An assessment of variation in foothills rough fescue [*Festuca campestris* (Rydb.)] in southern Alberta

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May, K. W., Willms, W. D., Mengli, Z. and Lysyk, T. J. 2003. **An assessment of variation in foothills rough fescue [*Festuca campestris* (Rydb.)] in southern Alberta**. Can. J. Plant Sci. **83**: 541–550. The genetic diversity of native plants is thought to be an important consideration in the selection of appropriate material for reclamation. Field trials were conducted in southern Alberta to determine the genetic variability, expressed through phenotypic and performance attributes, of several populations of foothills rough fescue [*Festuca campestris* (Rydb.)] found in southern Alberta and south-central British Columbia. The objectives of this study were to determine the extent of genetic variability among plants of foothills rough fescue. Sixty-four plants from four populations were sampled in 1992, propagated vegetatively to produce clones for replicated trials and planted in four locations in 1993. Eleven plant characteristics, including phenotypic and performance variables, were observed from 1994 to 1997. Since the plants were grown in common environments, variations among them were assumed to be caused by genetic differences. All variables were affected ($P < 0.05$) by collection site and, with a few exceptions, test location, year and their two and three-way interactions. The most important factors specific to our objectives were collection site and its interactions with test location and year. The rough fescue plants expressed differences ($P < 0.05$) among populations for all selected traits but displayed considerable overlap in the range of values for all variables both within and among test sites. Therefore, while the populations may be different, individuals within populations have common attributes that suggest sufficient genetic variability to allow successful establishment over a greater range of environmental variability than present at their origins. Results from a secondary test suggest that selection pressure, induced by grazing, resulted in genotypes that were more winter-hardy. However, this observation needs further validation with a more robust test.

Keywords: Foothills rough fescue, genetic diversity, southern Alberta

May, K. W., Willms, W. D., Mengli, Z. et Lysyk, T. J. 2003. **Variation de la population de fétuque scabre [*Festuca campestris* (Rydb.)] dans les contreforts du sud de l'Alberta**. Can. J. Plant Sci. **83**: 541–550. La diversité génétique des plantes indigènes est un facteur important à considérer, croit-on, lors de la sélection du matériel végétal utilisé pour bonifier les terres. Les auteurs ont effectué des essais au champ dans le sud de l'Alberta en vue de déterminer la variabilité génétique de plusieurs peuplements de fétuque scabre [*Festuca campestris* (Rydb.)] du sud de l'Alberta et du centre-sud de la Colombie-Britannique, d'après le phénotype et les paramètres du rendement,. L'étude devait établir l'étendue de cette variabilité chez les plants prélevés dans les contreforts. Les auteurs ont recueilli 64 plants de quatre populations en 1992, les ont multipliés par voie végétative afin d'obtenir des clones pour les essais puis ont planté ces derniers à quatre endroits différents en 1993. De 1994 à 1997, ils ont observé onze caractères, y compris des variables du phénotype et du rendement. Les plantes poussant dans des milieux courants, les auteurs ont assumé que les variations résultaient de différences dans le génotype. Toutes les variables sont affectées ($P < 0,05$) par le lieu du prélèvement et, à quelques exceptions près, par l'endroit du test, par l'année et par les interactions à deux et à trois voies de ces paramètres. Les facteurs les plus importants dans le cadre des objectifs poursuivis sont le site du prélèvement et ses interactions avec le lieu de l'essai et l'année. Les plants de fétuque scabre présentent en effet des variations ($P < 0,05$) d'une population à l'autre pour tous les caractères retenus entre les différents sites expérimentaux et au même site. Par conséquent, même s'il s'agit de peuplements différents, les individus qui constituent le peuplement ont des attributs communs, ce qui laisse croire à une variabilité génétique suffisante pour une bonne implantation dans une plus grande variété d'environnements que c'est actuellement le cas. Les résultats d'un essai secondaire donnent à penser que la pression sélective causée par la paissance procure un avantage aux génotypes plus rustiques. Néanmoins, il conviendrait de valider cette observation par des essais plus rigoureux.

Mots clés: Fétuque scabre, diversité génétique, sud de l'Alberta

The genetic diversity of native plants has become an important consideration in the selection of appropriate material for reclamation (Native Plant Working Group 2000; Larson et al. 2000) because of the desire to use adapted genotypes and to meet the requirements for genetic purity within the context of native vs. introduced material. Consequently, the recommendation is to keep the source of native plants as close to the planting site as possible (Native Plant Working Group 2000). This recommendation is a precaution against using inappropriate genotypes in the absence of data that might enable broadening the range of acceptability.

Foothills rough fescue [*Festuca campestris* (Rydb.)] is a highly desirable grass species in southern Alberta and British Columbia because of its ecological dominance in the Fescue Grassland communities. It is one of three species

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that comprise the rough fescue (*F. scabrella* Torrie) complex together with plains [*F. hallii* (Vassey) Piper] and northern (*F. altaica* Trinius) rough fescue (Aiken and Darbyshire 1990). Foothills rough fescue is an octaploid ($2n = 56$) while the other two are tetraploids ($2n = 28$).

The Fescue Grasslands represent a relatively small area dispersed over a distance of about 700 km in western Canada fragmented by the plains in Alberta and several mountain ranges in British Columbia. The soils are mostly Black Chernozemic, which are indicative of a cooler and more mesic climate than those of the Mixed Prairie to the east. The fragmentation and isolation of these grasslands contributes to the problem of providing an economically viable supply of genetically suitable seed of foothills rough fescue. Therefore, it would be desirable if seed harvested in one location were suitable for an expanded region. The objective of this study was to determine the genetic variability among plants of foothills rough fescue at four locations expressed through phenotypic and performance characteristics. Since grazing pressure may contribute to genetic selection, and therefore contribute to variability within a population, we also compared the plants that were taken from a heavily grazed paddock with those taken from a lightly grazed paddock.

MATERIALS AND METHODS

Tussocks of 64 plants of foothills rough fescue were collected from sites on the Milk River Ridge, in the foothills south of Calgary, in Cypress Hills Provincial Park in Alberta and at Kamloops in British Columbia (11, 22, 12 and 14 plants, respectively) in 1992. The Milk River collection came from five sites in the vicinity of the McIntyre Ranch and Del Bonita; the Foothills collection came from eight sites located east of the Waterton Park boundary, near Pincher Creek, and the Porcupine Hills west of Claresholm and Stavely; the Cypress Hills collection came from four sites near Reesor Lake and about 10 km further west; the Kamloops collection originated from four sites north of Kamloops in the vicinity of Goose Lake and Kootenay.

In addition to the 22 plants sampled from the Foothills population, five others were sampled from an area that had been subject to heavy grazing pressure, which removed about 80% of standing crop (Willms 1988), and were in close proximity to four plants sampled from a lightly grazed paddock in that population. The five heavily grazed plants were also propagated and included in the field trials with the others, but were not included in the primary analyses of the four populations. Instead, they were compared in a separate statistical test with the collection of four lightly grazed plants in a preliminary examination of within-population variability produced by heavy grazing pressure. The heavily grazed plants could not be sampled randomly because they were inconspicuous by their small size and were more likely found near shrubs and identified by their inflorescence.

The tussocks were grown in a controlled environment chamber at Lethbridge Research Centre to verify that the sampled plants were foothills rather than plains rough fescue. The 64 tussocks were then vegetatively propagated to yield clones of 84 plants each for trials at four sites. The design at each site consisted of an 8 (blocks) × 8 (clones) lattice design with three replicates. Individual plots consisted of seven plants of the same clone spaced 50 cm apart in rows that were 1 m apart. Weeds were controlled mechanically and chemically as required. The four sites were at Lethbridge (49°43′, 112°43′; elevation 910 m), near Lundbreck (49°36′, 114°10′; elevation 1220 m), on the Milk River Ridge south of New Dayton (49°14′, 112°25′; elevation 1260 m), and west of Stavely (50°12′, 113°54′; elevation 1365 m) in May 1994. Supplemental irrigation was given only at the Lethbridge test site where sufficient water was applied to meet average crop demand.

Data were recorded from 1994 to1997 on phenotypic and performance variables in common environments at each site. Therefore, at each site, differences among clones were probably due to their genetic background and thus yielding an expression of genetic variability. The variables, estimated by row, were:

1. Spring plant height: Measurement of average height of the longest leaves taken from a representative plant in the row.
2. Anthesis: Recorded as the number of days from 1 January when anthers were observed on at least one head of half of the plants in a row. Missing values are a result of no heads in the row, small heads that were not observed, or late anthesis that was not recorded.
3. Resistance to lodging: Scored (1–9) on seed heads. Data were missing when seed heads were absent or had been broken off before the rating.
4. Percent of plants with one or more flowering tillers: The estimate was based on the number of live plants rather than on the number of plants originally transplanted.
5. Number of flowering tillers per plant: The number of flowering tillers on each plant were counted (an estimate was taken if the number was very high) and the average for each row was determined. A zero indicates that none of the plants in the row had any flowering tillers.
6. Height of flowering tillers: The average height of flowering tillers was measured for each plant and averaged for the row. Plants without any flowering tillers were excluded from the estimate. A blank indicates that none of the plants in the row had flowering tillers.
7. Crown circumference: Measured for each plant in the row, after annual growth was completed, and averaged for each row.
8. Fall leaf height: Determined as the average length of the longest leaves in each plant and averaged for the row.
9. Disease rating: Scored 1–5. During mid-summer the leaves of some plants became covered with reddish brown postules or lesions, which had a rust-like appearance although the condition was not verified. The affected plants regrew new leaves without symptoms later in the year.
10. Seed yield: The data presented are the total amount of seed obtained.
11. Winter kill: Scored 1–10. Each plant was rated and the average of each row was calculated.

Measurements in spring were made: At Lethbridge on 24 April 1995, 30 April 1996, and 24 April 1997; at Stavely on 17 May 1995, 27 May 1996, and 6 May 1997; at Lundbreck on 10 May 1995, 17 May 1996, and 9 May 1997; and at New Dayton on 11 May 1995 and 22 May 1997. All other measurements were made after growth ceased or the characteristics were expressed, for example, number of flowering tillers. Weather over the study period was measured at the nearest meteorological station for each test site.

Data Analyses

In order to simplify the statistical model, the structure of the lattice design of the plots was ignored and each replicate was treated as a randomized complete block with collection area represented by an unequal number of plants. The analyses were weighted by the number of clones. Each replicate was represented by 64 clones (representing four collection areas), of seven plants each, which were partitioned into eight randomly assigned groups. All plant data were analyzed as a split block design in a mixed model with test location (n = 4) and collection area (n = 4) as fixed effects, replication (blocks, n = 3) a random effect and year (n = 2 to 4) a fixed and repeated effect nested in test location.

The data were analyzed using mixed effects ANOVA (SAS Institute, Inc. 1999) using the Repeated Statement with the covariance structure specified in four different types: Compound Symmetry, Autoregressive, Heterogeneous Autoregressive and Heterogeneous Compound Symmetry. The fit statistics (Akaike's Information Criterion, Schwarz Bayesian Information Criterion, -2 Res Log Likelihood) from each model were compared and the best one selected to analyze the specific variable. Differences between paired means were compared using single degree of freedom contrasts. A second analysis was made of five and four clones propagated from plants collected from the heavily and lightly grazed paddocks, respectively, at Foothills to test the effects of grazing history on plant variables. The analyses were performed in the same manner as above but with collection site representing grazing history.

All variables were not determined consistently in each year or test location. Therefore, in order to balance the data in all univariate analyses, factors with missing levels were excluded.

The degree of differences among the populations was analyzed using discriminant analyses on the 1996 data using spring leaf length, fall leaf length, plant circumference, seed yield and average number of flowering tillers. This analysis calculates functions and classifies the plants according to their membership in the populations. Analyses were made for all data combined and for each individual test site.

RESULTS

The growing season (April to August, inclusive) precipitation was greater in 1995 and 1997 than in 1994 and 1996 (Table 1). Average monthly temperatures over the same period tended to be warmer in 1994 and 1996 than in 1995 and 1997. The Lethbridge site was the warmest and received the most water from precipitation and irrigation combined.

All measured variables were affected ($P < 0.05$) by collection site and, with a few exceptions, test location, year and their two and three-way interactions (Table 2). Test location and year were both expected to influence plant growth because they affect the environment and therefore the growing conditions. Furthermore, year could not be considered a random effect because measurements were made on the same plants that continued to grow over the study period. Leaf height and circumference increases with plant age in the first few years after planting while the number of flowering tillers also appears to be dependent on the age of plants. Consequently, the most important factors that address our objectives were collection site and its interactions with test location and year.

The influence of year was modified ($P < 0.05$) by collection site, but the order of its ranking within collection site tended to be consistent (Table 3). Growth parameters such as basal circumference and, to a lesser extent, leaf height and number of flowering tillers increased with plant age, but would be expected to be altered by weather. The effect of precipitation and growth was reflected in the height of flowering tillers, which tended to become taller with plant age but were shortest ($P < 0.05$) in 1996 when growing season precipitation was about 50% of that in 1995 and 1997. The longer spring leaves in 1996 could have resulted from measurements taken later in spring than in 1995 or 1997.

The Lethbridge test site tended to produce larger plants with a greater number of flowering tillers resulting in more ($P < 0.05$) seed yield and shortened ($P < 0.05$) time to anthesis (Table 4). The Stavely test site produced the shortest plants and the least seed yield ($P < 0.05$). However, collection site of the plants produced an inconsistent response of most variables among test sites that was present not only in magnitude but also in ranking (Table 4). The inconsistencies appeared to be influenced primarily by the Lethbridge test site where differences for some variables were reduced or eliminated. For example, plant circumference and days to anthesis were similar ($P > 0.05$) among collection sites at Lethbridge, whereas differences among collection sites existed ($P < 0.05$) in other test sites. However, while collection site also influenced the results of lodging, disease resistance, flowering tiller number and height and seed weight, their orders of ranking for means among collection sites were similar at each test site. For the latter variables, the Lethbridge test site appeared to magnify the differences among collection sites.

Heavily grazed plants had a greater ($P < 0.05$) number of flowering tillers per plant, were less ($P < 0.05$) susceptible to winter kill and had taller ($P < 0.05$) flowering tillers, which made them more ($P < 0.05$) susceptible to lodging (Tables 5 and 6). The effect of grazing on the number of flowering tillers per plant was modified by test site with the greatest response originating at Lethbridge. Over years, heavily grazed plants, in comparison with lightly grazed plants, tended to increase in circumference ($P < 0.05$), achieve a larger proportion of plants with flowering tillers ($P < 0.05$), increase the number of flowering tillers per plant ($P < 0.05$) and produce more seed ($P < 0.05$, Table 6).

Despite differences ($P < 0.05$) in the response variables of plants collected from different sites, the average range in values for each variable overlapped those of all other collection and test sites (Table 7). This suggests that phenotypic plasticity for traits observed is present among the sampled populations.

Table 1. Average monthly temperature and precipitation for test sites over the duration of the study

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Growing season[z]
							Average daily temperature (°C)						
Lethbridge													
1994	–7.1	–12.4	4.1	7.1	12.0	14.9	18.8	17.8	15.6	6.5	–1.6	–3.0	14.1
1995	–6.2	–2.7	–0.3	4.3	10.1	14.6	17.3	15.8	12.5	6.0	–1.1	–8.9	12.4
1996	–14.5	–3.7	–3.9	7.4	8.8	15.7	18.5	19.6	11.1	6.3	–7.1	–10.8	14.0
1997	–10.2	0.0	–0.7	3.9	11.3	16.0	18.2	18.6	15.9	7.7	0.0	–0.6	13.6
New Dayton													
1994[y]	–4.2	–11.2	3.4	5.1	10.6	13.7	17.5	16.7	14.5	5.2	–2.3	–3.5	12.7
1995[y]	–3.6	–3.6	–1.1	3.6	8.7	13.0	16.3	14.8	11.8	4.5	–0.5	–6.3	11.3
1996	–14.6	–5.6	–5.8	6.2	7.5	14.8	17.3	18.0	9.9	4.2	–9.0	–12.5	12.8
1997	–11.8	–2.1	–2.0	1.8	10.1	13.9	16.6	17.1	13.7	5.7	–2.1	–2.4	11.9
Stavely													
1994[x]	–6.3	–11.8	3.8	6.4	11.1	14.0	18.2	17.0	14.1	6.5	–1.9	–4.2	13.3
1995[x]	–7.2	–3.3	–1.4	3.7	9.2	14.1	16.1	15.0	11.9	5.6	–1.8	–9.8	11.6
1996[x]	–15.1	–4.1	–4.7	6.7	7.6	14.8	17.6	18.5	10.1	5.6	–8.3	–11.1	13.0
1997	–7.1	–0.3	–2.0	2.0	8.8	12.9	15.5	16.3	14.3	6.4	1.4	–0.1	11.1
							Precipitation (mm)						
Lethbridge													
1994	26.3	18.7	0.8	14.1	82.4	78.4	24.7	25.4	10.8	58.4	20.0	12.5	225
1995	3.8	3.2	9.6	38.4	105.8	137.8	65.5	43.5	18.8	32.5	14.9	19.8	391
1996	32.3	6.0	44.7	21.0	21.7	53.5	18.1	4.8	70.0	6.3	26.5	24.4	119
1997	16.7	9.2	33.1	14.2	95.7	100.6	31.8	32.8	7.6	10.0	4.6	9.9	275
New Dayton													
1994	1.2	0.4						24.6[y]	3.4[y]	27.4[y]	3.6[y]	3.4[y]	
1995	3.6	1.4	4.4	19.4	72.2	41.6	70.8	29.4	10.0	29.4	14.8	9.0	233
1996	5.8	2.8	18.2	18.3	20.9	54.8	22.2	0.4	79.1	6.6	7.7	22.8	117
1997	3.4	4.3	9.6	18.0	94.1	91.8	2.4	40.6	10.8	12.4	7.7	19.8	247
Stavely													
1994[x]	15.8	15.6	2.1	7.3	–	–	0	15.6	1.4	35.2	6.8	7.1	
1995[x]	9.3	0.2	5.5	14.4	91.7	82.6	75.2	39.4	62.6	29.6	5.6	11.4	303
1996[x]	1.5	5.7	36.4	32.2	76.2	40.2	3.8	2.8	55.5	18.9	16.5	18.3	155
1997	0	7.1	14.8	21.4	138.0	73.1	28.0	77.0	34.9	0.2	0.2	4.7	338

[z]Represents months from April to August, inclusive.
[y]Data from Cardston.
[x]Data from Claresholm.

Table 2. Probability of *F* values for collection site, test location, year of test and their interactions on the 11 characteristics observed on foothills rough fescue collections

Source of variation	Circ.[z] (cm)	Lodg.[y] (score)	Win. kill[x] (score)	Dis. res.[w] (score)	Leaf height: Spring[v] (cm)	Leaf height: Fall[u] (cm)	Flowering tillers: Plants[v] (%)	Flowering tillers: Height[v] (cm)	Flowering tillers: Numb.[v] (plant^{-1})	Anthes.[t] (d)	Seed wt.[t] (g)
						Probability					
Collection site (1)	0.021	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Test location (2)	<0.001	<0.001	0.048	0.128	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Year (3)	<0.001	<0.001		0.216	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 × 2	0.001	0.001	0.130	0.021	0.002	0.035	0.296	<0.001	<0.001	0.001	<0.001
1 × 3	<0.001	0.008		0.217	<0.001	<0.001	0.010	<0.001	<0.001	<0.001	<0.001
2 × 3	<0.001	<0.001		0.839	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001
1 × 2 × 3	0.122	0.489		0.159	0.054	0.680	0.009	<0.001	<0.001	0.142	<0.001

[z]Analyzed for 4 yr (1994 to 1997) and three locations (Stavely, Lundbreck and Lethbridge).
[y]Analyzed for 2 yr (1996 and 1997) and two locations (Stavely and Lundbreck).
[x] Analyzed for 1 yr (1996) and two locations (Stavely and Lundbreck).
[w]Analyzed for 2 yr (1995 and 1996) and two locations (Lundbreck and Lethbridge).
[v]Analyzed for 3 yr (1995 to 1997) and three locations (Stavely, Lundbreck and Lethbridge).
[u]Analyzed for 3 yr (1994 to 1996) and four locations (Stavely, New Dayton, Lundbreck and Lethbridge).
[t]Analyzed for 2 yr (1995 and 1996) and four locations (Stavely, New Dayton, Lundbreck and Lethbridge).

Discriminant analyses develops discriminant criterion based on a set of variables that is used to classify each observation into one of the groups according to the membership criterion. Consequently, results of the classification,

Table 3. Means of collection site, year of test and their interaction on plant variables of foothills rough fescue

					Leaf height		Flowering tillers				
Source	Circ. (cm)	Lodging[z] (score)	Win. kill[y] (score)	Dis. res.[x] (score)	Spring (cm)	Fall (cm)	Plants (%)	Height (cm)	No. (plant^{-1})	Anthes. (d)	Seed[w] (g)
Collection site (C)											
Milk River (MR)	33*b*	4.0*b*	3.2*b*	2.6*b*	21*c*	29*b*	86*b*	82*d*	28*d*	165*c*	10.8*b*
Foothills (FH)	32*a*	4.1*b*	3.6*c*	3.0*c*	20*b*	29*b*	77*a*	75*c*	13*a*	164*b*	3.3*a*
Cypress Hills (CH)	33*b*	2.6*a*	2.3*a*	1.8*a*	19*a*	28*a*	90*b*	63*a*	21*c*	165*c*	10.4*b*
Kamloops (KA)	33*b*	4.2*b*	3.7*c*	2.0*a*	21*d*	30*c*	86*b*	71*b*	19*b*	164*a*	3.4*a*
Probability	0.021	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Year (Y)											
1994	13*a*	–[v]	–	–	–	18*a*	–	–	–	–	–
1995	29*b*	–	–	2.3*a*	0.17	34*b*	73*a*	69*b*	7*a*	166*b*	4.2*a*
1996	41*c*	4.3*b*	–	2.4*a*	24*c*	35*c*	84*b*	66*a*	17*b*	164*a*	9.7*b*
1997	49*d*	3.2*a*	–	–	21*b*	–	97*c*	82*c*	37*c*	–	–
Probability	<0.001	<0.001	ND[u]	0.216	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction (Collection site × Year)											
MR × 1994	14*a*	–	–	–	–	17*a*	–	–	–	–	–
MR × 1995	30*b*	–	–	2.6*a*	16*a*	34*b*	76*a*	81*b*	9*a*	166*b*	7.0*a*
MR × 1996	41*c*	4.8*b*	–	2.6*a*	24*c*	36*c*	83*b*	71*a*	17*b*	164*a*	14.5*b*
MR × 1997	50*d*	3.3*a*	–	–	21*b*	–	99*c*	93*c*	56*c*	–	–
FH × 1994	14*a*	–	–	–	–	18*a*	–	–	–	–	–
FH × 1995	29*b*	–	–	2.9*a*	16*a*	34*b*	64*a*	71*b*	4*a*	165*b*	2.9*a*
FH × 1996	39*c*	4.3*b*	–	3.0*a*	22*c*	35*c*	71*b*	66*a*	7*b*	164*a*	3.6*b*
FH × 1997	47*d*	3.8*a*	–	–	21*b*	–	96*c*	88*c*	28*c*	–	–
CH × 1994	11*a*	–	–	–	–	17*a*	–	–	–	–	–
CH × 1995	28*b*	–	–	1.8*a*	15*a*	32*b*	79*a*	58*a*	7*a*	166*b*	4.6*a*
CH × 1996	42*c*	3.1*b*	–	1.9*a*	22*c*	34*c*	95*b*	62*b*	25*b*	164*a*	16.2*b*
CH × 1997	52*d*	2.2*c*	–	–	20*b*		95*b*	70*c*	32*c*	–	–
KA × 1994	14*a*	–	–	–	–	21*a*	–	–	–	–	–
KA × 1995	30*b*	–	–	1.8*a*	17*a*	36*c*	72*a*	66*a*	7*a*	165*b*	2.3*a*
KA × 1996	41*c*	5.0*b*	–	2.1*a*	25*c*	34*b*	89*b*	67*a*	19*b*	162*a*	4.4*b*
KA × 1997	47*d*	3.4*a*	–	–	21*b*	–	97*c*	79*b*	31*c*	–	–
Probability	<0.001	0.008	ND	0.217	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001

[z]Visual assessment: 1 upright to 9 flat on the ground.
[y]Rating: 1= no damage to 10 = all dead.
[x]Rating: 1= no effect, 2 = a few pustules, however the plant was mostly green, 3 = pustules with some brown leaves, 4 = pustules and a lot of brown, 5 = pustules and all brown except the newest leaves.
[w]g 7 plants^{-1}.
[v]Level within a factor of a variable was not included in the analyses.
[u]Factor, or its interaction, within a variable could not be tested because of missing data.
a–c Means having the same letter, within subset of column, do not differ significantly ($P < 0.05$).

whether correct or wrong, provide an indication of group distinction or, conversely, similarity. According to the discriminant analysis, in 1996, the Foothills population was more often classified correctly than all other populations while the Milk River population was incorrectly classified most often (Table 8). Most incorrect classifications of the Milk River, Cypress Hills and Kamloops populations were assigned to the Foothills population. Of the test sites, Stavely had the greatest proportion of correct assignments (67%) while Lethbridge had the least (57%).

DISCUSSION

The rough fescue plants expressed differences ($P < 0.05$) among populations for all selected traits but displayed considerable overlap in the range of values for all variables both within and among test sites. Therefore, while the populations may be different, individuals within the populations have common attributes. Samman et al. (2000) reported greater genetic variability within populations of *Festuca idahoensis* than between populations. This observation is also supported by evidence from Canonical Classification in the present study where the contribution of multiple variables to discriminant functions yielded from 18 to 85% wrong classifications depending on the population and test site. Such evidence indicates that a large proportion of plants behaved more like those from other populations than their own, at least for the six plant variables included with the discriminant function, and suggests sufficient genetic variability among

Table 4. Means of test location and their interaction with collection site on plant variables[z] of foothills rough fescue

Source	Circ. (cm)	Lodging[y] (score)	Win. kill[x] (score)	Dis. res.[w] (score)	Leaf height: Spring (cm)	Leaf height: Fall (cm)	Flowering tillers: Plants (%)	Flowering tillers: Height (cm)	Flowering tillers: No. (plant^{-1})	Anthesis (d)	Seed[v] (g)
Test location											
Stavely (ST)	33*b*	4.0*b*	3.6*b*		17*a*	26*a*	82*a*	66*a*	15*b*	168*c*	4.7*a*
Lundbreck (LU)	27*a*	3.5*a*	2.9*a*	2.3*a*	22*b*	27*b*	83*a*	70*b*	12*a*	165*b*	6.6*b*
New Dayton (ND)						29*c*				168*c*	5.2*a*
Lethbridge (LE)	39*c*			2.4*a*	22*b*	34*d*	89*b*	82*c*	34*c*	158*a*	11.5*c*
Probability	<0.001	<0.001	0.048	0.128	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction (Test location × Collection site[u])											
ST × MR	32b	4.0*b*	3.6*b*		17*a*	25*a*	84*bc*	72*c*	18*c*	168*b*	5.7*b*
ST × FH	31a	4.4*c*	4.1*b*		16*a*	25*a*	71*a*	67*b*	7*a*	168*b*	1.5*a*
ST × CH	34c	3.0*a*	2.4*a*		17*a*	26*a*	89*c*	60*a*	18*c*	168*b*	10.4*c*
ST × KA	33bc	4.7*d*	4.1*b*		18*b*	28*b*	82*b*	66*b*	16*b*	167*a*	1.4*a*
LU × MR	29b	4.1*c*	2.7*ab*	2.5*b*	23*c*	28*b*	85*b*	79*d*	16*c*	166*c*	11.0*c*
LU × FH	27a	3.8*bc*	3.2*bc*	2.8*c*	22*b*	28*b*	76*a*	72*c*	7*a*	165*b*	2.9*a*
LU × CH	27a	2.3*a*	2.2*a*	1.9*a*	20*a*	25*a*	87*b*	59*a*	13*c*	165*bc*	8.3*b*
LU × KA	26a	3.8*b*	3.4*c*	2.0*a*	23*c*	28*b*	85*b*	69*b*	11*b*	164*a*	4.3*a*
ND × MR						28*ab*				168*c*	6.8*b*
ND × FH						29*b*				167*b*	3.6*a*
ND × CH						27*a*				168*c*	7.4*b*
ND × KA						30*b*				166*a*	2.9*a*
LE × MR	39a			2.8*b*	22*b*	35*b*	89*ab*	94*d*	49*c*	158*a*	19.6*c*
LE × FH	39a			3.2*c*	21*a*	33*a*	85*a*	85*c*	25*a*	158*a*	5.1*a*
LE × CH	38a			1.8*a*	21*a*	32*a*	92*b*	70*a*	32*b*	158*a*	15.6*b*
LE × KA	39a			1.9*a*	22*b*	34*ab*	92*b*	78*b*	29*ab*	158*a*	4.8*a*
Probability	<0.001	<0.001	0.130	0.021	0.002	0.035	0.296	<0.001	<0.001	0.001	<0.001

[z]All estimates are based on seven clones representing each tussock and averaged over the three replicates at each location.
[y]Visual assessment: 1 upright to 9 flat on the ground.
[x]Rating: 1= no damage to 10 = all dead.
[w]Rating: 1= no effect, 2 = a few pustules, however the plant was mostly green, 3 = pustules with some brown leaves, 4 = pustules and a lot of brown, 5 = pustules and all brown except the newest leaves.
[v]g 7 plants^{-1}.
[u]MR, Milk River Ridge; FH, Foothills of Rocky Mountains and Porcupine Hills; CH, Cypress Hills; KA, Kamloops, British Columbia.
a–d Means having the same letter, within subset of column, do not differ significantly ($P < 0.05$).

Table 5. Probability of *F* values for grazing history, test location, year of test and their interactions on the 11 characteristics observed on foothills rough fescue collections

Source of variation	Circ.[z] (cm)	Lodg.[y] (score)	Win. kill[x] (score)	Dis. res.[w] (score)	Leaf height: Spring[v] (cm)	Leaf height: Fall[u] (cm)	Flowering tillers: Plants[v] (%)	Flowering tillers: Height[v] (cm)	Flowering tillers: No.[v] (plant^{-1})	Anthes.[t] (d)	Seed wt.[t] (g)
						Probability					
Grazing History (1)	0.933	0.013	0.028	0.092	0.555	0.079	0.643	0.001	0.026	0.780	0.348
Test Location (2)	<0.001	0.02	0.066	0.011	<0.001	<0.001	0.132	<0.001	<0.001	<0.001	<0.001
Year (3)	<0.001	0.003		0.175	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 × 2	0.102	0.295	0.320	0.807	0.819	0.635	0.867	0.391	0.031	0.109	0.105
1 × 3	0.050	0.793		0.376	0.692	0.885	<0.001	0.688	0.002	0.004	0.009
2 × 3	<0.001	0.022		0.137	<0.001	<0.001	0.056	<0.001	<0.001	0.001	0.012
1 × 2 × 3	0.557	0.566		0.597	0.871	0.933	0.868	0.248	0.110	0.597	0.331

[z]Analyzed for 4 yr (1994 to 1997) and three locations (Stavely, Lundbreck and Lethbridge).
[y]Analyzed for 2 yr (1996 and 1997) and two locations (Stavely and Lundbreck).
[x]Analyzed for 1 yr (1996) and two locations (Stavely and Lundbreck).
[w]Analyzed for 2 yr (1995 and 1996) and two locations (Lundbreck and Lethbridge).
[v]Analyzed for 3 yr (1995 to 1997) and three locations (Stavely, Lundbreck and Lethbridge).
[u]Analyzed for 3 yr (1994 to 1996) and four locations (Stavely, New Dayton, Lundbreck and Lethbridge).
[t]Analyzed for 2 yr (1995 and 1996) and four locations (Stavely, New Dayton, Lundbreck and Lethbridge).

plants within any population to allow successful establishment in other environments (Petit and Thompson 1997).

Of all the test sites, Lethbridge offered the greatest divergence in growing conditions from the population source by

Table 6. Means of grazing history and interaction between test location and year on plant variables of foothills rough fescue

Source	Circ. (cm)	Lodging[z] (score)	Win. kill[y] (score)	Dis. res.[x] (score)	Leaf height: Spring (cm)	Leaf height: Fall (cm)	Flowering tillers: Plants (%)	Flowering tillers: Height (cm)	Flowering tillers: No. ($plant^{-1}$)	Anthesis (d)	Seed[w] (g)
Grazing history											
Lightly grazed (LG)	33*a*	3.6*a*	3.9*b*	2.5*a*	19*a*	26*a*	78*a*	69*a*	13*a*	165*a*	4.3*a*
Heavily grazed (HG)	33*a*	4.5*b*	2.9*a*	2.8*a*	19*a*	27*a*	79*a*	74*b*	18*b*	165*a*	4.9*a*
Probability	0.993	0.013	0.028	0.092	0.555	0.079	0.643	0.001	0.026	0.78	0.348
Interaction (grazing history × test location)											
LG × ST[v]	33*a*	4.2*a*	4.1*a*		17*a*	23*a*	76*a*	64*a*	10*a*	167*a*	3.1*a*
HG × ST	31*a*	4.8*a*	3.4*a*		16*a*	24*a*	76*a*	67*a*	10*a*	168*b*	2.6*a*
LG × LU[u]	27*a*	3.0*a*	3.7*b*	2.2*a*	20*a*	25*a*	74*a*	66*a*	8*a*	165*a*	3.3*a*
HG × LU	28*a*	4.3*b*	2.5*a*	2.6*a*	20*a*	25*a*	78*a*	71*b*	9*a*	165*a*	4.8*a*
LG × ND[t]						25*a*				168*a*	4.3*a*
HG × ND						25*a*				168*a*	2.9*a*
LG × LE[s]		39*a*		2.8*a*	21*a*	30*a*	82*a*	77*a*	23*a*	158*a*	6.5*a*
HG × LE		40*a*		3.1*a*	21*a*	32*a*	84*a*	83*b*	34*b*	158*a*	9.2*b*
Probability	0.102	0.295	0.320	0.807	0.819	0.635	0.867	0.391	0.031	0.109	0.105
Interaction (grazing history × year)											
LG × 94	14*b*					15*a*					
HG × 94	13*a*					16*b*					
LG × 95	30*a*			2.5*a*	16*a*	30*a*	70*b*	65*a*	5*a*	166*a*	3.4*b*
HG × 95	29*a*			3.0*b*	15*a*	32*a*	51*a*	70*b*	4*a*	167*b*	2.2*a*
LG × 96	40*a*	4.1*a*		2.4*a*	22*a*	32*a*	70*a*	65*a*	10*a*	164*b*	5.2*a*
HG × 96	40*a*	5.0*b*		2.6*a*	22*a*	32*a*	91*b*	68*b*	17*b*	163*a*	7.5*a*
LG × 97	48*a*	3.1*a*			20*a*		93*a*	77*a*	25*a*		
HG × 97	50*a*	4.1*a*			20*a*		96*a*	82*b*	32*a*		
Probability	0.050	0.793		0.376	0.692	0.885	<0.001	0.688	0.002	0.004	0.009

[z]Visual assessment: 1 upright to 9 flat on the ground.
[y]Rating: 1= no damage to 10 = all dead.
[x]Rating: 1= no effect, 2 = a few pustules, however the plant was mostly green, 3 = pustules with some brown leaves, 4 = pustules and a lot of brown, 5 = pustules and all brown except the newest leaves.
[w]g 7 $plants^{-1}$.
[v]Stavely.
[u]Lundbreck.
[t]New Dayton.
[s]Lethbridge.
a–c Means having the same letter, within subset of column, do not differ significantly ($P < 0.05$).

receiving supplemental irrigation and having higher growing season temperatures (Table 1). This resulted in a shortened period to anthesis with larger plants that produced more seed (Table 4). The effect ($P < 0.05$) of the test site on population response was produced primarily from a shift in magnitude since the order of response appeared to be relatively consistent among variables (Table 4). Therefore, despite a wide range of test-site conditions, population response was similar and indicated a high level of stability in the genetic expression of the populations. This supports the observation of Billington et al. (1990) that environmental variation rather than genetic variation had the greatest effect on phenotypic variability.

The Kamloops population was clearly different from the Milk River and Cypress Hills populations and was more likely to be associated with the Foothills population; while the Foothills population was the most clearly defined and least likely to capture false membership from all other populations (Table 8). On the other hand, the Milk River population was the least predictable with most plants classified with the Foothills population.

Considerable potential for selection exists both within and among populations of rough fescue. Besides population differences, there is also a considerable range of variability among plants within populations (Table 7). While all measured plant variables exhibited clear differences among populations, those having particular economic importance are seed yield and the associated flowering characteristics such as the number of flowering tillers per plant. When taken together with the ability to resist disease and winter kill, the

Table 7. Average maximum and minimum values[z] of selected characteristics among plants from four collection areas when grown at four locations in southern Alberta in 1996

		Circum.		Lodging[x]		Winter Kill[w]		Disease res.[v]		Leaf height				Flowering tillers						Anthesis		Seed wt.	
		cm · plant^{-1}		score (1–9)		score (1–10)		score (1–5)		Spring (cm)		Fall (cm)		Plants (%)		Height (cm)		No.		(d)		(g)[u]	
Collection area[y]	Test location	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Milk River	Stavely	47	32	7.0	2.5	8.1	2.1			25	18	37	22	100	26	79	38	30.6	0.4	171	166	22.1	0.2
Foothills	Stavely	44	27	7.0	2.3	7.4	2.1			31	15	40	20	100	9	75	31	20.5	0.1	172	166	8.5	0.1
Cypress Hills	Stavely	48	30	5.7	2.3	3.2	1.7			25	17	39	19	100	52	66	31	60.6	2.0	171	166	36.8	0.8
Kamloops	Stavely	47	30	7.3	3.7	6.8	2.2			31	19	36	21	100	42	63	46	56.1	0.6	167	166	10.6	0.1
Milk River	Lundbreck	44	25	8.0	2.3	5.1	1.2	4.3	1.7	27	16	44	25	100	13	88	40	33.9	0.3	166	163	59.6	0.3
Foothills	Lundbreck	42	24	8.0	2.7	6.8	1.7	4.3	1.3	32	14	51	24	100	0	100	34	18.3	0	166	162	12.1	0
Cypress Hills	Lundbreck	44	25	4.0	2.3	2.8	1.6	3.0	1.0	26	15	38	22	100	71	70	32	43.4	1.9	166	162	41.4	0.7
Kamloops	Lundbreck	40	25	6.0	3.0	7.4	2.2	3.7	1.0	29	20	39	24	100	67	75	46	50.5	3.0	166	162	29.9	1.6
Milk River	N. Dayton	49	34	7.0	2.7			5.0	1.3	31	19	45	29	100	51	99	46	30.7	1.6	170	165	18.5	1.0
Foothills	N. Dayton	50	30	6.3	2.0			5.0	2.0	31	17	50	26	100	0	88	44	20.0	0	169	164	10.6	3.1
Cypress Hills	N. Dayton	54	32	5.3	2.5			4.7	1.7	29	17	44	21	100	45	79	46	34.9	2.3	170	165	22.1	1.0
Kamloops	N. Dayton	51	36	7.0	2.7			3.7	1.7	32	20	43	26	100	47	79	51	48.0	0.6	169	164	11.1	0.1
Milk River	Lethbridge	60	38	7.0	2.3			4.0	1.7	33	20	53	35	100	13	122	56	69.1	0.2	159	155	76.1	0.2
Foothills	Lethbridge	62	34	7.5	2.0			4.0	1.3	32	19	52	33	100	0	121	58	54.9	0	159	154	37.2	0
Cypress Hills	Lethbridge	56	32	4.0	1.0			3.0	1.0	32	21	52	32	100	62	88	38	53.3	2.5	158	154	46.1	1.4
Kamloops	Lethbridge	58	40	7.0	2.7			4.0	1.0	34	22	49	30	100	85	108	58	62.5	3.1	157	154	17.7	0.8

[z]All estimates are based on seven clones representing each tussock and averaged over the three replicates at each location.
[y]No. plants represented from each collection site: Milk River, 11; Foothills, 27; Cypress Hills, 12; Kamloops, 14.
[x]Visual assessment: 1 upright to 9 flat on the ground.
[w]Rating: 1 = no damage to 10 = all dead.
[v]Rating: 1 = no effect, 2 = a few pustules, however, the plant was mostly green, 3 = pustules with some brown leaves, 4 = pustules and a lot of brown, 5 = pustules and all brown except the newest leaves.
[u]gm 7 plants^{-1}.

Table 8. Results of canonical classification of four rough fescue populations tested at four sites in southern Alberta and analyzed by all sites and by individual site

Population	Test site	Milk River	Foothills	Cypress Hills	Kamloops	*n*
				Group membership (%)		
Milk River	All sites	22	55	9	14	163
	Stavely	12	50	25	12	40
	Lundbreck	42	51	5	2	40
	New Dayton	15	51	22	12	40
	Lethbridge	46	44	5	5	40
Foothills	All sites	2	81	2	16	269
	Stavely	6	81	0	13	68
	Lundbreck	2	75	6	18	68
	New Dayton	3	81	4	12	68
	Lethbridge	4	82	0	14	68
Cypress Hills	All sites	16	45	27	11	141
	Stavely	6	23	71	0	35
	Lundbreck	6	37	46	11	35
	New Dayton	11	23	51	14	35
	Lethbridge	31	44	11	14	35
Kamloops	All sites	1	42	3	54	168
	Stavely	0	31	0	69	42
	Lundbreck	2	36	2	60	42
	New Dayton	0	26	2	71	42
	Lethbridge	0	33	0	67	42

Cypress Hills population displays superior attributes that may be attractive in an agronomic application. However, within any population the range of variation for any characteristic ensures the opportunity to select for the desired traits (Petit and Thompson 1997). Nevertheless, the Cypress Hills population may provide superior genetics from which to develop the first selections because it is represented by genotypes that tend to produce the greatest amount of seed or the greatest resistance to disease and winter kill (Table 7).

Observations from the collections from the Foothills that represent a sub-population of historically heavily grazed and lightly grazed plants should be considered preliminary because of the limited numbers tested and the non-random manner in which the heavily grazed plants were selected. Greater height and number of flowering tillers of the heavily grazed plants might reflect their initial selection when the plants were identified by the presence of inflorescence. Flowering in rough fescue is sporadic among years and sparse even with optimal conditions. Therefore, the initial selection of plants with inflorescence may have biased selection for those with a greater tendency to flower. In fact, the effect of grazing pressure on *Agropyron smithii* Rydb. and *Bouteloua gracilis* (H.B.K.) Griffiths seemed to favor plants with fewer and shorter flowering tillers when grown in a common garden (Painter et al. 1989). However, the greater resistance of heavily vs. lightly grazed plants to winter kill may reflect greater fitness in a cold environment. Soil temperatures on heavily grazed areas tend to be colder in winter (Weaver and Rowland 1952; Johnston et al. 1971) due to the diminution of litter (accumulated dead herbage) by grazing. Lightly grazed areas on this study site may have up to 20 times more litter than heavily grazed areas (Willms et al. 1988) thereby producing selection pressure for winter-hardy genotypes.

CONCLUSIONS

Rough fescue displays considerable variation among genotypes of all populations, which ensures opportunity for selecting desirable traits that might be useful in commercial applications. Nevertheless, some populations include maximum or minimum limits that might be exploited when collecting material for selection. For example, the Cypress Hills and Milk River populations had genotypes that produced about twice the seed yield than the best genotypes of the other two populations.

In applications where diversity is desirable, such as in pipeline reclamation on rangelands, the source of bulk seed collections of foothills rough fescue appears to be relatively unimportant since most genotypes of all populations survived and expressed a broad range of variability, among the traits we measured, at widely dispersed sites. However, among the populations we studied, some appeared to be more catholic than others. For example, at least a significant proportion of the plants from the Milk River population were classified into each of the other three populations while the Kamloops and Foothills populations were more exclusive.

The conclusions from this study are based on selected attributes tested in a variety of environments. Since all traits could not be included in the study, the possibility remains that an important characteristic that could influence the results was not recognized. For this reason, reclamation projects utilizing foothills rough fescue genotypes from remote populations should proceed cautiously with an understanding of the risk associated with the practice.

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