DISEASE MANAGEMENT

Leaf Spot Diseases of Barley and Spring Wheat as Influenced by Preceding Crops

J. M. Krupinsky,* D. L. Tanaka, M. T. Lares, and S. D. Merrill

ABSTRACT

Crop diversification and crop sequencing can influence plant disease risk in cropping systems. The objective of this research was to determine the effect of 10 previous crops on leaf spot diseases of barley (*Hordeum vulgare* L.) and hard red spring wheat (*Triticum aestivum* L.). Barley and spring wheat were direct-seeded (no till) in the crop residue of 10 crops {barley, canola (*Brassica napus* L.), crambe (*Crambe abyssinica* Hochst. ex R.E. Fr.), dry bean (*Phaseolus vulgaris* L.), dry pea (*Pisum sativum* L.), flax (*Linum usitatissimum* L.), safflower (*Carthamus tinctorius* L.), soybean [*Glycine max* (L.) Merr.], sunflower (*Helianthus annuus* L.), and spring wheat}. Barley was evaluated for leaf spot diseases 15 times over 2 yr. Results indicate that risk for leaf spot disease on barley would be lower following wheat, crambe, canola and dry pea compared with the barley-after-barley treatment. Although barley yields were similar across all treatments one year, differences were detected in another year with the barley-after-barley treatment having the lowest yield. Spring wheat was evaluated for leaf spot diseases 22 times over 2 yr. Differences among treatments were more detectable in earlier evaluations, indicating a greater influence of crop residue and carryover of inoculum early in the season compared with later. The risk for leaf spot disease was lower when wheat was grown after canola, barley, crambe, and flax than when grown after the other crops. Although wheat yields were similar across all treatments one year, differences were detected in another year with the wheat-after-wheat treatment having the lowest yield.

In the past, a cereal–fallow sequence has been used in the northern Great Plains to reduce the risk of crop failure due to lack of soil moisture. More recently, there has been a greater emphasis on the retention of crop residues on the soil surface, thereby increasing precipitation use efficiency and water storage and minimizing soil erosion (Peterson et al., 1996). Improved methods of soil water storage have led to the development of more intensive cropping systems than the crop–fallow system (Greb, 1983; Halvorson et al., 2000; Tanaka and Anderson, 1997). Annual cropping, which includes alternative crops such as oilseeds, pulses, and forages, has become a viable option for producers with the adoption of conservation or reduced-tillage systems. Decreasing commodity prices for traditional small-grain crops have also encouraged greater crop diversification in the northern Great Plains. Diversification of cereal cropping systems with alternative crops presents the producer with a range of agronomic and economic options. A number of alternative crops have shown good potential for diversifying cropping systems in the semiarid prairie (Miller et al., 2002). As new crops are incorporated into producer's crop rotations, more information is necessary to determine the benefits and/or disadvantages of previous crop and crop residues on crop production. Proper sequencing of crops is recognized as an important component of cropping systems (Leighty, 1938; Pierce and Rice, 1988; Tanaka et al., 2002).

Crop diversification can improve the management of plant diseases through crop selection and interruption of disease cycles through crop rotation. The survival of fungi on residue from a previous crop is an important means of carryover from one crop to the next. Crop rotations take advantage of the fact that plant pathogens important on one crop may not cause disease problems on another crop. Appropriate crop rotations lengthen the time between crop types so that pathogen populations have time to decline. Crop rotation allows time for the decomposition of residue on which pathogens carry over, and natural competitive organisms reduce the pathogens on the remaining residue while unrelated crops are being grown (Cook and Veseth, 1991; Krupinsky et al., 2002a). Leaf spot disease severity can be greater in monoculture compared with following an alternative crop. For example, when tan spot [*Drechslera tritici-repentis* (Died.) Shoemaker] and stagonospora nodorum blotch [*Stagonospora nodorum* (Berk.) Castellani & E.G. Germano] were the dominant diseases, Fernandez et al. (1998) observed that wheat after wheat had a higher disease severity than wheat grown after flax or lentil. This was particularly evident in years with high disease pressure but not in years with low disease. Even when rotations have limited impact on wheat disease severity, pathogen populations are generally reduced, and higher yields are associated with wheat grown in diversified crop rotations compared with wheat in monoculture (Bailey et al., 2001). Disease risks associated with different crop rotations used in the northern Great Plains have been summarized (Anonymous, 1994; Krupinsky et al., 2002a; McMullen and Lamey, 1999).

Spring wheat is a major crop in the northern Great Plains area and can be impacted by leaf spot diseases. The major leaf spot diseases on wheat in this area are tan spot and stagonospora nodorum blotch. Other leaf spot diseases present on wheat in this region include

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spot blotch [*Bipolaris sorokiniana* (Sacc.) Shoemaker], stagonospora avenae blotch (*Stagonospora avenae* Bissett f. sp. *triticea* T. Johnson), and septoria tritici blotch (*Septoria tritici* Roberge in Desmaz) (Fernandez et al., 1998; Gilbert and Woods, 2001; Krupinsky and Tanaka, 2001; Wiese, 1987). In a survey of 248 producers' fields in southern Manitoba over several years, Gilbert and Woods (2001) reported that *S. nodorum, D. tritici-repentis, S. tritici*, and *B. sorokiniana* were commonly isolated, with no significant rotation effect on isolation of *P. tritici-repentis* or *S. nodorum.*

Barley is a major crop in the northern Great Plains semiarid area. Leaf spot diseases on barley can cause economic losses in yield and quality. Net blotch [*Drechslera teres* (Sacc.) Shoemaker], spot blotch, and scald [*Rhynchosporium secalis* (Oudem.) J. J. Davis] are widely distributed on barley. *Septoria* spp. and *Stagonospora* spp. diseases present on barley include septoria speckled leaf blotch (*Septoria passerinii* Sacc.), stagonospora avenae leaf blotch, and stagonospora nodorum blotch (Kiesling, 1985; Mathre, 1997). In a 1998 survey of North Dakota fields, the most common leaf spot diseases were net blotch, spot blotch, septoria speckled leaf blotch, and stagonospora avenae leaf blotch (Krupinsky and Steffenson, 1999). These diseases were similar to those in Saskatchewan, Canada, north of western North Dakota, where net blotch was considered the most common leaf-spotting disease followed by spot blotch, which was more common than *Septoria* spp. (Fernandez et al., 1999). In Manitoba, Canada, north of eastern North Dakota, leaf spot diseases were considered to cause minimal damage in 1998. Net blotch and spot blotch were found in 90 to 93% of the barley fields, and septoria speckled leaf blotch was recovered in 22% of the fields (Tekauz et al., 1999).

The influence of previous crops and crop residues on plant diseases and crop production should be more fully understood to develop effective crop sequences that include barley and wheat in diverse cropping systems.

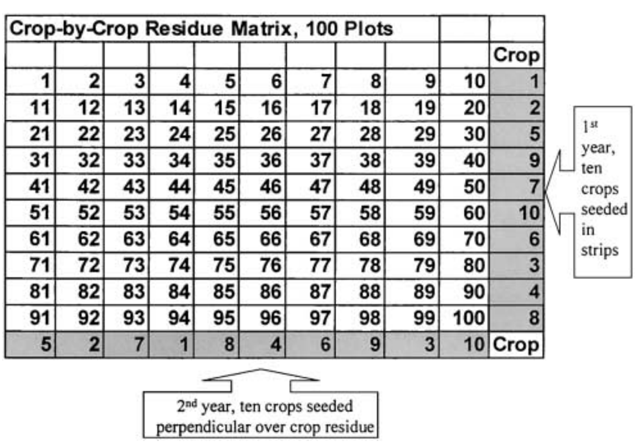

Fig. 1. Design of one replicate of a crop-by-crop residue matrix used to evaluate the influence of crop sequence on leaf spot diseases of barley and wheat. During the first year, 10 crops (numbered 1 through 10) were seeded into a uniform crop residue. During the second year, the same crops were no-till–seeded perpendicular over the residue of the previous year's crop. Individual plot numbers were assigned for each of the four replications.

The objective of this research was to determine how previous crops affect the severity of leaf spot diseases of barley and wheat with no-till management under semiarid conditions of central North Dakota.

MATERIALS AND METHODS

Research was conducted at the Area IV Soil Conservation Districts/Agricultural Research Service Research Farm near the Northern Great Plains Research Laboratory, southwest of Mandan, ND, on Wilton silt loam (fine-silty, mixed, superactive frigid Pachic Haplustolls). Before this research project, the field (12 ha) was in a hard red spring wheat–winter wheat–sunflower rotation for 14 yr. In 1997, the year before research began, a direct-seeded (no-till) winter wheat crop was present. In 1998, the field area was divided into two research sites, east and west. Research was started on the east site in 1998 and on the west site in 1999. Barley was direct-seeded on the west site in 1998.

Because only a limited number of crop sequences can be evaluated in a fixed cropping system study, an experimental crop matrix design was used allowing the simultaneous evaluation of numerous combinations of crops in the same experiment under similar weather and soil conditions. Two years were required to form a crop-by-crop residue matrix in which 10 crops could be direct-seeded into the crop residue of the same 10 crops (Fig. 1). During the first year (east site in 1998 and west site in 1999), four replicates of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and hard red spring wheat) were direct-seeded in strips (9 m wide and 90 m long) with a John Deere 750 no-till drill into a uniform cereal residue (winter wheat residue on east site in 1998 and barley residue on west site in 1999). During the second year (east site in 1999 and west site in 2000), the same 10 crops were direct-seeded perpendicular over the residue of the previous year's crop. This established four replicates of a 10 × 10 matrix with 100 treatment combinations where each crop was grown on 10 crop residues (Fig. 1). The four replicates of the crop-by-crop residue matrix were present in the field for two consecutive years. Each experimental unit was a 9- by 9-m plot. Nitrogen was applied as a band application of NH_4NO_3 at 67 kg N ha^{-1} (60 lb/acre) during seeding. Phosphorus was applied with the seed as treble super phosphate at 11 kg P ha^{-1} (10 lb/acre). Glyphosate [*N*-(phosphonomethyl) glycine isopropylamine salt] was applied after the early seeded crops (canola, crambe, dry pea, flax, safflower, barley, and spring wheat) and before the late-seeded crops (dry bean, sunflower, and soybean). The 10 cultivars were Montola 2000 safflower, Stander barley, Dynamite canola, Meyer crambe, Shadow Black Turtle dry bean, Profi dry pea, Omega flax, Jim soybean, Cenex 803 oilseed sunflower, and Amidon spring wheat. Growing season precipitation (May through August) was 197% in 1999 and 112% in 2000 of an 85-yr long-term average [25 cm (10 in)]. Seed yield was determined by harvesting (11.4 m^2) with a plot combine.

Residue Carryover

After the spring wheat crop was seeded, the percentage of soil surface covered with residues from the previous crops was evaluated within the strip of wheat following the 10 crops. A 7.6-m (25-ft) cable with 25 marked points at 30-cm (1-ft) intervals was stretched across each plot four times to count the number of residue hits. Two V patterns were formed on each plot, in the same direction of the seeding. If residue intersected with a point on the cable, it was counted as a hit. The total number of residue hits and number identified as wheat residue were recorded.

Leaf Spot Disease Severity

The barley crop was evaluated for leaf spot disease severity 11 times in 1999 (16 July through 6 August) and four times in 2000 (6 July through 19 July). The wheat crop was evaluated for leaf spot disease severity 14 times in 1999 (16 July through 11 August) and eight times in 2000 (6 July through 31 July). Twenty leaves of the same leaf type (e.g., flagleaf, the uppermost leaf) from plants at the same stage of plant development (Large, 1954) were evenly collected from each plot for each evaluation (20 leaves per plot × 10 residue treatments = 200 leaves per replicate for each evaluation of barley or wheat). Thirty plots (10 residue treatments × 3 replications) were sampled each time disease severity was evaluated in 1999. One replicate was not evaluated in 1999 because of excess soil wetness and movement of residue. All barley and wheat plots (10 residue treatments × 4 replications = 40 plots per crop) were evaluated in 2000. The total percentage of necrosis and chlorosis was visually assessed for individual leaves and used as an indicator of the severity of leaf spot diseases. The leaves rated were the flagleaf (the uppermost leaf, FL), flagleaf-1 (the first leaf below the flagleaf, FL-1), flagleaf-2 (FL-2), and flagleaf-3 (FL-3).

Leaf Spot Diseases Present

To determine which leaf spot diseases were present during the evaluations, green leaves with lesions were collected, pressed, allowed to dry, and stored in a refrigerator at 2 to 4°C until they were processed to identify fungi present. One to six months after collection, eight leaf sections (≈3 cm long) from each plot were surface-sterilized for 3 min in a 1% (v/v) sodium hypochlorite solution containing a surfactant, rinsed in sterile distilled water, plated on water agar in plastic Petri dishes, and incubated under a 12-h photoperiod (cool-white fluorescent tubes) at 20°C. After 7 d, leaf sections were examined, and fungi were microscopically identified. The number of leaf sections infected with a particular fungus was used as an indicator of the relative importance of that fungus in causing leaf spot diseases in the field. Fungal identifications were conducted for one replicate from two or three evaluations (early, mid-, and late season) from each year. From the 1999 growing season, 240 barley (8 leaves × 10 plots × 3 evaluations) and 160 wheat leaf samples were processed for fungi present. From the 2000 growing season, 240 barley and 240 wheat leaf samples were processed.

Statistical Analysis

The severity of leaf spot diseases on barley and spring wheat were analyzed using ANOVA (replicate and crop residue as main factors, and replicate × crop residue interaction as error term) and Dunnett's one-tailed test on the arcsin square-root–transformed percentage necrosis data for each of the field evaluations (SAS 8.0, SAS Inst., Cary, NC). The barley-after-barley and the wheat-after-wheat treatments were considered to have the highest potential for disease development and were used as checks for all barley and wheat comparisons, respectively. Analysis of variance and Dunnett's one-tailed test were used to compare yields from each treatment with the check treatments. Residue carryover was analyzed using ANOVA and Student–Newman–Keuls' multiple-comparison procedure (SNK). Statistical differences were evaluated at a probability level of $P \leq 0.05$. An initial report with limited data was made (Krupinsky et al., 2002b, 2002c).

RESULTS AND DISCUSSION

Barley Leaf Spot Diseases

Of all the barely leaf sections processed, 73% were infected with *D. teres*, 49% with *S. avenae* f. sp. *triticea*, 48% with *S. passerinii*, 40% with *B. sorokiniana*, 25% with *S. nodorum*, and 7% with *D. tritici-repentis*. Using the number of leaf sections infected with a particular fungus as an indicator of the relative importance of a disease, the most common disease over both years was net blotch, followed by stagonospora avenae leaf blotch, septoria speckled leaf blotch, and spot blotch. Although stagonospora nodorum blotch and tan spot, important diseases on wheat (Wiese, 1987), were present, they are generally considered to be minor diseases on barley (Mathre, 1997). In general, these results are comparable to a leaf spot disease complex on barley reported by Krupinsky and Steffenson (1999) and similar to Canadian reports from Saskatchewan (Fernandez et al., 1999) and Manitoba (Tekauz et al., 1999).

Wheat Leaf Spot Diseases

Of all the wheat leaf sections processed, 85% were infected with *D. tritici-repentis*, 81% with *S. nodorum*, 51% with *S. tritici*, 40% with *S. avenae* f. sp. *triticea*, and 35% with *B. sorokiniana*. Thus, tan spot and stagonospora nodorum blotch were the most common diseases on Amidon spring wheat over both years. In general, results are consistent with the pattern of fungal isolations from wheat in the northern Great Plains (Fernandez et al., 1998; Gilbert and Woods, 2001; Krupinsky and Tanaka, 2001). Other diseases such as powdery mildew (*Erysiphe graminis* DC. f. sp. *tritici* E. Marchal), stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Ericks. & E. Henn.), or leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici*) were not evident.

Residue Carryover

After direct-seeding wheat in 1999, the total amount of soil surface covered by crop residue was similar, ranging from 96% after wheat to 77% after dry bean (Table 1), but wheat residue coverage varied among treat-

Table 1. Soil surface covered by crop residues in 1999 and 2000 after seeding wheat following 10 different crops. Values followed by the same letter within a column are not significantly ($P \leq 0.05$) different from each other.†

Previous crop	1999 Total‡	1999 Wheat§	Previous crop	2000 Total	2000 Wheat
	residue coverage, %			residue coverage, %	
Wheat	96a	93a	Wheat	94a	60a
Barley	91a	19b	Barley	92a	0b
Flax	90a	17b	Flax	87ab	0b
Canola	90a	21b	Canola	86ab	0b
Safflower	85a	24b	Crambe	77b	0b
Soybean	85a	23b	Safflower	54c	0b
Crambe	82a	24b	Soybean	52c	0b
Dry pea	81a	13b	Dry bean	36d	0b
Sunflower	78a	32b	Dry pea	32d	0b
Dry bean	77a	24b	Sunflower	31d	0b

† A cable with marked points at 30-cm intervals was stretched across each plot four times to count the number of residue hits.
‡ A total of all residue hits without considering the plant type.
§ Number of hits that were wheat residue.

Table 2. Summary of analyses of variance for leaf spot severity (percentage necrosis and chlorosis) on Stander barley grown on the residue of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and wheat) in 1999 and 2000.

Source of variation	df	Rating dates, leaf evaluated, and disease severity					
		16 July 1999 FL-3† 18%‡	20 July 1999 FL-3 42%	26 July 1999 FL-3 80%	26 July 1999 FL-2 28%	28 July 1999 FL-2 42%	30 July 1999 FL-2 60%
		P > *F*					
Replicate	2	0.0007**	0.0081**	0.0005**	0.1748NS	0.0064**	0.0019**
Residue	9	0.0031**	0.0041**	0.0005**	0.0003**	0.0007**	0.0005**
		3 Aug. 1999 FL-2 84%	28 July 1999 FL-1 13%	30 July 1999 FL-1 22%	3 Aug. 1999 FL-1 56%	6 Aug. 1999 FL-1 80%	
		P > *F*					
Replicate	2	0.0338*	0.4979 NS	0.0017**	0.0009**	0.0009**	
Residue	9	0.0137*	0.0169*	0.0076**	0.0089**	0.0562 NS	
		6 July 2000 FL-3 59%	10 July 2000 FL-2 47%	13 July 2000 FL-1 24%	19 July 2000 FL 63%		
		P > *F*					
Replicate	3	0.0022**	0.0001**	0.013*	0.0001**		
Residue	9	0.0002**	0.039*	0.021*	0.1286 NS		

* Significant at $P \leq 0.05$.
** Significant at $P \leq 0.01$.
† FL-1 = first leaf below the flagleaf, FL-2 = second leaf below the flagleaf, and FL-3 = third leaf below the flagleaf. The growth stages for the flagleaf-3 ratings ranged from heading through milk dough [10.5 to 11.3, Feekes scale (Large, 1954)], and the flagleaf-2 and flagleaf-1 ratings were made during the milk dough stage [11.3, Feekes scale (Large, 1954)].
‡ Overall average disease severity, percentage necrosis and chlorosis.

ments. Wheat residue accounted for 93% of the residue coverage after wheat to 13% after dry pea, with wheat coverage being significantly different from all other treatments. This would be expected since the wheat residue following wheat carried over from the previous year (wheat treatment grown in 1998), whereas the wheat residue following the other crops was from 2 yr before (1 yr without a wheat crop).

Residue covering the soil surface varied among treatments after direct-seeding wheat in 2000. The total amount of soil surface covered by crop residue ranged from 94% after wheat to 31% after dry pea, with significant differences among treatments. The treatments with the most residue were those following wheat, barley, flax, canola, and crambe. The treatments with the least residue followed dry bean, dry pea, and sunflower. Wheat residue was present after wheat but lacking after the other treatments (Table 1).

When looking at differences in total residue between years, one can speculate that the higher-than-average precipitation during 1999 facilitated the breakdown of crop residue from the 1999 crop, leading to a greater difference in residue carryover among treatments at the beginning of the 2000 season. The difference in the carryover of wheat residue between years probably was due to the number of years without a wheat crop, 1 yr out of wheat in 1999 vs. 2 yr out of wheat in 2000.

Disease Severity on Barley after Different Crops

There were differences among residue treatments, indicating that the severity of leaf spot diseases on barley was influenced by the previous crop. These differences were evident for 10 of 11 evaluations in 1999 and for three of four evaluations in 2000 (Table 2). When comparing disease severity on barley after each crop residue and the barley-after-barley treatment, which was used as a check, several treatments had less disease than the barley-after-barley treatment. The number of treatments different from the barley-after-barley check varied over time. In 1999, the number of treatments different from the barley-after-barley treatment varied from eight to one (Fig. 2). In 2000, the number of treatments different from the barley-after-barley treatment varied from eight in the first evaluation to none for the last evaluation (Fig. 2). Multiple ratings during the season appear to be necessary for a better understanding of disease severity following residue treatments compared with an individual rating. If only one evaluation was done each year, different conclusions could be reached depending on the timing of the evaluation.

The impact of leaf spot diseases during the growing season was detected for various crop sequences with multiple evaluations. The barley-after-wheat treatment consistently had less leaf spot disease than the barley-after-barley treatment when differences were detected (Table 3). Other treatments with a pattern of less disease severity than the barley-after-barley treatment were barley after canola, barley after crambe, and barley after dry pea (Table 3). Conversely, barley after dry bean, barley after flax, and barley after soybean tended to be similar to the barley-after-barley treatment most of the time (Table 3). The barley-after-safflower and barley-after-sunflower treatments were not consistent in their effect on disease severity (Table 3).

These results indicate that the risk for leaf spot disease on barley would be lower following wheat, crambe, canola, and dry pea compared with barley after barley; moderate following safflower and sunflower; and similar to barley after barley following dry bean, flax, and soybean. Disease severity following crambe, canola, and dry pea would be expected to be lower compared with following barley because of crop diversity; in other words,

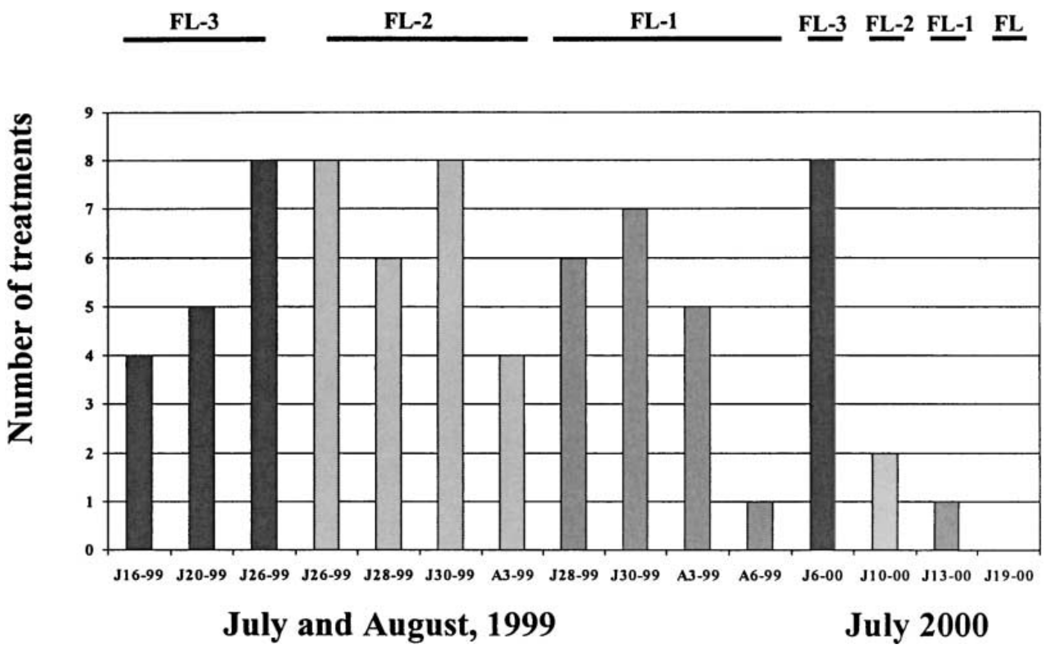

Fig. 2. Number of crop residue treatments in 1999 and 2000 with significantly less ($P \leq 0.05$) disease than the barley-after-barley treatment used as the check (Dunnett's one-tailed comparison). FL-1 = first leaf below the flagleaf, FL-2 = second leaf below the flagleaf, and FL-3 = third leaf below the flagleaf.

the major diseases on crambe, canola, and dry pea do not cause leaf spot diseases on barley. For the same reason, one would not expect disease severity in the barley-after-dry bean treatment to be similar to the barley-after-barley treatment.

Surprisingly, the severity of leaf spot diseases associated with the barley-after-wheat treatment is consistently lower than that of the barley-after-barley treatment even though wheat and barley have some diseases in common, e.g., spot blotch. Considering that Duczek et al. (1999) have reported that the major pathogens on wheat, *S. nodorum* and *P. tritici-repentis*, readily overwinter on wheat residue, one can speculate that wheat pathogens dominate the wheat residue in the barley-

Table 3. Leaf spot severity (percentage necrosis and chlorosis) on Stander barley grown on the residue of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and wheat) in 1999 and 2000. Only data from evaluations where differences were detected with Dunnett's one-tailed test are included.

Previous crop	Rating date and leaf evaluated							
	16 July 1999 FL-3†	20 July 1999 FL-3	26 July 1999 FL-3	26 July 1999 FL-2	28 July 1999 FL-2	28 July 1999 FL-1	30 July 1999 FL-2	30 July 1999 FL-1
Wheat	10.2*	27.0*	71.6*	23.6*	33.5*	10.9*	48.7*	20.1*
Canola	13.2*	31.7*	69.3*	23.0*	32.2*	10.8*	47.2*	16.6*
Crambe	14.0*	36.4*	72.9*	24.0*	34.0*	9.9*	48.5*	15.4*
Dry pea	15.3*	38.9*	82.6*	24.7*	38.7*	11.6*	55.3*	20.7*
Safflower	16.9	38.9*	72.3*	20.2*	30.6*	9.1*	51.9*	16.4*
Sunflower	19.0	46.4	81.9*	25.5*	42.5*	11.9*	59.6*	20.0*
Soybean	18.4	47.4	83.8*	25.6*	44.6	12.9	63.2*	24.0*
Flax	23.3	51.3	81.2*	31.8*	46.7	18.1	64.8*	28.4
Dry bean	22.3	50.0	87.9	36.9	52.9	16.9	76.6	28.7
Barley	24.3	56.3	94.2	45.4	66.0	21.1	80.8	32.2

Previous crop	3 Aug. 1999 FL-2	3 Aug. 1999 FL-1	6 Aug 1999 FL-1	6 July 2000 FL-3	10 July 2000 FL-2	13 July 2000 FL-1	Total percentage different‡
							%
Wheat	73.4*	45.7*	69.3*	37.0*	30.2*	11.6*	100
Canola	77.1*	48.1*	75.4	58.2*	41.9	21.4	79
Crambe	71.9*	41.0*	71.8	54.2*	45.4	21.2	79
Dry pea	83.6	48.6*	74.5	54.2*	40.6*	28.1	79
Safflower	86.2	46.0*	79.8	65.8*	45.1	30.3	64
Sunflower	84.2	57.1	84.3	70.4	61.7	32.1	43
Soybean	91.6	64.4	88.7	52.6*	41.5	20.9	36
Flax	82.2*	58.6	76.1	56.4*	53.6	24.3	36
Dry bean	96.2	70.9	92.7	60.4*	46.5	20.2	7
Barley	97.9	78.5	91.2	85.2	66.4	27.5	

* Indicates that disease severity was significantly less ($P \leq 0.05$) than the barley-after-barley check.

† FL-1 = first leaf below the flagleaf, FL-2 = second leaf below the flagleaf, and FL-3 = third leaf below the flagleaf. The growth stages for the flagleaf-3 ratings ranged from heading through milk dough [10.5 to 11.3, Feekes scale (Large, 1954)], and the flagleaf-2 and flagleaf-1 ratings were made during the milk dough stage [11.3, Feekes scale (Large, 1954)].

‡ Total percentage is based on the number of evaluations where differences were detected.

Table 4. Summary of analyses of variance for leaf spot severity (percentage necrosis and chlorosis) on Amidon spring wheat grown on the residue of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and wheat) in 1999 and 2000.

Source of variation	df	Rating dates, leaf evaluated, and disease severity							
		16 July 1999 FL-3†	20 July 1999 FL-3	22 July 1999 FL-2	27 July 1999 FL-2	29 July 1999 FL-2	27 July 1999 FL-1	29 July 1999 FL-1	
		35%‡	76%	29%	68%	81%	13%	20%	
		$P > F$							
Replicate	2	0.0425*	0.2829 NS	0.0005**	0.0144*	0.0037**	0.0113*	0.0529 NS	
Residue	9	0.0497*	0.3647 NS	0.0337*	0.1199 NS	0.2043 NS	0.5732 NS	0.5921 NS	
		2 Aug. 1999 FL-1	5 Aug. 1999 FL-1	9 Aug. 1999 FL-1	2 Aug. 1999 FL	5 Aug. 1999 FL	9 Aug. 1999 FL	11 Aug. 1999 FL	
		36%	57%	86%	12%	21%	48%	67%	
		$P > F$							
Replicate	2	0.1360 NS	0.0695 NS	0.0312*	0.0890 NS	0.3092 NS	0.0703 NS	0.0770 NS	
Residue	9	0.9275 NS	0.9070 NS	0.9989 NS	0.3125 NS	0.0141*	0.7040 NS	0.6838 NS	
		6 July 2000 FL-2	10 July 2000 FL-2	13 July 2000 FL-2	19 July 2000 FL-1	24 July 2000 FL	26 July 2000 FL	28 July 2000 FL	31 July 2000 FL
		37%	56%	82%	53%	29%	46%	60%	86%
		$P > F$							
Replicate	3	0.0045**	0.0070**	0.0005**	0.0001**	0.0004**	0.0809	0.0727	0.0891
Residue	9	0.0067**	0.0450*	0.0821	0.2921	0.0039**	0.0242*	0.1451	0.493

* Significant at $P \leq 0.05$.
** Significant at $P \leq 0.01$.
† FL = flagleaf or top leaf, FL-1 = first leaf below the flagleaf, FL-2 = second leaf below the flagleaf, and FL-3 = third leaf below the flagleaf. The growth stages were made during heading [10.5, Feekes scale (Large, 1954)] for the flagleaf-3 ratings, anthesis through milk dough [10.5.1 to 11.1, Feekes scale (Large, 1954)] for the flagleaf-2 ratings, and milk dough [11.1 to 11.3, Feekes scale (Large, 1954)] for the flagleaf-1 and flagleaf ratings.
‡ Overall average disease severity, percentage necrosis and chlorosis.

after-wheat plot area. And because *D. teres*, an important pathogen on barley, can be controlled by *S. nodorum,* an important pathogen on wheat (Jorgensen et al., 1996), one can further speculate that the wheat pathogens on the wheat residue create a competitive environment and impact the severity of leaf spot diseases on barley.

Disease Severity on Wheat after Different Crops

Differences in disease severity following different crops, which indicated an influence of the previous crop and crop residues on wheat leaf spot diseases, were significant for 3 of 14 evaluations in 1999 and four of eight evaluations in 2000 (Table 4). One can speculate that there were relatively fewer differences among treatments in 1999 (21%) than in 2000 (50%) because the carryover of wheat residue, which would promote the carryover of wheat pathogens (Duczek et al., 1999), was higher in 1999, ranging from 13 to 32% in the alternative crop treatments (Table 1).

Considering comparisons of disease severity between the wheat-after-another crop treatment and the wheat-after-wheat treatment, several treatments had less disease than the wheat-after-wheat treatment. Differences were detected with the Dunnett's test in 5 of the 14 evaluations in 1999 and in three of the eight evaluations in 2000 (Table 5). More differences were found with evaluations done earlier in the season. This indicates a greater influence of crop residue and carryover of inoculum early in the season compared with later in the season. One can speculate that the absence of significant differences among treatments later in the season may

Table 5. Leaf spot severity (percentage necrosis and chlorosis) on Amidon spring wheat grown on the residue of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and wheat) in 1999 and 2000. Only data from evaluations where differences were detected with Dunnett's one-tailed test are included.

Previous crop	Rating date and leaf evaluated: 16 July 1999 FL-3†	22 July 1999 FL-2	27 July 1999 FL-2	29 July 1999 FL-2	5 Aug. 1999 FL	6 July 2000 FL-2	10 July 2000 FL-2	13 July 2000 FL-2	Total percentage different‡
									%
Canola	27.4*	25.2*	65.2*	81.6	23.7	31.9*	39.3*	66.2*	75
Barley	29.5*	21.8*	61.6*	77.3	13.2*	37.2*	53.5	79.6	63
Crambe	37.2	28.9*	65.6*	80.5	17.9*	22.7*	47.1	72.7	50
Flax	32.4*	28.2*	62.5*	79.6	24.6	26.3*	54.2	82.9	50
Soybean	29.8*	27.7*	67.6*	71.5*	21.1	47.4	53.5	82.3	50
Sunflower	34.7	22.6*	66.0*	81.9	23.4	28.7*	58.2	88.2	38
Dry bean	32.0*	26.5*	70.9	84.7	20.0	30.7*	55.0	83.8	38
Dry pea	37.4	30.4	64.8*	76.2	20.6	30.6*	65.7	88.4	25
Safflower	40.4	33.0	68.1	79.8	17.9*	46.6	65.8	91.0	13
Wheat	49.1	43.4	85.4	92.7	29.7	63.8	66.2	87.0	

* Indicates that disease severity was significantly less ($P \leq 0.05$) than the wheat-after-wheat check.
† FL = flagleaf, FL-1 = first leaf below the flagleaf, FL-2 = second leaf below the flagleaf, and FL-3 = third leaf below the flagleaf. The growth stages were made during heading [10.5, Feekes scale (Large, 1954)] for the flagleaf-3 ratings, anthesis through milk dough [10.5.1 to 11.1, Feekes scale (Large, 1954)] for the flagleaf-2 ratings, and milk dough [11.1 to 11.3, Feekes scale (Large, 1954)] for the flagleaf-1 and flagleaf ratings.
‡ Total percentage is based on the number of evaluations where differences were detected.

be related to the movement of fungal spores among plots (interplot interference) or the influx of aerial spores from other areas.

In cases where differences were detected with Dunnett's comparisons (8 out of 22 ratings), treatments with less disease severity than the wheat-after-wheat treatment (averaging less disease 50% of the time or more) were wheat after canola, barley, crambe, flax, and soybean (Table 5). Conversely, the amount of disease severity on wheat grown after safflower, dry pea, dry bean, or sunflower was more similar to the wheat-after-wheat sequence. These trends indicate that the risk for leaf spot disease on wheat would be lower for wheat grown after canola, barley, crambe, flax, and soybean than when grown after the other crops. A lower leaf spot disease severity following crambe, canola, and flax would be expected because the major diseases on crambe, canola, and flax do not cause leaf spot diseases on wheat.

Similar to the above phenomenon, when disease severity on barley in the barley-after-wheat treatment was lower than that in the barley-after-barley treatment, the disease severity associated with the wheat-after-barley treatment was lower than that in the wheat-after-wheat treatment. Again, Duczek et al. (1999) has reported that *D. teres*, a major pathogen on barley, readily overwinters on barley residue. It has also been reported that *D. teres* can act as a potential biological control agent for *S. nodorum* and *S. tritici*, pathogens on wheat (Nolan and Cooke, 2000). Apparently, the major barley pathogens dominate the wheat-after-barley plot area because of the abundance of barley residue and impact the severity of leaf spot diseases on wheat.

Barley Yield

Barley yield on the 10 treatments was similar in 1999, but differences were evident in 2000 (Table 6). As expected, the barley-after-barley treatment had the lowest yield in 2000. The barley-after-flax, barley-after-crambe, barley-after-wheat, barley-after-dry bean, and barley-after-dry pea treatments had higher yields than the barley-after-barley treatment. Although treatments with lower risk for leaf spot disease had higher yields [barley following crambe (33% higher yield), wheat (30% higher), dry pea (26% higher), and canola (13% higher)] than the barley-after-barley treatment, differences in yield did not always follow the disease severity ratings. In contrast, the barley-after-flax treatment, which had a high risk for leaf spot disease, yielded more (33% higher) than the barley-after-barley treatment. Thus, similarity in leaf spot diseases for some comparisons early in the growing season do not appear to impact yield. One can speculate that in addition to the effect of leaf spot diseases on barley yield, there are other factors or interactions occurring within certain crop sequences impacting yield that are not fully understood and need to be more fully explored. Apparently, the beneficial effect of crop sequence on leaf spot diseases only accounts for part of increased crop performance.

Table 6. Yield of Stander barley and Amidon spring wheat grown on the residue of 10 crops (barley, dry bean, canola, crambe, flax, dry pea, safflower, soybean, sunflower, and wheat) in 1999 and 2000. Data was compared with Dunnett's one-tailed test with the barley-after-barley and the wheat-after-wheat treatments used as checks for all barley and wheat comparisons, respectively.

	Barley			Wheat	
Previous crop	1999	2000	Previous crop	1999	2000
	yield, kg ha^{-1}			yield, kg ha^{-1}	
Wheat	4728	3748*	Canola	3591	3318
Canola	4680	3282	Barley	3385	3267
Crambe	4981	3850*	Crambe	3217	3592*
Dry pea	4674	3628*	Flax	3651	3348
Safflower	4579	3568	Soybean	3466	2999
Sunflower	4852	3192	Sunflower	3388	3212
Soybean	4363	3417	Dry bean	3308	3505*
Flax	4617	3879*	Dry pea	3114	3367
Dry bean	4189	3663*	Safflower	3031	3673*
Barley	4482	2905	Wheat	3428	2846

* Indicates that yield of barley or wheat was higher than the barley or wheat checks at a probability level of $P \leq 0.05$.

Wheat Yield

Wheat yield of the 10 treatments was similar in 1999, but differences were detected in 2000 (Table 6). As expected, the wheat-after-wheat treatment had the lowest yield in 2000. The yield from the wheat-after-safflower (30% higher), wheat-after-crambe (20% higher), and wheat-after-dry bean (23% higher) treatments was higher than the wheat-after-wheat treatment (Table 6). Considering that when there were statistical differences, the disease severity for the wheat-after-safflower, wheat-after-crambe, and wheat-after-dry bean treatments was similar to the wheat-after-wheat treatment for seven, four, and five times, respectively, out of eight evaluations, the difference in yield was apparently more related to other factors than to differences in the severity of leaf spot diseases. This is consistent with a report from Saskatchewan that indicates that leaf spot diseases may have a limited impact on wheat yields under dryland conditions (Wang et al., 2002).

Rotating among crop types is a valuable tool for reducing plant diseases in cropping systems (Cook and Veseth, 1991; Krupinsky et al., 2002a; McMullen and Lamey, 1999). Proper crop rotations may be used to reduce the severity of leaf spot diseases, but producers should not rely exclusively on a single management practice to minimize disease risk but rather integrate a combination of practices to develop a consistent long-term strategy for disease management that is suited to their production system and location. For example, in addition to using crop sequence/crop rotations to lower plant disease risk, risks can be lowered through cultivar selection, fungicide application, seeding rate and seeding date, balanced fertility, control of weeds and volunteer crop plants, and modification of the microenvironment within the crop canopy using tillage practices and stand density (Krupinsky et al., 2002a).

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