The Effect of Previous Crop Residues and Tillage on Fusarium Head Blight of Wheat

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ABSTRACT

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Effects of previous crop residues and tillage practices on Fusarium head blight (FHB) of wheat were examined. Fusarium head blight was monitored in plots of the FHB-susceptible spring wheat cultivar Norm following crops of corn, wheat, and soybeans in 1995, 1996, and 1997. Moldboard plow, chisel plow, and no-till treatments were imposed perpendicular to crop strips to establish a range of residue levels in each of the previous crop residues. Fusarium head blight incidence and severity were greatest when wheat followed corn and least when wheat followed soybeans. Incidence and severity were lower in moldboard plowed plots than in either chisel plowed or no-till plots, although differences among chisel plow and no-till treatments were not apparent. Yields of wheat were approximately 15% lower in plots where wheat followed corn or wheat than in wheat following soybeans and were 10% greater in moldboard plowed plots than in either chisel plowed or no-till treatments. The deoxynivalenol (DON) content of harvested grain was significantly correlated with FHB incidence and severity. The DON level in wheat following soybeans, averaged across tillage treatments, was 25% lower than in wheat following wheat and 50% of the level in wheat following corn. These findings suggest that changes in regional tillage practices, principally the move toward conservation tillage and reduced-till systems, contributed to the recent FHB epidemics in the Upper Midwest. Because differences in the type and quantity of crop residues in small plots affected disease development, it is likely that local sources of inoculum, such as those within a grower's field, contribute directly to the inoculum load and disease potential. The implication of these findings is that selection of cultural practices aimed to reduce inoculum-borne residues will assist in the control of FHB.

Additional keywords: *Fusarium graminearum*, *Gibberella zeae*, wheat scab

Fusarium head blight (FHB) of wheat has become a major problem in the eastern and midwestern United States. Epidemics have caused extensive damage through direct losses in yield and test weight and by price discounting due to the presence of *Fusarium*-damaged kernels and their associated mycotoxins, mainly the trichothecene deoxynivalenol (6,19). The principal pathogen associated with FHB in the Upper Midwest is *Fusarium graminearum* and its teleomorph *Gibberella zeae* (35). Other causal organisms linked to FHB include *F. avenaceum*, *F. culmorum*, *F. poae*, and *Microdochium nivale* (24,29,34,35).

The *Fusarium* species and *M. nivale* are all capable of surviving saprophytically on host debris (4,7,16,25,28). *F. graminearum*

can occur on a wide range of gramineous hosts (3), although FHB epidemics are generally considered to originate from inoculum associated with host residues (29), especially those of corn and small grain cereals (33,36). There is considerable evidence that continuous wheat cropping (28) or wheat following corn in a rotation system (12,13,17,26,29,32) significantly increases the incidence and severity of FHB. Potential inoculum for FHB is reported to be mainly ascospores produced on host residues that have remained at or above the soil surface (15). Practices for suppressing initial inoculum, especially rotation of wheat and corn with nonhost crops and plowing infested residues, have long been recommended for managing FHB (9,12,34).

Despite our knowledge that crop residue at the soil surface is a principal source of inoculum, conservation tillage has increased significantly throughout the United States over the past decade (2). Conservation tillage systems involve leaving all or part of the crop residue on the soil surface after harvest in an effort to reduce soil erosion caused by wind and water runoff. In 1990, federal farm legislation required the adoption of conservation plans that mandated a minimal requirement of 30%

residue cover at the time of crop emergence for land classified as subject to soil erosion (1). This legislation, following extreme drought conditions in the Upper Midwest in 1988, led to the rapid adoption of reduced tillage practices throughout much of the region. These practices contributed to significant increases in crop residues across much of the small grains production area in Minnesota.

The devastating epidemics of FHB in the Upper Midwest raised questions about the causes of these outbreaks and generated new interest in developing effective management strategies (19). The wheat crop in the Upper Midwest in 1993, when FHB re-emerged, comprised almost exclusively susceptible or very susceptible varieties (14). This plus the wet weather throughout much of the growing season, particularly at and immediately after anthesis, were the major factors contributing to the upsurge of the disease; however, crop residues were also implicated (19).

Genetic immunity to FHB in wheat has not been reported (24), and combining the available genes conferring partial resistance with the desired agronomic characters is difficult. Given the incomplete resistance and a lack of highly effective fungicides (19), effective disease management will likely rely on an integrated management system using a number of control options. Reducing inoculum of *F. graminearum* in host debris and other reservoirs may be a key to disease management. There is little quantitative data on sources of inoculum, the effects of management practices on inoculum (29), or the relationship of inoculum levels to disease development. The objective of this study was to examine the effect of crop rotation in conjunction with tillage practices on the development of FHB. Such information may assist in the development of management systems to aid in the control of FHB in wheat.

MATERIALS AND METHODS

Two sites, one under natural rainfall conditions and one with supplemental mist irrigation, were established at the University of Minnesota's Agricultural Experiment Station at Morris during the 1994, 1995, and 1996 wheat cropping seasons. The sites were within 700 m of each other. The soil at both sites was a Flom Loam-Hamerly Clay Loam complex. Plots of corn (*Zea mays*), wheat (*Triticum aesti-*

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vum), and soybean (*Glycine max*) were established in a randomized complete block design (RCBD) with five replicates in 6.1- by 22.4-m strips. Crop strips were treated with appropriate herbicides to control weeds and were combine harvested at full maturity, using appropriate equipment to remove grain. After harvest, maize stalks in the moldboard plow and chisel plow treatments were chopped using a stalk chopper, as would be standard practice in these production systems.

Soil samples (0- to 15-cm depths) were collected (three probes per replicate) for each of the previous crop strips, bulked for a site, and submitted to the University of Minnesota Soil Testing Lab, St. Paul, for fertility analyses. Fall (potassium) and spring (nitrogen and phosphorus) fertilizer applications were made according to laboratory recommendations. Fertilizer applications were conducted prior to and incorporated with tillage operations. Fertilizer in no-till (NT) plots was not incorporated.

Tillage operations (moldboard plowing and chisel plowing) and no-till were performed in 9.1-m-wide strips perpendicular to the crop strips, resulting in previous crop residue-tillage treatment combination plots of 9.1 by 6.1 m. Moldboard plow (MP) treatments consisted of a fall moldboard plowing with an International turn-over 3 bottom plow and a spring tillage of either two passes with a Lely roterra (1995) or one pass with a Wil-rich field cultivator (1996 and 1997). Chisel plow (CP) treatments consisted of a fall chisel using a Glencoe soil saver and one pass in the spring with a field cultivator. Fall tillage occurred on 4 November 1994, 7 November 1995, and 25 October 1996, and spring tillage on 4 May 1995, 24 May 1996, and 9 May 1997. All tillage operations within a replicate were done in the same direction in the fall and the opposite direction in the spring. Tillage treatments were designed to establish residue percentages as near as possible to 0, 30, and 100% for the MP, CP, and NT treatments, respectively.

In the spring (1995, 1996, and 1997) following the establishment of previous crop residue-tillage treatments, the hard red spring wheat cultivar Norm (FHB susceptible) was established in all plots. The seed used in the trial in all years was grown in the winter of 1994-95 in Sumer-ton, Arizona, where FHB is not generally present, to ensure the seed was free of *Fusarium*. The wheat was planted using a no-till drill with 19-cm row spacing on 18 May, 28 May, and 12 May in the consecutive years of the study. Following the establishment of the Norm plots in each year, corn residue that had been transported by wind was removed by hand from the plots previously planted to wheat and soybeans.

Weeds were controlled throughout the study using both preplant and postemergent herbicides, appropriate to the particular

crop, at the recommended label rates. Hand weeding was used to supplement chemical weed control in all years. Control of green foxtail (*Setaria viridis*) and yellow foxtail (*S. lutescens*) was only partially successful in the 1996 season, and a significant weed population developed in plots at both the dryland and mist-irrigated sites.

One week after planting, soil surface coverage by residue from the appropriate previous crop was measured, based on 75 observations (3 × 25 m line transects) per plot (27). One to three pieces of residue, 0.5 cm or greater in length, were collected in each plot at the time that residue cover was determined. The residue samples collected were bulked by previous crop (1995 only) or previous crop × tillage combination (1996 and 1997) within each site. Soybean and wheat residue consisted almost exclusively of stem fragments, while corn residue samples included stem, husk, and cob pieces. The size of the residue pieces collected varied in length from less than 1 cm to more than 10 cm. Residue samples were stored at -20°C until after the field season, when the colonization of the residue by *Fusarium* spp., and specifically *F. graminearum*, could be determined. Small pieces (approximately 4 mm diameter) were taken from the collected residue, surface-sterilized by immersion in a 70% ethanol solution for 15 to 20 s, rinsed in sterile distilled water, immersed in a 2% NaOCl solution for 1.5 min, and rinsed three times in sterile distilled water. Wheat stem pieces generally included a node, in which case isolations were conducted from the node tissue. The surface-sterilized tissue pieces were then blotted dry on sterile filter paper. One hundred pieces from each bulked sample were plated onto PCNB agar medium (15 g of peptone, 1 g of KH₂PO₄, 0.5 g of MgSO₄·7H₂O, 1 g of Terrachlor [75% pentachloronitrobenzene wt/wt], 15 g of agar, 0.12 g of neomycin sulfate, and 1 g of streptomycin sulfate per liter of deionized water), a medium selective for *Fusarium* spp. (22), and placed under a 14-h photoperiod provided by a 1:1 combination of cool-white (F40/CWX/CVP, Sylvania, St. Marys, PA) and blacklight, UVA source (F40BL GE lighting, Fairfield, CT) fluorescent lamps at 21 to 23°C. After 4 to 6 days, the plates were examined, and "Fusarium-like" isolates from each plate were transferred either to potato dextrose agar (PDA) medium (20 g of dextrose, 20 g of agar, and the filtered broth of 250 g of white potatoes boiled until soft in 500 ml of deionized water made up to 1 liter with additional deionized water) or carnation leaf agar (CLA) medium (one 5- to 8-mm-diameter sterile carnation leaf piece per 2 ml of 2% water agar [11]), where the recovered *Fusarium* species could be identified following the descriptions of Nelson et al. (23).

Mist irrigation was applied to one location in each year using Rainbird Micro-Bird II spinner nozzles mounted at 6.1-m

spacing on 1-m risers staggered in relation to adjacent irrigation lines, with the lines spaced 6.1 m apart. The spray mist from each nozzle had a diameter of 8.4 m. The output of the mist irrigation system provided the equivalent of 0.79 mm of water during a 10-min misting period. Misting commenced when 50% of the heads were out of the boot (8 July 1995, 11 July 1996, 12 July 1997) and was discontinued at the time of assessment, when the majority of the plants were at milk (24 July 1995, 24 July 1997) or soft dough (5 August 1996) growth stages. In 1995, plots were misted 2 to 10 min/h, depending on temperature and rainfall, from 0800 till 2100 h to maintain continuous free moisture on the heads throughout the mist period. In 1996 and 1997, three 30-min misting cycles per night, beginning at 1900, 2300, and 0500 h, maintained moisture on the wheat heads. The use of fewer wetting and drying cycles prevented the rapid buildup of calcium carbonate, present in the water supply at 2.3 ppm, on plant surfaces. While the calcium carbonate had little effect on disease development, its presence masked disease symptoms, making visual rating difficult. Daily minimum and maximum temperatures and precipitation were recorded at the nearest meteorological station situated less than 3 km from the trial sites.

Field assessments of FHB were conducted when plants were at midmilk (Feekes [18] growth stage 11.1) on 26 July 1995 and 25 July 1997 or at soft dough (Feekes growth stage 11.2) on 9 August 1996. Ninety heads were assessed in each plot: 15 main heads consecutive within a row in six randomly selected locations within the center of each plot. FHB incidence was determined as the percentage of heads with necrotic spikes in 90 single heads, and severity as the percentage of spikelets necrotic in 90 heads.

Grain was harvested when the wheat reached full maturity (21 August 1995, 4 September 1996, 22 August 1997). A 1.5-m-wide swath, approximately 7 m long, was harvested from the interior of each plot. Plot lengths were hand-measured following harvest to enable grain yields to be determined per unit area. Harvested grain was dried to 12.5% moisture at 38°C in a forced-air dryer, cleaned to remove weed seeds and straw, and used for yield determinations. The grain volume was then reduced to approximately 500 g with a 16-chute riffle-divider with 2.5-cm openings (Model H-3987, Homboldt Testing Equipment, Norridge, IL). Test weight and deoxynivalenol concentrations were determined on this grain sample.

The deoxynivalenol (DON) concentration of harvested grain samples was determined on 100-g samples prepared according to the method of Mirocha et al. (21). The samples were ground for 2 min with a Stein Laboratories Mill (model M-2, Stein Laboratories, Inc., Atchison, KS). DON

was extracted from 25 g of the ground sample in 100 ml of acetonitrile–water (84:16 vol/vol) placed on a rotary shaker for 1 h. Extracts were filtered (Whatman no. 4), a 4-ml sample was eluted through a specially prepared cleanup column (31), and the recovered eluent was evaporated to dryness with nitrogen. DON was derivatized and analyzed as its trimethylsilyl ether derivative (21). Twenty microliters of the derivatized solution was analyzed using gas chromatography–mass spectrophotometry (GC/MS) (Shimadzu Model QP-500, Shimadzu Ltd., Kyoto, Japan) and selected ion monitoring. Standards were prepared from crystalline DON and injected every tenth sample. Concentrations of DON in samples were determined based on retention times, and peak areas were compared with standards.

Where appropriate, data were analyzed by analysis of variance. Where the *F* ratio was significant ($P < 0.05$), differences among treatment means were determined using Bonferroni's multiple range test. Data for individual years and sites were analyzed separately and in a combined

analysis. Relationships between the assessment variables used in this study were tested using Pearson correlation coefficients.

RESULTS

Soil coverage with crop residues was the lowest in moldboard plow treatments (9%) and greater in chisel plow (31%) and no-till (65%) treatments. Residues were greater in plots following corn (MP, 12%; CP, 42%; NT, 67%) than wheat (MP, 9%; CP, 34%) except in no-till wheat (NT, 83%), where residues were the most abundant of all treatments examined (Table 1). Soybeans generated less residue (23% coverage) than the other crops tested (corn, 41%; wheat, 42%). The isolations conducted on the collected residue samples confirmed the presence of *Fusarium* species in the residue of each of the previous crops (Table 2). *F. graminearum* was the predominant *Fusarium* species isolated from corn and wheat, while other *Fusarium* species, especially *F. sporotrichioides*, predominated in the soybean residue. Differences in the frequency of

isolation of *Fusarium* spp. and *F. graminearum* among years were greater than differences among sites (dryland, mist irrigated) within a year (Table 2).

In the 3 years of the study when FHB development was observed (1995, 1996, and 1997), temperatures during the months of June, July, and August were moderate, with daily minimums and maximums about 15 and 26°C, respectively. Rain day events for June, July, and August were 9, 16, and 12 in 1995; 8, 15, and 7 in 1996; and 12, 11, and 13 in 1997. Rainfall during June averaged 59 mm in the 3 years of the study. Rainfall totals in July and August were lower in 1996, with 85 and 48 mm, respectively, than in either 1995 or 1997 (July, 171 and 159 mm, and August, 131 and 100 mm, for 1995 and 1997, respectively). Rainfall events greater than 20 mm occurred at less than half the frequency in July and August of 1996 compared with 1995 or 1997.

Disease incidence was influenced significantly ($P = 0.05$) by previous crop and tillage in each year of the study. The average disease incidence for all treatments at

Table 1. Residue cover, *Fusarium* head blight incidence and severity, yield, test weight, and deoxynivalenol content of harvested grain for nine previous crop (corn, wheat, and soybean)–tillage (moldboard plow, chisel plow, no-till) treatments^v

	Corn	Wheat	Soybean	Avg. ^w		Corn	Wheat	Soybean	Avg.
Residue cover (%)					Yield (kg/ha)				
MP ^x	12.4 bc ^y	9.1 ab	4.9 a	8.8 r	MP	2,203 bc	2,182 bc	3,279 cd	2,255 r
CP	41.7 e	34.1 d	16.7 c	30.8 s	CP	1,919 a	1,915 a	2,285 b-d	2,037 s
NT	67.4 f	82.8 g	45.9 e	65.4 t	NT	1,918 a	1,945 a	2,394 cd	2,080 s
Avg.	40.5 y	42.0 y	22.5 z	Int. ^z	Avg.	2,013 y	2,015 y	2,353 z	Int.
Disease incidence (%)					Test weight (kg/hl)				
MP	65.9 a-c	63.7 ab	61.0 a	63.5 r	MP	62.5 b-f	62.6 c-f	63.7 d-f	62.9 r
CP	79.7 d	70.3 c	65.1 a-c	71.8 s	CP	60.2 a-c	61.0 a-d	62.6 c-f	61.3 s
NT	79.7 d	67.5 bc	64.9 a-c	70.8 s	NT	60.4 a-c	61.6 a-e	62.9 c-f	61.6 s
Avg.	75.1 z	67.2 y	63.6 x		Avg.	61.0 x	61.7 y	63.1 z	
Disease severity (%)					Deoxynivalenol content (ppm)				
MP	17.4 b-e	15.6 a-d	13.9 a-c	15.6 r	MP	9.7 c-f	7.9 a-e	6.5 a-c	8.1 r
CP	25.9 f	19.0 c-e	16.0 a-e	20.3 s	CP	15.0 g	9.2 b-f	7.4 a-e	10.6 s
NT	25.6 f	20.4 de	17.4 b-e	21.3 s	NT	15.6 g	10.7 d-f	6.9 a-d	11.1 s
Avg.	23.0 z	18.3 y	15.8 x	Int.	Avg.	13.5 z	9.2 y	6.9 x	

^v Main plot treatments (previous crop and tillage) are also shown. Values represent the combined data of dryland and mist-irrigated sites established at Morris, Minnesota, in 1994, 1995, and 1996.

^w Average.

^x MP = moldboard plow; CP = chisel plow; NT = no-till.

^y Means followed by the same letter are not significantly different at $P \leq 0.05$. Means of main effects were tested separately (previous crop treatments = r,s,t; tillage practices = x,y,z) from means of previous crop–tillage combinations (a through g).

^z Int. = interaction (previous crop × tillage) significant at $P \leq 0.05$ indicated in the lower right of each section of table.

Table 2. Percent recovery of *Fusarium graminearum* and total *Fusarium* spp. from residues of wheat, corn, and soybeans collected from plots at dryland and mist-irrigated sites over 3 years

	Site	Previous crop					
		Corn		Wheat		Soybean	
		<i>F. graminearum</i>	<i>F. spp.</i> ^y	<i>F. graminearum</i>	<i>F. spp.</i>	<i>F. graminearum</i>	<i>F. spp.</i>
1994-95	D ^z	19	45	19	46	6	17
	M	9	24	29	50	5	32
1995-96	D	45	72	94	98	29	69
	M	44	75	78	94	27	85
1996-97	D	34	63	17	48	19	36
	M	10	25	20	43	3	27
Average 1995-1997		27	51	43	63	15	44

^y *Fusarium* spp.

^z D = dryland site; M = mist-irrigated site.

all sites was 68.7%, with treatment means for dryland sites ranging from 30.2 to 79.1% and for mist-irrigated sites from 60.3 to 92.9%. Disease incidence at all six sites and in the combined analysis was greatest when wheat was planted on corn residue and least when wheat followed soybeans. Disease incidence was lower in moldboard plowed plots than in either chisel plowed or no-till plots at all six sites. Differences among chisel plow and no-till treatments were not apparent at any site, and no significant differences among these treatments were detected in the combined analysis (Table 1). Among the previous crop tillage combinations, disease incidence was significantly higher in the chisel plow and no-till treatments of corn residue than in any other treatment combination.

Disease severity was significantly ($P = 0.05$) influenced by previous crop and tillage. Disease severity was moderate, averaging 19.1% for all treatments at all sites, and ranged for previous crop-tillage treatments from 4.9 to 27.2% in dryland sites and from 12.7 to 35.7% in mist-irrigated sites. The readings at mist-irrigated sites averaged 7 to 10% more than readings at dryland sites, indicating that the mist irrigation promoted disease development slightly, although weather conditions appeared favorable for FHB development in each year of the study. Disease in the 3 years was surprisingly consistent, although disease severities were lower in 1996 (dryland, 9.3%; mist irrigated, 18.6%) than in the other years (dryland, 18.4 and 17.9%, and mist irrigated, 25.5 and 24.6%, for 1995 and 1997, respectively). Disease severity readings at all sites paralleled disease incidence data, being higher in wheat following corn than in wheat following wheat or soybeans (Table 1). The lowest disease severities were observed in wheat following soybeans at all sites except the 1997 mist-irrigated site, where disease severity was not significantly different from that of plots of wheat following wheat. Disease severities were lower in moldboard plowed plots than in either chisel plowed or no-till plots at all six sites and in the combined analysis. Differences between chisel plow and no-till treatments were not apparent at any site, and a signifi-

cant difference between these treatments was not detected in the combined analysis (Table 1).

Grain yields were significantly ($P = 0.05$) affected by previous crop and tillage in each year of the study. Grain yield was greater in wheat following soybeans than in wheat following wheat or corn at all six sites and in the combined analysis (Table 1). In the wheat-after-soybean treatments, tillage practices appeared to have little effect; however, in wheat-on-wheat and wheat-on-corn treatments, an effect of tillage was evident. For all wheat-on-wheat residue and wheat-on-corn residue treatments, excepting wheat-on-corn residue in the 1997 irrigated site, yield was greater following moldboard plowing than in either chisel plowed or no-till treatments. Differences ($P = 0.05$) in plot yields between chisel plowed and no-till plots, irrespective of the previous crop, were not evident at individual sites or in the combined analysis (Table 1).

Test weights were generally greater in moldboard plowed treatments, irrespective of the previous crop. Among previous crop treatments, test weights were greater in wheat following soybeans than in wheat following either wheat or corn. At each site, and in the combined analysis, the highest test weights were generally recorded either in moldboard plowed treatments or in treatments where soybeans were the previous crop (Table 1).

Analysis of the deoxynivalenol content of grain samples indicated that significant differences ($P = 0.05$) in the contamination of grain by this mycotoxin resulted from the influence of previous crop residue and the tillage practices employed. Differences in the DON content of grain for the residue-tillage treatments reflected the findings for FHB disease levels and grain yield. DON was significantly ($P = 0.05$) lower in wheat following soybeans than in wheat following wheat or corn (Table 1). DON levels were higher in wheat following corn than in wheat following wheat (Table 1). In the combined analysis of the six sites, the DON level in grain from plots of wheat following soybeans, averaged across tillage treatments, was 25% lower than that from plots of wheat following wheat, and almost 49% of the level found

in grain from plots of wheat following corn. DON levels were lower in wheat harvested from moldboard plowed treatments. There was no apparent effect of tillage practices within the treatments where soybean was the previous crop; however, DON levels were higher in grain harvested from no-till treatments than from chisel plowed treatments for the previous crop residues of wheat and corn (Table 1).

The relationship between the assessment variables used in this study was examined. A correlation matrix for the variables examined is presented in Table 3. All correlation coefficients were significant at $P \leq 0.01$, with the exception of the correlation for percent residue cover with DON.

DISCUSSION

The previous crop residue and tillage practices differentially affected the incidence and severity of FHB. Wheat grown after soybeans reduced incidence and severity of FHB compared with wheat grown after wheat or corn, regardless of the tillage practice. FHB levels were higher when wheat was grown after corn than after wheat. The observed relationship of increased FHB with corn residue agrees with earlier studies in which epidemics of FHB were associated with wheat-corn rotations (17,32). Both incidence and severity of FHB were reduced in plots where moldboard plowing was used following corn or wheat, but tillage had little impact on FHB in treatments of wheat following soybeans. The isolations conducted on the collected residue samples confirmed the presence of *F. graminearum* in each of the previous crops. The percentage of wheat residue pieces infested with *F. graminearum*, which was generally higher than the percentage of infested corn residue, may reflect the use of the wheat cultivar Norm, known to be highly susceptible to FHB, and the presence of favorable conditions for FHB development in 1994, 1995, and 1996 when the previous crops were established. While *F. graminearum* dominated the *Fusarium* species isolated from corn and wheat, other species, especially *F. sporotrichioides*, predominated in the soybean residue. While *F. graminearum* is not considered a pathogen of soybeans, the presence of *F. graminearum* in 3 to 29% of residue samples is consistent with its saprophytic nature on the residues of many crops (10). While a statistical analysis was not conducted on our data, the frequency of isolation of *Fusarium* spp. and *F. graminearum* among years appeared greater than differences among sites within a year and suggests the importance of annual climatic conditions in promoting the colonization and survival of these fungal saprophytes. The differential FHB response presumably resulted in part from effects of the treatments on the colonization of crop residues by *F. graminearum*,

Table 3. Pearson correlation coefficients for correlations of residue, disease incidence (DI), disease severity (DS), yield, test weight, and deoxynivalenol content of harvested grain (DON)

Variable	Variable					
	Residue	DI	DS	Yield	Test wt.	DON
Residue	...	0.25 ^z	0.36	-0.25	-0.19	(0.11)
DI	...	...	0.85	-0.78	-0.76	0.62
DS	...	...	...	-0.66	-0.68	0.58
Yield	...	...	...	...	0.92	-0.38
Test wt.	...	...	...	...	...	-0.44
DON	...	...	...	...	...	...

^z All correlation coefficients shown are significant at $P \leq 0.01$ except where indicated by parentheses. Correlation coefficients in parentheses were not significant at $P \leq 0.05$.

the relative densities of these residues on the soil surface, and the inoculum produced by these residues. The reduction in FHB with moldboard plowing agrees with studies in which burying residues has been reported to favor the decline of residue-associated pathogens in residue of wheat including *F. graminearum* (8,16,30). Residue burial will also prevent the functional development of the *Gibberella* stage of *F. graminearum*.

Available evidence indicates that FHB epidemics are incited by a single infection cycle (29). The relatively short time following anthesis (10 to 20 days) in which wheat heads are highly susceptible to infection by *Fusarium* limits the chances of multiple disease cycles. In monocyclic epidemics, disease is directly related to the amount of primary inoculum (37). Continual use of susceptible host cultivars and cultural practices that leave abundant infested residue on the soil surface have been observed to increase the risk of FHB in subsequent crops (12,17,29). The findings of this study support claims (19) that changes in regional tillage practices, principally the move toward conservation tillage and reduced-till systems, contributed to the recent FHB epidemics in the Upper Midwest.

Inoculum potential may be related to the density and distribution of infested residues as well as to the susceptibility of the host. The lack of a difference in the levels of FHB among chisel plow and no-till treatments in our study may be related to differences in the contribution of the residues to the inoculum potential. In no-till plots, the density and layering of residue reduced residue to soil contact, influencing the residue microclimate and possibly negatively influencing the sporulation potential of *G. zeae*. In studies of the density of pseudothecia of *Pyrenophora tritici-repentis* in wheat residues, Sutton and Vyn (30) observed declining densities of pseudothecia on residues where residues were abundant and suggested that altered microclimate or increased concentrations of organic acids or other antifungal substances may act to suppress pseudothecial production.

The assessment of FHB in wheat for breeding and epidemiology studies is complicated by the highly variable expression of disease (24). Some of this variability undoubtedly results from environmental influences on the host-pathogen interaction, and variability is especially problematic in field studies. In attempts to define disease levels, researchers have developed multiple methods for the assessment of FHB (24). In this study, we elected to use a number of different methods to assess disease in the anticipation of finding one or more methods that would differentiate the experimental treatments. All five variables selected to quantify FHB were successful in differentiating among the experimental

treatments. A high correlation of FHB incidence with severity was expected, given that these variables are closely related and that incidence readings were moderate. Significant correlations between incidence and severity have previously been reported, and both measures of disease have been widely adopted by North American FHB workers as useful estimates of FHB reaction (5). Similarly, correlation coefficients of incidence and severity with grain yield, test weight, and the DON content of harvested grain indicate that these variables are highly correlated in susceptible varieties. Correlations of the percent residue cover with incidence, severity, yield, test weight, and DON content of grain were either poor or nonsignificant. This could suggest that fairly small amounts of residue can provide sufficient inoculum for epidemics to develop. Further studies on the colonization of crop residues by *Fusarium* spp. and the relationship between colonization and inoculum potential are warranted.

The detection of significant differences in disease levels among treatments and the subsequent differences in grain yield and quality indicate that the experimental design used in this study was adequate to detect differences among treatments. The small plot (9.1 × 6.1 m), although similar to those employed in previous studies (20,30), was of concern to us in planning this experiment, as little data is reported on the relative importance of short-distance and mesoscale dispersal of inoculum. The fact that we were able to detect significant differences in the incidence and severity of FHB and in the yield and quality parameters of harvested grain suggests that previous crop residue-tillage treatments do affect FHB development, even over the relatively small plot-to-plot distances examined in this study.

Dispersal of inoculum from the residue to wheat heads is a critical event in the disease cycle. Knowledge of the dispersal of inoculum (ascospore and macroconidia) would greatly assist in understanding the importance of residue in generating inoculum within a field or region. The results obtained in these experiments indicate that differences in the type and quantity of crop residues in small plots may affect disease development, which suggests that local sources of inoculum, such as those within a grower's field, contribute directly to inoculum load and disease potential. While control of FHB will likely rely on host resistance and fungicide treatments, the implications of these findings are that selection of cultural practices aimed to reduce inoculum-borne residues will assist in the management of FHB.

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