The Effect of Stand Density on the Development of *Puccinia graminis* f. sp. *tritici* in Barley

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ABSTRACT

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The progress of stem rust epidemics caused by race *Pgt-QCCJ* of *Puccinia graminis* f. sp. *tritici* was examined in field plots of the six-rowed barley cvs. Robust and Steptoe at four stand densities, and in short rows and hill plots. Cv. Robust carries *Rpg1*, which confers resistance to most races of *P. graminis* f. sp. *tritici*, other than *Pgt-QCCJ*, while cv. Steptoe lacks any reported genes for resistance to *P. graminis* f. sp. *tritici*. The stand-density treatments established were approximately double, the equivalent of, half of, and one quarter of the planting rate recommended for commercial barley. Stem rust caused by race *Pgt-QCCJ* spread more rapidly in cv. Steptoe than in cv. Robust, irrespective of the stand-density treatment. The effect of stand density on rust severity was, however, greater than the effect of cultivar. Rust severity was 18 to 36% greater in sparse stands than in dense stands of both cultivars. Reductions in kernel size were most severe in sparse stands where rust development was greatest. Knowledge that reduced stand densities may promote the development of stem rust in barley may be useful in refining procedures for screening breeding material for resistance to stem rust, and in allaying concern over the high levels of stem rust occasionally reported in lightly seeded seed increases and in commercial fields where sparse stands are encountered.

Additional keywords: *Hordeum vulgare*

A race (*Pgt-QCCJ*) of *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn., new to the Upper Midwest barley-growing area of the United States, was detected in 1989 (17). Race *Pgt-QCCJ* is thought to have originated in the Pacific Northwest (18). In 1989, severity of stem rust in southeastern North Dakota and west-central Minnesota ranged from a trace to 60%, making this the most severe epidemic of stem rust in barley since 1954 (22,25). Surveys indicate that race *Pgt-QCCJ* overwintered on susceptible winter wheats

in Oklahoma and Kansas in 1989 to 1990 and was prevalent on wild grasses including *Hordeum jubatum* L. in the northern Great Plains (18). This race has since become established on barley, certain winter wheats, and grasses in this region (7-9,12,13,18-21).

All of the barley cultivars presently grown in the Upper Midwest possess *Rpg1*, which conferred resistance to the common races of *P. graminis* f. sp. *tritici* prior to the appearance of race *Pgt-QCCJ*. Lines possessing *Rpg1* are moderately susceptible to race *Pgt-QCCJ* (5,18). In 1991, concern over the presence of race *Pgt-QCCJ* was heightened when stem rust was detected at high levels in seed increases of breeding lines destined for commercial release. Race *Pgt-QCCJ* appeared to threaten the production of barley in years favorable for stem rust development. Research was directed toward the identification of resistance and development of resistant germ plasm. Although race *Pgt-QCCJ* has caused only minor losses in recent years (12,13,18-21), the potential exists for a serious epidemic in years favorable for disease development if sufficient inoculum is generated in southern states.

In nurseries established to screen barley lines for resistance and in field surveys, distribution of stem rust within plots was frequently uneven and appeared to be related to the spatial distribution of plants (6; R. Dill-Macky, *unpublished*). Plants on the

edges of larger plots, plants on the ends of short rows, and plants in thin stands were often severely infected when plants of the same genotype in the center of plots or in fields at normal densities had much less rust. The observed distribution of stem rust was not related to the appearance of late tillers, which are frequently observed to be severely infected. Field experiments were conducted in 1993 and 1994 to examine the effect of plant density on the development of *P. graminis* f. sp. *tritici* in barley.

MATERIALS AND METHODS

Two barley cultivars, Robust and Steptoe, were tested. Cv. Robust (PI 476976), a six-rowed malting barley, which is currently the most popular malting cultivar in the Upper Midwest, accounted for 42 to 85, 38 to 56, and 35 to 50% of the barley acreage in Minnesota, North Dakota, and South Dakota, respectively, between 1989 and 1998. Cv. Robust is reported to carry the gene *Rpg1*, conferring resistance to *P. graminis* f. sp. *tritici* (16). Cv. Steptoe (CIho 15229), a six-rowed barley developed at Washington State University, is a widely adapted feed-type cultivar that lacks any of the reported genes for resistance to *P. graminis* f. sp. *tritici* (14).

A single isolate of race *QCCJ* of *P. graminis* f. sp. *tritici* (23) was used. The isolate (90MN3572) was collected from a commercial field of spring barley in Roseau County, Minnesota in August 1990. The isolate was increased on cv. Baart wheat in the greenhouse (5). Urediniospores were collected, dried to 20% relative humidity, and stored in cryovials in an ultra-low temperature freezer (-80°C) until needed.

Field experiments were conducted at the University of Minnesota, Agricultural Experiment Station, Rosemount, Minnesota in 1993 and 1994. The experimental design was a randomized complete block with four replicates. Planting rates were adjusted to establish plots (1993, 3.7 by 3.6 m and 1994, 3.7 by 1.8 m) of each of the two cultivars at four stand-density treatments (Table 1). The established plant densities were approximately double, the equivalent of, half of, and one quarter of those recommended for commercial barley production in Minnesota. The standard planting rate for barley is 95 kg/ha (85 lb/acre), equivalent to 276 viable seeds/m². Seed was tested for germination prior to

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Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Table 1. Planting rates used to establish stand density treatments in Robust and Steptoe barley cultivars and emerged plant populations for 1993 and 1994 experiments

Cultivar	Stand density treatment	Planting rate (kg/ha) ^w	Plant population (plants/m row) ^v	
			1993	1994
Robust	2 × RPR ^x	191	96.3 ± 12.0	75.0 ± 8.6
	RPR	95	45.8 ± 8.9	39.6 ± 8.2
	0.50 × RPR	48	23.3 ± 5.2	26.6 ± 6.0
	0.25 × RPR	24	11.3 ± 3.3	13.0 ± 3.0
	Hills ^y	...	(8.8 ± 2.1)	(9.3 ± 1.0)
Steptoe	Short rows ^z	77	...	103.9 ± 15.8
	2 × RPR	191	91.0 ± 23.9	77.6 ± 11.9
	RPR	95	47.0 ± 5.1	54.4 ± 12.5
	0.5 × RPR	48	27.5 ± 5.3	31.1 ± 3.8
	0.25 × RPR	24	16.8 ± 4.4	17.5 ± 2.4
	Hills	...	(8.3 ± 1.5)	(8.9 ± 0.8)
	Short rows	77	...	91.9 ± 9.6

^v Values are means and standard deviations of four replicates with two samples per replicate except for 1993 hill plots, where means are of four individual hills not included in the plot design. Values for hill plots, indicated by parentheses, are the number of plants per hill plot.

^w Planting rates were calculated assuming 100% germination and 28 seeds/g.

^x RPR = recommended planting rate for commercial barley, 95 kg/ha (85 lb/acre).

^y Hill plot = 1993, 15 seeds/hill with hills planted on 46-cm grid (16 kg/ha); 1994, 10 seeds/hill with hills planted on 30-cm grid (18 kg/ha).

^z Short rows = 5 g of seed planted in 1.5-m rows.

Fig. 1. Development of stem rust epidemics for four stand-density treatments of Robust and Steptoe barley cultivars inoculated with race QCCJ of *Puccinia graminis* f. sp. *tritici* in 1993. Disease progress is recorded as (A, B) rust incidence (% tillers with visible uredinia) and (C, D) rust severity (% sheath area rusted) for (A, C) Robust and (B, D) Steptoe. Error bars indicate standard errors of means. Asterisks indicate the date of anthesis (growth stage 65) for the barley cultivars.

planting. Seeding rates were adjusted to produce equivalent stand densities for the two cultivars tested. When planting rates were below the standard planting rate for barley, autoclaved grain was mixed with the plot seed to ensure a uniform distribution of live seed within the plots. Following emergence, plant populations were determined for each treatment by counting the number of seedlings in two randomly selected 1-m lengths of rows for each plot (Table 1). Plots were surrounded by a minimum distance of 1.2 m with barley (1993, 1:1, cvs. Robust:Excel and 1994, 5:2, cvs. Robust:M88-6), planted 21 and 27 days prior to the plots in 1993 and 1994, respectively. Cvs. Robust and Excel (PI 542047) were selected as spreaders in 1993 because they are adapted cultivars possessing *Rpg1* and moderately susceptible to race *Pgt-QCCJ*. In 1994, M88-6 was substituted for cv. Excel because this advanced breeding line from Minnesota is highly susceptible to race *Pgt-QCCJ*. Plots and spreaders were planted using a 10-row planter and a standard row spacing of 18 cm. Plot rows, 3.7 m long, were parallel to the length of the plot. In addition to the four stand-density treatments, hill plots of cvs. Robust and Steptoe were established adjacent to the machine-planted plots in 1993. Hill plots consisted of 15 seeds hand-planted in one spot at 46-cm spacing and equidistant from spreader rows established 91 cm apart. In 1994, hill plots and short rows were incorporated into the trial design as additional treatments. The 1994 hill-plot treatments consisted of 25 hills centered within the plot (3.7 by 1.8 m) in a five-by-five grid pattern. Individual hills were hand planted and consisted of 10 seeds planted in one spot. Hills were spaced at 30-cm centers within the grid. Short rows, 1.5 m long, were planted with a Planet Junior hand planter. A total of 10 short rows were planted in each plot space and arranged as two columns of five rows, with rows parallel to the long side of the plot space. Rows within columns were spaced 30 cm from each other and the surrounding spreader rows and the columns were spaced 20 cm from each other and the surrounding spreader rows. Short-row and hill plots were of interest because both plot types are commonly used in rust nurseries for screening breeding material.

Spreader plants surrounding the plots were inoculated with race *Pgt-QCCJ* of *P. graminis* f. sp. *tritici* on 17, 20, and 25 June in 1993, and 19, 22, 24, and 30 June in 1994. The majority of plants in the spreaders had flag leaves and sheaths emerging (Zadoks growth stage [GS] 37 to 41; 27) and plants within the plots were tillering (GS 21 to 22). Urediniospore suspensions of approximately 0.7 and 0.9 g of viable urediniospores/1.0 liter of light mineral oil (Soltrol 170, Phillips Petroleum Co., Bartlesville, OK) were applied to spreaders in 1993 and 1994, respectively.

Inoculum was distributed using a backpack sprayer at approximately 4 ml/m².

Broadleaf weeds and grasses were controlled by a single application of bromoxynil (585 g a.i./ha) and (4-chloro-2-methylphenoxy) acetic acid (805 g a.i./ha) on 11 June 1993. In 1994, a single application of bromoxynil (585 g a.i./ha) and diclofop-methyl (532 g a.i./ha) applied on 20 June was used to control weeds. Hand weeding at regular intervals supplemented chemical weed control in both years.

Rust development was assessed seven times, at 3- to 4-day intervals, after the initial appearance of symptoms in the plots. A total of 20 randomly selected primary tillers from each plot were assessed visually to determine the incidence and severity of rust. In 1993, tillers in hill plots generally numbered fewer than 20; therefore, 10 tillers per plot were assessed. Rust severity was assessed for each tiller using the key of James (11) to estimate the percentage of sheath area rusted. Rust inci-

dence was recorded as the proportion of tillers with uredinia. The growth stage of each treatment was recorded at each assessment using the decimal code for growth stages of cereals (27) with adaptations for barley (26).

At maturity, 100 heads from primary tillers were hand harvested from plots of all treatments in 1993, except hills where all primary tillers were harvested. In 1994, 200 heads from primary tillers were harvested from each plot. Hand-harvested heads were used to measure hundred-head weight and thousand-kernel weight (TKW) in 1994. Kernel size distribution was examined in both years of the study following threshing with a belt thresher. Percentage of plump kernels (above 2.4 mm in diameter), percentage of medium-sized kernels (2 to 2.4 mm diameter), and screenings (less than 2 mm in diameter) were determined by shaking 50 g of grain for 2 min through screens with slits 2.4 and 2 mm wide, respectively. The seed har-

vested from hill plots in 1993 was insufficient to assess kernel size distribution.

Analysis of variance (ANOVA; SAS Institute, Cary, NC) for rust incidence, rust severity, hundred-head weight, TKW, and kernel size distribution was performed to test for cultivar, stand density, and interactions among the main effects for individual years. The 1993 hill-plot treatments, which were not included in the experimental design, were not included in the analysis. Where the *F* ratio was significant ($P < 0.05$), differences among treatment means were determined using least significant differences. Regression of rust incidence on stand density was performed on the data from the assessment date in each year for which the range in treatment means was the greatest (Julian day 190, 1993 and Julian day 192, 1994). Regression of rust severity on stand density was performed on the data from the final assessment (Julian day 208, 1993 and Julian day 213, 1994).

RESULTS

A total of 30 rust samples were arbitrarily collected throughout the field site in 1993 and 1994 and were tested to determine if contamination of the epidemic by other races had occurred. Race identification confirmed the presence of race *Pgt-QCCJ* from over 80% of the collections in each year of the study.

Significant differences in the incidence of stem rust were evident among treatments at the initial assessments in 1993 and 1994 (Figs. 1 and 2). Rust incidence increased rapidly, exceeding 50% by the third assessment of all treatments in both years. At final assessment, uredinia were evident on all tillers examined in both years. Rust incidence at early assessments was greater in plots of cv. Steptoe than cv. Robust, irrespective of the stand-density treatment (Figs. 1 and 2), and cultivar effects were evident in the first four assessments in each year of the study. The effect of stand density within a cultivar was generally not significant at $P \leq 0.05$ in 1993. In 1994, a higher incidence of rust was observed in treatments with higher stand density within a cultivar at the first three assessments, although the differences between these treatments in cv. Steptoe were generally not significant. Differences in rust incidence were not evident after 19 July 1993 (Julian day 200) and 22 July 1994 (Julian day 203), by which time rust incidence exceeded 90% in all treatments for that year (Figs. 1 and 2).

Significant differences in rust severity also were evident among treatments in the 1993 and 1994 experiments (Figs. 1 and 2). ANOVA indicated that stand density treatment effects were significant ($P = 0.05$) at all assessments except the first two assessments in 1994. Cultivar treatment effects, while not significant at several of the later assessments in 1994, were otherwise significant ($P = 0.05$). The interactions of

Fig. 2. Development of stem rust epidemics for six stand-density treatments of Robust and Steptoe barley cultivars inoculated with race QCCJ of *Puccinia graminis* f. sp. *tritici* in 1994. Disease progress is recorded as (A, B) rust incidence (% tillers with visible uredinia) and (C, D) rust severity (% sheath area rusted) for (A, C) Robust and (B, D) Steptoe. Error bars indicate standard errors of means. Asterisks indicate the date of anthesis (growth stage 65) for the barley cultivars.

cultivar and stand-density treatments were generally not significant ($P = 0.05$). In 1993, rust developed most rapidly in stand-density treatments with lower stand densities. Although not included in the trial

Fig. 3. Relationship between (A) stem rust incidence (% tillers affected) and (B) severity (% sheath area affected) and plant density (plants/m row) for Robust and Steptoe barley cultivars inoculated with race QCCJ of *Puccinia graminis* f. sp. *tritici* in 1993 and 1994. Stem-rust incidence values used are those from the assessment date in each year for which the range in treatment means was the greatest (Julian day 190, 1993 and Julian day 192, 1994). Stem-rust severity values used are those from the final assessment in each year (Julian day 208, 1993 and Julian day 213, 1994).

design, rust severities in the hill plots were observed to be high, with rust severities of 55 and 57% for cvs. Robust and Steptoe, respectively, at the time of the final assessment in 1993. In 1994, rust development was highest in hill plots and treatments with low stand density, and lowest in treatments with high stand density (Fig. 2). Regression analysis indicates a poor correlation of the incidence of stem rust (GS 73 to 75 in 1993 and GS 49 to 57 in 1994) with stand density, while indicating a negative correlation between increasing plant populations and rust severity at the final assessment (GS 87 to 90), independent of the resistance genes of these two cultivars (Fig. 3).

Cv. Steptoe was observed to develop a little more rapidly than cv. Robust, with head emergence completed 2 to 3 days ahead of Robust in plots at equivalent stand density treatments. Plants of both cultivars in treatments with lower stand density generally developed more slowly than plants in treatments with higher stand density. The differences in maturity were most evident during dough development in cv. Robust treatments in 1994, where plants in the treatments with lowest stand density reached hard-dough stage (GS 87) up to 5 days after plants in the treatment with highest stand density.

Hundred-head weight measurements of cvs. Robust and Steptoe were affected by the stand-density treatments established. Losses were evident in treatments where thin stands were established and were greatest in the hill plot treatments in 1994. There were no significant differences in hundred-head weight of treatments representative of commercial planting rates (95 kg/ha) and the higher planting rate (191 kg/ha; Tables 2 and 3). Similarly, TKW values determined from the grain harvested in 1994 showed no increase in head weight in plots at the planting rate which exceeded the planting rate recommended for commercial fields (Tables 2 and 3). In sparse stands, where stem rust was more severe, losses of up to 61 and 40% for cvs. Robust

and Steptoe, respectively, were recorded (Table 3). Losses in hundred-head weights for cv. Robust were larger in magnitude than those of cv. Steptoe, likely because Robust had a greater yield potential in the absence of rust (5). Reductions in head weight and kernel weight were reflected in losses in the percentages of plump kernels and, similarly, in increases in the percentage of screenings recovered from the grain samples (Tables 2, 3, and 4).

DISCUSSION

Attempts to isolate and quantify planting density as a factor in disease development are limited, although it is generally accepted that planting density affects disease development (3). Burdon and Chilvers (3) categorized the effect of plant density into direct geometrical effects on the frequency of inoculation, and indirect effects through interactions with the environment. In our study, plant density was found to significantly affect rust incidence and severity. Increasing plant populations either did not significantly effect or significantly increased the incidence of stem rust in barley plots, while a negative correlation between increasing plant populations and rust severity was evident and independent of the resistance genes of the two cultivars tested. There are no reports of which the authors are aware that support this finding, and reports on the effect of seeding rates on other cereal pathogens are not consistent. Reports of powdery mildew epidemics being more severe in cereals planted with wider row spacing (1,24) and at reduced seeding rates (1) contrast with studies indicating a positive relationship between host density and disease development (2,10). Broschius et al. (1) reported that Septoria blotch severity in winter wheat was positively associated with seeding rate, and speculated that changes in microclimatic conditions resulting from increased tiller density led to such results. Pflieger and Mundt (15) examined the severity of wheat leaf rust in plots ranging in planting density from 81 to 324 seeds/m² and found no

Table 2. Hundred-head weight, thousand-kernel weight (TKW), plump kernels, medium-sized kernels, and screenings for six stand-density treatments for Robust and Steptoe barley cultivars in 1994^y

Cultivar	Treatment ^z	Hundred-head weight (g)	TKW (g)	Plump kernels (%)	Medium-sized kernels (%)	Screenings (%)
Robust	2 × RPR	117.9 e	32.0 g	59.9 g	34.5 a	5.8 a
	RPR	105.4 d	30.1 fg	50.7 fg	39.8 abc	9.5 ab
	0.50 × RPR	96.3 d	27.4 ef	35.1 de	46.2 bcd	18.6 c
	0.25 × RPR	74.0 c	23.6 bc	15.2 ab	46.8 cd	38.0 e
	Hills	45.8 ab	20.8 ab	8.7 a	40.7 abc	50.6 f
	Short rows	83.9 c	27.0 def	32.1 de	49.0 d	18.9 c
Steptoe	2 × RPR	53.6 b	29.7 fg	50.0 fg	34.2 a	15.8 bc
	RPR	57.1 b	27.8 ef	39.5 ef	39.4 ab	21.1 c
	0.50 × RPR	53.9 b	24.2 cd	24.0 bcd	43.0 bcd	33.0 de
	0.25 × RPR	54.9 b	23.7 bc	17.0 abc	45.5 bcd	37.5 de
	Hills	36.1 a	20.2 a	9.7 a	39.3 ab	51.0 f
	Short rows	52.4 b	25.2 cde	28.8 cde	41.0 abc	30.2 d

^y Values are means of four replicates. Values within a column followed by the same letter are not significantly different at $P = 0.05$ using the least significant difference t tests.

^z RPR = recommended planting rate for commercial barley, 95 kg/ha (85 lb/acre). Hill plot = 10 seeds/hill with hills planted on 30-cm grid (18 kg/ha). Short rows = 5 g of seed planted in 1.5-m rows.

significant effect of planting density on rust severity, although they did speculate that increased stand density and changes to microclimatic factors may contribute to the positive correlation between plant density and disease severity reported by others (Shitikova-Rusakova and Gassner in 4).

The high rust severities often observed in hill plots within rust-screening nurseries suggests that the spatial arrangement of plants may have a significant impact on the development of stem rust in barley. Fox (6) suggested that the level of intra-plot shading in hill plots could lead to more variable rust severity readings and suggested that competition between plants in hill plots, which is higher than in row plots, may effect rust severity readings in other ways. In Australia, the north side of hill plots and rows were often more severely rusted whereas, in the United States, stem rust was frequently observed to be heavier on the south side of plots (R. Dill-Macky, unpublished). These observations suggest an environmental effect on the host-pathogen interaction. It is clear that varying the plant number per unit area, and their relative distribution within a given area, will not only change plant density per se but will also change numerous other factors which interact with it. Tillering, plant growth rate, plant nutrient status, and plant-water relations are host factors which may be affected by host density. Similarly, the microenvironment within the canopy may be impacted by differences in air circulation, light penetration, temperature differential between day and night, relative humidity, and dew period among differing plant-density treatments. Our observations suggest that an effect may be observed that is due either directly or indirectly to light, and merits further investigation. As a result of these findings, stem-rust nurseries at the University of Minnesota are now designed to minimize the effects of plant distribution

on stem-rust development. A design incorporating plots of short rows aligned east-west, at 30 cm spacings, abutting spreader rows aligned north-south, has now been utilized for four seasons to facilitate the screening of breeding lines for stem rust resistance.

In the additional treatments created by the planting of short rows of cvs. Robust and Steptoe, rust severities were comparable to those observed in stand densities of 48 kg/ha, despite the plant populations being extremely high within the rows (Table 1 and Fig. 2). This finding also suggests that the spatial arrangement of plants, not only the number per unit area, impacts the development of race *Pgt-QCCJ* in barley. This finding supports observations made by the authors and the observation described in a 1940 annual report by R. G. Shands (Division of Cereal Crops and Diseases, USDA and Department of Agronomy and Plant Pathology, University of Wisconsin), that rust development is not uniform within stands or with plants on the outside of fields; plants on the "sunny side" (south side in the Northern Hemisphere and north side in the Southern Hemisphere) of hill plots are more severely infected than plants situated within a uniform stand.

The effect of stand density on stem rust development has important implications for the barley industry. Seed increases of advanced lines for commercial release are frequently seeded at rates below that of commercial fields in order to achieve a greater volume of seed. The practice of thinly seeding stands favors the development of stem rust. Barley cv. Stander (PI 564743) is an example. The high level of stem rust in cv. Stander in 1991, when seed of this cultivar was increased, caused concern among researchers. Prior to this seed increase, cv. Stander had not appeared to be more susceptible than other Minnesota varieties, and subsequent testing has confirmed that the resistance in Stander is at least equivalent to that in cv. Robust (5). It is possible that reduced planting rates promoted the development of stem rust in the cv. Stander increases. In 1995, in the Red River Valley of Minnesota, stem rust was noted in several thinly planted fields. Interestingly, this phenomenon has not been observed in wheat and the observation of high levels of stem rust in seed increases of a wheat cultivar would almost certainly lead to the termination of the release process. Variability in the distribution of stem rust is observed in wheat; however, the

Table 4. Plump kernels, medium-sized kernels, and screenings for five stand-density treatments for Robust and Steptoe barley cultivars in 1993^y

Cultivar	Treatment ^z	Plump kernels (%)	Medium-sized kernels (%)	Screenings (%)
Robust	2 × RPR	47.6 de	44.6 bc	7.8 a
	RPR	35.5 bc	50.9 cd	13.7 bc
	0.50 × RPR	21.2 a	55.2 d	23.7 d
	0.25 × RPR	17.5 a	49.5 cd	33.1 e
Steptoe	2 × RPR	63.5 f	29.7 a	6.9 a
	RPR	55.6 ef	33.9 a	10.6 ab
	0.50 × RPR	43.3 cd	41.1 b	15.7 c
	0.25 × RPR	26.1 ab	46.7 bc	27.2 d

^y Values are means of four replicates. Values within a column followed by the same letter are not significantly different at $P = 0.05$ using the least significant difference t test.

^z RPR = recommended planting rate for commercial barley, 95 kg/ha (85 lb/acre).

Table 3. Percent reductions in hundred-head weight (HHW) and thousand-kernel weight (TKW) and reductions in percentage plump kernels and increase in the percentage screenings for four stand density treatments for Robust and Steptoe barley cultivars in 1993 and 1994^w

Cultivar	Treatment ^x	Reduction in HHW (%) ^y		Reduction in TKW (%) ^y		Reduction in plump kernels (%) ^z		Increase in screenings (%) ^z	
		1994	1994	1994	1994	1993	1994	1993	1994
Robust	2 × RPR	0	0	0	0	0	0	0	0
	RPR	10.6	ns	12.1	9.2	5.9	3.7		
	0.50 × RPR	18.3	14.3	26.4	24.8	15.9	12.8		
	0.25 × RPR	37.2	26.3	30.1	44.7	25.3	32.2		
	Hills	61.2	35.0	...	51.2	...	44.8		
	Short rows	28.8	15.6	...	27.8	...	13.1		
Steptoe	2 × RPR	0	0	0	0	0	0		
	RPR	ns	ns	7.9	10.5	3.7	5.3		
	0.50 × RPR	ns	18.5	20.2	26.0	8.8	17.2		
	0.25 × RPR	ns	20.2	37.4	33.0	20.3	21.7		
	Hills	32.6	32.0	...	40.3	...	35.3		
	Short rows	ns	15.2	...	21.1	...	14.4		

^w ns indicates that the treatment mean did not differ significantly from the mean of the reference sample.

^x RPR = recommended planting rate for commercial barley, 95 kg/ha (85 lb/acre). 1994 Hill plot = 10 seeds/hill with hills planted on 30-cm grid (18 kg/ha). Short rows = 5 g of seed planted in 1.5-m rows.

^y Within a cultivar, the 2 × RPR (191 kg/ha) stand-density treatment was used as the reference sample to determine the percentage of reduction in hundred-head weight and TKW.

^z Within a cultivar, the 2 × RPR (191 kg/ha) stand-density treatment was used as the reference sample to determine the reduction in percentage of plump grain and increase in percentage of screenings.

distribution of stem rust is generally related to available moisture (for example, wheat in low-lying areas may be more heavily rusted than the wheat on the crest of a hill).

Commercial barley growers sometimes encounter difficulties in stand establishment, and stresses can reduce tillering and result in sparse stands. Information on the effect of stand density on the development of stem rust is useful to producers. By adjusting planting rates or adopting cultural practices to maintain dense stands of barley, producers will reduce the potential of severe stem rust epidemics. Portions of commercial fields such as headlands, field edges, and access points are areas where soil compaction, reduced seeding and fertilization rates, and competition with weeds may result in reduced plant populations. A knowledge that stem rust may be severe in sparse stands of barley may also be important to observers scouting fields for diseases. Headlands and access points are often places where observers "scout" for disease; therefore, stem rust severities may be overestimated by looking at plants in these "thin" areas.

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