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Russian wildrye nutritive quality as affected by accession and environment[1]

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Karn, J. F., Mayland, H. F., Berdahl, J. D., Asay, K. H. and Jefferson, P. G. 2005. **Russian wildrye nutritive quality as affected by accession and environment**. Can. J. Plant Sci. **85**: 125–133. High-quality forage for spring and fall grazing is an important need of ranchers in the Northern Great Plains and Intermountain-West regions of the United States of America and in the prairie provinces of Canada. Russian wildrye [*Psathyrostachys juncea* (Fischer) Nevski] has been used to meet this grazing need, especially in Canada. However, its use has probably been limited by its reputation for seedling establishment difficulties and scattered reports of grass tetany. The purpose of this research was to characterize the variation in nutritive quality of Russian wildrye accessions used in a multi-location grass tetany project, to access the effect of environment on quality components, and to determine the relationship between forage nutritive quality components and entities associated with grass tetany. Sixty-seven Russian wildrye accessions from the US National Plant Germplasm System were established in spaced-plant nurseries at Logan, UT, Mandan, ND, and Swift Current, SK, Canada. Plants were sampled at two stages of development over 2 yr. Location, year, and stage of development effects were significant ($P < 0.01$) for in vitro true dry matter digestibility (IVDMD), crude protein (CP), and neutral detergent fiber (NDF). At the early stages of development used in this study the range in nutritive quality traits among entries was rather narrow. Relatively high positive correlation coefficients between K and IVDMD, and K and CP suggest that breeding for higher nutritive quality may also produce a more tetany-prone forage, because high K concentration is usually associated with grass tetany. On the other hand, Mg concentrations were also highly correlated with IVDMD and CP, and higher Mg concentrations would be beneficial in preventing grass tetany. The K/(Mg + Ca) ratio, which has been suggested as an indicator of grass tetany, was only moderately related to IVDMD, CP, and NDF.

Key words: Digestibility, crude protein, neutral detergent fiber, stage of plant development

Karn, J. F., Mayland, H. F., Berdahl, J. D., Asay, K. H. et Jefferson, P. G. 2005. **La valeur nutritive de l'élyme de Russie est affectée par l'obtention et l'environnement**. Can. J. Plant Sci. **85**: 125–133. Les éleveurs des grandes plaines du nord et de la région intermontagneuse de l'ouest des États-Unis ont besoin de fourrages de haute qualité pour faire paître leurs animaux au printemps et à l'automne. Pour répondre à ce besoin, les éleveurs recourent à l'élyme de Russie [*Psathyrostachys juncea* (Fischer) Nevski], surtout au Canada. Néanmoins, l'usage de l'élyme est probablement entravé par une implantation réputée difficile et par des rapports sporadiques de tétanie d'herbage. L'étude devait préciser dans quelle mesure la valeur nutritive des obtentions d'élyme de Russie varie dans le cadre d'une expérience sur la tétanie d'herbage poursuivie à plusieurs sites, vérifier l'incidence de l'environnement sur les composantes de la qualité et établir des liens entre la valeur nutritive des fourrages et les paramètres associées à la tétanie d'herbage. À cette fin, les auteurs ont cultivé 67 obtentions d'élyme de Russie du National Plant Germplasm System américain sur des parcelles distinctes aux pépinières de Logan (Utah), de Mandan (Dakota Nord) et de Swift Current (Saskatchewan, Canada). Deux années durant, ils ont prélevé des échantillons des plants à deux stades de croissance. L'emplacement, l'année et le stade de développement ont tous une incidence significative ($P < 0{,}01$) sur la digestibilité réelle de la matière sèche *in vitro* (DMSIV), sur la concentration de protéines brutes (PB) et sur celle de fibres au détergent neutre (FDN). Aux premiers stades de développement examinés dans le cadre de cette étude, la qualité nutritive des obtentions se caractérise par un éventail de paramètres assez étroit. Les coefficients de corrélation relativement très positifs entre K et la DMSIV ainsi qu'entre K et les PB laissent croire qu'hybrider l'élyme en vue d'une meilleure qualité nutritive pourrait produire des variétés qui favorisent la tétanie d'herbage davantage, ce problème étant couramment associé à une concentration de K élevée. Parallèlement, la concentration de Mg présente elle aussi une grande corrélation avec la DMSIV et les PB. Or, une concentration supérieure de Mg devrait concourir à prévenir la tétanie d'herbage. Le ratio K/(Mg + Ca), qu'on croit servir d'indicateur à la tétanie d'herbage, ne présente qu'une corrélation modérée avec la DMSIV, les PB et les FDN.

Mots clés: Digestibilité, protéines brutes, fibres au détergent neutre, stade de développement végétal

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Abbreviations: **CP**, crude protein; **DOY**, day of year; **IVDMD**, in vitro dry matter digestibility; **NDF**, neutral detergent fiber

The need for high-quality forages to facilitate early- and late-season grazing in the Northern Great Plains is an ongoing concern for cattle producers. Russian wildrye was officially introduced from Siberia in 1927 and released for use in the Northern Plains in 1941 (Rogler and Schaaf 1963). Although this grass produces high-quality forage (Heinrichs and Carson 1956; Smoliak and Bezeau 1967), especially for fall and winter grazing (Heinrichs and Carson 1956; Holt and Knipfel 1993), it has not been seeded as extensively as crested wheatgrass [*Agropyron desertorum* (Fisch. Ex Link) Schultes]. There are likely two reasons why less land has been seeded to Russian wildrye. One reason is because early cultivars lacked seedling vigor (Berdahl and Barker 1991), making pasture establishment difficult. A second reason is that early spring forage has been reported to have a high potential for causing grass tetany (Karn et al. 1983; Asay and Mayland 1990). High concentrations of K and N and low concentrations of Mg and Ca and a K/(Mg + Ca) ratio (on a milliequivalent basis) in excess of 2.2 are most often associated with the potential for grass tetany (Kemp and t'Hart 1957). Asay and Mayland (1990) indicated that mineral concentrations in Russian wildrye could be altered through breeding and that breeding for higher levels of Mg would be accompanied by increased Ca and to a lesser extent increased K.

Although other aspects of Russian wildrye nutritional quality have received limited attention from breeders, Asay et al. (2001) using plants from a rather limited gene base, concluded that levels of CP, NDF, IVDMD and P could be positively altered through breeding. Research with intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. and Dewey] indicated that selection for IVDOM should result in increased digestibility of this species (Berdahl et al. 1994). In smooth bromegrass (*Bromus inermis* Leyss.), selection for increased IVDMD produced a small increase in IVDMD as well as an increase in yield (Casler et al. 2000). In switchgrass (*Panicum virgatum* L.) accessions, genotype by environment interactions were important, but it was concluded that selection for IVDMD within accessions selected for yield at heading should be effective (Hopkins et al.1995). Research with timothy (*Phleum pratense* L.) indicated that it was possible to select for high yield and superior nutritive value (Brégard et al. 2001). With tall fescue (*Festuca arundinacea* Schreber), selection for high IVDMD was found to be successful in spring but not summer forage (De Santis and Chiaravalle 2001). The encouraging results from other grass species suggest the need for further study of the genetic variability of nutritive quality traits in Russian wildrye. Thus, nutritive quality components in a broad-based sample of Russian wildrye accessions were characterized to determine the extent of their variability, to access the effect of environment on quality components, and to determine relationships between forage nutritive quality components and entities associated with grass tetany.

MATERIALS AND METHODS

Russian wildrye germplasm evaluated in this study consisted of 62 diploid and 3 tetraploid plant introductions described by Berdahl et al. (1999). A 21-clone synthetic (Syn-A) developed at Logan, UT, and the cultivar Mankota (Berdahl et al. 1992) were included as checks. Plant materials were established in three geographically and environmentally diverse test areas where Russian wildrye is adapted. Plots were located at Mandan, ND (46°48′N latitude, 100°55′W longitude) on fine-silty, mixed Pachic Haplustolls (silty loam) soil; at Logan, UT (41°41′N latitude, 111°50′W longitude), on fine mixed, mesic, semiactive Aquic Argiutolls (silty clay loam) soil; and at Swift Current, SK, Canada (50°17′N latitude, 107°50′W longitude) on fine, mixed, mesic, Aridic Haploborolls (sandy loam) soil. Eight plants of each entry, initially started in the greenhouse as seedlings, were transplanted on 1.0-m centers in single-row plots according to a randomized complete-block design with four replicates at each location. Plantings were established in the spring of 1990 at Mandan and Swift Current and in 1991 at Logan. Plots were fertilized with ammonium nitrate in the fall at the rate of 45 kg N ha^{-1}.

In 1991 and 1992 at Swift Current and Mandan, and in 1992 and 1993 at Logan, two of the eight plants in each plot were sampled at V4 (vegetative tillers with four leaves) and E2 (seed head palpable at the second node) stages of plant development (Moore et al. 1991) for chemical analyses. The biomass from one vertical half (half of the tillers) of each of two plants was sampled at each development stage and combined into a single sample per plot as described by Jefferson et al. (2001). Samples were collected when individual plant tillers were predominantly at the V4 and E2 stages. Harvest dates at Logan, Mandan and Swift Current at the V4 and E2 stages were Apr. 14 and 29, May 09 and 15, and May 23 and 27, respectively, in year 1, and May 12 and 20, May 10 and 18, and May 6 and 13 in year 2, respectively. Samples were clipped at a stubble height of 5 cm. Weather data related to plant growth and development were collected at each location, both years (Table 1).

Samples for determination of forage quality were dried at 60°C, double ground through a 1-mm screen, and scanned with a model 6250 near infrared reflectance spectrophotometer (Pacific Scientific, Silver Spring, MD). Spectra were stored on 3049 samples [(67 entries × 4 replications × 3 locations × 2 maturities × 2 years) – 167 missing samples]. For a variety of reasons we were not able to scan all entry, replication and location samples each year. Using NIRSystem CENTER and SELECT programs (Infrasoft International 1991), representative samples from each year and location were selected as a calibration set for wet lab analyses. The calibration set consisted of 395 samples, which represented about 13% of the total number of samples in the study. Calibration samples included 95 and 52 from Mandan, 41 and 57 from Swift Current, and 46 and 104 from Logan for the 2 sampling years, respectively. Calibration samples were analyzed for N concentration using a Carlo Erba Model NA 1500 Series 2 N/C/S analyzer (CE Elantech, Lakewood, NJ). Neutral detergent fiber and IVDMD were determined according to procedures described by Goering and Van Soest (1970). Neutral detergent fiber concentration in forage samples and in the residue following a 48-h in vitro fermentation was determined with an ANKOM fiber analyzer (Vogel et al. 1999). Rumen fluid for the in vitro digestion procedure was obtained from a

Table 1. Temperature and precipitation data at Mandan, ND, Swift Current, SK, and Logan, UT, during the 2-yr study[z]

Month	Temperature (°C)			Precipitation (mm)		
	Year 1	Year 2	L. T. avg.[y]	Year 1	Year 2	LT avg.[y]
			Mandan			
March	–0.3	1.6	–3.9	8.4	17.8	13.0
April	8.1	4.9	5.3	47.5	7.9	39.1
May	13.9	15.0	12.5	67.3	37.3	57.4
			Swift Current			
March	–2.5	2.0	–4.7	13.9	4.4	17.5
April	5.8	5.9	4.6	50.3	11.2	22.3
May	10.7	11.1	10.9	95.5	29.4	43.7
			Logan			
March	6.6	2.2	4.0	27.4	64.8	47.5
April	10.3	7.1	7.5	11.7	60.7	50.3
May	14.4	14.4	12.2	24.1	40.4	64.5

[z]Samples were collected in 1991 and 1992 at Mandan, ND, and Swift Current, SK, and in 1992 and 1993 at Logan, UT.
[y]LT avg. = long-term average; for 30 yr at Mandan, 118 yr at Swift Current and 10 yr at Logan.

mature Hereford steer. In vitro true digestibility was determined on forage samples by measuring NDF on the residue following a 48-h fermentation, instead of determining apparent digestibility by following the fermentation with a 48-h pepsin digestion (Tilley and Terry 1963). After wet lab analyses were completed on calibration samples, equations were developed to predict N, NDF, and IVDMD using NIRSystem programs. Equations were developed using only samples from the current study. Calibration statistics for N were, SECV (standard error of cross validation) = 1.4 g kg^{-1}, and R^2 =0.96; for NDF, SECV = 13.4 g kg^{-1} and R^2 = 0.96; for IVDMD, SECV = 19.6 g kg^{-1} and R^2 = 0.88. Crude protein was calculated by multiplying N concentration by 6.25.

Due to missing data for some replications of four entries, only 63 of the 67 entries were statistically analyzed. Data were analyzed using a SAS PROC MIXED analysis (Littell et al. 1996), with location, year, and stage of development considered as fixed effects, and replication within location, entry, and all interactions with entry considered as random effects. Least squares means for year and stage of development were separated by an *F*-test. Location, location × year, and stage of development × year means were separated using the SAS PDIFF option. The relative magnitude of variance components for entry, entry × location, entry × stage of development, and entry × year were used to compare the contribution of these sources of variation. Pearson correlation coefficients for entry means averaged over replication, year, stage of development, and location were calculated to determine the relationships among IVDMD, CP, NDF, and selected minerals. Mineral concentrations were reported in a related paper (Jefferson et al. 2001).

RESULTS

Location, stage of development, year, and all main effect interactions for IVDMD, CP and NDF were significant (Table 2), somewhat complicating the interpretation of these data. Although all fixed effects were significant, *F*-values for stage of development and location × stage of development were much larger than *F*-values for the other effects for all three nutritive quality components. Entry variance components for IVDMD, CP, and NDF were all greater than variance components for the next highest effect for each nutritive quality entity, which was entry × location for IVDMD and CP and entry × stage of development for NDF. The entry variance component for IVDMD was about three times as large as the IVDMD variance component for entry × location. The entry variance component for NDF was about 15 times as great as the entry × stage of development variance component for NDF.

Table 2. Russian wildrye IVDMD, NDF and CP *F*-values and probabilities for main effects and interactions for fixed effects and variance components for random effects

Effect	IVDMD[z]	CP[y]	NDF[x]
Location (L)	62**	122**	33**
Stage of development (SD)	1701**	1176**	1163**
Year (Y)	490**	38**	13**
Y × SD	45**	180**	8**
L × SD	1470**	668**	1170**
L × Y	344**	158**	559**
L × SD × Y	235**	134**	412**
Variance components			
Entry (E)	0.64	0.44	2.54
E × L	0.20	0.29	0.12
E × SD	0.13	0.11	0.16
E × Y	0.05	0.01	0.04

[z]IVDMD = in vitro true dry matter digestibility.
[y]CP = crude protein.
[x]NDF = neutral detergent fiber.
** Significant at $P < 0.01$ probability level.

Entry Effects

Since a large number of entries were evaluated in this study, three groups of five entries having high, medium, and low IVDMD were selected to demonstrate the consistency of variation among entries (Table 3). In vitro dry matter digestibility means for the high, medium, and low groups were 861, 845, and 821 g kg^{-1}, indicating relatively small differences among groups representing the 63 entries.

Table 3. Russian wildrye entry means and rank for in vitro dry matter digestibility (IVDMD), crude protein (CP), and neutral detergent fiber (NDF) with entries grouped according to high, medium, or low IVDMD values. IVDMD, CP and NDF data were averaged over location, year, stage of development, and replication. Anthesis DOY[z] was averaged over years at Mandan

Entry	Anthesis DOY	IVDMD ($g\ kg^{-1}$)	rank	CP ($g\ kg^{-1}$ DM)	rank	NDF ($g\ kg^{-1}$ DM)	rank
				High IVDMD group			
AJC 596	159.3	866	1	258	37	465	63
AJC 598	157.5	861	2	255	45	469	62
PI 499674	160.7	860	3	258	36	485	60
AJC 600	159.7	859	4	253	54	478	61
PI 314675	160.7	857	5	258	38	486	59
Group mean	159.6	861		256		477	
				Medium IVDMD group			
PI 430873	158.5	845	30	264	7	508	30
PI 430867	158.1	845	31	262	14	505	33
PI 502572	158.7	845	32	261	20	500	48
PI 406468	158.6	844	33	254	53	500	40
PI 430871	159.4	844	34	264	9	498	46
Group mean	158.7	845		261		502	
				Low IVDMD group			
PI 430866	158.2	830	59	254	51	524	8
PI 429805	157.8	828	60	243	59	523	10
PI 429803	157.5	822	61	239	62	533	3
PI 429802	158.0	821	62	241	61	534	2
PI 314671	159.3	805	63	209	63	582	1
Group mean	158.2	821		237		539	
Entry mean	159.0	843		257		507	
SE		1.2		1.1		2.2	
Entry range	156.9–162.0	805–866		209–270		465–582	

[z]DOY = day of year that anthesis occurred.

Entries ranged from 805 to 866 g kg^{-1} IVDMD, 209 to 270 g kg^{-1} CP, and 465 to 582 g kg^{-1} NDF. Most entries in the high IVDMD group had the lowest NDF, but CP differences in the group were negligible and did not appear related to IVDMD. In the low IVDMD group, all entries ranked low in CP and high in NDF.

Entries varied little in rate of development, with a range of 156.9 to 161.9 and a mean of 159 d to anthesis at Mandan (Table 3). High, medium and low IVDMD groups only varied 1 or 2 d in the time to anthesis; thus, any effects on nutritive quality components caused by differences in stage of development among entries should have been small.

Location and Stage of Development

In year 1 of the 2-yr study, IVDMD was highest in entries grown at Mandan, while means for IVDMD at Logan and Swift Current were not different (Table 4). However, in the second year IVDMD for plants grown at Mandan and Swift Current were not different, while plants grown at Logan were slightly but significantly lower in IVDMD. Over all three locations, IVDMD was slightly higher in the first year. Over the three locations, IVDMD was higher in both years at the early (V4) stage of development. There was, however, a location by stage of development interaction for IVDMD (Fig. 1A), which shows the decline between the two stages of development was much greater at Logan than at Mandan and Swift Current. There was also a location by year interaction for IVDMD, which shows there was little difference between years at Swift Current, while at Logan IVDMD was slightly lower the second year and at Mandan IVDMD was sharply lower the second year (Fig. 1D).

Crude protein was highest in plants grown at Mandan and lowest in plants grown at Swift Current in the first year (Table 5), while in year 2 CP was similar for Mandan and Logan entries and lower in Swift Current entries. Crude protein at the early (V4) stage of development was highest in both years (Table 5), but the decline in CP between stages of development was much greater at Logan than at the other two locations (Fig. 1B), which was similar to location differences in IVDMD. A year by location interaction for crude protein shows that CP declined slightly between years at Mandan, was about the same between years at Logan, and increased somewhat between years at Swift Current (Fig. 1E).

There were also location differences in NDF (Table 6). Plants grown at Swift Current had the highest NDF in year 1 while Mandan had the lowest NDF in year 1; however, in year 2, there was little numerical difference in NDF among locations. As with IVDMD and crude protein, NDF differed between stages of development (Table 6). However, there was also a location by stage of development interaction for NDF (Fig. 1C), where plants grown at Logan had sharply higher NDF at the later stage of development, reflecting the lower IVDMD for Logan plants at the later stage of development. A location by year interaction (Fig. 1F) shows that NDF at Mandan and Logan increased in the second year while NDF decreased sharply between years at Swift Current.

Table 4. In vitro dry matter digestibility means and SE for Russian wildrye accessions and cultivars. Means are averaged over entry and replication for stage of development and year main effects and location × year, stage of development × year and stage of development × location × year interactions

Location	Year	Stage of development			SE
		V4[z]	E2[z]	Loc. mean	
		(g kg^{-1})			
		First year			
Logan, UT	1992	871	791	831*b*	3.0
Mandan, ND	1991	898	890	894*a*	3.0
Swift Current, SK	1991	846	826	836*b*	3.0
Stage of development mean		871*a*	835*b*		2.1
Year mean				854*a*	2.0
		Second year			
Logan, UT	1993	875	760	817*b*	3.0
Mandan, ND	1992	855	822	838*a*	3.0
Swift Current, SK	1992	832	844	838*a*	3.0
Stage of development mean		854*a*	808*b*		2.1
Overall stage of development mean		863*a*	822*b*		2.0
Year mean				831*b*	2.0

[z]V4 = four leaves per vegetative tiller; E2 = seed head palpable at second node (Moore et al. 1991).

a, b Stage of development, year, stage of development × year, and location × year means with different letters differ ($P < 0.05$).

Nutritive Quality Relationships

Correlation coefficients calculated among IVDMD, CP, NDF, and the minerals K, Ca, Mg, and P, which were reported in a related study (Jefferson et al. 2001), indicate some potentially useful relationships (Table 7). In vitro digestible dry matter was negatively correlated with NDF ($r = -0.95$) and positively correlated with K ($r = 0.83$), CP ($r = 0.68$), and Mg ($r = 0.65$). Correlation coefficients between IVDMD and Ca or P were low. There were significant negative correlations between NDF and K, NDF and Mg, and NDF and CP, but correlations between NDF and Ca or P were low. Crude protein was moderately correlated with K, Mg, and P but was not significantly correlated with Ca. In vitro dry matter digestibility and CP had moderate positive correlations, and NDF had a moderate negative correlation with the K/(Ca + Mg) ratio.

DISCUSSION

Entry Effects

A description of the entries used in this study, including their country of origin and significant attributes has been presented in a related paper (Berdahl et al. 1999). There were only three tetraploid entries in the study (AJC 596, AJC 598, and AJC 600). All were from Kazakhstan, and all were in the high IVDMD group (Table 3). The 2-yr average day of year (DOY) at anthesis for the high IVDMD group at Mandan was 159.3, 157.5, 159.7, 160.7, and 160.7 for AJC596, AJC598, AJC600, PI 314675 and PI 499674, respectively, compared to an average DOY for all entries of 159.0. Entries PI 429802, PI 429803, PI 429805, and PI 430866 were all noted for their early maturity and were all in the low IVDMD group. The DOY at anthesis for these accessions was 158.0, 157.5, 157.8 and 158.2, respectively. Even though these entries were reported to be early maturing, there was only a 1.4-d difference in anthesis date between the mean of the groups with high and low IVDMD.

Correlation coefficients between entry DOY at anthesis and IVDMD, NDF and CP, respectively, for plots at Mandan were $r = 0.002$, -0.17 and -0.13 at the V4 stage and $r = 0.50$, -0.50 and 0.30, at the E2 stage. Although relationships at the E2 stage are more of a concern, they indicate that only 25% ($R^2 = 0.25$) of the variation in IVDMD and NDF among entries could be accounted for by corresponding covariation in anthesis date.

The entry (PI 314671) with the lowest concentrations of IVDMD and CP, and the highest concentration of NDF was from Kazakhstan and was unique in that it had resistance to *Septoria spraguei* (Berdahl et al. 1999). It has been suggested that lignin-like materials and phenolic compounds may be important in protecting plants from attack by fungal disease organisms (Buxton and Casler 1993). These compounds are also known to decrease forage digestibility (Van Soest 1982).

Although there was some confounding of genetic and maturity effects on nutritive quality, most of the variation among entries would appear to be genetic. Most entries that were in the high and low IVDMD groups averaged over location, year and stage of plant development (Table 3) were also in the high and low groups at both stages of development at each location. Correlation coefficients between anthesis DOY and IVDMD or NDF were small and non-significant ($P > 0.05$) at the V4 stage of development. Both the V4 and E2 categories as defined by Moore et al. (1991) represented early stages of plant development. Other work (Karn and Berdahl 1984) has suggested that heritable differences in IVDOM and NDF among plant populations tended to be amplified when sampling was conducted after anthesis at a relatively late stage of development.

Entries used in this study were sampled at early stages of plant development, because they were also evaluated by Jefferson et al. (2001) to determine if breeding and selection could be used to produce plants that were less likely to cause grass tetany in grazing cattle. Grass tetany usually occurs early in the grazing season. Results of the grass tetany research

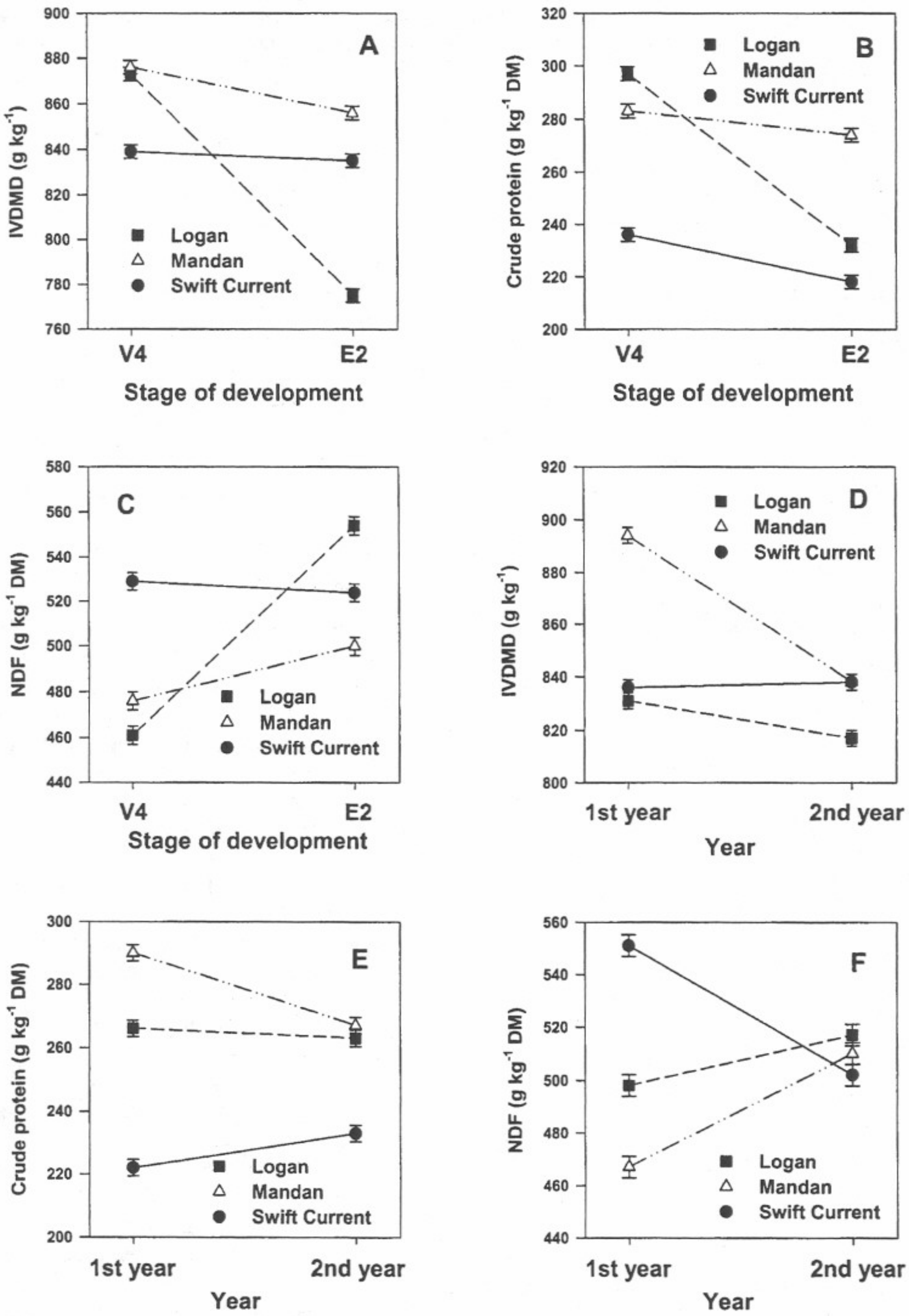

Fig. 1. Interaction effects of location and stage of development for (A) in vitro dry matter digestibility (IVDMD), (B) crude protein, (C) neutral detergent fiber (NDF), and location and year for (D) IVDMD, (E) crude protein, and (F) NDF. Stages of development are as follows: V4 = four leaves per vegetative tiller; E2 = seed head palpable at second node.

(Jefferson et al. 2001) suggest that if K and the K/(Ca + Mg) ratio were reduced to decrease the likelihood of grass tetany, forage and seed yields, because of their correlation with K and the K/(Ca + Mg) ratio, would also be reduced. In the current research, IVDMD, NDF, and CP were also highly correlated with K and Mg, indicating that if forage quality were improved through breeding, K and Mg concentrations would also be increased. Increasing forage Mg concentrations would of course be beneficial, but increasing K concentrations would not be desirable, and the correlation coefficients between the quality components and K were higher than they were with Mg. This relationship is further supported by accession PI 314671,

Table 5. Crude protein means and SE for Russian wildrye accessions and cultivars. Means are averaged over entry and replication for stage of development and year main effects and location × year, stage of development × year and stage of development × location × year interactions

Location	Year	Stage of development			SE
		V4[z]	E2[z]	Loc. mean	
		(g kg^{-1} DM)			
			First year		
Logan, UT	1992	295	237	266*b*	2.6
Mandan, ND	1991	282	297	290*a*	2.6
Swift Current, SK	1991	233	211	222*c*	2.6
Stage of development mean		270*a*	248*b*		1.8
Year mean				259*a*	1.7
			Second year		
Logan, UT	1993	299	227	263*a*	2.7
Mandan, ND	1992	283	252	267*a*	2.6
Swift Current, SK	1992	240	225	233*b*	2.6
Stage of development mean		274*a*	235*b*		1.8
Overall stage of development mean		272*a*	242*b*		1.7
Year mean				254*b*	1.7

[z]V4 = four leaves per vegetative tiller; E2 = seed head palpable at second node (Moore et al. 1991).
a, b Stage of development, year, stage of development × year, and location by year means with different letters differ ($P < 0.05$).

Table 6. Neutral detergent fiber means and SE for Russian wildrye accessions and cultivars. Means are averaged over entry and replication for stage of development and year main effects and location × year, stage of development × year and stage of development × location × year interactions

Location	Year	Stage of development			SE
		V4[z]	E2[z]	Loc. mean	
		(g kg^{-1} DM)			
			First year		
Logan, UT	1992	467	530	498*b*	4.1
Mandan, ND	1991	457	476	467*c*	4.0
Swift Current, SK	1991	539	563	551*a*	4.0
Stage of development mean		488*b*	523*a*		3.0
Year mean				505*b*	2.9
			Second year		
Logan, UT	1993	456	579	517*a*	4.1
Mandan, ND	1992	495	524	510*ab*	4.0
Swift Current, SK	1992	518	486	502*b*	4.0
Stage of development mean		490*b*	530*a*		3.0
Overall stage of development mean		489*b*	526*a*		2.9
Year mean				510*a*	2.9

[z]V4 = four leaves per vegetative tiller; E2 = seed head palpable at second node (Moore et al. 1991).
a, b Stage of development, year, stage of development x year, and location by year means with different letters differ ($P < 0.05$).

Table 7. Correlation coefficients among in vitro dry matter digestibility (IVDMD), neutral detergent fiber (NDF), crude protein (CP), K, Ca, Mg, and P for 63 accessions and cultivars averaged over replication, year, stage of development, and location

	K	Ca	Mg	P	K/(Ca + Mg)	CP	NDF
IVDMD	0.83**[y]	0.24	0.65**	–0.05	0.39**	0.68**	–0.95**
NDF	–0.88**	–0.10	–0.66**	–0.09	–0.49**	–0.64**	
CP	0.54**	0.20	0.40**	0.55**	0.26*		

[z]Values for K, Ca, Mg, and P were reported in a related paper (Jefferson et al. 2001).
[y] *,** Significant at $P < 0.05$ and $P < 0.01$, respectively.

which had the lowest IVDMD and CP and the highest NDF of the 63 entries, and was also reported by Jefferson et al. (2001) to have the lowest K concentration among these entries. Thus, it may be difficult to develop Russian wildrye plants with both improved nutritive quality and decreased grass tetany potential. However, Jefferson et al. (2001) suggested that a reduced tetany potential index (Mayland and Asay 1989) was a better grass tetany indicator than K or the K/(Ca + Mg) ratio, and the index was not correlated with forage yield, seed yield, or N concentration.

Location and Stage of Development

The nutritive quality of Russian wildrye accessions used in this study was high, as would be expected of plants harvested at relatively immature stages of plant development. In vitro digestible dry matter values in this study represent true digestibility, whereas most in vitro digestibility values that have been published represent apparent digestibility. True digestibility values are always higher than apparent values, because they have been corrected for dry matter from bacterial sources (Van Soest 1982). True in vitro digestibility values comparable to our data have been reported for Russian wildrye (Assay et al. 2001) and timothy (Claessens et al. 2004). Crude protein was also relatively high, but Smoliak and Bezeau (1967) reported comparable values for Russian wildrye and crested wheatgrass (*Agropyron cristatum*) prior to heading, while Bittman et al. (1988) reported comparable nitrogen levels in early-cut smooth bromegrass. Excess crude protein beyond animal requirements is usually just a wasted resource. However, in immature spring forage, high nitrogen concentrations may reduce magnesium utilization, which could contribute to the potential for grass tetany in cattle (Committee on Mineral Nutrition 1973). More recently, high concentrations of K and low concentrations of Ca and Mg have received greater attention in grass tetany research (Asay and Mayland 1990).

Location by stage of development interactions for IVDMD and CP show that these nutritive quality measurements declined between V4 and E2 stages of plant development at all three locations as would be expected, but the rate of decline was much greater at Logan than at Mandan or Swift Current (Fig. 1A and B). An interaction between location and stage of development also existed for NDF, where NDF at Swift Current actually decreased slightly, while it increased between stages of maturity as would be expected at Mandan and Logan, but the rate of increase at Logan was much greater than at Mandan (Fig. 1C). The small changes in NDF and IVDMD at Swift Current suggest that environmental factors may have moderated the normal effects of plant maturity at this location. At Logan, a more pronounced decline in quality between V4 and E2 stages than at the other locations may have been partially due to a greater time span between harvests in year 1. However, in year 2 the time between harvests was comparable among all three locations; yet data in Tables 4, 5, and 6 show that quality changes between maturities at Logan in year 2 were as great or greater than in year 1. Therefore, environmental conditions at Logan may have accelerated a decline in quality. Logan was warmer and drier than the other locations in year 1, but was wetter with comparable temperatures in year 2. Warm March temperatures in year 1 likely hastened early plant development, while more normal April temperatures probably slowed plant development resulting in a slightly greater number of days between V4 and E2 stages at Logan. Drought can cause leaf senescence and lower quality in cool-season grasses (Bittman et al. 1988), but leaf senescence in the current study was unlikely, because plants were harvested at early stages of plant development.

A location by year interaction (Fig. 1D) shows that IVDMD declined at a much greater rate between years at Mandan than at the other two locations, suggesting that environmental conditions at Mandan were less conducive to the production of high-quality forage in year 2 than in year 1. In year 1, precipitation levels at Mandan (Table 1) for April and May were 21 and 17%, above normal, respectively, while precipitation levels for April and May of the second year were 80 and 35%, respectively, below normal. Higher precipitation levels in year 1 than year 2, also occurred at Swift Current (Table 1), but the effects on IVDMD were not the same. In contrast to Mandan, IVDMD values at Swift Current were slightly higher in the dry year (year 2). In other studies, water-stressed tropical grass (*Panicum maximum* var. *trichoglume*) was lower in digestibility (Wilson and Ng 1975), while water-stressed alfalfa (*Medicago sativa* L.) often was higher in IVDMD (Vough and Marten 1971). It seems clear that water stress on plants at Mandan and Swift Current, in year 2, could have had an affect on forage quality, but the direction of that effect is not clear. Timing of precipitation in relation to stage of plant development may be important. Early-season precipitation or high stored soil water could result in a higher proportion of reproductive tillers and possibly lower nutritive quality, even at an early stage of plant development. These inconsistencies between locations demonstrate the need for multi-location, and multi-year evaluation before new cultivars are released to the public.

A location by year interaction for NDF (Fig. 1F) shows that NDF decreased sharply at Swift Current in year 2, suggesting that low precipitation in year 2 had a more beneficial effect on NDF than IVDMD (Fig. 1D). In contrast to Swift Current, NDF increased in samples at Mandan and Logan in year 2, which is consistent with reductions in IVDMD and CP at these two locations in year 2. There were also some inconsistencies among locations, stages of development, and years for K, Ca, and Mg concentrations that were measured on these entries by Jefferson et al. (2001). The narrow range in IVDMD and CP among entries, combined with stage of development and year interactions with location suggest that it may be difficult to improve Russian wildrye nutritive quality through breeding, although consistent differences were found among entries for high and low levels of IVDMD.

CONCLUSIONS

Plants were sampled at relatively early stages of maturity. As a result, values for IVDMD and CP were high, and NDF values were low. The range in variation among entries for these nutritive quality traits was narrow at early stages of plant development. Significant stage of development by location and year by location interactions for all three quality components suggest that environmental differences between locations may have affected the consistency of year and stage of development effects on nutritive quality. In vitro dry matter digestibility, CP, and NDF were highly correlated, indicating that selection for higher IVDMD concentration should result in plants with higher CP and lower NDF as well. However, IVDMD had high positive and NDF had high negative correlations with K, suggesting that selection for high nutritive quality might also result in plants with a greater potential to cause grass tetany. Possible confounding of entry and development effects, and stage of development and year interactions with location suggest that it may be difficult to improve

Russian wildrye nutritive quality through breeding, at least at early stages of plant development. However, there were consistent differences among entries for high and low levels of both IVDMD and NDF.

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