Crop density and seed production of tall fescue (*Festuca arundinacea* Schreber). 1. Yield and plant development

N. A. Fairey[1] and L. P. Lefkovitch[2]

[1]*Beaverlodge Research Farm, Agriculture and Agri-Food Canada, P.O. Box 29, Beaverlodge, Alberta, Canada T0H 0C0 (e-mail: faireyn@em.agr.ca);* [2]*51 Corkstown Road, Nepean, Ontario, Canada K2H 7V4.*
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Fairey, N. A. and Lefkovitch, L. P. 1999. **Crop density and seed production of tall fescue (*Festuca arundinacea* Schreber). 1. Yield and plant development.** Can. J. Plant Sci. **79**: 535–541. A field study was conducted with tall fescue (*Festuca arundinacea* Schreber) to determine the effect of the initial population density and spatial arrangement of plants on crop development and seed yield. Individual seedling plants were transplanted at seven densities (1.6, 3.1, 6.3, 12.5, 25, 50, and 100 plants m^{-2}) and three row spacings (20, 40, and 80 cm), and characteristics of seed production were determined for 3 yr (1991–1993). Over the 3 yr, heading commenced at dates differing by 15 d and was delayed, as density increased, by 8, 6, and 2 d, respectively, in the first, second, and third production years. The time of seed maturity differed among years (21 July to 4 August) but was generally unaffected by density or row spacing. In the first production year, seed yield increased with density up to 25 plants m^{-2} for each row spacing, then remained constant to at least 50 plants m^{-2} with both 20- or 40-cm rows; it decreased slightly at 100 plants m^{-2} with 20-cm rows. In the second production year, seed yield was relatively independent of plant density except that it decreased when the initial density was less than 6 plants m^{-2} with a row spacing of 80 cm, and tended to be greatest with the 40-cm row spacing at 6–25 plants m^{-2}. In the third production year, seed yield was much lower than in the previous 2 yr but the pattern of response to the density and row spacing treatments was similar to that in the second production year. The seed yield of tall fescue can be optimized for at least 3 consecutive years by establishing an initial density of 20–100 plants m^{-2} in rows spaced 20–60 cm apart. If the maximization of first-year seed yield is a priority, then the initial establishment should be at a density of 25–50 plants m^{-2} in rows spaced 20–40 cm apart.

Key words: Tall fescue, *Festuca arundinacea* Schreber, population density, plant spacing, seed production

Fairey, N. A. et Lefkovitch, L. P. 1999. **Densité de peuplement et production semencière de la fétuque élevée (*Festuca arundinacea* Schreber). 1. Rendement et phénologie reproductive**. Can. J. Plant Sci. **79**: 535–541. Une étude au champ a été réalisée sur la fétuque élevée (*Festuca arundinacea* Schreber) pour établir les effets de la densité de peuplement initiale et de la disposition dans l'espace des plantes sur le développement phénologique et sur le rendement semencier. Sur des jeunes plants de semis repiqués à sept densités de peuplement (1,6, 3,1, 6,3, 12,5, 25, 50 et 100 plantes au m^2) et à trois largeurs d'interligne (20, 40 et 80 cm), nous avons observé pendant 3 ans (1991–1993) les caractères associés à la production semencière. Durant cette période, un écart de 15 j séparait les dates du début de l'épiaison entre la première et la troisième année de production. En plus, l'accroissement de la densité de peuplement retardait l'épiaison par 8, 6 et 2 j, respectivement, dans la première, la deuxième et la troisième année de production. La date de maturité des graines différait, selon l'année, du 21 juillet au 4 août, mais elle était généralement peu sensible à la densité de peuplement ou à la largeur d'écartement des lignes. Dans la première année de production, le rendement semencier augmentait en fonction de la densité de peuplement jusqu'à concurrence de 25 plantes par m^2, dans chaque largeur d'interligne, pour ensuite plafonner jusqu'à la densité d'au moins 50 plantes par m^2, sur les lignes écartées de 20 et de 40 cm, et enfin retomber légèrement à la densité de 100 plantes au m^2, dans les lignes écartées de 20 cm. Dans la seconde année de production, le rendement semencier était relativement insensible à la densité de peuplement, sauf qu'il marquait une baisse lorsque la densité initial etait inférieure à 6 plantes par m^2, dans les lignes écartées de 80 cm et qu'il atteignait son maximum quand elle était de 6 à 25 plantes par m^2 dans les lignes écartées de 40 cm. Dans la troisième année de production, le rendement semencier était considérablement inférieur à celui des deux années précédentes, mais l'allure de la réponse à la densité et à la largeur de l'interligne était la même que dans la seconde année. Le rendement semencier optimal de la fétuque peut être maintenu pour au moins 3 années consécutives à partir d'une densité de peuplement initiale de 20 à 100 plantes par m^2, sur lignes écartées de 20 à 60 cm. S'il faut privilégier le rendement semencier en première année de production, la densité initiale devrait alors être de 25 à 50 plantes par m^2, sur lignes écartées de 20 à 40 cm.

Mots clés: Fétuque élevée, *Festuca arundinacea* Schreber, densité de peuplement, écartement des plantes, production semencière

There has been a dramatic increase in the use of tall fescue (*Festuca arundinacea* Schreber) in the USA since the mid-1980s, and by the early 1990s it was grown on more than 14 million ha (Ball et al. 1993). Tall fescue is a deep-rooted bunchgrass that is grown for amenity purposes and for livestock feed. Within North America, most of the seed of this species is currently grown in Oregon and Missouri in the USA (Young 1997). With the continuing increase in demand for seed for amenity purposes, and the proliferation in the number of proprietary varieties, it is becoming increasingly difficult to provide adequate genetic isolation in the seed-growing zone of the Pacific Northwest USA. Thus, an opportunity exists for diversifying the grass seed industry in Canada, provided seed production systems can

Abbreviations: **BRS**, between-row spacing; **ISTA**, International Seed Testing Association; **WRS**, within-row spacing be developed that are economically competitive. Previous research has demonstrated the agronomic feasibility of growing tall fescue for seed in the Peace region of Canada (Fairey and Lefkovitch 1993) but information is required on management practices to optimize seed productivity in such northern environments.

The spatial arrangement of plants at seeding has been shown to have a strong influence on the yield and longevity of seed stands of tall fescue (Youngberg and Wheaton 1979). Based on earlier reports (Rampton 1949; Spencer 1950; Cowan 1956; Wheeler and Hill 1957; Rampton 1965), Youngberg and Wheaton (1979) indicated that the standard practices for seed production of tall fescue in the western USA involved establishment in 30- or 46-cm rows, post-harvest burning, heavy fertilizer application, and the annual use of herbicides; the combined use of these practices resulted in seed stands that remained productive for 8–10 yr. Wheeler and Hill (1957) indicated that in Oregon and Kentucky excellent first-year seed crops may be harvested from solid-seeded stands sown with 4.5–6.7 kg ha^{-1} of seed, but that better subsequent seed productivity may be realized by using only 2.2–3.4 kg ha^{-1} of seed at a row spacing of 76–122 cm.

Studies by Holliday (1963) indicated that except for cases in which there is extreme rectangularity in spatial arrangement of plants, the population density of plants has a greater effect on crop performance than spatial arrangement and, furthermore, that there is a point somewhere between extreme rectangularity and square planting at which the yield from the rectangular spacing is as good as that from the square spacing. The objective of this current study was to determine, for the northerly, short-season, environment of the Peace region, whether the yield of several, consecutive, seed crops of tall fescue could be optimized by manipulating the population density and spatial arrangement of plants at crop establishment.

MATERIALS AND METHODS

The study was conducted in the Peace 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). In late May 1990, at the time of year when field establishment of grass-seed crops normally occurs, a batch of seed of Mustang tall fescue was imbibed with water and placed in a germination cabinet set at 20°C. After the appearance of the coleoptile, individual seedlings were pricked-out, one per cell, into multi-celled root trainers containing a peat-vermiculite potting mixture. For subsequent seedling growth, the flats of root-trainers were placed in a greenhouse with a day/night temperature regime of 18–22°C/14–18°C and natural light. The seedlings were watered weekly with a complete nutrient solution and given additional water as required. In late July, after several weeks of hardening in a screen-house exposed to natural temperature and light, the individual plants, each with four to six tillers, were transplanted to the field. Prior to transplanting, 150 kg ha^{-1} each of 11-55-0 and 0-0-50-17S fertilizer were worked into the topsoil in accordance with soil fertility requirements. After transplanting, the

Within-row spacing (WRS, cm)

Between-row spacing (BRS, cm)

	20	40	80
20	25[z]	12.5	6.3
40	12.5	6.3	3.1
80	6.3	3.1	1.6

Block 1

	10	20	40
20	50[z]	25	12.5
40	25	12.5	6.3
80	12.5	6.3	3.1

Block 2

	5	10	20
20	100[z]	50	25
40	50	25	12.5
80	25	12.5	6.3

Block 3

[z] Highest density within the block

Fig. 1. The arrangement of the plant density treatment plots (plants m^{-2}) for the three blocks within each replicate, prior to randomization.

experimental site was irrigated to assist plant establishment, and any plants that lacked vigour or died before mid-September 1990 were replaced with reserve plants.

The field layout was based on a proposal made by Lin and Morse (1975). Each of four replicates was divided into three blocks of nine plots, and the plots within each block were arranged in three rows for between-row spacing treatments (BRS) and three columns for within-row spacing treatments (WRS). Seven density treatments were selected as fractions or multiples of 25 plants m^{-2}, the basic density selected for the design. The densities were 1.6, 3.1, 6.3, 12.5, 25, 50, and 100 plants m^{-2}, the specific values being selected to form a mathematical doubling series. These density treatments were incorporated into the experimental design (Fig. 1) to provide the greatest precision on the estimation of the treatment effects of the central density of the series, *viz*. 12.5 plants m^{-2}. The allocation of the experimental treatments to the blocks and plots within each of the four replicates was accomplished in three stages:

1. randomly assigning the highest density (25, 50 or 100 plants m^{-2}) to each of the three blocks within each replicate;
2. randomly assigning the three BRS treatments (20, 40, or 80 cm) to the rows within each block; and
3. randomly assigning the three appropriate WRS treatments for each block to the three columns within each

block (viz. 20, 40, or 80 cm when the highest density treatment for the block was 25 plants m^{-2}; 10, 20, or 40 cm when the highest density treatment for the block was 50 plants m^{-2}; and 5, 10, or 20 cm when the highest density treatment for the block was 100 plants m^{-2}).

To balance for possible directional effects of sunlight and wind, the four replicates were oriented in different directions in the field. The rows were oriented on the North–South axis in replicate 1, the Northeast–Southwest axis in replicate 2, the East–West axis in replicate 3, and the Northwest–Southeast axis in replicate 4.

The dimensions of the individual plots within each block of each replicate were determined according to the specific density treatments allocated to that block, and the requirement for a minimum of 12 adjacent, adequately bordered, plants in the centre of each plot on which observations were scheduled to be made. Thus, in blocks in which the highest density treatment was 25 plants m^{-2}, the plots consisted of eight rows of four plants and observations were made on the two central plants of the six inner rows. In blocks in which the highest density treatment was 50 plants m^{-2}, the plots consisted of five rows of six plants and observations were made on the four central plants of the three inner rows. In blocks in which the highest density treatment was 100 plants m^{-2}, the plots consisted of four rows of 12 plants and observations were made on the six central plants of the two inner rows. 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.

The study was maintained for 4 consecutive years of seed production, 1991 to 1994 inclusive. In the fall (late September or early October) before each seed production year, 200 kg ha^{-1} of 34-0-0 fertilizer (ammonium nitrate) was broadcast over the experimental site. Weeds were removed by hand as necessary. Observations were made in the first 3 production years on plant development and seed-yield characteristics; the trial site was retained for the fourth production year but no quantitative observations on crop performance were made. Plant survival was determined each spring as the number of live plants. Heading date was determined as the first day when the tips of at least three panicles were visible per plot, and was recorded as days after 1 May. The number of panicles per plot was counted soon after emergence was completed. Panicles were harvested by sickle from each plot on the first day of seed shattering, and the date was recorded as days after 1 July. Panicles from each plot were placed in a cotton bag and dried outdoors on a well-ventilated rack. After air-drying, the seed was threshed, weighed, cleaned, and re-weighed. The procedures of the International Seed Testing Association (1985) were used to determine the moisture content of the clean seed (one replicate of a 5-g subsample) and seed yield was adjusted to 12% moisture on a fresh-weight basis. The number of days between heading and harvest was calculated from the heading and harvest dates.

Table 1. Precipitation (mm) and pan evaporation (mm) at Beaverlodge

Month	Year 1990	1991	1992	1993	Long-term mean (1916–1981)
January	33	7	25	14	33
February	10	5	21	5	26
March	6	8	12	10	26
April	13	15	22	42	20
May	67	44	32	15	40
June	190	90	45	134	58
July	59	28	57	79	61
August	46	55	50	81	55
September	17	29	81	23	43
October	33	41	8	29	28
November	55	48	12	12	30
December	53	47	31	19	31
Annual total	580	417	397	464	453
Pan evaporation	942	944	869	846	813
Moisture deficit[z]	–362 (101%)	–527 (146%)	–472 (131%)	–382 (106%)	–360 (100%)

[z]Annual precipitation – evaporation (mm and percent long-term mean).

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) with an error distribution and link function appropriate for the variate (Lefkovitch 1993). For each variate, the deviance-standardized residuals were plotted against the fitted values to detect any unequal variability that could be attributable to the different plot sizes; no abnormal trends were evident. For each variate, except the date of heading, the tests of significance were made by referring the ratio of mean deviances to the *F*-distribution. The date-of-heading variate was analyzed using an inverse gauss distribution and a power link function, which necessitated referring the deviance to the chi-squared distribution for tests of significance. Probabilities of less than 5% were considered to be significant. Tabulated means are the natural averages of means predicted by the generalized linear model fitted to each response variate.

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 (Table 1). Plant survival was greater than 97% in the spring of each production year, and was unaffected by the treatments. In the spring of 1993, after two drier-than-normal growing seasons and a winter with lower-than-normal snow cover, some winter injury was observed. The tillers in the central core of many plants were killed, greatly reducing plant vigour. Seed yields were reduced in the third production year but, in the subsequent year, crop performance (assessed visually) was comparable to that observed in the first 2 production years.

The patterns of response to density and year for the date of heading and harvest (seed maturity) were similar for each

Table 2. A summary of the analysis of deviance of four variates

Source	Date of heading			Date of harvest			Days from heading to harvest			Clean seed yield (kg ha^{-1})		
	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability	df	Mean deviance	Probability
Plant density (PD)												
PD regression[z]	1	0.0093	<0.001***	1	0.1017	<0.001***	1	0.4315	<0.001***	1	11.7030	<0.001***
Deviations	5	0.0001	0.678NS	5	0.0075	0.034*	5	0.0035	0.262NS	5	0.9234	<0.001***
Between-row spacing (BRS)												
BRS regression[z]	1	0.0003	0.183NS	1	0.0371	<0.001***	1	0.0005	0.654NS	1	1.5900	<0.001***
Deviations	1	0.0001	0.369NS	1	0.0136	0.036*	1	0.0002	0.806NS	1	2.8918	<0.001***
Year (Y)	2	0.0673	<0.001***	2	5.5184	<0.001***	2	0.9887	<0.001***	2	70.0616	<0.001***
Y × PD regression	2	0.0037	<0.001***	2	0.0512	<0.001***	2	0.0482	<0.001***	2	3.1956	<0.001***
Y × BRS regression	2	0.0004	0.614NS	2	0.0099	0.040*	2	0.0072	0.070NS	2	0.5374	0.008**
Residual	298	0.0002		296	0.0030		296	0.0027		293	0.1804	

[z]On natural logarithm of factor.

Table 3. The effect of plant density on the date of heading of tall fescue in 3 consecutive production years

Population density (plants m^{-2})	Production year 1991	1992	1993
1.6	30 (1.0[z])	35 (1.3)	44 (1.8)
3.1	30 (0.6)	37 (0.8)	44 (1.1)
6.3	32 (0.5)	39 (0.6)	44 (0.8)
12.5	32 (0.4)	40 (0.6)	45 (0.7)
25.0	35 (0.5)	40 (0.7)	46 (0.8)
50.0	37 (0.8)	40 (0.9)	46 (1.1)
100.0	38 (1.5)	41 (1.6)	46 (1.9)

[z]Approximate standard error.

Table 4. The effect of plant density and row spacing on the date of harvest (days after 1 July) of tall fescue in 3 consecutive production years

Row spacing (cm)	Population density (plants m^{-2})	Production year 1991	1992	1993
20	6.3	25 (0.4[z])	22 (0.3)	34 (0.5)
	12.5	25 (0.3)	21 (0.3)	34 (0.5)
	25.0	24 (0.3)	21 (0.3)	34 (0.4)
	50.0	24 (0.4)	21 (0.3)	34 (0.5)
	100.0	25 (0.7)	22 (0.6)	34 (0.9)
40	3.1	26 (0.5)	22 (0.4)	34 (0.6)
	6.3	25 (0.3)	22 (0.3)	34 (0.4)
	12.5	25 (0.3)	22 (0.3)	34 (0.4)
	25.0	24 (0.3)	22 (0.3)	34 (0.4)
	50.0	24 (0.4)	21 (0.4)	34 (0.6)
80	1.6	27 (0.7)	27 (0.7)	34 (0.9)
	3.1	27 (0.4)	23 (0.4)	34 (0.5)
	6.3	26 (0.3)	23 (0.3)	35 (0.4)
	12.5	25 (0.3)	23 (0.3)	35 (0.5)
	25.0	25 (0.4)	22 (0.3)	35 (0.5)

[z]Approximate standard error.

BRS treatment (Table 2). Heading commenced on 30 May in 1991, 4 June in 1992, and 13 June in 1993. It was delayed as density increased from 1.6–100 plants m^{-2}, the delay being 8, 6, and 2 d, respectively, in 1991, 1992, and 1993 (Table 3). Seed maturity also differed among year (21 July to 4 August); it was generally unaffected by the treatments except for a delay of up to 2 d at densities less than 12.5 plants m^{-2} and a BRS of 40 or 80 cm in 1991, and a delay of 5 d at the lowest density (and widest row spacing) in 1992 (Table 4). The time between heading and harvest was decreased by 10 d as density increased in 1991 and 1992 but was unaffected by the initial crop density in 1993 (Table 5).

There was a pronounced effect of production year on the yield of clean seed, but it was modified by both density and row spacing (Tables 2 and 6). In 1991, seed yield increased with density up to 25 plants m^{-2} for each row spacing, then remained constant to 50 plants m^{-2} with both 20 and 40 cm rows, and then decreased slightly at 100 plants m^{-2} with 20 cm rows. In 1992, seed yield was relatively independent of plant density except that it decreased when the initial density was less than 6 plants m^{-2} with a row spacing of 80 cm, and tended to be greatest with the 40 cm row spacing at 6 to 25 plants m^{-2}. In 1993, seed yield was much lower than in

Table 5. The effect of plant density on the number of days between heading and harvest (seed maturity) of tall fescue in 3 consecutive production years

Population density (plants m^{-2})	Production year 1991	1992	1993
1.6	58 (1.4^z)	53 (1.3)	51 (1.3)
3.1	58 (0.9)	46 (0.7)	51 (0.7)
6.3	54 (0.6)	45 (0.5)	51 (0.5)
12.5	54 (0.5)	43 (0.4)	50 (0.5)
25.0	51 (0.5)	42 (0.5)	49 (0.5)
50.0	48 (0.7)	42 (0.6)	49 (0.7)
100.0	48 (1.2)	43 (1.1)	49 (1.2)

^{z}Approximate standard error.

Table 6. The effect of plant density and row spacing on the clean seed yield (kg ha^{-1} 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	1085 (100.8^z)	1126 (105.1)	272 (26.7)
	12.5	1427 (116.6)	1152 (94.6)	327 (27.0)
	25.0	1696 (128.9)	1181 (92.4)	289 (22.1)
	50.0	1819 (175.8)	998 (101.4)	257 (24.9)
	100.0	1334 (247.2)	1399 (224.7)	277 (44.5)
40	3.1	671 (72.2)	1221 (131.3)	181 (20.7)
	6.3	1088 (88.1)	1411 (114.3)	301 (24.9)
	12.5	1432 (103.0)	1443 (104.0)	360 (26.0)
	25.0	1702 (137.8)	1479 (120.7)	319 (25.9)
	50.0	1824 (196.1)	1250 (137.8)	283 (30.5)
80	1.6	328 (52.7)	780 (125.2)	63 (10.1)
	3.1	466 (45.1)	983 (95.0)	115 (11.5)
	6.3	756 (57.5)	1136 (86.3)	191 (14.7)
	12.5	995 (81.3)	1162 (95.0)	229 (18.9)
	25.0	1183 (109.9)	1191 (111.2)	202 (19.0)

^{z}Approximate standard error.

the previous 2 yr but the pattern of response to the density and row spacing treatments was similar to that in 1992 (Table 6).

For interpretive purposes, it is instructive to summarize the effect of the initial density at each row spacing on the cumulative yield of clean seed over the 3 consecutive production years (Fig. 2). At a BRS of 80 cm, the cumulative seed yield increased from 1171 to 2576 kg ha^{-1} as plant density increased from 1.6 to 25 plants m^{-2} but it was always considerably lower than that realized with an equivalent plant density on 20- or 40-cm rows. At a BRS of 40 cm or 20 cm, the cumulative seed yield increased as plant density increased up to a density of 25 plants m^{-2} and then remained constant at the higher densities of 50 and 100 plants m^{-2}. The response pattern observed for the 3-yr cumulative seed yield was essentially a reflection of that realized in 1991, the first production year.

DISCUSSION

The initial density and arrangement of tall fescue plants at establishment are important determinants of seed yield. These factors have a particularly dominant influence on seed yield in the first production year and the effects persist for several successive seed crops. The results confirm the importance of an adequate density of tillers prior to winter for seed yield of tall fescue (Robson 1968; Hare 1992, 1993, 1994). The pattern of response of seed yield to plant density was similar for each of the three row spacings in this study. Both the first-year and the three-year cumulative seed yields increased as plant density increased to about 25 plants m^{-2}, above which they remained essentially constant up to the highest density treatment of 100 plants m^{-2}. When compared at an equal plant density, the cumulative seed yield over the 3 production years was lowest for the 80-cm rows, considerably greater for the 20-cm rows, and greater still for the 40-cm rows. These results suggest that an adequate density of plants with a good spatial distribution is more important for maximizing seed yield of tall fescue over several production years than any specific row spacing. This result is similar to that from another Peace region study on the effect of row spacing on the seed yield of 11 grass species (but not including tall fescue) in which the narrowest spacing, 16 cm, was generally most beneficial (Darwent et al. 1987). Based on visual observations in the present study, a row spacing of 80 cm, regardless of the within-row plant spacing and density, or a density of less than 25 plants m^{-2}, regardless of the row spacing, resulted in an incomplete leaf canopy and inefficient light interception, and this precluded the attainment of greater seed yield. Such a wide row spacing was also found to be too great for optimizing seed yield of rhizomatous red fescue in Washington State, USA (Canode 1968) and in the Peace region (Fairey and Lefkovitch 1996a, b). Another study in Washington, however, reported no differential effect of row spacings of 18 to 107 cm on the cumulative seed yield of red fescue over three consecutive crops (Austensen and Peabody 1964). In the present study, a density of 25 plants m^{-2} in 40-cm rows produced the greatest cumulative seed yield over the 3 yr, with 1702, 1479, and 319 kg ha^{-1}, respectively, being produced in 1991, 1992, and 1993. Winter injury of tillers, exposed to abnormally dry fall conditions followed by a lower-than-normal accumulation of soil-insulating snow, reduced yield in the third year.

The results indicate that, for maximal seed yield over several consecutive crops, tall fescue stands should be established to provide an initial density of 20–100 plants m^{-2} on rows spaced 20–60 cm apart. If maximization of first-year seed yield, however, is more of a priority than cumulative productivity over several consecutive crops, then an initial density of 25–50 plants m^{-2} on rows spaced 20–40 cm apart is recommended. Such a range of plant densities and row spacings for maximizing seed yield are by no means extreme. In early studies of crop competition and plant spatial arrangement, moderate densities were shown to maximize seed yield (Donald 1963) and, in annual ryegrass, 90% of the maximum seed yield was achieved at plant densities covering a 37-fold range (Donald 1954). The present results agree with the western USA practice of growing tall fescue for seed in 30 or 46 cm rows to maintain productivity for several years (Youngberg and Wheaton 1979). The findings do not support the earlier recommendation, developed for

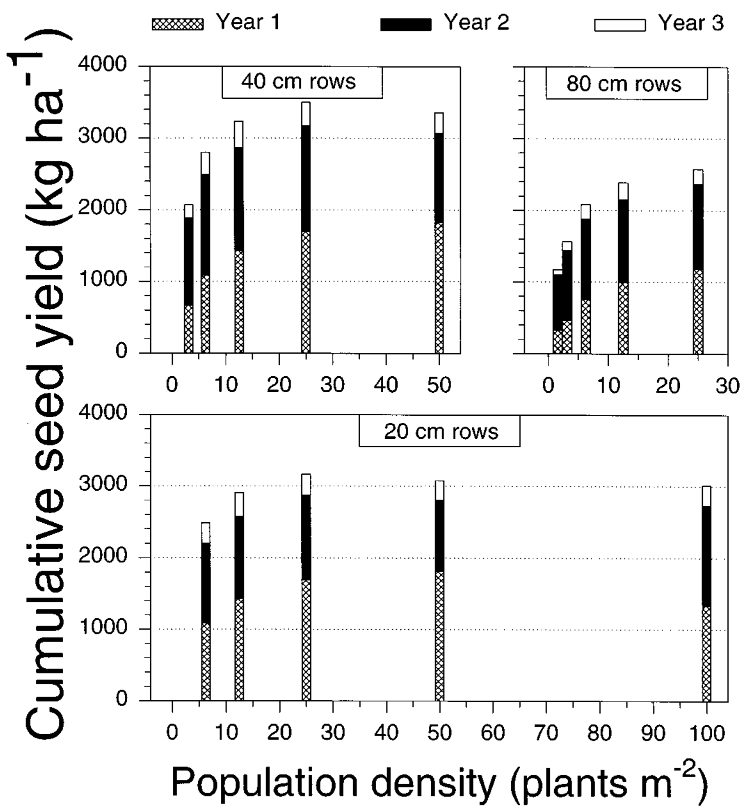

Fig. 2. The effect of plant population density and row spacing on the cumulative clean seed yield per hectare (at 12% moisture) of tall fescue for three consecutive production years.

Oregon and Kentucky (Wheeler and Hill 1957), for using 76- to 122-cm rows to optimize seed production of tall fescue for multiple crops.

There are many factors, including seed germinability, seedling vigour, soil conditions and seeding practices that determine the proportion of sown seed that survives to produce seed-bearing plants in commercial fields. Despite that, the present results support the use of a relatively low seeding rate for tall fescue seed production at northerly, short-season latitudes, and definitely no more than has been previously advocated in regions of lower latitude with longer growing seasons. To achieve the optimal, initial density of 20–100 plants m^{-2} found in the present study requires only 0.4–1.9 kg ha^{-1} seed, assuming a 1000-seed weight of 1.88 g (the mean in this study) and a 100% seedling establishment. Using these same assumptions, and after making allowances for some loss of seedlings during emergence in the field, the present results provide general support for the seeding rate of 2.2–3.4 kg ha^{-1} advocated by Wheeler and Hill (1957), which would result in a maximal density of 117–181 plants m^{-2}. More studies are required, however, to determine the actual seeding rate required to ensure that the plant density attained in commercial fields in the Peace region is within the optimal range.

CONCLUSIONS

1. Seed yield of tall fescue can be optimized for at least 3 consecutive years by manipulating plant density and row spacing.
2. An initial density of 20–100 plants m^{-2} on rows spaced 20–60 cm apart maximizes tall fescue seed yield for several consectutive years. Based on a 1000-seed weight of 1.88 g (the average observed for the cultivar used in this study) and 100% seedling establishment, the required seeding rate is 0.4–1.9 kg ha^{-1}.
3. An initial density of 25–50 plants m^{-2} on rows spaced 20–40 cm apart maximizes tall fescue seed yield in the first production year.
4. In the Peace region, low soil moisture in the fall combined with little subsequent snow cover, reduces spring vigour and subsequent seed production of tall fescue. The use of practices to enhance snow cover, particularly the selection of sheltered field sites, is recommended.

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