J. Range Manage.
45:369-374, July 1992

Seasonal trends in herbage yield and quality of *Agropyrons*

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Abstract

Crested wheatgrasses (*Agropyron* spp.) are grown on 6 million ha in the U.S. and Canada, where they provide excellent early-season forage, but lose nutritional quality by midsummer. Some producers believe that *A. fragile* maintains its quality longer than other crested wheatgrasses. This study compared herbage yield and quality of 3 *A. fragile* entries with *A. desertorum, A. cristatum*, I-28 (induced tetraploid of *A. cristatum)*, and the hybrid 'Hycrest'. Entries were established near Logan, Ut., on 1-m spacings. Herbage yield and quality were determined in year 2 and 3 at vegetative, boot, flower, seed ripe, and post-seed-ripe maturity stages (harvests 1 through 5) and on regrowth following the vegetative and boot-stage harvests. All entries flowered within 1 to 2 days of each other. Dry-matter yield increased for all grasses, but digestibility (IVDMD), crude protein, and elemental concentrations declined with maturity. Mean IVDMD values for all grasses were 741, 642, 534, 485, and 444 mg g^{-1} for harvests 1 through 5 and 490 and 560 mg g^{-1} for the regrowth following harvest 1 and 2. The *A. fragile* entries had higher N, Ca, P, and Ca/P, but lower yield, IVDMD, and grass tetany potential values than other *Agropyrons*. Contrary to expectations, IVDMD of *A. fragile* decreased to 500 mg g^{-1}, 6 to 11 days earlier than for the other *Agropyrons*. The I-28 and Hycrest entries had higher yield, IVDMD, K, and grass tetany risk and lower N, Ca, P, and Ca/P than the other *Agropyrons*.

Authors acknowledge the technical assistance provided by S.B. Hansen, T.W. Hansen, G.E. Shewmaker, and University of Idaho statistician B. Shafii.
The mention of a trade name does not imply endorsement by the USDA-ARS.
Manuscript accepted 23 November 1991.

Key Words: grass tetany, plant analysis, elements, crude protein, in vitro digestibility, wheatgrass

Crested wheatgrass (*Agropyron* spp.) was first successfully introduced into North America from Eurasia in 1906 (Dillman 1946). Additional accessions have been introduced since then and new hybrids have been developed (Asay et al. 1986). This genus has been widely used for range improvement in the central and northern Great Plains, Intermountain, Great Basin, Snake River, and Columbia Plateau regions of the United States and the prairie provinces of Canada (Mayland 1986). It grows in areas receiving 200 to 450 mm precipitation and produces 900 to 1,000 kg ha^{-1}, and sometimes 3,500 kg ha^{-1}. Digestible nutrients are high during the green-feed period, but decline rapidly as herbage matures (Mayland 1986, Murray et al. 1978, Newell and Moline 1978).

Increasing the dry-matter yield and extending the green-feed period would enhance the value of crested wheatgrass. Such a breeding and selection program would first require characterization of the available genetic base. A comparative evaluation of *A. fragile* was deemed necessary to evaluate the perception by some producers and researchers that it maintained its green-feed period longer than other *Agropyrons*. Our objectives were to characterize herbage yield and quality of 7 selected *Agropyron* entries and to determine if *A. fragile* or other entries conserved herbage quality later into the summer.

Materials and Methods

The selected entries included 'P-27', an experimental strain designated 'Syn-F', and a strain collected from Park Valley, Utah designated 'PV' [all *Agropyron fragile* (Roth) Candargy]; 'Fairway' [*A. cristatum* (L.) Gaertner]; an induced tetraploid strain of *A. cristatum* designated as 'I-28'; 'Nordan' [*A. desertorum* (Fisch. ex Link) Schultes]; and 'Hycrest', a hybrid between induced tetraploid *A. cristatum* and *A. desertorum.*

The study site was located 2 km south of Logan, Ut. (41° 45′ N, 111° 48′ W) at an altitude of 1,350 m. The soil was a Nibley silty clay loam classified as a fine, mixed mesic aquic argiustoll. The experimental area received an annual autumn application of 45 kg N ha^{-1}, and only natural precipitation. October through September precipitation was 404, 300, and 392 mm in 1986–87, 1987–88, and 1988–89, respectively.

Seedlings were transplanted from the glasshouse to the field on a 1-m grid. Individual plots, each consisting of a single 9-plant row of a given entry, were arranged in a split-plot design with 4 replications. Whole plots were randomly assigned to 5 harvest dates within each block and sub-plot effects were randomly assigned to the 7 grass entries. Plots were subjected to the same harvest treatments in both years.

Following a year of establishment in 1987, the plants were harvested by hand clipping at an approximate 5-cm stubble height on 10 and 12 May, 31 May and 2 June, 21 and 23 June, 12 and 14 July, and 2 and 4 August 1988 and 1989, respectively. These dates corresponded to vegetative, boot, bloom, seed ripe, and post-seed ripe stages of plant development (identified as 'primary' harvests 1 through 5), respectively. Regrowth from harvest treatments 1, 2, and 3 was also harvested on the fifth harvest date, after 84-, 63- and 42-day regrowth periods, respectively. Harvested herbage from all the plants in an individual plot was consolidated into 1 sample. Herbage was dried at 60° C in a forced-draft oven and then ground by a Wiley mill to pass through a 1-mm stainless steel screen. Since some plots had only 8 survivors, dry weights were expressed as g $plant^{-1}$, which when multiplied by 10 is equivalent to kg ha^{-1}.

Herbage subsamples were digested in 3:1 nitric:perchloric acid, diluted with water and analyzed for Na, Mn, Fe, Cu, and Zn by atomic absorption and colorimetrically for P using the vanadomolybdate procedure. A second aliquot was diluted with 1 g La $liter^{-1}$ as $LaCl_2$ and analyzed for Mg and Ca by atomic absorption and K by flame emission. Total N was determined by the Kjeldahl procedure, modified by excluding the selenium catalyst in the digestion salt. This omission lengthened digestion time by 15 minutes. Analytical accuracy (percent recovery) and precision (percent coefficient of variation) were determined using the National Institute of Standards and Technology, NIST-1572, citrus leaf sample which was analyzed with the grass samples. These values were: 82 ± 1.7 Ca, 100 ± 2.2 Mg, 93 ± 1.6 K, 118 ± 3.8 Na, 97 ± 3.7 Cu, 83 ± 5.2 Mn, 96 ± 5.3 Fe, 97 ± 3.0 Zn, 98 ± 0.8 P, and 101 ± 0.7% N.

Dry matter digestibility (IVDMD) of 1-mm Wiley-ground material was determined for all samples by near-infrared-reflectance spectroscopy (NIRS). Sixty samples were automatically selected to represent the whole population by a computer program called "SUBSET" (Windham et al. 1989). The selected samples were analyzed for in vitro dry matter digestibility (IVDMD) by the Tilley and Terry (1963) procedure. Calibration equations were computed between IVDMD and spectral reflectance at 2,398, 2,238, and 2,358 nm for the selected samples using the program called "BEST" (Shenk 1989). Samples were split, using 40 for calibration and 20 for validation. The selected prediction equation produced the lowest error of calibration and validation, and correlation coefficients with an F value greater than 10 (Table 1). This equation was then used to generate IVDMD for the samples not selected for chemical analysis.

Table 1. Calibration and validation statistics for IVDMD determinations.

Samples	Mean	Range	Standard error	Bias	R^2
	(g kg^{-1})				
Calibration	625	423–819	36		0.92[1]
Validation	611	436–807	32	2.3[2]	0.93[3]

[1]Multiple correlation coefficient for equation development.
[2]Difference between NIRS and laboratory determined values.
[3]Correlation coefficient between predicted and measured IVDMD.

Two indexes were computed from the above data. The KRAT was computed on a chemical valency basis as $[K(Ca + Mg)^{-1}]$, which is an index of the grass tetany hazard of these forages (Mayland and Grunes 1979). A selection index (SI), which combined yield and IVDMD into a single value, was also computed for each entry (Vogel et al. 1984).

Forage yield and quality differences among entries across years, and between entries within years, were evaluated by analysis of variance using a linear model (GLM, SAS Institute, Cary, N.C., PC version 6.1). Differences between entries or groups of entries were evaluated by single degree of freedom contrasts (Table 2). The comparison of IVDMD of *A. fragile* versus the other entries was of direct interest. The primary and regrowth data were analyzed as a split-split-plot with harvests as whole plot, entries as split-plots, and years as split-split plots. Replications and harvests were tested with replication × harvest as the error term, while entries were tested with the entry × harvest error term. A 5% probability level

Table 2. Single degree of freedom contrasts of selected wheatgrass entries for measures of yield and quality of primary and regrowth herbage.

Contrast	Yield	IVDMD	N	Ca	Mg	K	P	KRAT	Ca/P
Primary growth									
Syn-F + PV + P-27 vs. others	**	**	**	**	—	—	**	**	**
Syn-F vs. PV + P-27	*	*	**	**	**	—	—	—	**
PV vs. P-27	—	—	—	—	—	—	—	—	—
Fairway vs. Nordan	—	*	—	—	—	—	—	—	—
I-28 vs. Hycrest	—	—	—	—	—	—	—	—	—
I-28 + Hycrest vs. others	**	**	**	**	—	**	**	**	**
Regrowth									
Syn-F + PV + P-27 vs. others	—	**	—	—	**	**	—	—	—
Syn-F vs. PV + P-27	—	—	—	—	—	—	—	—	—
PV vs. P-27	—	—	—	—	—	—	—	—	—
Fairway vs. Nordan	**	—	—	**	—	—	—	—	—
I-28 vs. Hycrest	**	—	—	—	—	—	—	—	—
I-28 + Hycrest vs. others	**	**	—	*	—	**	—	**	**

*,**Significant differences between selected grasses or groups of grasses at $P \leq 0.05$ and $P \leq 0.01$; (—) is not significant.

($P<0.05$) was chosen as the critical threshold for these comparisons. We have shown the least significant difference ($LSD_{0.05}$) where appropriate. The linear and quadratic responses to primary-harvest number were also computed by the GLM procedure of SAS.

Primary forage yield and dry matter digestibility (within years) were also regressed upon harvest number for each entry. Differences in seasonal tends (intercepts and slopes) were evaluated using the T-test (Neter and Wasserman 1974, Steele and Torrie 1960). Data for entries were merged when slopes and intercepts for a given characteristic were not different at $P<0.01$.

Results

Primary Growth

Plant yield, IVDMD, and mineral concentrations of primary growth were determined for 7 crested wheatgrasses harvested at 5 different growth stages in each of 2 years (Table 3). Significant ($P<0.05$) differences occurred among entries and among harvests for all parameters. Year effects were significant only for plant yield. Entry × year interactions were not significant (data not shown).

Yield, IVDMD, and elemental concentrations were linearly related to harvest number (Table 3). The quadratic regression also accounted for a statistically significant ($P<0.05$) portion of the variation, but this was biologically important only for KRAT. The 7 entries were statistically segregated ($P<0.05$) into 3 groups on the basis of seasonal trends in herbage yield (Fig. 1). These groups consisted of Hycrest and I-28, Fairway and Nordan, and the 3 *A. fragile* entries. The entries segregated into *A. fragile* versus all others when considering their IVDMD (Fig. 2). Yield and IVDMD interactions of year × harvest were significant ($P<0.01$) and resulted from a change in the magnitude of yield and IVDMD differences between the 2 years and not from a difference in order of response (Figs. 1, 2). The 3 *A. fragile* entries had significantly

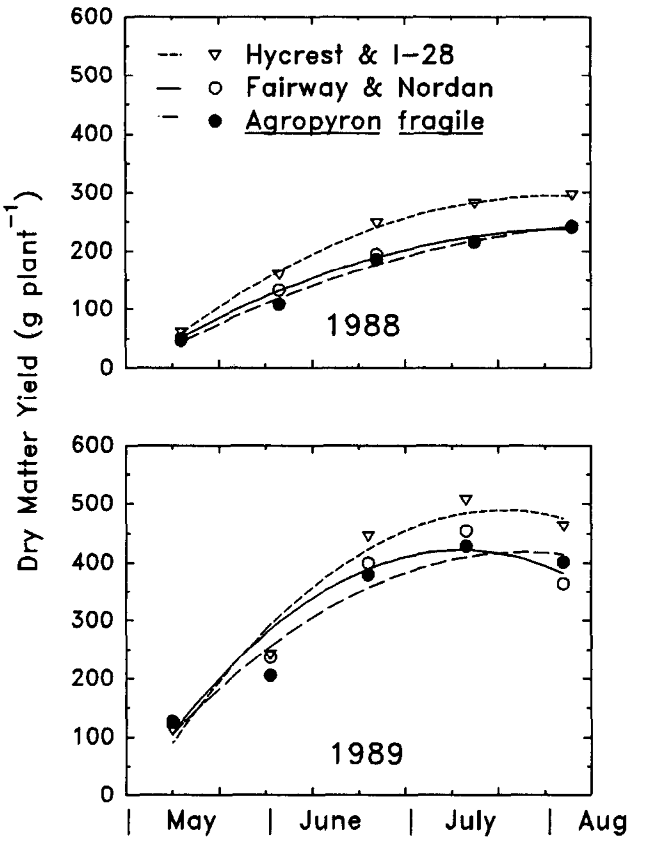

Fig. 1. Seasonal dry matter yield in each of 2 years for Hycrest and I-28, Fairway and Nordan, and the 3 *A. fragile* entries.

Table 3. Summary of yield and quality traits of primary growth combined over harvests and years, harvests and cultivars, and cultivars and years, and linear and quadratic responses of those traits to harvest number.

Source	Primary yield	IVDMD	N	Ca	Mg	K	P	KRAT	Ca/P
	($g\ plant^{-1}$)	($mg\ g^{-1}$)							
Entry									
Hycrest	290	583	18.4	2.4	0.90	17	1.5	2.3	1.9
I-28	280	586	18.3	2.4	0.89	17	1.5	2.3	1.9
Nordan	250	563	19.5	2.7	0.95	16	1.5	1.9	2.1
Fairway	230	580	19.3	2.7	0.93	16	1.5	2.0	2.2
PV	220	563	20.3	3.2	0.92	17	1.6	1.9	2.4
P-27	230	561	21.1	3.4	0.91	16	1.6	1.9	2.4
Syn-F	250	549	19.4	3.0	0.95	16	1.6	1.8	2.1
$LSD_{0.05}$	30	15	1.2	0.3	0.06	1	0.1	0.2	0.3
Year									
1988	180*	564	19	2.7	0.91	17	1.6	2.0	2.0
1989	320	574	20	2.9	0.93	17	1.5	1.9	2.3
Harvest									
1	80	741	37.6	4.5	1.42	27	2.7	2.1	1.7
2	180	642	24.2	3.2	0.99	21	2.0	2.3	1.6
3	300	534	15.7	2.4	0.79	15	1.4	2.2	1.7
4	350	485	11.0	2.0	0.70	11	0.9	1.9	2.3
5	340	444	9.0	2.0	0.70	10	0.6	1.6	3.5
$LSD_{0.05}$	30	17	1.8	0.3	0.11	1	0.1	0.3	0.3
Regression[1]									
Linear, r^2	0.46	0.88	0.87	0.61	0.64	0.89	0.93	0.18	0.50
Quadratic, r^2	0.52	0.91	0.96	0.73	0.69	0.93	0.95	0.31	0.68

*Year effects are different at $P\leq0.05$.

[1] r^2 is the proportion of trait variability, across entries, accounted for by the linear or quadratic relationship with harvest number.

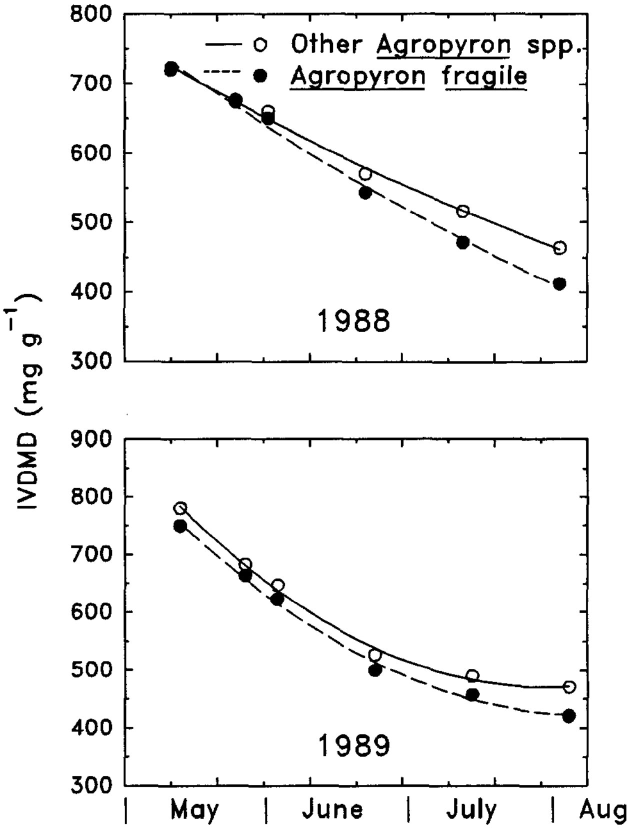

Fig. 2. Seasonal in vitro dry matter digestibility in each of 2 years for the 3 *A. fragile* and 4 other wheatgrasses.

($P<0.01$) lower dry matter yield (Fig. 1) and IVDMD than did the other *Agropyrons* (Fig. 2). The *A. fragile* entries contained greater N, Ca, P, and Ca/P and had smaller KRAT values than other *Agropyrons* (Tables 2, 3). The I-28 and Hycrest selections, however, had the highest yield, IVDMD, K, KRAT and lowest N, Ca, P, and Ca/P values of all *Agropyrons* tested. The *A. fragile* entries had much lower selection index (SI) values ($P<0.01$) than other grasses (not shown), while the I-28 + Hycrest had much higher ($P<0.01$) SI values. Other contrasts for SI were not significant.

Trace element concentrations were relatively high in immature vegetative herbage, but declined significantly ($P<0.05$) as herbage matured. Seasonal declines in trace element concentrations were 90-63 Na, 10-5 Cu, 42-19 Mn, 140-78 Fe, and 21-10 μg Zn g^{-1} (data not shown). Trace element concentrations were not different between entries (tested with single degree of freedom contrasts as in Table 2), however, significant ($P<0.01$) quadratic decreases occurred in the elemental concentrations as the herbage matured.

Regrowth

Regrowth following primary harvests 1, 2, and 3 accounted for 60, 17, and less than 1% of the total growth (Table 4). The regrowth following the third harvest was omitted from further analyses, because it was insignificant. IVDMD, N, Ca, K, and P were lower for the more mature herbage. Significant ($P<0.01$) differences occurred between entries for yield, IVDMD, Ca, Mg, K, P, KRAT, and Ca/P.

The total (primary + regrowth) and regrowth-forage yields for the 7 entries are shown in Table 4. Hycrest had the greatest and Fairway and *A. fragile* had the least total yield. There was significantly ($P<0.01$) greater yield in the second year and there was more regrowth following the first (120 g plant^{-1}) than the second harvest (37 g plant^{-1}). Regrowth from the *A. fragile* entries had the lowest IVDMD, Mg, and K concentration of the *Agropyrons* tested. The I-28 and Hycrest entries had the highest yield, IVDMD, K, and KRAT, but the lowest Ca and Ca/P values of the *Agropyrons* in this study (Table 2, 4).

Trace elements and their concentration ranges (decreasing with maturity) were 65–64 Na; 8–7 Cu; 33–22 Mn; 183–106 Fe; and 35–26 μg Zn g^{-1} (data not shown). Trace element concentrations were not different between the wheatgrass comparisons shown in Table 2.

Discussion

Each *Agropyron* evaluated in this study declined in quality as the season progressed and plants matured. This seasonal decline in quality parameters like digestibility, N, and P occurred in a quadratic fashion for most, if not all, grasses as they progressed from the vegetative through the reproductive stages of growth. Coulman and Knowles (1973), Murray et al. (1978), and White and Wight

Table 4. Summary of regrowth and total (regrowth + primary) yield and quality traits of regrowth combined over harvests and years, harvests and entries, and entries and years.

Source	Regrowth yield	Total yield	IVDMD	N	Ca	Mg	K	P	KRAT	Ca/P
	(g plant^{-1})	(g plant^{-1})	(mg g^{-1})							
Entry										
Hycrest	97	240	550	16.9	3.2	1.3	14	1.3	1.5	2.5
I-28	73	210	550	16.9	3.4	1.3	15	1.3	1.4	2.7
Nordan	79	220	530	19.5	3.4	1.3	13	1.4	1.2	2.5
Fairway	60	190	540	18.4	4.1	1.5	13	1.3	1.1	3.3
PV	76	190	520	17.4	3.7	1.1	13	1.2	1.3	3.0
P-27	84	200	510	17.7	3.6	1.1	14	1.2	1.3	3.0
Syn-F	80	210	490	16.9	3.4	1.2	12	1.3	1.2	2.7
$LSD_{0.05}$	23	50	30	2.3	0.5	0.2	2	0.1	0.2	0.6
Year										
1988	71**	160**	520	17.0	3.3	1.3	13	1.2**	1.3	2.8
1989	86	260	530	18.4	3.8	1.2	14	1.3	1.3	2.9
Harvest										
1	120**	200	490	13.6**	2.8**	1.00	11.6**	1.0	1.4	2.8
2	37	220	560	21.8	4.3	1.49	15.3	1.5	1.2	2.8

*,**significant difference at $P\leq0.05$ and $P\leq0.01$.

(1981) have also shown that the second order decline in the value of these traits is characteristic of grasses including the *Agropyrons*. This decline occurs because the uptake of soil-derived mineral elements slows or even stops while photosynthate accumulation continues through the flowering stage. Meanwhile, assimilated carbon is partitioned into structural components that are less easily digested. The net result is a dilution of mineral element concentration and reduction in digestibility of herbage.

Historic data on dry matter yields of *Agropyron* were summarized by Mayland (1986) and could be generalized as follows. Nordan and other *A. desertorum* types tended to yield more than P-27, 'Summit,' and other *A. fragile* types, which in turn yielded more than Fairway, 'Ruff,' and other *A. cristatum* types. Recent studies have shown a wide range in both yield and quality over the array of available *Agropyrons* (Lamb et al. 1984; Vogel et al. 1984, 1989).

Hycrest, Ephraim, I-28, Ruff, and Syn-F have been developed since the 1970's (Asay et al. 1986). Three of those grasses were included in this study. Yield and IVDMD of Hycrest and I-28 were greater than for the other entries tested. These yield responses were similar to those reported by Asay et al. (1986) for several sites where yields of Hycrest were greater than Nordan and least for Fairway. Hycrest and I-28 are similar in many respects, but differ from the 3 *A. fragile* selections as well as from Nordan and Fairway. Genetic traits contributing to higher yields in Hycrest and I-28 were also accompanied by lower N concentrations and higher grass tetany risk. Additional fertilizer N would likely prolong the green-feed period, but that would only occur in the presence of adequate soil water to support the extra growth. Annual variations in herbage N concentrations were noted at similar phenological stages (Angell et al. 1990). These fluctuations, which did not occur in our study, were attributed to yearly differences in forage yield, available soil water and N, and production of root exudates (Angell et al. 1990).

The Syn-F entry yielded more than the other *A. fragile* selections, but the digestibility was lower than for any of the grasses tested in this study. If Syn-F is to be a useful forage grass, the IVDMD must be increased. Information on quality characteristics is based largely on laboratory data and the forage value must be verified by animal-grazing studies.

Bedell's studies at Archer, Wyo.(Mayland 1986), showed that as long as soil moisture was available and the growing point was removed, crested wheatgrass remained vegetative and highly nutritious. Miller et al. (1990) reported that early removal of the apical meristem prevented extension of the reproductive tiller and encouraged vegetative growth. They reported that the amount of regrowth was correlated ($P<0.05$) with phenological growth stage and amount of standing crop present at time of primary harvest, and amount of soil water available to sustain regrowth. Primary harvests 1 and 2 in our study occurred at the vegetative and boot stage, respectively. Clipping at the vegetative and boot stage removed the apical meristem, allowing for continued vegetative growth.

Regrowth occurred after the first and second primary harvest, but regrowth following the third harvest was interrupted because available soil water had been depleted. Miller et al. (1990) noted that regrowth following clipping at the early, mid, and late vegetative stages contributed 68, 50, and 34% of the total forage produced. Regrowth following early and late boot stage clipping accounted for 21 and 11% of total harvested forage. Similar results were found in this study, where regrowth following the first (vegetative) or second (boot stage) primary harvest produced 60 and 17% of the total growth, respectively.

Measuring the net production of digestible matter is another way to evaluate the advantage of early harvesting followed by harvesting of the regrowth. The mass of digestible dry matter for primary growth plus regrowth across entries was 118, 136, 160, 170, and 151 g for the 1, 2, 3, 4, and 5 harvest sequence, respectively. The SI values, which reflect both yield and IVDMD, were greatest for Hycrest and I-28 and least for the *A. fragile* group. Digestible dry matter yield does not reflect the effect of herbage maturity on grazing behavior and dry matter intake. The presence of reproductive tillers deterred sheep (Murray 1984) and cattle (Ganskopp, D.C., personal communication) from grazing these bunch grasses.

Hycrest and I-28, while producing more dry matter and having higher IVDMD than other entries, also had higher grass tetany risk. Differences in Ca, Mg, and K led to increasing KRAT values, thereby posing a greater risk of grass tetany to grazing cattle and sheep. An evaluation of the genetic variability of Mg, Ca, K, and KRAT provides evidence that in crested wheatgrass there is opportunity to reduce the grass tetany risk through selection and breeding (Mayland and Asay 1989, Vogel et al. 1989). The IVDMD in the 3 *A. fragile* grasses declined to 500 mg g^{-1} 6 to 11 days earlier than it did for the other *Agropyrons* in this study. This earlier loss in quality of *A. fragile* occurred even though all entries flowered within 1 or 2 days of each other.

Animals grazing these grasses in summer and fall might benefit from supplemental Na, Cu (only if diet is also high in S or Mo), and Zn (Mayland et al. 1980, Miller et al. 1988, Minson 1990). Maximum grass tetany index (KRAT) occurred during late May and early June (not shown). Animals grazing crested wheatgrass pastures in May and June often succumb to grass tetany in this area. In dairy cows, the tetany incidence is about 3% when herbage KRAT is 2.2 and increases rapidly with higher KRAT (Mayland and Grunes 1979). In general, the 3 *A. fragile* entries posed a smaller risk than I-28 and Hycrest of causing grass tetany (Table 3). Nordan and Fairway posed an intermediate risk. Ruminant animals, especially those in early lactation, are susceptible to grass tetany and may be supplemented with additional Mg to minimize loses (Mayland and Grunes 1979, Minson 1990).

The perception that *A. fragile* maintains its green-feed period longer than do other *Agropyrons* is not supported by results of this study. Nevertheless, entries from this species may provide a breeding program some valuable genetic characteristics, like high Mg and Ca uptake.

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