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CRESTED WHEATGRASS:

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Factors Affecting Yield and Nutritional Quality of Crested Wheatgrass

H. F. Mayland

ABSTRACT: This paper reviews the literature on factors affecting the yield and nutritional value of crested wheatgrass (*Agropyron cristatum*, *A. desertorum* or *A. fragile*). The *Agropyrons* are cool-season perennial bunch grasses that are grown in the western United States and Canada where annual precipitation ranges from 9 to 18 inches (230 to 460 mm) and forage yield ranges from 400 to 3000 pounds of dry matter per acre (450 to 3360 kg/ha). Forage production in the northern Great Plains is best correlated with April to June precipitation whereas in the area west of the Rocky Mountains production is best correlated with total autumn to spring precipitation.

Yields are responsive to applications of 20 to 30 pounds of nitrogen per acre (22 to 34 kg/ha) in areas receiving at least 12 inches of precipitation (300 mm). Early forage growth is stimulated by fertilizer nitrogen, thereby advancing the grazing period by as much as two weeks. Yield responses to phosphorus fertilization are frequently measured when soil moisture and nitrogen are adequate. Sulfur deficiencies occur in some soils in the Pacific Northwest and yield responses to sulfur fertilization may be obtained under conditions where nitrogen and moisture are adequate for additional plant growth.

Digestible nutrients in the forage are high and adequate for growing yearlings, cow-calf, and ewe-lamb pairs during the green feed period, but decline rapidly as the forage matures. Chemical curing at flowering time, interseeding with legumes, or supplementing the protein-energy requirements of grazing livestock have been used to counter the forage quality deficiencies in maturing crested wheatgrass. Grazing systems that utilize crested wheatgrass in spring, native range in summer, and Russian wildrye grass (*Psathyrostachys juncea*) in late summer and autumn have been successful in maintaining high daily gains for beef production in the northern Great Plains. Animal health problems that are associated with, but not limited to grazing crested wheatgrass include silicosis, white muscle disease, grass tetany, and marginal zinc deficiency.

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INTRODUCTION

Crested wheatgrass is composed of several cool-season, perennial, bunchgrass species taxonomically identified as *Agropyron cristatum*, *A. desertorum* or *A. fragile* (Dewey 1983). It was successfully introduced into North America in 1906 from Eurasia (Westover et al. 1932, Dillman 1946, Richardson et al. 1980 and Rogler and Lorenz 1983). It has since been seeded on millions of acres in the northern Great Plains, Intermountain, Great Basin, Snake River, and Columbia Plateau regions of the United States and the prairie provinces of Canada (Reynolds and Springfield 1953). Smoliak et al. (1981a) estimated that crested wheatgrass had been seeded on 2.5 million acres in Canada and Dewey and Asay (1975) estimated 12 million acres of seedings in the western United States.

There are a number of reasons why crested wheatgrass was planted so extensively. Land managers discovered that the grass was an excellent competitor with weeds when planted properly (Pavlychenko 1942). For example, crested wheatgrass was seeded in many areas to displace halogeton (*Halogeton glomeratus*), a weed poisonous to sheep (Frischknecht 1968a), and Russian thistle (*Salsola kali*), an alternate host to the sugar beet leaf-hopper (*Circulifer tenellus*). This insect is a carrier of the curly top virus that reduced production of susceptible varieties of bean (*Phaseolus vulgaris*), tomato (*Lycopersicon esculentum*) and sugar beet (*Beta vulgaris*) (Douglass and Cook 1954). Crested wheatgrass was also planted as an alternative to cheatgrass (*Bromus tectorum*), a winter annual that provides a very short green-feed period and is very flammable when mature (Hull and Stewart 1948). Crested wheatgrass was seeded in areas denuded by fire (Piemeisel et al. 1951) to protect the soil from wind and water erosion. In fact, many acres of farmland in the United States and Canada were abandoned because of drought during the 1930's and were later seeded with crested wheatgrass to increase soil stability (Hubbard 1949).

First and foremost, however, crested wheatgrass was seeded to increase the forage resources available to grazing livestock. This review examines the factors affecting the yield and nutritional quality of crested wheatgrass for domestic livestock. The taxonomic classification by Dewey (1983) is used here. The genus *Agropyron* is confined to crested wheatgrass. Most of the other former *Agropyrons* are now classified in the *Elytrigia*, *Elymus*, or *Pascopyrum* genera. The common names of plants used in this review and their Latin binomials are listed in the appendix. Values of annual precipitation are drawn from the referenced sources, the 1941 Yearbook of Agriculture (Kincer 1941), or World Weather Records (U.S. Department of Commerce 1965).

FACTORS AFFECTING DRY MATTER YIELDS OF CRESTED WHEATGRASS

Productivity Studies

Forage yield trials began within a few years after crested wheatgrass was introduced to North America. Results of early studies conducted on the USDA Great Plains stations were summarized by Westover et al. (1932) as listed in Table 1.

Table 1.--Average air dry forage yields of crested wheatgrass for given number of years and precipitation at seven locations in the northern Great Plains (Westover et al. 1932).

Location	Years	Rainfall	Yield
		Inches	Pounds per acre
Havre, MT	10	13.1	1600
Moccasin, MT	9	15.5	1900
Sheridan, WY	6	15.1	1917
Mandan, ND	15	15.2	1940
Archer, WY	13	15.9	1460
Redfield, SD	6	18.7	2140
Ardmore, SD	10	15.8	1910

In the prairie region of western Canada, Hubbard (1949) measured an average dry matter yield of 352 pounds per acre near Manyberries, Alberta, with an average annual precipitation of only 11.3 inches. On areas receiving run-on water, dry matter yields were 1660 pounds per acre. Areas in Alberta and Saskatchewan with greater precipitation have yields similar to the latter amount. *Agropyron cristatum* is better adapted to more moist conditions, while *A. desertorum* grows best in drier areas (Smoliak and Bjorge 1981).

Much farther south Reynolds and Springfield (1953) reported that crested wheatgrass was adapted to moderately moist sites in the big sagebrush, pinyon-juniper, and ponderosa pine vegetational types of northern New Mexico and Arizona, where it produced 500 to 800 pounds per acre in pinyon juniper, 900 to 1500 in big sagebrush, and 1100 to 1200 in the ponderosa pine type. After 1950, the production potential of crested wheatgrass was evaluated in many areas of the western United States and Canada and some of these results are shown in Table 2. Average annual yields ranged from 400 up to nearly 1900 pounds per acre in experiments that were 3 to 13 years in length; the 13-year mean yield in southeastern Idaho was 500 pounds.

The dry matter yields of crested wheatgrass are related to rate of growth, which is dependent upon soil and climate parameters. Williams and Post (1941) reported that crested wheatgrass was a valuable grass in the northern Great Plains because it furnished two to three weeks earlier grazing than did either native or bromegrass pastures. Sharp (1970) reported the daily rate of growth (air dry pounds per acre per day) during 1967 at Point Springs, Idaho as follows:

Late March - Mid-April	3.6
Mid-April - Late April	6.8
Late April - Mid-May	7.1
Mid-May - Late May	19.1
Late May - Mid-June	25.5

These rates when multiplied by 15 days per interval give a mid-June dry matter yield of 930 pounds per acre, almost twice the 13-year mean yield (Table 2) of 500 pounds. Precipitation during the November through June period in 1967 was greater than normal, 10.27 vs. 8.82 inches, explaining the difference.

Five reports (Table 3) compared yields of various cultivars within the *Agropyron* genus. With either Nordan or Standard used as a reference, yields for the other cultivars ranged from 85 to 144% of the reference varieties. The wide range in yield within the genus could be exploited to produce high yielding or high quality forage plants. Others (Coulman and Knowles 1974, Murphy 1942, and Schaff et al. 1962) have arrived at similar conclusions. Lamb et al. (1984) and Vogel et al. (1984) screened 50 strains including 38 accessions (PI lines). They were ranked for yield and *in vitro* dry matter digestibility (IVDMD) using the Nebraska Index (NI):

$$NI = \frac{Yield - \bar{X}(yield)}{s(yield)} + \frac{IVDMD - \bar{X}(IVDMD)}{s(IVDMD)}$$

where $\bar{X}$ was the mean and s was the square root of the error mean square in the F test for the appropriate trait. Values of NI ranged from -4.0 to +2.8, with the varieties Ruff (*A. cristatum*) and Nordan (*A. desertorum*) scoring 2.49 and 2.08, respectively. This indicates that good material is already in use, but some opportunity may exist for improvement.

Comparisons of crested wheatgrass yields with smooth brome (*Bromus inermis*) and slender wheatgrass (*Elymus trachycaulus*) were made by Reitz et al. (1936) at Moccasin and Havre, Montana, with annual precipitation of 15.5 and 13.1 inches, respectively. Average yields over the 15 years at Moccasin (14 years at Havre) in pounds of air-dry forage per acre were:

	Moccasin	Havre
Crested wheatgrass	1860	1660
Smooth brome	1780	1190
Slender wheatgrass	1770	1740

The ability of crested wheatgrass to maintain a productive stand throughout the 14-year period encouraged these investigators and others to further evaluate this promising forage resource. Hyder and Sneva (1963b) compared the forage-yielding potential of grasses grown in eastern Oregon in pounds of dry matter per acre:

Standard crested wheatgrass	1650
P-27 Siberian wheatgrass	1450
Whitmar beardless wheatgrass	1350
Alkar tall wheatgrass	1260
Topar pubescent wheatgrass	1190
Sherman big bluegrass	1110

Hull and Johnson (1955) summarized forage production data from 28 studies conducted at 20 locations in the Ponderosa pine zone of Colorado. Crested wheatgrass was the best adapted species and Russian wildrye (*Psathyrostachys juncea*) also did well. Average yields at six locations were 1060 pounds per acre for crested wheatgrass and 634 pounds per acre for Russian wildrye.

Cooper and Hyder (1958) reported the mean yields (12% moisture) of 11 grasses grown in a 5-year study at Squaw Butte, Oregon. These forage yields are for eight crested wheatgrass cultivars reported in pounds per acre.

A. fragile	1310
A. cristatum	
Commercial	800
A-1770	793
A. desertorum	
Commercial	910
Mandan 571	950
Nebraska-10	970
Utah 42-1	900
5% LSD	360

Hull (1972) reported that in southern Idaho Fairway produced only 79 percent as much forage as Standard. However, Fairway spread 112 percent further and was grazed more uniformly than Standard. He reported forage yields of *Agropyron desertorum* and *A. cristatum* for 15 sites.

Row Spacing

The effect of row spacing on forage yield of crested wheatgrass was studied in southern Idaho by Hull (1948) and Hull and Holmgren (1964). Row spacings of 6, 12, 18, and 24 inches produced similar forage yields, but the 6- and 12-inch spacings gave better protection against soil erosion and weed invasion, and produced a more palatable forage.

Reitz et al. (1936) reported that 12-year average forage yields were 1770 pounds per acre from rows spaced 36 inches apart, but only 1300 pounds per acre from drilled rows 7 to 9 inches apart. The 36-inch rows were periodically cultivated which may have stimulated production. During a 5-year study at Squaw Butte, however, Hyder and Sneva (1963b) did not measure any difference in yields when crested wheatgrass was planted in rows spaced 6, 12, 24, 36, 48, or 60 inches apart. It is probable that these plots were not tilled. Hubbard (1949) also found that after 12 years different row spacings (6, 12, or 24 inches) had no effect on plant density or yield.

McGinnies (1970) seeded crested wheatgrass during each of three years at 10, 20, or 30 seeds/foot in rows spaced 6, 12, 18, 24, and 30 inches apart. Stand survival after 6 years was best at the highest seeding rate. Forage yield was not affected by seeding rate, but was highest in rows spaced 12 to 18 inches apart and lowest in 30-inch rows. Invasion by other perennial grasses was also greatest at the widest spacing. Forage yields in pounds per acre were:

Spacing	
6	850
12	1010
18	1000
24	900
30	760

The effect of row spacing on forage yield was also studied in southwestern Saskatchewan (Leyshon et al. 1981). "Mayak" Russian wildrye, "Summit" crested wheatgrass, and "Drylander," a creeping

Table 2.--Dry matter yield responses of crested wheatgrass to fertilizer nitrogen and mixtures with legumes at 19 locations in Canada and the United States.

Location		Reference[8]		Expt. years	Annual ppt.	Total dry matter yields for given levels of annually applied N fertilizer, lb/a 0	20	30	40-60	Alfalfa + crested wheatgrass
					Inches	Pounds per acre				
Pincher	ALB	Lutwick	77	3	[1]17.6	1870	-	-	[2]2510	3520
Mandan	ND	Rogler	69	10	[3]15.4	1680	-	-	2760	2440
Mandan	ND	Power	80	6	16.8	1000	-	1790	-	-
Mandan	ND	Smika	60	7	16.8	470	-	1370	1890	-
Mandan	ND	Lorenz	62	12	16.8	530	-	1320	1990	1270
Alliance	NE	Schultz	82	2	16.5	-	-	-	-	1771
Holbrook	ID	Hull	74	6	[3]16.0	1220	-	-	-	-
Manitou	CO	McGinnies	68	6	15.7	630	1070	-	1280	-
Moccasin	MT	Stitt	58	8	15.5	1620	-	-	-	1860
Gillette	WY	Rauzi	82	8	15.1	1870	-	-	-	1930
Sidney	MT	Black	68	4	14.9	970	-	-	1440	-
Archer	WY	Rauzi	75	3	14.7	800	-	-	-	-
Red Bluff	MT	Gomm	64	3	[3]14.1	1330	-	-	-	[5]2580
Swift Current	SAS	Kilcher	58	4	14.0	700	1200	1400	2200	-
Goodwell	OK	Huffine	59	3	[3]13.4	740	-	-	-	-
Tintic	UT	Havstad	83	[4]3	13.0	680	-	-	-	-
Point Springs[7]	ID	Sharp	70	13	[3]12.5	500	-	-	-	-
Glorieta	NM	Reynolds	53	5	[3]12.3	420	-	-	-	-
W. Central	NV	Eckert	61	4	12	490	-	-	550	-
Squaw Butte	OR	Sneva	76	[6]10	11.3	810	1200	1190	1280	-
Twin Falls	ID	Hull	74	6	9.3	670	-	-	-	-
N. Central	NV	Eckert	61	4	9	620	-	-	840	-

1 Exclusive of August precipitation.
2 Fertilizer applied only once.
3 Mean annual precipitation during the study.
4 Includes data from D.L. Scarnecchia.
5 Yellow sweet clover plus crested wheatgrass.
6 May 15 yield plus regrowth harvested August 1.
7 Now the Lee A. Sharp Experimental Area.
8 Senior author and year of publication.

Table 3.—Forage yields (12% moisture) of *Agropyron* cultivars grown at different locations.

Cultivar	Susanville, CA[1]	Perkins, OK[2]	Burns, OR A[3]	Burns, OR B[4]	Sheridan and Gillette, WY[5]
	Pounds per acre				
Agropyron desertorum					
Standard	-	[6]670	910	750(1980)	2500
Nordan	1140	1070	-	-	2530
Nebraska -10	1290	-	970	1000(1710)	-
Mandan 571	-	910	950	870(1810)	-
Summit	-	-	-	-	2480(2420)
Agropyron cristatum					
Fairway	1080	740	800	780(1930)	2220
A-1770	-	[6]820	790	760(1630)	-
Parkway	-	-	-	-	2340(1960)
Agropyron fragile					
P-27 Siberian	1060	930	1310	850(2220)	-

1 Mean yields for 3 years at Black Mountain Experimental Station, 18.6 inches annual precipitation (Cornelius and Williams 1961).
2 Mean yields for 2 years, 34.1 inches annual precipitation (Huffine et al. 1959).
3 Mean yields for 5 years at Squaw Butte Experiment Station, 11.3 inches annual precipitation (Cooper and Hyder 1958).
4 Mean yields for 4 years at Squaw Butte. Values in parentheses are forage yields achieved with 30 pounds nitrogen per acre applied annually (Hyder and Sneva 1961).
5 Mean yields for 5 years at Sheridan and 4 years at Gillette, 15.1 and 14.4 inches annual precipitation, respectively (values in parentheses are for a second experiment (Richardson et al. 1980).
6 Mean yields for 2 years at Goodwell, OK, 17.0 inches annual precipitation (Huffine et al. 1959). The value shown here for Standard was identified as Commercial by this reference.

Table 4.--Mean annual forage yields over five years and three row spacings (Leyshon et al. 1981).

Forage	Yield for spacing, inches 12	24	36
	------ Pounds per acre ------		
Summit	1250	1330	1480
Mayak	570	1030	1640
Drylander	2250	2070	2180

Table 5.--Mean forage yield during year four at three row spacings (Leyshon et al. 1981).

Forage	Yield for spacing, inches 12	24	36
	------ Pounds per acre ------		
Summit	410	460	890
Mayak	140	460	1280
Drylander	560	870	1430

alfalfa, were seeded at 12-, 24-, and 36-inch row spacings. Dry matter yields were generally greater for the 12-inch spacing the first year. By the second year, both grasses had greater production on the wider spacings. By the fifth year, the yield advantage had shifted to the 36-inch rows (Table 4). In the fourth year, which received below normal precipitation, the dry matter yields were much greater for the 36-inch spacing (Table 5). To explain the benefit of the wider spacing, the authors argued that "there is only enough moisture and nutrients available for a limited amount of dry matter production by a limited number of plants." Apparently soil water is used more efficiently under the 36-inch row than under closer spacing (Kilcher 1961).

This concept is supported by spacing and seeding rate studies at Fort Valley in northern Arizona (Lavin and Springfield 1955). The highest forage yields were produced in the narrower spacings during wet years and the wider spacings in dry years.

Springfield (1965) conducted similar rate and spacing studies near Tres Piedras, New Mexico. The site was a medium textured, rocky, shallow soil at 8500 feet elevation having 13 inches annual precipitation. The plots were seeded at 3 rates and 3 row spacings in 1951, and grazed from 1953 until 1956. The forage yields are shown in Table 6. These yields reflect a period of low rainfall from October 1955 to May 1956 dry enough to restrict growth at all row spacings. Thus, the 12- to 18-inch row spacing still seems best.

Forage yield responses to wider row spacings have been noted in the northern Great Plains, but not in the Great Basin, Snake River, or Columbia Plateau regions (Sneva and Rittenhouse 1976, Sims 1969). Perhaps the summer rainfall pattern and somewhat higher precipitation amounts in the northern Great Plains develop the spacing response.

Sims (1969) examined the effect of stand density on characteristics of wheatgrasses in Utah. He found that dense stands of crested wheatgrass, tall wheatgrass (Elytrigia pontica), intermediate wheatgrass Elytrigia intermedia), and pubescent wheatgrass (E. intermedia ssp. barbulato) produced more herbage per acre, had fewer and shorter seed stalks, fewer viable seeds, narrower and shorter leaves, and a lower stem/leaf ratio than open stands. More research is needed to identify the contrasting results of plant or row spacing between the northern Great Plains and the Intermountain and Snake River Plains.

Stand Age

Crested wheatgrass has been frequently seeded in fields that have been fallowed one or more seasons. The accumulation of mineralized soil nitrogen and soil water may have boosted forage production the first couple of years after seeding. After the plants adjusted to current precipitation and available nitrogen levels, yields often declined with age.

Some researchers in the northern Great Plains found that yields of old stands could be increased by land scarification or renovation (Black 1968, Houston 1957, Lorenz and Rogler 1962, Lodge 1960, and Stitt 1958) and nitrogen application. Smoliak et al. (1967) examined 29- to 38-year old stands of A. cristatum and found that they consistently outyielded native mixed prairie vegetation by a ratio ranging from 12.4 to 1.1. Soil analyses showed that exhaustion of nitrogen was not a factor in the persistence of stands. Crested wheatgrass had become a permanent part of the vegetation and forage yield was dependent mainly on current rainfall.

Lodge (1960) measured the effects of burning, cultivation, and mowing on the yield of crested wheatgrass grown near Swift Current, Saskatchewan. He noted that all treatments reduced yields the first year and spring burning even longer. In the long run, however, basal area was not affected by any of the treatments. Rauzi et al. (1971) measured yields for 5 years after light discing or chiseling on 16- or 24-inch centers at Archer and Gillette. Forage yields were depressed the first year after renovation and were not different from untreated plots after that.

Table 6.--Mean annual forage yields of crested wheatgrass planted in three row spacings (Lavin and Springfield 1955).

Year	October-May precipitation	Yield for spacing, inches 6	12	18
		---- Pounds per acre ----		
1956	33% of normal	50	55	53
1957	110% of normal	1090	1180	1210
1959	90% of normal	432	455	468
Mean		525	564	578

Hull and Klomp (1966) reported that crested wheatgrass was well adapted to southern Idaho, and that during 7 to 14 years of production, it could maintain itself and even spread. Smoliak et al. (1981b) reported that a stand seeded in 1928 at the Manyberries Research Station was still productive after 50 years. Many of the seedings in the prairie region of Canada remained as monocultures for 15 to 20 years. Native plants then began to invade, but seldom made up more than 10 percent of the plant density, and yield loss was negligible (Looman and Heinrichs 1973). Dormaar et al. (1978) reported that forage yields on 40 to 59 year-old stands still out-yielded native range by 1.1 to 1.5 times.

Hubbard (1949) noted an average yield of 1675 pounds air-dry hay for 30 consecutive years at Mandan. Because of experiences there and at Havre and Swift Current, he suggested that most stands would yield well for 20 to 30 years. Others have felt that crested wheatgrass stands would become decadent with age and encroaching shrubs and weeds would further reduce productivity. Scarifying the soil surface has been used to stimulate wheatgrass stands, but little evidence exists that a net improvement in forage yield is produced by this treatment (Black 1968, Stitt 1958, Lorenz and Rogler 1962, Smika et al. 1963). Weed and shrub control may be necessary and nitrogen fertilizer application may be helpful in stimulating forage production (Stauber et al. 1974). Forage yield response to nitrogen fertilizer may be greater for new stands than for old stands. Sneva (1973b) found that 16 pounds of forage were produced per pound of nitrogen on new stands, but only 8 pounds on old stands. These findings might explain why Seamands and Lang (1960) found that the most efficient yield per unit of nitrogen applied to an old stand was 7 pounds of forage per pound of nitrogen.

Precipitation

Crested wheatgrass is grown in semiarid areas of the United States and Canada. It is, therefore, logical to assume that precipitation is the primary factor limiting forage production (Sneva and Hyder 1962), and that production increases with additional precipitation. However, the forage production data for the 19 experimental sites of Table 2 are not well correlated with precipitation (r^2 = .2). This is probably due to large differences in the seasonal distribution or "quality" of precipitation, in addition to variability in soil fertility, temperature, etc.

Figure 1 illustrates the relative amount of annual precipitation occurring in any month, expressed as a percentage of total precipitation, for a number of locations where crested wheatgrass is grown. Areas east of the Rocky Mountains such as Mandan, North Dakota, receive a majority of their rainfall as summer storms. This rainfall pattern tends to extend the green-feed period compared to areas west of the Rocky Mountains. It also may increase the yield response to nitrogen fertilizer. Precipitation in the Great Basin, Snake River Plateau, and Columbia Plateau primarily occurs during winter and spring followed by a relatively dry summer and fall season. The subfigures for Ritzville, Washington and Austin, Nevada are examples of this seasonal pattern. Precipitation in the Intermountain area may be evenly distributed throughout the year as shown for the Benmore, Utah site.

Experimental seedings of crested wheatgrass and other grass and legume forages have been made at Susanville, California (Cornelius and Talbot 1955, Cornelius and Williams 1961). Although at the extreme western periphery of the Great Basin, this area has a mediterranean type climate with very dry, warm summers. Long-term studies in this and similar regions indicate that rhizomatous wheatgrass types (pubescent and intermediate wheatgrass) out-spread and out-persist the bunch-type wheatgrasses (A. cristatum/desertorum and other non-rhizomatous wheatgrass species now identified in the Elytrigia and Elymus genera). The dry summers apparently limit seed formation and establishment of new crested wheatgrass plants (Graves et al. 1984).

Experimental seedings of crested wheatgrass have also been made at Perkins, Oklahoma (Huffine et al. 1959). Forage yields were satisfactory the first two years, but few plants remained in the third and fourth year after establishment. The area receives 34.1 inches of annual precipitation, but average January (37°F, 3°C) and July (81°F, 27°C) temperatures are about 10 Fahrenheit degrees higher than areas where the Agropyrons persist. Warm season grasses are more adapted to sites like this and can outcompete the Agropyrons.

Forage yields of crested wheatgrass have been predicted from soil moisture values or from precipitation and temperature data. June forage production in New Mexico averaged 980 pounds per acre over four years, and was best predicted as:

$$Y = 203X - 368, \ (r^2 = .99)$$

where X was the January through May precipitation in inches (Gray and Springfield 1962). The wheatgrass yield of 980 pounds per acre compared with a yield of only 114 pounds on native range.

Sharp (1970) reported that 70 to 80 percent of the variability in annual production of crested wheatgrass at Point Springs, in south central Idaho, could be attributed to variation in the April to June precipitation. In eastern Oregon, Sneva (1977) found that spring yields were best predicted from mean February temperature and March precipitation (r^2 = .83). The best combination for predicting mature yield was July (of the previous year) through May precipitation plus mean March through May temperature (r^2 = .64).

Sneva and Hyder (1961, 1962) used an indexing system to predict yield. They defined the yield index (YI) for a given year as the actual yield divided by the mean yield expressed as a percentage. The precipitation index (PI) was defined in the same way for the crop year (September 1 to June 30). Regressing the YI values against the PI values produced the prediction equation (r^2 = .77; $s_{y.x}$ = 18.4 pounds per acre).

$$YI = 1.11PI - 10.6$$

Sneva and Britton (1983) reassessed the yield relationship within the sagebrush-bunchgrass zone in Washington, Oregon, Idaho, Utah, Nevada, and

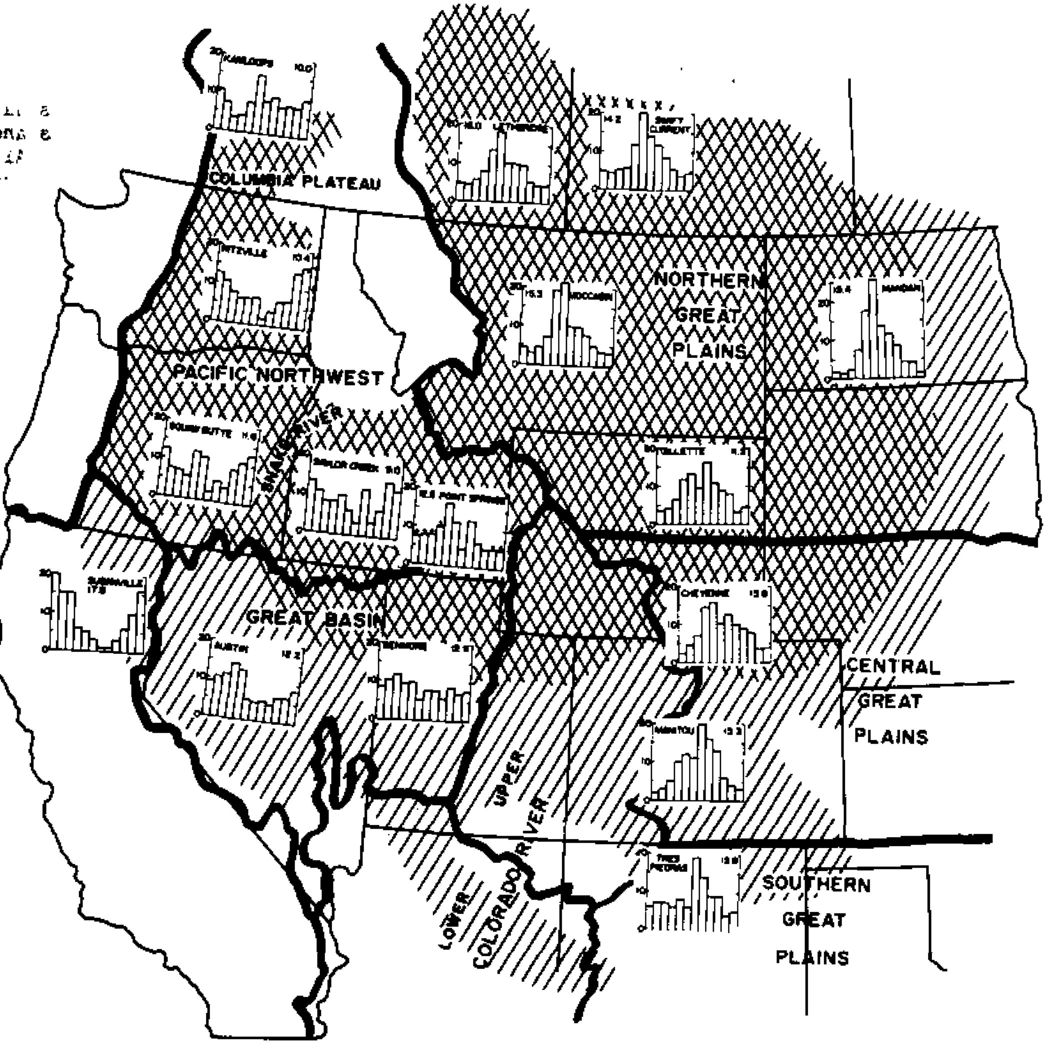

Figure 1.--The quantity (inches/year) and distribution of precipitation for areas where crested wheatgrass is grown. The bars from left to right represent relative January through December precipitation, as a percentage of the total. Major watersheds and primary (cross hatched) and secondary (diagonal lines) areas of crested wheatgrass distribution are illustrated.

California. This report increased the length of record and extended the use of the precipitation index (PI) and yield index (YI) to additional sites.

A more direct approach was used by Power (1970) and Power and Alessi (1970) who reported that the growth of crested wheatgrass at Mandan was linearly related to available soil water (Fig. 2). The yield was described (r^2 = .98) as:

$$Y = 190X - 990$$

where Y was yield in pounds per acre and X was inches of available soil water. A threefold increase in yield occurred as available soil water increased from 8 to 14 inches.

Love and Hanson (1932) reported that most roots of crested wheatgrass were above 3 feet, but that some extended to 8 feet (Fig. 3).

However, Brown et al. (1982) reported that crested wheatgrass used water from a 13-foot soil depth compared with an average 20-foot depth for 10 alfalfa varieties. Soil conditions, plant competition in mixed stands, and time when soil water is being extracted are all factors that may control water use and growth. Nevertheless, 2200 to 2500 pounds of dry matter per acre may be the yield potential for the presently available lines of crested wheatgrass.

Increasing soil water by snow-trapping or run-on techniques has been used to increase forage production. In the northern Great Plains, snow moves laterally or horizontally, losing some of its moisture by sublimation until it is finally trapped in depressions, in standing vegetation, or on the leeward side of snow barriers. Rauzi and Landers (1982) evaluated 13 and 26-foot wide level benches as snow catchment devices at Gillette, Wyoming. The benches trapped more snow and increased soil water

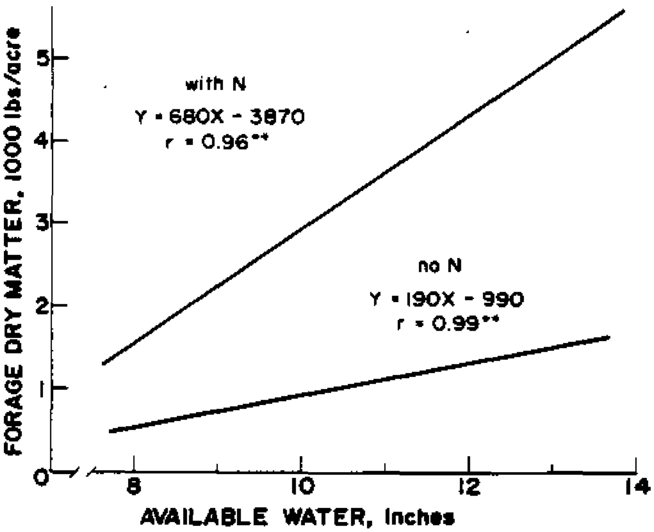

Figure 2.--Forage yields of control- and nitrogen-fertilized crested wheatgrass grown at Mandan, North Dakota, as related to available soil water (Power 1970).

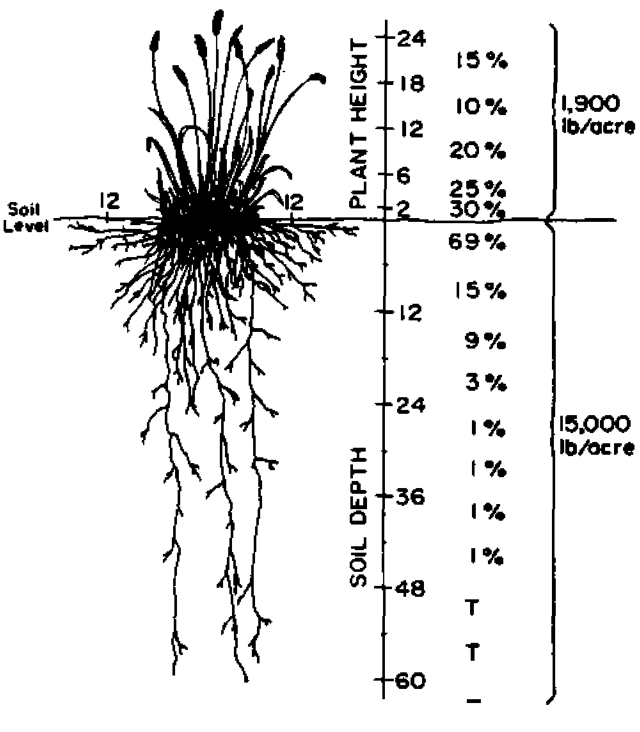

Figure 3.--The distribution of above and below ground biomass of a flowering crested wheatgrass plant growing on a deep friable silt loam soil with 16 inches annual precipitation. Data are primarily drawn from Hull and Klomp (1974) with additional information from Caldwell et al. (1981), Richards (1984), and the author. The length and depth increments are in inches.

by 12 to 20 inches when compared to control areas. It is possible that this extra water percolated below the root zone of crested wheatgrass plants where it was available only to the deeply rooted alfalfa. The average yields of the crops grown on the two different benches were compared to those on the control in pounds per acre:

	Control	Level Bench
Alfalfa	2590	3230
Crested wheatgrass	2300	2240
Alfalfa plus crested wheatgrass	2470	3310

Increasing the effectiveness of precipitation is another way to improve forage production. Rauzi (1968) compared yields on native undisturbed rangeland with areas that had been pitted, and with a third area that was pitted and seeded. The areas were grazed by sheep with the results shown in Table 7.

The review to this point has discussed the relationship of dry matter yields of crested wheatgrass to precipitation or soil moisture. Robertson et al. (1970a) extended the value of precipitation regressions by relating steer-weight gains to precipitation and temperature parameters of an area in northeastern Nevada where annual precipitation was 16 inches. Animal gains were best predicted by the November through June precipitation ($r^2 = .53$). Other precipitation periods or temperature data reduced the correlation values.

Nitrogen Fertilization

Forage yield responses to fertilizer nitrogen are limited to a large extent by available soil water. Power (1980a, 1980b) showed that the forage yield of crested wheatgrass grown at Mandan, North Dakota was linearly related to available soil water

Table 7.--Forage and lamp production on shortgrass native range (control), pitted or pitted plus interseeded with crested wheatgrass (Rauzi 1968).[1]

Parameter	Parameter response for given treatment: Control	Pitted	Pitted and interseeded
1955-60			
Forage production, lbs/acre	410	630	1050
Sheep days/acre	42	59	72
Lamb gain, lbs/head	52	49	52
Lamb gain, lbs/acre	28	36	45
1961-65			
Forage production, lbs/acre	720	1070	1350
Sheep days/acre	46	61	66
Lamb gain, lbs/head	56	52	51
Lamb gain, lbs/acre	31	36	40

[1]Pitting removed a piece of soil 4 inches deep, 7 inches wide, and 5.5 feet long in every 8 feet.

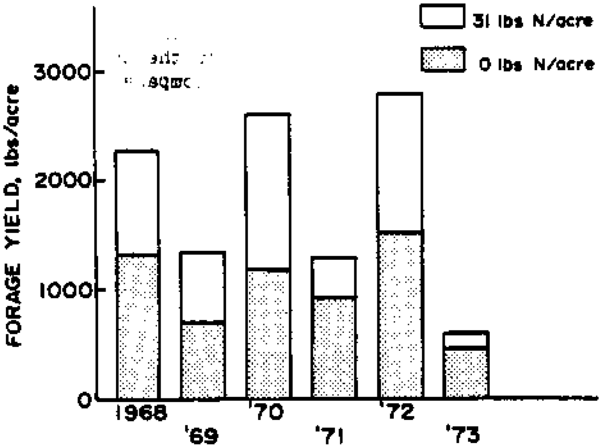

Figure 4.--Forage production of crested wheatgrass with annual applications of ammonium nitrate at Mandan, North Dakota (adapted from Power 1980a).

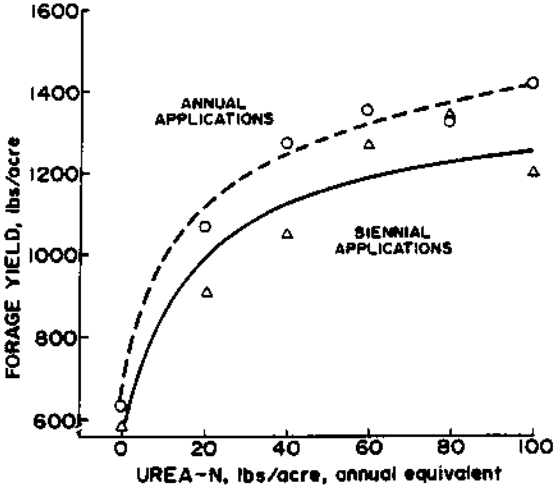

Figure 5.--The forage yield of crested wheatgrass on the Manitou Forest in Colorado in relation to annual application of urea-nitrogen (adapted from McGinnies 1968).

(Fig. 2), and that the yield response per increment of water between 7 and 14 inches was greater when nitrogen fertilizer was applied. Conversely, the yield response per increment of nitrogen fertilizer was greater at above-normal levels of soil water as indicated by the yield of unfertilized plots (Fig. 4).

The magnitude of the response to nitrogen fertilizer on perennial grasslands was site specific, integrated over the capacity of the soil to immobilize nitrogen, the capacity of plants to take up nitrogen, the nitrogen transformations active at the site and, of course, the amount of available soil water. These conclusions were supported by cumulative yield responses of bromegrass, crested wheatgrass, and native grasses to cumulative nitrogen applications over a 5- to 6-year period on several sites (Power 1980a). The order of response was least for native grasses, intermediate for crested wheatgrass and greatest for bromegrass at Mandan. The yield responses of crested wheatgrass at two sites were predicted by:

$$Y = 12.95X - 0.0037X^2 + 833 \ (r^2 = .90) \text{ and}$$
$$Y = 11.79X - 0.0037X^2 + 544 \ (r^2 = .72)$$

where Y was cumulative dry matter yield and X was cumulative fertilizer nitrogen applied.

McGinnies (1968) reported yield data for the Manitou Experimental Forest in Colorado, in response to urea-nitrogen applied annually or biennially (Fig. 5). The latter was twice the annual rate, but was treated as an annual equivalent for the regression analysis. The regressions were:

$$Y = 598 + 402 \log N \ (r^2 = .98)$$
$$Y = 532 + 367 \log N \ (r^2 = .89)$$

for annual and biennial treatments, respectively. About 80 percent of maximum forage production was achieved by applying 20 pounds of nitrogen per acre. Biennial application of nitrogen at twice the amount was less efficient than the annual application (slopes are not equal, $P = .12$), even though the same amount of nitrogen was applied in both treatments.

Lang and Landers (1968) summarized 10 years of Wyoming data and concluded that 20 pounds of nitrogen per acre was the most efficient level for increasing crested wheatgrass forage production. However, Fairbourn and Rauzi (1982) reported that 20 to 30 pounds of nitrogen per acre appeared too low to effectively increase crested wheatgrass yields at their site, and concluded that nitrogen was immobilized in litter and soil.

Power and Legg (1984) followed nitrogen-15 recovery for five years after application as ammonium nitrate to crested wheatgrass. Annual forage yields varied as a function of available soil water, and the nitrogen content was about 25 percent greater than unfertilized plants. Cumulative recovery of nitrogen-15 in tops increased with time; 12 to 52 percent being recovered the first year after application. After four seasons about 75 percent of the total initially applied nitrogen was recovered. About 70 to 95 percent of the total was accounted for in tops, roots, and soil.

Wight (1976) noted that water use efficiency was increased by nitrogen fertilization and that annual applications of 30 to 50 pounds of nitrogen per acre doubled forage production and subsequent beef production in the northern Great Plains. These findings are supported by those of Williams et al. (1979) in Kamloops. Rogler and Lorenz (1969) reported that over a 10-year period, crested wheatgrass forage production was increased by annual applications of 40 and 80 pounds of nitrogen per acre (Fig. 6). Beef production was increased with the application of 40 pounds, but was not further increased with the 80-pound rate. A mixed planting of crested wheatgrass and alfalfa produced as much forage and beef as crested wheatgrass fertilized with about 15 pounds of nitrogen per acre.

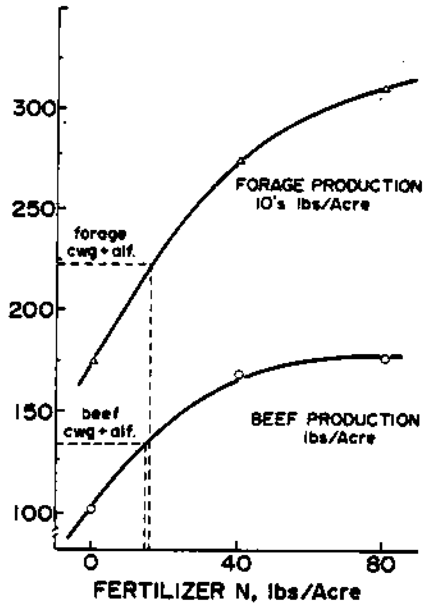

Figure 6.--Ten-year mean production of forage and beef on crested wheatgrass fertilized annually with nitrogen compared with a mixed seeding of crested wheatgrass and Ladak alfalfa at Mandan, North Dakota (adapted from Rogler and Lorenz 1969).

Bleak and Keller (1974) reported that the benefit of applying nitrogen fertilizer to crested wheatgrass grown near Logan, Utah was nil. Sneva et al. (1958), however, reported that 20 pounds of nitrogen per acre returned 25 pounds of forage for each pound of nitrogen applied at Squaw Butte, Oregon. Perhaps more importantly, they found that nitrogen-fertilized crested wheatgrass initiated growth earlier in the season and that the relative amount of growth occurring prior to June 1 (as percent of total yield at maturity) was nitrogen - rate (given in pounds per acre) dependent:

Fertilizer N	Yield
0	44
10	53
20	63
30	69
40	66

Miller (1960) reported that nitrogen-fertilized plots near Fort Collins, Colorado were ready for grazing 10 to 14 days sooner the first year, but that there was no difference the second year. Forage moisture concentrations were significantly increased by nitrogen fertilizer at vegetative and boot stages, but were unaffected at the dough stage. Forage, seed yield, and crude protein concentration were increased by nitrogen fertilization, but dates of flowering and seed maturation were not affected.

In another fertilizer study near Fort Collins, Hull et al. (1958) measured forage production fertilized with 0 or 33 pounds per acre of nitrogen. Air dry forage yields in pounds per acre were:

	0N	33N
Crested wheatgrass	2160	3050
Fairway wheatgrass	1700	3100
Pubescent wheatgrass	1400	2680
Tall wheatgrass	3360	4290
Smooth brome, northern strain	960	1840
Smooth brome, southern strain	1700	2400

McCormick and Workman (1975) conducted an economic analysis of the early range readiness of crested wheatgrass produced by 25 to 30 pounds per acre of nitrogen fertilizer. The study was based on the Curlew National Grassland located north of Snowville, Utah, and on the Benmore seedings located south of Vernon, Utah. Annual precipitation was 11 and 13 inches, respectively. They calculated that in 1973 ranchers could have profitably substituted nitrogen fertilizer for purchased hay. Their costs included $0.12 per pound of nitrogen and $1.50 per acre for application.

Sneva (1973a) showed that 30 pounds of nitrogen per acre increased yields 375 pounds (583 lbs/acre on control and 958 on fertilized). Costs were $8.00 and expected returns were $8.40. This was a very simple analysis and did not consider proportion of increased feed that might be lost to trampling, or nutrient availability, or increased risk of grass tetany. In 1984-1985, fertilizer nitrogen costs are about $0.30 per pound and application costs are also higher. Purchased feed costs are not greatly different. Expected profitability should be calculated for each situation using figures appropriate for that time and place.

Another economic analysis was conducted at Hooper, Washington with applications of 0 to 80 pounds of nitrogen per acre (Patterson and Youngman, 1960). They found that at this 13-inch precipitation site the 5-year mean yields in pounds per acre and nitrogen use efficiency (lbs/lb) were:

Fertilizer N	Yield	Efficiency
0	1220	
20	1490	13.5
40	2300	40.5
60	2730	21.5
80	2960	11.5

The most efficient yield response came with the 40 pound rate where 40.5 pounds of forage were produced for each pound of nitrogen applied. However, most of this extra herbage was cheatgrass, an early competitor for nutrients and water, particularly in the Snake River and Columbia River Plateau regions where normal precipitation is often less than 13 inches and winters are relatively mild (Eckert and Evans 1963).

Hyder and Sneva (1961) reported 4-year mean yield responses of various *Agropyron* cultivars to nitrogen fertilizer at 30 pounds per acre (Table 8). *Agropyron fragile* (Siberian wheatgrass) produced more dry matter per pound of nitrogen fertilizer than the other *Agropyrons*. This may be a genetically controlled trait or simply a site-specific response.

Schlatterer (1974) reviewed the use of fertilizers to increase production on rangelands. For the Great Basin and Snake River Plateau he concluded that:

1. Nitrogen consistently increased production, but only in areas receiving more than 13 inches annual precipitation.

2. Introduced grasses responded more to nitrogen than did native species.

3. Residual fertilizer effects are usually limited to less than three years on grazed ranges.

4. Cheatgrass responds more quickly than perennial grasses to nitrogen fertilizer.

5. The high costs of nitrogen and of application, lack of consistent year-to-year production increases, and lack of long term residual effects under grazed conditions raise serious questions as to the economic practicality of using nitrogen fertilizer.

Crested wheatgrass is grown extensively in the northern and central Great Plains where summer-type precipitation occurs (Fig. 1), and most areas receive in excess of 13 inches precipitation. Under these conditions, nitrogen fertilization to increase forage production is a viable management option.

Phosphorus, Sulfur, and Trace Element Fertilization

As noted before, available water is the factor most limiting production. Available nitrogen may be the second most limiting factor and phosphorus may be the third (Thomas and Osenbrug 1964). Available soil phosphorus is generally adequate to support the growth of crested wheatgrass in the absence of fertilizer nitrogen. Power and Alessi (1970) annually applied a series of nitrogen fertilizer rates with and without fertilizer phosphorus to crested wheatgrass grown at Mandan, North Dakota. Over the 5-year period, dry matter yields averaged 380 pounds per acre for each inch of precipitation in excess of 5 inches. A greater response, 490 pounds, was measured when phosphorus was also applied.

Table 8.--Forage yield and nitrogen use efficiency for seven Agropyron cultivars (Hyder and Sneva 1961).

Cultivar	Yield when fertilized at level of 0N	Yield when fertilized at level of 30N	Nitrogen use efficiency
	Pounds per acre		
Agropyron fragile	852	2223	46
Agropyron desertorum			
Standard	752	1982	41
Mandan 571	873	1806	31
Nebraska 10	1002	1708	24
Utah 42.1	874	1792	31
Agropyron cristatum			
Fairway	780	1927	38
A-1770	756	1634	29

Table 9.--Spring and regrowth forage yields of crested wheatgrass when fertilized with nitrogen or nitrogen plus phosphorus (Segura 1962).[1]

Fertilizer	Spring growth	Regrowth	Total
	Pounds per acre		
0N + 0P	1470	590	2060
45N + 0P	2390	1360	3750
90N + 0P	2200	1250	3450
90N + 18P	2390	1780	4170

[1]Nitrogen applied as ammonium nitrate and phosphorus as treble superphosphate.

Phosphorus fertilizer has generally been drilled into the soil. Yield increases of 340 pounds per acre have been attributed to the scarifying action of the disc openers on the drill (Black 1968, Smika et al. 1963). Nitrogen fertilizers are more water soluble than phosphorus sources and readily move into the rooting zone. Thus maximum yield responses to nitrogen often occur the first year after application and decrease in subsequent years as fertilizer N is immobilized. Maximum yield responses to phosphorus, in the presence of adequate moisture and nitrogen, however, may not occur until the second or third year after application because of the delay in movement of phosphorus into the root zone (Stitt et al. 1955).

In a Colorado study, Segura (1962) reported that surface applications of nitrogen and phosphorus increased yields of crested wheatgrass (Table 9). Some of these values greatly exceed those reported elsewhere in this review. Nevertheless they illustrate that crested wheatgrass responded to the first increment of nitrogen fertilizer (45 lbs), but not to the second (90 lbs) unless accompanied by phosphorus.

Smoliak et al. (1981) summarized crested wheatgrass production for a 5-year period after a single application of nitrogen or phosphorus at Manyberries, Alberta. Yields were not affected by phosphorus. Nitrogen increased yields the first year and less with each succeeding year (Table 10).

Table 10.--Forage yields of crested wheatgrass following a single application of fertilizer (Smoliak et al. 1981).

Fertilizer	First year	Second Year	Five year total
	Pounds per acre		
Check	240	240	1410
30P	240	250	1490
30N	510	310	1890
30N + 30P	510	320	1910
60N	650	380	2180
60N + 30P	640	390	2100

At some sites crested wheatgrass yields did not respond to phosphorus even when nitrogen was applied. This suggests that resident soil phosphorus was adequate to sustain growth under the soil water and nitrogen levels present at these sites (Kilcher 1958, Read and Winkleman 1982).

Soil moisture, nitrogen, and phosphorus may affect forage quality in addition to yield. Thomas and Osenbrug (1964) reported that forage nitrogen concentrations increased with nitrogen fertilization and decreased with precipitation. Smika et al. (1960) demonstrated in a 7-year study how the availability of soil nitrogen and phosphorus affected quantity and quality of crested wheatgrass (Fig. 7). Dry matter yields were increased with each increase in fertilizer nitrogen up to the 90 pound per acre rate. Yields were only slightly responsive to phosphorus fertilizer, but were greater at the higher nitrogen rates. Crude protein values increased with increasing fertilizer nitrogen rates, but were not affected by fertilizer phosphorus levels. On the other hand, nitrogen promoted growth, but not phosphorus uptake, thus diluting the phosphorus concentration in the forage from a level of .20 to .13 percent, which is low for some classes of livestock. Phosphorus fertilization, while not greatly affecting yield, did maintain the concentration of phosphorus in the forage.

Many of the rangeland soils in the Pacific Northwest were derived from volcanic materials. Because selenium and sulfur are easily volatilized it is common to encounter low concentrations of these two elements in area forage crops, especially legumes. Only sulfur is required by plants in significant quantities and it is not unusual to find sulfur responses in crops grown in this area, especially when fertilized with non-sulfur nitrogen sources (Westermann and Robbins 1974). Sneva and Rittenhouse (1976) reported that adding sulfur to nitrogen fertilizer caused spring yields of crested wheatgrass to double when compared with yields from unfertilized plots. Crested wheatgrass yields were increased on some but not all sites, only in some years, and only when accompanied by nitrogen (Sneva 1978). The growth rate of crested wheatgrass is dependent on soil factors, including the levels of nitrogen and sulfur that must be mineralized from

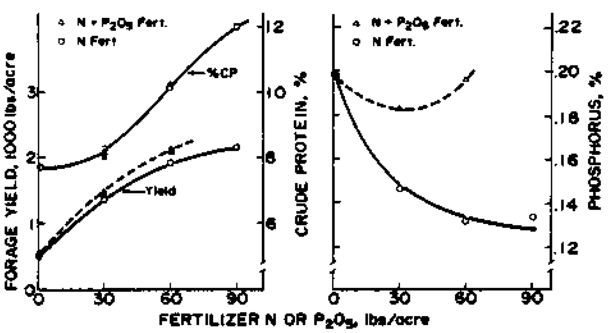

Figure 7.--Seven-year mean forage production and concentration of crude protein and phosphorus in crested wheatgrass fertilized annually with ammonium nitrate (N) or N plus treble superphosphate (P_2O_5) at Mandan, North Dakota (adapted from Smika et al. 1960).

organic forms. Activity in these transformations is site dependent and may explain why forage yields are only sometimes responsive to nitrogen, phosphorus, and sulfur fertilization.

Crested wheatgrass is grown in semiarid areas where soils are largely calcisols which means that they have a high proportion of exchangeable calcium and perhaps even free lime, and an alkaline to neutral pH. These soils generally have adequate potassium and magnesium for plant growth. Trace mineral levels in these soils are generally adequate (Eckert et al. 1961) and no trace element deficiencies have been identified with the exception of sulfur. There are many discussions of appropriate plant tissue tests that can be conducted to determine the adequacy of trace elements. Mayland (1983) is only one of many that presents information on critical nutrient ranges. Little directed progress will be made in the evaluation of fertilizer responses until investigators utilize soil and tissue testing to determine the status of nutrient availability in crested wheatgrass.

Forage Mixtures

In 1938, Stitt (1958) seeded 14 grasses and two forage mixtures at the Central Montana Branch Station at Moccasin. The seed mixtures contained the following species and seed weights as pounds per acre:

No. 1	
Crested wheatgrass	2
Russian wildrye	3
Smooth brome	3
Ladak alfalfa	4
No. 2	
Crested wheatgrass	2
Slender wheatgrass	2
Western wheatgrass	1
Smooth brome	1
Big bluestem	1
Side-oats grama	1
Switchgrass	1
Ladak alfalfa	1

These were planted in 7-inch rows and the next year about half of the plants in alternate rows were cultivated out. Good stands of blue grama, side-oats grama, Sandberg bluegrass and western wheatgrass were obtained the first year, but by 1941 these stands had been invaded by crested wheatgrass. Indian ricegrass was seeded, but not harvested, because of thin stands. By 1941, the forage resulting from the first mixture contained 15 percent alfalfa and 85 percent crested wheatgrass; while that from the second mixture contained 45 percent alfalfa and 55 percent crested wheatgrass. Mean forage yields in pounds per acre for the eight-year period were:

Crested wheatgrass	1620
" " M24-3	1580
" " M24-17	1480
Fairway wheatgrass	1420
Beardless wheatgrass	1520
Smooth brome	1260
Russian wildrye	860
Big bluegrass	1600
Green needlegrass	1220
Mixture No. 1	1680
Mixture No. 2	2040
LSD 5 %	160

Table 11.--Total forage yield and percent composition of Nordan crested wheatgrass (cwg) when seeded with native grasses in a 25:75 mixture (cwg:other) of pure live seed (Schuman et al. 1982).

Year	Slender + cwg		Thickspike + cwg		Western + cwg		Green needle-grass + cwg		4-natives + cwg	
	Yield	cwg	Yield	cwg	Yield	cwg	Yield	cwg	Yield	cwg
	Pounds per acre	Percent	Pounds per acre	Percent	Pounds per acre	Percent	Pounds per acre	Percent	Pounds per acre	Percent
1977	1260	30	1230	58	1000	78	880	78	980	38
1978	2090	61	2170	55	2360	74	1640	67	2000	69
1979	3560	96	2830	91	3310	89	3540	77	2890	79
1980	3420	97	1590	85	2130	85	3640	64	2150	96

Only the number 2 mixture produced more than crested wheatgrass. Ladak alfalfa made up a larger portion of the forage in mixture 2 than in mixture 1, even though seeded at one-fourth the rate.

In 1976, Schuman et al. (1982) seeded crested wheatgrass with several other grasses at Cheyenne where annual rainfall is nearly 16 inches. Crested wheatgrass became a strong dominant in all mixtures by 1980, even though seeded at one-fourth the rate. When seeded with slender wheatgrass, the stand became essentially a pure stand of crested wheatgrass (Table 11). This was attributed to the competitive nature of crested wheatgrass and the short-lived nature of slender, even though the latter is easily established and initially quite productive.

Johnson and Nichols (1969) planted 11 grasses in monoculture stands with 0 or 100 pounds of nitrogen applied annually or as a 50:50 mixture with alfalfa. The studies were conducted at Newell, South Dakota where annual precipitation was 15.5 inches. Forage was harvested at anthesis of the grasses during the fourth and fifth year after establishment. Crude protein concentrations in the grass (Table 12) were least in the unfertilized stands, and were not different in the grass fertilized with nitrogen or grown with alfalfa ($P < .05$). Forage yields of crested wheatgrass in pounds per acre were:

Crested wheatgrass	2300
Crested + 100 lb N A	6200
Crested + alfalfa	6350

Kilcher and Heinrichs (1958) evaluated the productivity of Fairway crested wheatgrass grown alone in pure stands with 30 pounds of nitrogen per acre and in a mixture or in alternate rows with alfalfa. Dry matter yields (lbs/acre) of these combinations when averaged over four years were:

Fairway + 30N	3120
Mixed Fairway + alfalfa	3720
Rowed Fairway + alfalfa	4000

The increased yield of alternate row versus mixed stand was attributed to a greater legume yield.

Schultz and Stubbendieck (1982) studied grass-legume mixtures in a 16.5-inch precipitation area of western Nebraska. Mixtures of Ruff crested wheatgrass (Agropyron cristatum) and either alfalfa or cicer milkvetch (Astragalus cicer) were fertilized with various combinations of nitrogen and phosphorus. Yields at the June 26 harvest were averaged across two years and all fertilizer treatments in pounds per acre:

Alfalfa	1650
Cicer	1510
Alfalfa + Ruff	2250
Cicer + Ruff	1950

The grass-legume mixtures out-yielded the legumes when the latter were grown alone.

Legume persistence is often limiting under some rangeland conditions. McGinnies and Townsend (1983) measured the persistence of sicklepod milkvetch, Ladak 65 alfalfa, Eski sainfoin, and Penngift crownvetch when seeded in alternate 12-inch rows with either Nordan crested wheatgrass, Vinall Russian wildrye, or Topar pubescent wheatgrass. The study was conducted near Fort Collins over a 7-year period. Long term annual precipitation was 14.4 inches, but two droughty years occurred in the middle of the study period. Crownvetch did not survive the first winter and pubescent wheatgrass gradually thinned out. Sainfoin declined and disappeared by the sixth year. The authors anticipated that pubescent wheatgrass would be marginal, and concluded that sainfoin was probably a

Table 12.--Crude protein concentrations in grass fertilized with two levels of nitrogen or grown with alfalfa at Newell, South Dakota (Johnson and Nichols, 1969).[1]

Forage	0N	100N	Alfalfa + grass
	Percent		
Wheatgrass			
Crested	10.8 cd	13.9 f	12.8 ef
Tall	7.5 a	8.3 a	9.0 a
Intermediate	8.2 ab	10.0 bcd	8.9 a
Slender	8.2 ab	8.5 ab	9.3 ab
Pubescent	8.7 ab	9.0 bc	9.4 ab
Smooth brome	9.5 bc	11.0 de	10.7 bcd
Orchard grass	9.6 bc	11.8 e	10.3 abc
Russian wildrye	11.2 d	16.5 g	14.0 f
Tall fescue	8.2 ab	11.1 de	10.7 bcd
Meadow fescue	9.7 c	12.1 e	12.0 de
Reed canarygrass	11.0 cd	10.4 cde	11.8 cde

[1]Means within the same column not followed by the same letter are different ($P < .05$).

short-lived species under rangeland conditions. Alfalfa also declined because of drought and depredation by pocket gophers except in the pubescent wheatgrass stand, where it was able to compete more effectively for available soil water.

The alternate-row planting of crested wheatgrass and sicklepod milkvetch yielded well, as did the Russian wildrye and sicklepod milkvetch (Table 13).

Canadian researchers at Lethbridge compared the productivity and persistence of Eski sainfoin and Ladak alfalfa in pure and mixed stands subjected to frequent clipping over five years (Hanna et al. 1977). The legumes were grown alone or in mixed- and alternate-row seedings with Nordan crested wheatgrass, Sawki Russian wildrye, or Greenleaf pubescent wheatgrass. Mixed-row seedings out-yielded alternate-row seedings in sainfoin-Russian wildrye, alfalfa-crested wheatgrass, and alfalfa-pubescent wheatgrass associations as shown in Table 14. Hanna and coworkers concluded that sainfoin was a suitable alternative to alfalfa in parts of the Canadian prairie region, but that particular attention should be given to the selection of companion species. Sainfoin longevity there, in contrast to Fort Collins, must be satisfactory.

Phosphorus fertilization often stimulates legume yields while nitrogen fertilization stimulates grass yields. However, fertilizer effects may be different as shown below where a 450 pound per acre yield response resulted when alfalfa was fertilized with either 40 pounds of nitrogen or 20 pounds of phosphorus per acre (Schultz and Stubbendieck 1982).

	Alfalfa	Alfalfa + Ruff
0N + 0P	1380	1770
40N + 20P	1570	2660
0N + 20P	1840	1980
40N + 0P	1820	2610

Table 13.—Relative legume composition and yields of grass and grass: legume mixtures grown at Ft. Collins (McGinnies and Townsend 1983).

Grass/legume	Legume in stand 1972	Legume in stand 1980	Forage yield 1972	Forage yield 1980
	--- Percent ---		Pounds per acre	
Crested wheatgrass				
Sicklepod milkvetch	13	19	2290	3850
Alfalfa	47	0	1630	2800
Sainfoin	46	0	1520	2920
Grass only, 60-cm rows			2350	2390
Grass only, 30-cm rows			2150	2150
Russian wildrye				
Sicklepod milkvetch	34	18	1580	3140
Alfalfa	72	0	1730	3050
Sainfoin	77	0	1300	2300
Grass only, 60-cm rows			1210	1540
Grass only, 30-cm rows			1340	1470
Pubescent wheatgrass				
Sicklepod milkvetch	12	35	1950	1290
Alfalfa	48	53	1620	2330
Sainfoin	51	0	1440	1200
Grass only, 60-cm rows			2200	1380
Grass only, 30-cm rows			1660	70

Table 14.—Forage yields of legume and legume grass forages grown in mixtures or alternate rows (Hanna et al. 1977).

Forage	Yield Mixed	Yield Alternate Row
	-- Pounds per acre --	
Sainfoin with:		
Crested wheatgrass	4650	4710
Russian wildrye	5160	4770
Pubescent wheatgrass	4320	4710
Sainfoin alone	5630	
Alfalfa with:		
Crested wheatgrass	6160	5740
Russian wildrye	5690	5540
Pubescent wheatgrass	5950	5540
Alfalfa alone	6330	

Applying nitrogen to grass-alfalfa mixtures often favors the grass component with subsequent reduction in the legume portion. Maximum forage yield was obtained with the grass-legume mixture fertilized with 40 pounds of nitrogen and 20 pounds of phosphorus per acre. Yield for the 40N + 0P treatment was not much different (2610 vs. 2660 lb/a). Because the proportion of grass and legume in each treatment was not reported, it is not possible to determine the net effect of fertilization on each component.

Another legume frequently seen with crested wheatgrass, especially along roadsides, is sweet clover. This legume will grow on calcareous soils of low fertility, and is more tolerant of soil salinity than alfalfa (U.S. Salinity Laboratory Staff 1954). However, it is a biennial and may be lost from the plant community during the third growing season unless soil moisture is adequate for reseeding. Even under good moisture conditions it is difficult to get satisfactory stands.

Gomm (1964) grew sweet clover, alfalfa, and crested wheatgrass singly, in mixture and in alternate rows at the Red Bluff Ranch west of Bozeman, Montana. The annual precipitation was 14.5 inches during the study. The two sweet clover varieties produced 3000 to 4700 pounds the second year, but none the third year (Table 15). Alternate rows of Nordan crested wheatgrass and sweet clover also produced well the first year, but yield was composed primarily of crested wheatgrass the second year. As expected, crude protein concentrations were much higher in the legumes than in the grass. The crude protein was also higher in the Nordan component when grown in the grass-legume mixture than when grown alone. This provides evidence that some biologically fixed nitrogen from the legume was available to the wheatgrass.

McWilliams and Van Cleave (1960) examined several pastures in southeastern Montana 17 years after they were seeded with a mixture containing crested wheatgrass (1 lb), western wheatgrass (1 lb), green needlegrass (1 lb), blue grama (1/2 lb), and sandberg bluegrass (1/2 lb) per acre. Crested wheatgrass was also planted singly at the 4-pound rate. The area was abandoned cropland receiving 12 to 13 inches rainfall. A 40-acre block was seeded to the crested wheatgrass alone and an adjacent

30-acre block was seeded to the mixture. These seedings were moderately grazed season-long from 15 April to 15 December. In a nearby pasture 24-foot wide strips of crested wheatgrass were alternated with similar strips of the mixture. It was moderately grazed during May and in winter.

Other forage species encroached upon both the monoculture and mixed seedings reducing the proportion of crested wheatgrass forage from its place in the initial seeding mixture (Table 16). Season-long grazing increased the presence of needle-and-thread, while spring and winter grazing increased green needlegrass in the strips of crested wheatgrass and mixed seedings alike. Seed mixtures resulted in higher yields. Crested wheatgrass provided early green feed and other species provided quality feed later in the season.

Cultivating strips 6 to 18 inches wide in native range and planting in the tilled area has been evaluated in a number of areas. This practice removes competition from low-producing native species and increases the opportunity for establishment of the seeded species. Early attempts at interseeding met with varying success (Heinrichs and Bolton 1950). In southern Saskatchewan, Fairway wheatgrass was seeded into existing native range, and made very large gains in basal cover especially where the original cover was low.

Lutwick and Smith (1977) measured the yield and composition of Ladak alfalfa and Fairway crested wheatgrass, grown singly and in a mixture. The study was conducted near Pincher Creek in southern Alberta where September through July precipitation averaged 17.6 inches. Nitrogen at 0, 40, 80, and 160 and phosphorus at 0 and 71 pounds per acre were surface broadcast as single applications during early spring in each of three years. Plots were harvested when alfalfa was in midbloom. Yields of alfalfa and crested wheatgrass were not affected by phosphorus fertilization. Grass yields are seldom

Table 15.--Forage yield and crude protein concentration (1959 only) of two legumes and Nordan crested wheatgrass grown singly, in mixture, and in alternate rows at Red Bluff, Montana (adapted from Cosa 1964).[1]

Species or mixture	Forage yield 1959[2]	Forage yield 1960[2]	Forage yield 1960[3]	Crude protein 1959[2]
	Pounds per acre			percent
Sweet clover				
Madrid	4730 a	0	960 a	17.9 a
PI-L57	2950 c	0	660 a	17.7 a
Ladak alfalfa	2700 cd	310 b	--	14.1 c
Nordan crested wheatgrass	1730 e	1300 a	980 a	6.5 e
Mixtures				
Madrid + Nordan	--	--	1280 a	15.0 bc
PI-L57 + Nordan	--	--	720 a	16.9 ab
Ladak + Nordan	--	--	--	13.7 c
Alternate rows				
Madrid & Nordan	4680 a	1610 a	1260 a	--
PI-L57 & Nordan	3580 b	1480 c	940 a	--
Ladak & Nordan	2250 e	1420 a	--	--
Nordan from Madrid + Nordan mixture				9.3 d
Nordan from PI-L57 + Nordan mixture				8.9 de
Nordan from Ladak + Nordan mixture				7.1 de

[1] Means in any column followed by a similar letter are not different as determined by Duncan's Multiple Range test at P = .05.
[2] Seeded in 1958.
[3] Seeded in 1959.

Table 16.--Herbage production in 1957 on areas seeded in 1940 to crested wheatgrass or a grass mixture (adapted from McWilliams and Van Cleave 1960).

Forage	Block Planting Crested	Block Planting Mixture	Strip Planting Crested	Strip Planting Mixture
	Percent			
Crested wheatgrass				
Proportion in 1940 seed mixture	100	25	100	25
Proportion in 1957 herbage	83	11	86	18
1957 yield	Pounds per acre			
Crested wheatgrass	780	170	1010	290
Green needlegrass	0	420	110	1020
Needleandthread grass	20	580	0	10
Total[1]	940	1510	1170	1640

[1] Total yield includes miscellaneous grasses and forbs.

affected by phosphorus fertilization, but the non-response by alfalfa in this study was a puzzlement even to the authors.

Mayland (1983) reported that the critical range for phosphorus concentration in the upper 6-inch portion of legumes was between .20 and .25 percent P when in the bud to first bloom stage. Alfalfa sampled in the Pincher Creek study contained an average of .19 percent P, but this represented entire top growth from more mature plants and could therefore have been adequate. This is especially true because the legume yield was not increased by phosphorus fertilization. Phosphorus percentages in the fertilized forage (71 lbs/acre) were:

	0P	71P
Alfalfa	.19	.23
Alfalfa in mixture	.17	.20
Crested in mixture	.16	.19
Crested	.16	.23

Thus, forage phosphorus concentration, but not yields, was increased when phosphorus fertilizer was applied to the grass, legume, or grass-legume mixture in this study.

Dry matter yields (lbs/acre) of crested wheatgrass and the grass - legume mixture, but not of alfalfa, were increased by the 40 pound nitrogen treatment the first year after fertilization (Lutwick and Smith 1977):

	0N	40N
Alfalfa	3830	3870
Fairway	1260	2630
Alfalfa plus Fairway	3400	3930

The application of nitrogen to a grass-legume mix, though not determined in this study, frequently results in a reduction of the legume component. The data from the Pincher Creek study, at first glance, appears to follow this observation. The proportion of alfalfa herbage in the alfalfa-crested wheatgrass mixtures for each of three nitrogen fertilizer levels is shown as a percentage of total yield.

	ON	40N	160N
Year 1	75	45	41
Year 2	73	65	61
Year 3	53	50	46

Alfalfa was obviously dying out in the unfertilized plots over the three-year period. Perhaps nitrogen fertilizer promoted grass growth at an earlier period, indirectly reducing soil water available to the alfalfa. That does not, however, explain the decline in alfalfa composition of the nonfertilized plots.

Forage yield and quality of grasses are often increased by nitrogen fertilization (Anonymous 1957). Growing the grass in a legume mixture may achieve similar results as shown in Table 17. Crude protein concentrations in crested wheatgrass grown in the grass-legume mixture were about three percent higher under both fertilized and unfertilized treatments.

Growth Regulators

The forage quality of immature grasses and forbs is often quite high, but as growth continues nutrient quality and digestibility decline as cell wall, fiber and other non-digestible components increase. The dry matter yield may continue to increase up to flowering time, and then decline as leaves fall off and seeds are shattered (Hyder and Sneva 1963a).

Miller et al. (1984) observed that older leaves of crested wheatgrass died and broke off from the plant as new leaves formed (Fig. 8). Crested wheatgrass plants seldom had more than three or four photosynthetically active green leaves. As the fourth leaf developed, the first died; and as the fifth began to elongate, the second died. The dead leaves lay on the ground and were unavailable to grazing animals. When plants were in the boot stage, the upper three leaves were green, but the lower three were dead and unavailable. When the plant reached full maturity, it consisted of a reproductive stem with only two or three attached leaves. More than 25 percent of the total material produced was not available in the standing crop.

Preventing the leaf loss and even the development of the reproductive tillers would produce a higher quality forage. Researchers have applied several growth regulator chemicals to grass, hoping to improve forage quality. Sneva (1967,

Table 17.—Crude protein concentrations in alfalfa and crested wheatgrass grown singly and in mixed stands that were not fertilized, or fertilized once with 180 pounds of nitrogen per acre 1, 2, or 3 years prior to harvest (adapted from Lutwick and Smith 1977).

Forage component	0N	180N 1st yr	180N 2nd yr	180N 3rd yr
	Percent			
Alfalfa	18.4	18.8	18.0	18.7
Alfalfa from mix	17.3	17.5	17.4	19.4
Crested wheatgrass from mix	11.3	16.1	11.2	10.8
Crested wheatgrass	8.0	13.6	8.4	7.6

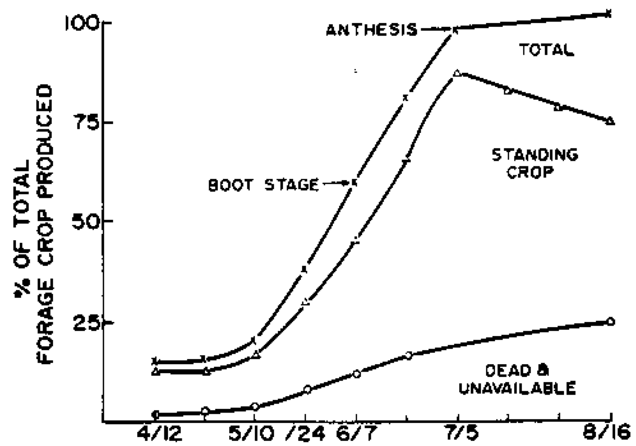

Figure 8.--The percent of standing, dead and unavailable, and total crested wheatgrass crop in relation to total current biomass at Squaw Butte, Oregon (adapted from Miller et al. 1984).

1973c) reported that the application of paraquat (1, 1'-dimethyl-4, 4'-bipyridinium di(methylsulphate)) on range grasses arrested growth and retained the nutrient quality. This procedure allowed "curing on the stump" for later grazing. The effect of 0.2 pounds paraquat and 20 pounds nitrogen applied singly or together on crested wheatgrass was measured at flowering time (Table 18). Paraquat reduced the standing dry matter but combined with nitrogen increased the yield and crude protein concentration.

Rainfall often reduces forage quality by leaching soluble nutrients from the plant and possibly hastening leaf senescence. Forage treated with paraquat retains its quality (Fig. 9) under those conditions, but yields in subsequent years may be reduced. The effectiveness of chemical curing was also shown by the results of a 3-year grazing experiment (Sneva et al. 1973), that showed the average daily gain of yearling steers grazing Paraquat-treated wheatgrass was 0.6 pounds per head higher than that of animals grazing naturally cured wheatgrass.

Table 18.--Forage yield and crude protein concentration in crested wheatgrass as affected by nitrogen and paraquat (Sneva 1967, 1973c).

Treatment	Yield	Crude protein[1]	
	Pounds per acre		Percent
Control	3270b	38a	3.8a
Paraquat	2530a	61b	7.6a
Nitrogen	5880d	68b	3.6a
Paraquat + N	4590c	94c	6.4b

[1]Data within a given column not followed by the same letter are different at the 5% probability

Table 19.--Effect of clipping date on forage regrowth production and characteristics at Archer, Wyoming. April to August precipitation was normal at 10.4 inches (adapted from Bedell 1973).

Initial clipping 1972		Regrowth		CP conc. in regrowth		CP yield in regrowth		DMD conc. in regrowth		DMD yield in regrowth	
Date	DM yield	June 29	Sept 7	June 29	Sept 7	June 29	Sept 7	June 29	Sept 7	June 29	Sept 7
	---- Pounds per acre -----			--- Percent ---		Pounds per acre		--- Percent --		Pounds per acre	
None	-	[1](1970)	[1](1460)	11	11	217	161	64	52	1260	760
May 16	255	1370a	1315a	13(24)[1]	12	178(61)[1]	158	62(79)[1]	50	849(201)[1]	658
May 26	645	885b	955b	16(20)	12	148(129)	115	70(75)	60	620(484)	573
June 2	663	610a	920b	17(18)	14	104(120)	129	68(72)	55	415(479)	506
June 9	945	255d	575c	20(16)	17	51(151)	98	69(71)	58	176(670)	334

[1]Characteristic of initially clipped forage.

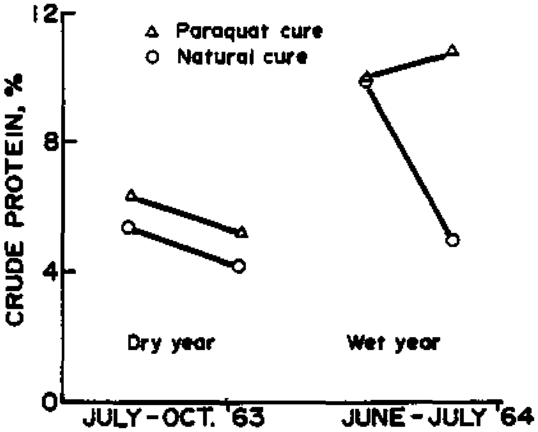

Figure 9.--Crude protein concentration in crested wheatgrass naturally or chemically cured with Paraquat during a dry and wet season at Squaw Butte, Oregon (adapted from Sneva 1967).

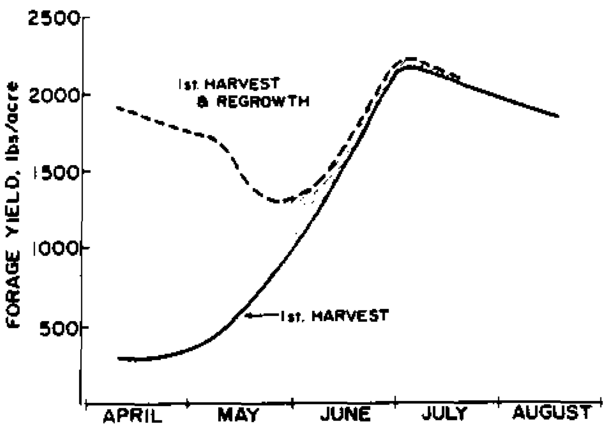

Figure 10.--Standing crop yields of crested wheatgrass, harvested at different dates, and cumulative first harvest plus the regrowth. The shaded area represents regrowth from new tillers at Squaw Butte, Oregon (adapted from Miller et al. 1984).

Forage quality decreases as plants mature. The appearance of reproductive tillers or stems initiates the decline in quality. Bedell (1973) reported that as long as soil moisture was available and the growing point was removed, then growth of crested wheatgrass remained vegetative and highly nutritious (Table 19). Removal of the growing point can be accomplished by high-intensity, short-duration grazing, but timing is very important. Various clipping treatments imposed in 1971 influenced the yield (lbs/acre) in 1972:

1971 Clipping	1972 Yield
May 4	885
May 21	815
June 3	640
June 13	615
July 9	435
Sept 7	1030

The research team at the Squaw Butte Experiment Station examined these relationships (Miller et al. 1984 and Angell et al. 1984), and reported that defoliating crested wheatgrass prior to mid-May had little effect on total forage produced (Fig. 10). Defoliating between mid-May and early June removed the reproductive stems, causing the plant to produce a second group of vegetative tillers. More than 90 percent of the 1200 to 1400 pounds per are of forage produced was leaf material. The reduction in total forage produced was caused by the absence of reproductive stems. Plants that were defoliated prior to mid-May developed reproductive stems just like those that were not clipped and contained less than 30 percent leaf material. Defoliating the plants during the mid-May to early-June period maximizes the amount of leaf material available for later grazing. The quality of this regrowth is also higher because of the larger proportion of leaves in the regrowth (Table 20).

White (1984) searched for means to reduce heading in foxtail barley. Several growth regulators and a desiccant were applied to the grass when floral primordia first appeared, reducing heading and dry matter yields that year and the year following. The _in vivo_ dry matter digestibility and crude protein concentrations were increased when compared to the untreated grass. Moisture stress, however, limited the effectiveness of the growth regulators.

Table 20.--Crude protein concentration and digestible organic matter for crested wheatgrass first harvested on given dates, or for regrowth (adapted from Angell et al. 1984).[1]

Date	Crude protein 1st harvest	Crude protein Regrowth	Digestible organic matter 1st harvest	Digestible organic matter Regrowth
	Percent			
4-12-83	-	3.3	-	58
4-26-83	14.7	3.4	77	59
5-10-83	13.6	3.4	80	58
5-24-83	11.0	5.4	73	63
6-7-83	7.8	7.8	71	62
6-20-83	6.4	9.1	72	58
7-5-83	4.9	8.9	65	58
7-18-83	3.6	NR[2]	61	NR
8-2-83	3.3	NR	58	NR
8-16-83	3.1	NR	53	NR

[1] All regrowth data are for samples harvested 8-16-83.
[2] NR is no regrowth.

Haferkamp et al. (1984) reported that the growth regulator Mefluidide [N-(2,4-dimethyl-5-[[(trifluoromethyl)- sulfonyl]amino]-phenyl) acetamide] inhibited reproductive shoot development in crested wheatgrass when applied before or during floral initiation. Mefluidide was applied at rates of 0, .12, and .25 pounds per acre and July dry matter yields were 890 and 700 pounds per acre for the control and treated plots, respectively. The treated forage had higher crude protein and detergent fiber, and reproductive shoot numbers were reduced by 64 to 90 percent. The use of growth regulators to maintain highly nutritious vegetative growth in grasses appears useful, but more research needs to be conducted.

Seed Yield

Most of the immediate concern with crested wheatgrass has centered on its yield of forage. However, seed production is another aspect that is of interest. During the mid-1930's, general information on seeding, forage utilization, and seed production of crested wheatgrass was made available through state and federal publications (Westover 1934, Westover and Rogler 1947, and Jackman et al. 1936).

The earliest document on crested wheatgrass available to this reviewer was an English translation of a Russian language report by Konstantinov (1923). It was a summary of data and observations, made during the period 1910 to 1920 on the wide-spiked "Zitniak" (A. cristatum) and the narrow-spiked "Zitniak" (A. desertorum). He reported 7 year-mean seed yields per plant as 17.7 and 22.7 g and 8 year-mean seed yields per acre of 248 and 364 pounds, respectively. Westover et al. (1932) noted that seed yields at the various experiment stations in the northern Great Plains ranged from a total failure in dry seasons to 600 to 800 pounds per acre in favorable years. The best seed yields were obtained under conditions that also produced the best forage yields. A good average yield would be about 250 to 300 pounds per acre. Double rows have yielded better than single rows, which in turn have generally produced better than rows spaced less than 12 inches apart. Birch and Lang (1961) reported that the application of 50 or 100 pounds of nitrogen per acre in each of four years increased Nordan seed yields in pounds per acre only slightly:

Fertilizer	Seed yields
Check	143
50N	153
100N	150

These yields were obtained from the Archer substation in southeastern Wyoming on the western edge of the central Great Plains. Precipitation averaged 14.4 inches during the 4-year period.

Reynolds and Springfield (1953) reported that about 100 pounds of seed per acre were produced normally by crested wheatgrass in northern New Mexico, with a maximum of 350 pounds per acre in some years.

Windle et al. (1966) measured seed yield at Tetonia, Idaho (elevation 6000 feet and annual precipitation 11.3 inches) in 36-inch rows (Table 21). Seed yields declined with increasing age of stand even though annual precipitation was greatest during the fourth and fifth years. During this same 5-year period, crested wheatgrass seed yields were reduced an average of 35 percent when planted in 6-inch rows compared with 36-inch rows.

Buglass (1964) also noted that crested wheatgrass initially produced several good crops of seed, but then yields declined to a uniformly low level, especially in close-row spacings. Ammonium nitrate fertilizer applied in the fall or spring increased seed yields in an established Fairway sod. Four-year average mean seed yields in pounds per acre were as follows:

N rate	Fall fertilized	Spring fertilized
0	40	40
20	180	100
40	320	170
60	350	140
80	510	260

This illustrated the benefits of nitrogen, especially when applied in the fall. Results of a similar 3-year study at Indian Head, Saskatchewan (8.4 inches annual precipitation) were reported for Summit crested wheatgrass planted in 12-inch rows and fertilized with ammonium nitrate (Fig. 11). There was no seed yield response to phosphorus treatments that included nitrogen (Buglass 1964).

Table 21.--Seed yields of three Agropyron species grown at Tetonia, Idaho (Windle et al. 1966).

Year after seeding	Precipitation	Fairway	Nordan	Siberian P-27
	Inches	Pounds per acre		
1st	12.9	630	740	690
2nd	12.2	360	440	500
3rd	11.5	130	250	280
4th	18.6	80	200	330
5th	17.0	70	120	210
Mean	13.9	250	350	400

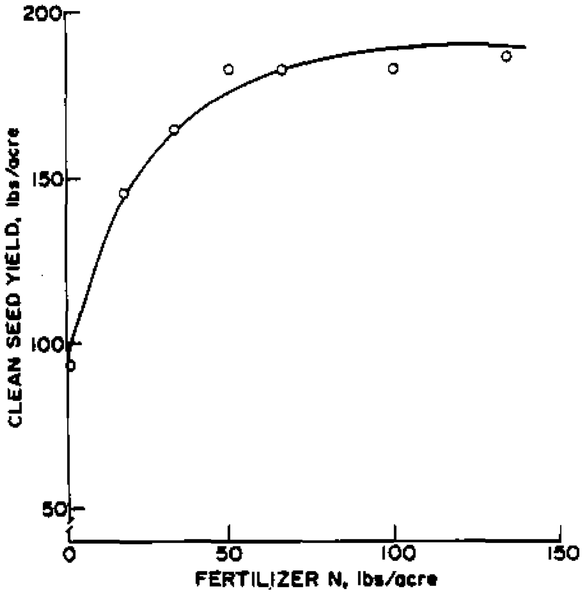

Figure 11.--Annual mean clean seed yield of Summit crested wheatgrass planted in 12-inch rows, fertilized annually and harvested during the third through the sixth year after seeding at Indian Head, Saskatchewan (adapted from Buglass 1964).

The effects of row spacing and nitrogen fertilizer on seed yields were evaluated in another 4-year experiment using Summit crested wheatgrass grown at Indian Head, Saskatchewan (Buglass 1964). Rows were spaced 6, 12, and 36 inches apart, or 12 inches apart and grouped by 2, 3, or 4 rows with 36 inches between groups. Seed yields (lbs/acre) obtained for plots receiving 0 or 68 pounds N per acre were:

Row spacing	0N	68N
6	90	210
12	120	230
36	220	220
2 x 12	140	190
3 x 12	130	180
4 x 12	120	190

Bennett et al. (1954) reported 4-year mean clean-seed yields of crested wheatgrass grown at Nephi, Utah were 50, 56, and 53 pounds per acre when grown at solid, 30-inch or 48-inch row spacings. The application of nitrogen fertilizer did not change these yields (annual rainfall was 12.7 inches). Yields as threshed were 313, 571, and 279 pounds per acre during 1937, 1938, and 1940, respectively.

Schaff et al. (1962) measured seed yields for 8 to 42 entries (including a wide range of crested wheatgrass genetic materials) established annually over an 11-year period. Seed yields were 513, 420, and 308 pounds per acre during the first, second, and third years, respectively. Seed weights were 0.36, 0.33, and 0.33 g/200 seeds, respectively.

McGinnies (1971) published the only information available on components of crested wheatgrass seed yield in relation to row spacing. This study was conducted over a 5-year period west of Fort Collins when the average rainfall was 14.7 inches. The mean data values found for clean seed are given in Table 22. During years of average precipitation, only plants of the 18- and 24-inch spacings produced enough to warrant harvesting. Seed yields ranged from 1 to 266 pounds per acre, with the highest yields at wider spacings in dry years and closer spacings in wet years. McGinnies opted for an 18-inch spacing and recommended that fields be cultivated.

Table 22.--Seed yield components for crested wheatgrass (McGinnies 1971).

Parameter	Yield for spacing, inches 6	12	18	24
Clean seed, lbs/acre	107	131	146	181
Seedheads/ft of row	13	27	37	51
Seedheads/ft	25	27	24	25
Weight, g/100 seedheads	4.5	5.7	7.1	8.5
Weight, g/200 seeds	.32	.34	.34	.36

Klages and Stark (1949) reported crested wheatgrass seed production at Moscow and Aberdeen, Idaho. They noted that 4-year mean yields were on the order of solid stand < solid stand + N < cultivated rows < cultivated rows + N. Seed yield in relation to age of seeding was year 2 > year 3 > year 4 = year 5. The fertility of culms in relation to age of seeding was on the order of year 2 > year 3 > year 4 > year 5. Fertility of culms in relation to row spacing was solid stand < solid stand + N < cultivated row < cultivated row + N.

Knowles and Kilcher (1983) reported relative seed yields (lbs/acre) of four varieties of crested wheatgrass grown in western Canada during 1976 to 1979:

Variety	Relative seed yield	Relative hay yield
Fairway	100	100
Parkway	124	104
Summit	98	110
Nordan	102	102

In general, the maximum yields of clean seed having a high germination will be obtained in young stands that are planted on 12- to 18-inch row spacings, fertilized with about 40 pounds N per acre, and cultivated.

Shrub Competition

Seeding of crested wheatgrass has continued for the past five decades on western rangelands. Historically, few seedings have remained free of shrub invasion for an extended period of time (Blaisdell 1949). Competition between big sagebrush and crested wheatgrass depressed yields of grass (Frischknecht 1963, Robertson 1947). The decision on when to control sagebrush depends largely on the rate of reinvasion by the shrub and the level of suppressed forage production.

Rittenhouse and Sneva (1976) summarized data from several locations. They reported that the production (lbs/acre) of crested wheatgrass declined 3 to 5 percent of its potential with each 1 percent increase in sagebrush crown cover from 0 to 22 percent. The average grass yield was related to crown cover in the relation:

$$\text{Yield} = 1030 - 42\ (\%\ \text{crown cover of sagebrush})$$

The standard error of the estimate was 128 pounds per acre. These data are in general agreement with those of Gobena (1984) in Utah (Table 23). Assuming 30-inch diameter crown cover for the shrubs, the regression of forage yield on cover was:

$$Y = 1230 - 73\ (\%\ \text{cover}),\ r = -.95$$

This equation predicts a 6 percent reduction in forage yields for each 1 percent increase in sagebrush canopy cover.

Frischknecht (1963) contrasted the effects of big sagebrush and rubber rabbitbrush on the production of crested wheatgrass grown at Benmore. Active growth periods of big sagebrush and crested wheatgrass coincide, whereas the growth of rabbitbrush occurs later. The depressed yields of grass around big sagebrush plants were associated with highly developed lateral brush roots in the grass-root zone. In contrast, relatively few lateral roots of rubber rabbitbrush occur in this zone.

Caldwell and Richards (1986) have studied the greater competitiveness of crested wheatgrass compared with bluebunch wheatgrass when growing with big sagebrush. They reported that while the root biomass of crested wheatgrass was similar to that of bluebunch (6.9 vs 7.0 oz or 196 vs. 199 g on the average), crested wheatgrass had more fine roots and greater length (11.3 vs 7.33 miles/plant or 18.2 vs 11.8 km/plant). These characteristics, together with a greater rooting depth by crested wheatgrass (> 40 vs 35 inches or 100 vs 90 cm for conditions at Green Canyon near Logan), undoubtedly made crested wheatgrass a better scavenger of nutrients and soil water. They provided a very interesting diagram illustrating root distributions of the two grasses and one shrub.

Table 23.--Herbage production for four densities of big sagebrush in central Utah (adapted from Gobena 1984).

Sagebrush Plants Acre^{-1}	Square Feet Plant^{-1}	Feet Between Plants	New Production, lbs/acre		Percent Cover[1]
			Sagebrush	Crested Wheatgrass	
0	-	-	0	1180	0
40.5	1076	35	12	1160	0.5
724	60	8	200	860	8.2
1242	33	6	376	90	14

[1]Cover is calculated on an assumed 30-inch diameter shrub.

Other papers presenting similar information on the effect of competition between big sagebrush and crested wheatgrass include those of Frischknecht and Bleak (1957), Hull and Klomp (1974), Johnson and Payne (1968), and Robertson (1969, 1972).

FACTORS AFFECTING QUALITY OF CRESTED WHEATGRASS

The first requirement in developing a range livestock management program is a quantitative and qualitative inventory of forage resources (Raleigh 1970). Many of the factors affecting the quantitative production of crested wheatgrass have already been discussed. This section reviews factors affecting the quality of crested wheatgrass.

Forage quality is a many-faceted term. It includes digestible organic matter, crude protein, readily fermentable carbohydrates, and available vitamins and minerals. Quality may also relate to the esthetic appearance, smell, taste, or touch of the forage to the grazing animal. This discussion deals primarily with *in vitro* and laboratory assessment of quality, even when used to explain grazing-animal behavior.

Site Effects

Some quality characteristics of field-grown materials may vary more between sites than between cultivars. This was true for the two *A. cristatum* and three *A. desertorum* cultivars tested by Junk and Austenson (1971) in western Canada. Location differences were found for all characteristics measured except iron and molybdenum. Varietal differences were *in vitro* dry matter digestibility (IVDMD), fat, crude fiber (CF), and stem diameter. The organic quality constituents, phosphorus and potassium, were associated with leafiness.

Rangeland sites may be described by climatic characteristics including temperature, solar radiation and precipitation, and by edaphic characteristics including soil structure, fertility, waterholding capacity, salinity, and alkalinity. These factors may also affect forage quality. Cook (1959) noted that cattle had a high preference for crested wheatgrass and several other grasses growing on unfavorable sites, located on low productive knobs previously dominated by juniper. No further description was provided, but the soils on these knobs may have been slightly hydrophobic, increasing the runoff and making them more droughty. Utilization on the unfavorable site was approximately twice that on the favorable site (Table 24). The preferred plants were more leafy and had lower stem/leaf ratios than the undesirable plants. Forage from the unfavorable site had slightly higher concentrations of crude protein and ash, but lower concentrations of lignin, cellulose, and ether extract (Table 25).

Droughty spots may occur because of gravelly subsoils or on knolls having low water holding capacity. This phenomenon also occurs where solodized-solenetz soils (Natra argid soils), commonly called slick-spots, are intermingled with normal soils. The slick spot has a sodium saturated B-horizon with very low water infiltration characteristics, making it a droughty soil. This soil complex occurs throughout the northern Great

Plains, on the lower end of the Snake River Plateau, and elsewhere. Observations of animal preference for plants growing in 10- to 50-foot diameter areas have been noted,[1] but not well documented. Soil conditions like the above result in a patterned droughtiness and subsequent patterned grazing behavior by animals.

Wurster et al. (1971b) described the quality of four grasses grown on a silty clay loam interspersed with areas of droughty soil in South Dakota. Forage samples were taken from smooth bromegrass and intermediate, crested, and Siberian wheatgrass at 6-day intervals from 23 May to 15 August. The forage grown on the droughty soils had higher digestibility and acid detergent fiber (ADF) values than did forage grown on moister soils. The higher digestibility of forage grown on the droughty soil was most pronounced in the early maturing crested wheatgrass, and may be related to slower development of structural material under suboptimum conditions. Dry matter yields were significantly lower on the droughty area for all species except intermediate wheatgrass.

Seasonal Effects

The morphological development of a grass progresses from the appearance of vegetative tillers and succulent leaves to leaf maturation and senescence. Reproductive tillers will develop and the plant will flower, set seed, and upon further curing will shed seed. This process is genetically controlled and carried out under restraints of the environment. Hyder and Sneva (1963a) noted that crested wheatgrass, like other grasses, continues to accumulate dry matter until flowering time when dry matter yields will level off for a while and then decline as leaves are lost and seed is shed (Fig. 7).

Table 24.--Plant characteristics and animal utilization of three wheatgrasses at the end of the spring grazing season on adjacent favorable and unfavorable sites in Utah (Cook 1959).

Site and species	Stem/leaf ratio	Height of seed culm	Utilization
		Inches	Percent
Favorable			
Crested wheatgrass	2.46	24	35
Intermediate wheatgrass	1.15	27	63
Tall wheatgrass	1.12	33	31
Unfavorable			
Crested wheatgrass	1.67	20	80
Intermediate wheatgrass	.71	24	96
Tall wheatgrass	.45	28	66

Table 25.--Mean chemical characteristics of three wheatgrasses grown on adjacent favorable and unfavorable sites in Utah (Cook 1959, Cook et al. 1958).

Site conditions	Plant part	Ether extract	Protein	Ash	Lignin	Cellulose
		Percent				
Favorable	Leaves	4.7	12.1	13.5	5.8	27.4
	Stems	1.6	8.1	7.4	6.9	33.6
	Whole plant	2.8	9.6	9.7	6.5	31.2
Unfavorable						
	Leaves	3.8	12.5	14.3	5.5	25.9
	Stems	1.5	8.9	7.5	6.5	32.2
	Whole plant	2.6	10.8	11.0	6.0	28.7

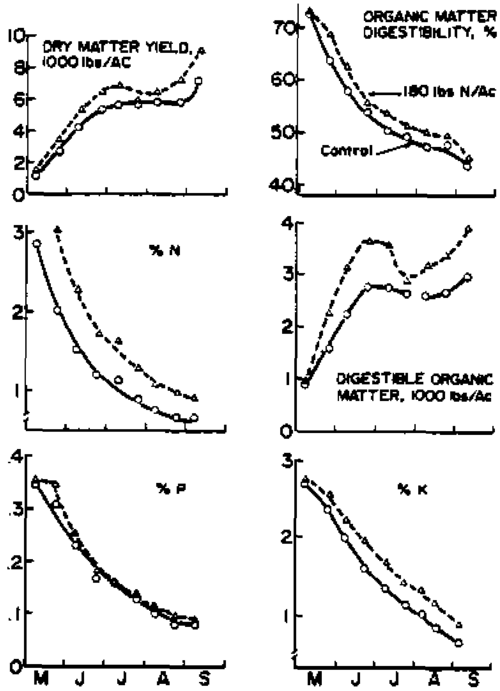

Figure 12.--Two-year mean yield and nutritional component values of crested wheatgrass grown at Swift Current, Saskatchewan with zero or 180 lbs N per acre (200 kg N/ha) and irrigated with 10 inches (26 cm) of supplemental water annually (adapted from Lawrence and Knipfel 1981).

If fall regrowth occurs then dry matter yields may continue to increase as shown in Figure 12.

During morphological development photosynthetic products are cycled through soluble sugars having a highly digestible organic matter (DOM) to other materials having low solubility and low DOM (Cook et al. 1958). Crested wheatgrass forage that has 70 percent DOM in early spring may decline to 50 to 55 percent DOM at flowering and even less by midsummer (Fig. 12). The amount of DOM increses up to flowering time. It may then decrease if either percent DOM or yield decreases, or may increase if fall regrowth occurs. Fertilizer nitrogen increased the amount of DOM by 35 percent when compared with the control. Crude protein concentration, shown as percent nitrogen, was elevated about three percentage units (0.5 percent N x 6.24). Even though nitrogen may change the amplitude of these response curves, the shape of the curve is not greatly different from that of the control response.

Seasonal changes in forage quality parameters are also available for a 9-inch precipitation area in south central Idaho (Murray et al. 1978). Like the results from Swift Current (Fig. 12), data from the Idaho location show curvilinear decreases in total digestible dry matter (TDDM), crude protein (shown as % N) and digestible cell wall (DCW) presented on an organic matter basis (Fig. 13).

[1]R.B. Murray, Dubois, Idaho, personal communication.

Willms et al. (1980) used polynomial regression analyses to describe the change in chemical constituent concentrations in A. desertorum and four other grasses sampled between 14 February and 31 May 1974 in south central British Columbia. Forage quality was high initially, but declined as the grasses matured. There were few differences in quality when new growth on fall-grazed pastures was compared with new growth on fall-deferred pastures.

Forage quality may have various definitions to researchers and producers. As a consequence, there is a variety of information in the literature. Rauzi (1975) reported the yield, crude protein and levels of several minerals in crested wheatgrass grown at Archer, Wyoming (Table 26). Dry matter yield continued to increase up to the time of anthesis or flowering. The quality parameters, however, declined as the plants matured.

Patton and Gieseker (1942) monitored changes on two quality parameters in Agropyron cristatum and A. desertorum grown in central Montana (Table 27). A general increase in cellulose and lignin occurred in both species as the plants matured. The A. desertorum plants were of lower forage quality than A. cristatum at the seed-ripe and seed-shed stages, because of higher cellulose and lignin contents.

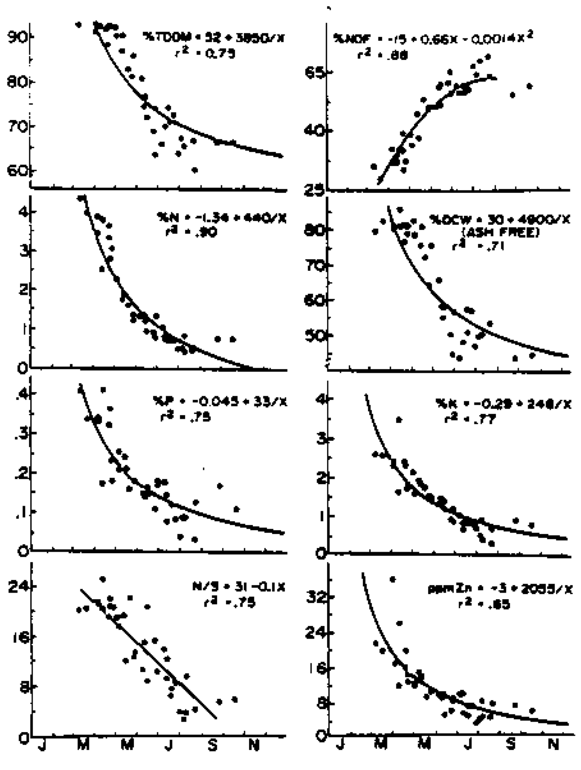

Figure 13.--Seven-years of forage quality data regressed against Julian date (x-axis) for crested wheatgrass grown at Saylor Creek in south central Idaho. Abbreviations are total digestible dry matter (TDDM), total nitrogen (N), phosphorus (P), nitrogen/sulfur ratio (N/S), neutral detergent fiber (NDF), digestible cell wall on an organic matter basis (DCW), potassium (K) and zinc (Zn) (adapted from Murray et al. 1978).

Table 26.--Three-year-mean of chemical constituents in crested wheatgrass for five phenological stages of growth in southeastern Wyoming (Rauzi 1975).[1]

Component	Stage of maturity: Early veg.	Late veg.	Boot	Seed head emerged	Early-full bloom
	Percent				
Crude protein	23a	20b	16c	13d	10e
Calcium	.37a	.35ab	.31c	.29c	.23d
Phosphorous	.26a	.22b	.23b	.22b	.19c
Potassium	2.07a	1.95b	1.76d	1.79c	1.35e

[1]Values for given component with the same letter are not different at P <.05.

Table 27.--Mean cellulose and lignin concentration in Agropyron desertorum and A. cristatum at five maturity stages (adapted from Patton and Gieseker 1942).

Stage of Maturity	Sampling date	Cellulose: A. de.	Cellulose: A. cr.	Lignin: A. de.	Lignin: A. cr.
		Percent			
Vegetative	5/16	20.2	22.5	5.3	5.7
Heading	5/31	25.2	25.5	7.2	7.5
Flowering	6/12	27.6	27.9	8.9	9.3
Seed ripe	6/26	32.4	29.1	13.2	11.6
Seed shed	9/4	40.4	36.9	15.6	14.1

In another study (Sotola 1940), crested wheatgrass forage samples were taken at two week intervals during the May through September period. Ash, crude fiber, and nitrogen free extract (NFE) increased with maturity. Crude protein decreased markedly at first and then changed very little after early summer.

Knowledge of the seasonal quality differences is helpful in prescribing grazing programs. Heinrichs and Carson (1956) harvested forage from nine grasses, including Fairway and Summit crested wheatgrass, at six stages of maturity. The samples were analyzed for proximate constituents, crude protein, crude fiber, calcium, phosphorus and ash. Nitrogen free extract was calculated. After they had examined the data, they recommended that crested and intermediate wheatgrass be used for spring and early summer grazing, smooth brome and green needlegrass for summer, and Russian wildrye and streambank wheatgrass for fall and possibly winter grazing.

Wight et al. (1983) reported that crested wheatgrass and Russian wildrye were more resistant to damage from early spring grazing than were most native species in the northern Great Plains. They also noted that Russian wildrye remained quite palatable after dormancy, making it particularly valuable for late summer and fall grazing.

A similar set of quality factors in A. cristatum was monitored over a 13-year period at Manyberries and Swift Current (Clarke and Tisdale 1945). These factors also demonstrated a reduction in forage quality as the wheatgrass matured (Table 28).

Table 28.--Mean chemical composition of *Agropyron cristatum* plants sampled at various stages of maturity from 1927 to 1940 at Manyberries and Swift Current, Alberta (adapted from Clarke and Tisdale 1945).

Stage of Maturity	Sampling date	Crude protein	Crude fiber	Ether extract	Nitrogen free extract	Total ash	Calcium	Phosphorus
		Percent						
Vegetative	5/10	22.7	19.9	2.7	45.8	8.85	.42	.27
Heading	6/8	13.9	29.2	1.6	48.0	7.45	.29	.24
Flowering	6/29	11.7	33.1	1.8	46.3	7.12	.32	.19
Seed ripe	7/30	8.5	32.5	1.9	51.1	5.92	.33	.14
Seed shed	10/21	4.5	34.7	1.9	52.1	6.85	.30	.05

The Canadians harvest mature crested wheatgrass for winter feeding programs. *Agropyron cristatum* harvested in late August was hammermilled through a .25 screen and pelleted. It was then compared with other sheep diets composed of wheat straw and hay processed in a similar way (Knipfel 1977). The straw-alfalfa mixtures were adequate for the pregnant ewe, but the wheatgrass diet was deficient in crude protein. A previous study (Beacon et al. 1973) reported that pelleting of various ratios of crested wheatgrass to concentrate mixtures increased dry matter intake, weight gain, and feed efficiency by 15, 47, and 23 percent, respectively, when fed to growing lambs. The crested wheatgrass served as a good roughage in this diet.

Plant Parts

Leaves have higher concentrations of crude protein, ash and ether extract than stems, and lower concentrations of lignin and cellulose (Table 25). Leaves initially make up most of the standing biomass of crested wheatgrass. As the plant matures, however, this proportion declines to almost zero as first the sheath and then the stem makes up an important part of the above ground biomass (Wurster et al. 1971a). Figure 14 illustrates the portions of leaf, sheath, and stem inflorescence, and the IVDMD of the plant parts of two *Agropyrons* grown in the field at Brookings, South Dakota. The IVDMD of each part, including the leaves, declines because of the formation of strongly bonded structural materials that are used for enlarging cells and thickening cell walls.

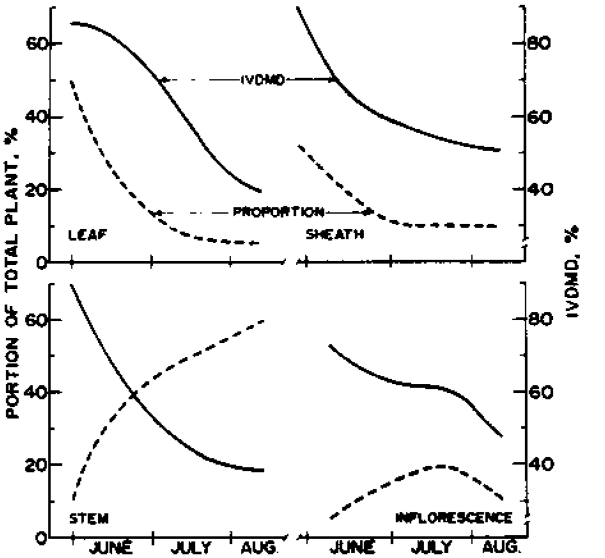

Figure 14.--Mean seasonal trends in the relative dry matter proportions (dotted lines) and *in vitro* dry matter digestibility (IVDMD) of those plant parts (solid lines) for P27 and Nordan crested wheatgrass grown at Brookings, South Dakota (adapted from Wurster et al. 1971a).

Seven wheatgrasses including three *Agropyrons* (Fairway, Nordan and Siberian) were grown on a calciorthid soil near Kimberly, Idaho. Whole plant samples were harvested at anthesis and separated into leaf, stem, and head components. The chemical composition of each is shown in Table 29. Of the three plant parts, stems had the highest dry matter and highest nitrate nitrogen, as expected. The heads had the highest soluble nitrogen, phosphorus, copper, and zinc concentrations, also as expected. Additional data on the nitrogen content of reproductive organs of crested wheatgrass are given by Sneva (1983). These mineral data illustrate the differences that occur in the composition of plant parts. The availability of these nutrients to grazing animals, however, may be different from their concentration in the plant part.

Table 29.--Mean chemical composition of seven wheatgrasses grown at Kimberly, Idaho, and harvested at anthesis. (Mayland unpublished).

	Leaves	Stems	Heads
	Percent		
Dry matter	42 ± 18	45 ± 10	19 ± 9
K	2.50 ± .43	2.10 ± .21	1.60 ± .15
Mg	.18 ± .01	.07 ± .01	.09 ± .01
Ca	.50 ± .12	.16 ± .03	.16 ± .05
P	.15 ± .01	.13 ± .03	.27 ± .03
Cl	.77 ± .17	.82 ± .12	.29 ± .06
N	3.40 ± .31	1.80 ± .33	2.70 ± .35
H_2O Sol. N	.96 ± .18	.67 ± .15	1.43 ± .26
t-aconitate	1.80 ± .5	.26 ± .32	.20 ± .16
	Parts per million		
NO_3 - N	300 ± 110	760 ± 120	380 ± 100
Na	310 ± 130	450 ± 250	300 ± 180
Fe	130 ± 50	60 ± 50	76 ± 15
Mn	70 ± 30	30 ± 9	30 ± 10
Zn	14 ± 2	12 ± 2	24 ± 2
Cu	5 ± 1	6 ± 3	9 ± 1
	Parts per billion		
Se	83 ± 24	98 ± 19	120 ± 60
Co	80 ± 20	80 ± 20	100 ± 90
Mo	870 ± 450	330 ± 260	630 ± 340
	milliequivalents per kilogram		
Ash alk.	700 ± 80	440 ± 50	330 ± 15
HFA	72 ± 11	31 ± 4	56 ± 4

Mineral Concentrations

Only a few studies on minerals in forages deal specifically with crested wheatgrass. Such reports may be categorized under one of two headings: those that discuss mineral concentrations in relation to animal health, and those that provide baseline data on mineral concentrations in relation to geochemistry of top soil or spoil material. Allway (1975) and Kubota and Allaway (1972) discuss the elements essential to animals and their role in the soil-plant-animal cycle.

Forage minerals and animal health.—Crested wheatgrass samples from various areas in northern Nevada (Dye 1962, Blincoe and Lambert 1972) contained the following mineral concentrations in parts per million:

	Range	Mean
Cobalt	0.56 to 23	12
Copper	0.84 to 5.4	2
Iron	180 to 802	117
Manganese	19 to 59	29
Molybdenum	0.8 to 3.4	2.4
Zinc	8 to 24	13

The cobalt concentrations were unusually high when compared with values from other plants (Lambert and Blincoe 1971), but the findings were verified by several different analytical procedures. The authors concluded that crested wheatgrass was a potential accumulator of cobalt. It is possible that their samples were contaminated with cobalt during collection, transportation, or processing. Analysis of separate samples taken from the San Jacinto seeding (an area also sampled by Blincoe and Lambert 1972), produced values of about 0.1 part per million (H. F. Mayland, unpublished), comparable with data from other sources.

Murray et al. (1978, 1979) sampled crested wheatgrass forage for mineral concentrations between March and December over a period of seven years (Fig. 13). The elements in crested wheatgrass in order of their being or becoming deficient for animals during the grazing season are as follows: Nitrogen (crude protein) > phosphorus > zinc > potassium. Magnesium deficiency often occurs in animals grazing crested wheatgrass. However, this occurs because of other factors that reduce its availability to ruminants.

Forage minerals and geochemistry.—Crested wheatgrass is common to many areas of the Western Energy Belt where spoils from coal and uranium mines are revegetated. Crested wheatgrass is used as a biological indicator of the solubility or availability of minerals in top soil and spoil. A mineral profile of the forage sample provides information about the elements that are entering the food chain.

Contamination of the forage by dust or soil splash must be considered in determining the selection, forage sampling, and chemical analysis of forages (Mayland and Sneva 1983). High iron concentrations (greater than 100 µg/g) are often associated with soil contamination, but some effects may be explained by differences in soil pH.

Ebens and Shacklette (1982) provided summary statistics for 59 elements contained in mineral and biological materials from 25 study areas. Cultivated cereals and native grasses and shrubs are among the biological materials included in the study. Crested wheatgrass is identified for some sites. This reference is a useful source of elemental-concentrations expected in soils and plant materials and the natural error associated with such values.

Fairway crested wheatgrass was selected as the biological subject to monitor mineral solubilities in a topsoil and spoil area in east-central Wyoming (Erdman and Ebens 1979). The concentration of 26 elements is reported for forage samples obtained at the seed ripe stage from a reclaimed-coal spoil and a topsoiled area (Table 30). Forage grown on the spoil contained higher concentrations of cadmium, cobalt, fluorine, manganese, uranium, vanadium, and zinc, but a lower concentration of phosphorus than forage grown on the topsoiled area. The data provide a valuable reference for those wishing to compare elemental-concentration data.

In another study, forage samples were collected in June and August from three reclaimed mine sites and adjacent undisturbed native sites in south central Montana and eastern Wyoming (Stanley et al. 1982). The plant material was analyzed for 14 elements by ICP (inductively coupled plasma atomic emission spectrometry) which, along with possible soil contamination of samples, may explain some of the variations. Selenium and crude protein concentrations were also determined. Nitrogen and nickel were the only elements not also reported by

Table 30.—Geometric mean concentrations and observed ranges of elements in crested wheatgrass from topsoil borrow areas and from reclaimed spoil areas in eastern Wyoming (Erdman and Ebens 1979).[1]

Element	Topsoil borrow areas Mean	Topsoil borrow areas Range	Reclaimed spoil areas Mean	Reclaimed spoil areas Range
	Parts per thousand			
Al	.69	.30-2.7	1.1	.41-3.7
Ca	2.6	2.2-3.0	2.3	1.6-3.5
K	11	9-14	12	7.2-16
Mg	1.2	.8-1.7	1.1	.8-1.7
[3]P	1.3	.9-1.9	.84	.41-1.7
S, total	1.7	1.0-2.7	1.8	.9-3.3
Si	12	7-19	9.8	4.4-19
	Parts per million			
B	15	11-28	17	11-48
Ba	12	6-22	10	6-22
[2]Cd	.054	.016-.15	.082	.034-.15
[3]Co	.069	<.05-.13	.099	<.06-.44
Cr	.27	11-.60	.40	.16-1.1
Cu	2.8	1.6-6.0	3.2	1.6-5.9
[2]F	4.5	3-6	6.2	3-10
Fe	190	81-350	270	120-740
Hg	.011	.01-.02	.011	.01-.02
Li	.82	.29-1.8	1.3	.58-4.0
[3]Mn	16	5.6-36	39	23-140
Mo	.39	<.4-.58	.43	<.4-.84
Na	8.4	3.6-22	11	3.5-21
Se	.23	.10-.60	.27	.10-.70
Sr	25	16-39	25	14-41
Ti	16	3-50	26	11-74
[2]U	.021	<0.2-.067	.062	<.03-.55
[2]V	.63	<.5-.98	.82	<.7-1.5
[3]Zn	20	13-28	26	18-32

[1]Data are based on 10 samples and their analytical duplicates from each area; concentrations are expressed on a dry basis.
[2]Means are significantly different at the P<0.05 level.
[3]Means are significantly different at the P<0.01 level.

Table 31.--Chemical composition and apparent digestibility of crested wheatgrass tissue eaten by sheep during spring and summer (after Cook and Harris 1968).

Growth stage	Chemical composition: Ether extract	Total protein	Lignin	Cellulose	Phosphorus	Apparent digestibility: Protein	Total nutrients	Metabolizable energy
	Percent							Kcal/lb
Fifth leaf 5-9-53	3.3	20	3.3	19	.27	16.2	76	1325
Early head 6-8-53	2.3	13	7.4	31	.23	6.6	51	683
Anthesis 6-16-54	2.4	11	7.3	31	.18	5.9	52	751
Hard seed 7-10-54	3.6	9	7.3	28	.14	5.5	57	914

Erdman and Ebens (1979). Stanley et al. (1982) reported that copper values ranged from 20 to 40 ppm which seems high by a factor of 10X when compared with other data. Zinc values ranged from 30 to 50 parts ppm and seem high by a factor of 2X.

Element profiles for plants growing on the reclaimed areas provide baseline data for the long term studies. In addition, these profiles are useful in determining the forage quality and suitability for animal consumption, and in determining the success of top-soiling the reclaimed areas.

Nielson and Peterson (1973) evaluated the ability of 54 species including grasses and legumes to grow on copper mine tailings. Nothing grew on untreated tailings. _Agropyron_ species were among the 16 that were established on leached tailings fertilized with nitrogen, phosphorus, and trace minerals. Grasses were more tolerant of salinity and high copper than were legumes.

Digestible Nutrients

Forage quality can be defined in many ways, but usually is related to some animal response, such as feed intake, weight gain, reproduction, or production of milk or wool (Murray et al. 1978). Sometimes forages are fed directly to animals to determine apparent or true digestibility and these values may be compared with information obtained through indirect methods. Cook and Harris (1968) using sheep examined both the chemical composition and the apparent digestibility of crested wheatgrass at four different growth stages (Table 31). Parameters like ether extract, crude protein (CP = %N x 6.24), phosphorus, metabolizable energy, and total nutrients are factors that relate positively to quality. Parameters like lignin and cellulose may contribute negatively to overall quality.

Sosulski et al. (1960) reported the lignin concentrations in five Agropyron species grown in the field in southeastern Washington. The lignin percentages at five growth stages were:

Early vegetative	4.0
Boot	4.7
Preheading	6.3
Heading	7.1
Flowering	7.7

These values were consistently higher than the concentrations in bromegrass and orchardgrass. Differences in lignin concentrations between _Agropyron_ cultivars were as great or greater at flowering than earlier. The lignin percentages for whole plants sampled at the flowering stage of maturity were:

Fairway	7.6
Siberian	7.6
A 1770	8.0
Nordan	8.3
Commercial	8.3
Nebraska 10	8.4

Sims and Cook (1970) evaluated the digestibility of four wheatgrasses harvested between 20 June and 22 July, and reported that cellulose digestibility was higher in plants grown in dense stands, perhaps relating to the retarding of plant maturation. Cellulose digestibility was also higher in leaves than in stems. Dry matter digestibility (%) was not affected by stand density, but was related to cultivars:

	DMD
A. cristatum	52
Intermediate	50
Pubescent	49
Tall	47

The forage quality of seven grasses was determined at anthesis in a 7-year study conducted in eastern Montana (Table 32).

Forage quality generally declines as crude protein values decline with plant progression from vegetative to seed-ripe stages. The levels can also be affected by cultural practices. For example, crested wheatgrass can be fertilized (Fig. 7), treated with growth regulators (Fig. 9) or planted in mixtures with a legume. Schultz and Stubbendieck (1983) showed the effect of fertilizer nitrogen and phosphorus on the crude protein percentages of alfalfa or a mixture of alfalfa and _A. cristatum_:

	Alfalfa	Alfalfa + *A. cristatum*
0N + 0P	15.6	10.3
45N + 0P	13.9	10.8
45N + 22P	14.3	11.2
0N + 22P	15.0	11.0

In the same study a small difference in IVDMD between alfalfa and the alfalfa-grass mix was reported, but no difference relating to fertilizer treatment.

	Alfalfa	Alfalfa + *A. cristatum*
0N + 0P	63	61
45N + 0P	64	62
45N + 22P	65	61
0N + 22P	64	61

Some of the older studies on forage quality reported data for parameters like ether extract (Tables 25 and 28) and digestible organic matter (Fig. 10, Table 16). Data on the negative aspects of forage quality are provided by nitrogen free extract (NFE), crude fiber (CF), cellulose and lignin (Tables 25, 27, and 28). Each of these parameters provides evidence that as the plant develops morphologically it becomes increasingly less nutritious for the grazing animal.

A newer method of measuring forage quality determines cell wall residues (total of lignin, cellulose and hemicellulose) and replaces crude fiber analysis (Van Soest 1966). The residues are considered to be chemical components that cannot be completely digested, separated into components that are (1) insoluble in a neutral detergent solution (NDF), (2) soluble in an acid detergent solution (hemicellulose), and (3) insoluble in the same solution (acid detergent fiber (ADF) including cellulose, lignin, lignified nitrogen compounds, and silica). The cell contents are soluble in neutral detergent solution. The method separates the highly digestible from the partially digestible and indigestible components of forage.

Table 32.--Forage yields, estimated *in vivo* dry matter digestibility (IVDMD), and crude protein (CP) concentrations in grasses grown at Sidney, Montana (White and Wight 1984).

Species	Yield	IVDMD	CP
	Pounds per acre	--- Percent ---	
Altai wildrye	3000	62	12
Russian wildrye	2900	61	10
Crested wheatgrass	2900	60	9
Green needlegrass	2700	60	10
Pubescent wheatgrass	2700	60	8
Meadow bromegrass	2100	63	9
Reed canarygrass	1600	65	15

The method of Van Soest (Goering and Van Soest 1970) was used to estimate the dry matter digestibility of seven grasses grown in south central Idaho over a seven-year period (Murray et al. 1978). The NDF (a measure of total fiber) data for crested wheatgrass are given in Figure 11. The values begin at about 25 percent in early March and increase to about 60 percent by early July, reflecting the maturation of the plants. The digestible cell wall (Fig. 13) is given on an ash free basis and as such is not exactly the inverse of the NDF curve, but it does have the inverse shape. The true dry matter digestibility (TDMD) corrected for ash is also shown in Figure 13. On an ash-free basis, the TDMD values decline from 90 percent early in the season to 60 to 65 percent during midsummer.

White and Wight (1981) using another approach estimated the *in vivo* digestibility of seven grasses plus alfalfa and cicer milkvetch grown in eastern Montana. The samples were subjected to a modified Tilley and Terry two-stage procedure as were three forage samples whose true dry matter digestibility was known from previous animal studies. Regression analyses were employed to calculate the estimated *in vivo* digestible values for crested wheatgrass and two wildrye species (Fig. 15). Digestibility of all species declined with increasing maturity. The wildrye species were more digestible during late summer and autumn than crested wheatgrass. This relationship was also verified by animal response data and leads to the recommendation that crested wheatgrass be used in early spring and wildrye in late summer and autumn.

Coulman and Knowles (1974) reported significant differences in IVDMD between plants of the diploid *A. cristatum* and those of the tetraploid *A. desertorum* strains. The values were highly correlated with proportion of leaves in the sample. The *A. cristatum* strains were more palatable and superior in IVDMD. Like others, Coulman and Knowles measured a sharp decline in IVDMD between heading and the end of anthesis with little subsequent change thereafter.

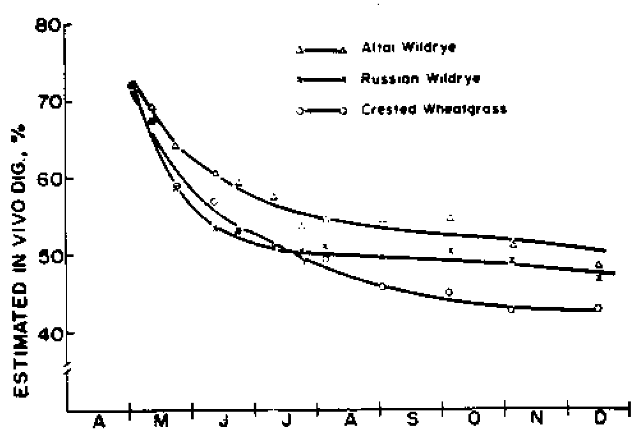

Figure 15.--Estimated *in vivo* digestibility of three grasses grown at Sidney, Montana (adapted from White and Wight 1981).

Lawrence (1978) published an evaluation of the yield and quality characteristics of thirty grasses grown in southwestern Saskatchewan. Data on forage yield, nitrogen, phosphorus, and digestible organic matter were provided for samples taken during spring, summer, late summer, fall, and late winter. The favorable and unfavorable characteristics were shown by an alpha-code in a summary table. A more quantitative approach would have been desirable.

Index values are often used in programs involving selection for two or more traits. Vogel et al. (1984) calculated an index (NI) based on forage yield and IVDMD for 38 crested wheatgrass introductions and experimental strains. Strains with high positive NI values usually had both high yield and high IVDMD values. The opposite was true for strains with negative NI values. The index, when calculated for two years and two locations in Nebraska, ranged from -4.00 to 2.80. The varieties Ruff (A. cristatum) and Nordon (A. desertorum) were among the top six selections. 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. Later maturing strains tended to be higher in IVDMD. Most of the differences were probably due to factors other than maturity, because most of the strains headed within the same week.

Using the above approach, the four Agropyrons described by Lawrence (1978) were indexed for yield and digestibility traits:

A. desertorum	1.18
A. cr. x A. de.	.42
A. cristatum	- .25
A. sibericum	- 1.34

The above indices were based equally on yield and digestibility. If desired, factors can be differentially weighted and more than two factors can be used. The index is a simple tool by which entries can be numerically ranked, remembering that some quality factors are not easily quantified.

Smoliak and Bezeau (1967) determined the chemical composition and in vitro digestibility of crested wheatgrass, Russian wildrye and pubescent wheatgrass relative to a standard of early-cut, chopped, dehydrated legume hay (Fig. 16). The nutritive value of crested wheatgrass was between that of the other grasses prior to the soft dough stage while Russian wildrye was superior to the other grasses after curing.

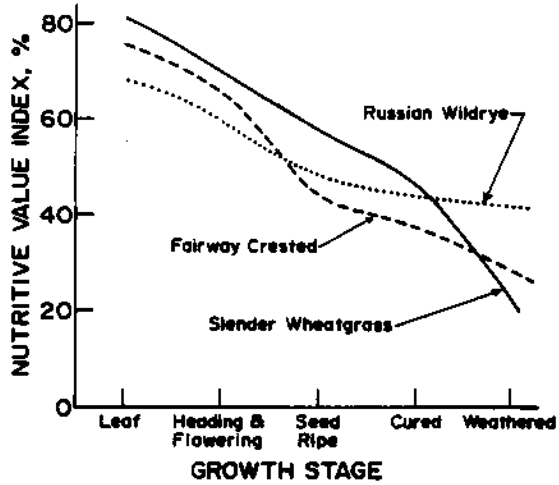

Figure 16.--Nutritive value index for three grasses compared to legume hay at Manyberries, Alberta (Smoliak and Bezeau 1967).

Feeding studies and chemical analyses are the two most common methods used to estimate quality. Feeding studies are labor intensive and costly, therefore not frequently used. Laboratory methods that predict forage value based on chemical composition and in vitro digestibility are also expensive and time consuming. An alternative may be the infrared reflectance (IR) technique that has potential for rapid, routine analyses and prediction of a wide variety of forage quality characteristics and animal responses to forages.

Park et al. (1983) evaluated the IR technique on forage samples of A. cristatum, A. desertorum, A. sibericum, and A. cristatum x A. desertorum. The instrument responses to each of 80 samples were regressed against forage quality data for several nitrogen and fibrous fractions in the laboratory. Values for these fractions were next predicted by the IR technique for 30 additional samples. The predicted values were then compared with laboratory results (Table 33). The IR technique can be used to predict some chemical values with accuracy and precision similar to conventional wet-chemistry methods. However, the IR technique requires a large number of representative samples upon which to develop and test the predictive equations.

Table 33.--Actual values of nitrogen and fiber fractions determined by wet chemistry compared with those values determined by IR for 30 samples of Agropyron cristatum, A. desertorum, A. sibiricum, and A. cristatum x A. desertorum (adapted from Park et al. 1983).

Component	Mean		Standard Deviation		Std. error of	r^2
	Actual	Predicted	Actual	Predicted	difference	
	Percent					
Total nitrogen (N)	1.01	1.00	.18	.16	.04	.96
N soluble in NaCl	.43	.40	.08	.07	.04	.76
Neutral detergent fiber	64.1	64.0	2.6	2.5	.96	.86
Acid detergent fiber	36.2	36.0	2.2	1.8	1.01	.83
Acid detergent lignin	5.24	5.19	.66	.53	.53	.38

The methods of forage chemical analyses are chosen to provide estimates of animal response in terms of preference, intake, digestibility, etc. Handl and Rittenhouse (1975) compared three methods of estimating digestibility for the purpose of predicting dry matter intake by cattle grazing crested wheatgrass range. Digestibility was determined by (a) the _in vitro_ method of Tilley and Terry using a 48-hour pepsin digestion, (b) the lignin ratio, and (c) the method of Van Soest for soluble cell wall constituents. Forage digestibility averaged 61, 63, and 72 percent for the three methods, respectively. Because the forage was highly digestible, variation among methods was small and each responded similarly within dates. Estimates of dry matter intake derived from (a) and (b) did not differ significantly, but both were greater than estimates derived from (c), which were lower than expected, perhaps because of the difficulty in estimating cell wall constituents in fecal samples.

Troelsen (1971) estimated the consumption of digestible energy by sheep from the concentrations of _in vitro_ digestible energy, cell wall constituents, and crude fiber in coarse roughage. Four grasses, including _A. cristatum_ and alfalfa were harvested annually at four to seven growth stages over a period of four years and fed to sheep. The concentration of _in vitro_ digestible energy, cell wall and crude fiber were each related to intake of digestible energy. For grass hays, _in vitro_ digestible energy gave the best prediction of consumed digestible energy with a coefficient of variation of 18 percent compared with 24 percent for other fiber measures.

Biological factors affecting forage quality include disease and insects. Karn and Krupinsky (1983) found field grown intermediate wheatgrass plants naturally infested with stem rust had lower IVDOM and higher NDF, ADF and lignin than smut-free plants. Intermediate wheatgrass plants infected with leaf spot diseases had lower IVDOM and higher NDF than healthy plants.

Clipping and Sampling

Factors affecting the proportion of leaves on the plant will have a major impact on forage quality. Cook et al. (1958) found that frequent clipping of crested wheatgrass increased forage quality. This was probably a result of increased vegetative growth and higher leaf to stem ratios. The frequent clipping, however, resulted in decreased dry matter yields. More recent research at Squaw Butte has shown that clipping crested wheatgrass during late May removed the apical meristem, increased regrowth and increased the proportion of leaf tissue (Miller et al. 1984). Clipping at that time, however, decreased the overall yield because reproductive tillers were not formed.

Sheep, and perhaps cattle also, will discriminate against plants having reproductive tillers and will be attracted to those having only vegetative tillers (Murray 1984). Because animals graze quite selectively, choosing some plants and plant parts while refusing others, it may be very important that herbage sampling mimic the same selectivity exhibited by the animals.

Hart et al. (1983a) checked their ability to manually sample crested wheatgrass forage against esophageal collections at Cheyenne, Wyoming. Crested wheatgrass samples were collected over the 15 May to 30 June period and analyzed for crude protein, lignin, ADF and IVDMD (Fig. 17). They found that as the season advanced there were linear increases in lignin and ADF fractions and linear decreases in crude protein and IVDMD. Quality data for the manually-collected samples did not mimic well the data from the esophageal-collected samples. Agreement can be achieved only after careful observations of grazing selectivity followed by careful sampling. Another source of error is that differences between grazing animals may be as great as differences between collection techniques.

FACTORS AFFECTING THE ANIMAL RESPONSE TO CRESTED WHEATGRASS

Many interacting factors influence animal response to grazing crested wheatgrass. These include not only what they eat, but the quantity and quality of the ingested forage.

Grazing Preferences

It is probable that animals ingest greater quantities of a preferred species, increasing their performance in terms of milk or wool production, or live weight gain. The less-preferred plants may have lower protein, magnesium, moisture, or carbohydrate concentrations, or higher silica levels.

Smoliak (1968) made daily observations of the grazing habits of yearling ewes having daily access to crested wheatgrass, Russian wildrye and native range at Manyberries, Alberta. Ewes preferred crested wheatgrass from initiation of grazing (late April - early May) until the third week of June. They then grazed Russian wildrye for about three

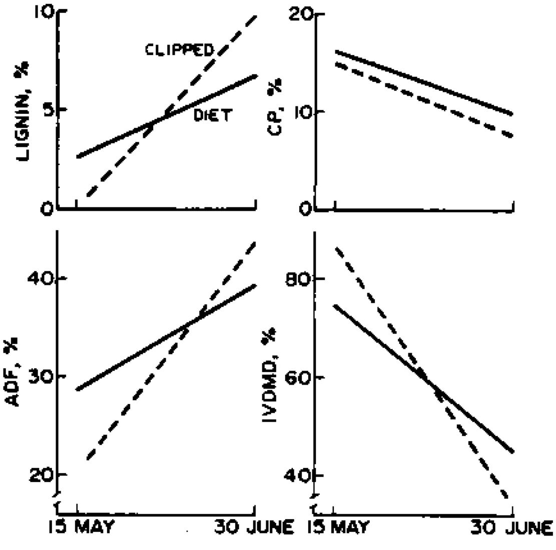

Figure 17.--Lignin, crude protein (CP), acid detergent fiber (ADF) and _in vitro_ dry matter disappearance (IVDMD) values for clipped or esophageal (diet) samples for one season at Cheyenne, Wyoming (adapted from Hart et al. 1983a).

Table 34.—Forage production and relative animal preference for six grasses at three growth stages (adapted from Gesshe and Walton 1980, 1981).

Forage	Production			Preference Rating[1]		
	Vegetative	Heading or flowering	Seed ripe	Vegetative	Heading or flowering	Seed ripe
	--------- Pounds per acre ---------					
Bromegrass	2070	5080	5480	1.2	1.0	1.2
Creeping red fescue	2590	4580	4630	1.1	.6	.0
Crested wheatgrass	1380	2800	3720	.8	.2	.0
Intermediate wheatgrass	2560	5490	5140	1.2	.2	.0
Red top	1120	3640	5650	.9	1.1	1.5
Russian wildrye	580	700	1410	1.2	1.9	1.7

[1] Values greater than 1.0 indicated preference, values less than 1.0 indicated avoidance.

weeks, shifted to native range from mid-July until mid-August, and then grazed the Russian wildrye again until late October. Toward the end of the grazing season ewes preferred crested wheatgrass during periods of deep snow and cold weather. The preference for a certain type of herbage was influenced not only by its palatability, but also its seasonal availability and accessibility. (See section on 'Winter Use').

A study evaluating cattle preference for several forages, including crested wheatgrass, was conducted at Kinsella, Alberta (annual rainfall 16.0 inches)(Gesshe and Walton 1980, 1981). Six grasses, three legumes and a forage mixture were seeded into three sets of pastures, each having four replications of each forage. The forages were grazed at three stages of maturity and grazing preferences were assigned (Table 34). Values greater than 1.0 indicated preference, less than 1.0 avoidance. Russian wildrye had the highest overall rating, but lowest dry matter yield of the grasses, attributed to wide row spacing (14 inches), and slow establishment. Crested wheatgrass had the lowest preference rating of the six grasses. The rating was highest at the vegetative stage, decreasing with advancing maturity to zero at the seed ripe stage.

Gesshe and Walton (1980) noted that each of the forages tested on the University of Alberta farm were all common pasture species, any one of which would be readily utilized by cattle if no alternatives were offered. The relatively high quality of all species in the early vegetative stage encouraged more random grazing. During later grazing periods forage quality differences became much greater and the multiple regression equation accounted for 94 percent of the variation in the animal preference ratings.

$$Y = -4.2 + .04X_2 + .07X_8 + .12X_9 - .07X_4 - .12X_7$$

where Y = Animal preference rating
X_1 = % moisture
X_2 = % leaves (W/W)
X_4 = % crude protein in leaves
X_7 = % crude protein in stem
X_8 = % crude fiber in stem
X_9 = % acid pepsin DM disappearance in stem

The moisture content of the forage was the major positive influence on the preference rating (R^2 = .77) in the seed-ripe stage where

$$Y = 2.42 + .16X_1 - .15X_8 + .01X_2$$

Many ranchers on semiarid rangeland know the value of moisture to 'soften up' mature forage and increase its palatability. It is also not surprising that crude protein, digestibility and crude fiber components appear in the regression equations indicating their importance in determining animal preference ratings.

Preference rankings are increased by some characteristics and decreased by others as shown below.

Positive factors
- Succulent forage
- High leaf:stem ratio
- High crude protein
- High digestibility

Negative factors
- Seed stalks present
- High lignin concentration
- High dry matter concentration
- Low leaf:stem ratio

Preference rankings of crested wheatgrass depend upon stage of growth. The Agropyrons are 'at their best' in early spring, but lose quality with advancing maturity. The dry matter intake of cattle restricted to mature crested wheatgrass will average 1.25 percent of body weight (Havstad et al. 1983) even when the organic matter digestibility averages only 33 to 43 percent. This level is not sufficient to maintain weight gains achieved earlier in the grazing season (Fig. 18). Under such circumstances cattle, if given a choice, would graze other species that were more palatable and nutritious.

Palatability of crested wheatgrass can be manipulated to some extent by applying nitrogen fertilizer. Thomas et al. (1964) applied nitrogen to a crested wheatgrass pasture in the Black Hills. The nitrogen increased yields, crude protein, phosphorus and calcium concentrations. Deer preferred the nitrogen-fertilized grass because of its increased nutritional value and succulence.

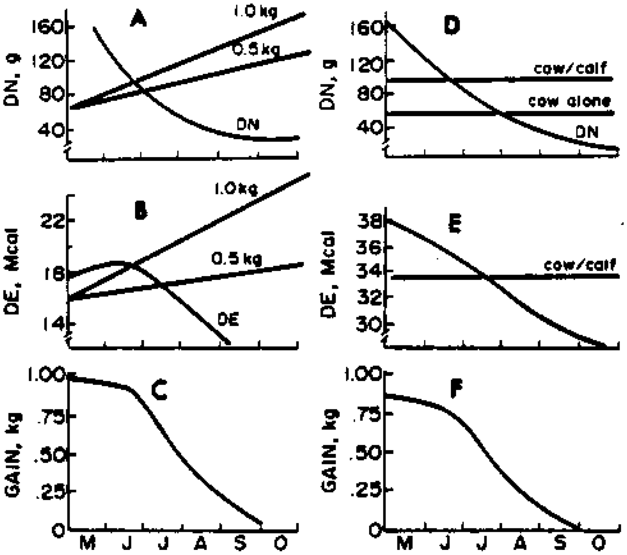

Figure 18.--Digestible nitrogen (DN, Fig. a) and digestible energy (DE, Fig. b) required for maintenance plus 0.5 or 1.0 kg (1.1 or 2.2 lb) daily gain by 250 kg (550 lb) yearling steers, the amount of DN (Fig. a) and DE (Fig. b) they will get from the range forage at Squaw Butte, Oregon, and the average daily gain (Fig. c). The DN (Fig. d) required by a cow-calf pair or cow alone, the DE (Fig. e) required by the cow-calf pair, the amount of DN (Fig. d) and DE (Fig. e) they will get from the range forage at Squaw Butte, and the average daily gain (Fig. f) by the suckling calf (adapted from Raleigh 1970).

Roberts (1977) noted cattle preference for nitrogen fertilized crested wheatgrass when they broke into an exclosure at Benmore, Utah and selectively grazed the fertilized plots.

There may be other factors that affect animal preferences for given forages. Chewing insects may have amino acid receptors that help select their host plants. Grasshoppers and locusts detected and preferentially fed on grasses treated with the amino acids proline and valine (Haglund 1980). These amino acids commonly increase in plants during drought stress. This may explain why chewing insects seek out drought-stressed plants, or it may be simply the higher leaf/stem ratio (Table 24) in the stressed plants. Cattle may also select forage that may be slightly water stressed[2].

Springfield and Reynolds (1951) also evaluated the grazing preferences of cattle for certain grasses. The grasses had been seeded into one-quarter acre plots, in three replications. Four years later it was grazed during the period 21 August through 12 September by 24 cows, 6 calves and 1 bull. This experiment was conducted in the Ponderosa pine type near Vallecitos, New Mexico where the annual precipitation averaged 22 inches. Utilization was determined by clipping the forage at the beginning, midpoint, and end of study.

[2]R.B. Murray, Dubois, Idaho, personal communication.

Utilization percentage at the end of the first week of grazing was:

Orchardgrass	26
Smooth brome	24
Slender wheatgrass	21
Crested wheatgrass	9
Kentucky bluegrass	9
Tall oatgrass	9
Western wheatgrass	1
Big bluegrass	1

As grazing continued and removed the more palatable forage the less palatable species became more important. By the second week dry matter intake of big bluegrass was 43 percent and that of orchardgrass was only 1 percent. Succulence strongly influenced preference and dietary composition was related to forage moisture concentration (r = .69). There was less discrimination when mature forage was wet from rain or heavy dew.

Cattle preferences for cured herbage of six grasses grown at Squaw Butte were evaluated by Hyder and Sneva (1963b). Relative palatability or cattle preference was evaluated in the first two weeks during August 1959-1961. Percent utilization of the cured forage was:

Big bluegrass	69
Tall oatgrass	65
Beardless wheatgrass	44
Pubescent wheatgrass	42
Siberian wheatgrass	17
Crested wheatgrass	15

Sheep at Swift Current (Heinrichs 1959) ranked the palatability of grasses in the following order: Russian wildrye > Summit crested wheatgrass > bromegrass = Fairway crested wheatgrass. In September and October cattle and sheep gained weight on Russian wildrye, but not on the other species. It should be noted that _A. desertorum_ ranked over _A. cristatum_ when indexed for yield and digestibility traits (see section Digestible Nutrients).

Fourteen grass accessions, including nine _Agropyrons_, were evaluated for yield, nutrient quality and palatability to sheep at Dubois, Idaho (Murray 1984). The results show a strong preference for the Russian wildrye cultivars and a low preference for the _Agropyrons_, especially in midsummer (Table 35). Murray noted that when preference was considered in the absence of seed stalks, then all cultivars were similarly preferred by sheep. Preference decreased as numbers of seed stalks increased.

Animal Performance

Crested wheatgrass initiates growth in early spring. Dry matter continues to increase until anthesis and then may remain static for several weeks prior to decreasing (Fig. 8). Throughout this period the leaf/stem ratio and forage quality decline until late summer or fall when standing forage is mainly stems and seed heads. An exception to this decline occurs when fall moisture is adequate for regrowth. A second exception occurs when early grazing removes the reproductive point

Table 35.--Nutrient quality and palatability characteristics of 14 grasses at the Dubois, Idaho Sheep Experiment Station (adapted from Murray 1984).

Accession	Relative value: Leafiness[1]	Relative value: Crude Protein[2]	K (Ca+Mg)[3]	Sheep use[4]: 5/14	Sheep use[4]: 7/14	Sheep use[4]: 9/15	Index[5]	Rank
	----- Percent -----							
Russian wildrye								
Bozoisky	100	100	1.99	7.0	7.9	9.6	295	1
RWR-V13	99	85	1.81	7.5	8.7	9.6	284	2
RWR-128	98	82	1.65	7.2	8.7	9.7	279	3
Tall fescue	93	72	2.23	5.1	8.3	9.1	252	4
Bluebunch X quackgrass	50	61	2.46	4.6	5.7	6.2	175	5
Agropyron cristatum								
Fairway-128	33	74	1.67	2.7	1.3	3.0	134	6
CWG-163	36	71	1.40	1.8	1.8	2.9	132	8
Fairway	38	72	1.17	1.9	1.1	1.7	128	9
CWG-R	30	75	1.09	2.2	1.6	1.4	125	10
Agropyron desertorum								
Nordan	32	79	1.35	4.3	.5	1.2	134	7
CWG(M34-38)	36	71	1.32	2.0	.9	1.8	125	11
CWG (V6-7)	22	79	1.38	2.2	.3	1.6	117	13
Agropyron fragile	33	67	1.25	2.2	.9	1.5	118	12
A. cristatum X A. desertorum	28	66	1.58	2.1	.8	1.1	110	14

[1]Leafiness, as percent of biomass during late August, relative to Bozoisky Russian wildrye.
[2]The sum of crude protein values for biomass relative to Bozoisky Russian wildrye.
[3]Expressed on a chemical equivalency basis.
[4]This is on a scale of 0 to 10 with 10 being maximum use.
[5]The index is the sum of the leafiness on 3 July relative to maximum plus the sum of crude protein concentrations on 30 June and 15 September relative to maximum, plus the sum of the sheep use values on the three dates relative to maximum. All values were initially expressed on a percentage basis for a possible 300 point maximum.

(apical meristem) and the plant produces mostly leaves and few seed stalks.

Nutrient levels during the green-feed period are adequate for grazing livestock (Springfield 1963, Watkins and Kearns 1956, and Woolfolk 1951). There may be some exceptions to this, because heavily lactating cows can lose weight on green crested wheatgrass[3]. Perhaps these animals were not able to eat enough dry matter because high moisture limited dry matter in the vegetative material. After anthesis, weight gains of yearlings and calves begin to decline.

Raleigh (1970) showed that the decline in animal performance was associated with a decline in digestible nitrogen and digestible energy in the forage at Squaw Butte. Forage quality of crested wheatgrass may be maintained for longer periods on higher elevation ranges or where summer precipitation encourages continued growth or regrowth in the fall.

[3] D.C. Adams, Miles City, Montana, personal communication.

Cattle and sheep have been used to assess the nutritive value of crested wheatgrass and other grasses and legumes on Utah foothill ranges (Cook and Stoddart 1961, Cook and Harris 1968, Houston and Urick 1972). Weight gains produced by ewes, lambs, cows, and calves during early spring grazing are given in Table 36. Weight gains during late spring began to decline as forage progressed toward anthesis.

Table 36.—Weight gains by sheep and cattle grazing crested wheatgrass on Utah foothills during early and late spring (after Cook and Harris 1968).

Period	Daily gain: Ewes	Daily gain: Lambs	Daily gain: Cows	Daily gain: Calves
	------------ Pounds ------------			
Early spring	.37	.56	1.5	2.3
Late spring	-.25	.39	.3	1.6

Hart et al. (1983b) measured animal-grazing performance on crested wheatgrass grown at Cheyenne. The pastures were grazed by steers during three spring periods and calves during two autumn periods at each of two stocking intensities (Table 37). Steers grazing the highly nutritious spring growth gained about 2.4 pounds per animal-day. Calves grazing much lower quality forage during the autumn period gained only about 20 percent of the steer rate. In addition, calves gained only 12 pounds per 1000 pounds of forage, while steers gained 4 to 5 times more efficiently.

In a 12-year study conducted on seeded pastures in central Colorado (Currie and Smith 1970), yearling heifers grazed four forage grasses plus a mixture of crested wheatgrass, yellow sweet clover, smooth brome and intermediate wheatgrass. Weight gains per acre and on a daily animal basis were:

	Gain/acre	Gain/day
Smooth brome	40.2	1.52
Crested wheatgrass	59.2	1.67
Intermediate wheatgrass	52.3	1.92
Mixture	71.6	1.81
Russian wildrye	48.8	1.53

The forage mixture produced the greatest gains over the entire period even though it tended to become dominated by crested wheatgrass. Perhaps the resulting mixture maintained a quality green-feed period longer than the monocultures. Or perhaps the heifers had a high preference for some of the feed, ate more, and performed better. The possible animal preference for species other than crested wheatgrass might explain why it began to dominate the stand.

Stocking Intensity

Harris et al. (1958) measured the effects of light (50%), moderate (65%), and heavy (80% utilization) stocking rates with cattle on _A. cristatum_ in a Utah study. Spring grazing at the moderate rate produced significantly greater individual gains than grazing at the heavy rate. Yields of rabbitbrush declined 53, 40, and 23 percent under light, moderate, and heavy grazing while yields of big sagebrush increased 6, 32, and 79 percent, respectively.

Table 37.--Beef production in spring by steers and autumn by calves at two stocking rates on crested wheatgrass at Cheyenne, Wyoming (Hart et al. 1983b).

Parameter	590 lb steers		425 lb calves	
Stocking rate				
Animals/acre	.46	.64	.96	1.26
Days/acre	22	30	54	60
Days/1000 lbs forage	23	32	24	31
Animal gain				
Lbs/day	2.38	2.44	.58	.41
Lbs/acre	45	74	28	26
Lbs/1000 lbs forage	48	68	12	12

The longterm animal response to stocking intensity will depend in part on the effect such stocking rates have on plant vigor. Horton and Weissert (1970) studied plant vigor on three sites in the oakbrush-sagebrush type of central Utah that had been grazed at 15 to 25, 60 to 70, and 85 to 90 percent utilization for eight years. At the end of that time vigor was mesured by average height of the tallest seed stalk, dry weight per square inch of basal cover, number of seed stalks per square foot, and percentage ground cover. Vigor was highest with the 60 to 70 percent utilization level.

Reynolds and Springfield (1953) measured weight gains by cattle in northern New Mexico stocked at light (15 to 35%), moderate (36 to 55%), heavy (56 to 75%), and very heavy (75% utilization). Daily weight gains were 1.7, 1.8, 1.5, and 1.1 pounds per animal with the 36 to 55 percent utilization rate producing the most gain.

Weight gain responses were measured in another New Mexico study for 1-month periods in early spring (Springfield and Reid 1967). Cow-calf pairs in an 8-year study and yearlings in a 4-year study were grazed on both crested wheatgrass and native range. Average daily gains (lbs/day) were:

	Crested Wheatgrass	Native Range
Cows	3.23	1.21
Calves	2.18	1.16
Yearlings	1.98	1.50

Weight gain by cows was largely compensatory gain, but nevertheless the data illustrate the availability and nutrition of the crested wheatgrass. The poorer performance on native range may have resulted from inadequate dry matter intake.

Grazing studies on crested wheatgrass were conducted as early as 1933 at Mandan, North Dakota (Sarvis 1941). Two-year old steers grazed crested wheatgrass at an average intensity of 52 animal days per acre (range of 14 to 86) for eight years. Grazing occurred from mid-May through July and occasionally in August. Daily weight gains in pounds were:

15 days in May	3.92
30 days in June	2.24
27 days in July	1.63
18 days in August	1.30

Johnson (1959) reported the results of a grazing intensity study on crested wheatgrass, smooth brome, intermediate wheatgrass, Russian wildrye, and a sweet clover-crested wheatgrass-smooth brome mixture in central Colorado. Grazing occurred from April or May to October on a put-and-take approach. Cattle expressed a higher preference for smooth brome than crested wheatgrass in the mixture by grazing it to a shorter stubble height. The mixture produced significantly more herbage than either species alone (Table 38) largely because of the presence of sweet clover. The biennial life cycle of this clover was not discussed. Yields decreased under all intensities of grazing, perhaps due to decreased rainfall. Grazing smooth brome and intermediate wheatgrass to 2-inch stubble height reduced the stand, but grazing Russian wildrye to 1.5-inch stubble had little effect on forage yield. Animal gains per day were greatest on the intermediate wheatgrass. Gains per

Table 38.--Mean annual forage and yearling heifer production under a five-pasture grazing system of four grasses and a mixture (adapted from Johnson 1959).

	Crested wheatgrass			Smooth Brome			Sweet clover, Crested + Brome			Intermediate wheatgrass			Russian Wildrye		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H[1]
Forage production, lb/acre	1200	820	990	730	730	580	1320	1310	1040	910	1090	650	910	840	790
Utilization, percent	31	46	67	31	41	61	35	46	65	33	47	63	11	20	41
Yearling, days/acre	27	32	46	19	24	29	31	37	47	29	34	32	31	34	46
Yearling gains, lbs/day		1.70			1.70			1.90			2.05			1.62	
Yearling gains, lbs/head		60			46			70			56			50	
Yearling gains, lbs/acre		51			37			60			51			50	

[1] Grazing intensities: Light (L), Moderate (M), and Heavy (H) corresponding to stubble heights of 6, 4, and 2 inches, respectively. Stubble heights for Russian wildrye were 4.5, 3, and 1.5 inches, respectively.

animal and gains per acre, however, were greatest for the forage mixture.

Grazing intensity studies were also conducted on a crested wheatgrass stand in central Colorado (Currie and Smith 1970). The intensity was judged by a stubble height of 6, 4, 2, and 1 inch which corresponded to a utilization of 31, 46, 67, and 81 percent, respectively. Forage production over the 13-year study averaged 1300, 1300, and 1200 pounds per acre for the 31, 46, and 67 percent utilization treatments. The authors concluded that the 2-inch stubble height appeared to be an optimum intensity of grazing.

Intensity data were also obtained from a study conducted in a northeastern Nevada area of about 16 inches annual precipitation (Robertson et al. 1970b). The 480-acre area was cleared of big sagebrush and seeded with a mixture containing Fairway, Standard and western wheatgrass, and bulbous bluegrass in 1944. Crested wheatgrass soon became the dominant species with small amounts of Sandberg bluegrass, bulbous bluegrass, and streambank wheatgrass (ranked in decreasing frequency). Forage yield during a 3-year period averaged 1130 pounds per acre. Responses measured on moderate and heavy intensity treatments were:

	Moderate	Heavy
Forage utilization, %	54	74
Steer gains, lbs/day	2.2	2.1
Steer gains, lbs/ acre	23.5	30.8

Gray and Springfield (1962) studied the performance of ewe-lamb pairs at four stocking rates on crested wheatgrass in northern New Mexico. The 3-year study provided the following results for May and June use:

	Light	Heavy
Forage utilization, %	39	84
Sheep days per acre	75	150
Lamb gains, lbs	76	73

Crested wheatgrass on these pastures produced 980 pounds dry matter per acre compared with only 110 pounds per acre on native range.

Another grazing intensity study on crested wheatgrass was conducted on foothill range in central Utah at 5600 feet elevation (Bleak and Plummer 1954). Ewe-lamb pairs were stocked at three intensity levels (light, moderate, and heavy) for seven years (Table 39). Sheep were placed on the pasture again in the fall at an intensity that provided a total of 151, 158, and 167 sheep days per acre for spring and fall on the light, moderate, and heavy use treatments, respectively. Crested wheatgrass maintained equally good production under light (59%) and moderate (71%) use during the 7-year period, but declined on the heavy use pasture because many of the plants died and those that were alive were small. The rate of lamb gains was slightly higher on the light versus moderate use

Table 39.--Sheep responses to grazing crested wheatgrass at three intensities for seven years in central Utah (Bleak and Plummer 1954).

Parameter	Utilization intensity Light	Moderate	Heavy
Utilization, percent	59	71	88
Spring grazing			
Sheep days/acre	117	134	149
Lamb gains, lbs/acre	28.2	32.0	35.41
Ewe gains, lbs/acre[1]	8.2	15.7	5.6
Lamb gains, lbs/day	.64	.58	.58
Ewe gains, lbs/day[1]	.18	.30	.08
Autumn grazing[2]			
Sheep days/acre	34	34	18
Sheep gain, lbs/acre	10.7	7.5	2.4
Sheep gain, lbs/day	.32	.17	.16

[1] Large year to year variation.
[2] These same pastures were grazed in the spring.

pasture, but gains per acre were higher on the moderate pasture. There were no differences in vegetation production between light and moderate use pastures. However, during the last year of the study Russian thistle produced 80, 67, and 364 pounds dry matter per acre on the light, moderate, and heavy use pastures.

Grazing experiments have been conducted at the Lee A. Sharp Experimental Area in southcentral Idaho since 1957. Stocking rate and animal performance data were available for 1960 through 1965 (Sharp 1970) and are given in Table 40. Utilization rates were 50, 65, and 80 percent at stocking rates of 12, 12.5, and 14.3 animal days per acre, which does not provide a very wide spread. It does illustrate the reduced performance by individual animals with a net increase in overall production at the higher stocking rates during spring and fall. Animals gained 125 pounds in spring and 32 pounds in fall while the weight gains per acre were 40 and 8 pounds, respectively. Weight gains by yearling cattle averaged 2.05, .95, and .56 pounds per animal-day during spring (May-June), summer (July-August) and fall (September-October), respectively.

Sharp (1970) concluded that 15 years of heavy spring grazing had not destroyed the stand of grass, but forage production and stand density had declined. Plant vigor and production of the heavily grazed pastures were restored by two years of deferred grazing during the green-feed period.

A grazing system and intensity study was conducted by Frischknecht and Harris (1968) and Frischknecht et al. (1953) on the Benmore Experimental Area in northern Utah, at an elevation of 5800 feet and annual precipitation of 12 to 13 inches. They determined cow and calf weight-gain

Table 40.--Yearling cattle responses to grazing crested wheatgrass at three intensities for six years in southern Idaho (adapted from Sharp 1970).

Parameter	Utilization intensity		
	Light	Moderate	Heavy
Utilization, percent	50	65	80
Stocking rate			
Acres (AUM)	2.5	2.4	2.1
Animal days/acre	12	12.5	14.3
Spring grazing[1]			
Gain per animal, lbs.	122	117	111
Gain per acre, lbs.	48	50	53
Fall grazing[2]			
Gain per animal, lbs.	26	25	25
Gain per acre, lbs.	9	10	14

[1] Spring grazing was primarily May and June.
[2] Fall grazing was primarily September and October.

Table 41.--Crested wheatgrass utilization and animal performance (Frischknecht and Harris 1968)

Variable	Light	Moderate	Heavy
Utilization, percent	50	65	80
Cow days/acre	10	13	17
Weight gain, lbs/day[1]			
Cows	3.03a	2.90a	2.21b
Calves	1.87a	1.87a	1.74b
Weight gain, lbs/acre			
Cows	29b	36a	35a

[1] Data within a given row not followed by the same letter are different at the 5% probability level.

responses to four grazing methods, each at three grazing intensities for four years (Table 41). They concluded that the moderate grazing rate was the best for long term productivity of forage and beef.

Grazing Systems

Currie (1970) examined the influence of spring, fall, and spring-fall grazing on crested wheatgrass grown on the Manitou Experimental Forest. He reported that grazing crested wheatgrass to a 1-inch stubble height for 10 years had little effect on the vegetative characteristics of the stand. Invasion by other species was greatest under spring and spring-fall use. Spring-fall use was most productive (177 lbs beef/acre) and fall grazing least for yearling heifer gains (lbs/day):

Spring	1.10
Spring-fall	0.80
Fall	0.10

Animal performance on crested wheatgrass utilized at 60 to 70 percent reflects both the palatability and quality of the forage. Harris et al. (1968) measured substantial weight gains by yearlings during all seasons except late fall on the Benmore Experimental Area. Weight gains by yearlings, cows and calves for the various grazing periods in pounds per day averaged:

25 April to 24 May	2.75
24 May to 21 June	1.48
21 June to 8 August	.99
8 August to 16 September	.49
16 September to 31 October	.59
31 October to 7 December	-1.08

Lang and Landers (1960) evaluated a grazing system on crested wheatgrass in the early season (Period I), intermediate wheatgrass during mid season (Period II) and Russian wildrye during late season (Period III) in southeastern Wyoming. These gains were compared with those on native shortgrass vegetation. The 5-year means in pounds per day were:

	Seeded	Native
I	2.22	2.13
II	1.90	1.91
III	1.03	1.18

Table 42.--Mean annual forage and animal production for three grazing systems evaluated at Manyberries, Alberta (Smoliak 1968, Smoliak and Slen 1974).

Parameter	Continuous: Crested wheat-grass	Continuous: Native	Continuous: Russian wildrye[1]	Rotation: Crested wheat-grass	Rotation: Native	Rotation: Russian wildrye[1]	Free choice: Crested wheat-grass	Free choice: Native	Free choice: Russian wildrye[1]
Yearling sheep study, 10 years									
Forage production, lbs/acre	832	393	646	813	453	677	821	359	600
Utilization, percent	40	47	63	46	49	65	32	52	63
Sheep days/acre	118	39	118	118	42	116		79	
Sheep gains, lbs/day	.18	.21	.23		.21			.23	
Spring, 58 days	.38	.35	.35	.35				.38	
Summer, 53 days	.19	.26	.26		.18			.24	
Fall, 86 days	.05	.08	.13			.13		.13	
Sheep gains, lbs/head	36.0	41.7	45.6		41.4			46.1	
Sheep gains, lbs/acre	21.7	8.3	26.3		16.5			18.5	
Lbs forage/lb gain	15.3	22.3	15.5		63			45	
Yearling steer study, 6 years									
Forage production, lbs/acre		310	1120	705	300	515	800	305	450
Utilization, percent		66	81	74	64	82	60	72	81
Steer days/acre		9	52	27	8	25		17	
Steer gains, lbs/day		1.74	1.85		1.45			1.56	
Spring, 65 days		2.21	2.41	2.02				2.18	
Summer, 41 days		2.01	2.05		1.86			2.06	
Fall, 65 days		1.10	1.18			0.63		0.62	
Steer gains, lbs/head		298ab	317a		249c			267bc	
Steer gains, lbs/acre		16.0b	96.2a		24.8b			26.6b	
Lbs forage/lb gain		19	12		46			40	

[1]Russian wildrye was seeded on 18-inch row spacing in the pasture continuously grazed by yearling steers, and on 6-inch row spacing in all others.

Stocking intensity was 4 times greater on seeded pastures. Beef gains per acre were 60 lbs on seeded pastures, but only 20 lbs on native range.

Crested wheatgrass on three dissimilar sites in Nevada was grazed by cattle on seven schedules over a 10-year study (Robertson et al. 1970). Quick utilization was achieved by heavy stocking. Alternate year or continuous protection from grazing favored pocket gophers. Early grazing generally resulted in an upward trend measured by most indicators. Time of grazing exerted major effects. Forage yields were not measured.

Smoliak (1968) evaluated weight gains of yearling ewes on three different grazing systems (continuous, rotation, free choice) at Manyberries, Alberta. Each involved crested wheatgrass, Russian wildrye and native range. For the rotational system ewes started on crested wheatgrass in spring, moved to native in summer and then finished on Russian wildrye in fall. Forage production, utilization and ewe performance for the 10-year study are shown in Table 42. The grazing period lasted about six months beginning in late April or early May and continuing through October. Ewe live weight gains were highest on the free choice pasture (46.1 lb) and continuously grazed Russian wildrye (45.6 lb) and lowest on the continuously grazed crested wheatgrass (36.0 lb). Daily gains declined with advancing season of use which was attributed to decreasing nutritive value of all forage species. Seasonal gains during spring were greatest on continuous crested wheatgrass and free choice pastures. During summer lowest gains were on continuously grazed crested wheatgrass and the native pasture grazed in rotation. For fall grazing, systems containing Russian wildrye produced the greatest weight gain. Gains per acre were highest on the continuously grazed Russian wildrye and lowest on the native range.

After completion of the 10-year sheep study, the grazing systems were reevaluated using yearling steers (Smoliak and Slen 1974), except that the continuously- grazed crested wheatgrass treatment was omitted. Steer gains were greatest with continuous grazing on Russian wildrye, but this may be due to its increased production when seeded in 18-inch row spacings (1120 lb/a) compared to 6-inch spacings (480 lb/a). Sheep and steers on the free choice system utilized Russian wildrye most and crested wheatgrass least. It was unfortunate that steer performance on continuously grazed crested wheatgrass was not included in the study. Results may be biased because of the difference in row spacing and yield of Russian wildrye. The basal area of the grasses on the three systems did not vary greatly between 1966 and 1973, except on the rotation crested wheatgrass where a 30 percent reduction occurred. These results led Smoliak and Bjorge (1981) to recommend a grazing calendar illustrating the best use of various pasture types in the Northern Great Plains (Fig. 19).

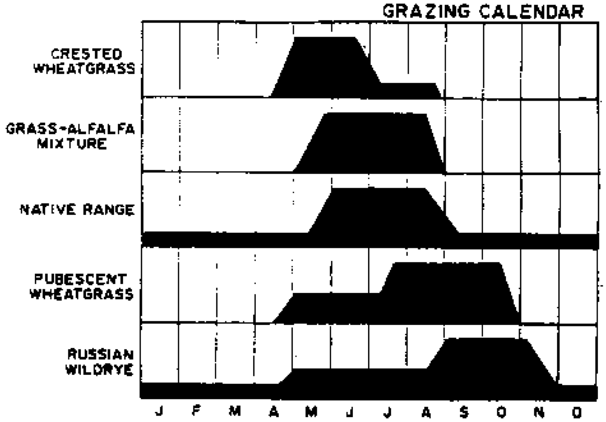

Figure 19.--Grazing calendar showing periods of high and low forage availability for pasture or rangeland forage types in Alberta (adapted from Smoliak and Bjorge 1981).

Lodge (1963) measured steer response to four grazing systems on the sandhills of the northern Great Plains. The systems were:

1. Rotation - crested wheatgrass from May to mid-June followed by native range until September.
2. Free choice - free access to equal areas of crested wheatgrass and native range from mid-June until September.
3. Complimentary - crested wheatgrass from May to mid-June followed by access to an equal sized area of native range until September.
4. Native - native range from May until September.

The grazing season averaged 137 days and produced the results shown in Table 43.

A three-pasture system was evaluated using yearling steers in a five year study at Dickenson, North Dakota (Nyren et al. 1983). It compared spring grazing of crested wheatgrass, summer grazing of native rangeland, and fall grazing of Russian wildrye (Table 44). One set of the crested and native pastures was fertilized with nitrogen that increased forage production by 42 and 50 percent and beef production by 70 and 52 percent, respectively. Utilization of Russian wildrye was similar to that shown in Table 37 (79 vs. 81%), but the daily weight gain was considerably less (.77 vs. 1.76 lb/day).

Table 43.--Steer performance on four grazing systems in northern Great Plains (Lodge 1963).

	System			
	1	2	3	4
Gain, lbs/head	211	233	243	185
Gain, lbs/acre	34.7	38.7	34.9	20.1
Animal days/acre	22.5	22.8	19.7	14.9

Table 44.--Mean annual forage and animal production from a three pasture system involving crested wheatgrass, native range, and Russian wildrye in North Dakota (adapted from Nyren et al. 1983).

Parameter	Crested wheat-grass	Native	Russian wild-rye
Unfertilized			
Forage production, lbs/acre	2110	2680	-
Utilization, percent	54	40	-
Animal days/acre	41	38	-
Beef gains, lbs/day	1.63	1.63	-
Beef gains, lbs/acre	67	63	-
Lbs forage/lb beef	17	17	-
Fertilized annually with 50 lbs N/a[1]			
Forage production, lbs/a	3000	4010	1740
Utilization, percent	61	45	79
Animal days/acre	83	57	46
Beef gains, lbs/day	1.39	1.65	.73
Beef gains, lbs/acre	112	96	34
Lbs forage/lb beef	16	19	40

[1] All Russian wildrye pastures were fertilized with 50 to 150 lbs N/acre plus 13 lbs P/acre.

Whitman et al. (1963) compared weight gains of steers grazing alfalfa plus crested wheatgrass with those grazing crested wheatgrass alone. Two of four crested wheatgrass pastures were seeded with 4 pounds of Ladak alfalfa and later grazed for 7 years during May and June. Forage and beef productivity at the Dickinson, North Dakota study were:

	Crested	Crested + Alfalfa
Forage yield, lbs/acre	920	1170
Utilization, percent	81	82
Steer days/acre	43	56
Steer gain, lbs/day	2.07	2.08
Steer gain, lbs/acre	88	117
Lb forage/lb gain	8.5	8.2

The grass-legume forage contained about 15 percent alfalfa with a higher yield and crude protein concentration which allowed a higher stocking intensity. Feed conversion ratios of 8 pounds of forage per pound of gain are often one-half or less than those calculated in Table 37, 42 or 44.

Another study conducted in the Northern Great Plains evaluated the benefits of fertilizing crested wheatgrass or growing it in a grass-legume mixture (Rogler and Lorenz 1969). Forage yield, stocking rate and beef production per acre were increased when nitrogen was applied to crested wheatgrass (Table 45). Forage yield and beef production from the grass-legume mixture were each increased about 30 percent compared with the unfertilized grass.

Yearling steers were used to compare continuous versus short duration grazing on crested wheatgrass at Squaw Butte (Daugherty et al. 1982). On short duration grazing, animals were moved to new pasture when 30 percent of the forage was utilized. The study was conducted for two seasons and illustrated a small increased weight gain by steers on the short

Table 45.—Mean annual forage and beef production on crested wheatgrass fertilized or grown in mixture with Ladak alfalfa at Mandan, North Dakota (Rogler and Lorenz 1969).[1]

Parameter	Responses on pastures treated with ON	40N	80N	Mixture
Forage yield, lbs/acre	1740a	2760c	3120d	2240b
Utilization, percent	52	60	60	63
Steer days/acre	38	66	71	48
Steer gains, lbs/day	2.66	2.63	2.53	2.82
Steer gains, lbs/acre	101a	169c	176c	135b
Lbs forage/lb beef	9.1	9.8	10.4	10.3

[1]Means on a given line followed by the same letter do not differ at P=.05.

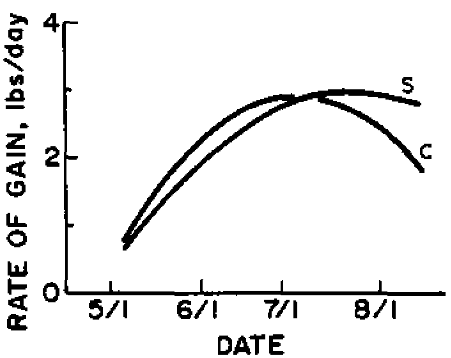

Figure 20.—Daily weight gains by steers grazing crested wheatgrass on short duration (s) or continuous (c) systems in eastern Oregon (adapted from Daugherty et al. 1982).

duration pasture when compared with continuous grazing (Fig. 20). This 'cream' type grazing (30% utilization) would use the more nutritious plant parts for maintenance and weight gain whereas the remaining forage might be used by livestock where only maintenance was required (Raleigh 1970). This would work best under a fall-calving program.

Sheep were used by Campbell (1961) at Swift Current to evaluate continuous and rotation grazed grass-legume mixtures (Table 46). Forage yields, utilization and stocking rates were higher here than reported for the sheep study in Table 42. Continuously grazed Russian wildrye with or without alfalfa outperformed crested wheatgrass (Tables 42 and 46).

Frischknecht et al. (1953) measured cow/calf performance over four years on crested wheatgrass at Benmore. Animals were stocked at light (50%), moderate (65%), and heavy (80% utilization) intensity. Superimposed on stocking rates were four methods of spring grazing. The treatments included (1) rotation, with cattle shifted periodically among three sections of the pasture so as to graze each section twice during a 60-day season; (2) continuous; (3) 10-day deferred where grazing started 10 days late; (4) 10-day short where grazing terminated 10 days early. Pastures in the first two groups were grazed for about 60 days in the spring while those in the latter two groups were grazed for about 50 days. The animal gains in pounds were as shown in Table 47. The four methods had little influence on calf gains and trends did not follow those of the cows. Early removal resulted in higher weight gains by cows because of higher forage quality early in the spring.

Animal Grazing with Supplementation

Reproduction, weight gain, and milk or wool production are traits controlled by genetics and influenced by environment. The latter includes temperature and availability and quality of both drinking water and forage. When the forage diet is inadequate for a desired level of production, it may be supplemented to correct the deficiency (Raleigh 1970). Supplements include salt (NaCl), crude protein, energy, and other minerals and vitamins. Supplementation may be provided orally via inorganic sources such as sodium chloride, biuret (nonprotein

Table 46.—Mean annual forage and yearling ewe production for continuous and rotation grazing systems on three grasses plus alfalfa at Swift Current, Saskatchewan (adapted from Campbell 1961).

Parameter	Continuous: Crested +alfalfa	Continuous: Intermediate +alfalfa	Continuous: Wildrye +alfalfa	Rotation: Crested +alfalfa 6/5-7/7	Rotation: Itermediate +alfalfa 7/8-8/20	Rotation: Wildrye +alfalfa 8/21-10/15	Rotation: Season Long
Forage production, lbs/acre	1160	1120	1210	1560	1340	1145	1350
Utilization, percent	86	79	90	85	79	82	82
Sheep days/acre	358	325	361	400	398	322	373
Sheep gains, lbs/day	.10	.11	.14	.14	.08	.12	.11
Sheep gains, lbs/head	14	14	24	5	3	6	14
Sheep gains, lbs/acre	35	36	50	55	32	40	42
Lbs forage per lb gain	26	24	21	24	33	23	26

Table 47.--The effect of four systems on gains of animals, grazing spring growth of crested wheatgrass, (Frischknecht et al. 1953).

	Gain/day		Gain/acre
	Cows[1]	Calves	cows
		Pounds	
Rotation	2.53a	1.79	34
Continuous	2.70a	1.87	33
10-Day deferred	2.68a	1.82	34
10-Day short	2.95b	1.83	33

[1]Means not followed by similar letters are different at P <.05.

nitrogen), monosodium phosphate, magnesium oxide, and various iodine salts. Injectable forms of copper and selenium are used to meet animal requirements or pellets, bullets, or wires composed of cobalt, copper, magnesium, or selenium can be placed in the rumen-reticulum to supplement dietary availability of these elements. The latter method has had varying degrees of success.

Protein may be provided as alfalfa hay or as meal from soybean, cottonseed, rape, or other high nitrogen seeds. Energy is often provided as barley or corn. Energy supplementation can sometimes be detrimental to performance of cattle grazing poor quality forage (Harris et al. 1968 and Kartchner 1981). To make the most profitable decisions it is important to know what the animal needs for a desired level of production, what the animal is presently getting in the diet, and then what supplement is needed to make up the deficiency if one occurs (Raleigh 1970).

Wallace et al. (1963) measured the weight gain response of yearling cattle on crested wheatgrass at Squaw Butte to energy (barley), protein (cottonseed meal), and salt (NaCl) supplements. Cattle grazed a common pasture from mid-May through August and were penned to receive their assigned supplement. The barley was fed at two pounds per animal day and cottonseed meal at a rate to assure that overall protein intake was about 10 percent of the diet. The least-squares mean values for daily weight gain (P<.05) were combined for simplification:

1. Energy-supplemented animals gained more (1.83 vs 1.70 lb/day) than controls.

2. Protein-supplemented animals gained more (1.83 vs 1.69 lb/day) than controls.

3. Salt-supplemented animals gained the same (1.78 lbs/day) as controls.

The effects of additional energy appeared more favorable when forage was limited or when dry matter concentrations were low. The benefit of protein supplementation occurred during the latter part of the season when protein levels in the forage were low.

Another approach to supplementation is to increase the diversity of the forage base that is inherent in native rangelands and to some extent in grass-legume mixtures. In both cases succulent forage having a relatively high feed value is available for a longer period of time than in monoculture grass, especially crested wheatgrass.

Another approach is the interseeding of grass stands with palatable shrubs. Springfield (1960) observed sheep making comparatively heavy use of big sagebrush, silver sagebrush, rubber rabbitbrush, and Douglas rabbitbrush in northern New Mexico. Otsyina et al. (1982) reported that shrubs were consistently higher in both total and digestible protein than crested wheatgrass. Pregnant ewes grazing mature crested wheatgrass and supplementing their diets with shrubs would have to consume 56 percent fourwing saltbush or 69 percent winterfat to meet their requirements. Mountain big sagebrush and rubber rabbitbrush were lower in digestible protein and therefore could not be used alone or with crested wheatgrass if the pregnant ewe was to receive adequate protein.

Winter Use

Williams et al. (1942) determined the performance of long-yearling steers when wintered on crested wheatgrass either as hay or standing grass at Judith Basin. Steers receiving average quality crested wheatgrass hay plus 1 lb/day of a supplement containing cottonseed, molasses and beet pulp gained 1 lb/day while those receiving 3 lbs of supplement gained 1.2 lb/day. Similar steers pastured on cured crested wheatgrass gained 0 lbs if given 1 lb of supplement or 0.34 lbs if given 3 lbs of supplement. Steers fed prebloom Fairway plus 3 lbs of supplement gained 1.51 lb/day. The authors noted that grazing steers preferred Fairway to Standard when not covered with snow.

Sheep were used to compare diet selection from a stand of crested wheatgrass or a mixed shrub-crested wheatgrass field during early, mid and late January (Gade and Provenza, In Press). Sheep grazing grass pasture consumed diets that were about 55 percent mature grass and 45 percent green vegetative growth during the first two periods. In late January green feed was no longer available because of trampling and snow cover and sheep consumed diets containing 93 percent mature grass. Sheep grazing the grass-shrub pastures consumed about 50 percent shrub and 50 percent grass during all three periods. Sheep on the mixed pastures consumed diets that were higher in crude protein than those grazing only grass during the early (9.0 vs. 5.8% CP), mid (7.3 vs. 6.6% CP) and late period (7.9 vs. 4.6% CP). The in vitro organic matter digestibilities of the diets were higher on the mixed pasture during the early (48 vs. 45%), mid (46 vs. 29%) and late period (32 vs. 24%). Utilization of shrubs was winterfat (100%) fourwing saltbush (79%), bitterbrush (52%), forage Kochia (34%), sagebrush (29%) and rubber rabbitbrush (17%).

Antiquality Factors

Some forbs and shrubs contain organic or inorganic compounds that pose health hazards to grazing livestock. Even some grasses contain toxins produced either by their own metabolism or that of endophytic organisms associated with the plant. Crested wheatgrass does not contain significant amounts of any of these toxic compounds, except for occasionally high levels of certain elements, nitrates, or trans-aconitic acid. The latter may reduce magnesium availability to livestock.

The literature contains some information on the accumulation of mineral elements in crested wheatgrass. It is not uncommon for spring and well water in semiarid areas to be high in fluorine (F). For example, high levels of fluorine are present in thermal springs throughout the Great Basin and Snake River Plains; concentrations frequently range from 2 to 17 ppm while the concentration in plants ranges from 0.1 to over 220 ppm depending on the species and soils. Fluorosis of animals is attributed to the fluorine in forage and drinking water. Kubota et al. (1982) collected over 300 plant samples in the Great Basin and identified the following fluorine levels (ppm):

	Median	Range
Grasses	2.3	.1 - 70
Sedges	7.0	.4 - 42
Rushes	4.7	.2 - 224
Desert shrub		
Leaves	1.3	.1 - 12
Stems	1.1	.4 - 7

Fluorine concentrations decreased with increasing distance to the fluorine source or spring.

Fallout from ore smelters may be a source of large amounts of fluorine. Severson and Gough (1976) published data on elements in soil and plant material in relation to distance from the phosphorus smelter at Pocatello, Idaho. Fluorosis was observed in a dairy herd located several miles downwind from the smelter (Mayland, unpublished). In general, however, high-fluorine levels will not be found in crested wheatgrass.

Rauzi and Landers (1979) evaluated crested wheatgrass forage production along Interstate Highway 90 in northeastern Wyoming. They concluded that grass grown in the medians and borrow areas was a valuable source of quality hay. The areas received run-on water and forage generally contained adequate crude protein, calcium, phosphorus and magnesium for maintenance. The lead content ranged from 3.9 to 4.3 ppm which was not toxic.

Both sulfur (S) and selenium (Se) are required for animal health. High sulfur levels might occur as fallout from ore smelters and power-generating plants that burn coal. Another, but fortunately infrequent, source was the ash fallout from the Mt. St. Helen eruption (Mahler 1984, Sneva et al. 1982). Sulfur may not occur in toxic concentrations in itself, but may reduce the availability of selenium to plants and animals (Miichunas et al. 1983). In other situations, agronomic practices that suddenly increase crop yields may reduce or dilute the selenium concentrations in forage (Westermann and Robbins 1974). If this occurs where forage selenium concentrations are marginal, then selenium deficiencies may appear in livestock, indicated by the occurrence of "White Muscle Disease" in calves, lambs, and other young animals. This problem has occurred many times in the Snake River and Columbia Plateau regions and is of great importance to livestock producers. However, the sulfur:selenium interaction occurs most often on irrigated lands and therefore is not a problem associated with crested wheatgrass.

Soils derived from sedimentary materials may have high selenium levels. Crops grown on these soils will contain corresponding levels of selenium. Crested wheatgrass grown in Lyman County, South Dakota, had 2 ppm Se in forage and 7 ppm Se in the heads (Williams et al. 1941). These values are probably similar to those of other grasses grown on the same soils. Such concentrations of selenium are marginally toxic to animals.

Lambert and Blincoe (1971) collected crested wheatgrass from 11 sites in northern Nevada and found them to contain 0.6 to 23 ppm cobalt with a mean of 6.9. They were able to confirm these unusually high concentrations in the wheatgrass samples by several analytical methods. While these cobalt concentrations may not be high enough to be toxic to livestock, they could interact with other elements. The authors suggested that the *Agropyrons* may accumulate cobalt. Mayland (unpublished) sampled crested wheatgrass from two of the 11 sites and measured concentrations of less than .2 ppm, which appear normal compared with other forages. Perhaps the 1971 samples were contaminated sometime between harvest and analysis.

Interactions between elements may greatly affect the availability of each. For example molybdenum, sulfur, and possibly manganese reduce copper availability to the grazing animal. Yearling heifers were fed tall fescue or quackgrass with the following elemental profile in ppm (Stoszek et al. 1979)

	Tall fescue	Quackgrass
Copper	6.6	4.6
Molybdenum	2.3	1.2
Sulfur	340.0	160.0
Manganese	91.0	38.0

The animals on the tall fescue had rapidly declining levels of liver and plasma copper, whereas those on the quackgrass maintained normal copper levels.

High nitrate levels in herbage can be found in rapidly growing, nitrogen-fertilized grass or in plants that become droughty while growing on fertile soil. Forage containing 1000 to 2200 ppm NO_3-N (0.5 to 1.0% nitrate) is safe for most animals, but higher levels of nitrate may produce haemoglobinuria and death in livestock. Lawrence et al. (1981) were able to increase nitrate nitrogen levels to more than 2000 ppm in crested wheatgrass by irrigation and fertilizing with 350 pounds of nitrogen, but levels declined with increasing maturity. Nitrate toxicity is not a likely problem in crested wheatgrass grown without irrigation and only modest amounts of nitrogen fertilizer.

Grasses contain silica (SiO_2) in concentrations approaching 10 percent on a dry matter basis (Mayland, unpublished), but forbs seldom have greater than .5 percent SiO_2. Some of the silica in grass is distributed as opaline silica bodies in the leaves. Their shape and color are unique for genera and can be used to identify the grassland type of a site even thousands of years after its disappearance (Blackman 1971).

Silica reduces the digestibility of herbage by about three percentage units for each unit of silica (Mayland, unpublished). The mechanism is not known, but may relate to the silica acting as a varnish on the cell wall, or to its precipitation with some trace mineral, limiting its availability to rumen flora. Another mechanism may entail the inactivation of some enzymatic reaction during rumination.

Silica is also responsible for the development of silica urolithiasis (water belly) in livestock, especially castrated males (Bailey 1981). The problem is particularly acute in the northern Great Plains. An eight-year survey was conducted in two areas, one with a low incidence and the other with a high incidence of urolithiasis in grazing animals (Bezeau et al. 1966). Silica concentrations were not different between the two areas, but were higher in grasses and sedges than in forbs and shrubs. It was apparent that reduced water intake by the livestock was as much of a problem as silica in the forage in inducing urolithiasis. A combination of low water intake with a forage silica content greater than two percent could be expected to induce the condition.

Soil ingestion can also affect animal health. The soil might be a source of small amounts of some trace elements. On the other hand, soils might absorb some elements. For example, some soils have the capacity to absorb phosphorus and ingestion by the animal could increase the dietary requirement. Mayland et al. (1977) measured soil ingestion of 1.6 to 2.2 pounds per day by heifers grazing crested wheatgrass during June and August in southcentral Idaho. Soil impaction of the gastrointestinal tract can be fatal, especially in lambs and horses. Most importantly, soil ingestion can increase the rate of tooth wear and reduce productive lifetime of breeding animals. The author is aware of eight-year old cows from one area that have worn teeth resembling those of 12-year old cows from another area. Local cattle buyers are known to take this into consideration.

Grass Tetany

Grass tetany (hypomagnesemia) is probably the most important antiquality factor associated with crested wheatgrass. Magnesium deficiency has produced large numbers of deaths and production losses in cattle and sheep. Mayland (unpublished) estimated that in the United States 30 percent of these losses occurred on crested wheatgrass, 40 percent on tall fescue, and the remaining 30 percent on perennial ryegrass, cereal grain forages, other cool season grasses, fodders, and hays (including alfalfa, Bohman et al. 1977).

Grass tetany is a deficiency of magnesium to the ruminant. The problem can result from a simple deficiency of magnesium in the diet, but more often from reduced availability of forage magnesium to the grazing animal. This reduction is attributed to a number of factors (Fig. 21).

Spring tetany occurs most often in older, lactating cows recently turned onto crested wheatgrass seedings. Forage growth preceding the occurrence of grass tetany is limited by cool or dry conditions. Rapid changes in weather conditions resulting in a flush of growth and the development of "washy" feed (low dry matter content) are often followed by grass tetany (Mayland and Grunes 1974b). The rapidly growing crested wheatgrass forage will contain high concentrations of trans-aconitic acid (Stout et al. 1967, Stuart et al. 1973, Mayland and Grunes 1979). It has been assumed that trans-aconitic and other organic acids are in some way associated with a reduction in magnesium availability. The field observations made by Mayland and coworkers were conducted on seedings of standard crested wheatgrass. Nordan and standard accumulate aconitic acid whereas Fairway crested wheatgrass accumulates malic acid as shown in the percentages below (Prior et al. 1973).

	Nordan	Fairway
Fumarate	T	T
Formate	1	1
Acetate	3	4
Aconitate	26	5
Malate	64	82
Citrate	6	8

It is not known whether there is a greater risk to tetany from grazing Nordan than Fairway.

Russell and Van Soest (1984) reported that an *in vitro* fermentation of trans-aconitic acid by mixed rumen bacteria led to the formation of tricarballylic acid that appears as an end product of aconitic acid metabolism. Evidence exists[4] that it may block portions of the citric acid cycle. Obviously much is yet to be learned about the role of organic acids in magnesium tetany.

Elevated concentrations of higher fatty acids (HFA) occur in crested wheatgrass coincident to the tetany (Stuart et al. 1973). Unsaturated HFA forms water-insoluble soaps with magnesium and calcium which are then excreted in the feces (Mayland and Grunes 1979). Nitrogen fertilization of grass pastures increases the tetany hazard and was shown by Mayland et al. (1976) to increase the HFA concentration in crested wheatgrass (Fig. 22).

Nitrogen concentrations in crested wheatgrass parallel the concentrations of total inorganic acids, aconitic acid, and HFA. Thus, forage nitrogen values are elevated when grass tetany occurs. Much of this nitrogen exists as non-protein nitrogen (NPN), which after ingestion is readily

[4] J. B. Russel, Ithaca, New York, personal communication.

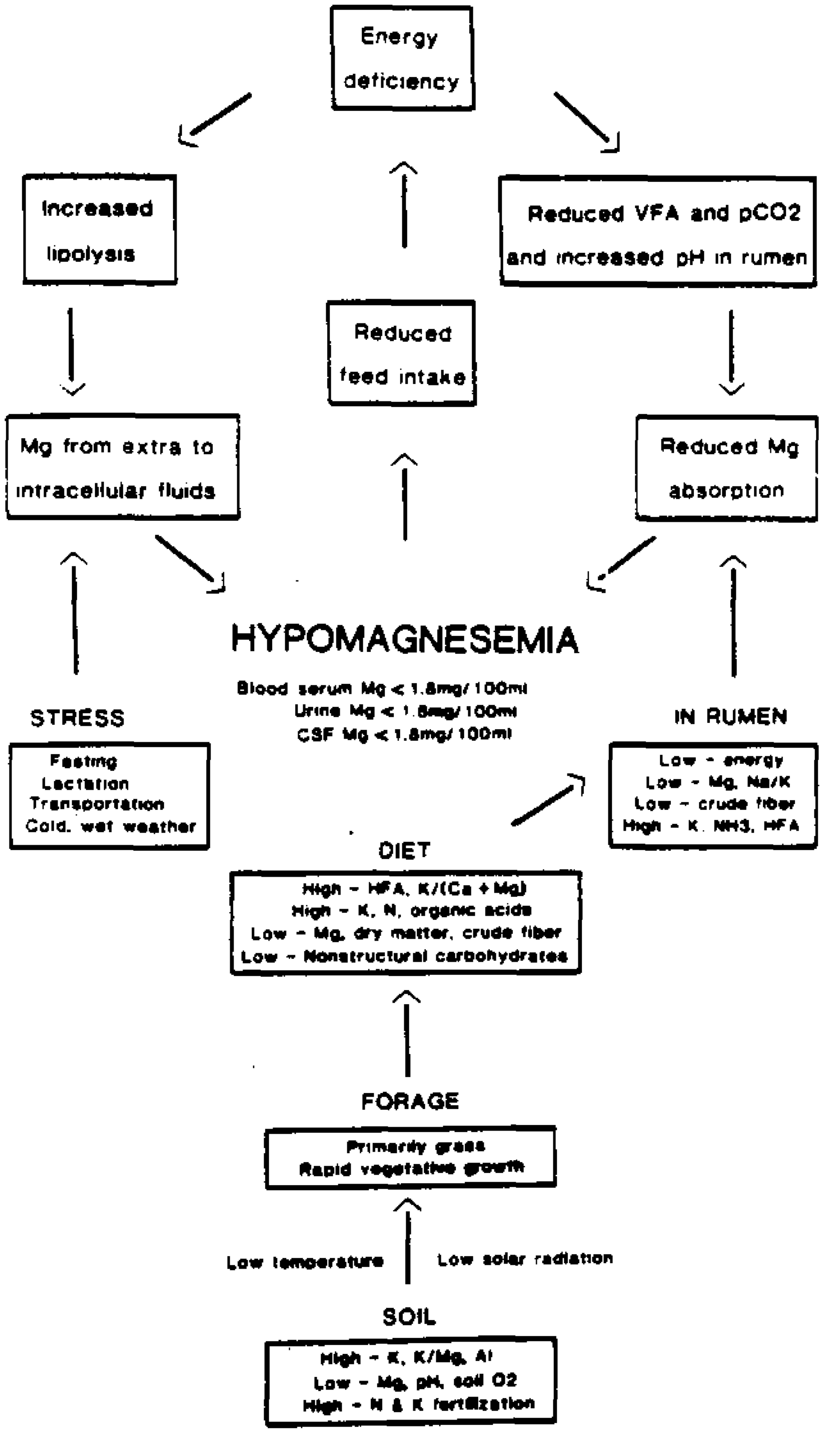

Figure 21.--Etiology of grass tetany.

available to the rumen flora. Total water soluble carbohydrate (TWSC) concentrations in the wheatgrass are particularly low at this time, because the plant used this energy source for rapid growth. Mayland et al. (1974c, 1975) reported that the N/TWSC values in crested wheatgrass peaked with the occurrence of grass tetany on the San Jacinto seedings south of Jackpot, Nevada (Fig. 23). The authors hypothesized that high NPN and low TWSC resulted in excess ammonia (NH_3), increased pH, and reduced magnesium availability. Later work by House and Mayland (1976) and Madsen et al. (1976) verified the hypothesis that elevated N/TWSC in the diet resulted in reduced magnesium availability.

The elemental cation concentrations in the forage also relate to the tetany hazard. Increased levels of potassium in the forage reduce the amount of magnesium absorbed by the animal (Fontenot 1979). Researchers related the chemical equivalency ratio of potassium (magnesium and calcium) in forage to the incidence of grass tetany (Mayland and Grunes 1979, Thill and George 1975). Animal death loss increases exponentially with an increase in the ratio and, at a value of 2.2, may reach 3 percent. At a ratio of 3.0, losses may exceed 10 percent.

A second approach, now identified as the Dutch nomograph (Mayland and Grunes 1979), uses information on forage nitrogen, magnesium, and potassium to predict the potential tetany hazard of the forage.

Fertilizing pastures or dusting forage with various magnesium salts has helped to reduce the incidence of grass tetany on acid soils in humid regions (Wilkinson and Stuedemann 1979). Crested wheatgrass is grown in the semiarid areas of the western United States and Canada where soils are generally calcareous and contain abundant levels of calcium and magnesium. Under these conditions, the application of magnesium is not a practical method of increasing magnesium in forage (Mayland and Grunes 1974a).

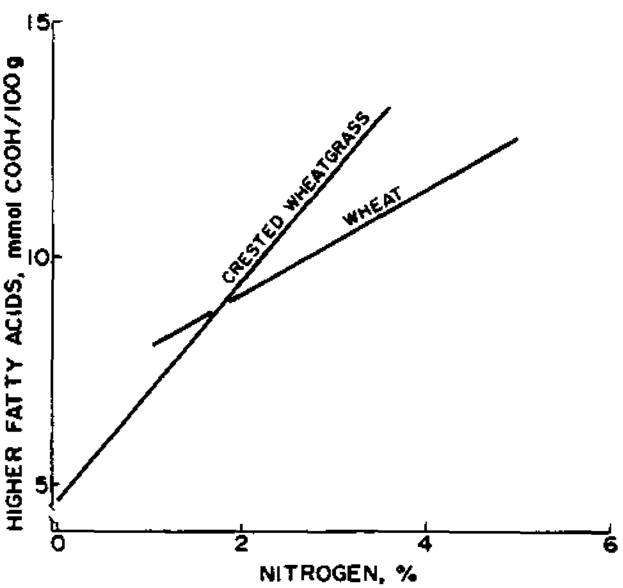

Figure 22.--Higher fatty acid concentrations in relation to the total herbage nitrogen in Nordan crested wheatgrass and cereal wheat (adapted from Mayland et al. 1976).

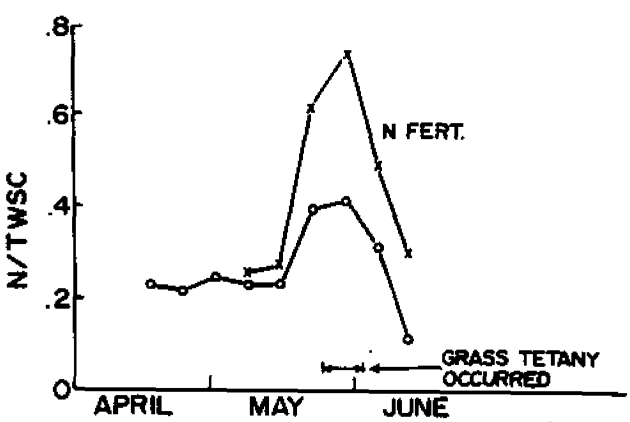

Figure 23.--The ratio of total nitrogen to total water soluble carbohydrates (N/TWSC) in crested wheatgrass as affected by N fertilization and its relation to the occurrence of grass tetany in northeastern Nevada (Mayland et al. 1975).

Controlling grass tetany on large pastures of crested wheatgrass can be accomplished by one or more of the following practices (Grunes and Mayland 1975).

1. Feed a supplement that will provide 1/2 oz of Magnesium per animal each day.

2. Magnesium sulfate as Epsom salt can be given in the drinking water if animals water only from closed water systems.

3. Animals that incur grass tetany may be given injections of magnesium sulfate or calcium-magnesium gluconate.

4. Use of native pastures or deferred seeded pastures is somewhat helpful, but animals are able to selectively graze the new growth which is the cause of the problem.

CONCLUSIONS

Crested wheatgrass is a valuable forage resource on semiarid rangeland in the western United States and Canada. It is tolerant of occasional drought or overgrazing. It provides feed several weeks earlier in the spring than native range, and yields are consistently greater than on native range. Forage yields within given areas are generally proportional to annual precipitation. The generally higher amounts and summer frequencies of rainfall in the Northern Great Plains compared with the Great Basin, Snake River, and Columbia Plateau regions favors higher forage yields. Overall yield and forage quality of the wheatgrass grown in the Northern Great Plains are often increased by planting alternate rows of creeping-rooted alfalfas with the grass. Wider row spacings, up to 24 inches apart, favor long-term yields of crested wheatgrass in the Northern Great Plains. However, information from areas west of the Rocky Mountains does not confirm this relationship.

The use of chemicals to prevent the development of reproductive florets or clipping and grazing management that removes the floret will result in a larger proportion of leaves. Dry matter yield reductions attributed to the absence of seed stalks can be accepted periodically in favor of the high quality leafy material. More research on these relationships is desirable.

Yield evaluations generally show similar productivity ranges for _A. desertorum_ and _A. cristatum_, but lower ranges for _A. fragile_. Breeding and selection programs indicate that a broad base of genetic material is available through which progress can be made for improved stand establishment, forage yield, and forage quality. Animal responses to these new materials must be carefully evaluated.

PUBLICATIONS CITED

Allaway, W.H. 1975. The effect of soils and fertilizers on human and animal nutrition. USDA Agr. Res. Serv. Bull. 378. 52 p.

Angell, R.F., R.F. Miller and M.R. Haferkamp. 1984. Defoliation and growth of crested wheatgrass. II. Defoliation effects on nutritive value, p. 18-21. In: Research in beef cattle nutrition and management. Oregon Agr. Exp. Sta. Spec. Rep. 714.

Anonymous. 1957. Investigations of the North Dakota Agricultural Experiment Station. Fargo, ND. 44 p.

Bailey, C.B. 1981. Silica metabolism and silica urolithiosis in ruminants: a review. Can. J. Anim. Sci. 61:219-235.

Beacon, S.E., S.O. Thorlacius and J.E. Troelsen. 1973. Effects of pelleting, roughage level, and hormone implantation on the utilization of finely ground crested wheatgrass by growing lambs. Can. J. Anim. Sci. 53:725-731.

Bedell, T.E. 1973. Clipping effects on growth form, yield, and nutritive quality of crested wheatgrass in eastern Wyoming. Wyoming Agr. Exp. Sta. Res. J. 76. 16 p.

Bennett, W.H., D.W. Pitman, D.C. Tingey, D.R. McAllister, H.B. Peterson and I.G. Sampson. 1954. Fifty years of dryland research at the Nephi Field Station. Utah Agr. Exp. Sta. Bull. 371. 81 p.

Bezeau, L.M., A. Johnston and S. Smoliak. 1966. Silica and protein content of mixed prairie and fescue grassland vegetation and its relationship to the incidence of silica urolithiosis. Can. J. Plant Sci. 46:625-631.

Birch, T.L. and R.L. Lang. 1961. Dryland grass-seed production as affected by three rates of nitrogen fertilization. Wyoming Agr. Exp. Sta. Bull. 382. 8 p.

Black, A.L. 1968. Nitrogen and phosphorus fertilization for production of crested wheatgrass and native grass in northeastern Montana. Agron. J. 60:213-216.

Blackman, E. 1971. Opaline silica bodies in the range grasses of southern Alberta. Can. J. Bot. 49:769-781.

Blaisdell, J.P. 1949. Competition between sagebrush seedlings and reseeded grasses. Ecology 30: 512-519.

Bleak, A.T. and W. Keller. 1974. Crested wheatgrass yields as influenced by water conservation practices. Agron. J. 66:326-328.

Bleak, A.T. and A.P. Plummer. 1954. Grazing crested wheatgrass by sheep. J. Range Manage. 7:63-68.

Blincoe, C. and T.L. Lambert. 1972. Micronutrient trace element composition of crested wheatgrass. J. Range Manage. 25:128-129.

Bohman, V.R., D.M. Stuart and E.I. Hackett. 1977. The mineral composition of Nevada hays as related to grass tetany, p. 137-140. In: Proc. Western Sec., Amer. Soc. Anim. Sci. Brigham Young Univ., Provo, Utah.

Brown, P.L., A.D. Halvorson, F.H. Siddoway, H.F. Mayland and M.R. Miller. 1982. Saline-seep diagnosis, control, and reclamation. USDA Agr. Res. Serv. Agr. Conserv. Res. Rep. 30. 22 p.

Buglass, E. 1964. Seed production of crested wheatgrass as influenced by various management practices. Can. J. Plant Sci. 44:66-73.

Caldwell, M.M. and J.H. Richards. Competing root systems: Morphology and models of absorption. In T. Givnish and R.H. Robichaux (eds). Economy of plant form and function. Cambridge Univ. Press. In Press, 1985.

Caldwell, M.M. and J.H. Richards. 1986. Competing root systems: morphology and models of absorption. p. 251-273. In: T.J. Givnish (ed.). On the economy of plant form and function. Cambridge Univ. Press, Cambridge, U.K.

Campbell, J.B. 1961. Continuous versus repeated-seasonal grazing of grass-alfalfa mixtures at Swift Current, Saskatchewan. J. Range Manage. 14:72-77.

Clarke, S.E. and E.W. Tisdale. 1945. The chemical composition of native forage plants of southern Alberta and Saskatchewan in relation to grazing practices. Canada Dep. Agr. Tech. Bull. 54. 60 p.

Cook, C.W. 1959. The effect of site on the palatability and nutritive content of seeded wheatgrasses. J. Range Manage. 12:289-292.

Cook, C.W. and L.E. Harris. 1968. Nutritive value of seasonal ranges. Utah Agr. Exp. Sta. Bull. 472. 55 p.

Cook, C.W. and L.A. Stoddart. 1961. Nutrient intake and livestock responses on seeded foothill ranges. J. Anim. Sci. 20:36-41.

Cook, C.W., L.A. Stoddart and F.E. Kinsinger. 1958. Responses of crested wheatgrass to various clipping treatments. Ecol. Monogr. 28:237-272.

Cooper, C.S. and D.N. Hyder. 1958. Adaptability and yield of eleven grasses grown on the Oregon high desert. J. Range Manage. 11:235-237.

Cornelius, D.R. and M.W. Talbot. 1955. Rangeland improvement through seeding and weed control on east slope Sierra Nevada and on southern Cascade Mountains. USDA Forest Serv. Agr. Handbook 88. 51 p.

Cornelius, D.R. and D.E. Williams. 1961. Wheatgrass variety performance on summer rangeland in northeastern California. Agron. J. 53:328-331.

Coulman, B.E. and R.P. Knowles. 1974. Variability for in vitro digestibility of crested wheatgrass. Can. J. Plant Sci. 54:651-657.

Currie, P.O. 1970. Influence of spring, fall, and spring-fall grazing on crested wheatgrass range. J. Range Manage. 23:103-108.

Currie, P.O. and D.R. Smith. 1970. Response of seeded ranges to different grazing intensities. USDA Forest Serv. Prod. Rep. 112. 41 p.

Daugherty, D.A., C.M. Britton and H.A. Turner. 1982. Grazing management of crested wheatgrass range for yearling steers. J. Range Manage. 35:347-350.

Dewey, D.R. 1983. Historical and current taxonomic perspectives of Agropyron, Elymus, and related genera. Crop Sci. 23:637-642.

Dewey, D.R. and K.H. Asay. 1975. The crested wheatgrasses of Iran. Crop Sci. 15:844-849.

Dillman, A.C. 1946. The beginnings of crested wheatgrass in North America. J. Amer Soc. Agron. 38:237-250. (now Agron. J.)

Douglass, J.R. and W.C. Cook. 1954. The beet leafhopper. U.S. Dep. Agr. Circ. 942. 21 p.

Dormaar, J.F., A. Johnston and S. Smoliak. 1978. Long-term soil changes associated with seeded stands of crested wheatgrass in southeastern Alberta, Canada, p. 623-625. In: D.N. Hyder (ed.). Proc. First Int. Rangeland Congress. Denver, Colo.

Dye, W.B. 1962. A micronutrient survey of Nevada forage. Nevada Agr. Exp. Sta. Tech. Bull. 227. 67 p.

Ebens, R.J. and H.T. Shacklette. 1982. Geochemistry of some rocks, mine spoils, stream sediments, soils, plants, and waters in the Western Energy Region of the conterminous United States. U.S. Geol. Surv. Prof. Pap. 1237. 173 p.

Eckert, R.E. Jr., A.T. Bleak and J.H. Robertson. 1961. Effects of macro- and micro-nutrients on the yield of crested wheatgrass. J. Range Manage. 14:149-155.

Eckert, R.E. Jr. and R.A. Evans. 1963. Response of downy brome (Bromus tectorum) and crested wheatgrass (Agropyron desertorum) to nitrogen and phosphorus in nutrient solution. Weeds 11:170-174.

Erdman, J.A. and R.J. Ebens. 1979. Element content of crested wheatgrass grown on reclaimed coal spoils and on soils nearby. J. Range Manage. 32:159-161.

Fairbourn, M.L. and F. Rauzi. 1982. Effect of annual low-nitrogen fertilization of crested wheatgrass. Soil Sci. 134:126-132.

Fontenot, J.P. 1979. Animal nutrition aspects of grass tetany, p. 51-62. In: V.V. Rendig and D.L. Grunes (eds.). Grass tetany. Amer. Soc. Agron. Spec. Pub. 35. Madison, Wisc.

Frischknecht, N.C. 1963. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. J. Range Manage. 16:70-74.

Frischknecht, N.C. 1968a. Factors influencing halogeton invasion of crested wheatgrass range. J. Range Manage. 21:8-12.

Frischknecht, N.C. and A.T. Bleak. 1957. Encroachment of the big sagebrush on seeded range in northeastern Nevada. J. Range Manage. 10:165-170.

Frischknecht, N.C. and L.E. Harris. 1968. Grazing intensities and systems on crested wheatgrass in central Utah: response of vegetation and cattle. U.S. Dep. Agr. Tech. Bull. 1388. 47 p.

Frischknecht, N.C., L.E. Harris and H.K. Woodward. 1953. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. J. Range Manage. 6:151-158.

Gade, A.E. and F.D. Provenza. Nutrition of sheep grazing crested wheatgrass versus crested wheatgrass-shrub pastures during winter. J. Range Manage. In Press.

Gesshe, R.H. and P.D. Walton. 1980. Forage preferences. Alberta Agr. and For. Bull. 3:10-13.

Gesshe, R.H. and P.D. Walton. 1981. Grazing animal preferences for cultivated forages in Canada. J. Range Manage. 34:42-45.

Gobena, A. 1984. Influence of sagebrush (Artemesia tridentata) invasion on crested wheatgrass production and its detection by landsat imagery. MS Thesis. Utah State Univ., Logan. 80 p.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). U.S. Dep. Agr. Handbook 379. 20 p.

Gomm, F.B. 1964. A comparison of two sweetclover strains and Ladak alfalfa alone and in mixtures with crested wheatgrass for range and dryland seeding. J. Range Manage. 17:19-23.

Graves, W.L., B.L. Kay, A.M. Gray, J.T. O'Rourke and M'Barek Fagouri. 1984. Long-term wheatgrass adaptation trials in the cold semi-arid Mediterranean-type climates of California and North Africa. In Proc. Second Int. Rangeland Congress, Adelaide, Australia. In Press.

Gray, J.R. and H.W. Springfield. 1962. Economics of lambing on crested wheatgrass in northcentral New Mexico. New Mexico Agr. Exp. Sta. Bull. 461. 34 p.

Grunes, D.L. and H.F. Mayland. 1975. Controlling grass tetany. U.S. Dep. Agr. Leaflet 561. 8 p.

Haferkamp, M.R., R.F. Miller and F.A. Sneva. 1984. Mefluidide affects growth and forage quality of crested wheatgrass. Abstracts 37th Annual Meeting Soc. Range Manage., Rapid City, S.D. Soc. Range Manage., Denver, Colo.

Haglund, B.M. 1980. Proline and valine - cues which stimulate grasshopper herbivory during drought stress? Nature 288:697-698.

Handl, W.P. and L.R. Rittenhouse. 1975. A comparison of three methods of estimating digestibility for determining intake of grazing cattle. J. Range Manage. 28:414-416.

Hanna, M.R., G.C. Kozub and S. Smoliak. 1977. Forage production of sainfoin and alfalfa on dryland in mixed-and alternate-row seedings with three grasses. Can. J. Plant Sci. 57:61-70.

Hanson, W.R. and L.A. Stoddart. 1940. Effects of grazing upon bunch wheatgrasses. Agron. J. 32:278-289.

Harris, L.E., N.C. Frischknecht and R.J. Raleigh. 1958. Cattle gains and vegetation changes as influenced by grazing treatments on crested wheatgrass over a ten-year period. J. Anim. Sci. 17:1209 [abstract].

Harris, L.E., N.C. Frischknecht and E.M. Sudweeks. 1968. Seasonal grazing of crested wheatgrass by cattle. J. Range Manage. 21:221-225.

Hart, R.H., O.M. Abdalla, D.H. Clark, M.B. Marshall, M.H. Hamid, J.A. Hager and J.W. Waggoner, Jr. 1983a. Quality of forage and cattle diets on the Wyoming High Plains. J. Range Manage. 36:46-51.

Hart, R.H., E.F. Balla and J.W. Waggoner Jr. 1983b. Gains of steers and calves grazing crested wheatgrass. J. Range Manage. 36:483-484.

Havstad, K.M., A.S. Nastis and J.C. Malechek. 1983. The voluntary forage intake of heifers grazing a diminishing supply of crested wheatgrass. J. Anim. Sci. 56:259-263.

Heinrichs, D.H. 1959. The status of Russian wild ryegrass. Forage Notes 5:36-37. (Herbage Abst. 30:101).

Heinrichs, D.H. and D.L. Bolton. 1950. Studies on the competition of crested wheatgrass with perennial native species. Sci. Agr. 30:428-443. (now Can. J. Agr. Sci.)

Heinrichs, D.H. and R.B. Carson. 1956. Chemical composition of nine grasses at six stages of development. Can. J. Agr. Sci. 36:95-106.

Horton, L.E. and R.H. Weissert. 1970. Relationship of utilization intensity to plant vigor in a crested wheatgrass seeding. J. Range Manage. 23:298-300.

House, W.A. and H.F. Mayland. 1976. Magnesium utilization in wethers fed diets with varying ratios of nitrogen to readily fermentable carbohydrate. J. Anim. Sci. 43:842-849.

Houston, W.R. 1957. Renovation and fertilization of crested wheatgrass stands in the Northern Great Plains. J. Range Manage. 10:9-11.

Houston, W.R. and J. Urick. 1972. Improved spring pastures, cow-calves production and stocking rate carryover in the Northern Great Plains. USDA Agr. Res. Serv. Tech. Bull. 1451. 21 p.

Hubbard, W.A. 1949. Results of studies on crested wheatgrass. Sci. Agr. 29:385-395 (now Can. J. Agr. Sci.)

Huffine, W.W., G.R. Waller, V.G. Heller and C. Dewald. 1959. Production characteristics of Oklahoma forages: chemical composition. Oklahoma Agr. Exp. Sta. Misc. Pub. MP-58. 91 p.

Hull, A.C. Jr. 1948. Depth, season and row spacing for planting grasses on southern Idaho rangelands. Agron. J. 40:960-969.

Hull, A.C. Jr. 1972. Growth characteristics of crested and Fairway wheatgrasses in southern Idaho. J. Range Manage. 25:123-125.

Hull, A.C. Jr., D.F. Harvey, C.W. Doran and W.J. McGinnies. 1958. Seeding Colorado range lands. Colorado Agr. Exp. Sta. Bull. 498-S. 46 p.

Hull, A.C. Jr. and R.C. Holmgren. 1964. Seeding southern Idaho rangelands. USDA Forest Serv. Res. Pap. INT-10. Intermountain Forest & Range Exp. Sta., Ogden, Utah, 33 p.

Hull, A.C. Jr. and W.M. Johnson. 1955. Range seeding in the Ponderosa pine zone in Colorado. U.S. Dep. Agr. Circ. 953. 40 p.

Hull, A.C. Jr. and B.J. Klomp. 1966. Longevity of crested wheatgrass in the sagebrush-grass type in southern Idaho. J. Range Manage. 19:5-11.

Hull, A.C. Jr. and B.J. Klomp. 1974. Yield of crested wheatgrass under four densities of big sagebrush in southern Idaho. USDA Agr. Res. Serv. Tech. Bull. 1483. 38 p.

Hull, A.C. Jr. and G. Stewart. 1948. Replacing cheatgrass by reseeding with perennial grass on southern Idaho range. Agron. J. 40:694-703.

Hyder, D.N. and F.A. Sneva. 1961. Fertilization on sagebrush-bunchgrass range--a progress report. Oregon Agr. Exp. Sta. Misc. Paper 115. 36 p.

Hyder, D.N. and F.A. Sneva. 1963a. Morphological and physiological factors affecting the grazing management of crested wheatgrass. Crop Sci. 3:267-271.

Hyder, D.N. and F.A. Sneva. 1963b. Studies of six grasses seeded on sagebrush-bunchgrass range: yield, palatability, carbohydrate accumulation, and developmental morphology. Oregon Agr. Exp. Sta. Tech. Bull. 71. 20 p.

Jackman, E.R., D.E. Richards and D.E. Stephens. 1936. Crested wheatgrass in eastern Oregon. Oregon Ext. Bull. 494. 38 p.

Johnson, J.R. and G.E. Payne. 1968. Sagebrush reinvasion as affected by some environmental influences. J. Range Manage. 21:209-213.

Johnson, J.R. and J.T. Nichols. 1969. Crude protein content of eleven grasses as affected by yearly variation, legume association, and fertilization. Agron. J. 61:65-68.

Johnson, W.M. 1959. Grazing intensity trials on seeded ranges in the ponderosa pine zone of Colorado. J. Range Manage. 12:1-7.

Junk, R.J.G. and H.M. Austenson. 1971. Variability of grass quality as related to cultivar and location in western Canada. Can. J. Plant Sci. 51:309-315.

Karn, J.F. and J.M. Krupinsky. 1983. Chemical composition of intermediate wheatgrass affected by foliar diseases and stem rust. Phytopathology 73:1152-1155.

Kartchner, R.J. 1981. Effects of protein and energy supplementation of cows grazing native winter range forage on intake and digestibility. J. Anim. Sci. 51:432-438.

Kilcher, M.R. 1958. Fertilizer effects on hay production of three cultivated grasses in southern Saskatchewan. J. Range Manage. 11:231-234.

Kilcher, M.R. 1961. Row spacing affects yields of forage crops in the brown soil zone of Saskatchewan. Can. Dep. Agr. Pub. 1100. 11 p.

Kilcher, M.R. and D.H. Heinrichs. 1958. The performance of three grasses when grown alone, in mixture with alfalfa, and in alternate rows with alfalfa. Can. J. Plant Sci. 38:252-259.

Kincer, J.B. 1941. Climate and weather data for the United States, p. 1202. In: G. Hambidge (ed.). Climate and man-yearbook of agriculture. U.S. Govt. Printing Office, Washington, D.C.

Klages, K.H.W. and R.H. Stark. 1949. Grass and grass seed production. Idaho Agr. Exp. Sta. Bull. 273. 48 p.

Knipfel, J.E. 1977. Nutritional adequacy of mature Altai wild ryegrass and crested wheatgrass, or of alfalfa-wheatstraw mixtures for the pregnant ewe. Can. J. Anim. Sci. 57:405-410.

Knowles, R.P. and M.R. Kilcher. 1983. Crested wheatgrass. Agriculture Canada Res. Branch. Saskatoon, Sask. 18 p.

Konstantinov, P.N. 1923. The geographical distribution of Agropyron cristatum and A. desertorum and the environment to which it is adapted. New Land, Moscow. 68 p. (Translated from Russian to English by T.K. Pavlychenko, Dominion Forage Crop Laboratory, Saskatoon, Saskatchewan, Canada.)

Kubota, J. and W.H. Allaway. 1972. Geographic distribution of trace element problems, p. 525-554. In: Micronutrients in agriculture. Soil Sci. Soc. Amer., Madison, Wisc.

Kubota, J., E.A. Naphan and G.H. Oberly. 1982. Fluoride in thermal spring water and in plants of Nevada and its relationship to fluorosis in animals. J. Range Manage. 35:188-192.

Lamb, J.F.S., K.P. Vogel and P.E. Reece. 1984. Genotype and genotype x environment interaction effects on forage yield and quality of crested wheatgrasses. Crop Sci. 24:559-564.

Lambert, T.L. and C. Blincoe. 1971. High concentrations of cobalt in wheat grasses. J. Sci. Food Agr. 22:8-9.

Lang, R. and L. Landers. 1960. Beef production and grazing capacity from a combination of seeded pastures versus native range. Wyoming Agr. Exp. Sta. Bull. 370. 12 p.

Lang, R. and L.R. Landers. 1968. Nitrogen fertilization of crested wheatgrass in northeastern Wyoming. Wyoming Agr. Exp. Sta. Res. J. 21. 20 p.

Lavin, F. and H.W. Springfield. 1955. Seeding in the southwestern pine zone for forage improvement and soil protection. U.S. Dep. Agr. Handbook 98. 52 p.

Lawrence, T. 1978. An evaluation of thirty grass populations as forage crops for southwestern Saskatchewan. Can. J. Plant Sci. 58:107-115.

Lawrence, T. and J.E. Knipfel. 1981. Yield and digestibility of crested wheatgrass and Russian and Altai wild ryegrasses as influenced by N fertilization and date of first cutting. Can. J. Plant Sci. 61:609-618.

Lawrence, T., G.E. Winkleman and F.G. Warder. 1981. Nitrate accumulation in Altai wild ryegrass, Russian wild ryegrass and crested wheatgrass. Can. J. Plant Sci. 61:735-740.

Leyshon, A.J., M.R. Kilcher and J.D. McElgunn. 1981. Seeding rates and row spacings for three forage crops grown alone or in alternate grass-alfalfa rows in southwestern Saskatchewan. Can. J. Plant Sci. 61:711-717.

Lodge, R.W. 1960. Effects of burning, cultivating and mowing on the yield and consumption of crested wheatgrass. J. Range Manage. 13:318-321.

Lodge, R.W. 1963. Complementary grazing systems for Sandhills of the northern Great Plains. J. Range Manage. 16:240-244.

Looman, J. and D.H. Heinrichs. 1973. Stability of crested wheatgrass pastures under long-term pasture use. Can. J. Plant Sci. 53:501-506.

Lorenz, R.J. and G.A. Rogler. 1962. A comparison of methods of renovating old stands of crested wheatgrass. J. Range Manage. 15:215-219.

Love, L.D. and H.C. Hanson. 1932. Life history and habits of crested wheatgrass. J. Agr. Res. 45:371-383.

Lutwick, L.E. and A.D. Smith. 1977. Yield and composition of alfalfa and crested wheatgrass, grown singly and in mixture, as affected by N and P fertilizers. Can. J. Plant Sci. 57:1077 -1083.

McCormick, P.W. and J.P. Workman. 1975. Early range readiness with nitrogen fertilizer: an economic analysis. J. Range Manage. 28:181-184.

McGinnies, W.J. 1968. Effects of nitrogen fertilizer on an old stand of crested wheatgrass. Agron. J. 60:560-562.

McGinnies, W.J. 1970. Effects of seeding rate and row spacing on establishment and yield of crested wheatgrass. Agron. J. 62:417-421.

McGinnies, W.J. 1971. Influence of row spacing on crested wheatgrass seed production. J. Range Manage. 24:387-389.

McGinnies, W.J. and C.E. Townsend. 1983. Yield of three range grasses grown alone and in mixtures with legumes. J. Range Manage. 36:399-401.

McWilliams, J.L. and P.E. Van Cleave. 1960. A comparison of crested wheatgrass and native grass mixtures seeded on rangeland in eastern Montana. J. Range Manage. 13:91-94.

Madsen, F.C., D.E. Lentz, J.K. Miller, D. Lowrey-Harnden and S.L. Hansard. 1976. Dietary carbohydrate effects upon magnesium metabolism in sheep. J. Anim. Sci. 42:1316-1322.

Mahler, R.L. 1984. The influence of Mount St. Helen's volcanic ash on alfalfa growth and nutrient uptake. Commun. Soil Sci. Plant Anal. 15:449-460.

Mayland, H.F. 1983. Assessing nutrient cycling in the soil/plant/animal system of semi-arid pasture lands, p. 109-117. In: Nuclear techniques in improving pasture management. Int. Atomic Energy Agency, Vienna.

Mayland, H.F. and D.L. Grunes. 1974a. Magnesium concentration in _Agropyron desertorum_ fertilized with Mg and N. Agron. J. 66:79-82.

Mayland, H.F. and D.L. Grunes. 1974b. Shade- induced grass-tetany-prone chemical changes in _Agropyron desertorum_ and _Elymus cinereus_. J. Range Manage. 27:198-201.

Mayland, H.F. and D.L. Grunes. 1979. Soil-climate-plant relationships in the etiology of grass tetany, p. 123-175. In: V.V. Rendig and D.L. Grunes (eds.). Grass tetany. Amer. Soc. Agron. Spec. Pub. 35. Madison, Wisc.

Mayland, H.F., D.L. Grunes and D.M. Stuart. 1974c. Chemical composition of _Agropyron desertorum_ as related to grass tetany. Agron. J. 66:441-446.

Mayland, H.F., D.L. Grunes, H.O. Waggoner, A. Florence, D.A. Hewes and P.K. Joo. 1975. Nitrogen effects on crested wheatgrass as related to forage quality indices of grass tetany. Agron. J. 67:411-414.

Mayland, H.F., L.F. Molloy and T.W. Collie. 1976. Higher fatty acid composition of immature forages as affected by N fertilization. Agron. J. 68:979-982.

Mayland, H.F., G.E. Shewmaker and R.C. Bull. 1977. Soil ingestion by cattle grazing crested wheatgrass. J. Range Manage. 30:264-265.

Mayland, H.F. and F.A. Sneva. 1983. Effect of soil contamination on the mineral composition of forage fertilized with nitrogen. J. Range Manage. 36:286-288.

Milchunas, D.G., W.K. Laurenroth and J.L. Dodd. 1983. The interaction of atmospheric and soil sulfur on the sulfur and selenium concentration of range plants. Plant and Soil 72:117-125.

Miller, R.V. 1960. Effects of nitrogen fertilization on Nordan crested wheatgrass. PhD Diss. Colorado State Univ., Fort Collins. 97 p.

Miller, R.F., M.R. Haferkamp and R.F. Angell. 1984. Defoliation and growth of crested wheatgrass. I. Defoliation effects on forage growth, p. 12-17. In: Research in beef cattle nutrition and management. Oregon Agr. Exp. Sta. Spec. Rep. 714.

Murphy, R.P. 1942. Methods of breeding crested wheatgrass _Agropyron cristatum_ (L.) Beauv. J. Amer. Soc. Agron. 34:553-565. (now Agron. J.).

Murray, R.B. 1984. Yields, nutrient quality, and palatability to sheep of fourteen grass accessions for potential use on sagebrush-grass range in southeastern Idaho. J. Range Manage. 37:343-348.

Murray, R.B., H.F. Mayland and P.J. Van Soest. 1978. Growth and nutritional value to cattle of grasses on cheatgrass range in southern Idaho. USDA Forest Serv. Res. Pap. INT-199. Intermountain Forest & Range Exp. Sta., Ogden, Utah. 57 p.

Murray, R.B., H.F. Mayland and P.J. Van Soest. 1979. Seasonal changes in nutritional quality of Agropyron desertorum compared with six other semi-arid grasses, p. 538-549. In: J.R. Goodin and D.K. Northington (eds.). Arid land plant resources. Int. Center Arid and Semiarid Land Studies, Texas Tech. Univ., Lubbock.

Nielson, R.F. and H.B. Peterson. 1973. Establishing vegetation on mine tailings waste, p. 103-115. In: R.J. Hutnik and G. Davis (eds.). Ecology and reclamation of devastated land. Vol. 2. Gordon and Breach, New York.

Nyren, P.E., W.C. Whitman, J.L. Nelson and T.J. Conlon. 1983. Evaluation of a fertilized 3-pasture system grazed by yearling steers. J. Range Manage. 36:354-358.

Otsyina, R., C.M. McKell and G. van Epps. 1982. Use of range shrubs to meet nutrient requirements of sheep grazing on crested wheatgrass during fall and early winter. J. Range Manage. 35:751-753.

Park, Y.W., M.J. Anderson, K.H. Asay and A.W. Mahoney. 1983. Predicting soluble nitrogen and fibrous fractions in crested wheatgrass with near-infrared-reflectance spectroscopy. J. Range Manage. 36:529-533.

Patterson, J.K. and V.E. Youngman. 1960. Can fertilizers effectively increase our range land production? J. Range Manage. 13:255-257.

Patton, A.R. and L. Gieseker. 1942. Seasonal changes in lignin and cellulose content of some Montana grasses. J. Anim. Sci. 1:22-26.

Pavlychenko, T.K. 1942. The place of crested wheatgrass, Agropyron cristatum L., in controlling perennial weeds. Sci. Agr. 22:459-460. (now Can. J. Agr. Sci.)

Piemeisel, R.L., F.R. Lawson and E. Carsner. 1951. Weeds, insects, plant diseases, and dust storms. Sci. Monthly 73:124-128.

Power, J.F. 1970. Nitrogen management of semiarid grasslands in North America, p. 468-471. In: Proc. 11th Int. Grassland Congress, Surfer's Paradise, Australia.

Power, J.F. 1980a. Response of semiarid grassland sites to nitrogen fertilization. I. Plant growth and water use. Soil. Sci. Soc. Amer. J. 44:545-550.

Power, J.F. 1980b. Response of semiarid grassland sites to nitrogen fertilization: II. Fertilizer recovery. Soil Sci. Soc. Amer. J. 44:550-555.

Power, J.F. and J. Alessi. 1970. Effects of nitrogen source and phosphorus on crested wheatgrass growth and water use. J. Range Manage. 23:175-178.

Power, J.F. and J.O. Legg. 1984. Nitrogen-15 recovery for five years after application of ammonium nitrate to crested wheatgrass. Soil Sci. Soc. Amer. J. 48:322-326.

Prior, R.L., D.L. Grunes, R.P. Patterson, F.W. Smith, H.F. Mayland and W.J. Visek. 1973. Partition column chromatography for quantitating effects of fertilization on plant acids. J. Agr. Food Chem. 21:73-77.

Raleigh, R.J. 1970. Symposium on pasture methods for maximum production in beef cattle: manipulation of both livestock and forage management to give optimum production. J. Anim. Sci. 30:108-114.

Rauzi, F. 1968. Pitting and interseeding native shortgrass rangeland. Wyoming Agr. Exp. Sta. Res. J. 17:1-14.

Rauzi, F. 1975. Seasonal yield and chemical composition of crested wheatgrass in southeastern Wyoming. J. Range Manage. 28:219-221.

Rauzi, F. and L. Landers. 1979. Forage production from along Interstate 90 in northeastern Wyoming. U.S. Dep. Agr. Cons. Res. Rep. 24. 10 p.

Rauzi, F. and L. Landers. 1982. Level benches for forage production in the Northern Plains. J. Range Manage. 35:166-171.

Rauzi, F., L. Landers and A. Herold. 1971. Renovating crested wheatgrass stands. Wyoming Agr. Exp. Sta. Res. J. 52. 8 p.

Read, D.W.L. and G.E. Winkleman. 1982. Residual effects of nitrogen and phosphorus fertilizer on crested wheatgrass under semiarid conditions. Can. J. Plant Sci. 62:415-425.

Reitz, L.P., M. A. Bell and H.E. Tower. 1936. Crested wheatgrass in Montana: comparisons with slender wheatgrass and bromegrass. Montana Agr. Exp. Sta. Bull. 323. 53 p.

Reynolds, H.G. and H.W. Springfield. 1953. Reseeding southwestern range lands with crested wheatgrass. U.S. Dep. Agr. Farmers Bull. 2056.

Richards, J.H. 1984. Root growth response to defoliation in two Agropyron bunchgrasses: field observations with an improved root periscope. Oecologia (Berlin) 64:21-15.

Richardson, L.R., R.H. Abernethy and G.P. Roehrkasse. 1980. Crested wheatgrass and miscellaneous grass variety tests in Wyoming. Wyoming Agr. Exp. Sta. Res. J. 150.2. 15 p.

Rittenhouse, L.R. and F.A. Sneva. 1976. Expressing the competitive relationship between Wyoming big sagebrush and crested wheatgrass. J. Range Manage. 29:326-327.

Roberts, D.L. 1977. Economics of carry-over forage production, increased grazing season length, and increased livestock production from rangeland fertilization. MS Thesis. Utah State Univ., Logan. 77 p.

Robertson, J.H. 1947. Response of range grasses to different intensities of competition with sagebrush (Artemisia tridentata Nutt.). Ecology 28:1-16.

Robertson, J.H. 1969. Yield of crested wheatgrass following release from sagebrush competition by 2,4-D. J. Range Manage. 22:287-288.

Robertson, J.H. 1972. Competition between big sagebrush and crested wheatgrass. J. Range Manage. 25:156-157.

Robertson, J.H., K.R. McAdams, D.L. Neal and P.T. Tueller. 1970a. Spring grazing of crested wheatgrass in Nevada - A case history. Nevada Agr. Exp. Sta. Pub. B23. 22 p.

Robertson, J.H., D.L. Neal, K.R. McAdams and P.T. Tueller. 1970b. Changes in crested wheatgrass ranges under different grazing treatments. J. Range Manage. 23:27-34.

Rogler, G.A. and R.J. Lorenz. 1969. Pasture productivity of crested wheatgrass as influenced by nitrogen fertilization and alfalfa. USDA Agr. Res. Serv. Tech. Bull. 1402. 33 p.

Rogler, G.A. and R.J. Lorenz. 1983. Crested wheatgrass - early history in the United States. J. Range Manage. 36:91-93.

Russell, J.B. and P.J. Van Soest. 1984. In vitro ruminal fermination of organic acids common in forage. J. Applied & Environ. Microbiology 47:155-159.

Sarvis, J.T. 1941. Grazing investigations on the northern Great Plains. North Dakota Agr. Exp. Sta. Bull. 308. 110 p.

Schaff, H.M., G.A. Rogler and R.J. Lorenz. 1962. Importance of variation in forage yield, seed yield and seed weight to the improvement of crested wheatgrass. Crop Sci. 2:67-71.

Schlatterer, E.F. 1974. A partial literature review on the use of fertilizers to increase production on rangelands. USDA Forest Serv. Range Improve. Note 19. Intermountain Reg., Ogden, Utah. 13 p.

Schultz, R.D. and J. Stubbendieck. 1982. Herbage yield of fertilized cool-season grass-legume mixtures in western Nebraska. J. Range Manage. 35:473-476.

Schultz, R.D. and J. Stubbendieck. 1983. Herbage quality of fertilized cool-season grass-legume mixtures in western Nebraska. J. Range Manage. 36:571-575.

Schuman, G.E., F. Rauzi and D.T. Booth. 1982. Production and competition of crested wheatgrass-native grass mixtures. Agron. J. 74:23-26.

Seamands, W.J. and R. Lang. 1960. Nitrogen fertilization of crested wheatgrass in southeastern Wyoming. Wyoming Agr. Exp. Sta. Bull. 364. 16 p.

Segura, M. 1962. Effect of nitrogen and phosphorus fertilization on the growth characteristics of crested wheatgrass. MS Thesis. Colorado State Univ., Fort Collins. 79 p.

Severson, R.C. and L.P. Gough. 1976. Concentration and distribution of elements in plants and soils near phosphate processing factories, Pocatello, Idaho. J. Environ. Qual. 5:476-482.

Sharp, L. 1970. Suggested management programs for grazing crested wheatgrass. Idaho Forest, Wildlife & Range Exp. Sta. Bull. 4. 19 p.

Sims, P.L. 1969. The effect of stand density on characteristics of wheatgrasses. Ph.D. Diss. Utah State Univ., Logan. Diss. Abstr. 1969, 29:12, 4482B.

Sims, P.L. and C.W. Cook. 1970. Herbage digestibility as influenced by community density. J. Anim. Sci. 31:1228-1231.

Smika, D.E., H.J. Haas and G.A. Rogler. 1960. Yield, quality and fertilizer recovery of crested wheatgrass, bromegrass and Russian wildrye as influenced by fertilization. J. Range Manage. 13:243-246.

Smika, E.E., H.J. Haas and G.A. Rogler. 1963. Native grass and crested wheatgrass production as influenced by fertilizer placement and weed control. J. Range Manage. 16:5-8.

Smoliak, S. 1968. Grazing studies on native range, crested wheatgrass, and Russian wildrye pastures. J. Range Manage. 21:47-50.

Smoliak, S. and L.M. Bezeau. 1967. Chemical composition and in vitro digestibility of range forage plants of the Stipa-Bouteloua Prairie. Can. J. Plant Sci. 47:161-167.

Smoliak, S. and M. Bjorge. 1981. Hay and pasture crops, p. 7-48. In: Alberta forage manual. Alberta Agr. Agdex 120 20-4. Edmonton, Alberta.

Smoliak, S., A. Johnston and R.W. Lodge. 1981a. Management of crested wheatgrass pastures. Agr. Can. Publ. 1473. 19 p.

Smoliak, S., M. Bjorge, D. Penney, A.M. Harter and J.S. Horricks. 1981b. Alberta forage manual. Alberta Agr. Agdex 120/20-4. Edmonton, Alberta. 87 p.

Smoliak, S., A. Johnston and L.E. Lutwick. 1967. Productivity and durability of crested wheatgrass in southeastern Alberta. Can. J. Plant Sci. 47:539-548.

Smoliak, S. and S.B. Slen. 1974. Beef production on native range, crested wheatgrass, and Russian wildrye pastures. J. Range Manage. 27:433-436.

Sneva, F.A. 1967. Chemical curing of range grasses with paraquat. J. Range Manage. 20:389-394.

Sneva, F.A. 1973a. Crested wheatgrass response to nitrogen and clipping. J. Range Manage. 26:47-50.

Sneva, F.A. 1973b. Wheatgrass response to seasonal applications of two nitrogen sources. J. Range Manage. 26:137-139.

Sneva, F.A. 1973c. Nitrogen and paraquat saves range forage for fall grazing. J. Range Manage. 26:294-295.

Sneva, F.A. 1977. Correlations of precipitation and temperature with spring, regrowth, and mature crested wheatgrass yields. J. Range Manage. 30:270-275.

Sneva, F.A. 1978. Nitrogen and sulfur impacts on the cold desert biome, p. 678-680. In: D. N. Hyder (ed.). Proc. First Int. Rangeland Congress. Soc. Range Manage. Denver, Colo.

Sneva, F.A. 1983. Nitrogen yield in reproductive organs of crested wheatgrass. Northwest Sci. 57:224-228.

Sneva, F.A. and C.M. Britton. 1983. Adjusting and forecasting herbage yields in the Intermountain big sagebrush region of the steppe province. Oregon Agr. Exp. Sta. Bull. 659. 61 p.

Sneva, F.A., C.M. Britton, H.F. Mayland, J. Buckhouse, R.A. Evans, J.A. Young and M. Vavra. 1982. Mt. St. Helen's Ash: considerations of its fallout on rangelands. Oregon Agr. Exp. Sta. Spec. Rep. 650. 27 p.

Sneva, F.A. and D.N. Hyder. 1961. Estimating herbage production on semiarid ranges of the Intermountain region. J. Range Manage. 15:88-93.

Sneva, F.A. and D.N. Hyder. 1962. Forecasting range herbage production in eastern Oregon. Oregon Agr. Exp. Sta. Bull. 588. 11 p.

Sneva, F.A., D.N. Hyder and C.S. Cooper. 1958. The influence of ammonium nitrate on the growth and yield of crested wheatgrass on the Oregon high desert. Agron. J. 50:40-44.

Sneva, F.A., R.J. Raleigh and H.A. Turner. 1973. Paraquat-cured herbage for late season grazing. J. Anim. Sci. 36:107-113.

Sneva, F.A. and L.R. Rittenhouse. 1976. Crested wheat production: impacts on fertility, row spacing, and stand age. Oregon Agr. Exp. Sta. Tech. Bull. 135. 26 p.

Sosulski, F.W., J.K. Patterson and A.G. Law. 1960. The lignin content of grass strains. Agron. J. 52:130-134.

Sotola, J. 1940. The chemical composition and apparent digestibility of nutrients in crested wheatgrass harvested in three stages of maturity. J. Agr. Res. 61:303-311.

Springfield, H.W. 1960. Shrub use by sheep on seeded range. USDA Forest Serv. Res. Note 49. Rocky Mountain Forest & Range Exp. Sta., Fort Collins, Colo.

Springfield, H.W. 1963. Cattle gains and plant responses from spring grazing on crested wheatgrass in New Mexico. USDA Forest Serv. Res. Prod. Res. Rep. 74. 46 p.

Springfield, H.W. 1965. Rate and spacing in seeding crested wheatgrass in New Mexico. USDA Forest Serv. Res. Note RM-42. Rocky Mountain For. & Range Exp. Sta., Fort Collins, Colo. 8 p.

Springfield, H.W. and E.H. Reid. 1967. Crested wheatgrass for spring grazing in northern New Mexico. J. Range Manage. 20:406-408.

Springfield, H.W. and H.G. Reynolds. 1951. Grazing preferences of cattle for certain reseeding grasses. J. Range Manage. 4:83-87.

Stanley, M.A., G.E. Schuman, F. Rauzi and L.I. Painter. 1982. Quality and element content of forages grown on three reclaimed mine sites in Wyoming and Montana. Reclam. Reveg. Res. 1:311-326.

Stauber, M.S., O. Burt and H. Houlton. 1974. Economics of crested wheatgrass fertilization at Havre, Montana, p. 55-66. In: Proc. Range Fertilization Symposium. Havre, Montana.

Stitt, R.E. 1958. Factors affecting yield and quality of dryland grasses. Agron. J. 50:136-138.

Stitt, R.E., J.C. Hide and E. Frahm. 1955. The response of crested wheatgrass and volunteer sweetclover to nitrogen and phosphorus under dryland conditions. Agron. J. 47:568-572.

Stoszek, M.J., J.E. Oldfield, G.E. Carter and P.H. Weswig. 1979. Effect of tall fescue and quackgrass on copper metabolism and weight gains of beef cattle. J. Anim. Sci. 48:893-899.

Stout, P.R., J. Brownell and R.G. Burau. 1967. Occurrence of _trans_-aconitate in range forage species. Agron. J. 59:21-24.

Stuart, D.M., H.F. Mayland and D.L. Grunes. 1973. Seasonal changes in _trans_-aconitate and mineral composition of crested wheatgrass in relation to grass tetany. J. Range Manage. 26:113-116.

Thill, J.L. and J.R. George. 1975. Cation concentrations and K to Ca+ Mg ratio of nine cool-season grasses and implications with hypomagnesemia. Agron. J. 67:89-91.

Thomas, J.R., H.R. Cosper and W. Bever. 1964. Effects of fertilizers on the growth of grass and its use by deer in the Black Hills of South Dakota. Agron. J. 56:223-226.

Thomas, J. and A. Osenbrug. 1964. Interrelationships of nitrogen, phosphorus, and seasonal precipitation in the production of bromegrass-crested wheatgrass hay. USDA Agr. Res. Serv. Prod. Res. Rep. 82. 27 p.

Troelsen, J.E. 1971. Consumption of digestible energy by sheep as predicted from the concentration of _in vitro_ digestible energy, cell-wall constituents, and crude fiber in coarse roughage. Can. J. Anim. Sci. 51:433-438.

U. S. Department of Commerce. 1965. World weather records 1951-60. Vol. 1. North America. Washington, D.C.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dep. Agr. Handbook 60. Washington, D.C. 160 p.

Van Soest, P.J. 1966. Non-nutritive residues: a system of analysis for the replacement of crude fiber. J. Assoc. Offic. Agr. Chem. 49:546-551.

Vogel, K.P., P.E. Reece and J.F.S. Lamb. 1984. Evaluation of crested wheatgrass introductions for forage yield and quality. Nebraska Agr. Exp. Sta. Res. Bull. 304. 13 p.

Wallace, J.D., F. Hubbert Jr. and R.J. Raleigh. 1963. The response of yearling cattle on crested wheatgrass pasture to energy and sodium supplementation. J. Range Manage. 16:1-5.

Watkins, W.E. and J.V. Kearns Jr. 1956. The nutritive value of various grasses and grass- legume mixtures. J. Anim. Sci. 15:153-162.

Westermann, D.T. and C. W. Robbins. 1974. Effect of SO_4-S fertilization on Se concentration of alfalfa (Medicago sativa L.). Agron. J. 66:207-208.

Westover, H.L. 1934. Crested wheatgrass. U.S. Dep. Agr. Leaf. 104. 8 p.

Westover, H.L. and G.A. Rogler. 1947. Crested wheatgrass. U.S. Dep. Agr. Leaf. 104. (rev.). 8 p.

Westover, H.L., J.T. Sarvis, L.H. Moomaw, G.W. Morgan, J.C. Thysell and M.A. Bell. 1932. Crested wheatgrass as compared with bromegrass, slender wheatgrass, and other hay and pasture crops for the northern Great Plains. U.S. Dep. Agr. Tech. Bull. 307. 35 p.

White, L.M. 1984. Foxtail barley heading, yield, and quality as influenced by growth regulators and a desiccant. Agron. J. 76:27-30.

White, L.M. and J. R. Wight. 1981. Seasonal dry matter yield and digestibility of seven grass species, alfalfa, and cicer milkvetch in eastern Montana. Agron. J. 73:457-462.

White, L.M. and J.R. Wight. 1984. Forage yield and quality of dryland grasses and legumes. J. Range Manage. 37:233-236.

Whitman, W.C., L. Langford, R.J. Douglas and T.J. Conlon. 1963. Crested wheatgrass and crested wheatgrass-alfalfa pastures for early-season grazing. North Dakota Agr. Exp. Sta. Bull. 442. 24 p.

Wight, J.R. 1976. Range fertilization in the Northern Great Plains. J. Range Manage. 29:180-181.

Wight, J.R., C.K. Gee and R.J. Kartchner. 1983. Integrated rangeland and cropland management, p. 435-459. In: Dryland Agriculture-Agronomy Monograph 23. Amer. Soc. Agronomy. Madison, Wisc.

Wilkinson, S.R. and J.A. Stuedemann. 1979. Tetany hazard of grass as affected by fertilization with nitrogen, potassium, or poultry litter and methods of grass tetany prevention, p. 93-121. In: V.V. Rendig and D.L. Grunes (eds.) Grass tetany. Amer. Soc. Agron. Spec. Pub. 35. Madison, Wisc.

Williams, K.T., H.G. Byers and H.W. Lakin. 1941. Selenium occurrence in certain soils in the United States, with a discussion of related topics: fifth report. U.S. Dep. Agr. Tech. Bull. 758. 69 p.

Williams, R.J., K. Broersma and A.L. VanRyswyk. 1979. The effects of nitrogen fertilization on water use by crested wheatgrass. J. Range Manage. 32:98-100.

Williams, R.M., R.T. Clark and A.R. Patton. 1942. Wintering steers on crested wheatgrass. Montana Agr. Exp. Sta. Bull. 407. 18 p.

Williams, R.M. and A.H. Post. 1941. Dry-land pasture experiments at the Judith Basin Branch Station. Montana Agr. Exp. Sta. Bull. 388. 25 p.

Willms, W., A. McLean and C. Kalnin. 1980. Nutritive characteristics of grasses on spring range in south central British Columbia in relation to time, habitat and fall grazing. Can. J. Plant Sci. 60:131-137.

Windle, L.C., H.C. McKay and R.B. Foster. 1966. Grass seed production on southern Idaho dryland farms. Idaho Agr. Exp. Sta. Bull. 473. 11 p.

Woolfolk, E.J. 1951. Crested wheatgrass grazing values. USDA Forest Service Northern Rocky Mountain Forest & Range Exp. Sta. Res. Note. 10 p.

Wurster, M.J., L.D. Kamstra and J.G. Ross. 1971a. Evaluation of cool season grass species and varieties using in vivo and in vitro techniques. Agron. J. 63:241-245.

Wurster, M.J., J.G. Ross, L.D. Kamstra and S.S. Bullis. 1971b. Effect of droughty soil on digestibility criteria in three cool season forage grasses. Proc. South Dakota Acad. Sci. 50:90-94.

APPENDIX

COMMON AND SCIENTIFIC NAMES OF PLANTS MENTIONED

Wheatgrasses

Beardless wheatgrass	Elytrigia spicata (Pursh) R. D. Dewey, previously Agropyron inerme (Scribn and Smith) Rydb.
Bluebunch wheatgrass	Elytrigia spicata previously A. spicata.
Crested wheatgrass	Agropyron desertorum (Fisch. ex Link) Schult. A. cristatum (L.) Gaertn.
Intermediate wheatgrass	Elytrigia intermedia (Host) Nevski, previously A. intermedium (Host) Beauv.
Pubescent wheatgrass	Elytrigia intermedia subsp. barbulato (Schur) A. Löve, previously A. trichophorum (Link) Richt.
Quackgrass	Elytrigia repens (L.) Nevski, previously A. repens. (L.) Beauv.
Siberian wheatgrass	A. fragile (Roth) Candargy, previously A. sibiricum (Willd.) Beauv.
Slender wheatgrass	Elymus trachycaulus (Link) Gould ex Shinners subsp. trachycaulus, previously A. tracycaulum (Link) Malte.

Streambank wheatgrass	Elymus lanceolatus, previously A. riparium Scribn. and Smith.
Tall wheatgrass	Elytrigia pontica (Podp.) Holub, previously A. elongatum (Host) Beauv.
Thickspike wheatgrass	Elymus lanceolatus (Scribn. and Smith) Gould, previously A. dasystachyum (Hook.) Scribn.
Western wheatgrass	Pascopyrum smithii (Rydb.) A. Löve, previously A. smithii Rydb.

Other Grasses

Altai wildrye	Leymus angustus (Trin.) Pilger, previously Elymus angustus Trin. not native to North America.
Big bluegrass	Poa ampla Merr.
Big bluestem	Andropogon gerardi (Vitman).
Blue grama	Boutelova gracilis (H.B.K.) Lag. ex Steud.
Bromegrass	Bromus inermis Leyss.
Bulbous bluegrass	Poa bulbosa L.
Cheatgrass	Bromus tectorum L.
Creeping red fescue	Festuca rubra L. subsp. rubra.
Foxtail barley	Hordeum jubatum L.
Green needlegrass	Stipa viridula Trin.
Green stipagrass	Stipa viridula Trin.
Indian ricegrass	Oryzopsis hymenoides (Roem. and Schult.) Ricker.
Kentucky bluegrass	Poa pratensis.
Orchard grass	Dactylis glomerata.
Red top	Agrostis alba L.
Russian wildrye	Psathyrostachys juncea, previously Elymus junceus Fisch.
Sandberg bluegrass	Poa secunda Presl.
Side-oats grama	Bouteloua curtipendula (Michx.) Torr.
Switchgrass	Panicum virgatum L.
Tall oatgrass	Arrhenatherum elatus.

Others

Alfalfa	Medicago sativa L. Medicago media Pers. "Drylander" also M sativa subsp. varia (Martyn) Arc.
Bean, dry cultivated	Phaseolus vulgaris.
Big sagebrush	Artemisia tridentata Nutt.
Bitterbrush	Purshia tridentata.
Cicer milkvetch	Astragalus cicer L.
Cotton	Gossypium hirsutum.
Crownvetch	Coronilla varia.
Douglas rabbitbrush	Chrysothamnus visidiflorus.
Forage kochia	Kochia prostrata.
Fourwing saltbrush	Atriplex canescens.
Halogeton	Halogeton glomeratus.
Pinyon-juniper	Pinus edulis Engelm., also P. monophylla; Juniperus monosperma (Engelm.) Sarg., also J. osteosperma.
Ponderosa pine	Pinus ponderosa Lawson.
Rubber rabbitbrush	Chrysothamnus nauseosus.
Russian thistle	Salsola kali.
Sainfoin	Onobrychis viciaefolia Scop.
Sicklepod milkvetch	Astragalus falcatus.
Soybean	Glycine max.
Sugar beet	Beta vulgaris (L.).
Sweet clover	Melilotus officinalis (L.) Lam.
Tomato	Lycopersicon esculentum.
Saltbrush	Atriplex canescens (Pursh Nutt.).
Silver sagebrush	Artemisia cana.
Winterfat	Ceratoides lanata (Pursh, Howell).

In: Johnson, K. L. (ed.). 1986. Crested wheatgrass: its values, problems and myths; symposium proceedings. Utah State Univ., Logan.