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DIAGNOSIS AND MANAGEMENT OF ROOT DISEASE IN DRYLAND WHEAT IN WESTERN NORTH DAKOTA

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Summary

Western North Dakota spring wheat and durum producers commonly plant into ground previously planted to wheat (*Triticum aestivum* L.), durum (*Triticum turgidum* L. Durum Group), or barley (*Hordeum vulgare* L.). The objective of this project was to demonstrate the extent that root diseases affect yield and quality of wheat in continuous wheat sequences and the effect that crop rotations have on reducing root disease. Field demonstrations were initiated at eight locations in western North Dakota. Methyl bromide fumigant was used in plots to control fungal root diseases. Root disease ratings were consistently lower in fumigated plots than in natural (non-fumigated) soil plots. Under continuous wheat sequences, yields from fumigated plots were 20% to 42% greater than from wheat grown in natural soil plots. Grain protein and test weight were often greater from fumigated than natural soil plots. When wheat was grown in fields having a two-year break from cereals, yields in the fumigated plots were not significantly different compared to natural soil plots. No significant differences in root rot ratings were found between treatments in wheat following a two-year break with non-cereal crops. Plots which included rotational, non-host crops for wheat and barley root pathogens, produced wheat yields nearly equal to fumigated plots yields.

Introduction

The flexibility allowed producers by the Federal Agriculture Improvement and Reform (FAIR) Act of 1996 and favorable prices for hard red spring wheat, durum, and barley in 1996 and 1997 prompted many western North Dakota producers to abandon summer fallow and initiate continuous cropping of these cereal grains. Statewide, North Dakota producers in 1997 seeded nearly 62% of their wheat acres on fields that were either in wheat or barley the previous year (McMullen, 1998). In western North Dakota, of the known previous crops reported in this study, 75% of the wheat grown had been in fields where wheat was grown the previous year.

Research conducted by North Dakota State University (NDSU) (Stack and McMullen, 1995) and Canadian (Ledingham, et. al., 1973; Mathieson, 1943; Butler, 1961) scientists suggests that root and crown diseases reduce yields on an average of between five and ten percent. In continuous cereal and cereal fallow rotations, yields are commonly lower than can be expected based on available soil moisture and growing season precipitation. Cook (1990) found over a 15-year period that when root and crown diseases were controlled with fumigation in continuous winter wheat rotations, an average 70% yield increase could be expected. A one-year break and two-year break between wheat crops produced a 22% and 7% yield increase, respectively, for fumigated compared to non-fumigated plots. Producers are encouraged to incorporate crop rotations into their farming practices. Crop rotations have been shown to reduce problems with insects, weeds, and diseases while improving yields and quality of subsequent crops (Black and Siddoway, 1975). Many producers do not fully realize the extent of yield and quality losses as a result of root and crown disease problems.

This project demonstrated the impact of root diseases on dryland wheat and durum wheat in western North Dakota and the role that crop rotation can play in their control.

Materials and Methods

Eight locations with a crop rotation history (Table 1) of either continuous cereal grain or cereal grain with a two year break of a crop other than wheat or barley were selected. Agronomic practices, estimated stored soil water and precipitation were recorded (Table 2). Stored soil water was estimated at the time of fumigation with the use of a Paul Brown Soil Moisture Probe (Brown and Carlson, 1990). Precipitation was recorded by producers for the on-farm locations and by the North Dakota Agricultural Weather Network (NDAWN) at the Dickinson Research Extension Center and at the Williston Research Extension Center locations.

A randomized complete block design with four replications was used at all locations except at Dickinson where a split block design was used. Each plot was 300 ft^2 (28 m^2). Plots to be fumigated were covered with a six mil plastic sheet, edges buried in trenches four to six inches deep (Figure 1) to seal the covered area, and methyl bromide was metered through plastic hoses at the rate of one pound per 100 ft^2 (50g m^{-2}). The fumigated plots remained covered for 48 to 72 hours after which time the plastic was removed (Figure 2). Non-fumigated or natural soil plots served as checks. After the plastic was removed, producers farmed through the fumigated and natural soil plots with their normal management practices (Figure 3).

Root samples were collected from plots between Haun stage 5 and 11.4 and again at Haun stage 14.5. Samples were carefully washed by hand. A visual evaluation of the first group of samples was completed at the Dickinson Research Extension Center. Root counts, evaluation of subcrown internodes, Take-all, and *Rhizoctonia* symptoms were noted. The second group was sent to the NDSU plant clinic for culture plate evaluation and a visual evaluation of root mass, root color, and extent of root rot lesions on the subcrown internode. Soil moisture was measured in fumigated and natural soil plots at the Williston Research Extension Center location with a neutron probe once a week.

Head density and mature plant height measurements were made at harvest. Except at Williston, yield samples were harvested from each plot by hand from an area four rows wide by 8 ft (2.4 m) long, bagged, threshed, and yield and quality factors measured. At Williston samples were machine harvested from an area 4 ft (1.2 m) wide by 16 ft (4.9 m) long. Protein was analyzed with an NIR analyzer at Southwest Grain Inc., Dickinson, ND.

All data was statistically analyzed using SAS Statistical software version 6.12 (SAS Institute Inc., 1996).

Results and Discussion

Yield and Quality

Significant differences in grain yield were detected between fumigated and natural soil plots in continuous cereal rotations except at Regent and Williston locations (Table 3). Wheat and durum grain yields were 34% greater at Dickinson (Table 4) to 42% greater at Hazen from fumigated plots compared to natural soil plots when grown in continuous wheat rotations and available water was 12 inches or more (Table 2 and Table 3). When less than 12 inches of water was available, grain yields were 20 to 26% greater from fumigated plots compared to natural soil plots when grown in continuous wheat rotations.

When two consecutive years of non-host crops were introduced into the rotation, fumigated plot grain yields were nearly the same as natural plot grain yields. Continuous wheat grain yields from fumigated plots at Amidon and Beach in 1997 were 40% greater than from natural soil plots (Ashley et. al., 1997) but with two years of non-host crops in the crop sequence, fumigated and natural soil plots yields were almost equal. The experimental design at Dickinson allowed for a direct statistical comparison between rotations but not between fumigation and natural soil plots (Table 4). When pea or millet was included in the rotation after oat, a significant improvement in grain yield of 20 to 30% occurred compared to the wheat-oat-wheat-wheat rotation. Oat is generally thought to not be a host or a poor host to many of the root pathogens that attack wheat. No significant improvement in yields was observed at Dickinson between rotations when the rotations were overlaid by fumigation.

Total above ground biomass was measured at the Williston site (data not shown). This amounted to 1519 pounds/acre (1702 kg/ha) more from the fumigated plots than from the natural soil plots. This difference was significant at the 0.05 level.

Test weight and protein content often improved with fumigation or when two consecutive years of non-cereal crops were included in the rotation (Table 3 and Table 4).

The hard red spring wheat variety, 2371, planted at Regent exhibited symptoms similar to those caused by the *Septoria* fungus. However upon close examination of chlorotic spots found on these plants (Figure 4), *Septoria* was dismissed as being the cause. Some varieties of soft white wheat are known to be sensitive to methyl bromide treated soils and symptoms similar to those described by Cook (1998) were found on 2371. Slight chlorotic spotting was seen at Amidon on 2398.

Plant Length, Mature Plant Height, and Head Density

Plant length measured during the first wheat plant-root evaluation was significantly longer for plants grown on fumigated plots at Williston and Hazen locations (Table 5). Plant length tended to be longer when a two-year break in wheat crops occurred compared to the wheat-oat-wheat-wheat rotation at Dickinson (Table 6). The significant difference in plant height was maintained to maturity only at the Hazen location (Table 3).

Plant population counts were made only at Williston (625,000 plants/acre fumigated vs. 465,000 plants/acre natural soil plots) but differences between fumigated and natural soil plots were visibly apparent where this demonstration was conducted in fields having a history of continuous wheat (Figure 5).

Head density was significantly greater for fumigated plots compared to natural soil plots in continuous cereal rotations except at Crosby (Table 3). In rotations where wheat was preceded with non-host crops for two years, no significant differences were detected in head density (Table 3 and Table 4).

Root Assessments

Significant differences were noted in the subcrown internode rating for the Garrison location during the initial root evaluation (Table 5) and at the Hazen, Crosby, and Williston locations for root evaluations done at the soft dough stage (Table 7). There was a trend towards more root rot lesions on subcrown internodes taken from natural soil plots than from fumigated soil plots at both early Haun stages and Haun stage 14.5. There were no significant differences in subcrown internode ratings at Dickinson at either the initial (Table 8) or at the soft dough stage (Table 9). *Cochliobolus santivus* and *Fusarium* are thought to primarily manifest symptoms on the subcrown internode and crown area of the plant (Wiese, 1987).

Rhizoctonia symptoms were often detected in continuous cereal rotations but were absent when non-cereals were included for two years between wheat crops or when fumigation was utilized to control root disease. *Rhizoctonia* and *Pythium* infections occur on smaller roots and rootlets rather than the subcrown internode and crown area of the plant, making detection difficult (Wiese, 1987).

Take-all caused by *Gaeumannomyces graminis* was not detected in any of the samples collected during these demonstrations.

Seminal and crown root counts were always greater on plants from fumigated than natural soil plots except at locations where a two-year break between host cereal crops in the rotation was used (Table 5). There was no significant difference in root counts between rotations at Dickinson for fumigated plots (Table 8). However there were significantly greater numbers of seminal and crown roots in rotations that incorporated a two-year break of oat and field pea or oat and millet compared to the single year of oat followed by two consecutive wheat crops.

Cochliobolus symptoms were detected in both fumigated and natural soil plots but *Rhizoctonia* symptoms were never detected in fumigated plots. Root mass was always larger and root color always whiter on plant samples from fumigated than from natural soil plots but not significantly whiter in rotations which included non-cereal crops the previous two years (Table 7 and Table 9).

Water-use

Water content of soils at the Williston Research Extension Center location was measured weekly with a neutron moisture gauge and water-use calculated (Table 10). Wheat grown on the fumigated plots tended to use more water earlier than wheat grown on natural soil plots. Water-use during the growing season in the fumigated plots was significantly greater in the 1 to 2 foot (0.3 to 0.6 m) depth than occurred in the natural soil plots. Water use by plants grown on the natural soil plots exceeded that of plants grown on the fumigated plots for the 0 to 1 foot (0.0 to 0.3 m) and the 1 to 2 foot (0.3 to 0.6 m) depths during the time period of July 15 to July 21. This corresponds with drier soils at these depths in the fumigated plots compared to the natural soil plots. The crop growing on the fumigated soils had essentially used all of the available water at these depths.

Implications of Demonstration

Rhizoctonia and *Pythium* are particularly sensitive to methyl bromide, and *Fusarium* to a lesser extent (Vanachter, 1979). In partial soil fumigation such as used in these demonstrations, sufficiently high concentrations for an extended period of time are not obtained to kill all fungi and microbial activity in the soil. Chloropicrin and fumigants containing sufficient concentrations of Chloropicrin injected into soils are known to be less selective and more detrimental to soil microbiology than methyl bromide. Methyl bromide's selectivity and relatively short after-effect may explain the subcrown internode ratings and the expected yield loss due to root disease. Further work is required to differentiate the yield loss cause by plant pathogens.

Root disease ratings were consistently lower in fumigated plots than non-fumigated plots when the field had a history of continuous wheat. When crop rotations included crops that are poor hosts to wheat root disease, wheat yield and quality was nearly the same from fumigated and natural soil plots.

Producers can expect reduced wheat and durum grain yields and quality when wheat or durum is grown in continuous wheat, durum, or barley rotations. Producers can also expect less straw returned to the soil by smaller and poorly tillered plants, typical of wheat with root disease. Less straw means less coverage, making soil more susceptible to water and wind erosion. This could eventually lead to a decline in soil health and productivity. Wheat plants with root disease are inefficient in utilizing water and nutrients, especially nitrogen. Also a crop with root disease can leave a wheat crop more vulnerable to weeds because diseased plants are less competitive.

Climatic conditions and crop rotations will affect the severity of disease. Dry conditions will reduce grain yield difference between fumigated and natural soil plots. Although soil fumigation is not economic for cereal growing, it does provide a valuable technique to demonstrate the potential productivity of soil. This demonstration has shown that crop rotations that include non-host crops will reduce the impact that root disease has on wheat and durum yields.

Cooperating Producers

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Table 1. Cropping history[1] of selected fields in western North Dakota.

Location	1997	1996	1995	1994	1993	1992
Amidon	soybean	fallow	hrsw	fallow	hrsw	fallow
Beach	field pea	corn	hrsw	hrsw	barley	hrsw
Crosby	durum	durum	durum	fallow	durum	fallow
Dickinson	hrsw	oat	hrsw	fallow	hrsw	fallow
Dickinson	field pea	oat	hrsw	fallow	hrsw	fallow
Dickinson	millet	oat	hrsw	fallow	hrsw	fallow
Garrison	durum	durum	durum	wheat	fallow	durum
Hazen	durum	durum	chem-fallow	durum	durum	durum
Regent	hrsw	hrsw	hrsw	hrsw	hrsw	hrsw
Williston	hrsw	hrsw	hrsw	hrsw	hrsw	hrsw

[1] Cropping history: hrsw = hard red spring wheat; durum = durum wheat.

Table 2. Agronomic practices and water, 1998.							
Location	Cultivar	Tillage system	Weed severity rating	Seed treatment	Estimated stored soil water inches	Growing season precipitation inches	Total available water inches
Continuous wheat							
Hazen	Renville durum	no-till hoe opener	none	Agsco DB Green/Double R (mancozeb + lindane + imazalil)	7.7	7.9	15.6
Crosby	Monroe durum	minimum-till	low-mod	RTU Vitavax Extra (carboxin + imazalil + Thiabendazole)	4.5	7.4	11.9
Williston	Ernest hrsw	no-till disc opener	none	none	3.3	6.2	9.5
Garrison	Munich durum	minimum-till hoe opener	low	none	3.3	7.0	10.3
Regent	2371 hrsw	conventional hoe opener	none	Agsco DB Green/Double R (mancozeb + lindane + imazalil)	4.0	9.4	13.4
Two-year break between wheat crops							
Beach	Ben durum	no-till hoe opener	none	none	7.7	7.1	14.8

Amidon	2398 hrsw	no-till disc opener	none	RTU Vitavax Extra (carboxin + imazalil + Thiabendazole)	7.0	9.3	16.3
DREC Crop Rotation Study							
Dickinson	Trenton HRSW	no-till disc opener	none	none	4.5	9.7	14.2

Table 3. Yield, test weight, protein, height, and head density of hard red spring wheat at selected locations in western North Dakota, 1998.					
Location/Treatment	Head density no./yd^2	Height inches	Yield bu/a	Test weight lb/bu	Protein %
Continuous wheat					
Hazen					
Fumigated	439.9	37.1	39.3	59.0	14.2
Natural	296.4	34.0	27.6	57.7	13.1
Mean	368.1	35.5	33.5	58.4	13.7
CV%	15.7	1.3	11.8	0.6	3.5
$LSD_{0.05}$	129.9	1.0	8.9	0.8	1.0
Crosby					
Fumigated	450.0	31.8	44.7	60.6	10.5
Natural	321.9	31.3	37.3	60.1	9.0
Mean	386.0	31.5	41.0	60.4	9.7
CV%	19.2	3.7	7.4	0.8	4.8

$LSD_{0.05}$	NS	NS	6.8	NS	1.1
Williston					
Fumigated	524.9	34.9	45.4	57.9	16.8
Natural	346.4	34.4	37.6	58.1	16.3
Mean	435.7	34.7	41.5	58.0	16.6
CV%	10.4	2.3	9.2	1.7	2.2
$LSD_{0.05}$	102.0	NS	NS	NS	NS
Garrison					
Fumigated	614.7	34.8	46.1	59.0	14.4
Natural	412.0	33.2	37.0	57.9	14.8
Mean	513.4	34.0	41.6	58.4	14.6
CV%	11.0	4.8	9.2	0.9	3.2
$LSD_{0.05}$	126.9	NS	8.6	NS	NS
Regent					
Fumigated	626.9	32.6	52.0	56.5	15.1
Natural	485.9	35.7	49.6	55.5	14.8
Mean	556.4	35.9	50.8	56.0	15.0
CV%	9.2	2.7	2.3	0.9	0.7
$LSD_{0.05}$	115.2	NS	NS	NS	0.2
Two year break between wheat crops					
Beach					
Fumigated	382.1	36.0	55.9	61.6	12.6
Natural	349.1	35.7	55.1	61.5	12.7

Mean	365.6	35.9	55.5	61.6	12.7
CV%	6.4	1.1	8.2	1.8	1.7
$LSD_{0.05}$	NS	NS	NS	NS	NS
Amidon					
Fumigated	461.3	30.4	53.9	61.1	13.2
Natural	420.8	30.3	57.8	60.3	13.6
Mean	441.1	30.4	55.9	60.7	13.4
CV%	4.2	3.3	10.7	1.1	2.9
$LSD_{0.05}$	NS	NS	NS	NS	NS

Table 4. Yield, test weight, protein, height, and head density of hard red spring wheat at Dickinson, ND, 1998.

Rotation[1]	Head density		Height		Yield		Test weight		Protein	
	Fum	Nat	Fum	Nat	Fum	Nat	Fum	Nat	Fum	Nat
	no./yd^2		inches		bu/a		lb/bu		%	
W-O-W-<u>W</u>	543	410	41.4	41.4	58.7	43.8	60.1	60.9	15.1	13.9
W-O-P-<u>W</u>	554	466	41.6	43.5	59.5	52.5	61.1	60.1	15.2	14.2
W-O-M-<u>W</u>	559	465	41.4	42.9	58.6	56.8	60.6	61.6	15.4	14.8
Mean	552	447	41.5	42.6	58.9	51.0	60.6	60.9	15.2	14.3
CV%	9.2	5.9	3.6	2.1	5.8	6.9	1.2	1.5	4.4	4.4
$LSD_{0.05}$	NS	3.6	NS	1.1	NS	1.3	NS	NS	NS	NS

[1] Rotation.
W-O-W-<u>W</u> = 1995 Wheat-1996 Oat hay- 1997 Wheat-1998 Wheat.

W-O-P-W = 1995 Wheat-1996 Oat hay-1997 Pea-1998 Wheat.
W-O-M-W = 1995 Wheat-1996 Oat hay-1997 Millet-1998 Wheat.

Table 5. Initial root and plant evaluations of wheat in various rotations in selected fields in North Dakota, 1998.

Location/ Treatment	Development stage Haun	Length[1] inches	Tillers no.	Subcrown rating[2]	Seminal Root		Crown root	
					No of roots	Rhizoc[3]	No of roots	Rhizoc[3]
Continuous wheat								
Hazen								
Fumigated	5.5	18.8	2.9	0.2	5.8	0.0	10.3	0.0
Natural	4.9	14.3	1.4	0.3	4.6	0.4	6.0	0.3
Mean	5.3	16.6	2.2	0.2	5.2	0.2	8.1	0.2
CV%	4.5	3.3	16.2	55.0	4.6	76.1	12.1	37.5
$LSD_{0.05}$	0.5	1.2	0.8	NS	0.3	0.3	2.2	0.1
Crosby								
Fumigated	6.6	18.5	1.7	0.2	5.3	0.0	8.7	0.0
Natural	6.1	16.6	1.7	0.4	5.1	0.1	8.2	0.2
Mean	6.4	17.5	1.7	0.3	5.2	0.1	8.4	0.1
CV%	4.5	8.6	37.8	147	10.6	97.3	42.4	52.6
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	0.1
Williston								
Fumigated	11.3	23.2	2.3	0.2	5.1	0.0	14.6	0.0
Natural	9.0	20.2	1.5	0.6	4.8	0.5	11.5	0.4

Mean	10.2	21.7	1.9	0.4	4.9	0.3	13.0	0.2
CV%	60.7	3.8	12.7	49.7	11.2	73.9	9.8	164
$LSD_{0.05}$	NS	1.9	0.6	NS	NS	0.4	2.9	NS
Garrison								
Fumigated	11.4	28.3	0.9	0.0	5.6	0.0	13.2	0.0
Natural	10.9	27.9	0.6	0.9	4.9	0.1	10.9	0.1
Mean	11.1	28.1	0.8	0.5	5.2	0.1	12.1	0.1
CV%	0.9	4.0	39.7	37.6	3.4	177	17.5	75.3
$LSD_{0.05}$	0.2	NS	NS	0.4	0.4	NS	NS	NS
Regent								
Fumigated	11.4	25.5	2.3	0.0	5.6	0.0	19.4	0.0
Natural	10.5	24.4	1.4	0.6	4.7	0.1	15.3	0.3
Mean	11.0	25.0	1.9	0.3	5.2	0.1	17.3	0.2
CV%	1.4	3.6	6.7	96.8	3.8	191	5.3	66
$LSD_{0.05}$	0.4	NS	0.3	NS	0.4	NS	2.1	0.2
Two-year break between wheat crops								
Beach								
Fumigated	6.4	22.6	2.7	0.4	5.8	0.0	16.4	0.0
Natural	6.4	22.6	2.8	0.2	5.9	0.0	17.0	0.0
Mean	6.4	22.6	2.8	0.3	5.8	0.0	16.7	0.0
CV%	2.5	6.7	6.6	60.7	2.5	-	6.4	-
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS
Amidon								

Fumigated	6.2	19.0	2.2	0.1	5.6	0.0	15.6	0.0
Natural	6.2	17.8	2.1	0.3	5.6	0.0	18.0	0.0
Mean	6.2	18.4	2.1	0.2	5.6	0.0	16.8	0.0
CV%	2.0	6.0	18.7	96.5	4.5	-	16.8	-
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS

[1]Length measured from the crown to the tip of the last fully extended leaf of the plant.
[2] Subcrown internode rating, 0-4. 0= no infection, 1= less than 25% of internode infected, 2= 25-50% of internode infected, 3= 51-75% of internode infected, multiple lesions, and 4= 75-100% of internode infected, lesions coalesced.
[3] Number of roots per plant which exhibited rhizoctonia symptoms.

Table 6. Wheat plant evaluation on July 3, 1998 at Dickinson, ND.

Rotation[1]	Development stage		Length[2]		Tillers	
	Fumigation	Natural	Fumigation	Natural	Fumigation	Natural
	Haun		inches		number	
W-O-W-W	10.7	9.9	33.0	33.1	1.5	0.7
W-O-P-W	10.7	10.1	32.2	34.0	1.5	1.3
W-O-M-W	10.8	10.3	32.3	33.5	1.3	1.3
Mean	10.7	10.1	32.5	33.5	1.4	1.1
CV%	1.5	2.6	4.0	4.3	19.2	23.3
$LSD_{0.05}$	NS	NS	NS	NS	NS	0.4

[1] Rotation.
W-O-W-W = 1995 Wheat-1996 Oat hay-1997 Wheat-1998 Wheat.
W-O-P-W = 1995 Wheat-1996 Oat hay-1997 Pea-1998 Wheat.
W-O-M-W = 1995 Wheat-1996 Oat hay-1997 Millet-1998 Wheat.
[2] Length measured from the crown to the tip of the last fully extended leaf of the plant.

Table 7. Visual root scores for wheat at soft dough stage grown at select locations in North Dakota, 1998.			
Location/Treatment	Subcrown[1] internode rating	Color index[2]	Root mass[3]
Continuous wheat			
Hazen			
Fumigated	1.6	1.5	3.5
Natural	1.9	2.8	3.0
Mean	1.8	2.1	3.3
CV%	4.1	9.6	1.8
$LSD_{0.05}$	0.2	0.5	0.1
Crosby			
Fumigated	2.1	1.8	3.5
Natural	2.7	2.8	2.6
Mean	2.4	2.3	3.1
CV%	4.0	12.8	11.1
$LSD_{0.05}$	0.2	0.6	0.8
Williston			
Fumigated	2.6	2.6	3.0
Natural	3.4	3.1	2.5
Mean	3.0	2.9	2.8
CV%	6.1	17.4	2.6

$LSD_{0.05}$	0.4	NS	0.2
Garrison			
Fumigated	1.7	3.0	2.8
Natural	1.7	3.6	2.3
Mean	1.7	3.3	2.5
CV%	8.6	5.3	11.5
$LSD_{0.05}$	NS	0.4	NS
Regent			
Fumigated	1.6	2.1	3.3
Natural	2.0	2.5	2.8
Mean	1.8	2.3	3.0
CV%	15.1	7.6	16.7
$LSD_{0.05}$	NS	NS	NS
Two-year break between wheat crops			
Beach			
Fumigated	1.4	2.3	3.4
Natural	2.0	2.9	2.5
Mean	1.7	2.6	2.9
CV%	29.2	13.2	6.0
$LSD_{0.05}$	NS	NS	0.4
Amidon			
Fumigated	1.7	1.8	3.4
Natural	1.8	2.6	2.5

Mean	1.7	2.2	2.9
CV%	13.5	20.3	6.0
$LSD_{0.05}$	NS	NS	0.4

[1] Subcrown internode rating, 0-4. 0= no infection, 1= less than 25% internode infected, 2= 25-50% of internode infected, 3= 51-75% of internode infected, multiple lesions and 4= 75 to 100% of internode infected, lesions coalesced.
[2] Root color index at soft dough stage, 1 to 4. 1= white, 4= dark brown.
[3] Root mass rating at soft dough stage, 1 to 4. 1= few roots and 4= substantial root system.

Table 8. Initial root evaluation of wheat in various rotations at Dickinson, ND, July 3, 1998.

Rotation[1]	Subcrown rating[2]		Seminal roots				Crown roots			
			No. of roots		Rhizoctonia[3]		No. of roots		Rhizoctonia[3]	
	Fum	Nat	Fum	Nat	Fum	Nat	Fum	Nat	Fum	Nat
W-O-W-<u>W</u>	0.1	0.3	5.6	5.1	0.0	0.1	20.9	13.0	0.0	0.2
W-O-P-<u>W</u>	0.1	0.1	5.6	5.6	0.0	0.0	19.3	19.9	0.0	0.0
W-O-M-<u>W</u>	0.1	0.2	5.6	5.3	0.0	0.0	19.1	19.3	0.0	0.0
Mean	0.1	0.2	5.6	5.3	0.0	0.03	19.8	18.2	0.0	0.1
CV%	194	105	1.6	3.7	-	173	9.5	10.2	-	183
$LSD_{0.05}$	NS	NS	NS	0.3	NS	NS	NS	0.9	NS	NS

[1] Rotation.
W-O-W-<u>W</u> =1995 Wheat-1996 Oat hay-1997 Wheat-1998 Wheat
W-O-P-<u>W</u> =1995 Wheat-1996 Oat hay-1997 Pea-1998 Wheat
W-O-M-<u>W</u> =1995 Wheat-1996 Oat hay-1997 Millet-1998 Wheat
[2] Subcrown internode rating, 0-4. 0 = no infection, 1 = less than 25% of internode infected, 2 = 25-50% of internode infected, 3 = 51-75% of internode infected, multiple lesions, and 4 = 75-100% of internode infected, lesions coalesced.
[3] Number of roots per plant which exhibited Rhizoctonia symptoms.

Table 9. Root evaluation of hard red spring wheat at soft dough stage grown in various rotations at the Dickinson Research Extension Center, Dickinson, ND, 1998.

Rotation[1]	Subcrown internode rating[2]		Root mass[3]		Color index[4]	
	Fumigated	Natural	Fumigated	Natural	Fumigated	Natural
W-O-W-W	2.1	2.6	3.0	2.4	2.9	3.2
W-O-P-W	2.0	3.0	3.5	2.5	2.1	2.7
W-O-M-W	2.5	3.0	3.6	3.0	2.4	2.7
Mean	2.2	2.8	3.4	2.6	2.5	2.9
CV%	19.3	17.3	11.8	10.5	11.7	12.6
$LSD_{0.05}$	NS	NS	NS	0.37	NS	0.38

[1] Rotation
W-O-W-W = 1995 Wheat-1996 Oat hay-1997 Wheat-1998 Wheat
W-O-P-W = 1995 Wheat-1996 Oat hay-1997 Pea-1998 Wheat
W-O-M-W = 1995 Wheat-1996 Oat hay-1997 Millet-1998 Wheat

[2] Subcrown internode rating, 0 to 4. 0 = no infection, 1 = less than 25% of internode infected, 2 = 25 to 50% of internode infected, 3 = 51 to 75% of internode infected, multiple lesions, and 4 = 75 to 100% of internode infected, lesions coalesced.

[3] Root mass rating, 1 to 4. 1 = few roots and 4 = substantial root system.

[4] Root color index, 1 to 4. 1 = white and 4 = dark brown.

Table 10. Water-use at various soil depths over specific periods for hard red spring wheat grown on fumigated and natural soil plots at Williston Research Extension Center, 1998.

Depth (ft)	Treatment	Water-use												
		Time period												
		11 May 18 May	19 May 26 May	27 May	2 Jun 8 Jun	9 Jun 15 Jun	16 Jun 23 Jun	24 Jun 30 Jun	1 Jul 7 Jul	8 Jul 14 Jul	15 Jul 21 Jul	22 Jul 28 Jul	29 Jul 4 Aug	SUM

		18 May	26 May	1 Jun	8 Jun	15 Jun	23 Jun	30 Jun	7 Jul	14 Jul	21 Jul	28 Jul	4 Aug	
		inches												
0-1	Natural	0.22	0.16	0.28	0.31	0.49	0.55	1.27	0.89	1.39	0.35	0.06	-0.36	5.59
	Fumigated	0.21	0.37	0.39	0.30	0.61	0.34	1.46	0.97	1.03	0.19	0.01	-0.04	5.85
$LSD_{0.05}$		NS	0.05	NS	NS	0.47	NS	0.04	NS	NS	0.04	NS	NS	NS
1-2	Natural	-0.10	-0.05	0.04	0.04	0.12	-0.18	0.14	0.01	0.58	0.46	0.11	-0.04	1.14
	Fumigated	-0.05	-0.05	0.16	0.11	0.11	0.01	0.15	0.06	0.58	0.28	0.06	0.01	1.44
$LSD_{0.05}$		NS	NS	NS	NS	NS	NS	NS	NS	NS	0.90	NS	NS	0.04
2-3	Natural	-0.05	-0.02	0.02	0.01	0.01	0.04	-0.01	0.00	0.26	0.34	0.13	-0.01	0.72
	Fumigated	-0.11	-0.04	0.03	0.06	0.06	0.04	0.11	0.06	0.34	0.30	0.14	-0.04	0.95
$LSD_{0.05}$		NS	NS	NS	NS	NS	NS	0.67	NS	NS	NS	NS	NS	NS
3-4	Natural	0.04	-0.14	0.02	0.09	-0.10	0.06	0.01	0.02	-0.01	0.08	0.07	0.09	0.22
	Fumigated	-0.07	0.03	-0.01	0.03	-0.03	0.01	0.04	-0.02	0.10	0.06	0.03	0.07	0.24
$LSD_{0.05}$		NS	0.60	NS	NS	NS	NS	NS	NS	0.03	NS	NS	NS	NS
4-5	Natural	-0.01	-0.22	0.10	-0.05	0.01	0.02	-0.03	0.04	-0.01	0.05	-0.09	0.07	-0.10
	Fumigated	0.07	-0.08	-0.06	0.08	-0.08	-0.11	0.08	0.05	-0.02	0.13	-0.11	0.00	-0.05
$LSD_{0.05}$		NS	NS	NS	0.90	NS	NS	NS	NS	NS	NS	NS	NS	NS
SUM	Natural	0.11	-0.27	0.46	0.40	0.52	0.49	1.37	0.95	2.21	1.29	0.28	-0.25	7.57
	Fumigated	0.04	0.22	0.51	0.58	0.68	0.29	1.84	1.11	2.03	0.96	0.14	0.01	8.43
$LSD_{0.05}$		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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