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Genotype and Genotype X Environment Interaction Effects on Forage Yield and Quality of Crested Wheatgrasses

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Genotype and Genotype × Environment Interaction Effects on Forage Yield and Quality of Crested Wheatgrasses[1]

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ABSTRACT

Genotype, environment, and genotype × environment interaction effects for forage yield and quality of the crested wheatgrasses (*Agropyron cristatum*) and (*A. desertorum*) were studied using an array of 42 crested wheatgrass introductions, experimental lines, and released cultivars that were selected to be representative of the mix of germplasm available to a breeder. They were grown in two environments, Lincoln and Alliance, Nebr., that differ markedly in climate. Forage yield and forage quality as measured by in vitro dry matter digestibility (IVDMD) and percent protein were determined in both locations in 1980 and 1981. In the combined analyses over years and locations, there were significant differences among strains or genotypes and locations for first-harvest forage yield, IVDMD, and protein. Strain × location interaction effects were significant only for first-harvest forage yield and for this trait its variance component was only 0.3 as large as the variance component for strains. Strain × year interaction effects were not significant. Spearmen correlations, used to show relative ranking of the strains at the two locations, were moderate and positive for all first-cut traits. The results indicate that existing genetic variability in forage yield and quality should permit the development of improved crested wheatgrasses and that at least in the initial stages of a breeding program, selection for these traits could be done in a single location and year.

***Additional index words:* *Agropyron cristatum*, *Agropyron desertorum*, IVDMD, Protein, Digestibility.**

CRESTED wheatgrass is a genetic complex made up of several species of which the two most important are *Agropyron cristatum* (L.) Gaertn. spp. *pectinatum* (Bieb.) Tzvel. and *A. desertorum* (Fisch. ex Link) (Asay and Dewey, 1983; Dewey, 1983). In North America, the commonly used cultivars of *A. desertorum* are often referred to as the Standard type and are typified by the cultivar Nordan while the cultivar Fairway typifies the *A. cristatum* spp. *pectinatum* or Fairway types. The standard types are tetraploids while the Fairway types are usually diploids (Dewey, 1983). For brevity, these two species will be referred to as crested wheatgrass in this paper as they are in commerce. Crested wheatgrass, which has the ability to become established, persist, and be productive under adverse rangeland conditions, has been seeded into thousands of acres of abandoned farmland and overgrazed rangeland in the Great Plains and the intermountain regions of western USA and Canada (Dillman, 1946; Rogler and Lorenz, 1983).

Despite the wide-spread use of crested wheatgrass, only limited research has been conducted on the variability of forage yield and quality in this grass and the stability of these traits over environments. Murphy (1942) studied forage yield among plants tested in clonal line nurseries and as replicated clonal progenies in Minnesota and found significant differences among clonal progenies for yield. Schaff et al. (1962) observed significant differences in yields of forage and seed among crested wheatgrass strains. Ranges in yield, expressed as a percentage of the mean, were 21 for forage yield and 71 for seed yield. Junk and Austenson (1971) evaluated forage samples for quality of five crested wheatgrass strains grown at six locations in Saskatchewan and Alberta, Canada. Only one forage sample per strain per location was analyzed and the location × strain interaction effect was used to test for strain and location effects. Strain effects were considerably smaller than location effects and were significant for in vitro dry matter digestibility (IVDMD), crude fiber, and stem diameter. Cultivar effects were not significant for protein, hay yield, or for 10 different minerals.

Coulman and Knowles (1974) found significant differences in in vitro organic matter digestibility (IVOMD) among eight strains of crested wheatgrass. They also demonstrated that significant differences in digestibility existed among the parent clones of 'Parkway' and an experimental strain. The IVDMD and plant yields were not correlated but IVDMD and leaf percentage were highly correlated (r = 0.89) in the clonal material. Narrow-sense heritability estimates ranged from 0.36 to 0.76. Weekly sampling of the strains in their study for IVDMD indicated that the post-anthesis sampling gave maximum strain differences. Year × clone interaction effects were not significant for digestibility, suggesting that breeding material could be adequately evaluated in one year for IVDMD.

The purposes of this study were to obtain estimates of the variability for forage yield and quality in the crested wheatgrass complex and to determine the relative magnitudes of genotype, environment, and genotype × environment interaction effects for these traits. Forage quality was estimated by IVDMD and protein percentages. Entries were chosen to be representative of the genetic diversity in the crested wheatgrass complex and were grown in two Nebraska locations that differ markedly in climate.

MATERIALS AND METHODS

The two locations used in this study were Alliance and Lincoln, Nebr. Alliance is located approximately 540 km west of Lincoln at about the same latitude. The climatic variables of Lincoln vs. Alliance are as follows: altitude 351 vs. 1226 m; annual precipitation 740 vs. 400 mm; average annual temperature 11 vs. 8°C; growing season 160 vs. 120 days (National Oceanic and Atmospheric Administration, 1979–1981.). The Lincoln and Alliance experiments were located on a Kennebec soil (fine-silty, mixed, mesic Cumulic Hapludoll) and a Keith soil (fine-silty, mixed, mesic Aridic Argiustoll), respectively.

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Forty-two strains of crested wheatgrass were included in this study. Thirty-one were plant introductions (16 *A. cristatum* and 15 *A. desertorum*); seven were Nebraska experimental strains which were derived primarily from 'Nebraska 10' intercrossed with Turkish introductions by L. C. Newell (1966); two were clonal lines vegetatively propagated from Nebraska 10. The cultivars Ruff (*A cristatum* spp. *pectinatum*) and Nordan (*A. desertorum*) were included as checks. The Lincoln nursery contained eight additional strains (7 plant introductions and 1 Nebraska experimental) for which there were insufficient seedlings for inclusion at the Alliance nursery.

Plants of all strains except the two clonal lines from Nebraska 10 were started in the greenhouse in February 1979 and were grown as individual seedlings in Cone-tainer[3] fir cells which are 12 cm long and 2.5 cm in diameter. The two clonal lines were formed by subdividing two clones of Nebraska 10 into 80 ramets each and transplanting those ramets into Cone-tainer fir cells. The plants were transplanted into nurseries at Lincoln on 10 May 1979 and at Alliance on 22 and 23 May 1979. Plots were single rows of ten plants with plants and rows spaced 1.1 m apart. The experimental design at each location was a randomized complete block with four replications. Each nursery was surrounded by a row of border plants.

The Lincoln nursery was fertilized with 100, 112, and 90 kg ha^{-1} N in September 1979, April 1980, and April 1981, respectively. The Alliance nursery was fertilized with 45 kg ha^{-1} N and 22 kg ha^{-1} P in April 1980 and 67 kg ha^{-1} N in May 1981. Weeds were controlled in both nurseries by hoeing, cultivation, and spring application of herbicides, primarily 2,4-D [(2,4-dichlorophenoxy) acetic acid] and DCPA (dimethyl tetrachloroterepthalate). Both nurseries were kept weed free in 1979 and were not harvested. Both nurseries were mowed in the early spring of 1980 to remove the previous years growth.

First cut or first harvest of forage was made after all plants in the nursery had headed which was the latter part of June at Lincoln and the first week of July at Alliance. Second cut of forage was harvested after a heavy frost had ended the growing season (last week of October in Alliance and 2nd week of November at Lincoln). A second cut was not harvested in 1980 at Alliance because of insufficient regrowth. Regrowth in 1981 was minimized by competition from warm-season grass weeds at both locations. In addition, crown rot due to *Helminthosporium* or *Fusarium* spp. in the Lincoln nursery and below average precipitation at the Alliance nursery further reduced regrowth. Only 24 strains that yielded at least an average of 230 g/plant in three out of the four replications at each location in 1981 were analyzed for second cut forage quality. All strains were analyzed for first cut forage quality.

Ten of the strains were harvested on an individual plant basis for the first cut to obtain an estimate of within strain variation while the remainder were harvested on a plot basis. The ten strains that were selected for individual plant harvest were those that appeared to have the most agronomic potential at Lincoln in June of 1980 and included six plant introductions, one experimental strain, Ruff, Nordan, and one of the clonal lines from Nebraska 10. Individual plants were cut with hand sickles (in Lincoln during 1980 and 1981; in Alliance during 1980) or with a plot mower (in Alliance during 1981) at a height of 13 cm. Strains harvested on a plot basis were cut at a height of 13 cm with a flail-type forage harvester. Second cut harvests were on a plot basis for all strains in both nurseries.

Subsamples for determination of dry matter, protein, and IVDMD consisted of approximately 200 g of freshly harvested forage, which was weighed in the field, dried in a forced air oven at 65°C and reweighed. Dry matter content was determined and yields were calculated on a dry weight basis. Dried samples were ground in a Wiley mill through a 1-mm screen. Ground samples from plots and individual plants were grouped and analyzed for quality traits by replication. Samples were organized in this manner to reduce the variability in IVDMD caused by differences in rumen fluid used in different runs. An entire replicate was analyzed in a single run. The Tilley and Terry (1963) procedure was used to determine IVDMD while the Kjeldahl procedure (AOAC, 1960) was used to determine percent N. Crude protein was calculated by multiplying Kjeldahl N percent by 6.25.

Days to heading was the number of days after 30 April when the majority of spikes had emerged from the boot of individual plants. Basal width of all plants were measured in April 1980 at Lincoln and in May 1980 at Alliance and represents the 1st year spread of plants. Height to the top of the spikes was measured for all plants in both years at Lincoln and in 1981 at Alliance. In 1980 at Alliance, only those strains harvested on an individual plant basis were measured for plant height.

To simplify comparisons among strains and to compensate for missing plants, all results were expressed and analyzed as individual plant means per plot. Mean plant yields per plot for strains harvested on a plot basis were determined by dividing the yield by the number of plants harvested in a plot. Quality traits were analyzed from one representative sample of fresh forage from the entire plot. For strains harvested on an individual plant basis, the mean individual plant values for each plot were used in the statistical analyses. The individual plant data will not be presented in this paper.

Analyses of variance procedures were used to evaluate results at each location for each year, over years for a single location, over locations for a single year, and over years for both locations. Replicate effects were removed from the combined analyses over years and locations to simplify the analyses and to still allow determination of the main effects of strain, location, and year.

Strains, locations, and years were considered to be random effects in all analyses. Only the 42 strains common to both locations were used in the over locations analyses. Variance components were calculated from the mean squares using conventional procedures. Standard errors of the variance components were calculated using procedures described by Crump (1951). Due to the diversity of the two locations, simple F tests (Steel and Torrie, 1960) were conducted for each year over locations and for the 2 years combined over locations to test for homogeneity of variances. Procedures from the Statistical Analyses System (Helwig and Council, 1979) were used for all analyses.

Pearson correlation coefficients were determined between traits. Ranked correlations were also determined between locations for each trait by using Spearman correlations (Steel and Torrie, 1960; Helwig and Council, 1979).

The selection index developed by the Nebraska corn breeding program for combining yield and IVDMD into a single index value (Roth, 1971) was also calculated for each strain. The index is: NI = yield $-$ $\bar{X}$ yield/ s (yield) + IVDMD $-$ $\bar{X}$ IVDMD/s(IVDMD) where s is the square root of the error mean square in the F test for the appropriate trait.

[3] Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA or Univ. of Nebraska and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Table 1. Location means and range values of agronomic traits of crested wheatgrass strains grown at Lincoln and Alliance, Nebr., in 1980 and 1981.

Location year	Statistics	Heading date	Plant Width	Plant Height	Yield Total	Yield Cut 1	Yield Cut 2	IVDMD Cut 1	IVDMD Cut 2†	Protein Cut 1	Protein Cut 2†
		days	cm	cm	g/plant	g/plant	g/plant	%	%	%	%
Lincoln:											
1980	$\bar{X}$	25**	20**	67**	331**	203**	128**	49.2**	54.9	12.4**	17.7
	range	22–30	15–25	51–76	126–608	114–361	17–253	42.3–55.6	47.6–60.6	8.6–15.4	14.9–19.7
1981	$\bar{X}$	23**		66**	246**	200**	44*	50.1**	47.4*	10.7**	18.2**†
	range	12–30		50–82	95–487	95–484	0–93	44.0–56.1	37.3–55.2	9.1–13.1	14.7–20.7
1980–1981	$\bar{X}$	24**		66**	293**	202**	90**	49.6**	52.5*	11.6**	17.8*
	range	17–28		50–78	140–484	105–378	0–172	42.9–54.1	44.8–57.9	8.9–14.1	15.8–19.8
	σ_g^2/σ_{gy}^2‡	1.2		3.7	2.3	2.0	NS	NS	NS	NS	NS
Alliance:											
1980	$\bar{X}$		18**	73**§		148**		42.7**		9.0**	
	range		12–20	60–80		74–218		34.5–48.2		7.3–10.8	
1981	$\bar{X}$	32**		57**	225**	191**	34**	51.8**	51.1*	9.2**	12.1**
	range	23–38		44–66	120–304	107–265	13–56	43.2–55.9	42.7–56.7	7.6–12.1	9.5–14.0
1980–1981	$\bar{X}$					170**		47.2**		9.1**	
	range					91–223		38.9–51.9		7.6–10.9	
	σ_g^2/σ_{gy}^2‡					2.1		NS		0.9	
Overall	$\bar{X}$					188*		48.5**		10.4**	
	range					111–294		41.8–53.8		8.7–12.5	
Ruff	$\bar{X}$					243		51.0		10.7	
Nordan	$\bar{X}$					267		49.4		10.9	
LSD 0.05						58		2.1		0.8	

*,** Indicate the F test for strains was significant at the 0.05 and 0.01 levels of probability, respectively.
† Analyzed with 23 df for strains in 1981.
‡ σ_g^2 and σ_{gy}^2 are the variance due to strains and the variance due to the interaction of strains and years, respectively; NS indicates that the mean square due to the interaction of strains and years was not significant in ANOVA.
§ Mean based on ten strains.

RESULTS AND DISCUSSION

The environments of Lincoln and Alliance represent nearly the opposite ends of the east-to-west climatic continuum of the Great Plains. Alliance is typical of the arid plains environment where crested wheatgrass is well adapted. While crested wheatgrasses can be grown in Lincoln, other cool-season grasses such as smooth bromegrass (*Bromus inermis* Leyss.) are usually more productive. Because of the large difference in climate between these two sites, they are useful for estimating the relative magnitude of genotype (G) and genotype × environment (GE) interaction effects. Strains will be referred to as genotypes to conform to conventional terminology while discussing GE interactions.

During the 3 years of this study (1979–1981), the mean annual precipitation and temperature at Lincoln were 621 mm and 11.1 °C, respectively, while at Alliance they were 383 mm and 8.5 °C, respectively (National Oceanic and Atmospheric Administration, 1979–1981.). As a result of the differences in climate, the forage yields for both first and second cuts were higher, heading date was earlier, and 1st year spread was greater at Lincoln than at Alliance (Table 1). Protein content for both cuts was lower at Alliance than at Lincoln. There were no other consistent trends between locations for the other traits evaluated. Tests for homogeneity of variance between locations indicated significant differences for some traits. However, the F-statistics for the homogeneity tests were all 2.6 or less, therefore combined analyses over locations were conducted.

In all four single year and location analyses, there were significant differences among strains for all traits evaluated except for second cut IVDMD and protein at Lincoln in 1980 (Table 1). There was considerable variation among strain means for all traits as indicated by the wide range of values. In the over-years analyses for each location, there were significant differences among genotypes for all traits for which 2 years' data were available (Table 1). In the over-years analyses within locations the mean squares for the genotype × year (GY) interaction effect was not significant for second-cut yield and for both first- and second-cut IVDMD and protein at Lincoln and for first cut IVDMD at Alliance. The ratio of the variance component for genotypes (σ_g^2) divided by the genotype × year variance component (σ_g^2/σ_{gy}^2) gives an indication of the relative magnitude of the genotype (G) and GY effects. For the traits for which the GY effect was significant the σ_g^2/σ_{gy}^2 ratio was ≥ 2.0 except for heading date at Lincoln and protein at Alliance. These results demonstrate that there are definite genetic differences among crested wheatgrasses within locations for the traits evaluated and that these differences are consistent over years. These results suggest that within a location, a single year of sampling should be sufficient to identify crested wheatgrass strains differing in first cut IVDMD. Once the plants are established, a single year of testing should be sufficient to separate strains with high- and low- first cut yields but additional testing may be needed to differentiate among the high yielding lines.

In the individual year analyses over locations for 1980 (not shown), mean squares for genotypes were

Table 2. Mean squares of plot means from the combined analyses of Lincoln and Alliance crested wheatgrass nurseries for 1981.

	Mean squares								
				First cut			Second cut		
Source	Heading date	Height	Total yield‡	Yield	IVDMD	Protein	Yield‡	IVDMD§	Protein§
	days	cm	g/plant		%		g/plant	%	
Location (L)	6 847**	7 083**	36 524	20 176	155.25	212.17**	5 586	685.92	1 591.66**
Rep (R)	8	160**	39 457**	24 499**	163.57**	4.21**	3 172**	182.27**	14.55**
Strain (G)	77**	249**	19 355*	17 249*	19.14**	3.81**	963	59.52	8.98
G × L	11*	38**	9 647**	8 294**	15.80	1.26*	677**	96.95**	7.54**
Error	6	20	2 153	1 827	15.43	0.80	316	40.88	2.67
σ^2_g/σ^2_{gy}†	6.6	5.8	0.6	0.7	29.0	2.6	0.4	−0.33	0.01

*,** Indicate significance at the 0.05 and 0.01 levels of probability, respectively.
† Defined in Table 1.
‡ Traits analyzed with 47 degrees of freedom for strains.
§ Traits analyzed with 23 degrees of freedom for strains.

Table 3. Analysis of variance form and mean squares of plot means for the combined analysis for the Lincoln and Alliance crested wheatgrass nurseries for 1980 and 1981 for the first cut.

			Mean squares		
			First cut		
Source	Degrees of freedom	Expected mean squares†	Yield	IVDMD	Protein
			g/plant	%	
Location (L)	1 (1−1)	$\sigma^2_{gyl} + \sigma^2_{lg} + g\sigma^2_{yl} + yg\sigma^2_l$	61 583	285.13	283.38*
Strain (G)	41 (g−1)	$\sigma^2_{gyl} + \sigma^2_{lg} + \sigma^2_{gy} + gl\sigma^2_g$	7 245**	20.07**	1.85*
L × G	41 (1−1)(g−1)	$\sigma^2_{gyl} + \sigma y\sigma^2_{lg}$	2 090**	3.29	0.55
Year (Y)	1 (y−1)	$\sigma^2_{gyl} + g\sigma^2_{yl} + l\sigma^2_{gy} + lg\sigma^2_y$	17 142	1 074.64	23.08
Y × L	1 (y−1)(1−1)	$\sigma^2_{gyl} + g\sigma^2_{yl}$	20 840**	664.75*	40.83**
Y × G	41 (y−1)(g−1)	$\sigma^2_{gyl} + l\sigma^2_{gy}$	1 369	2.29	0.23
Y × L × G	41 (y−1)(1−1)(g−1)	σ^2_{gyl}	1 003	2.21	0.34

*,** Indicate significance at the 0.05 and 0.01 levels of probability, respectively.
† l = number of locations; g = number of strains; y = number of harvests; σ^2_l = variance due to locations; σ^2_g = variance due to strains; σ^2_{lg} = variance due to the interaction of location and strain; σ^2_{yg} = variance due to the interaction harvest year and strain; σ^2_{ly} = variance due to the interaction of location and year; σ^2_{ylg} = variance due to the interaction of year, location, and strain.

Table 4. Variance component estimates over years and locations for first cut forage yields and quality for created wheatgrasses grown at Lincoln and Alliance in 1980 and 1981.

	Variance ± SE		
Component	Yield	IVDMD	Protein
	g/plant	%	
σ^2_l	472 ± 631	−4.53 ± 7.03	2.89 ± 2.78
σ^2_g	1197 ± 417	4.17 ± 1.10	0.35 ± 0.11
σ^2_{gl}	543 ± 250	0.54 ± 0.43	0.11 ± 0.07
σ^2_y	−48 ± 262	4.88 ± 12.18	−0.21 ± 0.46
σ^2_{yl}	472 ± 405	15.77 ± 12.92	0.96 ± 0.79
σ^2_{gy}	197 ± 183	0.04 ± 0.34	−0.06 ± 0.04
σ^2_{gyl}	1003 ± 216	2.21 ± 0.48	0.34 ± 0.07

significant for all traits. The genotype × location effects (GL) were significant only for first-cut forage yield and first-cut protein and the σ^2_g/σ^2_{gl} ratio for these traits was 3.0 and 0.8, respectively. The term σ^2_{gl} is the variance due to the interaction of strains and locations. In 1980, second-cut forage yields were not harvested at Alliance. In 1981, there were significant differences among genotypes for all traits except for second-cut yield, IVDMD, and protein (Table 2). As pointed out previously, second-cut yields in 1981 were small at both locations and only 24 strains produced enough forage to be used in the quality analyses. The small quantity of available forage probably contributed to the large experimental errors. In contrast to 1980, 1981 GL effects were significant for all traits except for first cut IVDMD (Table 2). Although GL effects were significant for heading date, height, and first cut protein the σ^2_g/σ^2_{gl} ratio was ≥ 2.6 indicating that the effects of genotypes were more important than the GL effects. However, for yield the GL effect was greater than the effect of genotypes.

The traits we were primarily interested in and for which we have two years' data for both locations were first cut yield, IVDMD, and protein. In the combined analyses over years and locations, there were significant differences among strains for these traits (Table 3). In this analyses the GL effect was significant for first-cut forage yield but not for IVDMD and protein. The GY effect was not significant for any of these traits in the overall analyses (Table 3). These results are consistent with the single location over years analyses and the single year over locations analyses. The variance component for strains (σ^2_g) was considerably larger than the variance components for GL (σ^2_{gl}) or GY (σ^2_{gy}) (Table 4). The σ^2_g/σ^2_{gl} and σ^2_g/σ^2_{gy} ratios were 2.2 and 6.1, respectively, for first cut forage yield. These ratios were even larger for first cut IVDMD and protein.

These results demonstrate that there are significant genetic differences among crested wheatgrasses for first cut forage yield, IVDMD, and protein and for heading date, height, and 1st year spread and that

Table 5. Spearman correlations for identical traits between Lincoln and Alliance for 1980, 1981, and for the mean of 1980 and 1981.

Year	Heading date	Width	Height	Total yield	First cut IVDMD	First cut Protein	First cut Yield	Second cut IVDMD	Second cut Protein	Second cut Yield
1980		0.57**	0.90**		0.69**	0.28	0.69**			
1981	0.81**		0.74**	0.46**	0.37*	0.40**	0.46**	−0.20	0.30	0.32
1980 and 1981 mean					0.60**	0.47**	0.69**			

*,** Indicate significance at the 0.05 and 0.01 levels of probability, respectively.

these differences are expressed even in diverse environments. In specific years, the GL interaction effects can be quite large particularly for yield.

Second cut forage yields comprised 38% of the total forage yield at Lincoln in 1980 and less than 20% for both Lincoln and Alliance in 1981. Because of the small quantity of regrowth forage produced, emphasis in a crested wheatgrass breeding program should be placed on improving first-cut forage yield and quality. First-cut forage yield and quality also appear to be more stable over environments than the same second-cut traits.

The validity of the variance components analyses in comparing the relative importance of genotype and GE effects can be evaluated by comparing the ranking of strains in the test environments. Spearmen correlations, which are correlations of order of ranking, were used to compare the ranking of the strains in the two environments (Table 5). A Spearman correlation of 1.0 would mean that the strains ranked exactly the same in both environments and that GE effects due to differences in the direction of response were nonexistent. There were large positive Spearman correlations between locations for heading date and height (Table 5). Correlations for 1st year width were lower. Spearman correlations between locations were high for first-cut yield and IVDMD in 1980 and for the 1980–1981 means for the same traits. The Spearman correlations for these traits for 1981 were lower. This was expected because of the small σ^2_g/σ^2_{gl} ratio for 1981. Except for 1981, the Spearman correlations for protein were lower than for IVDMD. In general, the Spearman correlations indicate that the rankings of strains at the two locations were fairly consistent for first-cut traits.

The 15 strains with the highest overall means for first-cut yields and IVDMD for both Lincoln and Alliance are listed in order of rank in Table 6. For yield (Spearman correlation was 0.69) there were 10 strains in common between locations while for IVDMD (Spearman correlation was 0.60) there were eight strains in common. Strains common to both Lincoln and Alliance lists probably have broad adaptability. Nordan, which is one of the most widely grown crested wheatgrasses in North America, ranked high on both lists for yield.

Pearson correlation coefficients were determined among traits for both locations and the correlations for Lincoln and Alliance in 1981 are listed in Table 7. The correlations for 1980 were similar to those for 1981. In general, the strains with the highest first-cut yields also had high second-cut yields and were taller but earlier in maturity than the low yielding strains. The strains with the highest first-cut IVDMD tended to be later in maturity. Although maturity

Table 6. Means ranked over years (1980 and 1981) for the fifteen strains with the highest first cut yields and IVDMD at each location.

$\bar{X}$	Lincoln strains	Rank	Alliance strains	$\bar{X}$
		Yield (g/plant)		
378	10b-1 c†	1	Nordan c	223
324	10b-2	2	NE #6	217
313	PI 325180 c	3	10b-1 c	210
310	Nordan c	4	PI 340060 c	204
297	NE #3 c	5	Ruff c	203
296	PI 369170 c	6	NE #3 c	202
286	PI 370645 c	7	PI 370645 c	201
285	Ruff c	8	NE #4 c	197
244	PI 277354	9	PI 369170 c	194
242	PI 401003	10	PI 325180 c	191
234	NE #4 c	11	PI 383538	190
229	PI 314596	12	PI 316121	189
224	NE #5 c	13	PI 315068	186
211	PI 340060 c	14	PI 369168	185
209	NE #8	15	NE #5 c	184
		IVDMD (%)		
55.7	PI 369167 c	1	PI 369167 c	51.9
54.1	NE #5	2	PI 172691	50.8
52.1	PI 206396	3	Ruff c	50.0
52.1	PI 172690	4	PI 369170 c	50.0
52.0	NE #7	5	PI 314596 c	50.0
51.9	PI 369170 c	6	PI 401003	49.9
51.9	Ruff c	7	PI 383538	49.6
51.8	PI 369168 c	8	NE #4 c	49.5
51.7	PI 272730 c	9	PI 325180	49.3
51.7	PI 325180 c	10	10b-1	49.1
51.5	PI 203443	11	PI 369168 c	49.0
51.4	PI 369169	12	NE #8	48.7
51.4	NE #4 c	13	PI 172690	48.7
51.2	PI 315066	14	Nordan	48.5
51.1	PI 314596 c	15	PI 273730 c	48.4

† Strains followed by a "c" were in the top 15 in both locations.

did affect forage quality as measured by first-cut IVDMD, most of the differences among strains for this trait was probably due to factors other than maturity since most of the strains headed within the same week at both locations.

The most important forage traits of crested wheatgrass are yield and digestibility (White and Wright, 1981). Since first-cut forage yields comprise the bulk of the forage produced by crested wheatgrass and since there is considerable genetic variation for both first-cut yield and IVDMD, breeding programs in crested wheatgrass should concentrate on improving these traits. Since the correlation between these traits is low (Table 7), it should be possible to concurrently improve both traits. The selection index developed by Roth (1971) gives equal weight to both yield and IVDMD and for brevity we will call it the Nebraska Index (NI). Selection for digestible yield is not suitable because only high yielding strains are usually selected. The strains with the highest and lowest NI values over years and locations are listed in Table 8.

Table 7. Phenotypic correlations between traits for 1981. The correlations for Lincoln are above the diagonal and those for Alliance are below the diagonal.

	Heading date	Height	First cut			Second cut			Total yield
			IVDMD	Protein	Yield	IVDMD	Protein	Yield	
Heading date		−0.43**	0.56**	0.29	−0.34*	0.28	0.29	0.14	−0.29
Height	−0.40**		−0.14	−0.33	0.56**	−0.23	−0.07	0.03	0.49**
IVDMD first cut	0.59**	−0.18		0.24	−0.17	0.20	0.27	0.05	−0.15
Protein first cut	0.34*	−0.22	0.36*		0.02	−0.24	−0.27	0.18	0.06
Yield first cut	−0.12	0.67**	0.10	−0.26		−0.45*	−0.34	0.33*	0.95**
IVDMD second cut	−0.38	0.55**	−0.05	−0.27	0.36		0.81**	−0.42*	−0.51*
Protein second cut	−0.28	0.75**	−0.22	0.20	0.30	0.49*		−0.45*	−0.41*
Yield second cut	−0.06	0.49**	0.18	0.02	0.61**	0.14	0.28		0.56**
Total yield	−0.10	0.66**	0.14	−0.22	0.98**	0.32	0.31	0.76**	

*,** Indicate significance at the 0.05 and 0.01 levels of probability, respectively.

Table 8. Strains with the highest and lowest first cut selection index calculated from the overall analysis.

Strain	Species†	Index	Yield	IVDMD
			g	%
High				
PI 369167	AC	2.8	181	53.8
PI 369170	AC	2.5	245	51.0
Ruff	AC	2.5	243	51.0
PI 325180	AC	2.4	252	50.5
10b-1	AD	2.2	294	48.7
Nordan	AD	2.1	267	49.4
Low				
PI 229521	AC	−4.0	152	42.6
PI 314927	AD	−3.1	142	44.6
10b-2	AD	−2.5	250	41.8
PI 203439	AC	−1.9	120	47.6
PI 315068	AD	−1.5	183	45.9
$\bar{X}$		0.0	188	48.5

† AC = *A. cristatum*; AD = *A. desertorum*.

The two released cultivars, Nordan and Ruff, were among the top 5, however, two PI lines had higher NI values. The PI lines 369167, 369170, and 325180 definitely merit further evaluation and probably should be included in any breeding work for yield and IVDMD in crested wheatgrass. There were seven strains in common between the lists of the 10 strains with the highest NI values at Lincoln and Alliance. This indicates that if selection for both first cut yield and IVDMD is conducted, the initial screening work in a breeding program could be done at a single location.

Eight of the ten strains that appeared to have the most agronomic potential when visually evaluated at Lincoln in the spring of 1980 ranked in the top 10 for overall mean NI values and the other two ranked 11th and 14th. Eight were in the top 10 for first-cut yield at Lincoln and seven were among the top 10 at Alliance. It thus appears that visual selection can be very effective in evaluating crested wheatgrass strains.

In summary, there appears to be substantial genetic variability for first cut forgae yield and quality in the crested wheatgrass complex and these traits could probably be substantially improved in a conventional breeding program.

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