Effect of post-harvest management on seed production of creeping red fescue, tall fescue, and Kentucky bluegrass in the Peace River region of north-western Canada

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); and [2]51 Corkstown Road, Nepean, Ontario, Canada K2H 7V4.
Contribution No. BRS 2000-08, received 15 September 2000, accepted 18 May 2001.

Fairey, N. A. and Lefkovitch, L. P. 2001. **Effect of post-harvest management on seed production of creeping red fescue, tall fescue, and Kentucky bluegrass in the Peace River region of north-western Canada**. Can. J. Plant Sci. **81**: 693–701. A field study in the Peace River region of northwestern Canada evaluated five post-harvest management (PHM) treatments on the seed yield and quality of four grasses, viz. Boreal creeping red fescue (*Festuca rubra* L. var. *rubra*), Safari and Tomahawk tall fescue (*F. arundinacea* Schreber), and Midnight Kentucky bluegrass *(Poa pratensis* L.). The PHM treatments were: straw removal after seed harvest plus trimming prior to winter; a single propane burn; a double propane burn; power cultivation; and diuron applied in spring. The study was conducted for 3 consecutive harvest years. The grass × harvest year × PHM interaction was not statistically significant ($P \le 0.05$) for any of 10 characteristics, viz. panicle density, time of seed maturity, seed yield (per unit land area and per individual panicle), whole-plant yield, harvest index, seed dockage, 1000-seed weight, specific seed weight, and germination capacity. The grass × harvest year interaction was statistically significant ($P \le 0.05$) for each of the 10 characteristics, primarily because of the differential response of the bluegrass as compared to the fescue grasses. The grass × PHM interaction was statistically significant ($P \le 0.05$) for seed yield of individual panicles, harvest index, seed dockage and 1000-seed weight. The PHM × harvest year interaction was statistically significant ($P \le 0.05$) for specific seed weight only. The main effect of PHM was statistically significant ($P \le 0.05$) for specific seed weight and germination capacity only. The average annual seed yield of the two tall fescue cultivars (1002 and 1171 kg ha^{-1} for Safari and Tomahawk) was approximately twice that of Boreal creeping red fescue (554 kg ha^{-1}) and four times that of Midnight Kentucky bluegrass (284 kg ha^{-1}). At this northerly latitude (55°N), the effects of any PHM treatment on the seed productivity of these grasses may be limited by the short period of environmental conditions between seed harvest and the onset of winter that are conducive to vegetative and reproductive tiller development.

Key words: Post-harvest management, propane burning, mechanical and chemical rejuvenation, grass seed yield, grass seed quality

Fairey, N. A. et Lefkovitch, L. P. 2001. **Incidence de la gestion post-messianique sur la production de semences de fétuque rouge traçante, de fétuque élevée et de pâturin des prés dans la région de la rivière de la Paix, dans le nord-ouest du Canada**. Can. J. Plant Sci. **81**: 693–701. Dans le cadre d'une étude effectuée sur le terrain, dans la région de la rivière de la Paix du nord-ouest canadien, les chercheurs ont évalué les effets de cinq traitements post-messianiques (TPM) sur le rendement grainier et la qualité de quatre graminées, soit la fétuque rouge traçante Boréal (*Festuca rubra* L. var. *rubra*), les fétuques élevées Safari et Tomahawk (*F. arundinacea* Schreber) et le pâturin des prés Midnight (*Poa pratensis* L.). Les TPM étaient les suivants : enlèvement de la paille après récolte des semences et coupe avant l'hiver; brûlis simple au propane; double brûlis au propane; binage mécanique; application de diuron au printemps. L'étude a duré trois années consécutives. L'interaction graminée × année × TPM n'est statistiquement significative ($P \le 0,05$) pour aucun des dix paramètres examinés, à savoir la densité des panicules, le nombre de jours avant maturité des graines, le rendement grainier (par unité de surface et par panicule), le rendement en plants entiers, l'indice de moisson, la quantité de criblures, le poids de mille graines, la densité des graines et la capacité de germination. L'interaction graminée × année est statistiquement significative ($P \le 0,05$) pour chacun des paramètres, surtout à cause de la réaction différente du pâturin et des fétuques. L'interaction graminée × TPM est statistiquement significative ($P \le 0,05$) pour le rendement grainier des panicules, l'indice de moisson, la quantité de criblures et le poids de mille graines. L'interaction TPM × année n'est statistiquement significative ($P \le 0,05$) que pour la densité des graines. L'effet principal du TPM n'est statistiquement significatif ($P \le 0,05$) que pour la densité des graines et la capacité de germination. Le rendement grainier moyen par année des deux cultivars de fétuque élevée (1 002 et 1 171 kg par hectare pour Safari et Tomahawk) est approximativement le double de celui de la fétuque rouge traçante Boréal (554 kg par hectare) et le quadruple de celui du pâturin des prés Midnight (284 kg par hectare). À cette latitude (55° N), il se peut que le moindre TPM ait une incidence restreinte sur la quantité de graines produites par les graminées en raison de la brève période séparant la récolte du début de l'hiver propice au développement des talles végétatifs et reproductifs.

Mots clés: Traitement post-messianique, brûlis au propane, rajeunissement mécanique et chimique, rendement grainier des graminées, qualité des semences de graminées

Seed crops of creeping red fescue have traditionally been grown in the Peace River region of north-western Canada for at least 50 yr on as much as about 50 000 ha annually

Abbreviations: **CRF**, creeping red fescue; **KBG**, Kentucky bluegrass; **PHM**, Post-harvest management; **TF**, tall fescue

(Fairey 1997). Since the early 1990s, there has been a steady increase in the contract seed production of tall fescue to about 3000 ha of pedigreed crop by 1998 (Canadian Seed Growers' Association 1999). Seed production of Kentucky bluegrass has been contemplated in the Peace River region, but concerns about consistent yield and quality have inhibited any significant commercial development to date; this species has a propensity for developing silver top disease (*Fusarium poae*) and a high probability of contamination with indigenous fowl bluegrass (*Poa palustris*). There is significant importation of Kentucky bluegrass seed and the total production of pedigreed seed in Canada in 1998 was only 360 ha. Most of this production is located in southern Alberta and Manitoba (Canadian Seed Growers' Association 1999).

The post-harvest management of grass-seed stands has been studied extensively in the Pacific Northwest USA, Europe and New Zealand (Simon et al. 1997; Rowarth 1998; Young et al. 1998, 1999), but, to date, has received little attention in the Peace River region of northwestern Canada. In the Pacific Northwest USA, stands of creeping red fescue are harvested for seed for numerous consecutive years by the application of various post-harvest management treatments, such as field burning, mowing, intensive controlled grazing, and mechanical or chemical thinning (Canode 1980; Chilcote et al. 1980; Simon et al. 1997; Rowarth 1998; Young et al. 1998, 1999). In the Peace River region, Pringle et al. (1969) reported that fall grazing of creeping red fescue seed fields from seed harvest to soil freeze-up, at moderate stocking rates of 3.7 animal units ha^{-1}, supported a liveweight gain of steers in excess of 1 kg d^{-1}, but subsequent seed yield was reduced by 8%. They also found that heavier fall grazing reduced seed yield by 16%, that a short period of spring grazing reduced it by 35% without resulting in any liveweight gain, and that the removal of aftermath as hay improved seed yield slightly (particularly in the second and third harvest years). Unfortunately, it is seldom feasible to graze grass seed stands in the Peace River region because of the limited availability of livestock and the lack of adequate fences. Furthermore, the feasibility of conducting a satisfactory, uniform, open burn is generally inhibited by an insufficient quantity and/or an uneven distribution of dry crop residue. Open field burning has also become increasingly undesirable from an environmental health-and-safety standpoint.

For creeping red fescue, the principal grass seed crop of the Peace River region, a method of periodic stand rejuvenation has been developed to combat the build-up of stem eyespot disease (*Didymella festucae*) and maintain stand productivity over years (Elliott and Baenziger 1977; Fairey 1997). The rejuvenation process generally follows the harvest of 2 consecutive years of seed crops and involves plowing the stand in the fall, or in the subsequent spring, packing and levelling the land, and allowing the plants to regenerate from rhizome buds and volunteer seedlings. In this situation at least 1 yr without seed harvest occurs. In some instances, the land is sown to an annual cereal or canola crop, which severely limits the seed yield of the fescue in the subsequent year.

The objective of this study was to compare the effectiveness of a diverse set of post-harvest management treatments on the yield and quality of 3 consecutive years of seed crops of creeping red fescue, tall fescue and Kentucky bluegrass in the Peace River region of northwestern Canada, in order to identify strategies for enhancing and maintaining the seed productivity and quality of each species.

MATERIALS AND METHODS

The study was conducted in the Peace River region at the Beaverlodge Research Farm of Agriculture and Agri-Food Canada (55°12′N, 119°25′W) on a soil classified as a clay loam (Albright Dark Grey Solod). The experimental site had grown an oat crop in 1994. A pre-seeding spray application of 1.25 L ha^{-1} Roundup (356 g L^{-1} gyphosate acid equivalent) + 0.25 L ha^{-1} Agral 90 surfactant was made on 9 May 1995 to control emerging weeds. Subsequent to seeding the experiment, it was noted that there had been sprayer problems with this pre-seeding application. As the drilled grasses had not yet emerged, the experimental site was re-sprayed on 21 May 1995 with 2.5 L ha^{-1} Roundup (356 g L^{-1} gyphosate acid equivalent) + 0.25 L ha^{-1} Agral 90 surfactant.

The experiment consisted of the factorial combination of two experimental factors, four grasses and five post-harvest management (PHM) treatments, arranged in a randomized complete block design with three blocks. The grasses were Boreal creeping red fescue (*Festuca rubra* L. var. *rubra*), Safari and Tomahawk tall fescue (*F. arundinacea* Schreber), and Midnight Kentucky bluegrass *(Poa pratensis* L.). The five PHM treatments were: 1) The removal of all crop/straw residue at a height of 8 to 10 cm with a flail-type forage harvester immediately after seed harvest (Standard) and again, about mid-October just prior to winter, if regrowth was taller than 15 cm (Control); 2) Standard plus a single pass at 3 km h^{-1} with a propane burner (Rear's Manufacturing Company, Eugene, Oregon, USA, with a propane pressure of 207 kPa, and burner nozzles spaced 15 cm apart across the full 3-m width of the machine) (Single Burn); 3) Standard plus two passes at 3 km h^{-1} with the propane burner, the first pass being scheduled on the same day as the Single Burn treatment and the second 2–4 d later (Double Burn); 4) Standard plus 2.8 kg ha^{-1} Karmex DF herbicide (80% diuron) in 250 L ha^{-1} water sprayed in early spring the following year, after snow-melt but before greening-up of the grass (Diuron); 5) Standard plus mechanical stand conditioning with a power harrow immediately after the seed harvest and removal of crop residue (Power Harrow). The Power Harrow PHM treatment was applied using a 3-m-wide Amazone KG30 with a tine rotor speed of 145 min^{-1} and a working depth for the vertical tines of 3 to 5 cm. It was driven at a forward speed of 3 km h^{-1}. These settings were selected in order to clean out crop residue and volunteer and weed seedlings from around the plants, and to deter excessive creeping of the rhizomatous grasses (creeping red fescue and Kentucky bluegrass), while leaving the plants of the bunch-grasses (the two tall fescue cultivars) basically intact.

On 16 or 17 May 1995, the central 1.8 m of each 3-m wide plot was direct-seeded, over its entire 30-m length, to its designated grass using a 6-row Hege 1000 drill with

Acra-Plant double-disk openers spaced 30-cm apart. Each grass was sown at a density of 200 viable seeds m^{-2}. The actual seeding rates were 2.8, 5.5, 5.2, and 0.9 kg ha^{-1} for Boreal, Safari, Tomahawk, and Midnight, respectively. In October 1995, a flail-type forage harvester was used to cut and remove all vegetative growth above a height of 8–10 cm. The effects of the treatments on seed yield and quality of the four grasses were determined for 3 harvest years, 1996 to 1998.

With the exception of the Diuron PHM treatment, the PHM treatments were applied to the full area of each plot (3×30 m), immediately after the seed harvest in 1996 (14 to 19 August) and 1997 (8 to 14 August). The Diuron PHM treatment was applied in the subsequent spring of each year, specifically on 29 April 1997 and 16 April 1998.

Prior to seeding, on 11 May 1995, 165 kg ha^{-1} of monoammonium phosphate fertilizer (12-52-0) was broadcast over the experimental area to supply N for grass establishment and P for at least two seed crops. According to the preseeding soil analysis, K and S concentrations were in the optimal range but concentrations of boron and copper were marginally deficient. These micronutrient deficiencies were corrected on 24 May 1995, with a spray application of boron and copper, 0.9 kg ha^{-1} of each element. A broadcast application of 200 kg ha^{-1} of ammonium nitrate fertilizer (34-0-0) was made in October 1995, 1996 and 1997 to support the growth of each subsequent grass-seed crop. Based on annual soil analyses, the nutrient concentrations of P, K and S were supplemented by a broadcast application of 300 kg ha^{-1} of a NPKS blend (4-16-34-12) on 27 August 1997.

In the establishment year (1995), weeds were controlled by the application of 1.0 L ha^{-1} Buctril M (280 g L^{-1} bromoxynil + 280 g L^{-1} MCPA) on 30 June, and a tank mix of 0.61 L ha^{-1} Banvel (480 g L^{-1} dicamba) and 1.13 L ha^{-1} 2,4-D Amine 500 (470 g L^{-1} 2,4-D amine) on 17 July. In 1996, weeds were controlled by spraying a tank mix of 0.25 L ha^{-1} Banvel (480 g L^{-1} dicamba) and 0.9 L ha^{-1} 2,4-D Amine 500 (470 g L^{-1} 2,4-D amine) on 21 May 1996. In the subsequent two growing seasons, weeds were controlled with 600 mL ha^{-1} Target (275 g L^{-1} MCPA + 62.5 g L^{-1} mecoprop + 62.5 g L^{-1} dicamba) on 28 May 1997, and 740 mL ha^{-1} Lontrel (360 g L^{-1} clopyralid) + 1.24 L ha^{-1} MCPA (500 g L^{-1} MCPA amine 500) on 11 May 1998.

In order to conform to the specific requirements for optimum seed productivity of each grass, some additional cultural inputs were applied to each plot seeded to tall fescue or Kentucky bluegrass. An additional 100 kg ha^{-1} of ammonium nitrate fertilizer (34-0-0) was broadcast on each tall fescue plot immediately after the PHM treatments were applied in August 1996 and 1997, in accordance with its known annual requirement (Fairey and Lefkovitch 1998). Also, as Midnight Kentucky bluegrass is susceptible to powdery mildew (*Erysiphe graminis*), each plot seeded to this grass was sprayed with a prophylactic application of 500 mL ha^{-1} Tilt (250 g L^{-1} propiconazole); in each harvest year, applications were made in early May (to the early-spring vegetative growth), in early-to-mid June, and in late August (to plots with PHM treatments where there was active vegetative growth).

After panicle emergence of each grass in each of the 3 harvest years, a 1-m-long segment of the plants was cut at 10-cm height from the centre of the second row within each 6-row plot. The samples were stored at –20°C. Subsequently, the number of panicles in each sample was counted and the results were used for the determination of panicle density. The time of seed harvest was determined as the first day on which seed shattering was observed when panicles were tapped gently by hand. The number of days from 1 July to the day of harvest was used as the assessment of the time of seed maturity. Just prior to seed maturity, the incidence of blind panicles was rated visually (scale 1 to 5 where 5 is a high incidence). At seed maturity, the central 10 m of the two middle rows of each six-row plot was harvested at a height of 8 to 10 cm with a rice binder. The samples were placed in a cotton bag and air-dried on a storage rack outdoors to mature the seed. After maturation, the samples were placed in a forced-air drier at room temperature for several days to complete the drying process. The weight of the whole-plant samples was recorded prior to threshing. The samples were threshed and the weight of the seed was recorded before and after cleaning. Seed dockage was calculated as the loss in weight during cleaning as a proportion of uncleaned seed weight. The harvest index was the weight of cleaned seed as a proportion of whole-plant weight. A subsample of the cleaned seed was used for the determination of moisture content, and cleaned seed yield was corrected to 12% moisture (fresh-weight basis). The remainder of the cleaned seed was retained at room temperature for subsequent assessment of seed quality characteristics (germination, 1000-seed weight, and specific weight), using the procedures of the International Seed Testing Association (1985). The assessment of germination was based on 200 seeds per plot. Immediately after the seed harvest sample was removed from each plot, the unharvested plants in each plot were harvested and discarded, in preparation for the application of the PHM treatments.

Genstat 5 Release 4.1 was used for all statistical analyses (Lawes Agricultural Trust 1997) and each response variable was analysed using a generalized linear model and an analysis of deviance (McCullagh and Nelder 1989). The guidelines of Lefkovitch (1993) were used to determine the nature of the distribution used for the analysis of each response variable. Thus, whole-plant yield (per unit land area), panicle density, specific seed weight and thousand-seed weight were analysed using a gamma distribution and the logarithmic link function. The seed yield per panicle and the day of seed maturity were analysed using a gamma distribution and the reciprocal link function. The germination capacity (i.e., the number of seeds that germinated out of the 200 evaluated) and the harvest index and seed dockage variables (i.e., the proportion of a component to the whole) were analysed using a binomial distribution and the logit link function. Except for germination capacity, the tests of statistical significance of the variance components for each variable were made by referring the ratio of the mean deviances to the F-distribution; for germination capacity, the Chi-squared statistic was used. Probabilities of less than 5% were considered to be significant.

Table 1. The effects of the grass, the post-harvest management, and the harvest year, and their interactions, on 10 characteristics of seed yield and quality

	Whole-plant yield (kg ha^{-1})		Panicle density (n m^{-2})		Seed maturity (day 1 = 1 July)		Grass seed yield (kg ha^{-1})		Grass seed yield (mg panicle^{-1})		Harvest index (%)		Seed dockage (%)		Specific seed weight (kg hL^{-1})		Thousand-seed weight (g)		Germination capacity (%)	
Factor	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Grass																				
Midnight KBG	1610	59	1179	67.4	21	0.2	284	15.5	31.4	2.40	18.1	0.72	26.2	0.48	23.8	0.25	0.37	0.015	71.0	1.07
Boreal CRF	2520	117	909	57.1	23	0.2	554	36.0	59.4	4.01	20.1	0.54	29.2	0.43	19.8	0.20	1.21	0.045	89.2	0.68
Safari TF	3750	159	595	33.7	32	0.2	1002	55.1	172.7	11.26	24.9	0.47	23.4	0.21	28.2	0.28	2.07	0.077	77.7	0.89
Tomahawk TF	3600	147	868	48.5	31	0.2	1171	63.9	135.3	8.86	30.2	0.50	21.1	0.17	28.1	0.28	1.87	0.070	74.8	0.94
Significance	***		***		***		***		***		***		***		***		***		***	
Post-harvest management (PHM)																				
Control	2900	124	881	57.1	27	0.2	714	43.3	92.1	7.09	23.5	0.58	24.0	0.29	24.3	0.27	1.43	0.065	76.8	1.01
Single burn	3110	134	939	59.8	27	0.2	811	48.8	101.4	7.95	24.7	0.59	22.9	0.26	25.3	0.28	1.40	0.065	78.0	1.00
Double burn	2820	125	929	59.8	27	0.2	780	48.4	100.6	7.95	25.6	0.61	23.2	0.27	26.1	0.30	1.41	0.066	81.0	0.95
Diuron	2790	123	901	58.6	27	0.2	735	46.9	100.4	8.49	24.5	0.60	24.0	0.29	25.4	0.31	1.43	0.068	77.3	1.05
Power harrow	2750	119	788	50.1	27	0.2	775	45.7	112.0	8.36	25.1	0.61	25.0	0.31	25.0	0.28	1.39	0.065	79.1	0.99
Significance	NS		NS		NS		NS		NS		NS		NS		**		NS		*	
Harvest year (HY)																				
1996	5160	171	1023	51.3	33	0.2	1411	63.0	164.0	9.57	25.1	0.35	22.3	0.15	24.1	0.21	1.37	0.049	87.1	0.63
1997	1500	48	771	43.0	31	0.2	308	13.8	56.2	3.24	19.4	0.60	30.9	0.52	24.6	0.22	1.36	0.049	82.0	0.74
1998	1920	63	868	42.9	16	0.1	557	27.4	82.1	5.22	27.8	0.60	23.5	0.26	27.1	0.25	1.52	0.056	64.7	0.95
Significance	***		***		***		***		***		***		***		***		NS		***	
Interaction significance																				
Grass × PHM	NS		NS		NS		NS		**		***		**		NS		*		NS	
Grass × HY	***		***		***		***		***		***		***		***		*		***	
PHM × HY	NS		NS		NS		NS		NS		NS		NS		***		NS		NS	
Grass × PHM × HY	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS	

*, **, *** Statistically significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively; NS, not significant.

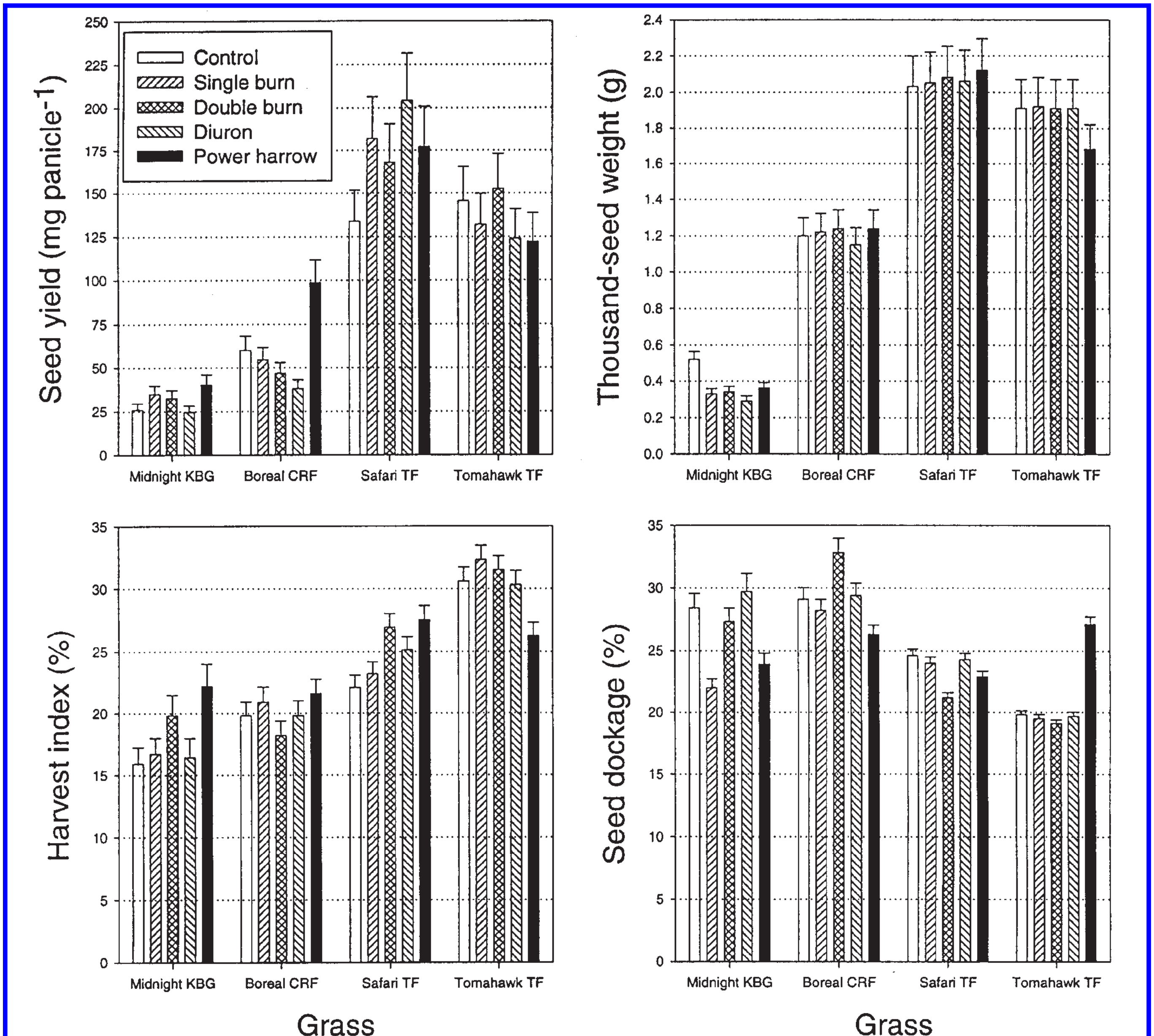

Fig. 1. The grass × PHM interaction for seed yield per panicle, harvest index, 1000-seed weight and seed dockage (vertical lines above the bars are SE).

RESULTS

The establishment year and the first 2 harvest years received more precipitation than normal and the third harvest year, 1998, was drier than normal. The total annual precipitation for 1995 to 1998, respectively, was 114, 119, 118, and 90% of the long-term mean of 456 mm. The precipitation received from 1 April to 30 September of 1995 to 1998, respectively, was 111, 132, 141, and 69% of the long-term mean of 287 mm.

The effects of the grass, PHM treatments, harvest year, and their interactions are summarized for 10 characteristics of seed yield and quality (Table 1). The grass × PHM × harvest year and the PHM × harvest year interactions were not statistically significant ($P \leq 0.05$) for any characteristic, with the exception of a PHM × harvest year interaction for specific seed weight. The grass × harvest year interaction was significant ($P \leq 0.05$) for each of the 10 characteristics and the grass × PHM interaction was significant ($P \leq 0.05$) for the seed yield of individual panicles, harvest index, seed dockage and 1000-seed weight. The main effect of PHM was only statistically significant ($P \leq 0.05$) for specific seed weight and germination capacity; the agronomic significance of the observed differences is not large as the ranges for the PHM treatment means were small, 24.3 to 26.1 kg hL^{-1} for specific seed weight and 76.8 to 81.0 % for germination capacity. Furthermore, for each of these characteristics, the Control PHM treatment had the lowest mean and the Double Burn PHM treatment had the highest.

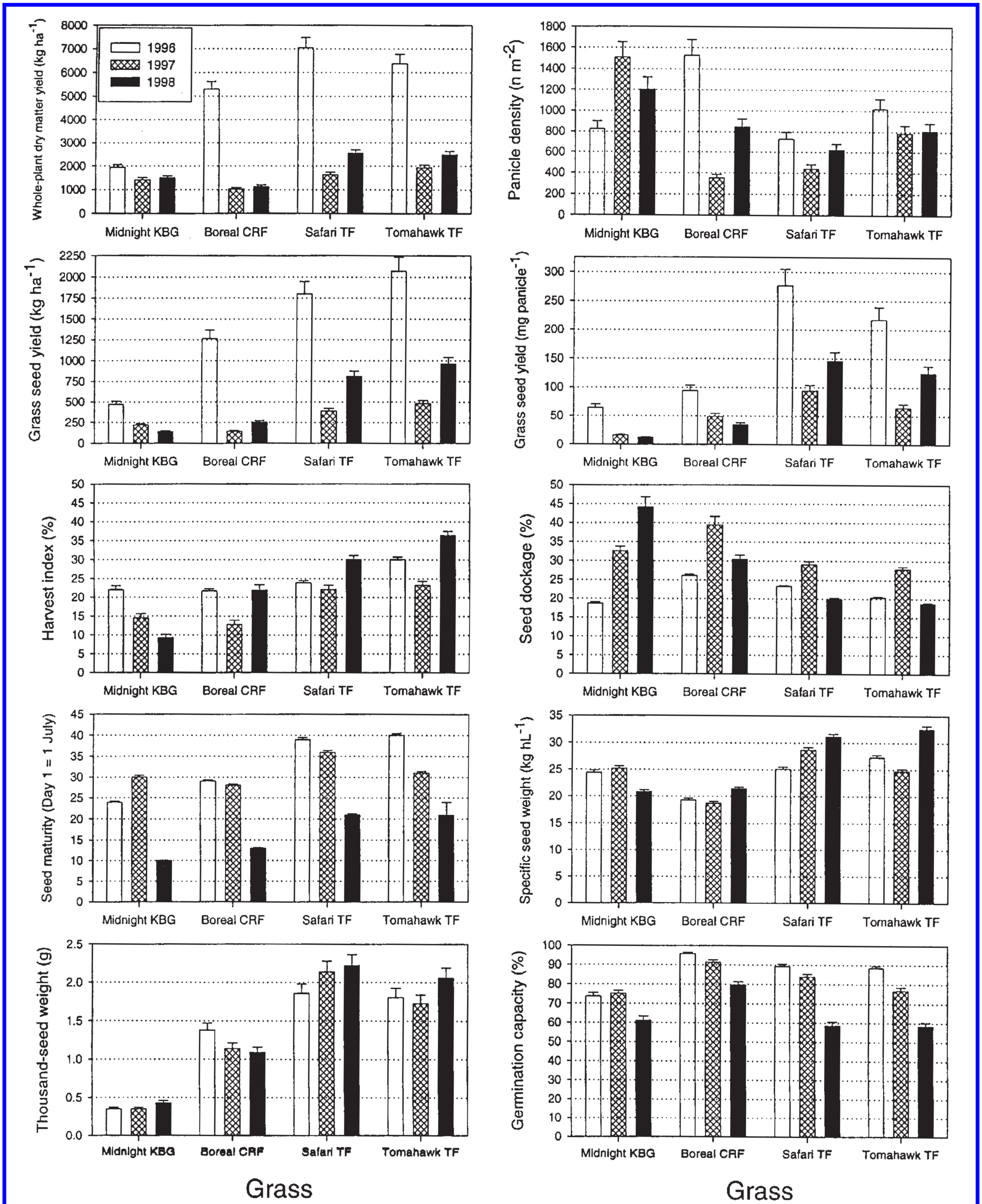

Fig. 2. The grass × harvest year interaction for 10 characteristics of seed yield and quality (vertical lines above the bars are SE).

For the characteristics for which the grass × PHM interaction was statistically significant ($P \leq 0.05$), the specific nature of the interaction is shown (Fig. 1). There was a particularly large increase in seed yield per panicle with the Power Harrow PHM treatment for Boreal CRF, a relatively high 1000-seed weight for Midnight KBG with the Control PHM treatment, and a relatively low harvest index and a high seed dockage for Tomahawk TF with the Power Harrow PHM treatment.

The specific nature of the grass × harvest year interaction is shown for each of the 10 characteristics of seed production (Fig. 2). For the two TF cultivars, whole-plant yield was highest in 1996, lowest in 1997, and intermediate in 1998. For Boreal CRF, whole-plant yields in 1997 and 1998 were similar but less than 20% of the yield in 1996. Midnight KBG was considerably less productive than the other three grasses in 1996. The whole-plant yields of Midnight KBG in 1997 and 1998 were similar and approximately two-thirds of that in 1996. Midnight KBG was intermediate in whole-plant yield between Boreal CRF and the two tall fescue cultivars in 1997 and 1998.

The panicle density was lowest in the first harvest year (1996) for Midnight KBG, but was highest in that year for the three fescue grasses (Fig. 2). The patterns of response over harvest years for grass seed yield per unit land area and grass seed yield per panicle were similar for each grass. The seed yield of Midnight KBG decreased progressively with each subsequent harvest year whereas the seed yield of the three fescue grasses was much greater in the first harvest year than in either of the subsequent 2 yr. Also, except for the seed yield per panicle of Boreal CRF, seed yield of the fescue grasses in the third harvest year was intermediate between that of the first and second harvest years (Fig. 2).

The harvest index of Midnight KBG decreased progressively over harvest years whereas that of the three fescue grasses was lowest in the second and highest in the third harvest year (Fig. 2). Seed dockage increased progressively over the 3 harvest years for Midnight KBG, but was highest in the second harvest year for the other three grasses (Fig. 2).

With the exception of Midnight KBG, seed maturity occurred slightly earlier in the second harvest year than in the first but considerably earlier in the third harvest year. In the first 2 harvest years, the relative time of seed maturity of Midnight KBG was the reverse of that of three fescue grasses (Fig. 2). Specific seed weight was highest in the third harvest year for the three fescue grasses but was lowest in that year for Midnight KBG (Fig. 2). From an agronomic viewpoint, the differences among harvest years in 1000-seed weight for each grass were relatively small but, with the exception of Boreal CRF, the weight was greatest in the third harvest year. The 1000-seed weight for Boreal CRF was higher in the first harvest year than in the subsequent two (Fig. 2). Also, with the exception of Midnight KBG, germination capacity decreased progressively over harvest years, and was particularly low in the third year. The germination capacity for Midnight KBG was similar for the first 2 production years and then decreased in the third year (Fig. 2).

DISCUSSION

The five PHM treatments resulted in distinct differences in the physical appearance of the grass stands, particularly during late summer and early fall. Despite these physical differences, the productivity and quality of the subsequent seed crops of each grass did not differ greatly for the five PHM treatments. Relative to the Control PHM treatment, specific seed weight and germination capacity were increased by each of the other four PHM treatments, particularly so by the Double Burn PHM treatment for specific seed weight and by the Double Burn and Power Harrow PHM treatments for germination capacity.

There were a few notable species-specific responses to particular PHM treatments. Firstly, the Power Harrow PHM treatment increased the seed yield of individual panicles of Boreal CRF to 99 mg panicle^{-1}, compared to 60 mg for the Control and 38 to 54 mg for the other three PHM treatments. The Power Harrow PHM treatment, however, resulted in the lowest density of panicles with Boreal CRF, and seed yield per unit land area was not significantly better than that of the other four PHM treatments (Fig. 1). Possibly, the Power Harrow PHM treatment was too aggressive in suppressing the growth of new tillers of Boreal CRF in the fall, or the time between harvest and the cessation of growth for winter was too short for the new tillers to develop adequately and become receptive to floral induction, a process that occurs in this grass in early November (Elliott 1966). Secondly, the Control PHM treatment produced seed of Midnight KBG that had a very high 1000-seed weight, 0.52 g versus 0.29 to 0.36 g for the other four PHM treatments (Fig. 1). Thirdly, compared to the other PHM treatments, the Power Harrow treatment resulted in a low harvest index, a high seed dockage, and a low 1000-seed weight for Tomahawk TF (Fig. 1). There is, however, no obvious explanation for these effects on the quality of the harvested seed but presumably they are related to competition for assimilates among the various reproductive structures (i.e., the glumes, lemmas, paleas, ovules, etc.) within the panicles of each of these grasses.

The lack of any major differential responses of seed yield and quality to the diverse set of PHM treatments contrasts considerably to those observed with grass seed crops grown in regions of the world where the growing season is longer and less harsh (Canode 1980; Chilcote et al. 1980; Simon et al. 1997; Rowarth 1998; Young et al. 1998, 1999). In the Peace River region, the growing season is characterised by a frost-free period of only 104 d (80-yr range of 48 to 140 d) and, using a 5°C base temperature, the average annual accumulation of growing-degree days is only 1306 (80-yr range of 1053 to 1595) of which less than 80 are received between 1 October and 31 March (Mills and Kowalchuk 1996).

In this perennial crop study, the harvest year represents the combined effects of the prevailing environmental conditions and the age of the stand. All 10 growth and seed production characteristics of the four grasses were modified by the harvest year. In general, the response pattern over years for Midnight KBG was different from that of the three fescue grasses. Furthermore, the whole-plant and seed yields of Midnight KBG were probably limited by its failure to colonise all the land area between the 30-cm-wide rows during the growth of the first seed crop. In regions with more favourable growing conditions, such as Washington State, USA, KBG produces more seed on 30 or 60 cm rows than on 90 cm rows but the yield difference is only apparent in the first 2 harvest years (Canode 1968). If KBG was to be grown commercially in the Peace River region, its initial seed productivity might be maximized by a broadcast-type establishment or a row spacing narrower than the 30 cm used for this trial, so that a more complete crop canopy is developed prior to the early spring of the first seed year. In the second and third harvest years, the panicle density of Midnight KBG was greater but seed yield per panicle was lower than that of the three fescue grasses, and its seed productivity decreased with each subsequent harvest year. An increasing incidence of blind panicles (silver top disease) was observed over the 3 harvest years, and the relative incidence among the grasses was Midnight KBG > Boreal CRF > Safari and Tomahawk TF. The variability was, however, too high to detect differences in incidence among the five PHM treatments for any of the four grasses. The cause of silver top disease is not clearly understood but involves the combined effects of thrips, mites and *Fusarium poae* (Hardison 1957; Couch 1973).

Averaged over the PHM treatments and the 3 harvest years, the seed productivity of the two TF cultivars was approximately double that of Boreal CRF, 1002 and 1171 versus 554 kg ha^{-1}, and four times that of Midnight KBG (284 kg ha^{-1}). The superior seed yield of tall fescue is in agreement with the comparative yields observed from adjacent but identical, plant-spacing trials conducted at the study site with creeping red fescue (Fairey and Lefkovitch 1996) and tall fescue (Fairey and Lefkovitch 1999). Based on this relative productivity, the contract production of seed of pedigreed tall fescue has expanded in Canada from zero about a decade ago to more than 3000 ha (Canadian Seed Growers' Association 1999). To date, most of this production has been in the Peace River region, but some production is now occurring in southern Alberta and Manitoba.

It may not be feasible to produce and sustain seed yields of KBG in the Peace River region that are economically competitive, over successive years, by manipulating crop management subsequent to the first seed crop. With the use of PHM treatments similar to the burning treatments in this study, such production is achievable in the Pacific Northwest USA (Canode 1980; Chilcote et al. 1980; Youngberg 1980) and in western Europe (Donner and Borm 1997). Simon et al. (1997) generalised that the burning of perennial grasses is only an advantage over other post-harvest practices in regions where there are dry conditions in summer and autumn. However, in recent studies with CRF, TF, Chewings fescue and perennial ryegrass (*Lolium perenne*) in the Pacific Northwest USA where, until recently, burning has been a common practice, mechanical removal of post-harvest residue was found to be equivalent to open burning for maintaining seed yield and quality, except with CRF and specific cultivars of TF and perennial ryegrass (Young et al. 1998, 1999). Although relatively dry conditions frequently prevail during the summers and autumns in the Peace River region, seed yields of the four grasses included in this study were not increased by the burning or by the other PHM treatments. At such a northerly latitude (55°N), the effects of any post-harvest crop management on the seed productivity of perennial grasses may be limited by the short period of environmental conditions between seed harvest and the onset of winter that are conducive to vegetative and reproductive tiller development.

CONCLUSIONS

1. Over 3 consecutive harvest years, the seed yield and quality of Midnight KBG, Boreal CRF, and Safari and Tomahawk TF were only marginally influenced by a diverse set of post-harvest management treatments (single and double propane burning, chemical and mechanical tiller suppression, and the removal of all harvest residue plus pre-winter trimming to about 10 cm).
2. The effect of the harvest year on seed yield and quality characteristics differed among the four grasses, primarily because of the differential responses of the bluegrass as compared to the fescue grasses.
3. Seed yield of Midnight KBG was limited in the first harvest year by its inability to colonise the land area between the 30-cm-wide rows and produce a high density of panicles. In the subsequent 2 harvest years, despite a higher density of panicles than the other three grasses, its seed yield per panicle and per unit land area were lower than that of the other three grasses.
4. The mechanical thinning of Boreal CRF increased the seed yield of individual panicles (to 165% of the control) but decreased their density such that seed yield per unit land area was not increased.
5. Averaged over 3 consecutive harvest years and five PHM treatments, the annual seed yield of the two TF cultivars was approximately twice that of Boreal CRF and four times that of Midnight KBG (viz. 1002 and 1171 kg ha^{-1} for Safari and Tomahawk TF, 554 kg ha^{-1} for Boreal CRF, and 284 kg ha^{-1} for Midnight KBG).

ACKNOWLEDGEMENTS

The technical assistance of Lois Connelly, Tom Cramer, Marlene Probst, and Lia Scheunhage is gratefully acknowledged, as is the financial support received from Turf-Seed Inc., Hubbard, Oregon, USA, for the first two years of this study.

Canadian Seed Growers' Association. 1999. 1998/99 Annual Report. Canadian Seed Growers' Association, Ottawa, ON. 74 pp.

Canode, C. L. 1968. Influence of row spacing and nitrogen on grass seed production. Agron. J. **60**: 263–267.

Canode, C. L. 1980. Grass-seed production in the Intermountain Pacific North-west USA. Pages 189–201, Chapter 13 *in* P. D. Hebblethwaite, ed. Seed production. Butterworths, London, UK.

Chilcote, D. O., Youngberg, H. W., Stanwood, P. C. and Kim, S. 1980. Post-harvest residue burning effects on perennial grass development and seed yield. Pages 91–103, Chapter 7 *in* P. D. Hebblethwaite, ed. Seed production. Butterworths, London, UK.

Couch, H.B. 1973. Silver top. Pages 139–142 *in* Diseases of turfgrasses. 2nd ed. Robert E. Krieger Publishing Co., Inc., New York, NY.

Donner, D. A. and Borm, G. E. L. 1997. *Poa pratensis* L. (Smooth-stalked meadowgrass/Kentucky bluegrass) in The Netherlands. Pages 329–338 *in* D. T. Fairey and J. G. Hampton, eds. Forage seed production. Volume 1: Temperate species. CAB International, Oxford, UK.

Elliott, C. R. 1966. Floral induction and initiation in three perennial grasses. Ph.D. thesis, University of Saskatchewan, Saskatoon, SK. 90 pp. Diss. Abstr. **27**(6): 1686-B.

Elliott, C. R. and Baenziger, H. 1977. Creeping red fescue. Revised ed. Agriculture Canada, Ottawa, ON. Publ. 1122. 19 pp.

Fairey, N. A. 1997. *Festuca rubra* L. (creeping red fescue) in Canada. Pages 297–310 *in* D. T. Fairey and J. G. Hampton, eds. Forage seed production. Volume 1: Temperate species. CAB International, Oxford, UK.

Fairey, N. A. and Lefkovitch, L. P. 1996. Crop density and seed production of creeping red fescue (*Festuca rubra* L. var. *rubra*). 1. Yield and plant development. Can. J. Plant Sci. **76**: 291–298.

Fairey, N. A. and Lefkovitch, L. P. 1998. Effects of method, rate and time of application of nitrogen fertilizer on seed production of tall fescue. Can. J. Plant Sci. **78**: 453–458.

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.

Hardison, J. R. 1957. Disease problems in forage seed production and distribution. Pages 89–108 *in* W. A. Wheeler and D. D. Hill, eds. Grassland seeds. D. Van Nostrand Company, Inc., Princeton, NJ.

International Seed Testing Association. 1985. International rules for seed testing: Rules 1985. Seed Sci. Technol. **13**: 299–355.

Lawes Agricultural Trust 1997. Genstat 5 Release 4.1 Command Language Manual. Genstat 5 Committee, Statistics Dept., IARC-Rothamsted, Harpenden, Hertfordshire, AL5 2JQ, UK. Numerical Algorithms Group Ltd., Oxford, UK. 384 pp.

Lefkovitch, L. P. 1993. Some fundamental concepts in planning and analysing field experiments. J. Appl. Seed Prod. (Suppl.) **11**: 26–39.

McCullagh, P. and Nelder, J. A. 1989. Generalized linear models. 2nd ed. Chapman and Hall, London, UK, Section 9.2.4.

Mills, P. and Kowalchuk. M. 1996. Beaverlodge meteorological station 1995 weather observations with 80-year long-term averages. Northern Agriculture Research Centre, Agriculture & Agri-Food Canada, Publication NRG 96-02. 12 pp.

Pringle, W. L., Elliott, C. R. and Dobb, J. L. 1969. Response of creeping red fescue seed fields to aftermath grazing by beef cattle. J. Br. Grassl. Soc. **24**: 59–64.

Rowarth, J. (ed.) 1998. Practical herbage seedcrop management. Lincoln University Press, Canterbury, NZ. 243 pp.

Simon, U., Hare, M. D., Kjaersgaard, B., Clifford, P. T. P., Hampton, J. G. and Hill, M. J. 1997. Harvest and postharvest management of forage seed crops. Pages 181–217 *in* D. T. Fairey and J. G. Hampton, eds. Forage seed production. Volume 1: Temperate species. CAB International, Oxford, UK.

Young, W. C., III., Gingrich, G. A., Silberstein, T. B. and Quebbeman, B. M. 1998. Post-harvest management of creeping red and Chewings fescue seed crops. Agron. J. **90**: 69–73.

Young, W. C., III., Mellbye, M. E. and Silberstein, T. B. 1999. Residue management of perennial ryegrass and tall fescue seed crops. Agron. J. **91**: 671–675.

Youngberg, H. 1980. Techniques of seed production in Oregon. Pages 203–213, Chapter 14 *in* P. D. Hebblethwaite, ed. Seed production. Butterworths, London, UK.

This article has been cited by:

1. Douglas J.Cattani, Sean R.Asselin. 2018. Extending the growing season: forage seed production and perennial grains. *Canadian Journal of Plant Science* **98**:2, 235-246. [Abstract] [Full Text] [PDF] [PDF Plus]
2. Dr. Doug Cattani, Mr. Sean Robert Asselin. Extending the Growing Season: Forage Seed Production and Perennial Grains. *Canadian Journal of Plant Science* **0**:ja. . [Abstract] [PDF] [PDF Plus]