CANADIAN JOURNAL OF PLANT PATHOLOGY 15:153–158, 1993

Relationships between common root rot, tillering, and yield loss in spring wheat and barley

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Accepted for publication 1993 03 01

Wheat grain yield decreased as symptoms of common root rot became more severe in plants with the same number of tillers. This trend was not as obvious in barley. However, as the season progressed, symptoms of common root rot were most severe on barley plants with the fewest tillers. In addition, the severity of the disease increased more rapidly on plants with the fewest tillers in wheat and barley. The major effect of the disease on yield reduction is that plants with more disease produce fewer tillers. A smaller effect is that grain yield per plant decreases as disease increases in plants with the same number of tillers, which indicates that common root rot decreases the yield of individual tillers.

Duczek, L.J., and **L.L. Jones-Flory.** 1993. Relationships between common root rot, tillering, and yield loss in spring wheat and barley. Can J. Plant Pathol. 15:153–158.

On a constaté, dans des plants de blé comptant le même nombre de talles, que le rendement en grain a diminué au fur et à mesure que les symptômes du piétin commun du blé ont pris de l'ampleur. Cette tendance n'était pas aussi évidente dans le cas de l'orge. Cependant, au fur que la saison progressait, les symptômes du piétin étaient plus graves dans le cas des plantes d'orge comptant le moins de talles. De plus, la gravité de la maladie a augmenté plus rapidement dans le cas des plants ayant le moins de talles et ce, aussi bien dans le cas du blé que dans celui de l'orge. Le principal effet de la maladie sur la réduction du rendement tient au fait que les plants les plus touchés par la maladie produisent moins de talles. Un effet secondaire tient au fait que le rendement en grain par plant diminue avec la gravité de la maladie dans le cas des plants comptant le même nombre de talles, ce qui indique que le piétin diminue le rendement des talles individuelles.

The main causal agent of common root rot of spring wheat and barley in the Canadian prairies is *Cochliobolus sativus* (Ito & Kurib.) Drechsl. ex Dastur, anamorph *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem. The disease reduces emergence, fresh weight of seedlings, and plant height in barley (Grey & Mathre 1984). Grain yield losses in spring wheat and barley are associated mainly with a reduction in the number of tillers per plant (Diehl et al. 1983, Duczek 1984, Grey & Mathre 1988, Johnston 1976, Ledingham et al. 1973, Piening et al. 1976, Pua et al. 1985), and sometimes with a reduction in kernel weight and in number of seeds per head (Diehl et al. 1983, Kidambi et al. 1985, Ledingham et al. 1973, Pua et al. 1985, Verma et al. 1976). This information was obtained by assigning plants to disease severity categories based on symptoms on the subcrown internode. As disease severity increased in these categories, the mean yield per plant and average number of tillers per plant decreased. There were, however, plants with different numbers of tillers in each disease category. Another approach has been to assign plants to tiller categories and then rate disease in each category. For wheat, this approach showed that as disease decreased, tiller number increased (Duczek 1989). Disease symptoms were highest on plants with the fewest tillers throughout the entire growing season. A similar study has not been done for barley.

The above approaches, of assigning plants to disease severity classes or to tiller categories, do not determine whether common root rot reduces yield of individual tillers. This was the purpose of the present study. The relationship between disease and tiller number in spring barley over the growing season was also studied.

Materials and methods

Relationship of tiller category to disease rating. Spring wheat (*Triticum aestivum* L.) cultivars Neepawa and Leader and spring barley (*Hordeum vulgare* L.) cultivars Bonanza and Melvin were sown 4–7 cm deep in two-row plots (6 m long, 23 cm apart) using a randomized block design with six replications at the Agriculture Canada Research Station Farm, Saskatoon. Soil was naturally infested with *C. sativus*. Each row was planted with 350 seeds and 40 kg/ha of 11–55–0 fertilizer was placed in-furrow with the seed. Seeding dates were 19 May 1988, 29 May 1989, and 28 May 1990. At maturity, a 3-m section of both rows was pulled on August 28 in 1988, September 1 in 1989, and August 27 (barley) and September 6 (wheat) in 1990. Plants were stored dry at 15–25°C until they were categorized and rated. For each plot, plants were separated into categories according to the number of tillers (stems with fertile heads). Plants in each tiller category were then separated into categories based on disease severity: 0–25%, 26–50%, 51–75% and 76–100% discoloration of the subcrown internode.

The disease rating for each tiller category in each plot was calculated by multiplying midpoint values for each disease category for every tiller category by the number of plants in each category, then dividing the sum of these values by the total number of plants in the tiller category. Some tiller categories contained very few plants on which to base a meaningful disease rating. For appropriate statistical analysis, categories with less than 4% of plants were combined with the previous lower tiller category. In 1988, 2% of wheat plants had 4 tillers so these were combined with plants with 3 tillers. In 1989, 3% of wheat plants had 4 or more tillers so they were combined with plants with 3 tillers; likewise for barley, the 2% of plants with 4 tillers were combined with plants with 3 tillers. In 1990, 4% of wheat plants had 5 or more tillers; these were combined with plants with 4 tillers, the 0.3% of barley plants with 5 tillers were combined with plants with 4 tillers.

To determine the disease reaction of cultivars, disease ratings were calculated for each plot by multiplying midpoint values for each disease category by the number of plants in each category (sum of all plants in all tiller categories in each disease category). Then the sum of these values was divided by the total number of plants in the plot.

Yield per plant, kernel weight, and number of seeds per head were determined, on a plot basis, for each tiller category, disease category, and tiller by disease category. Yield loss, reduction in kernel weight and reduction in number of seeds per head were calculated according to Diehl et al. (1983). The yield per plant by disease category was determined for each plot by dividing the yield of plants in a disease category by the number of plants in that category.

Relationship between tillering and disease over the growing season. Seed of Bonanza and Melvin barley was sown in 8-row plots, 6 m long with 350 seeds per row, using a randomized block design with six replications following the procedures outlined above and published by Duczek (1989). Seeding was done on 19 May 1987, 16 May 1988, and 29 May 1989. Samples were collected five times during the growing season by pulling about 200 plants from each plot at each sampling date, starting at one end and from all rows, in a block pattern. Sampling dates and growth stages of plants (Tottman & Broad 1987) were: 1987, June 23 (tillering, G.S. 20), July 2 (early boot, G.S. 41), July 13 (milk, G.S. 70), July 20 (soft dough, G.S. 85), and August 25 (ripe, G.S. 90); 1988, June 21 (tillering, G.S. 20), July 4 (late boot, G.S. 47), July 18 (soft dough, G.S. 85), August 4 (hard dough, G.S. 87), and August 18 (hard dough, G.S. 87); 1989, June 26 (tillering, G.S. 20), July 10 (early boot, G.S. 43), July 24 (soft dough, G.S. 85), August 8 (hard dough, G.S. 87), and September 10 (ripe, G.S. 90). At each date, plants were sorted into categories according to the number of tillers. For the first two sampling dates of each year, tillers were immature and all tillers were counted in the sample. For the last three dates in each year only fertile tillers were included. Plants were rated for disease reaction based on the extent of lesions on the subcrown internode, using the Horsfall-Barratt system (Couture 1980). For the last sample date, yield per plant and 1000 kernel weight were determined also.

Statistical analyses. Statistical analyses were carried out using a general linear model procedure or analysis of variance procedure using the F test (SAS Statistics, Version 6, SAS Institute, Box 8000, Cary NC 27511-8000).

Results and discussion

Relationship of tiller category to disease rating. Growing conditions varied among seasons. The hottest and driest year was 1988, where May to July rainfall totalled 84.8 mm; this resulted in the lowest number of tillers per plant (Table1). The maximum number of tillers produced by barley plants was two. For the same period, precipitation was 179.7 mm in 1989 and 177.2 mm in 1990. Plants produced more tillers in 1990 than in 1989. The only major climatic difference between these growing seasons was the average temperature in July which was lower in 1990 (17.5°C) than in 1989 (20.0°C).

As indicated in other studies, Leader was more susceptible to common root rot than Neepawa in

Table 1. Common root rot on plants with various numbers of tillers in two cultivars of spring wheat (Neepawa and Leader) and two cultivars of spring barley (Bonanza and Melvin)

Cultivar	Number of tillers	Disease rating* (n = 6)			Total number of plants in all reps		
		1988	1989	1990	1988	1989	1990
Neepawa	1	36	49	47	655	319	166
	2	30	39	39	468	692	447
	3**	28	39	32	184	539	830
	4–9			30			339
Leader	1	36	63	70	684	324	202
	2	31	52	57	319	443	312
	3**	28	48	56	136	495	652
	4–7			50			346
Bonanza	1	62	63	59	891	622	362
	2	57	56	55	263	265	511
	3***		53	51		175	481
	4–5			46			223
Melvin	1	70	81	83	660	445	457
	2	68	80	79	640	337	655
	3***		80	78		248	500
	4–5			76			206
S.E. of means		1.53	2.06	2.08			

* Disease ratings were calculated for each plot by multiplying midpoint values of each of four categories (0–25, 26–50, 51–75, 76–100%) by the number of plants in each category and then dividing by the total number of plants in the plot.

** Plants with 3–4 tillers in 1988 and 3-5 tillers in 1989.

*** Plants with 3–4 tillers in 1989.

Table 2. Yield per plant for disease categories of common root rot for spring wheat (Neepawa and Leader) and spring barley (Bonanza and Melvin) cultivars in 1988, 1989, and 1990

		Yield per plant (g)				
		Disease category (n = 6*)				S.E. of the mean
Cultivar	Year	0–25	26–50	51–75	76–100	
Neepawa	1988	0.687	0.661	0.595	0.545	0.035
	1989	1.573	1.548	1.442	1.266	0.081
	1990	2.115	1.981	1.838	1.490	0.081
Leader	1988	0.694	0.674	0.659	0.490	0.035
	1989	1.737	1.686	1.475	1.393	0.081
	1990	2.200	2.135	1.969	1.853	0.081
Bonanza	1988	0.928	1.003	1.022	0.904	0.035
	1989	1.541	1.572	1.587	1.449	0.081
	1990	3.339	3.334	3.265	2.978	0.081
Melvin	1988	1.157	1.190	1.188	1.121	0.035
	1989	1.349	2.074	2.066	2.048	0.081
	1990	3.316	3.231	3.462	3.016	0.081

*Except for Melvin in 1989 where for category 0–25 n=1 and for category 26–50 n=2, and in 1990 for category 0–25 n=5.

wheat and Melvin more susceptible than Bonanza in barley (Duczek 1984, 1989). Disease ratings were significantly different (P = 0.001) in all three years and the mean disease rating for all years was 36% for Neepawa, 48% for Leader, 58% for Bonanza and 76% for Melvin.

There was a significant F test (P = 0.001) for the effect of number of tillers per plant on the disease rating in 1989 and 1990, but not in 1988 (Table 1). A reduced number of tillers was associated with increased disease levels. This occurred in both wheat and barley, but the effect was more evident in wheat. In 1989, the disease rating for plants with one tiller was 56 for wheat and 72 for barley, while for plants with 3 or more tillers it was 43 for wheat and 66 for barley. In 1990, the disease rating for plants with one tiller was 58 for wheat and 71 for barley, while for plants with 4 or more tillers, it was 40 for wheat and 61 for barley. The tiller by cultivar within species interaction on disease was not significant. This means the reaction of tillers to disease was the same for cultivars and for species and it supports the results of an earlier study on wheat (Duczek 1989). In the present study, there were no significant effects of number of tillers on kernel weight or seeds per head (data not shown).

There was a significant (P = 0.001) association between yield per plant and disease category (Table 2). As disease increased, yield per plant decreased. This was more evident in wheat than in barley and supports results from previous studies (Duczek 1984, 1989, Ledingham et al. 1973, Piening et al. 1976, Verma et al. 1976). In the present study, there were no significant effects of disease categories on kernel weight or number of seeds per head (data not shown).

The general linear model procedure done after plants in each plot were separated first into tiller

Table 3. Yield per plant and reduction in kernel weight and seeds/ head for tiller category by disease category for wheat (Neepawa and Leader) and barley (Bonanza and Melvin) cultivars

			Yield per plant (g)						Reduction (%)	
			Disease categories (n = 3)							
Year	Cultivar	Tiller number	0–25	26–50	51–75	76–100	F-value	S.E. of mean	Kernel weight	Seeds/ head
1988	Neepawa	one	0.457	0.411	0.394	0.392	n.s.	.025	4.7	8.4
		two	0.788	0.836	0.741	0.629	**	.025	8.6	-1.7
	Leader	one	0.443	0.411	0.415	0.381	n.s.	.035	5.6	3.8
	Bonanza	one	0.865	0.838	0.873	0.773	n.s.	.039	2.6	1.7
	Melvin	one	0.912	0.892	0.887	0.937	n.s.	.058	-1.9	2.6
		two	1.409	1.508	1.492	1.337	n.s.	.088	1.8	-4.6
1989	Neepawa	one	0.677	0.658	0.609	0.594	n.s.	.029	-2.8	8.4
		two	1.412	1.394	1.296	1.354	*	.019	3.4	1.1
		three	2.157	2.150	2.110	2.050	n.s.	.039	0.2	2.3
	Leader	two	1.439	1.451	1.377	1.390	n.s.	.104	1.4	0.9
		three	2.238	2.109	2.011	2.173	n.s.	.082	1.3	5.0
	Bonanza	one	0.962	0.966	1.087	1.000	n.s.	.047	0.6	-6.3
1990	Neepawa	two	1.371	1.384	1.226	1.232	n.s.	.061	0.3	6.3
	Leader	three	2.142	2.196	2.039	2.068	*	.029	4.2	-2.4
	Bonanza	one	1.516	1.489	1.524	1.463	n.s.	.076	2.0	-0.4
		two	2.706	2.760	2.766	2.763	n.s.	.084	0.8	-2.4
		three	3.759	3.891	3.962	4.078	n.s.	.093	0.1	-5.9
		four	5.247	5.417	5.295	5.306	n.s.	.169	2.7	-4.7
Mean (n=18)			1.694	1.709	1.672	1.662	*	.018	2.1	0.7

n.s. indicates not significant.
* indicates significance at P = 0.05.
** indicates significance at P = 0.01.

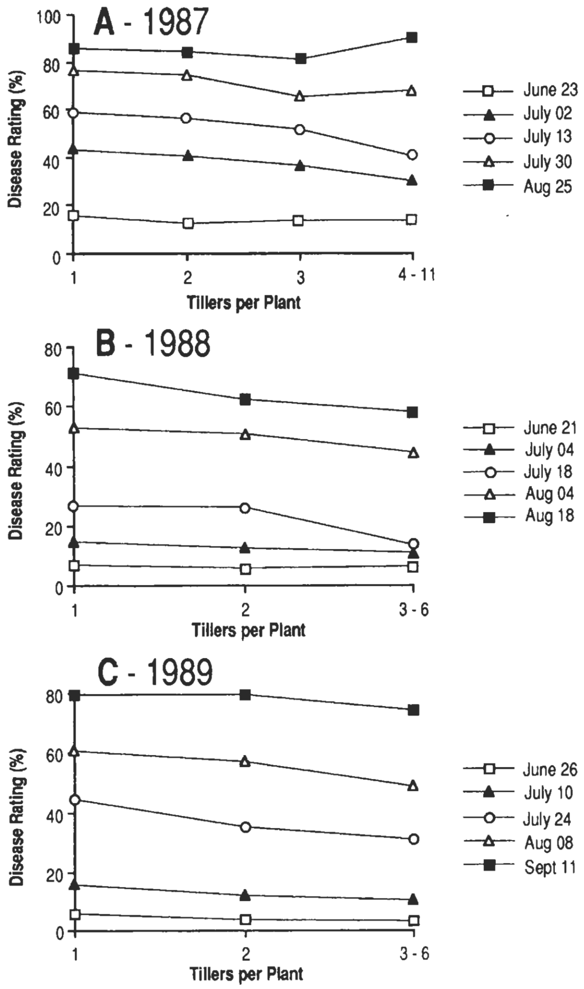

Figure 1. Common root rot severity on spring barley plants with different numbers of tillers collected at five times throughout the growing season in **A)** 1987, **B)** 1988 and **C)** 1989. The data combined for two cultivars, Bonanza and Melvin, were based on immature tillers at the first two sample dates in each year and on fertile tillers on the last three dates. The pooled standard errors for tiller categories and for sampling dates were 1.2 and 1.3 in 1987, 1.1 and 1.4 in 1988, and 0.5 and 0.7 in 1989.

categories and secondly into disease categories, showed that there was no significant effect of the disease on the number of tillers. This result is unusual as the analysis after plants were only separated into tiller categories in this study and in previous studies (Diehl et al. 1983, Duczek 1984, Grey & Mathre 1988, Johnston 1976, Ledingham et al. 1973, Piening et al. 1976, Pua et al. 1985) showed that common root rot significantly reduced tillering. The unusual result might be explained by many subdivisions having few or no plants. To overcome some of these problems in the analysis, data were combined to derive yield per plant as follows: replicates 1 and 2, 3 and 4, and 5 and 6. Individual cultivar-tiller data sets were analyzed using an analysis of variance procedure. Only sets containing values in all three combined replications and in all disease categories were analyzed. To reduce the effect of outliers, only values derived from 10 or more plants were used. There were only 18 complete sets in all three years (Table 3). As the variance was related to the mean, the data were analyzed following a square root conversion. For all sets, the mean value of yield per plant showed a significant (P = 0.05) difference in the F test for disease categories; yield decreased as disease increased except that plants in the 26–50% disease category had a higher yield than those in the 0–25% category. In the analysis of individual sets only three were significant and these involved wheat cultivars. The other wheat sets also showed a trend for decreased yield as disease became more severe. When only the 10 wheat sets were included in the analysis, the F test indicated significant differences in yields among disease categories (P = 0.0001). Mean yields were 1.312, 1.300, 1.222, and 1.226 g for the 0–25, 26–50, 51–75, and 76–100 disease categories, respectively. This trend was not present in barley where the F test was not significant and mean yields were 2.172, 2.198, 2.236, and 2.207 g for the 0–25, 26–50, 51–75, and 76–100 disease categories, respectively. There was no consistent relationship between yield loss and reductions in kernel weight or in numbers of seeds per head. One or both of these factors could be involved in yield loss. In summary, the data indicate that yield decreases as disease increases in plants with the same number of tillers.

Relationship between tillering and disease over the growing season. As in the previous study, Melvin had significantly (P = 0.001) higher disease levels than Bonanza in all three years of the study. The overall mean disease rating for Melvin was 60%, 31%, and 48%, in 1987, 1988, and 1989, respectively, while for Bonanza it was 42%, 25%, and 27%. Level of disease severity increased significantly (P = 0.001) at each sampling date. In 1987, at the first sampling date Bonanza had a disease rating of 11.5%. For the subsequent sample dates the disease rating increased from 30.7, 38.1, 56.8, to 75.8% at maturity. Melvin at the first sampling date, had a disease rating of 13.9%, increasing at subsequent sampling dates to 41.1, 68.2, 85.5, and 92.0% at maturity. This pattern was repeated in 1988 and 1989 (data not shown).

In 1987, up to 11 tillers per plant were recorded, while in 1988 and 1989 the maximum number of tillers was six. In 1987 and 1989 most plants were in the three-tiller category, 36.2% and 32.2%, respectively. In 1988, as a result of a severe drought, most plants (60.9%) had only one tiller. For statistical analysis, the small numbers of plants in the higher

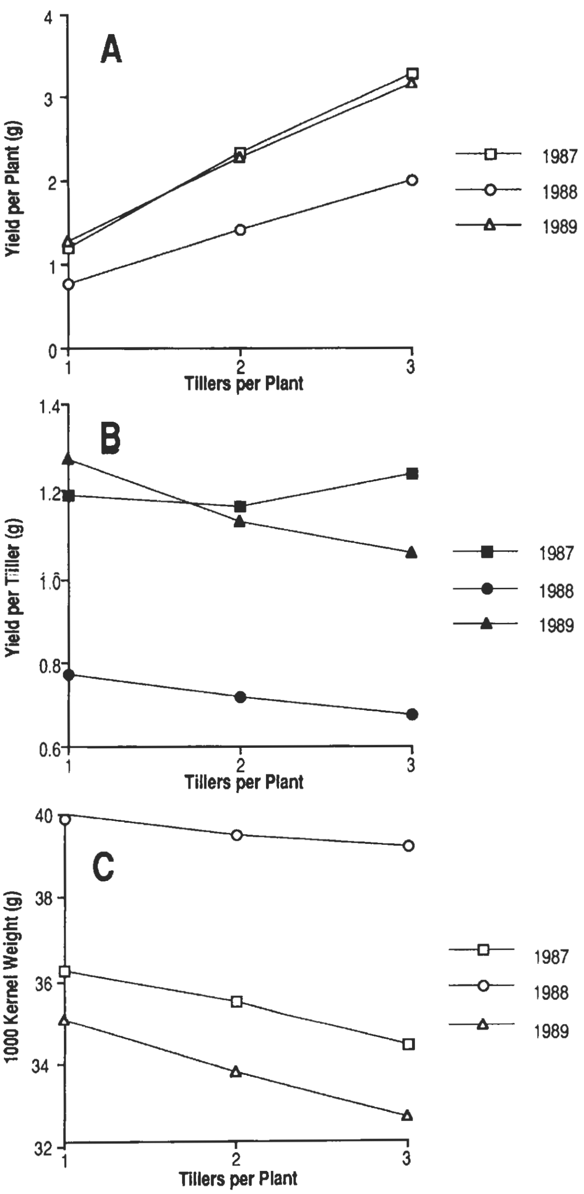

Figure 2. **A)** Yield per plant, **B)** yield per tiller, and **C)** thousand kernel weight in spring barley plants combined for two cultivars, Bonanza and Melvin, with one, two, and three tillers. The pooled standard errors for yield per plant, yield per tiller, and thousand kernel weight were 0.101, 0.044, and 0.326 in 1987, 0.076, 0.021, and 0.530 in 1988, and 0.042, 0.023, and 0.354 in 1989.

tiller number categories were combined into one group. In 1987 the categories were reduced to 1, 2, 3, and 4–11 because categories from 5–11 contained 4.8% of all plants. In 1988 and 1989 the categories were 1, 2, and 3–6. Categories from 4–6 contained 6.4% of all plant in 1988 and 12.8% in 1989.

In all three years disease severity increased significantly (P = 0.001) as the number of tillers per plant decreased in barley (Fig. 1). In 1987, plants in the tiller categories 1, 2, 3, and 4–11 had mean disease ratings for all sampling dates of 56%, 53%, 50%, and 41% respectively. In 1988 the disease rating in tiller categories 1, 2, and 3–6 were 34%, 31%, and 26%, respectively; in 1989 they were 41%, 38%, and 33%, respectively. There were few differences in disease rating among tiller categories in the first and the second dates of sampling but at later sampling dates, disease ratings were higher in plants with fewer tillers. An exception was in 1987 where plants in the 4–11 tiller category had the highest disease rating at the last sampling date.

In all three years, the yield per plant increased significantly (P = 0.001) as the number of tillers per plant increased (Fig. 2A). Only data from plants with one, two, and three tillers are shown. Plants with fewer tillers had a significantly higher yield per tiller in 1988 (P = 0.05) and 1989 (P = 0.001) but not in 1987 (Fig. 2B). Thousand kernel weight decreased as number of tillers per plant increased (Fig. 2C). The differences were significant (P = 0.001) only in 1989 where yield per tiller and 1000 kernel weights for plants with one tiller were 1.26 g, and 35.0 g, respectively, while for those with two tillers the values were 1.13 g, and 33.7 g and for three tillers they were 1.06 g, and 32.6 g. Numbers of seeds per head were significantly (P = 0.001) different between plants with different numbers of tillers only in 1989; plants with one, two, and three tillers had 35.9, 33.4, and 32.3 seeds per head, respectively. The trend was similar in 1987 and 1988 but the differences were not significant. In 1987 plants with one, two, and three tillers had 36.3, 31.8, and 28.6 seeds per head, respectively, while in 1988 these values were 21.3, 18.2, and 17.4.

In the present study, higher levels of common root rot in barley were associated with lower numbers of tillers. Kidambi et al. (1985), using a different rating system, found that tiller numbers decreased as disease increased in only one year out of five. Yield reductions occurred in only two years and this was caused mainly through a reduction in kernel weight. Pua et al. (1985) found that yield loss in barley was due to a reduction in the number of tillers per plant and in the number of kernels per head. Johnston (1976) found also that the number of tillers per plant decreased as disease increased. In wheat, loss in yield was due, in descending order, to reductions in number of tillers, number of seeds per head, and seed weight (Diehl et al. 1983).

The results indicated a level of compensation for disease in barley in that yield per tiller and thousand kernel weight increased as the number of tillers per plant decreased. This compensation was not observed in wheat. Previous work has shown that, as the number of tillers decreased in barley, kernel number and kernel weight both increased (Grey & Mathre 1984, 1988).

In summary, the major effect of common root rot on yield of wheat and barley is reduced tillering but for wheat, there is also a smaller effect in that yield decreases as disease increases in plants with the same number of tillers. Yield losses were not as high or as consistent in barley as previously reported for wheat (Duczek 1989). Also, the association between tillering and disease in barley was not as obvious as it was in wheat.

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