Pathogenic Fungi Associated with Fusarium Foot Rot of Winter Wheat in the Semiarid Pacific Northwest

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ABSTRACT

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Winter wheat plants and soil were collected from 288 nonirrigated fields in the semiarid Pacific Northwest during 1993 and 1994. Fungi associated with 5,390 crown and subcrown internodes from 10 Oregon and nine Washington counties were identified. *Fusarium graminearum* Group 1 was most widespread and the dominant pathogen associated with a crown and root rot named Fusarium foot rot or dryland root rot. *F. culmorum* was widely distributed in soil but was detected in plants in only half as many locations as *F. graminearum*. Other pathogens included *Bipolaris sorokiniana, Microdochium nivale,* and *F. avenaceum*. Highly variable isolation frequencies for all five pathogens were presumed related to a very dry and a very wet survey year. Each pathogen was considered dominant or co-dominant at one or more sites during one or more years. All five species and *F. acuminatum* and *F. oxysporum* included isolates capable of killing wheat seedlings in the greenhouse.

Additional keywords: common root rot, crown rot, *F. graminearum* Group 2, pink snow mold, *Triticum aestivum*

Fusarium culmorum (Wm. G. Sm.) Sacc. and *F. graminearum* Schwabe limit production of winter wheat (*Triticum aestivum* L.) in the Pacific Northwest (PNW) states of Idaho, Oregon, and Washington (7,8,9). These fungi rot roots, subcrown internodes, crowns, and stem bases. The disease is known locally as Fusarium foot rot, dryland foot rot, or dryland root rot. A survey of foot rot pathogens in nonirrigated fields in the PNW (7) during 1966 and 1967 revealed that *F. culmorum* was present in 90% or more of infected plants and was the only pathogenic *Fusarium* sp. in many crowns and lower stems. *F. graminearum* is the dominant cause of the disease in irrigated fields (39), and in counties with summer temperatures warmer than those where *F. culmorum* is dominant (7, 10). *F. avenaceum* (Fr.:Fr.) Sacc. was also associated with Fusarium foot rot but was considered to be less important than *F. culmorum* and *F. graminearum* (7).

Bipolaris sorokiniana (Sacc.) Shoemaker and species of *Fusarium* coexist in many cereal production regions of the world. Complex interactions among climate and crop production procedures influence the dominance among these pathogens. While *F. culmorum* is considered the dominant member of the pathogen complex in nonirrigated fields in the PNW, *F. graminearum* is recognized as dominant in eastern Australia (2,4), California (23), Minnesota (41), and New York (18); *B. sorokiniana* predominates on the North American prairies (15,19,35,44) and South Australia (42); and *Microdochium nivale* (Fr.) Samuels & I. C. Hallett predominates in Europe (5,6,27,29).

Diseases caused by these pathogens are difficult to differentiate, and shifts in dominance over time have been reported (4). Although *B. sorokiniana* was once reported as omnipresent in arid and semiarid regions of the western U.S., and a primary component of the cereal foot rot complex in Oregon and Washington (36,37), this fungus has not been reported or investigated in the PNW since agricultural systems were modified for producing semidwarf wheat 30 years ago. *B. sorokiniana* and *F. graminearum* were considered dominant pathogens in several recent field experiments in Oregon (33,34). Changes in cropping systems to emphasize production of semi-dwarf soft-white wheat cultivars may have altered the importance of specific foot rot pathogens in the PNW. Such changes include development of high residue, moisture-conserving tillage systems in which deep-furrow drills are used to plant winter wheat deeply into warm soil (12, 20,25). Soils are also becoming more acid through use of nitrogen fertilizers (21,28). Smiley et al. (31) reported that the incidence of foot rot caused by *F. graminearum* was directly related to increasing soil acidity, amount of surface residue, and frequency of wheat in the rotation.

Wheat is an important crop in the PNW, with more than 8.3 million Mg produced on 1.9 million hectares in Idaho, Oregon, and Washington. Most modern Fusarium foot rot management research was conducted where *F. culmorum* was the dominant or only species present (11,16,24,32). The occurrence of other species in several experiments in Oregon and Washington (33,34) indicated that another survey was needed to provide information that may improve opportunities for capitalizing on recent advances in wheat breeding, pathogen identification, fungicide development, pesticide labeling, cultural practices, and other aspects of disease management.

MATERIALS AND METHODS

Pathogens associated with crowns and subcrown internodes of winter wheat in the nonirrigated semiarid wheat belt of eastern Oregon and Washington were examined in randomly selected fields during two growing seasons. Winter wheat plants and soil were collected from 146 fields in 10 Oregon and seven Washington counties (Fig. 1) during late spring to early summer 1993 (Feekes growth stages 9 to 11) (12). Plants were collected at random with respect to field selection, field history, sampling loci within fields, selection of individual plants, and disease severity. Numbers of fields sampled in each Oregon county were approximately proportional to hectares of winter wheat harvested during 1992 (Table 1). The climate is temperate with warm, dry summers and cool, wet winters (Fig. 2). Precipitation occurs mostly from November to May and evaporative potential exceeds precipitation from March through October. Most soils are silt loams of loess origin.

Samples consisted of 15 or more plants collected along a circle (10 to 15 m diameter) located 20 to 70 m within each field. Plants were removed with intact subcrown internodes and partial root systems. Plants were stored in coolers from the time of collection until further processing. Approximately 500 g of soil between drill rows (spaced 30 to 40 cm apart) was collected from the same sites where plants were collected. Soil samples consisted of composites of about 10 subsamples collected to about 10-cm depth. Extension service agents and wheat producers pre-

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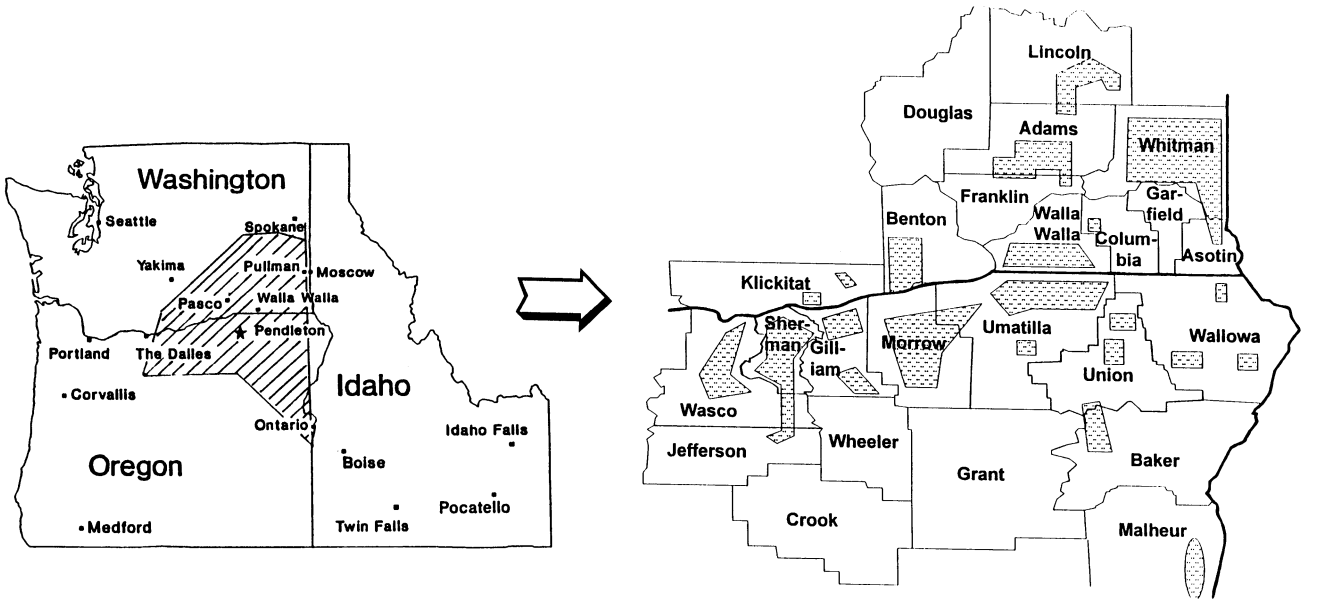

Fig. 1. Survey sites in 19 eastern Oregon and Washington counties; stippled areas represent sampling regions within each county.

pared field history information for most sites after sampling was complete.

Plants were washed to remove soil. Crown (3 mm diameter) and subcrown internode (10 mm) tissues were excised from 15 plants per field. The tissue sections were surface disinfested in 1.25% sodium hypochlorite for 30 s, rinsed three times in sterile deionized water, and blotted on filter paper. One half of each tissue piece was plated onto peptone-PCNB agar medium (22) and a modified Czapek-Dox agar medium containing benomyl at 10 µg/ml (38). These media are semiselective for *Fusarium* spp. and *B. sorokiniana*, respectively. Plates were incubated at 20°C in the dark for 7 days or longer, then observed for fungal growth, color, and conidiation. *B. sorokiniana* was identified directly on the selective medium and a single spore cultured onto half-strength potato dextrose agar (PDA) medium for confirmation. Fungi thought to be *Fusarium* were transferred onto blocks of water agar plus rifampicin (100 µg/ml) and then placed on both PDA medium and wheat-leaf agar medium (22) for identification. Selected isolates of other fungi were also transferred for identification to assess the diversity of fungal species associated with wheat crowns. Cultures were grown at 20 to 25°C under lights (two 20-watt Sylvania Gro-Lux plus two 20-watt Sylvania cool-white fluorescent plus one 40-watt black light) suspended 0.6 m above the cultures. Cultures were identified with taxonomic guides (1,3,22,40). Single-spore cultures of selected isolates were transferred to PDA medium in tubes for preservation. All cultures of *F. graminearum* were retained to determine their capacity to produce perithecia of *Gibberella zeae* (Schwein.) Petch on wheat-leaf agar (22). Cultures producing perithecia were designated *F. graminearum* Group 2 and nonproducers were designated Group 1.

Table 1. Wheat production and long-term (30 year) physio-climatic characteristics near survey sites in Oregon and Washington

County	Wheat area[a]	Elevation (m)	Annual precipitation (mm)	Growing degree days[b]	Mean monthly temperature (°C)	
					January	July
Oregon						
Baker	2	1,000 to 1,050	250 to 300	600 to 700	–4	19 to 20
Gilliam	37	330 to 880	225 to 350	700 to 1,000	0	19 to 24
Jefferson	3	730 to 790	225 to 280	600 to 800	1	18 to 19
Malheur	14	640 to 670	225 to 250	900 to 1,000	–2	24 to 25
Morrow	60	270 to 670	200 to 380	900 to 1,100	0	20 to 21
Sherman	46	480 to 850	250 to 330	700 to 900	–2	20 to 21
Umatilla	105	240 to 730	250 to 600	900 to 1,100	1	21 to 23
Union	16	780 to 800	280 to 600	700 to 800	–1	19 to 21
Wallowa	5	880 to 1,200	350 to 580	500 to 700	–4	15 to 18
Wasco	24	360 to 850	280 to 640	700 to 1,000	1	19 to 23
Washington						
Adams	122	420 to 550	200 to 330	900 to 1,000	–3	20 to 22
Asotin	8	1,000 to 1,050	480 to 510	500 to 600	–4	17 to 18
Benton	51	60 to 200	200 to 250	1,000 to 1,200	0	21 to 24
Columbia	34	450 to 500	350 to 480	900 to 1,000	0	20 to 21
Franklin	43	200 to 450	200 to 300	900 to 1,100	–1	21 to 24
Klickitat	17	580 to 780	330 to 400	700 to 1,200	–2	19 to 20
Lincoln	153	570 to 750	225 to 510	700 to 800	–4	20 to 22
Walla Walla	79	270 to 450	350 to 460	900 to 1,200	1	21 to 24
Whitman	194	450 to 750	330 to 560	700 to 900	–2	19 to 21

[a] 1,000 ha in 1992.
[b] January 1 to May 31. Growing degree days based on a 0°C minimum.

Soil samples were air dried, passed through a 2-mm sieve, and assayed by dilution-plate procedures (22) using peptone-PCNB agar medium semiselective for *Fusarium* spp. Cultures were incubated under light, as described above. Colonies of interest were transferred to both PDA and wheat-leaf agar media for identification. This process was effective for detecting *F. culmorum*, which survives for long periods in soil as chlamydospores and can therefore be quantified by dilution plating, but not for pathogens that survive primarily as mycelial fragments in plant residue, such as *F. graminearum* and *F. avenaceum*.

The survey was continued in 1994 and expanded to include two additional counties in Washington; 142 fields were sampled, 83 in 10 Oregon counties and 59 in nine Washington counties. All samples were collected during the spring (Feekes growth stages 9 to 10.5) (12) from a wheat field nearest that sampled during 1993.

RESULTS AND DISCUSSION

Samples were collected from a total of 178 nonirrigated fields in 10 Oregon counties and 110 nonirrigated fields in nine

Washington counties. Numbers of wheat crowns and subcrown internodes excised from plants and plated onto culture media in the laboratory included 3,445 from Oregon and 1,945 from Washington. Approximately half of the 5,390 plants from 288 fields were examined during each of the 2 years.

Fungi isolated from 2,550 wheat crowns and subcrown internodes during 1993 included 831 *Fusarium* isolates representing 19 species (Table 2). No attempt was made to separate species on the basis of their association with crowns versus subcrown internodes or changes in prevalence as plants matured. Recognized members of the foot rot complex included *F. graminearum* (254 isolates; 253 of Group 1 and 1 of Group 2), *F. culmorum* (74 isolates), *F. avenaceum* (32 isolates), *M. nivale* (16 isolates), and *B. sorokiniana* (8 isolates). Fungi isolated from 2,840 wheat crowns and subcrown internodes during 1994 included 487 *Fusarium* isolates representing 19 species. Foot rot pathogens included *F. graminearum* (108 isolates; all were Group 1), *M. nivale* (37 isolates), *B. sorokiniana* (30 isolates), *F. culmorum* (22 isolates), and *F. avenaceum* (3 isolates). Other fungi that were associated with excised crowns and subcrown internodes but not enumerated included species of *Alternaria, Aspergillus, Cephalosporium, Chaetomium, Cladosporium, Fumago, Heterosporium, Mucor, Penicillium, Pythium, Rhizoctonia, Stemphyllium*, and *Verticillium*.

Percentages of fields yielding isolates of selected foot rot fungi from plant crowns and subcrown internodes are presented in Table 3. *F. graminearum* Group 1 was isolated at about twice the frequency of *F. culmorum* during each year in each state. The third-most prevalent pathogen was *F. avenaceum* during 1993 and *M. nivale* during 1994. The least prevalent foot rot pathogen was *B. sorokiniana* during 1993 and *F. avenaceum* during 1994. There was no apparent relationship between pathogen detection and production practices and field history during 1993. Most fields were in wheat-fallow rotation and we did not attempt to quantify disease severity on the basis of crop management practices such as planting date and residue management. For this reason results of 1993 are not reported and we did not prepare field history statements during 1994.

Seasonal variation in detection frequency was presumed to be associated with contrasting climatic conditions. Winter wheat in the survey region is typically planted either into summer fallow during September to October (areas with <400 mm mean annual precipitation) or later in annually cropped fields (areas with >400 mm mean annual precipitation). The 1991 to 1992 growing season had annual precipitation equal to the 20-year average for the region, with higher than average rainfall during July. Excellent soil moisture in the summer fallow prompted many growers to plant winter wheat earlier than normal in the autumn of 1992. Infections by foot rot pathogens occurred early and the disease became intense in some fields as early as November 1992. The winter and spring of the 1992 to 1993 season were very wet, with precipitation 30% higher than normal in some areas. The summer and autumn of the 1993 to 1994 season were very dry; 67% less precipitation than the 20-year mean. Plantings were often delayed until rains began during November. Seedlings were very small throughout the winter and plants showed signs of drought stress as early as April 1994. Total precipitation during the 1993 to 1994 crop year was 52% of the long-term mean. This survey, therefore, was performed during one very wet year (1993) and one very dry year (1994). Since the objective of this survey was to examine the diversity of Fusarium foot rot pathogens and their apparent dominance among regions and seasons, the study was not sufficiently comprehensive to differentiate the prevalence of specific pathogens on the basis of prevailing weather conditions during a particular season.

Pathogens known to be associated with Fusarium foot rot were readily detected in plant tissue in most counties (Table 4). *F. graminearum* was detected more fre-

Table 2. Numbers of *Bipolaris*, *Fusarium*, and *Microdochium* spp. isolated from 2,550 winter wheat crowns and subcrown internodes during 1993 and 2,840 tissue sections during 1994

Species	1993	1994
B. sorokiniana	8	30
F. acuminatum	31	1
F. avenaceum	32	3
F. compactum	1	0
F. culmorum	74	22
F. decemcellulare	2	0
F. dimerum	4	1
F. episphaeria	3	0
F. equiseti	22	17
F. graminearum Group 1	253	108
F. graminearum Group 2	1	0
F. graminum	0	11
F. lateritium	9	1
F. merismoides	0	1
F. moniliforme	22	5
F. oxysporum	260	93
F. proliferatum	0	1
F. reticulatum	67	101
F. sambucinum	30	35
F. scirpi	0	1
F. semitectum	2	0
F. solani	12	50
F. sporotrichioides	1	32
F. sulphureum	0	1
F. tricinctum	1	3
F. trichothecoides	4	0
M. nivale	16	37

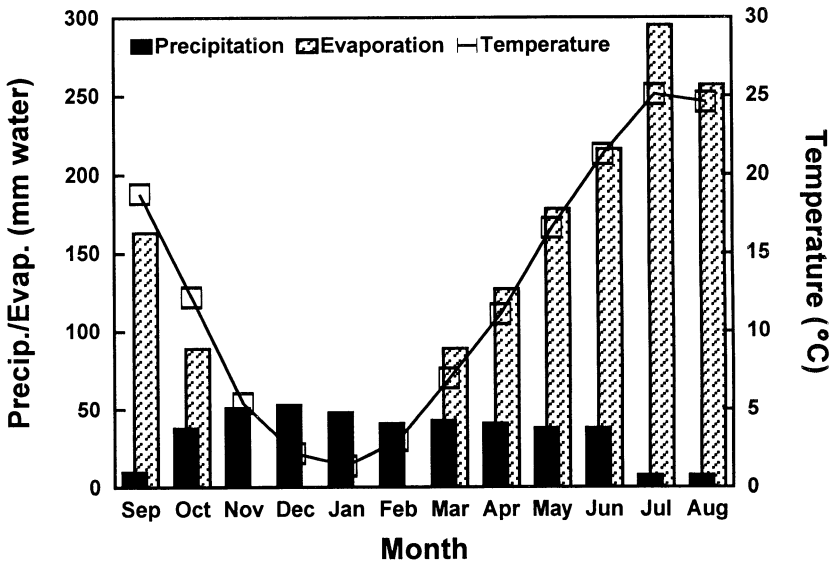

Fig. 2. Temporal distribution of mean annual precipitation, evaporation, and soil temperature (10-cm depth) at Pendleton, Oregon.

Table 3. Percentages of winter wheat fields yielding isolates of Fusarium foot rot pathogens from crowns and subcrown internodes during surveys conducted in eastern Oregon (OR) and Washington (WA) during 1993 and 1994

	1993			1994		
Pathogen species	OR	WA	OR+WA	OR	WA	OR+WA
Fusarium graminearum	37	45	40	25	20	23
Fusarium culmorum	18	24	20	10	10	10
Fusarium avenaceum	14	10	12	1	3	2
Bipolaris sorokiniana	2	6	3	5	22	12
Microdochium nivale	6	10	8	19	27	23
Number of fields sampled	95	51	146	83	59	142

quently than *F. culmorum* in nine counties and the reverse occurred in three counties. *F. culmorum* was much more prevalent than *F. graminearum* in Lincoln Co., WA, where much of the earlier research on Fusarium foot rot in the PNW was conducted (11,16,24,32). *M. nivale* was present in significant proportions in three Oregon and five Washington counties. *B. sorokiniana* was present in a significant number of fields in one Oregon and four Washington counties. The Oregon county where this occurred (Umatilla Co.) differed from that (Union Co.) where *B. sorokiniana* was previously determined to be an important member of the foot rot complex (33). The lack of detection of a Fusarium foot rot pathogen in winter wheat tissue in Columbia Co. was an artifact of small sample size. Fusarium foot rot occurs in Columbia Co. and *F. culmorum* was isolated from soil collected in that county (discussed below).

Regionally and seasonally, each pathogen was dominant or co-dominant at one time or another (Table 5). *F. graminearum* Group 1 was considered to be more important than *F. culmorum* in more regions than reported by Cook (7). *B. sorokiniana* was a dominant member of the foot rot complex in three Washington counties during 1994 (dry year) and *M. nivale* was dominant in two Oregon counties during 1993 and five Oregon and Washington counties during 1994. *F. graminearum* Group 2 is a primary agent of scab in irrigated PNW fields (39) but was rare in nonirrigated fields examined in this survey.

F. culmorum was detected in more soil than plant tissue samples in 1993 (20 and 6% of 146 fields, respectively), in more plant than soil samples in 1994 (18 and 10% of 142 fields), was seldom (3% of fields during the 2 years) detected in both plants and soil in the same field, and was detected in 25% of 288 fields when isolations from both plants and soils were combined over the 2-year period. *F. culmorum* was more prevalent in Washington than in Oregon (36 and 23% of fields, respectively). When evaluated at the county level, *F. culmorum* was detected in 16 of 19 counties. Only one or two fields were evaluated in the counties (Baker, Franklin, and Jefferson) where this fungus was not detected. Infrequent detection of this pathogen in several other counties (e.g., one of 11 fields in Benton Co. and one of 10 fields in Wasco Co.) leads us to conclude that *F. culmorum* was present but was not detected because of the small sampling population in the three counties. As such, we consider *F. culmorum* ubiquitous but not always of greatest importance in the Fusarium foot rot complex.

Climates and soils are highly variable in the PNW wheat belt. Agronomic zones based on areas with similar growing degree days, precipitation, and soil depth are used to identify regions with comparable growing conditions (13). The occurrence or frequency of Fusarium foot rot pathogens in this survey were not related to the agronomic zones. Also, there were no clear relationships between the occurrence or frequency of a specific pathogen and physioclimatic characteristics (Table 1) in the 19 counties included in this survey. Detection of *F. graminearum* on a per county basis was weakly but consistently correlated with mean monthly temperature during July (r^2 = 0.42, P = 0.06). This finding supports in concept the observation of Cook (7) but not the precise delimiting temperature as stated by Sitton and Cook (30) and Cook (9). We also found a weak inverse relationship (r^2 = 0.49, P = 0.03) between *F. graminearum* and elevation, and elevation was inversely related ($P < 0.001$) to mean monthly temperatures during

Table 4. Number of winter wheat fields sampled in 19 Oregon and Washington counties and numbers of fields in which one or more Fusarium foot rot pathogens were detected in association with crown or subcrown internode tissue during 1993 and 1994

County	Fields sampled	Fields with pathogens[a]	Occurrence of specific pathogens[b]				
			Fg	Fc	Fa	Bs	Mn
Oregon							
Baker	3	1	0	0	0	0	1
Gilliam	22	14	9	6	1	1	1
Jefferson	4	1	0	0	0	0	1
Malheur	10	3	2	2	0	0	1
Morrow	16	7	4	4	1	1	3
Sherman	35	26	24	7	4	1	4
Umatilla	52	23	14	4	7	4	9
Union	8	3	0	0	1	1	1
Wallowa	8	2	0	2	0	0	0
Wasco	20	4	3	0	0	1	0
Washington							
Adams	13	9	4	4	0	4	4
Asotin	7	3	3	0	0	0	0
Benton	20	14	10	0	3	1	3
Columbia	4	0	0	0	0	0	0
Franklin	1	1	1	0	0	0	0
Klickitat	5	2	0	1	0	0	1
Lincoln	14	11	2	8	0	4	3
Walla Walla	23	14	12	4	3	3	4
Whitman	23	9	3	1	1	4	6

[a] Numbers of total fields identified for specific pathogens may exceed the number of fields in which Fusarium foot rot pathogens were detected, indicating that multiple species were detected in some fields and/or individual plants.

[b] Fg = *Fusarium graminearum* Group 1; Fc = *F. culmorum*; Fa = *F. avenaceum*; Bs = *Bipolaris sorokiniana*; Mn = *Microdochium nivale*.

Table 5. Identities and relative prevalence of Fusarium foot rot pathogens isolated from winter wheat crowns and subcrown internodes during surveys conducted during 1993 and 1994[a]

County	1993						1994					
	Fields	Fg	Fc	Fa	Bs	Mn	Fields	Fg	Fc	Fa	Bs	Mn
Oregon												
Baker	2					X	1					
Gilliam	13	X	X	x	x		9	X	x			x
Jefferson	2					X	2					
Malheur	5	X	X			x	5					
Morrow	9	x	x	x			7	X	X		x	X
Sherman	19	X	X	x			16	X	x	x	x	x
Umatilla	29	X	x	X	x	x	23	x	x		x	X
Union	4			x	x	x	4					x
Wallowa	2		X				6					
Wasco	10	x					10	X			x	
Washington												
Adams	5	x	X		x		8	X	x		X	X
Asotin	3	X					4	x				
Benton	11	X		x		x	9	x			x	x
Columbia	2						2					
Franklin	0						1	X				
Klickitat	0						5		x			x
Lincoln	7	x	X		x	x	7		X		X	x
WallaWalla	13	X	x	x	x		10	X	x	x	x	X
Whitman	10	X	x	x		x	13				X	X

[a] An "X" indicates the pathogen was dominant among isolates; an "x'" indicates the pathogen was isolated from at least one field in the county. Fg = *Fusarium graminearum* Group 1; Fc = *F. culmorum*; Fa = *F. avenaceum*; Bs = *Bipolaris sorokiniana*; Mn = *Microdochium nivale*.

January and July, and with growing degree days during the period of winter wheat growth in each county. The strongest relationship in our data occurred when *F. graminearum* was regressed against both elevation and mean annual precipitation ($r^2 = 0.46$, $P = 0.05$), suggesting that it may be expected to become less prevalent as both elevation and precipitation increase. In view of this observation, and the seasonal variability detected in our survey, it was of interest to examine precipitation records associated with the previous (7) and current survey intervals. Annual precipitation during both seasons of Cook's survey was less than the long-term average. Not only was the 1966 crop year very dry, but the crop produced that year was on the same fields where wheat was produced during another very dry year (1963 to 1964) in the winter wheat–summer fallow rotation. Precipitation during the second year of Cook's survey (1966 to 1967) was also slightly less than normal but followed the previous crop (1964 to 1965) in the same field in which precipitation matched the 20-year mean. In comparison, precipitation for years associated with our survey varied from very wet (1992 to 1993) to very dry (1993 to 1994), and crops produced each year followed crops produced in those same fields (1990 to 1991 and 1991 to 1992, respectively) with less than average precipitation.

F. graminearum is now more important than *F. culmorum* in most areas of the PNW. This is opposite the findings in a survey three decades earlier (7). Reasons for the reversal remain unclear. Accuracy in identification of principal pathogens is not questioned. Climatic conditions may have been partly responsible, but it appears unlikely that precipitation can explain the majority of this difference. Differences in times of sample collection would also affect results because the apparent dominance of these fungi changes as plants mature (4,17,26,29). However, this too seems unlikely to provide adequate explanation. While puzzling, comparable changes in species dominance over time in this and other regions are well documented and also not understood. For instance, the dominant pathogen in eastern Australia was once defined as *F. culmorum* but then shifted to *F. graminearum* within about two decades (4). Inglis and Cook (16) also described the disappearance or dramatic reduction in numbers of *F. culmorum* propagules from many fields in Whitman Co., WA. While we found *F. culmorum* still dominant in Lincoln Co., there is ample evidence that under some climatic conditions *B. sorokiniana* is now also important in that county, and that *F. graminearum* and *M. nivale* are present there. In adjacent Adams Co., the dominance among *F. culmorum* and *F. graminearum* was reversed during the 2 years of this survey, possibly in response to contrasting weather conditions during those years.

It is of interest that several of the driest years in recent PNW history (1964, 1966, and 1968) coincided with the first release of semi-dwarf soft white wheat cultivars. Seasons in which cumulative rainfall for the months of March through August was less than 125 mm at Pendleton occurred only during 1949, 1951, 1964, 1968, and 1973. The long-term average for that period is 200 mm. Inglis and Cook (16) reported that Fusarium foot rot was particularly damaging in the PNW during 1964, 1968, and 1974. The first semi-dwarf cultivar, Gaines, became widely produced in Oregon and Washington during 1963. Nugaines replaced the original cultivar in 1967 and Stephens became the most widely produced cultivar during the 1970s. Each of these cultivars has high-temperature dormancy, poor emergence from deep planting depths, and moderate to high susceptibility to Fusarium foot rot. In areas most affected by Fusarium foot rot, seed is often placed as deep as 15 cm below the soil surface at times when seed-zone temperatures are above 24°C (20,32). The 1967 Field Day report for the Washington State University Dryland Research Unit at Lind (Adams Co.) indicated that "There had been a general increase in damage from the foot rot diseases in the low rainfall area. *Fusarium* sp. foot rot is serious in isolated fields, especially in some early seeded fields." When semi-dwarf wheat was introduced into the drier production regions growers often applied high rates of nitrogen fertilizer in an attempt to produce yields comparable to those in higher rainfall areas. This practice caused plant water stress that greatly favored development of severe Fusarium foot rot (12,24). It appears plausible that the coincidental occurrence of a drought period, release of high-temperature sensitive cultivars, and excess application of nitrogen may have led to severe Fusarium foot rot episodes during the 1960s. It is also plausible that such interactions favored colonization of winter wheat by *F. culmorum* more so than by other species.

Preliminary screening in the greenhouse has demonstrated that each of the Fusarium foot rot pathogens detected in our survey includes isolates highly pathogenic to winter wheat (R. W. Smiley and L.-M. Patterson, unpublished data). Certain isolates of *F. graminearum*, *F. culmorum*, *F. avenaceum,* and *B. sorokiniana* were each capable of causing seedling damping-off and/or rotting of stem bases leading to seedling death. *M. nivale* was the least damaging species of recognized foot rot pathogens; some isolates caused basal stem rot and plant death but not seedling damping-off. Preliminary results in field experiments have confirmed that selected isolates of *F. graminearum*, *F. culmorum,* and *B. sorokiniana* can cause damping-off and severe crown rot. Other species of *Fusarium* capable of causing death of wheat plants in preliminary greenhouse tests included some isolates of *F. acuminatum*, *F. oxysporum*, *F. reticulatum,* and *F. sporotrichoides*. We detected high numbers of *F. oxysporum* during both years and of *F. acuminatum* during 1993. The importance of this finding remains uncertain although *F. acuminatum* and *F. oxysporum* have both been reported as pathogens of wheat (14,15,29,35). Rossi et al. (29) also isolated *F. oxysporum* more frequently than other fungi and suggested that it may be a colonizer of senescing tissue late in the growing season. Fidel-Moen and Harris (14) indicated that *F. oxysporum* is usually a root colonist rather than an invader of subcrown internodes or crowns, as occurred in our survey. *F. oxysporum* and *F. acuminatum* frequencies had no apparent relationship to physio-climatic characteristics in the survey region.

F. graminearum must be considered an important component of the Fusarium foot rot complex in the PNW. We have also observed that Fusarium foot rot can be very damaging in Oregon during very wet seasons as well as during drought. Inglis and Cook (16) reported that Fusarium foot rot was particularly damaging in the PNW during 1964, 1968, and 1974. As discussed earlier, drought occurred during 1964 and 1968 and production practices at that time often included higher rates of nitrogen fertilizer than used at present. In contrast, rainfall during the 1974 winter wheat season was 40% above the long-term average; rainfall at Pendleton was 600 mm at a time when the 20-year mean was 435 mm. While Fusarium foot rot is most recognized during very dry years it also causes extensive damage during years that are very wet, particularly where heavy cereal residues are maintained near the soil surface to control erosion and where high nitrogen application rates contribute to plant water stress. The complexity of Fusarium foot rot in the PNW suggests that genetic resistance, chemical seed treatment, and cultural management practices must be developed to improve overall plant health rather than specifically targeted to one or two pathogen species.

Specific names for crown and root diseases caused by these pathogens are now required in journals of the American Phytopathological Society. The names (43) are "foot rot" for diseases caused by *Fusarium* spp., "pink snow mold" for diseases caused by *M. nivale,* and "common root rot" for diseases caused by *B. sorokiniana* and/or species of *Fusarium*. Research worldwide and in this survey indicates that these names refer to different aspects of a continuum of ecologically related pathogens. We prefer to restrict the name "common root rot" to disease caused dominantly or entirely by *B. sorokiniana*. This usage will aid in avoiding confusion with reports from regions where *B. sorokiniana* is dominant, and will alleviate further confu-

sion regarding the increasing precision required by pesticide labels and wheat breeding. The name "foot rot" is applicable to most observations in this survey but could be misconstrued where *M. nivale* and/or *B. sorokiniana* were co-dominant. It would become difficult, however, to alter the reportable name to "pink snow mold" or "common root rot" on a seasonal and micro-regional basis, depending upon the particular mix of pathogens associated with "foot rot." Likewise, without further definition, the term "foot rot" in the PNW is usually used to define the disease officially known as eyespot, caused by *Pseudocercosporella herpotrichoides* (Fron) Deighton. The transition in nomenclature from "foot rot" to "eyespot" is occurring very slowly. We therefore propose that the name "Fusarium foot rot" be used to designate the *Fusarium*-dominant complex as it occurs in the PNW, recognizing that it is simply a different end of the continuum than "common root rot." The name "foot rot" should not be used in local or technical reports, including journals of the American Phytopathological Society. The name "pink snow mold" should also be reevaluated. Symptoms caused by *M. nivale* in many areas of the world, including the PNW, are not confined to the concept of snow mold and do not cause pink coloration of affected tissue except under very wet and cool conditions. Foot rot and brown root rot are terms used for diseases caused by *M. nivale* in Europe (27,29).

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