Effects of Crop Rotation and Residue Management Practices on Severity of Tan Spot of Winter Wheat

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ABSTRACT

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Tan spot (caused by *Pyrenophora tritici-repentis*) severity was determined for wheat (*Triticum aestivum*) grown in rotation with sorghum (*Sorghum bicolor*), which allowed a 15-mo break between wheat crops, and was compared with severity in wheat grown continuously. Three wheat residue management schemes were used within each crop sequence: chisel plow, V-blade, and no-till for the wheat-sorghum rotation and moldboard plow, chisel plow, and no-till for continuous wheat. Tan spot severity was determined during 4 yr; multiple ratings were taken in the last 2 yr for the calculation of area under the disease progress curve. For continuous wheat production, plowing significantly reduced tan spot throughout the season relative to the other tillage practices. Rotation to sorghum was as effective as plowing for control of tan spot; however, in one of the 4 yr, early season tan spot was noted in the wheat-sorghum rotation with no-till. Under certain conditions, crop rotations as short as 1 yr controlled tan spot.

Additional keywords: *Drechslera tritici-repentis*

Tan spot is an important disease of winter wheat (*Triticum aestivum* L.) around the world and is caused by the fungus *Pyrenophora tritici-repentis* (Died.) Drechs. The pathogen survives between wheat crops as mycelium or pseudothecial initials in infested host residue. The teleomorph is produced on the straw during the fall and winter, and primary inoculum (ascospores) is discharged in the spring and initiates epidemics (6,10,19). Wind-dispersed conidia are produced later in the season from lesions (19) or leaves killed by the pathogen (4) and serve as secondary inoculum.

The amount of primary inoculum is an important determinant of the severity of disease during the entire crop season. During 2 yr, the number of pseudothecia required to significantly increase the area under the disease progress curve (AUDPC) relative to the uninoculated check was 2,500 or 100,000 per square meter (1). Similarly, moderate to severe disease developed when inoculum densities were 12,700–31,200 pseudothecia per square meter, but relatively light disease occurred with densities of 127–3,120 per square meter (19). Therefore, even though *P. tritici-repentis* produces airborne secondary inoculum, the amount of primary inoculum present in a field greatly affects disease progress.

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Tan spot has long been associated with fields in which relatively large amounts of straw remain on the soil surface. During the early part of an epidemic in Nebraska, incidence was highest in fields with abundant wheat residue on the surface, although fields without residue had severe disease near the end of the season (18). Rees et al (11) showed a logarithmic relationship between grain yield loss from disease and amount of infested stubble added to plots.

Because of the association of the disease with surface wheat residue, stubble management practices have been investigated as a possible cultural control. Sutton and Vyn (17) found that tan spot increased in wheat under minimum or zero tillage compared with wheat under conventional tillage (moldboard plow). Rees and Platz (9) found that disease severity was highest where stubble was not burned and no-till was practiced and lowest where stubble was burned followed by conventional tillage. These differences were still evident at the end of the crop season in spite of interplot interference from secondary spread of inoculum. Similar data were obtained for early season severity at two additional sites in Australia (8). The effectiveness of burning was confirmed in another study (16) in which burning stubble was shown to significantly reduce tan spot through the milk stage as compared with retaining stubble (blade plow).

Although crop rotations have been advocated as a control for tan spot (3,8,14), few controlled experiments have been conducted to test this possibility. Crop sequences of soybean, corn-barley, and alfalfa-alfalfa, each after mixed oats and barley, were shown to reduce tan spot in a subsequent wheat crop (17). Reductions from these sequences were similar to those seen from moldboard plowing in which wheat was grown continuously after barley (17). The goals of the present research were to expand these findings. To do so, we used winter wheat as the sole winter cereal crop to quantify the effect of a 1-yr crop rotation (2-yr, two-crop cycle) on tan spot relative to continuous wheat production and to determine the impact of three different primary tillage methods on tan spot under crop rotation and continuous wheat production.

MATERIALS AND METHODS

Plot design. A long-term field experiment was established in Ladysmith silty clay loam in October 1984 at the Harvey County Experiment Field near Hesston, Kansas. Plots (9.1 × 15.2 m) were arranged in a randomized, complete-block design with four replications and 12 treatments. Alleys between blocks were 10.7 m wide, and weeds were controlled by tillage and/or herbicides in these areas. Additionally, blank sorghum plots were incorporated into the design whenever two plots of wheat were adjacent to each other; therefore, wheat plots were separated by about 9 m in all directions.

Treatments and crop management. Four crop sequences were used: continuous wheat, continuous sorghum (*Sorghum bicolor* (L.) Moench), and two sequences of a wheat-sorghum rotation that resulted in a 1-yr break between wheat crops (2-yr, two-crop cycle). The latter two treatments were identical but were staggered such that wheat planted after sorghum was available each year. Three primary tillage treatments were used within each crop sequence: moldboard plow, chisel plow, and no-till for continuous wheat; chisel plow, V-blade, and no-till for wheat-sorghum rotations; and chisel plow, disk, and no-till for continuous sorghum. In the wheat-sorghum rotation, tillage treatments were applied only to stubble between wheat harvest and sorghum planting in the following spring. Soon after sorghum harvest in the fall of the following year (15 mo after wheat harvest), wheat in the rotation treatments was seeded into sorghum residue without tillage.

All of the tillage treatments included appropriate secondary tillage with a disk and/or field cultivator for weed control as necessary. In no-till continuous wheat, weeds during the fallow were controlled by applications of glyphosate (0.43–1.68 kg a.i./ha) or glyphosate plus 2,4-dichlorophenoxyacetic acid (2,4-D) (0.43 + 0.71 kg a.i./ha). Postemergent herbicides (bromoxynil + MCPA at 0.43 + 0.43 kg a.i./ha) were applied to all wheat plots for broadleaf weed control in 1 yr (1988). Also in 1988, propiconazole (126 g a.i./ha) was applied to all wheat 15 days after disease was evaluated.

Weeds in no-till sorghum after wheat were controlled with similar applications of glyphosate and 2,4-D, a fall treatment with atrazine in 1988 (1.7 kg a.i./ha) and in 1990 (1.1 kg a.i./ha), and spring applications of alachlor (2.8–3.4 kg a.i./ha) plus cyanazine (1.3–4.2 kg a.i./ha). Sorghum in tilled plots received preemergent applications of alachlor (2.2 kg a.i./ha) plus cyanazine (1.0–1.3 kg a.i./ha) without (1987 and 1989) or with (1988) atrazine at 0.28 kg a.i./ha. In 1990, propachlor plus atrazine (3.4 + 0.14 kg a.i./ha) was substituted for preemergent weed control.

A double-disk opener drill with 20-cm row spacing was used to seed Arkan, a hard red winter wheat cultivar that is susceptible to tan spot. Seeding occurred annually in mid-October at the rate of 67.2 kg/ha (1988) or 84 kg/ha (1989–1991). Nitrogen fertilizer (N-P-K) was preplant broadcast as 46-0-0 (165 kg/ha) in 1988 or as 34-0-0 (255 kg/ha) in 1989–1991. Also, 18-46-0 (78 kg/ha) was banded annually in the furrow with the seed at planting. The central area (1.8 × 15.2 m) of each wheat plot was harvested in mid- to late June with a modified Gleaner E combine.

Sorghum (Funks G-1498 in 1987 or Funks G-1460A in 1988–1990) treated with oxabetrinil herbicide safener was planted at approximately 103,700 seeds per hectare during the second or third week of June (early July in 1989). Fertilizer for sorghum consisted of an annual average of 109 kg/ha of 34-0-0 broadcast before planting and 63 kg/ha of 46-0-0 banded near the row at planting.

Disease assessment. Tan spot ratings were started in the spring of 1988. For assessments during the first 3 yr, we used a 0–5 scale to visually rate disease severity (7). The scale was as follows: 0, no symptoms; 1, flecks covering less than 1% of the leaf area; 2, distinct necrotic lesions with chlorotic halos covering less than 10% of the leaf area; 3, 10–50% of the leaf area affected; 4, greater than 50% of the leaf area affected; and 5, entire leaf dead. For the fourth year (1990–1991 crop season), leaves were rated for percentage of leaf area affected by chlorosis and/or necrosis and were placed into one of the following categories: 0, 1, 5, 10, 25, 50, 75, or 100% of the leaf area affected. At each sampling time, 25 randomly selected tillers from each plot were rated in situ. Depending on the sample date, either the third fully expanded leaf from the top, the penultimate, or the top three leaves were rated. Single ratings were made during 1988 (20 April, flag leaf emergence) and 1989 (30 May, milk-soft dough). Five ratings were made during 1990 (17 April, 1 May, 15 May, 29 May, and 6 June) at the following growth stages: leaf sheath strongly erected, flag leaf emerging, boot, flowering-watery ripe, and milk-soft dough, respectively. There were four ratings in 1991 (3 April, 17 April, 1 May, and 14 May) at the growth stages of leaf sheath strongly erected, flag leaf emerging, boot, and watery ripe-milk, respectively.

Table 1. Effect of crop rotation and tillage method on tan spot disease severity and area under the disease progress curve (AUDPC) for winter wheat during 1988–1991

		Leaf rating[v]		AUDPC[w]	
Crop-sequence	Tillage	20 April 1988	30 May 1989	1990	1991
Wheat-wheat	Plow	0.73 b[x]	3.73 b	57 d	295 c
Wheat-wheat	Chisel	1.70 a	4.07 a	106 b	623 b
Wheat-wheat	No-till	1.93 a	4.05 a	160 a	1,415 a
Wheat-sorghum[y]	Chisel[z]	0.80 b	3.21 c	80 c	225 c
Wheat-sorghum	V-blade	0.78 b	2.77 d	78 c	243 c
Wheat-sorghum	No-till	0.86 b	3.01 cd	122 b	243 c

[v] A 0–5 scale was used: 0, no symptoms; 1, flecks covering less than 1% of the leaf area; 2, distinct lesions covering less than 10%; 3, 10–50% covered; 4, greater than 50% covered; and 5, leaf dead.

[w] AUDPC calculated (13) by using five rating times for 1990 (0–5 scale) and four rating times for 1991 (percentage of leaf area affected).

[x] Averages of four replications with the leaves of 25 randomly selected tillers per plot were rated. Values in a column followed by the same letters do not differ significantly according to analysis of variance (ANOVA) and least significant difference (LSD, $P = 0.05$).

[y] Sorghum planted about 12 mo after wheat harvest, and wheat planted soon after sorghum harvest.

[z] Primary tillage practices applied to wheat residues soon after wheat harvest. Wheat was planted into sorghum residue without tillage in all instances.

Statistical analysis. For each sample date, leaf ratings were averaged to obtain a mean score for each replicate plot. Disease severity means and grain yields were analyzed by analysis of variance (ANOVA) followed by mean separation by protected least significant difference (LSD, $P = 0.05$). AUDPC values also were calculated, according to the method of Shaner and Finney (13), for the latter two seasons and were compared by using ANOVA and LSD ($P = 0.05$). Homogeneity of variances among years for data sets was determined by Bartlett's test. When variances were homogeneous, year × treatment F tests were calculated with a split-plot ANOVA, and treatments were main plots and years were subplots.

RESULTS AND DISCUSSION

Annual wheat year (July to June) precipitation was near normal (78 cm) for the 1988 crop, but was below normal (−6.6 to −21 cm) for the succeeding crops. In each of the 4 yr, precipitation was substantially below normal for the wheat-growing season (October to June).

Tan spot developed at the site in each year and was the most important foliar disease noted. Significant differences in leaf ratings and AUDPC values between treatments were detected in each year (Table 1). However, other factors that contributed to the chlorosis and necrosis of leaves included drought stress and leaf rust (caused by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici* (Eriks. & E. Henn.) D. M. Henderson). Significant leaf rust did not develop until about the milk stage and later.

Continuous wheat. Under continuous wheat production, moldboard plowing consistently reduced tan spot severity compared with the chisel or no-till treatments (Table 1). During the 1989–1990 and 1990–1991 crop seasons, the moldboard plow treatment had very low severity ratings (usually less than 10% of the leaf area affected) through the watery ripe growth stage (Tables 2 and 3). In contrast, the no-till treatment had the highest ratings at each sampling time (Tables 1–3), although the chisel plow treatment was similar to no-till on 20 April 1988 and 30 May 1989 (Table 1). Variances of data sets for disease severity among the different years were not homogeneous. Because no obvious transformation could remedy the situation, the significance of year × treatment interactions was not determined.

Results from these experiments confirm other reports (3,5,8,14,16–19) that tan spot is most severe where wheat residue is retained on the soil surface. Moderate to severe tan spot occurred in the continuous wheat and no-till plots during each year. Because the numbers of pseudothecia per square meter are correlated with tan spot severity throughout the season (1,19), the more infected residue retained on the soil surface, the more severe the disease will be (11). Under continuous winter wheat production, reduced tillage (especially no-till) will result in tan spot becoming a significant yield-limiting factor (1,2,7, 11,12,19).

Where the primary tillage method for continuous wheat was moldboard plowing, tan spot was not a significant problem. During eight of 11 rating times over 4 yr (Tables 1–3), average leaf ratings were less than 2 (0–5 scale; 2, less than 10% of the leaf area affected) or less than 10% (percentage of leaf area affected). Levels of control obtained by plowing were similar to those reported for stubble burning (9,16). Early in the season, burning treatments had severities that were 2–4% of those where stubble was retained (16); however, severities later in the season were 39–80% of those of stubble treatments (9,16). During our experiments in 1990–1991, ratings for the plow treatment at any time in the season were 15–29% of those for the no-till treatment (Table 3). Sutton and Vyn (17) also showed that moldboard plowing greatly reduced tan spot when wheat was grown continuously. Therefore, moldboard plowing is an alternative to burning for control of tan spot under continuous wheat production.

Interplot interference did not appear to be important in our experiments. Differences among treatments that were detected early persisted at least through the milk stage (Tables 2 and 3). Because about half of the yield loss from tan spot occurs before the boot stage (12), these persistent differences should relate to yield loss under the various tillage methods. Although long-distance dispersal of inoculum of *P. tritici-repentis* has been reported (5,8), in other situations inoculum was dispersed only a few meters (6). Similarly, interplot interference has been significant later in the season in some experiments (11,16) and not as apparent in others (1,9,17). The results presented here imply that, under Kansas conditions, dispersal of secondary inoculum is not of sufficient distance or amount to negate control achieved by cultural measures such as moldboard plowing. Neighboring fields with large amounts of inoculum should not significantly affect fields that have been plowed.

Tillage effects on wheat yields (Table 4) were significant in 1988 and 1990, when yield of continuous wheat was highest under plow tillage. Variances among years for the grain yield data were homogeneous, and there were significant year × treatment interactions; therefore, grain yields averaged over the 4 yr are reported but not separated statistically. Nevertheless, over the 4-yr period, average continuous wheat yields were 0.39 Mg/ha (14.4%) less with no-till compared with the plow treatment. In addition to tan spot effects, cheat (*Bromus secalinus* L. and *B. japonicus* Thunb. ex J. A. Murray) infestation also probably lowered the yield for no-till continuous wheat in 1990 and 1991.

Wheat-sorghum rotations. Crop rotations as short as 1 yr controlled tan spot. Severities of tan spot for the wheat-sorghum rotations were generally similar to those of the continuous wheat under plow treatment (Tables 1–3). These relatively low ratings, when compared with the continuous wheat under no-till, were evident late in the season for all 3 yr when late ratings were taken. Sutton

Table 2. Effect of crop rotation and tillage method on severity of tan spot of winter wheat during 1990

		Mean leaf rating[w]				
Crop sequence	**Tillage**	**17 April**	**1 May**	**15 May**	**29 May**	**6 June**
Wheat-wheat	Plow	1.10 c[x]	0.42 c	0.98 d	1.36 c	3.78 c
Wheat-wheat	Chisel	2.05 b	2.11 b	2.04 bc	1.67 c	3.87 bc
Wheat-wheat	No-till	3.25 a	3.49 a	3.03 a	2.64 a	4.33 a
Wheat-sorghum[y]	Chisel[z]	1.11 c	0.93 c	1.71 c	1.75 c	3.86 c
Wheat-sorghum	V-blade	0.98 c	0.85 c	1.79 bc	1.72 c	3.69 c
Wheat-sorghum	No-till	2.00 b	2.54 b	2.28 b	2.20 b	4.17 ab

[w] A 0–5 scale was used: 0, no symptoms; 1, flecks covering less than 1% of the leaf area; 2, distinct lesions covering less than 10% of leaf; 3, 10–50% covered; 4, greater than 50% covered; and 5, leaf dead.

[x] Averages of four replications with the leaves of 25 randomly selected tillers per plot per date were rated. The third fully expanded leaf (17 April and 1 May), penultimate (15 May), or top three leaves (29 May and 6 June) were rated. Values in a column followed by the same letters are not significantly ($P = 0.05$) different according to analysis of variance (ANOVA) and least significant difference (LSD).

[y] Sorghum planted about 12 mo after wheat harvest, and wheat planted soon after sorghum harvest.

[z] Primary tillage practices applied to wheat residues soon after wheat harvest. Wheat was planted into sorghum residue without tillage in all instances.

Table 3. Effect of crop rotation and tillage method on severity of tan spot of winter wheat during 1991

		Leaf area covered (%)			
Crop sequence	**Tillage**	**3 April**	**17 April**	**1 May**	**14 May**
Wheat-wheat	Plow	3.59 c[x]	11.19 c	6.81 c	3.33 c
Wheat-wheat	Chisel	9.59 b	17.86 b	19.06 b	7.44 b
Wheat-wheat	No-till	18.05 a	39.00 a	46.55 a	17.60 a
Wheat-sorghum[y]	Chisel[z]	3.16 c	9.39 c	4.14 c	2.38 c
Wheat-sorghum	V-blade	2.69 c	10.50 c	4.37 c	2.77 c
Wheat-sorghum	No-till	4.42 c	9.77 c	4.10 c	2.99 c

[x] Averages of four replications with the leaves of 25 randomly selected tillers per plot per date were rated for percentage of leaf area chlorotic and/or necrotic. The third fully expanded leaf (3 April, 17 April, and 1 May) or the penultimate leaf (14 May) was rated. Values in a column followed by the same letters are not significantly ($P = 0.05$) different according to analysis of variance (ANOVA) and least significant difference (LSD).

[y] Sorghum planted about 12 mo after wheat harvest, and wheat planted soon after sorghum harvest.

[z] Primary tillage practices applied to wheat residues soon after wheat harvest. Wheat was planted into sorghum residue without tillage in all instances.

Table 4. Effect of crop rotation and tillage method on wheat yield during 1988–1991

		Yield (Mg/ha)				
Crop sequence	**Tillage**	**1988**	**1989**	**1990**	**1991**	**Av**
Wheat-wheat	Plow	3.53 a[x]	2.44 a	1.89 b	2.96 a	2.70
Wheat-wheat	Chisel	3.20 ab	2.70 a	1.67 b	2.46 a	2.51
Wheat-wheat	No-till	3.04 b	2.54 a	1.34 c	2.32 a	2.31
Wheat-sorghum[y]	Chisel[z]	2.11 c	0.56 b	2.34 a	2.75 a	1.94
Wheat-sorghum	V-blade	1.90 c	0.68 b	2.43 a	2.59 a	1.90
Wheat-sorghum	No-till	1.96 c	0.67 b	2.37 a	2.71 a	1.92

[x] Averages of four replications adjusted to 12.5% moisture. Values in a column followed by the same letters are not significantly ($P = 0.05$) different according to analysis of variance (ANOVA) and least significant difference (LSD).

[y] Sorghum planted about 12 mo after wheat harvest, and wheat planted soon after sorghum harvest.

[z] Primary tillage practices applied to wheat residues soon after wheat harvest. Wheat was planted into sorghum residue without tillage in all instances.

and Vyn (17) also found that a 1-yr break (soybean) in small grain production significantly reduced tan spot relative to continuous small grains. However, the rotation to soybean was between a barley and wheat crop, and it was noted that tan spot was mild in wheat succeeding barley (17). Presumably, few ascospores were dispersed from the barley residue. Our experiments differed in that we used only winter wheat as the small grain.

In Kansas, wheat is harvested during June and July, and ascospores of *P. tritici-repentis* are usually first observed in April (7). Therefore, under continuous wheat production, *P. tritici-repentis* survives saprophytically on the wheat straw about 9 mo, until the parasitic phase of the disease cycle is initiated. In the wheat-sorghum rotation described here, that time is increased to 21 mo. Apparently, the fungus declines sufficiently during 21 mo in Kansas, and severe tan spot does not develop.

At most sampling times, ratings for all of the tillage regimes within the wheat-sorghum rotation were equal to or less than those for the continuous wheat under plow treatment (Tables 1–3). A notable exception was during 1990 when each rating for wheat-sorghum with no-till was significantly higher than ratings for the other wheat-sorghum rotations and the continuous wheat under plow (Table 2). Besides this exception, and a minor difference on 30 May 1989 (Table 1), there were no significant differences among tillage treatments for the wheat-sorghum rotations (Tables 1–3). Therefore, the method of primary tillage usually does not affect the control of tan spot achieved by a 1-yr wheat-sorghum rotation. Similarly, tillage method (conventional, minimum, and no-till) did not affect tan spot severity in wheat after barley-soybean, barley-corn-barley, or barley-alfalfa-alfalfa in Canada (17). However, under certain conditions in Kansas, *P. tritici-repentis* can survive under a 1-yr rotation, but only when the maximum amount of residue is retained on the soil surface (no-till). Cool, and especially dry, conditions favor the survival of the pathogen in host residue (15); those conditions probably occurred at a higher than normal frequency during summer 1988 to spring 1990.

One-year rotations may not be of sufficient duration in other environments to result in significant control. Summerell and Burgess (14) reported 46% survival of *P. tritici-repentis* in stubble that was retained on the soil surface for 104 wk in Australia. For these conditions, they recommended rotations of 2–3 yr (14).

Wheat after sorghum showed no effect of prior tillage method on yield (Table 4). In 1988 and 1989, wheat yields in the rotation were reduced in comparison with continuous wheat because of less available soil moisture after the sorghum crop. This effect was accentuated by below normal precipitation during the wheat-growing season. Atypically low wheat yields in 1989 after sorghum were the result of extremely dry fall conditions that delayed stand establishment. However, wheat yields in 1990 in the rotation were higher than in continuous wheat, which results in a significant year × treatment interaction.

Sorghum yields in the rotation averaged 5.10 Mg/ha, whereas continuous sorghum produced an average of 4.46 Mg/ha for 1987–1990 (data not shown). This advantage for sorghum after wheat, attributed primarily to accumulation of soil moisture during the fallow period after wheat harvest, offset much of the reduced yield of wheat in the rotation.

In the central one-third of Kansas, continuous wheat production is commonly practiced. Because this area receives approximately 78 cm of rainfall annually, a year of fallow is not cost-effective. Nevertheless, under normal wheat-sorghum rotations, a fallow year often occurs between the sorghum and wheat crops, because sorghum is planted in mid-June and harvest is delayed beyond the normal time for wheat planting. For our experiments, a 1-yr crop rotation (2 yr, two crops) was used so that the loss of a cropping season did not occur. This system has potential for this area of Kansas and has the advantage of combining reduced tillage with yearly cropping without the buildup of serious pests such as *P. tritici-repentis*.

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