF) and propiconazole (0.43 kg/L, Tilt 3.6E) were tank mixed with foliar nutrients in some treatments. Boron (0.2 kg/ha, Liquid B from Stoller) was added to the urea + calcium chloride solution during 1991–92. Treatments were applied in 100 liters of water per hectare through fan nozzles mounted on a motorized boom sprayer. Applications in May coincided with the time of flag leaf emergence (Haun growth stage 6.7). Leaf spot was not present on the flag leaf or the next two lower leaves when nutrients were applied during May, but had reached moderate severity ratings on the F-3, and was severe on the F-4 and F-5. Plots were 1.5 × 10 m, replicated five times, and arranged in a randomized complete block design. Leaf spot ratings (0–10 scale) on the main stem were made after head emergence in June, and grain yields were measured with a plot combine during July. Regression analyses were used to estimate yield loss associated with physiologic leaf spot (23,40).

Cultivar × nitrogen rate and timing interactions. Winter wheat was planted in a 4 × 9 factorial experiment containing four cultivars and nine nitrogen treatments. Cultivars were Hyak, Madsen, Malcolm, and Stephens. Nitrogen treatments included no applied N, 45 or 90 kg/ha of N applied preplant as anhydrous ammonia during late summer, 45 or 90 kg/ha applied as liquid urea + ammonium nitrate placed 3 cm below the seed at planting, 90 kg/ha applied as ammonium nitrate top-dressed by broadcast during the spring, 90 kg/ha split application with half as preplant anhydrous ammonia and half as ammonium nitrate topdressing in the spring, 90 kg/ha split application with half as urea at planting and half as ammonium nitrate topdressing in the spring, and 67 kg/ha with one-third as urea at planting and two-thirds as ammonium nitrate topdressing in the spring. Cultivars (3-m-wide strips) and nitrogen treatments (6.7-m-wide strips) were perpendicular with the latter continuing in-line through each of the four replicates. Anhydrous ammonia was injected at a 15-cm depth at 35-cm spacings into moist soil underlying a 6-cm-deep dust mulch maintained with a rod weeder. Cultivars were planted on 5 October 1991 with a drill equipped with double disk openers at 25-cm spacings. Physiologic leaf spot severity was evaluated on 21 April.

Herbicide × nitrogen rate and timing interactions. This experiment was appended to the cultivar × nitrogen experiment described above. Madsen wheat was utilized to evaluate interactions among two herbicide management levels and nine nitrogen treatments. Two additional drill strips of Madsen wheat were planted across each of four replicates of the nine nitrogen treatments described previously. Herbicide management levels consisted of no herbicide for control of downy brome (*Bromus tectorum* L.) or diclofop-methyl at 1.12 kg a.i./ha applied as a preplant incorporated treatment. Herbicides were incorporated with a rod weeder set to a 4-cm depth, followed by a rotary hoe. The incorporation operation was performed on both herbicide-treated and untreated plots. All other cultural operations were performed as described for the nitrogen rate and timing study discussed above.

Cultivar × surface residue interactions. Four winter wheat cultivars and three levels of wheat stubble residue on the soil surface at seeding time were examined in a 4 × 3 factorial design with four replicates. Cultivars were Daws, Hyak, Moro, and Stephens. Residue levels (low = 17% of surface area covered, moderate = 39%, and high = 49%) were achieved by the primary tillages moldboard plow, offset disk, or chisel plow, respectively. Nitrogen was injected as anhydrous ammonia (90 kg/ha of N) into the fallow during the summer. Wheat was planted in 30-cm rows on 3 October 1991 with a plot drill equipped with double-disk openers. Physiologic leaf spot was evaluated on 21 April.

Planting date. Stephens wheat was planted at 15-day intervals on six planting dates from 1 September to 15 November 1991. Paired 6-m-long rows 30 cm apart were replicated six times for each planting date. Wheat was planted 2–3 cm deep with a single row drill. Each planting date block was watered shortly after planting with a line-source sprinkler irrigation system to ensure rapid seedling emergence and establishment during a drought. Leaf spot severity was assessed on 6 and 21 April. Plants in all except the 15 November planting were in the boot stage on 21 April. Percent necrotic leaf area was evaluated individually on F, F-1, F-2, and F-3 leaves on 6 May and 4 June. On 6 May, the heads were emerging from plants seeded in September. On 4 June, plants were in the soft dough to milk stages of caryopsis development. Although all replicates for each planting date were aligned linearly to facilitate the watering requirement, data for each leaf position in each planting date were analyzed as randomized complete blocks.

Long-term crop management experiments. The Columbia Basin Agricultural Research Center near Pendleton maintains five long-term experiments (35) that include treatments of crop residue management, tillage × nitrogen interactions, annual winter wheat, tillage systems for wheat/pea rotations, and native pasture. Wheat on four experiments (all except the native pasture) was evaluated for leaf spot severity during June 1991 and 1992. The cultivar Stephens was used on the plots during 1990–91 and Malcolm during 1991–92. Wheat (85 kg/ha) was planted in October at a 5–7-cm depth with a deep-furrow drill equipped with John Deere HZ openers, split packer wheels, and row spacings of 25 cm.

Long-term crop residue management. This experiment was established in 1931 and includes duplicate, offset treatments that allow a crop to be produced every year in a winter wheat–fallow rotation. Two replicates of nine 12 × 40 m treatments are prepared each year. Treatments include ammonium nitrate at 0, 45, or 90 kg/ha of N, with stubble either retained or burned during the spring (six treatments), no added N and stubble burned during autumn, and the addition of cow manure (22,460 kg/ha per crop) or pea vines (2,250 kg/ha per crop) in the spring. Primary tillage is performed by a moldboard plow (20 cm deep) in the spring. Secondary tillage consists of repeated shallow tillage with a rod weeder to conserve moisture and control weeds during the fallow.

Long-term tillage × nitrogen interactions. This experiment was established in 1940 and consists of a winter wheat–fallow rotation, with wheat produced only during alternate years. The experiment contains three main-plot tillage treatments and six subplot levels of nitrogen application. Subplots are 6 × 40 m and are replicated three times in a randomized complete block design. Tillage treatments are moldboard plow (23 cm depth, 5% of soil surface covered by residue), one-way disk (15 cm depth, 40% residue cover), and 30-cm subsurface sweeps (15 cm depth, 65% residue cover). Urea + ammonium nitrate is applied at rates of 0, 45, 90, 135, and 180 kg/ha of N.

Long-term annual winter wheat. This experiment began in 1931. Management of the entire plot area has been uniform since 1950, following 19 yr of fertilizer rate and source treatments. A preplant broadcast application of 90 kg/ha of N is now applied as a mixture of ammonium nitrate and ammonium phosphate sulfate. Soil is then moldboard plowed (20 cm deep) and planted.

Long-term wheat/pea rotation. A winter wheat/pea rotation with four treatments of conventional vs. conservation tillage systems was initiated in 1963. Main plots are 7 × 36 m and are arranged as randomized blocks with eight replicates; four replicates are planted to dry seed peas and four to wheat each year. The treatments are 1) rototill in autumn before planting spring peas, and Noble sweep and chisel plow in autumn before planting wheat; 2) moldboard plow in autumn before peas and Noble sweep before wheat; 3) moldboard plow in spring before peas, and Noble sweep and moldboard plow in autumn before wheat; and 4) no tillage before planting peas and Noble sweep before planting wheat. Rototilling, all plowing, and sweeping are to depths of 13, 51, and 5 cm, respectively.

RESULTS

Wheat cultivars. Winter wheat cultivars exhibited a wide range of susceptibility ($P < 0.001$) to leaf spot in each of the six nurseries. Leaf spot was not present at Lexington during 1991 and was of minor consequence at Pendleton during 1990. In the latter test, Stephens had a leaf spot rating of 3.7, and all other entries rated 0–1.7, with a plot mean of 0.8. Data for six other nurseries are reported in Table 1.

Rankings among cultivars for susceptibility to physiologic leaf spot varied only slightly by location and year. It was clear, however, that shifts in relative rankings were generally fewer than two severity rating units. The stability of ratings among the six plot-years was reflected by standard deviations that were generally one unit or less.

Entries of club-type soft white winter wheat were among the cultivars least susceptible to this leaf spot, with mean ratings of 1.6–2.8 (Table 1). A wide range of susceptibility occurred among cultivars of common-type soft white winter wheats (mean ratings of 1.7–5.3) and hard red winter wheat (mean ratings of 1.3–4.1). Stephens, the dominant cultivar (70% of the acreage) produced in the region, was the most susceptible cultivar overall and in most (four of seven) nurseries where the disease occurred. Two triticale cultivars (Whitman and Flora) were highly resistant to this leaf spot; ratings were 0–0.5 in all nurseries (*data not shown*).

Nitrogen rate. Leaf spot severity on Malcolm wheat was reduced by increasing rates of nitrogen ($P = 0.001$). Disease ratings were 7.8, 3.3, 2.5, and 1.3 (LSD = 3.7) for rates of 0, 56, 112, and 168 kg/ha of N.

Foliar nutrients. Leaf spot was absent on most flag leaves prior to crop maturation during 1991 (Table 2). On 15 May, plants were of uniform size and appearance, except that plants were taller (6–10 cm), greener, and more dense in the multiple urea + calcium chloride treatments. From 50 to 80% of the leaves exhibited symptoms of leaf spot on 15 May. At that time the disease was moderately severe in the lower plant canopy (i.e., the F-2, F-3, and lower leaves). A subsequent assessment on 5 June indicated that multiple applications of urea + calcium chloride had simply delayed the rate of disease progress, and did not affect its ultimate expression. Disease severity was uniformly present at a rating of six (0–10 scale) for all treatments on 5 June.

A single application of urea + calcium chloride on 6 May did not reduce leaf spot severity on 15 May or increase grain yield during 1991. In contrast, two or more applications to actively growing wheat during a mild winter and spring not only reduced disease severity on each of the upper four leaves but also increased grain yield ($P < 0.05$). Grain test weights and protein contents (7.5–8.6%) did not differ ($P > 0.10$) among treatments.

The severity of leaf spot for a specific leaf type (F, F-1, etc.) on the main stem during 1991 did not differ ($P > 0.05$) from the severity on the same leaf type for the two oldest tillers (*data not presented*). Likewise, the severity of disease on each leaf type was always correlated ($P < 0.01$) with the severity on each of the other leaves (*data not presented*).

Disease severity during 1992 was more pronounced than in 1991 (Table 2). When evaluations were made on 2 June, it was not possible to assign severity ratings to the F-2 and lower leaves because they had become chlorotic and prematurely senescent. Leaf spot on the F and F-1 leaves was reduced ($P < 0.05$) by one or two applications of urea + calcium chloride. Grain yield was also increased by one or two applications of calcium chloride. Test weights and protein contents (12.4–12.9%) of grain did not differ significantly. The addition of benomyl or propiconazole to the first of two applications of urea + calcium chloride did not improve control of leaf spot or increase grain yield compared to urea + calcium chloride alone.

The application of urea + micronutrients during February and April reduced the severity of leaf spot to levels intermediate between the control and the urea + calcium chloride treatment. The addition of benomyl or propiconazole to the urea + micronutrient mixture did not improve disease control. Grain yield was not increased by urea + micronutrients.

Regression analysis of leaf spot severity and grain yield during 1992 indicated highly significant inverse relationships ($P < 0.001$) in ratings made on the F and F-1. The regression equation for F was as follows: yield = 5,936 kg/ha − 53 (percent necrotic leaf area), ($P = 0.0002$, $r^2 = 0.50$). The equation for F-1 was: yield = 5,997 kg/ha − 27 (percent necrotic leaf area), ($P = 0.0007$, $r^2 = 0.46$).

Cultivar × nitrogen rate and timing interactions. Leaf spot severity differed significantly among cultivars ($P < 0.0001$) and nitrogen treatments ($P = 0.0004$) in this 4 × 9 factorial experiment. There was no cultivar × nitrogen interaction ($P = 0.37$). Nitrogen application procedures were compared to the typical industry practice of applying anhydrous ammonia at 90 kg/ha of N prior to planting. Leaf spot severity of the three most susceptible cultivars was significantly increased at N rates lower than the 90 kg/ha industry standard (Table 3). However, none of the treatments in which nitrogen application rates and timings varied from the standard caused leaf spot to differ on the cultivars Stephens, Madsen, and Malcolm. In contrast, applying 90 kg/ha below the seed at planting, rather than into fallow before planting, reduced the severity of leaf spot on the more resistant cultivar Hyak. None of the treatments caused an increase in disease severity on Hyak compared to the 90 kg/ha preplant standard. When date of application was disregarded, the tendency for disease severity to be less at high rates of nitrogen was present for susceptible cultivars (Fig. 1). Regression coefficients (r^2) and significance levels ($P > 0.05$ = NS, $P < 0.05$ = *, $P < 0.01$ = **, and $P < 0.001$ = ***) were 0.71*, 0.87**, 0.92***, and 0.65(NS) for Stephens, Malcolm, Madsen, and Hyak, respectively.

Table 3. Influence of nitrogen[a] rate and timing on leaf spot of four wheat cultivars during 1992

N rate (kg/ha) and timing			Leaf spot rating (0–10)[b]				
Summer	Autumn	Spring	Stephens	Madsen	Malcolm	Hyak	Mean
0	0	0	4.5	3.5	4.0	1.5	3.4
45	0	0	3.8	2.8	3.8	1.3	2.9
0	45	0	4.3	2.8	3.0	1.2	2.8
0	22	45	3.0	2.4	2.9	1.0	2.3
90	0	0	3.5	2.3	3.0	1.3	2.5
0	90	0	3.8	1.5	2.8	0.8	2.2
0	0	90	3.3	2.0	2.3	1.0	2.2
45	0	45	3.8	2.3	2.5	1.3	2.5
0	45	45	3.0	2.0	2.3	1.0	...
Mean			3.6	2.4	3.0	1.1	...
LSD ($P = 0.05$)			0.9	0.8	0.8	0.4	0.5

[a] Sources were preplant applied as anhydrous ammonia in late summer, liquid urea banded below the seed at planting in autumn, and/or ammonium nitrate broadcast topdressing in spring.

[b] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.

Herbicide × nitrogen rate and timing interactions. Leaf spot severity on Madsen wheat differed among nitrogen application treatments ($P = 0.002$) but not among herbicide management levels ($P = 0.53$) in this 2 × 9 factorial experiment. There was no herbicide × nitrogen interaction ($P = 0.33$). In contrast to the experiment described above, each of the four nitrogen application procedures that involved a topdressing during the spring significantly reduced ($P < 0.05$; LSD = 0.7) leaf spot severity (disease ratings of 1.9–2.4) on Madsen, as compared to the preplant application of 90 kg/ha of N (rating of 3.1). Applications of only 45 kg/ha of N preplant or at planting, or no application of N, led to disease ratings of 3.0–3.6.

Cultivar × surface residue interactions. Cultivars and residue levels each had significant effects ($P < 0.0001$ and $P = 0.008$, respectively) on leaf spot, and there was a significant cultivar × residue interaction ($P = 0.001$). The amount of straw residue remaining on the soil surface at the time of seeding increased leaf spot severity on the highly susceptible Stephens cultivar but not on the more resistant cultivars Daws, Moro, and Hyak (Table 4). Leaf spot on Stephens was more severe with moderate to high amounts of residue than with low residue.

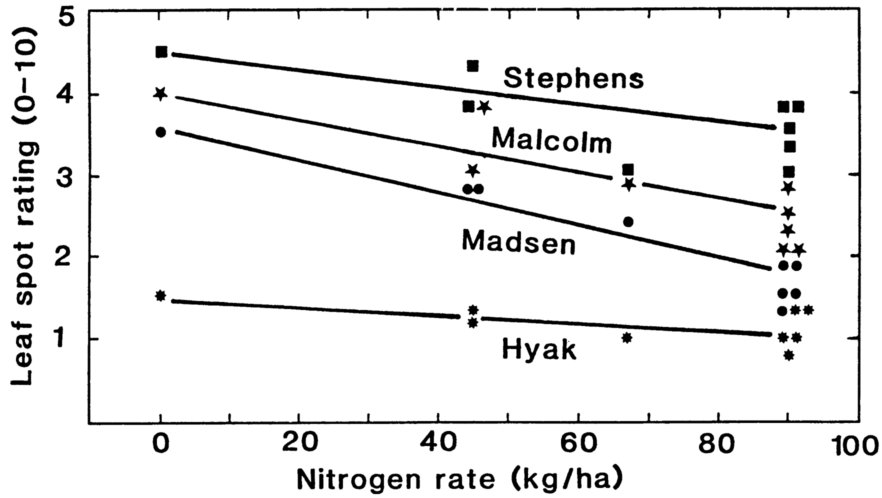

Fig. 1. Influence of nitrogen application rates on severity of leaf spot for four winter wheat cultivars. Nitrogen was from anhydrous ammonia, urea, or ammonium nitrate applied either preplant, at planting, or as a topdressing (nitrogen source and timing of application did not affect the response to nitrogen rate). For leaf spot ratings, 0 = no symptoms, 1 = fewer than four spots on the fourth (F-4) or third (F-3) leaf below the flag leaf, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on second (F-2) leaf below flag, and 5 = >25% on F-2. ■ = Stephens, ★ = Malcolm, ● = Madsen, and * = Hyak.

Table 4. Influence of the amount of crop residue (wheat stubble) on severity of leaf spot[a] on four cultivars of winter wheat during 1992

Crop residue[b]	Stephens	Daws	Moro	Hyak
Low	2.1	1.9	0.8	0.4
Moderate	4.0	1.8	1.0	0.5
High	3.6	1.6	0.6	0.3
LSD ($P = 0.05$)	0.9	NS[c]	NS	NS

[a] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.
[b] Low = 17% of soil surface covered, moderate = 39%, and high = 49%.
[c] NS = Not significant.

Planting date. Leaf spot severity on Stephens wheat during midspring (April) declined significantly in response to planting dates spaced in 15-day increments from 1 September to 15 November (Table 5). The heads had not emerged when plants were sampled during April. By 6 May, the heads for the September plantings had emerged. Very little leaf spot occurred on the flag leaf, and disease severity became more severe with each next oldest leaf (Table 5). The influence of planting date on leaf spot severity was still present for the F-1 and F-2 leaves, but was not obvious on F-3 leaves. On 4 June, when plants were in the soft dough stage, the influence of planting date on disease severity was becoming obscure on all leaves for all except the November plantings.

Long-term crop management experiments. *Long-term crop residue management.* The severity of leaf spot in a wheat–fallow rotation (Table 6) during 1991 was highest at intermediate levels of nitrogen fertility. Leaf spot ratings were lowest when no nitrogen was applied, became significantly higher with the application of 34 kg/ha of N as pea vines, and peaked with the application of 45 kg/ha of N as anhydrous ammonia. The ratings then declined with 90 kg/ha as anhydrous ammonia and with 111 kg/ha as cow manure. The maximum severity occurred between 45 and 90 kg/ha of N, as described by the following polynomial equation: percent leaf spot $= 2.22 + 0.06N + 2.97N^2$ ($P = 0.004$). The source of nitrogen had no effect on disease response. Although leaf spot severity was not significantly affected by these treatments during 1992, the shape

Table 5. Influence of planting date on leaf spot severity[a] on Stephens wheat

Planting date (1991)	Assessment date (1992) and leaf or leaves									
	6 Apr. (all leaves)	21 Apr. (all leaves)	6 May				4 June			
			F	F-1	F-2	F-3	F	F-1	F-2	F-3
1 Sept.	8.3	7.6	0.3	5.6	7.5	7.9	3.2	7.1	S[b]	S
15 Sept.	8.4	5.5	0	3.7	6.9	8.1	3.4	7.2	8.5	S
1 Oct.	5.3	5.3	0	3.1	5.3	7.7	2.9	6.8	7.1	S
15 Oct.	4.6	4.7	0	1.5	5.2	7.4	3.1	6.2	7.3	S
1 Nov.	2.5	3.4	0	0.2	0.4	5.4	2.1	3.1	4.9	6.7
15 Nov.	1.3	1.7	0	0	0.5	3.2	0.2	2.5	3.4	6.9
LSD ($P = 0.05$)	1.4	1.2	NS[c]	1.9	0.8	1.3	1.5	2.1	1.8	...

[a] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.
[b] S = Many or most leaves senesced prematurely.
[c] NS = Not significant.

of the plotted data curve was similar to that for 1991.

At comparable rates of nitrogen, there was no difference among leaf spot ratings when wheat stubble remained standing through the winter and was then either burned in the spring or incorporated into the soil with a moldboard plow. Additionally, burning the stubble during the autumn was equivalent to burning it during the spring (*data not presented*). These observations are contrary to the response of Stephens wheat to three levels of residue in the cultivar × surface residue interaction study (Table 4).

Table 6. Influence of crop residue management and nitrogen on leaf spot ratings[a]

Nitrogen rate (kg/ha)	Nitrogen source	Stubble burned		Stubble incorporated	
		1991	1992	1991	1992
0	Ammonium nitrate	2.3	5.5	2.2	4.5
45	Ammonium nitrate	4.3	6.0	4.4	5.0
90	Ammonium nitrate	3.8	4.0	3.8	3.5
34	Pea vines	...	...	2.9	4.5
111	Cow manure	...	...	3.1	3.5
LSD ($P = 0.05$)		0.4	NS[b]	0.4	NS

[a] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.
[b] NS = Not significant.

Table 7. Influence of tillage implement and nitrogen rate[a] on leaf spot ratings[b] during 1991

Nitrogen (kg/ha)	Tillage			Mean	LSD ($P = 0.05$)
	Plow	Disk	Sweep		
0	3.0	2.7	3.0	2.9	NS[c]
45	4.7	3.3	3.3	3.8	0.4
90	3.3	3.0	2.3	2.9	0.4
135	2.7	2.3	2.7	2.6	NS
180	2.3	1.7	1.3	1.8	NS
Mean	3.2	2.6	2.5	...	...
LSD ($P = 0.05$)	0.6	0.4	0.5	0.5	...

[a] Differences were significant for nitrogen ($P = 0.001$) and tillage ($P = 0.001$), but not for nitrogen × tillage interaction ($P = 0.297$).
[b] Leaves are flag leaf (F) and first (F-1), second (F-2), third (F-3), and fourth (F-4) leaves below the flag leaf. Ratings are on a 0–10 scale, where 0 = no symptoms, 1 = <4 spots on the F-4 or F-3, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on F-2, 5 = >25% on F-2, 6 = <25% on F-1, 7 = >25% on F-1, 8 = <15% on F, 9 = 15–40% on F, and 10 = >40% on F.
[c] NS = Not significant.

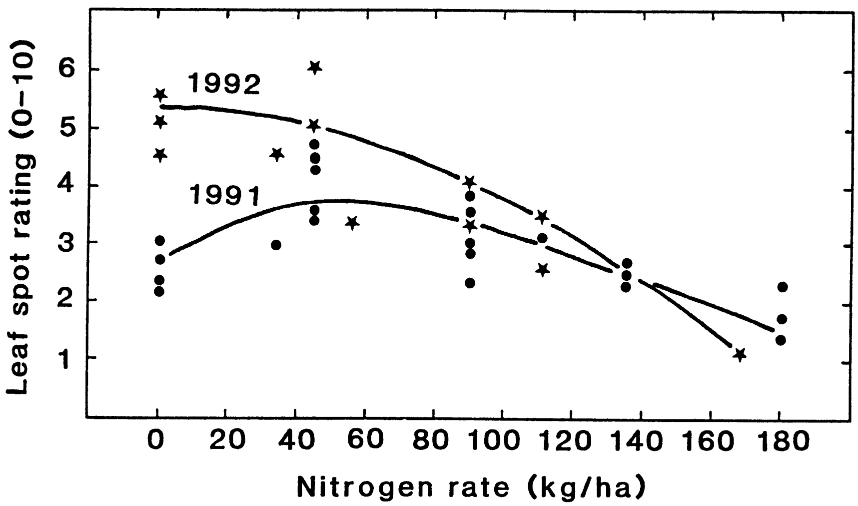

Fig. 2. Severity of leaf spot in response to rates of nitrogen during 1991 and 1992. Source of N (anhydrous ammonia, ammonium nitrate, cow manure, or pea vines), time of application (summer preplant, at-plant banding, or spring topdressing), and tillage (moldboard plow, disk, or sweep) had no effect on disease severity. For leaf spot ratings, 0 = no symptoms, 1 = fewer than four spots on the fourth (F-4) or third (F-3) leaf below the flag leaf, 2 = <25% necrosis on F-3, 3 = >25% on F-3, 4 = <25% on second (F-2) leaf below flag, 5 = >25% on F-2, and 6 = <25% on first (F-1) below the flag. ● = 1991 and ★ = 1992.

Long-term tillage × nitrogen interactions. Leaf spot was more severe when the moldboard plow was used than when soil was treated less intensively with a disk or sweep (Table 7). Examination of this treatment effect indicated that most of the response to tillage equipment occurred at intermediate rates (45 and 90 kg/ha) of nitrogen application. Differences were less apparent, and usually not significant ($P > 0.05$), when no nitrogen was added and when application rates were more than those commonly used (90–120 kg/ha) to produce wheat in the study area. The severity of leaf spot for all three tillage systems was higher at 45 kg/ha of N than at lower or higher application rates. The effects of tillage on leaf spot severity in this experiment were opposite those observed for Stephens wheat in the cultivar × surface residue interaction experiment (Table 4).

Because the relationship of leaf spot severity to nitrogen application rate was similar for data presented in Tables 6 and 7, the data sets were combined (Fig. 2). The highest leaf spot ratings occurred at approximately 45 kg/ha of N. The model describing this relationship is: percent leaf spot = $8.83 + 1.91N + 6.93N^2$ ($P < 0.001$).

Long-term annual winter wheat and wheat/pea rotations. Leaf spot severity did not differ among tillage treatments in the wheat/pea rotation. Mean disease severity ratings during assessments on 3 April 1992 were 0.5 (+/−0.2) for the wheat/pea rotations. Ratings in the annual winter wheat plot averaged 7.1. These experiments were located adjacent to one another. In contrast, the mean rating was 3.5 in a comparable nitrogen rate treatment (90 kg/ha) of the nearby wheat/fallow rotation. Later in the growing season the ratings became more uniform; leaf spot ratings on 5 June were 4.6, 7.3, and 5.1 in the wheat/pea, annual wheat, and wheat/fallow plots, respectively. These comparisons were not subjected to statistical analysis.

DISCUSSION

This is the first report of crop management procedures for reducing damage to winter wheat by physiologic leaf spot. Leaf spot incidence and severity were reduced by cultivar selection, delaying the planting date, increasing the rate of soil-applied nitrogen fertilizer, applying urea + calcium chloride to foliage, and reducing the frequency of wheat in the crop sequence. We also provide evidence to support an earlier report (37) that physiologic leaf spot can reduce grain yield by at least 10% and is not controlled by fungicides. Control measures are likely to result in a yield response during years when this disease causes necrotic spots on the flag leaf and other uppermost leaves.

Management practices that had no apparent effect on leaf spot severity included the application of diclofopmethyl herbicide, different application timings or sources of nitrogen, and burning stubble of the previous wheat crops. Tillage practices that left different amounts of straw residue on or near the soil surface gave inconclusive results.

Winter wheat cultivars varied in susceptibility to physiologic leaf spot and were relatively consistent in response over seasons and locations. There was no apparent relationship between leaf spot susceptibility and genotype heritage, maturation date, or market class. Heritability studies such as those used for tan spot (25) are needed to determine if genotypes with higher levels of resistance to physiologic leaf spot can be selected.

It is important to identify crop management practices that minimize the risk associated with errors in disease identification, because it is difficult to distinguish physiologic leaf spot from tan spot (*Pyrenophora tritici-repentis* (Died.) Drechs.) or Septoria leaf blotch (*Septoria tritici* Roberge in Desmaz., *S. nodorum* (Berk.) Berk. in Berk & Broome, and/or *S. avenae* A.B. Frank f. sp. *triticea* T. Johnson). Symptom descriptions and effects of management practices for tan spot and Septoria leaf blotch are well described and illustrated (4,11,18,22,24,28,30,31,41,42). Physiologic leaf spot, tan spot, and Septoria leaf blotch are each suppressed by crop rotation, selection of resistant cultivars, and delayed seeding. Septoria leaf blotch can also be controlled with fungicides and by avoiding excessive rates of nitrogen fertilizers. Tan spot and Septoria leaf blotch are suppressed by avoiding dense plant canopies early in seedling development, and by reducing primary inoculum by destroying (burning or burying) residues from previously infected wheat stubble. In our studies, these management practices either were ineffective for reducing damage by physiologic leaf spot or were inconclusive. Excess nitrogen, which reduces the severity of tan spot, also reduced the severity of physiologic leaf spot.

Urea + calcium chloride suppressed physiologic leaf spot, prolonged the juvenility of leaves, and increased grain yield. Urea plus a mixture of micronutrients which did not contain calcium or chloride provided an intermediate level of disease control but no increase in grain yield. These results suggest that physiologic leaf spot damage was reduced by calcium chloride either alone or in combination with urea, rather than by urea alone. This possibility requires further investigation.

Calcium is required in plants to protect the roots from the deleterious effects of low pH, toxic ions, salinity, and ion imbalance (10). Calcium delays senescence and reduces membrane damage and leakiness. Calcium deficiency has been associated with reduced cold hardiness, increased risk of magnesium toxicity, and reduced growth of meristematic tissues (20,26,29). Although calcium is well known for improving plant resistance to diseases caused by some soilborne plant pathogens (17), there is little evidence that this element in natural soils has an important role in foliar diseases. Calcium deficiency in nutrient solution was, however, associated with enhanced lesion development in tobacco (*Nicotiana glutinosa* L.) plants infected by the tobacco mosaic virus (6). Although soil acidification is occurring in silt loams of the Pacific Northwest (2,33), there is no evidence that calcium concentrations (1) have reached a critical level for wheat growth and metabolism (5).

Chloride is necessary for photosynthesis and osmotic relations of guard cells in leaves (10,20,26,29). Laboratory-induced chloride deficiency results in loss of turgor (wilting), chlorosis, and reduced leaf growth (reduced cell multiplication); however, it is highly unlikely that chloride deficiency occurs in wheat produced in natural soils (14). Nevertheless, application of chloride salts to soil or foliage has suppressed wheat diseases caused by species of *Septoria* (8,12,16, 19) and *Puccinia* (8,16,21,36). Grain yields also have been increased by applied chloride, and these responses have (3,7,9,34,38) or have not (15,39) been associated with reductions in the severity of diseases caused by soilborne plant pathogens. The uptake of chloride also has been associated with reduced wheat leaf water potential and increased leaf turgor potential without markedly altering leaf xylem potential (9). Fixen et al (19) reported that Septoria avenae blotch was reduced by applied chloride at one of six field locations where chloride increased wheat yield. Fixen et al (19) also found that chloride did not affect yield at eight of 14 sites. Trolldenier (39) observed that flag leaves remained green longer when chloride was applied. He concluded that chloride fertilizers increase grain yields by prolonging photosynthetic activity. Engel et al (16) reviewed reports indicating that chloride affected a wide range of developmental processes, including rate of spikelet formation and maturation, and volume and weight of kernels.

Although the specific relationship between chloride application and crop yield is not understood, it is clear that the beneficial effects of chloride on grain yield are not always dependent on reduction in disease severity (15,16,19,39). It appears possible that chloride may affect physiological processes such as water relations, photosynthesis, or kernel development to minimize damage caused by physiologic leaf spot. Additional studies are required to determine if the response of physiologic leaf spot to the application of urea plus calcium chloride is indeed associated with the chloride ion.

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