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Influence of continuous cropping on severity of common root rot in wheat and barley

R.L. Conner and T.G. Atkinson

Research Station, Agriculture Canada, Lethbridge, Alberta, T1J 4B1, and Research Station, Agriculture Canada, Winnipeg, Manitoba, R3T 2M9. Contribution 3878853.

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In greenhouse tests, the severity of common root rot, caused by *Cochliobolus sativus*, was high in wheat and low in barley grown in soil from a field where a root-rot-susceptible wheat cultivar had been grown continuously for the previous 5 years. The opposite occurred when a susceptible barley had been grown the 5 preceding years. Likewise, varietal differences in root rot reactions were most apparent in wheat grown in soil from continuous wheat and in barley tested in soil from continuous barley. Sampling of field tests at anthesis, mid-dough stage, and maturity confirmed the reciprocal effect of cropping history on root rot severity in wheat and barley. Tests of *C. sativus* isolates from wheat and barley demonstrated that these isolates were highly virulent on their original host species but weakly virulent on the alternative host species.

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Dans des essais en serre, la fréquence du piétin commun causé par *Cochliobolus sativus* est élevée chez le blé et faible chez l'orge cultivés en sol provenant d'un champ où un cultivar de blé sensible avait été cultivé en continu pendant les cinq années précédentes. Le contraire s'est produit lorsque de l'orge sensible avait été cultivée au cours des cinq années antérieures. De même, les différences dans les réactions au piétin entre les cultivars sont très apparentes chez le blé cultivé en sol issu d'une culture continue de blé ou chez l'orge cultivé en sol issu d'une culture continue d'orge. L'échantillonnage d'essais sur le terrain à l'anthèse, au stade mi-pâteux et à maturité confirme l'effet réciproque des antécédents culturaux sur la gravité du piétin de l'orge et du blé. Des essais d'isolats de *C. sativus* du blé et de l'orge révèlent qu'ils sont très virulents sur leur planté-hôte principale, mais peu virulents sur leur plante-hôte intermédiaire.

Common root rot, caused by *Cochliobolus sativus* (Ito and Kurib.) Drechs. ex Dastur, is one of the most prevalent diseases of wheat and barley on the Canadian prairies (Ledingham et al. 1973, Piening et al. 1976). The most recent surveys have shown that on average common root rot annually reduces yield of wheat (Ledingham et al. 1973) and barley (Piening et al. 1976) by 5.7% and 10.3%, respectively. Common root rot is an insidious disease that seldom produces aboveground symptoms in western Canada. In severe cases, root rot can cause stunting or premature plant death, but usually disease severity can only be determined by examining the roots and subcrown internode. Root rot results in reduced yield by decreasing tiller number, kernel number per head and kernel weight (Ledingham et al. 1973, Piening et al. 1976).

Root rot severity is strongly influenced by crop rotation. A rotation of at least 2 years with noncereal crops is generally recommended for disease control (Broadfoot 1934, Ledingham 1961). Chinn (1976) demonstrated that a cereal monoculture maintains high numbers of *C. sativus* conidia in the soil. However, in many parts of the Canadian prairies the choice of an economically viable alternative crop is limited. In most dryland areas of Alberta and Saskatchewan continuous production of wheat or barley is common.

This study was initiated to determine if continuous cropping to wheat or barley differentially affected the root rot reactions of susceptible and moderately resistant cultivars of wheat and barley.

Materials and methods

Greenhouse experiments. *Lines and cultivars of wheat and barley* — The root rot reactions of the breeding lines and cultivars of wheat and barley are listed in Table 1. Wheat entries examined in greenhouse experiments included the susceptible cultivar Cypress (Harding 1972), the susceptible lines S-615 and C-R5B (Larson & Atkinson 1970), and the moderately susceptible cultivar Leader (De Pauw et al. 1982). Other wheat cultivars and lines tested included the moderately resistant Neepawa, Glenlea, Chester, Canuck, Apex, Cadet, and lines S-A5B and R-C5B (Harding 1972, Larson & Atkinson 1970, Tinline & Ledingham 1979), the soft white spring wheat cultivar Fielder, the Canada Prairie Spring wheat HY320, and the moderately resistant durum cultivars Wakooma and Wascana (Tinline & Ledingham 1979). Barley cultivars included the susceptible Galt and Olli and the moderately resistant Klages, Conquest, and Bonanza (Duczek 1984).

Table 1. Root rot severity of different lines and cultivars of wheat and barley in soil from different cropping regimes in experiment 1

Cultivars and lines	Disease† reaction	Root rot severity (% RR) Wheat soil	Barley soil	Control soil
Wheat				
S-615	S	93.9	28.7	8.5
C-R5B	S	95.1	13.7	12.0
Cadet	MR	43.2	15.3	13.8
Canuck	MR	42.9	19.2	9.3
R-C5B	MR	35.1	26.2	14.2
S-A5B	MR	29.5	15.2	9.0
Fielder	NR	23.3	6.8	10.1
HY320	NR	21.9	4.1	4.7
Wascana	MR	19.1	6.0	6.1
Apex	MR	19.1	5.9	9.9
Chester	MR	17.7	8.6	6.2
Glenlea	MR	14.9	14.9	3.8
Neepawa	MR	13.9	14.0	0.6
Leader	MS	10.3	4.0	8.0
Wakooma	MR	4.1	19.7	10.2
Barley				
Olli	S	53.6	57.0	15.7
Galt	S	34.0	52.1	10.9
Conquest	MR	13.6	32.9	4.9
Klages	MR	4.4	19.7	3.0
Bonanza	MR	9.2	15.8	2.7

†S = susceptible, MS = moderately susceptible, MR = moderately resistant, NR = not reported.
LSD = 9.1 (P = 0.05) for comparison of means within columns.

Screening procedures — The studies were carried out in the greenhouse at 21 ± 4°C under natural light supplemented with fluorescent light to ensure a 16-h photoperiod and an average light intensity of 195 $\mu E \cdot m^{-2} \cdot s^{-1}$. Seven weeks after seeding, the plants were removed from the soil and the subcrown internodes rated as 0 (nil), 2 (slight), 5 (moderate), or 10 (severe) for root rot damage, according to the method of Ledingham et al. (1973). Data on the number of plants in each category were summarized as percentage root rot (% RR) according to the formula described by Burrage and Tinline (1960):

$$\% \text{ RR} = \frac{\Sigma \text{ (no. of plants in category} \times \text{numerical value)} \times 10}{\text{Total number of plants}}$$

Experiment 1 — This study examined the influence of soils from different cropping regimes on root rot severity in wheat and barley. Wheat and barley cultivars were tested in six large greenhouse beds (264 × 145 cm). The soil came from three different fields at the Lethbridge Research Station. The "wheat" soil came from a field where the root rot-susceptible wheat cultivar Cypress had been grown for at least 5 successive years. The "barley" soil was from a field where the susceptible barley cultivar Galt had been grown for the preceding 5 years. The "control" soil came from a cultivated field in which neither wheat nor barley had been grown previously for at least the preceding 5 years. Concentrations of conidia in the different soils were not determined. It was assumed that under continuous cropping of wheat or barley, conidial numbers would not be a limiting factor in disease development, since Duczek et al. (1985) showed that only low numbers of *C. sativus* conidia are needed for high disease severity. Soil preparation and seeding were carried out following the procedure described by McKenzie and Atkinson (1968). Prior to seeding, the top 10 cm of soil was removed from each greenhouse bed, mixed and screened separately to ensure an even distribution of inoculum of *C. sativus*, and then returned to refill the bed to a level 8 cm below the original soil surface. The cultivars were seeded on the soil surface and covered with the remaining soil, which returned the soil to its original depth. Deep seeding (8 cm) was used to promote long subcrown internodes.

Sixty kernels of each line or cultivar were seeded in a 1.2-m single-row plot. The plots were arranged in a split plot design using different soils (separate beds) as the main treatments and cultivars or lines as the subtreatments. The test was replicated over time using two replicates each time and six replications in total.

Experiment 2 — To test the influence of different sources of *C. sativus* on root rot severity in wheat and barley, an isolate from Leader wheat grown on wheat soil and an isolate from Galt barley grown on barley soil were compared. Each isolate was initially increased in petri dishes containing potato dextrose agar (PDA). Then a spore suspension was used to inoculate a straw-vermiculite substrate (developed by Atkinson, unpublished data) contained in 250-mL erlenmeyer flasks. Each flask contained a mixture that consisted of 60 mL vermiculite, 30 mL of ground wheat straw, and 30 mL of distilled water. Following inoculation, the cultures were incubated on a laboratory bench at a temperature of 21 ± 1°C under continuous near-UV light for 10 weeks. At the end of this time, the concentration of conidia was determined using the spore floatation procedure (Duczek 1981).

The control soil was infested with a predetermined amount of straw-vermiculite medium of either the wheat or barley *C. sativus* isolate to obtain a spore concentration of 250 conidia per gram of soil. The soil was infested in 1-kg amounts and shaken by hand for 60 sec to ensure even distribution of spores in the soil. The soil was placed in a plastic tray (33 × 25 × 15 cm) to a depth of 8 cm and then seeded. The wheat cultivars Cypress, Canuck, and Leader and the barley cultivars Galt, Klages, and Bonanza were used. Following seeding, additional soil was added to the trays to bring the final soil depth to 14 cm. Uninfested soil was included in the test to serve as the untreated check. The experiment was arranged as a split plot design with five replications using *C. sativus* isolates as the main plot treatments and cultivars as the subplots. Plants were grown for 7 weeks and rated as previously outlined. After rating, 10 subcrown internodes from plants in each plot were removed, surface-sterilized in a 1:1 mixture of 95% ethanol and 6% sodium hypochlorite for 45 seconds and then plated on PDA. Seven days later, the percentage of subcrown internodes infected by *C. sativus* was determined.

Field tests. In 1986 and 1987, field trials to determine the influence of cropping regime on root rot severity in wheat and barley were conducted at the Lethbridge Research Station. Plots of wheat and barley were seeded in the same fields from which the wheat and barley soil used in experiment 1 had been obtained. Areas of the field not used in the study were seeded to the susceptible wheat cultivar Cypress on the wheat site and the susceptible barley cultivar Galt on the barley site. Each year, the fields were fertilized with 200 kg/ha of ammonium nitrate and 90 kg/ha of triple superphosphate. A single application of bromoxynil (0.28 kg a.i./ha) was used for weed control. No area of the field was used more than once as an experimental site during the study. The disease-free site was not used because recurring bird damage prevented yield determinations. The six cultivars in experiment 2 were tested at each site. Eight-row plots (2 × 6 m) were arranged in a randomized complete block design with six replications. Four rows on one side of each plot were designated for harvest; the four rows on the other side of the plot were sampled at three specific times during the growing season. Fifty plants from each plot were sampled and rated for root rot severity at 7, 10, and 13 weeks after seeding, corresponding to anthesis, mid-dough stage, and maturity, respectively. At each sampling date, samples of subcrown internodes from wheat and barley at both sites were surface-sterilized for 30 sec in silver nitrate solution and placed on potato dextrose agar or SM-GGT3 media (Juhnke et al. 1984). Ten days later, the fungi infecting the subcrown internodes were identified.

Table 2. Analysis of variance of the effect of soil source or *Cochliobolus sativus* isolate and cultivar on percent root rot rating in experiments 1 and 2

Source of variation	d.f.†	Mean square	F ratio‡
Experiment 1			
Soil	2	15 496.2	46.2**
Replicate	5	1 762.7	5.3*
Soil x Replicate (Error a)	10	335.6	5.2**
Cultivar	20	1 840.7	28.7**
Soil x Cultivar	40	923.1	14.4**
Error b	300	64.2	
Experiment 2			
Isolate	2	7 386.4	32.8**
Replicate	4	19.8	0.1n.s
Isolate x Replicate (Error a)	8	225.4	2.2*
Cultivar	5	1 658.7	16.1**
Isolate x Cultivar	10	1 400.7	13.6**
Error b	60	103.2	

†d.f. = degrees of freedom.
‡n.s. = not significant; *significant at P = 0.05; **significant at P = 0.01.

At maturity, the four rows in each plot that had not been sampled were trimmed to 5 m in length and harvested. The grain from each plot was left to air dry for a week before weighing. An analysis of variance was carried out for percentage root rot for each sampling date and yield for each location.

Results

Analysis of root rot severity data demonstrated highly significant differences between soils and cultivars, and a large soil × cultivar interaction (Table 2). Differences in root rot severity among the wheat cultivars were greater in the wheat soil than in the barley soil (Table 1). Root rot severity in susceptible wheat cultivars grown on barley soil was usually only slightly higher than that found in the control soil. Root rot severity in a susceptible barley, such as Galt, was much higher in barley soil than in wheat soil and the largest differences in root rot resistance among barley cultivars occurred in barley soil. With the exception of the cultivar Olli, root rot severity in the barley cultivars was lower in wheat soil than in barley soil.

Results from experiment 2 indicate that the differential effect of cropping history on root rot severity in wheat and barley may largely be due to differences in virulence among *C. sativus* isolates. Root rot severity in experiment 2 showed that it was strongly influenced by isolate, cultivar, and an isolate-cultivar interaction (Table 2). The *C. sativus* isolate from wheat caused more disease on susceptible wheat than on susceptible barley while

Table 3. Average percentage root rot in wheat and barley cultivars grown in soil infested with *Cochliobolus sativus* isolates from different hosts in experiment 2

Cultivar	Disease reaction†	Root rot severity (% RR) Wheat isolate	Barley isolate	Untreated
Wheat				
Cypress	S	79.3	39.4	9.7
Canuck	MR	32.9	37.2	10.8
Leader	MS	45.1	34.7	10.8
Barley				
Galt	S	12.0	53.2	6.3
Klages	MR	10.6	38.1	3.5
Bonanza	MR	3.7	27.2	7.6

LSD = 12.8 (P = 0.05) for comparison of means within columns.
‡S = susceptible, MS = moderately susceptible, MR = moderately resistant.

the opposite was true for the barley isolate (Table 3). As in experiment 1, differences in root rot reaction among wheat cultivars were most apparent when tested against the wheat isolate and for the barley cultivars when tested against the barley isolate. Root rot severity was lower in susceptible wheat and barley when tested against the alternative isolate.

In experiments 1 and 2, disease severity was low in all cultivars grown in the control soil. It appears that a low level of inoculum was carried in by machinery, wind-blown soil from adjacent fields or through an association with grassy weeds.

The percentage of subcrown internodes of barley infected by *C. sativus* was low in soil infested with the wheat isolate but high when inoculated with the barley isolate (Table 4). However, the percentage of infected subcrown internodes was high in the wheat cultivars regardless of the isolate source. Only a small percentage of plants was infected in the untreated soil. In both wheat and barley there were no differences between susceptible, moderately susceptible and moderately resistant cultivars in the percentage of subcrown internodes infected with *C. sativus*. Similarly, isolations from field plots indicated that infection was caused by *C. sativus* and to a lesser extent by *Fusaium* spp.

Each year the results from sampling of the field tests at anthesis, mid-dough stages, and maturity showed the same influence of cropping regime on root rot severity in wheat and barley as that found in experiments 1 and 2 (Table 5). At all of these sampling dates differences in root rot resistance between wheat cultivars were most evident on land where wheat had been grown continuously. Similarly, differences in disease severity among barley cultivars were most apparent where barley had been grown during the preceding years. Root rot severity increased gradually with time in the susceptible wheat cultivar in the barley field and in the susceptible barley in the wheat field. Differences in root rot severity between moderately resistant and susceptible cultivars of wheat and barley were readily apparent at either site at maturity.

This delay in root rot development following the alternative crop tended to reduce the yield differences between moderately resistant and susceptible barley cultivars in 1986 but not in 1987 (Table 6). In both years, yield differences among wheat cultivars were not related to differences in root rot severity. It was also noted that the barley cultivars consistently outyielded the wheat cultivars in the wheat field but not in the barley field.

Discussion

This study provides evidence of a level of host specificity for *C. sativus* in wheat and barley not previously reported. The results of our study differ from those of Tyner (1940), who did not detect any differences in root rot ratings caused by isolates of *C. sativus* from wheat and barley. However, Ashworth et al. (1960) reported that isolates of *C. sativus* differed in their ability to cause root rot in wheat, oats, and sorghum. Similarly, Wood (1962) noted differences in the ability of *C. sativus* isolates to cause seedling blight in several cereal crops. He identified certain isolates that severely damaged only wheat or barley and other isolates that could attack both hosts. Other studies have also shown that isolates of *C. sativus* differ for the range of

Table 4. Average percentage of subcrown internodes infected by *Cochliobolus sativus* in the different cultivar-isolate combinations in experiment 2

Cultivar	Disease reaction‡	Percentage of subcrown internodes infected with *C. sativus* Wheat isolate	Barley isolate	Untreated
Wheat				
Cypress	S	72.0	66.0	8.0
Canuck	MR	56.0	70.0	12.0
Leader	MS	84.0	58.0	6.0
Barley				
Galt	S	30.0	90.0	18.0
Klages	MR	22.9	76.0	2.0
Bonanza	MR	16.0	78.0	8.0

LSD = 22.0 (P = 0.05) for comparison of means within columns.
†S = susceptible, MS = moderately susceptible, MR = moderately resistant.

Table 5. Root rot severity (% RR) in different wheat and barley cultivars at different stages of crop development in fields grown annually for at least 5 years to either wheat or barley

Year and cultivar	Disease reaction	Anthesis		Mid-dough		Ripe	
		Wheat	Barley	Wheat	Barley	Wheat	Barley
Wheat — 1986							
Cypress	S	54.5	29.0	82.1	41.9	92.8	49.4
Canuck	MR	29.7	12.5	45.6	11.7	43.6	23.7
Leader	MS	24.7	11.1	38.1	15.8	30.6	29.7
Barley — 1986							
Galt	S	13.9	25.6	42.1	70.9	75.3	90.7
Klages	MR	16.9	11.2	35.1	27.9	45.3	62.2
Bonanza	MR	3.4	5.6	15.8	13.9	28.6	42.4
LSD (0.05)		7.8	7.5	9.9	12.8	13.0	12.0
Wheat — 1987							
Cypress	S	88.6	15.2	86.5	25.1	90.8	48.9
Canuck	MR	46.6	13.8	60.0	20.2	66.5	30.7
Leader	MS	31.5	12.6	37.3	18.3	51.7	31.2
Barley — 1987							
Galt	S	12.0	53.0	30.5	82.7	70.6	93.8
Klages	MR	15.1	21.6	26.3	38.6	53.8	76.2
Bonanza	MR	11.6	16.7	15.2	25.9	34.7	54.7
LSD (0.05)		8.5	7.8	9.6	11.0	8.5	9.7

hosts on which they produced spot blotch symptoms (Nelson & Kline 1961, 1962; Berkenkamp 1971). Kline & Nelson (1963) also noted that some isolates tended to cause more extensive lesion formation on certain hosts than did other isolates.

Continuous cropping to susceptible cultivars of wheat or barley apparently resulted in selection of isolates that were more damaging on the host species being grown continuously. This phenomenon was apparent throughout the course of the growing season. A limited comparison of *C. sativus* isolates from wheat and barley showed obvious differences in virulence. However, further testing with a large number of *C. sativus* isolates is needed to confirm that continuous cropping of one host species results in a shift in virulence.

Table 6. Yield of wheat and barley cultivars in fields where either wheat or barley had been grown annually for at least 5 years

Cultivar	Yield (kg/ha) 1986		1987	
	Wheat	Barley	Wheat	Barley
Wheat				
Cypress	1044	1284	1084	2502
Canuck	1286	1490	1958	3162
Leader	1290	1640	1048	3034
Barley				
Galt	1824	1756	3356	3136
Klages	1656	1424	4480	4618
Bonanza	1806	1924	2824	2728
LSD (0.05)	254	264	679	475

It is clear that *C. sativus* isolates differ in their ability to damage wheat and barley. The late development of severe symptoms on susceptible wheat in barley soil or on susceptible barley in wheat soil could be due to the low frequency of virulent biotypes in those *C. sativus* populations. Tinline (1963) suggested that virulence in a heterokaryon may depend on the ratio of nuclei carrying virulence genes to those that are not virulent. Nelson and Kline (1962) reported that the ability to cause spot blotch on a specific host appeared to be controlled by a complex of genes. Tinline et al. (1960) also speculated that virulence for root rot was not simply inherited. It has been demonstrated that isolates of *C. sativus* are heterokaryotic for many morphological and cultural traits (Tinline et al. 1960), so it is possible that continuous cropping of susceptible wheat or barley increases the frequency of nuclei that carry genes for virulence on that particular host, while simultaneously decreasing the frequency of nuclei in the heterokaryon that carry genes which code for virulence on the alternative host.

Isolations from barley and wheat indicated that the wheat isolate of *C. sativus* infected barley less frequently than did the barley isolate. However, there was no corresponding reduction in the ability of the barley isolate to infect wheat. Based on these observations it appears that the influence of cropping history on root rot severity may be due to factors controlling infection and subsequent lesion development. The absence of differences between resistant and susceptible cultivars in the percentage of subcrown internodes infected by *C. sativus* was noted previously by Harding (1972).

In the past it has generally been recommended that wheat or barley not follow each other in a crop rotation because of the risk of increased root rot damage (Broadfoot 1934, Chinn 1976). This study demonstrated that root rot was less severe in barley immediately following wheat and in wheat following barley.

The extent to which the yield of wheat or barley improved when they followed the alternative crop was difficult to determine because the cultivars differ in yield potential in the absence of the disease. Differences in the ability of certain cultivars to compensate for root rot damage (Piening 1973, Tinline & Ledingham 1979) further complicate a determination of the yield benefit of alternating wheat and barley. Additional tests with agronomically similar lines, cultivars, or possibly near-isogenic lines are needed to clearly establish the effect of cropping history on yield.

Different barley-wheat rotations should be compared to determine the most effective rotation for minimizing root rot severity. Studies should also be conducted to determine the factors involved in shifts in aggressiveness for wheat and barley in the *C. sativus* populations.

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