Seedling Blight Development and Control in Spring Wheat Damaged by *Fusarium graminearum* Group 2

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ABSTRACT

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Aspects of seedborne infection in *Fusarium*-damaged and undamaged seed lots of hard red spring wheat were studied. In a 22°C environment, seedling blight developed from plantings of *Fusarium*-damaged seed that were characterized by both reduction and delay in emergence and postemergence seedling death. After 28 days, stand counts from the *Fusarium*-damaged seed lot averaged 46%, compared with 98% from the undamaged seed lot. However, the mean dry weight of surviving seedlings from the *Fusarium*-damaged lot was not statistically different from that of seedlings from the undamaged seed lot. Surface-sterilization reduced recovery of *Fusarium graminearum* group 2 from the damaged lot by 7% and increased germination by 32%, suggesting that seed are both infected and contaminated with viable propagules of the fungus. In field experiments, seed treatment with maneb- or thiabendazole-containing fungicide combinations significantly reduced seedling blight and improved stands derived from the *Fusarium*-damaged seed lot. Triazole fungicides, including difenoconazole, fenbuconazole, and tetraconazole, were less effective. Triazole fungicides and carboxin-containing fungicide combinations controlled loose smut in these trials, while maneb seed treatments did not. In four field tests, seedling blight incidence in plantings of *Fusarium*-damaged seed increased as soil temperatures during emergence increased. The distribution of blighted seedlings was random and not clustered. Seedling blight did not develop in field plantings of the undamaged seed lot.

Additional keywords: chemical control, *Gibberella zeae*

Hard red spring wheat (*Triticum aestivum*) in the north central region of the United States has been affected in recent years by epidemics of *Fusarium* head blight (FHB). Severe outbreaks developed in 1993 and 1994 (15,19) and again in 1997. In Minnesota, FHB is primarily caused by *Fusarium graminearum* group 2 (*Gibberella zeae*), although other *Fusarium* species have been recovered from infected plant parts (33). Seed obtained from fields within FHB-affected areas exhibits characteristic signs and symptoms of *Fusarium* damage (3,4). Seed lots are often mixtures of visually damaged kernels, kernels that are infected but not visibly damaged, and uninfected, undamaged seed (16). Concern exists about the suitability of such seed for planting purposes. Seed of adapted cultivars is often produced locally within the region, and the widespread nature of recent FHB epidemics limits the availability of unaffected seed.

Fusarium species that attack the roots and crowns of wheat include *F. culmorum*

(8) and *F. graminearum* group 1 (11). Although occasionally recovered from seed (21), these fungi lack a functional ascigerous stage, are adapted to survival in the soil (28), and are widely distributed in the more arid regions of the United States (8,28,29). *F. culmorum* is rarely identified as a component of the FHB complex affecting wheat in Minnesota (16,33), and *F. graminearum* group 1 was not identified in recent studies of crown rot (34,35).

Seedling blight associated with *G. zeae* has been described by various authors, including Atanasoff (3), Dickson (9,10), and more recently by Bergstrom (5). The interaction of the anamorphic stage with germinating seed is described by Halfon-Meiri et al. (14). Damage caused by the fungus is expressed in loss of germinability, reduced emergence, and a postemergence blight of seedlings. Seedling blight develops over a broad temperature range, but damage is greatest at temperatures between 20 and 28°C (9,14).

Seed treatments reduce the activity of *F. graminearum* (6,7,12,18,20), although growers in Minnesota often report that benefits from planting treated seed are not consistent and that germination tests are not reliable indicators of seed lot performance. Some variability may be due to the reported decrease in viability of *F. graminearum* in stored seed over time (5,13). Four to five months may elapse

between fall (October to November) germination testing of seed lots and the April to May planting of spring wheat in the Upper Midwest. Temperature variation during emergence (warm versus cool) may also represent a factor contributing to variation in seed lot performance (12). Bergstrom (5) discusses the difficulties encountered by seed testing services in evaluating the results of blotter tests and estimating field performance of *Fusarium*-damaged seed lots. Official test procedures (2) include blotter assay protocols of 20°C (16 h)/16°C (8 h) incubation. These temperatures are lower than those reported as optimal for the expression of seedling blight (14).

Spring wheat producers in Minnesota usually treat seed with carboxin-containing fungicides to control loose smut (caused by *Ustilago tritici*). Carboxin is typically combined in two-way or three-way combinations with imazalil or thiram to broaden the spectrum of activity (26). Imazalil is registered to control seedborne and soilborne phases of common root rot (caused by *Bipolaris sorokiniana*). Seed treatment fungicides containing ethylene bis dithiocarbamates (such as maneb or mancozeb) are also registered for use in spring wheat (26). In Minnesota, these are frequently used as two-way mixtures with the insecticide lindane for temporary protection against wireworms. Recently, new three-way combinations containing carboxin, imazalil, and thiabendazole (Vitagav-Extra) and broad-spectrum triazole fungicides including difenoconazole (Dividend) have become registered for use on spring wheat seed.

The purpose of this study was to compare and contrast the quality and performance characteristics of two seed lots of hard red spring wheat from *Fusarium*-damaged (1993) and -nondamaged (1992) sources. Seed lots examined in this study were selected to represent extreme differences in their degree of damage. Another purpose was to evaluate the efficacy of currently registered and selected experimental seed treatments on seedling blight, stand establishment, loose smut, and yield.

MATERIALS AND METHODS

Seed lot quality. The study involved two lots of hard red spring wheat cv. Norm produced in the Red River Valley of Minnesota in 1992 and 1993 (Table 1). Norm is considered highly susceptible to FHB

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(15,16). Seed had been commercially cleaned and was used as submitted by seed growers to the Minnesota Crop Improvement Association (MCIA) for certification. The 1992 source had been stored at 10°C and 50% relative humidity for 12 months prior to use in this study. Infection frequency was determined based on 100 sterilized or 100 unsterilized seed plated (5 per plate) on potato dextrose agar (PDA). Plates were incubated under continuous cool-white light for 7 days at 24°C, and colonies of *Fusarium* spp. were identified using standard keys (22). Germination tests were conducted on blotters containing 100 seed incubated at 24°C for 7 days. Surface-sterilized and unsterilized treatment sets were assessed. Seed was surface-sterilized in 95% ethanol (5 s) followed by immersion in a solution of 0.5% NaOCl for 1 min, then rinsed in sterile distilled water and dried. Vigor tests were conducted by planting 100 seed in flats of steam-sterilized soil incubated in controlled-environment chambers at 22°C for 28 days. Seedlings were counted at 7-day intervals during the tests. Fresh weight and dry weight were determined after 28 days. Intact seedlings were washed free of soil, placed in forced-air ovens at 95°C for 48 h, and weighed. Tests for infection frequency, germination, and vigor were repeated six

times each using 100 surface-sterilized and 100 untreated seed. *t* tests were used in hypothesis testing for differences between seed lots.

Seed treatment. Seed lot 93-4843 (1993 produced, *Fusarium*-damaged source) and 92-0071 (1992 produced, undamaged source) were treated at registered rates with commercially formulated fungicides (Table 2). Key comparisons included Vitavax-Extra (a mixture of 27.8% carboxin, 2.5% thiabendazole, and 2.0% imazalil; Gustafson Inc., Dallas, TX) and DB-Green L (a mixture of 25.6% maneb and 8.6% lindane; Agsco Inc., Grand Forks, ND). Additional treatments were evaluated on the *Fusarium*-damaged lot 93-4843. Triazole fungicides tested included Dividend (a formulation containing 32.8% difenoconazole; Novartis Inc., Greensboro, NC), AG-4452 (a formulation containing 0.425% fenbuconazole; Agsco), and AG-4454 (a formulation containing 0.425% tetraconazole; Agsco). Agsco RR (a formulation of 10% imazalil; Agsco) was also tested in combination with DB-Green L. Chemicals were mixed with water (1:15 vol/vol for the formulation of difenoconazole; 1:3 vol/vol for all others), applied as a misted slurry (Laboratory Seed Treater, Gustafson), and allowed to dry before planting. Experiments were established at the North-

west Experiment Station, Crookston (two planting dates), the West Central Experiment Station, Morris, and the West Plant Research Farm, Roseau. These sites are separated north and south by a distance of approximately 360 km (Roseau north, Morris south, and Crookston between them). Planting dates were 20 April and 11 May (Crookston), 11 May (Morris), and 3 May (Roseau) in 1994. Plots (1.5 × 6.1 m) were seeded at a rate of 134.5 kg/ha, and treatments were replicated six times in a randomized complete block design. The number of seed per kg was determined for each lot from gram weight conversions of ten 1,000-kernel counts. Soil temperature at 10-cm depth was continuously recorded at each site.

Disease assessments. Plant stand was assessed 21 days after planting at the three-leaf stage from the inner six rows of each 10-row plot. Seedlings were counted from the middle 0.3 m of 0.9-m row sections beginning at the front corner of each plot and sampling down and across rows at 0.9-m intervals (total of six locations). Counts were combined for each plot and analyzed by analysis of variance. Tukey's honestly significant difference (1) was calculated at the $\alpha = 0.05$ level. Percent stand was calculated by dividing the number of surviving seedlings by the estimated number of seed planted and multiplying by 100. Loose smut was assessed approximately 60 days after planting at Feekes (17) growth stage 10.5.2 (flowering-complete) by counting the number of plants with smutted heads per 12 row-meters (two outer rows in each plot). Smut infection was assumed to be seedborne (27) and therefore randomly distributed. Counts were then adjusted to percent smut infection based on stand counts and analyzed statistically. Plots were combine-harvested at maturity, dried to uniform moisture content, and yields were determined. The percent visu-

Table 1. Characteristics of seed lots 93-4843 (*Fusarium*-damaged) and 92-0071 (undamaged) of spring wheat cv. Norm

Seed lot	Source	Seed/kg ^a	Seed/ha ^b	Germ. (%) ^c	Test wt. (kg m ⁻³)	VSK (%) ^d
93-4843	1993 harvest	29,646	3,985,000	49.0	840	24.2
92-0071	1992 harvest	27,234	3,661,000	96.0	938	0.3

^a Number of seed per kilogram was determined from 10 replicate samples of 1,000 kernels.

^b Number of seed planted per hectare in field experiments.

^c Percent germination determined from 400 seed (50 seed replicated eight times incubated on blotters at 20°C for 7 days) by the Minnesota Crop Improvement Association (MCIA, St. Paul, MN).

^d Percent visually scabby kernels estimated from six replicate samples using visual comparison standards (16).

Table 2. Influence of seed treatments on stand, loose smut, yield, and percent visually scabby kernels on two planting dates for spring wheat, Northwest Experiment Station, Crookston, Minn., 1994

Treatment (ml/kg)	Planted 20 April				Planted 11 May			
	Stand (%) ^a	Smut (%) ^b	Yield ^c	VSK (%) ^d	Stand (%) ^a	Smut (%) ^b	Yield ^c	VSK (%) ^d
Vitavax-Extra (1.95)	83.1	0.03	1,533	35.7	77.8	0.00	1,143	34.5
DB-Green L (3.24)	85.8	2.36	1,452	35.2	73.8	1.89	1,109	33.3
DB-Green L (3.24) + Agsco RR (0.43)	89.1	1.66	1,607	35.8	69.4	0.82	1,130	34.2
Dividend (0.16)	72.3	0.00	1,479	36.8	53.4	0.06	1,035	35.2
Dividend (0.32)	79.2	0.00	1,614	36.7	58.5	0.02	1,008	36.2
Agsco-4452 (3.24)	60.0	0.09	1,472	38.0	37.6	0.00	827	39.7
Agsco-4452 (4.54)	66.6	0.04	1,325	37.2	38.4	0.03	760	40.0
Agsco-4454 (1.62)	67.8	0.00	1,197	38.0	42.4	0.00	867	37.5
Agsco-4454 (3.24)	69.6	0.00	1,325	38.5	54.4	0.00	901	36.3
Untreated lot 93	54.4	2.02	1,365	36.5	33.1	1.60	659	42.5
Vitavax-Extra lot 92 (1.95)	97.3	0.06	1,493	35.7	90.3	0.00	1,095	33.7
DB Green - L lot 92 (3.24)	93.6	0.90	1,493	37.2	89.6	0.60	1,088	33.0
Untreated lot 92	98.0	0.84	1,513	36.8	96.7	0.68	1,095	33.7
T _{critical} ($\alpha = 0.05$)	18.4	0.59	NS ^e	NS	15.4	0.56	256	NS

^a Stand counts 21 days after planting expressed as percent seed planted.

^b Incidence of loose smut expressed as percent of stand.

^c Yield in kilograms per hectare.

^d Percent visually scabby kernels in harvested grain estimated using visual comparison standards (16).

^e Not significant.

ally scabby kernels (% VSK) in harvested grain was estimated from two 50-g subsamples using visual comparison standards (16).

RESULTS

Seed lot quality varied between lot 92-0071 (hereafter referred to as lot 92) and lot 93-4843 (hereafter referred to as lot 93). Lot 92 contained 27,234 seed per kg, had a test weight of 938 kg m⁻³, and contained less than 1% VSK (Table 1). In HPLC tests performed six times (16), lot 92 was found to contain no detectable deoxynivalenol, a secondary metabolite of *F. graminearum* (16) that is stable in storage. Lot 92 contained 1.7% *Fusarium*-infected kernels and exhibited 98.5% germination on blotter tests (Table 3). In contrast, lot 93 contained 29,646 seed per kg, had a test weight of 840 kg m⁻³, and contained 24.2% VSK (Table 1). In tests performed six times, samples of lot 93 were found to contain 16.6 ± 1.4 µg of deoxynivalenol per gram. Lot 93 averaged 70% *Fusarium*-infected kernels and germinated at 40% (Table 3). Both lot 92 and lot 93 contained other *Fusarium* spp. at <1.0% and *Bipolaris sorokiniana* at <1.0% and were selected for use, in part, as a result of this finding. Surface-sterilization of seed of lot 93 reduced the percent infected kernels to 62% and increased germination in the blotter tests to 72% (Table 3).

Germination and vigor tests. Plants were established from 98% of unsterilized seed and 97% of surface-sterilized seed of lot 92 (Table 3). Seed of lot 93 emerged more slowly than seed of lot 92. At 7 days after sowing, only 34% of unsterilized seed and 45% of surface-sterilized seed had emerged. Plants in these treatments began to die of seedling blight during the next 14 days, even as some additional emergence continued. By 21 days after planting, seedling blight reached a maximum, and plant loss was not observed between 21 and 28 days, when the experiments were terminated (Table 3). Surviving plants in all treatments remained healthy and normal in size and color. Plant counts in lot 92 averaged 98 and 97% of sown seed in unsterilized and surface-sterilized treatments, respectively (Table 3). Plant counts in lot 93

averaged 46 and 68% of sown seed in unsterilized and surface-sterilized treatments, respectively (Table 3). The dry weight of harvested plants established from unsterilized seed lots averaged 2.543 g per pot and 0.026 g per plant for lot 92 and 1.155 g per pot and 0.025 g per plant for lot 93 (Table 3). Seed that had been surface-sterilized averaged 2.432 g per pot and 0.025 g per plant for lot 92 and 1.632 g per pot and 0.024 g per plant for lot 93 (Table 3). *t* tests identified significant differences ($P < 0.01$) between the dry weights on a per pot basis in both untreated and surface-sterilized comparisons (lot 92 compared with lot 93), but paired comparisons of the dry weights on a per plant basis were not statistically different (Table 3).

Field tests. Stands that developed from plantings of untreated seed of the *Fusarium*-damaged lot 93 were affected by seedling blight at each location. Emergence was delayed slightly, and soon after emergence, seedlings began to exhibit chlorosis and die. Stand loss continued over the next 10 days and ceased approximately 14 to 18

days after planting. At 21 days after planting, plant populations derived from untreated seed of lot 93 were uniformly thinned due to seedling blight losses (Fig. 1). The mean number of surviving plants per m² of lot 93 were 270, 224, 137, and 124 for the four respective sites of Roseau, Crookston PD1, Crookston PD2, and Morris. The variance to mean ratios of individual plant counts ($n = 36$; six observations per replicate, six replicates) were 2.04, 1.45, 1.06, and 1.07, respectively. This suggests that the distribution of seedling blight within plots can be characterized as random, as opposed to clustered.

Plant counts of 21-day-old seedlings that developed from untreated seed of the *Fusarium*-damaged lot 93 varied from 66% (Roseau) to 30% (Morris). Soil temperatures (10 cm depth) for the 10 consecutive days after planting averaged 11.3 and 19.3°C, respectively, at these locations. At Crookston, untreated seed of lot 93 averaged 54% stand when planted 20 April and 33% when planted 5 May (Table 2). Soil temperatures (10 cm depth) for 10 days

Fig. 1. Stand of spring wheat photographed 1 June (21 days after planting) at Crookston, Minn. Foreground left, untreated seed of lot 92 (undamaged seed lot); center, untreated seed of lot 93 (*Fusarium*-damaged seed lot); and extreme right, untreated seed of lot 93 treated with DB-Green L. Background left, lot 92 treated with Vitavax-Extra; left center, DB-Green L; right center, untreated; and right, lot 93 untreated.

Table 3. Seed quality of *Fusarium*-damaged and undamaged seed lots of spring wheat^a

Treatment	Seed lot	Infection (%) ^b	Germ. (%) ^c	Plants emerged (%) ^d				Dry weight	
				7d	14d	21d	28d	g/pot	g/plant
Untreated	93-4843	69.7	40.5	34.4	55.8	46.2	46.2	1.155	0.025
	92-0071	1.7	98.5	66.3	97.8	97.8	97.8	2.543	0.026
	<i>P</i> value from <i>t</i> test	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01	0.712
Surface-sterilized ^e	93-4843	62.3	72.0	45.4	74.5	68.2	68.0	1.632	0.024
	92-0071	0.7	99.3	67.0	95.7	97.2	97.2	2.432	0.025
	<i>P</i> value from <i>t</i> test	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01	0.689

^a Values are based on six replicates of 100 seeds.

^b Seed incubated on potato dextrose agar for 7 days at 24°C.

^c Seed incubated on blotters 7 days at 24°C.

^d Seed grown in steam-sterilized soil for 28 days at 22°C.

^e Sterilized in 95% ethanol (5 s) and in 0.5% NaOCl (1 min), rinsed in sterile water, and dried.

after planting averaged 12.2 and 21.2°C for the respective planting dates.

Seed of lot 93 treated with Vitavax-Extra produced stands that averaged 83% of the estimated seed planted (an increase of 37% compared with the mean of 46% for untreated seed of this lot). Treatment with DB-Green L resulted in stands that averaged 82% of seed planted (an increase of 36%) across all sites. Seed of lot 93 treated with DB-Green L plus Agsco RR (containing 10% imazalil) resulted in stands of 80% across all sites or 1.8% less than DB-Green L alone. Seed of lot 93 treated with Dividend (difenoconazole) at a rate of 0.32 ml/kg resulted in stands that averaged 71% of seed planted. Dividend was significantly ($P = 0.05$) less effective than Vitavax-Extra or DB-Green L when planting was delayed, and stand loss due to seedling blight was high (11 May planting date at Crookston [Table 2] and 11 May planting at Morris [Table 4]). When soil temperatures were lower (20 April planting date at Crookston [Table 2] and 3 May planting date at Roseau [Table 5]), stand counts were lower in Dividend treatments compared with Vitavax-Extra or DB-Green

L, but differences were not statistically different ($P = 0.05$). Seed treatments containing fenbuconazole (AG-4452) and tetraconazole (AG-4454) improved stands derived from the *Fusarium*-damaged lot 93 compared with untreated seed, but in the 11 May planting at Crookston, they were less effective than Vitavax-Extra or DB-Green L (Table 2). The higher rate of the triazole-type fungicides consistently produced higher stand counts than the lower rate, but in no case were these differences statistically significant ($P = 0.05$).

Plant populations that developed from the undamaged-uninfected lot 92 averaged 99% of the sown seed without any fungicide treatment (Tables 2 and 5). Lot 92 treated with Vitavax-Extra averaged 95% and treated with DB-Green L averaged 93%. In an independent analysis of variance, the reductions in plant population associated with the treatment of healthy seed (lot 92) were statistically significant ($P = 0.05$).

The incidence of loose smut in untreated plantings of lot 93 was 1.9% across all locations (Tables 2, 4, and 5). Vitavax-Extra, Dividend, and the experimental

triazole-type fungicides (fenbuconazole and tetraconazole) effectively controlled loose smut. Seed treated with DB-Green L averaged 1.9% smutted plants and was not statistically different than untreated seed at any of the sites. Lot 92 averaged 0.65% smutted plants (Tables 2 and 5). Vitavax-Extra controlled loose smut in plantings of this lot, and DB-Green L was ineffective (Tables 2 and 5).

FHB developed in all experiments. Symptoms were evident as grain development approached Feekes growth stage 11.2 (soft dough stage). In harvested grain, the %VSK varied by location and was not related to the amount of seedling blight (Tables 2, 4, and 5). At Crookston, the 20 April planting date averaged 36.8% VSK and the 11 May planting date averaged 36.1% (Table 2). At Roseau, planted 3 May, FHB was less and treatments averaged 16.7% VSK. Within sites, the %VSK tended toward an inverse relationship with percent stand, but there were no significant differences ($P = 0.05$) among treatments for %VSK at these locations. At Morris, planted 11 May, the untreated plots averaged 15.7% VSK, and treatment with Vitavax-Extra or DB-Green L significantly ($P = 0.05$) reduced the %VSK in harvested grain (Table 4).

The yield of harvested grain was severely affected by FHB at Crookston. Treatments planted 20 April averaged 1,451 kg/ha, and there were no significant differences ($P = 0.05$) among treatments (Table 2). In the second planting, yields ranged from 1,143 to 659 kg/ha, and several treatments produced stands that resulted in yields that were statistically greater ($P = 0.05$) than the yield from untreated seed of lot 93 (Table 2). The yield of untreated lot 92 (1,095 kg/ha) was also significantly greater ($P = 0.05$) than that of untreated lot 93 (Table 2), suggesting that these effects may have been a result of plant population. At Roseau, yields from harvested plots ranged from 3,052 to 2,474 kg/ha (Table 5). There were no statistically significant differences ($P = 0.05$) among treatments. At Morris, the yield of plots planted with untreated seed of lot 93 was 1,730 kg/ha (Table 4). The yields of all treatments were statistically greater ($P = 0.05$) than those from untreated seed.

DISCUSSION

The activity of *F. graminearum* in standard blotter tests is a major difficulty facing seed testing services. Results reported in this study suggest that germination and vigor tests conducted at higher temperatures (22 to 24°C), coupled with determinations of percent seed infection, are useful indicators of seedling blight potential. However, the degree of postemergence seedling blight that develops in field plantings of *Fusarium*-damaged seed is strongly influenced by soil temperatures at and during emergence. Infected seed lots

Table 4. Influence of seed treatments on stand, loose smut, yield, and percent visually scabby kernels in spring wheat planted 11 May 1994, West Central Experiment Station, Morris, Minn.

Treatment (ml/kg)	Stand (%) ^a	Smut (%) ^b	Yield ^c	VSK (%) ^d
Vitavax-Extra (1.95)	88.6	0.00	2,609	10.0
DB-Green L (3.24)	82.9	1.61	2,562	11.6
DB-Green L (3.24) + Agsco RR (0.43)	79.6	0.81	2,636	11.3
Dividend (0.16)	58.4	0.00	2,117	12.5
Dividend (0.32)	64.0	0.00	2,199	12.5
Untreated lot 93	30.1	1.85	1,730	15.8
T _{critical} (alpha = 0.05)	10.9	0.43	350	4.2

^a Stand counts 21 days after planting expressed as percentage of seed planted.

^b Incidence of loose smut expressed as percentage of stand.

^c Yield in kilograms per hectare.

^d Percent visually scabby kernels in harvested grain estimated using visual comparison standards (16).

Table 5. Influence of seed treatments on stand, loose smut, yield, and percent visually scabby kernels in spring wheat planted 3 May 1994, West Plant Research Farm, Roseau, Minn.

Treatment (ml/kg)	Stand (%) ^a	Smut (%) ^b	Yield ^c	VSK (%) ^d
Vitavax-Extra (1.95)	81.2	0.00	2,595	15.3
DB-Green L (3.24)	83.4	1.88	2,716	17.0
DB-Green L (3.24) + Agsco RR (0.43)	80.5	0.63	2,710	16.6
Dividend (0.16)	78.0	0.00	2,736	17.8
Dividend (0.32)	80.8	0.00	2,474	16.3
Agsco-4452 (3.24)	76.6	0.02	2,777	18.0
Agsco-4452 (4.54)	76.9	0.00	2,750	18.0
Agsco-4454 (1.62)	77.5	0.03	2,757	15.4
Agsco-4454 (3.24)	77.3	0.00	2,676	15.9
Untreated lot 93	65.5	2.17	2,703	18.0
Vitavax-Extra lot 92 (1.95)	98.6	0.00	3,012	16.6
DB-Green L lot 92 (3.24)	96.1	0.80	2,992	17.0
Untreated lot 92	102.7	0.82	3,052	15.4
T _{critical} (alpha = 0.05)	21.6	0.64	NS ^e	NS

^a Stand counts 21 days after planting expressed as percentage of seed planted.

^b Incidence of loose smut expressed as percentage of stand.

^c Yield in kilograms per hectare.

^d Percent visually scabby kernels in harvested grain estimated using visual comparison standards (16).

^e Not significant.

can produce satisfactory stands with the use of an effective seed treatment. As a result of this investigation, the Minnesota Crop Improvement Association has adopted a protocol to conduct germination tests on *Fusarium*-damaged seed lots both with and without Vitavax-Extra. This information is then reported to the grower and is used in the decision-making process with regard to seed treatment. Spring wheat producers utilizing germination and vigor tests are encouraged to have these tests conducted as close as possible to the actual time of planting, as infection frequency declines over time due to a loss of viability of the fungus within seed (5,13).

The response of *Fusarium*-damaged seed lots to seed treatment will vary depending on the degree of damage and the association or disassociation of damage with seed sizes that can be removed by special cleaning operations, including gravity tables (30). Germination test results suggest that only 40% of the seed in lot 93 were viable; yet effective seed treatments produced plants from approximately 90% of these seed when they were planted in the field. Current Extension Service recommendations are to thoroughly clean *Fusarium*-damaged seed using gravity tables, then treat with an effective fungicide, to increase the seeding rate at planting by 10% (15). These recommendations appear sound if disease-free seed is unavailable. Adjustments in seeding rate should correctly compensate for stand losses caused by this seedborne fungus. Refining this adjustment on a percentage basis may prove difficult. The adjustment cannot be directly estimated from the results of germination tests. It may be more accurately modeled from soil temperature information if seed infection information is available.

The stand loss resulting from planting seed infected with *F. graminearum* group 2 is characterized by both a germination failure and a postemergence seedling blight. The degree of postemergence seedling blight can be reduced by an effective seed treatment. The rank order of seed treatment performance in the experiments reported here was consistent across all plantings. Thiabendazole and maneb were the most effective fungicides tested. Difenoconazole was intermediate, and fenbuconazole and tetraconazole were less effective. Loose smut was controlled by the systemic fungicide carboxin and all of the triazole-type fungicides tested. Maneb seed treatments were ineffective against loose smut. Across four sites, the addition of imazalil failed to improve stands of *Fusarium*-damaged wheat compared with maneb alone. The average stand from *Fusarium*-damaged seed of lot 93 treated with DB-Green L was 77.3% compared with 75.6% for DB-Green L + Agsco RR. This suggests that imazalil contributes little to control of seedborne *F. graminearum*.

Late planting increased the benefits from seed treatment. This contradicts Extension Service recommendations in which seed treatments were thought to be needed most when planting into cold, wet soils (26). *F. graminearum* is more active in warm versus cool soils (9). Cleaning and conditioning seed, increasing seeding rates, and treating seed with an effective fungicide appear to be sound recommendations when *Fusarium*-damaged seed lots must be used. These recommendations may be more important for spring wheat producers (who are planting in conditions when soil temperatures are likely to warm), as opposed to winter wheat producers, who often plant in conditions where soil temperatures may be expected to cool as seeding is delayed.

Ocamb and Kommedahl (24,25) described *F. graminearum* group 2 as rhizosphere incompetent. Yet Nyvall (23) reported that chlamydospores formed and survived in excess of 16 months in nonautoclaved field soil. Results reported here indicate that under field conditions, the seedborne inoculum associated with stand loss attributable to *F. graminearum* group 2 is more important than soilborne inoculum. Stand loss associated with a healthy seed lot averaged 3% planted immediately adjacent to plantings where stand loss exceeded 67% (Fig. 1). In addition, the distribution of seedling blight appeared to be random and uniform within each location. This also suggests that seed and not soil represented the primary source of inoculum. The lack of rhizosphere competence may also account for the observed activity of protectant fungicides like maneb against *F. graminearum* group 2. *F. culmorum* and *F. graminearum* group 1 survive longer in soil (28). The crown rot fungi may be more rhizosphere competent, and systemic seed treatments could have advantages when these fungi are involved (21,31).

Seedling blight affected yield in the second planting date at Crookston (Table 2) and at Morris (Table 4). Plant populations at these locations fell below 113 plants per m². Populations of spring wheat plants that fall below this level cannot compensate for stand loss with tillering and are considered candidates for replanting (26). Other plant population effects have been observed to be associated with stands reduced by seedling blight. These include an increase in populations of grassy weeds, particularly green foxtail (*Setaria viridis*), that become more competitive in spring wheat stands that are thinned by seedling blight.

FHB developed in each of the field trials, but the severity of the disease varied with factors other than the amount of seedling blight, including the amount of rainfall and the number of rain-day events during anthesis (32). The cultivar Norm is considered highly susceptible to FHB, and disease severity is directly proportional to the percentage of VSK for this cultivar (16).

FHB was most severe at Crookston (20 April planting and 11 May planting), least severe at Morris, and intermediate at Roseau. There was no evidence of seed transmission of the head blight phase of this disease in these studies.

Halfon-Meiri et al. (14) observed perithecia of *G. zeae* on dying seedlings grown in sterilized sand culture. Dickson (9) observed that perithecia form on the culm of diseased seedlings near the soil line of field-grown plants. Although diseased tissues were not examined for formation of perithecia in this study, it would be of interest to know if blighted seedlings are capable of functioning as a source of primary inoculum for the head blight phase of this disease. If so, it may explain observed outbreaks of FHB in fields that were rotated the previous year to nonhost crops and would also suggest an additional benefit from seed treatment if the treatment is able to eliminate this inoculum source.

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