Crop density and seed production of tall fescue (*Festuca arundinacea* Schreber). 2. Reproductive components and seed characteristics

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Fairey, N. A. and Lefkovitch, L. P. 1999. **Crop density and seed production of tall fescue (*Festuca arundinacea* Schreber). 2. Reproductive components and seed characteristics**. Can. J. Plant Sci. **79**: 543–549. The population density and spatial arrangement of plants may influence the productive life and performance characteristics of a perennial grass-seed crop. A study was conducted to determine the effects of the initial density (1.6, 3.1, 6.3, 12.5, 25, 50 and 100 plants m^{-2}) and row spacing (20, 40, and 80 cm) of plants on reproductive yield components and seed characteristics of tall fescue (*Festuca arundinacea* Schreber), over 3 consecutive production years (1991–1993) in the Peace region of Canada. The weight proportion of cleaned-to-uncleaned seed was 85–86% for the three lowest plant densities and then decreased, as density increased, to 82% at 12.5 plants m^{-2} and 66% at 100 plants m^{-2}. The 1000-seed weight decreased as density increased and ranged from 1.68 to 2.22 g (i.e., 595 000 to 450 000 seeds kg^{-1}). The specific seed weight ranged from 18 to 31 kg hL^{-1}; it differed among years, but the effect of plant density was inconsistent. The germination capacity of the seed was unaffected by plant density, but differed among years; it averaged 87%, 88% and 59% in 1991, 1992 and 1993, respectively. The seed yield/plant, the number of panicles/plant, and the number of seeds/plant decreased exponentially as plant density increased. The number of clean seeds/panicle decreased, as plant density increased, in the first year but was less affected subsequently, particularly with the 20-cm row spacing. The seed yield was correlated closely with the number of panicles m^{-2} (r = 0.659***). An initial density no greater than 25 plants m^{-2} in rows spaced 20–40 cm apart enhanced seed quality by producing a greater proportion of clean seed which had a higher 1000-seed weight. Such a plant density, however, is at the low end of the optimum range for maximizing seed yield per unit land area.

Key words: Tall fescue, *Festuca arundinacea* Schreber, population density, plant and row spacing, yield components, seed quality

Fairey, N. A. et Lefkovitch, L. P. 1999. **Densité de peuplement et production semencière de la fétuque élevée (*Festuca arundinacea* Schreber). 2. Composantes du rendement semencier et caractère des graines.** Can. J. Plant Sci. **79**: 543–549. La densité de peuplement et la disposition des plantes dans l'espace peuvent avoir une influence sur la durée de vie productive et sur les caractères de production d'une culture semencière de graminées vivaces. Nous avons entrepris des recherches pour mesurer les effets de la densité de peuplement initiale (1,6, 3,1, 6,3, 12,5, 25, 50 et 100 plantes par m^2) et de l'écartement des lignes (20, 40 et 80 cm), sur les composantes du rendement grainier et sur les caractères des graines de la fétuque élevée (*Festuca arundinacea* Schreber), dans trois années de production consécutives : 1991 à 1993, dans la région de la Rivière-de-la-Paix au Canada. La proportion en poids graines propres/graines tout-venant était de 85 à 86 % aux trois densités de peuplement inférieures, mais en fonction de l'accroissement de la densité elle descendait à 82 % à celle de 12,5 plantes m^2 et à 66 % à celle de 100 plantes au m^2 . Le poids de 1000 graines diminuait à mesure qu'augmentait la densité, présentant un écart de 1,68 à 2,22 g (c.-à-d. 595 000 à 450 000 graines kg^{-1}). Le poids à l'hectolitre des graines fluctuait de 18 à 31 kg et, bien que différent d'une année à l'autre, il ne manifestait aucun effet régulier de la densité de peuplement. Le pouvoir germinatif des graines était le même quelle que soit la densité de peuplement, mais il différait selon l'année, s'établissant, dans l'ordre, à 87, 88 et 59 % en moyenne en 1991, 1992 et 1993. Le rendement grainier, le nombre de panicules et le nombre de graines par plante diminuaient en fonction exponentielle de l'accroissement de la densité de peuplement. Le nombre de graines nettoyées par panicule diminuait à mesure qu'augmentait la densité dans la première année, mais à un moindre degré par après, particulièrement dans les lignes écartées de 20 cm. Le rendement grainier était étroitement lié au nombre de panicules par m^2 (r = 0,659***). Une densité initiale ne dépassant pas 25 plantes au m^2, sur lignes écartées de 20 à 40 cm, jouait en faveur de la qualité des graines, produisant une plus forte proportion de graines nettoyées possédant un poids de 1 000 graines plus lourd. Il faut dire, cependant, que cette densité se situe au bas de l'échelle acceptable si l'on recherche le rendement grainier maximal par unité de surface.

Mots clés: Fétuque élevée, *Festuca arundinacea* Schreber, densité de peuplement, espacement sur la ligne et entre les lignes, composantes du rendement, qualité des graines

Since the mid-1980s there has been a dramatic increase in the use of tall fescue (*Festuca arundinacea* Schreber) in the USA; according to Ball et al. (1993) it was being grown on more than 14 million ha of land. Tall fescue is a deep-rooted bunchgrass that is grown for amenity purposes, such as sports fields and golf courses, and for livestock feed. Most of the seed of this species is currently grown in Oregon and Missouri in the USA (Young 1997). Previous research has indicated the agronomic feasibility of growing tall fescue

Abbreviations: **CSGA**, Canadian Seed Growers' Association; **ISTA**, International Seed Testing Association for seed in the Peace region of Canada (Fairey and Lefkovitch 1993) and has shown that a minimum of 100 kg ha^{-1} of N is required to optimize the yield of each consecutive seed crop (Fairey and Lefkovitch 1998). In recent years, pedigreed seed production of tall fescue has expanded in Canada, mostly in the Peace region, from a range of 40 to 170 ha between 1990 and 1995 to 420 ha in 1996, 1380 ha in 1997, and 3200 ha in 1998 (Canadian Seed Growers' Association 1990–1998). A Peace region study with initial plant densities of 1.6 to 100 plants m^{-2} has shown that maximum seed yield of tall fescue can be achieved for each of at least 3 consecutive production years with an initial density of 20 to 100 plants m^{-2} in rows spaced 20 to 60 cm apart (Fairey and Lefkovitch 1999). However, seed yield is the integration of many components of reproductive growth, including plant density and arrangement, fertile tiller production and survival per plant, and seed number and weight per panicle. The objective of this study was to determine the effects of the density and spatial arrangement of plants on components of reproductive growth of tall fescue grown in the northerly environment of the Peace region.

MATERIALS AND METHODS

The study was conducted in the Peace River region of Canada at Agriculture and Agri-Food Canada's Research Farm in Beaverlodge (55°12′N, 119°23′W) on a Landry clay-loam soil (Black Solod, Udic Ustocrept). Full details of the experimental procedures are given by Fairey and Lefkovitch (1999). Briefly, a plant density experiment was established by transplanting individual plants of Mustang tall fescue, each with four to six tillers, to a field site in late July 1990. The field layout was based on a design proposed by Lin and Morse (1975). There were four replicates and each was divided into three blocks of nine plots, with the highest plant density treatment within each of the three blocks being 25, 50 or 100 plants m^{-2}. The nine plots within each block were arranged in three rows (one for each of the three between-row spacing treatments of 20, 40 and 80 cm) of three columns (one for each of the three within-row spacing treatments: viz. 20, 40 and 80 cm when the highest density treatment for the block was 25 plants m^{-2}; 10, 20 and 40 cm when the highest density treatment for the block was 50 plants m^{-2}; and 5, 10 and 20 cm when the highest density treatment for the block was 100 plants m^{-2}). There were seven density treatments, viz. 1.6, 3.1, 6.3, 12.5, 25, 50 and 100 plants m^{-2}, which were incorporated into the three blocks within each of the four replicates to provide greatest precision in the estimation of the effects of the central density of the series, i.e. 12.5 plants m^{-2}.

The study was maintained for 3 consecutive years of seed production, 1991 to 1993 inclusive. In the fall (late September or early October) before each seed production year, 200 kg ha^{-1} of 34-0-0 N fertilizer was broadcast over the experimental site. Weeds were controlled by hand weeding.

Observations on reproductive components of growth and seed characteristics were based on 12 adjacent plants in the centre of each treatment plot. The perimeter of the ground area occupied by these 12 plants in each plot was delineated permanently at the commencement of the study with highly visible plastic rods (1 cm diameter). Observations and harvests for each plot were restricted to plant material originating within this delineated zone. Panicles (fertile tillers) were counted soon after their emergence and were harvested by sickle on the first day when seed shattering was evident with gentle shaking by hand. Each sample was placed in a cotton bag and dried outdoors on a well-ventilated rack. The seed was threshed, weighed, cleaned, and re-weighed. These measurements, together with the number of plants per plot (12) and the land area occupied per plant, were used to derive other variates of agronomic interest, viz. the number of clean seeds per plant and per panicle, the number of panicles per plant and per unit land area, and the yield of clean seed per plant adjusted to 12% moisture on a fresh-weight basis.

The procedures of the International Seed Testing Association (1985) were used to determine the moisture content of the uncleaned and cleaned seed (each based on one 5-g sample), the 1000-seed weight (based on eight samples of 100 seeds), and the germination capacity (based on two samples of 100 seeds). When sufficient seed was harvested for proper determination, the specific weight of the cleaned seed was calculated from duplicate determinations using a standard quick-discharge funnel and a measuring cup; the outlet of the funnel was 3.2 cm in diameter and was controlled by a sliding-gate valve positioned 5 cm above the rim of the 142-mL measuring cup (1/4 Imperial pint). After dispensing, the seed above the rim was removed, and the net seed weight recorded.

Statistical Analyses

Genstat 5, Release 2.2, (Lawes Agricultural Trust 1987, 1990) was used for all statistical analyses. Each variate was analyzed using a generalized linear model (McCullagh and Nelder 1989); the error distribution and link function were determined using procedures given by Lefkovitch (1993). To allow for the possibility of unequal variability due to differing plot sizes, scatter diagrams of the deviance-standardized residuals against fitted values were examined in detail. For none of the analyses reported in the results were there obvious systematic trends in mean values or in variability revealed by the scatter diagrams. The resulting procedures should be considered as providing maximizing quasi-likelihood estimates. The responses analyzed and their generalized linear models are:

1. The yield of clean seed per plant, the 1000-seed weight and the specific weight of the cleaned seed were analyzed assuming a constant coefficient of variation (achieved by specifying a gamma distribution and log link).
2. The number of panicles (per plant and per unit land area) and the number of clean seeds (per plant and per panicle) were analyzed assuming a (compound) Poisson distribution with the log link.
3. The germination capacity (i.e. the number of normal seedlings out of 200 evaluated) was analyzed assuming a binomial distribution with the logit link.
4. The weight proportion of cleaned-to-uncleaned seed (dry matter basis) was analyzed assuming a pseudo-binomial distribution with the logit link.

Tests of significance referred the ratio of mean deviances to the F-distribution and probabilities of less than 5% were considered to be significant. The means presented in the tables of results were those generated by the generalized linear model fitted to each response variate, and are equivalent to the least-square means associated with an analysis of variance.

RESULTS

During the 4 yr of the study, 1990 to 1993, the annual moisture deficit (annual precipitation minus pan evaporation during the growing season) was 101%, 146%, 131%, and 106% of the long-term average. In the spring of 1993, after 2 yr with greater-than-normal moisture deficits and a winter during which the insulating layer of accumulated snow was lower than normal, the vigour of many plants was reduced and the central tillers of many plants were killed (Fairey and Lefkovitch 1999).

A summary of the analysis of deviance of five characteristics of reproductive growth is given in Table 1. The yield of clean seed/plant was at a maximum of 49.9 g for the lowest plant density (and widest row spacing) in the second production year. It decreased as density increased for each production year and with each row spacing (Table 2) but production year affected the pattern of response (Table 1). The decrease in seed yield/plant with increasing density was exponential for each row spacing in the first and second production years but was essentially linear in the third year when plant growth had been affected by winter injury (Table 2). The pattern of the response to treatments and year for the number of seeds/plant was virtually identical to that for seed yield/plant (Table 1), a consequence of these two characteristics being closely correlated (r = 987*** for raw variates, and r = 0.966*** for residuals from fitted values; n = 180).

The number of panicles/plant decreased as plant density increased; the nature of the response was similar for each row spacing within each year but, in the second production year, there were significantly greater numbers of panicles/plant at the lower plant densities within each row spacing, particularly at the 40 and 80 cm row spacings (Tables 1 and 3).

The pattern of response to increasing plant density for the number of panicles m^{-2} was similar for each row spacing (Tables 1 and 4). In the first production year, as plant density increased, the number increased to a maximum of about 900 panicles m^{-2} at 100 plants m^{-2} with the 20- and 40-cm row spacings but, at the 80-cm row spacing, fewer panicles were produced at comparable plant densities. A similar response pattern was evident in the second year although the number of panicles m^{-2} was considerably greater, particularly at densities less than 12.5 plants m^{-2} for the 40- and 80-cm row spacings. In the third year, the number of panicles m^{-2} increased with plant density up to 25 plants m^{-2} and decreased significantly at 100 plants m^{-2}; the maximum number was about 400 for the 20- and 40-cm rows but less than 300 for the 80-cm rows (Table 4). The seed yield per unit land area was correlated closely with the number of panicles m^{-2} (r = 0.659*** between raw variates, and r = 0.657*** between residuals from fitted values; n = 180).

Table 1. A summary of the analysis of deviance of five characteristics of reproductive growth

	Clean seed yield (g plant^{-1})			Clean seeds (n plant^{-1})			Panicles (n plant^{-1})			Panicles (n m^{-2})			Clean seeds (n panicle^{-1})		
Source	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability
Plant density (PD)															
PD regression[z]	1	156.8343	<0.001***	1	138.8521	<0.001***	1	100.7320	<0.001***	1	38.9005	<0.001***	1	7.5646	<0.001***
Deviations	5	0.8736	<0.001***	5	0.9116	<0.001***	5	0.8766	<0.001***	5	0.9018	<0.001***	5	0.0909	0.130NS
Between-row spacing (BRS)															
BRS regression[z]	1	1.4162	<0.001***	1	1.6703	<0.001***	1	1.9660	<0.001***	1	2.0762	<0.001***	1	0.0064	0.729NS
Deviations	1	2.8031	<0.001***	1	2.6233	<0.001***	1	1.8054	<0.001***	1	1.8502	<0.001***	1	0.3975	0.006**
Year (Y)	2	70.3555	<0.001***	2	70.0859	<0.001***	2	45.7629	<0.001***	2	46.2617	<0.001***	2	33.2068	<0.001***
Y × PD regression	2	3.3088	<0.001***	2	3.7819	<0.001***	2	3.8157	<0.001***	2	3.6987	<0.001***	2	0.0824	0.212NS
Y × BRS regression	2	0.4897	0.011*	2	0.4420	0.015*	2	0.1018	0.215NS	2	0.1157	0.190NS	2	0.1769	0.037*
Residual	293	1.1063		292	0.1045		294	0.0659		294	0.0693		288	0.0528	

[z]On natural logarithm of factor.

Table 2. The effect of plant density and row spacing on the yield of clean seed per plant (g at 12% moisture) of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year 1991	1992	1993
20	6.3	17.1 (1.57[z])	18.0 (1.67)	4.4 (0.42)
	12.5	11.4 (0.92)	9.2 (0.75)	2.6 (0.21)
	25.0	6.9 (0.52)	4.7 (0.37)	1.2 (0.09)
	50.0	3.6 (0.35)	2.0 (0.20)	0.5 (0.05)
	100.0	1.5 (0.28)	1.4 (0.22)	0.3 (0.04)
40	3.1	21.6 (2.30)	39.1 (4.17)	5.8 (0.66)
	6.3	17.3 (1.39)	22.6 (1.81)	4.8 (0.40)
	12.5	11.5 (0.82)	11.5 (0.82)	2.9 (0.21)
	25.0	6.9 (0.56)	5.9 (0.48)	1.3 (0.10)
	50.0	3.7 (0.39)	2.5 (0.27)	0.6 (0.06)
80	1.6	21.0 (3.35)	49.9 (7.94)	4.0 (0.64)
	3.1	15.3 (1.47)	31.5 (3.01)	3.7 (0.37)
	6.3	12.3 (0.92)	18.2 (1.37)	3.1 (0.23)
	12.5	8.2 (0.66)	9.3 (0.75)	1.8 (0.15)
	25.0	4.9 (0.45)	4.8 (0.44)	0.8 (0.08)

[z]Approximate standard error.

Table 3. The effect of plant density and row spacing on the number of panicles per plant of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year 1991	1992	1993
20	6.3	51 (3.7[z])	144 (10.4)	42 (3.0)
	12.5	42 (2.6)	83 (5.3)	30 (1.9)
	25.0	28 (1.6)	48 (3.0)	16 (0.9)
	50.0	19 (1.4)	24 (1.8)	8 (0.6)
	100.0	9 (1.2)	15 (1.8)	2 (0.3)
40	3.1	52 (4.3)	235 (19.4)	56 (4.6)
	6.3	48 (2.9)	154 (9.7)	44 (2.8)
	12.5	39 (2.2)	89 (5.0)	32 (1.8)
	25.0	26 (1.6)	51 (3.2)	17 (1.1)
	50.0	17 (1.4)	26 (2.2)	8 (0.7)
80	1.6	45 (5.5)	246 (30.3)	36 (4.4)
	3.1	41 (3.1)	184 (13.6)	37 (2.7)
	6.3	38 (2.2)	120 (7.2)	29 (1.7)
	12.5	31 (1.9)	69 (4.4)	21 (1.3)
	25.0	21 (1.5)	41 (2.9)	11 (0.8)

[z]Approximate standard error.

Table 4. The effect of plant density and row spacing on the number of panicles m^{-2} of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year 1991	1992	1993
20	6.3	325 (24[z])	900 (67)	259 (19)
	12.5	526 (34)	1038 (68)	374 (24)
	25.0	693 (41)	1211 (77)	406 (24)
	50.0	932 (71)	1216 (93)	388 (30)
	100.0	876 (111)	1483 (187)	232 (29)
40	3.1	162 (14)	736 (62)	172 (15)
	6.3	299 (19)	965 (62)	277 (18)
	12.5	484 (27)	1113 (65)	400 (23)
	25.0	638 (41)	1298 (84)	434 (28)
	50.0	858 (73)	1304 (111)	414 (35)
80	1.6	70 (9)	384 (49)	56 (7)
	3.1	126 (10)	574 (44)	112 (9)
	6.3	233 (14)	753 (46)	181 (11)
	12.5	377 (24)	868 (56)	261 (17)
	25.0	497 (36)	1013 (75)	283 (21)

[z]Approximate standard error.

Table 5. The effect of plant density and row spacing on the number of clean seeds per panicle of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year 1991	1992	1993
20	6.3	166 (11.0[z])	71 (4.8)	56 (3.9)
	12.5	138 (8.0)	64 (3.8)	48 (2.8)
	25.0	129 (7.0)	57 (3.4)	41 (2.2)
	50.0	107 (7.0)	49 (3.6)	37 (2.5)
	100.0	107 (17.4)	63 (7.2)	65 (7.4)
40	3.1	191 (14.7)	88 (6.8)	55 (4.5)
	6.3	181 (10.4)	81 (4.7)	59 (3.5)
	12.5	150 (7.7)	73 (3.9)	49 (2.5)
	25.0	141 (8.1)	64 (3.8)	42 (2.4)
	50.0	117 (9.0)	55 (4.4)	37 (2.9)
80	1.6	204 (23.4)	93 (10.7)	61 (7.0)
	3.1	165 (11.4)	92 (6.3)	55 (3.9)
	6.3	156 (8.4)	84 (4.7)	56 (3.1)
	12.5	130 (7.6)	76 (4.5)	47 (2.8)
	25.0	122 (8.1)	66 (4.5)	40 (2.7)

[z]Approximate standard error.

At each row spacing, the number of clean seeds/panicle was highest in the first production year, decreasing progressively from 204 at 1.6 plants m^{-2} to 107–117 at 50 and 100 plants m^{-2}; values were similar, at comparable plant densities, for each row spacing. In the subsequent 2 production years, clean seed number/panicle was affected less by plant density, particularly at the 20-cm row spacing. The number of clean seeds/panicle was generally unaffected by row spacing but decreased progressively over year for each combination of density and row spacing (Tables 1 and 5).

A summary of the analysis of deviance of four characteristics of the seed is given in Table 6. The weight proportion of cleaned-to-uncleaned seed differed with the year of production, and averaged 85, 83, and 78% for the 3 consecutive years, respectively. It decreased progressively, as plant density increased, at densities greater than 6.3 plants m^{-2} and, when averaged over the 3 production years, was 86, 85, 85, 82, 80, 73, and 66% for the low- to high-density treatments, respectively.

The 1000-seed weight was influenced by the combined effects of plant density and production year (Table 6). In each year, the decrease in 1000-seed weight with increasing plant density was most pronounced at the 80-cm row spacing. In general, within each row spacing and at a comparable plant density, values were highest in the first and lowest in the second production year. In the third year, the effect of density was only marginally significant, except at the 80-cm row spacing (Tables 6 and 7).

Table 6. A summary of the analysis of deviance of four characteristics of the seed

	Cleaned-to-uncleaned seed (% by weight)			1000-seed weight (g)			Germination capacity (%)			Specific seed weight (kg hL^{-1})		
Source	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability
Plant density (PD)												
PD regression[z]	1	176.501	<0.001***	1	0.4197	<0.001***	1	41.880	0.089NS	1	0.0005	0.771NS
Deviations	5	7.117	0.002**	5	0.0046	0.463NS	5	31.420	0.054NS	5	0.0127	0.084NS
Between-row spacing (BRS)												
BRS regression[z]	1	0.714	0.537NS	1	0.0172	0.064NS	1	3.730	0.610NS	1	0.0227	0.061NS
Deviations	1	0.689	0.543NS	1	0.0043	0.354NS	1	73.890	0.024*	1	0.0098	0.219NS
Year (Y)	2	75.410	<0.001***	2	0.3774	<0.001***	2	3456.110	<0.001***	2	1.4758	<0.001***
Y × PD regression	2	8.045	0.014*	2	0.0479	<0.001***	2	39.860	0.065NS	2	0.0462	0.001**
Y × BRS regression	2	1.206	0.525NS	2	0.0031	0.533NS	2	8.910	0.541NS	2	0.0040	0.539NS
Residual	293	1.866		293	0.0050		294	14.470		160	0.0244	

[z]On natural logarithm of factor.

The germination capacity of the seed was generally unaffected by plant density and row spacing but differed significantly among production year (Table 6), averaging 87, 88, and 59% in the 3 consecutive years. The specific weight of the seed differed with production year, being 29.6, 24.9, and 20.6 kg hL^{-1}, respectively, for each successive yr but the effect of plant density was not consistent over years (Tables 6 and 8).

DISCUSSION

The yield of seed/plant decreased as the plant density at establishment increased but, for each specific plant density in each year, it was generally greatest with the 40-cm rows, intermediate with the 20-cm rows, and lowest with the 80-cm rows. The maximal yield of 49.9 g plant^{-1} was recorded in the second production year, at the lowest plant density of 1.6 plants m^{-2} that was only present at the widest, 80-cm, row spacing. It has long been known that low plant densities result in maximal seed yield/plant while moderate densities result in maximal seed yield per unit land area (Donald 1954, 1963) but the present study also confirms the effect of the rectangularity of plant spacing on seed productivity reported by Holliday (1963), as the seed yield/plant differed with the various combinations of within- and between-row spacing used to achieve a specific plant density. Yield/plant was also influenced markedly by production year, an effect presumably mediated via the previous and prevailing environmental conditions, and the responsiveness of the current population of tillers. A specific environmental effect was evident in the third production year when seed yield never exceeded 5.8 g plant^{-1} and decreased almost linearly with increasing plant density; these low yields were primarily a consequence of the previously mentioned winter injury that killed numerous, potentially reproductive tillers in the central core of most plants. In this year, the maximum number of panicles/plant never exceeded the 246 observed at the lowest density (1.6 plants m^{-2} on 80-cm rows) and was just outside the range of 250–400 panicles/plant reported for spaced tall fescue plants by Cowan (1956). In the current trial, the mean seed yield was 1237, 1225, and 264 kg ha^{-1} for the first, second, and third production years, respectively. The trial was retained but not harvested in the fourth production year, and the plants recovered to produce a good seed crop that was estimated visually to be comparable to the first two seed crops. Thus, the reduced seed yield in the third production year was probably a consequence of the specific and atypical winter conditions, and is unlikely to be a natural decrease in productivity with increasing stand age.

The dependence of tall fescue seed yield on the number of panicles m^{-2} has been well documented in New Zealand by Hare (1992, 1993, 1994) who also found that fertile tiller density was particularly important for the first seed crop (Hare 1994). Based on these studies, and on others from the USA (Watson and Watson 1982; Albeke et al. 1983; Chastain and Grabe 1989) and Japan (Suzuki 1989), which each reported a maximum density of reproductive tillers of 400 to 600 m^{-2}, Hare (1993) agreed with the earlier interpretation of Robson (1968) that the density of reproductive tillers in tall fescue may be limited genetically, and that insufficient nutrient resources may preclude the attainment of reproductive tiller densities as high as 1000 to 2000 m^{-2}. The present results do not support the existence of such a limitation. For instance, in the first production year, reproductive tiller density exceeded 600 m^{-2} whenever the population density was greater than 25 plants m^{-2} with row spacings of 20 or 40 cm; reproductive tiller density ranged from 638 to 932 m^{-2}. In the second production year, reproductive tiller density exceeded 600 m^{-2} at all plant densities with 20 and 40 cm row spacings (i.e. at densities from 3.1 to 100 plants m^{-2}), and at the three highest densities of 6.3, 12.5 and 25 plants m^{-2} with the 80-cm row spacing; reproductive tiller density ranged from 736 to 1483 m^{-2}. This current investigation was conducted with transplanted seedlings but, in a subsequent study on the nitrogen fertility responses of the same tall fescue cultivar, machine-drilled in 30 cm rows at 200 viable seeds m^{-2}, a reproductive tiller density in excess of 600 m^{-2} was found again, with treatment means all in the range 692 to 745 m^{-2} (Fairey and Lefkovitch 1998). Whether this capacity to support a greater density of reproductive tillers is controlled by the genetic constitution of the particular cultivar used for this study, by management factors, by environmental conditions (e.g. the

Table 7. The effect of plant density and row spacing on the 1000-seed weight (g) of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year		
		1991	1992	1993
20	6.3	2.03 (0.04[z])	1.77 (0.04)	1.84 (0.04)
	12.5	1.97 (0.04)	1.71 (0.03)	1.85 (0.03)
	25.0	1.94 (0.03)	1.68 (0.03)	1.80 (0.03)
	50.0	1.83 (0.04)	1.71 (0.04)	1.84 (0.04)
	100.0	1.86 (0.08)	1.58 (0.06)	1.86 (0.06)
40	3.1	2.16 (0.05)	1.86 (0.04)	1.89 (0.05)
	6.3	2.05 (0.04)	1.85 (0.03)	1.86 (0.03)
	12.5	1.98 (0.03)	1.78 (0.03)	1.87 (0.03)
	25.0	1.95 (0.03)	1.76 (0.03)	1.82 (0.03)
	50.0	1.84 (0.04)	1.79 (0.04)	1.86 (0.04)
80	1.6	2.22 (0.08)	2.14 (0.07)	1.94 (0.07)
	3.1	2.20 (0.05)	1.86 (0.04)	1.88 (0.04)
	6.3	2.08 (0.03)	1.84 (0.03)	1.86 (0.03)
	12.5	2.01 (0.04)	1.78 (0.03)	1.87 (0.03)
	25.0	1.98 (0.04)	1.75 (0.04)	1.81 (0.04)

[z]Approximate standard error.

Table 8. The effect of plant density and row spacing on the specific seed weight (kg hL^{-1}) of tall fescue in three consecutive production years

Population density (plants m^{-2})	Production year		
	1991	1992	1993
1.6	29.5 (1.16[z])	28.4 (1.12)	18.1 (0.82)
3.1	31.1 (0.71)	24.9 (0.57)	19.8 (0.60)
6.3	30.1 (0.50)	25.4 (0.41)	21.0 (0.48)
12.5	29.0 (0.49)	24.1 (0.38)	20.9 (0.77)
25.0	28.1 (0.59)	24.4 (0.52)	IS
50.0	28.2 (2.22)	IS[y]	IS
100.0	31.4 (2.47)	IS	IS

[z]Approximate standard error.
[y]IS, Insufficient seed available for proper determination.

longer photoperiod during the growing season at more northerly latitudes), or by a combination of these influences, deserves further investigation.

The observed decrease in the number of clean seeds/panicle over year for each density and row spacing combination is possibly explained by a progressively limiting supply of available N from the soil, as only 68 kg ha^{-1} N was provided annually. This study was the first in the Peace region to investigate the agronomic requirements of a tall fescue seed crop, and so the rate of N applied was based on recommendations for local seed crops of creeping red fescue. However, a recent study (Fairey and Lefkovitch 1998) has revealed that the N requirement of a tall fescue seed crop in the Peace region is in the range of 100 to 150 kg ha^{-1}, and similar to the maximum of 120 kg ha^{-1} N recommended in New Zealand (Hare and Rolston 1990).

The results of this study emphasize that, as plant density increases, individual plants and panicles each contribute less to the final seed yield. This is in agreement with the previous results for seed production of many crops, including annual grasses and legumes (Donald 1954, 1963). The results reinforce the importance of establishing an adequate density of tall fescue plants, which are well distributed spatially, in order to maximize seed productivity over successive production years (Fairey and Lefkovitch 1999). They also support the contention of Holliday (1963), who indicated that except when extreme rectangularity in plant spacing is involved, plant population density has a greater effect on yield than spatial arrangement. An insufficient density and/or particularly uneven distribution of plants at establishment cannot be compensated for, in a subsequent production year, as readily in a seed crop of a tufted grass, such as tall fescue, as it can in one of a rhizomatous grass such as creeping red fescue (Fairey and Lefkovitch 1996a).

In addition to maximizing seed yield, the quality characteristics of the seed were enhanced by establishment at a relatively low plant density. The weight proportion of cleaned-to-uncleaned seed decreased considerably below 80% at initial densities greater than 25 plants m^{-2} and, as the initial plant density increased, there was an increase in the proportion of light seed and associated floral structures in the uncleaned seed. This is presumably a consequence of an increase in inter-plant competition as plant density increases (Donald 1954, 1963). This explanation is supported by the consistent decrease in the 1000-seed weight, as plant density increased, for each row spacing in the first two production years. In the third production year, 1993, the development and growth of the seeds was atypical because of the decreased survival of tillers over winter; the 1000-seed weight was unaffected by plant density at the 20- and 40-cm row spacings, although it decreased as density increased at the 80-cm row spacing. These results confirm the general conclusion of Youngberg and Wheaton (1979) that higher seed quality, and a longer stand life, may be attained with tall fescue by establishment on relatively wide rows (76–107 cm versus 30–36 cm) using a relatively low seeding rate (3.4–5.6 kg ha^{-1} versus 9–11 kg ha^{-1}).

No consistent benefit of lower plant density was found for the specific weight or germination capacity of the clean seed, both of which were profoundly influenced by production year. The specific seed weight was in the range of 18.1 to 31.4 kg hL^{-1}, greater than the 16 to 25 kg hL^{-1} observed in a plant density study with creeping red fescue (Fairey and Lefkovitch 1996b). The germination capacity of the seed was only affected significantly by production year and exceeded the 80% required by the Seeds Act for Canada Foundation No. 1 seed (Supply and Services Canada 1987) in the first 2 production year. It is unclear as to why the germination values for the third production year were consistently lower than those of the previous 2 yr. In that year (1993), however, such low values were not restricted to this study or grass species, as an average of only 69% was observed in an adjacent trial with creeping red fescue (Fairey and Lefkovitch 1996b); we therefore attribute the low values to the environmental conditions prevailing during seed maturation.

Other results from this study (Fairey and Lefkovitch 1999) have shown that seed yield of tall fescue can be maximized over a period of at least 3 production year by establishing a stand with an initial density of 20–100 plants m^{-2}

in rows spaced 20–60 cm apart or, if maximization of the first-year seed yield is also a priority, then with an initial density of 25–50 plants m^{-2} in rows spaced 20–40 cm apart. The present results indicate that these plant-spacing arrangements also produce seed of acceptable quality for commerce but, if a higher 1000-seed weight (i.e. larger or plumper seed) or a greater proportion of clean seed (i.e. a decrease in seed dockage at cleaning) are specific priorities, then an initial plant density no greater than about 25 plants m^{-2} is beneficial.

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