Proactive Management of Crested Wheatgrass

Crested wheatgrass is a long-lived perennial, cool season, drought tolerant, winter hardy grass with an extensive root system. It was introduced from Eurasia and has naturalized in the Northern Plains. Numerous accessions of plant material originating from Turkey, Iran, Kazakhstan, central Asia, western and southwestern Siberia, and the steppe region of European Russia have been brought to North America. A total of three recognized species were introduced: *Agropyron desertorum* (Fisch. ex Link) Schult. (Nordan type and MT Standard type), *Agropyron cristatum* (L.) Gaertn. (Fairway type), and *Agropyron fragile* (Roth) Candargy (Siberian type). Even though each species has distinct characteristics, specific identification of individual plants is difficult because the morphological variation has developed into a continuum as a result of the extensive intercrossing that has occurred since the 1930's.

Millions of acres of crested wheatgrass exist as mixtures or monocultures in the Northern Plains because it has been the principal grass selected for revegetation of previously plowed rangelands in the United States and Canada (Lorenz 1986). During the first 20 years of the 20th Century, millions of acres of rangeland were turned over with steel moldboard plows in order to fulfill the compliance requirements of the Homestead Acts of both countries and because of the high demand for wheat, flax, and a few other crops. The region was experiencing favorable climatic conditions during this period and cropland production was generally successful, which stimulated the plowing of additional acres of rangeland. Both Canada and the United States suffered economic depression during the late 1920's and many years with severe drought conditions during the 1930's. Much of the cropland areas were abandoned and exposed to wind and water erosion.

Crested wheatgrass was seeded into the abandoned cropland areas to reduce the erosion problems and stabilize the land. Crested wheatgrass successfully revegetated these exposed areas primarily because of its seedling vigor and its ability to survive unfavorable conditions of low precipitation and cold winters.

Some of the revegetated cropland were large enough to be used and managed separately as hay fields or spring pastures. However, much of the revegetated land were small parcels located within management units that consist mainly of some other type of plant cover. These small parcels of crested wheatgrass usually cannot be isolated and managed as separate units because the cost of fence material and separate livestock watering facilities cannot be economically justified. Proper management of these small parcels of crested wheatgrass is still a problem in the Northern Plains.

Crested wheatgrass is a very beneficial grass and has made significant contributions to the production of livestock in the Northern Plains (Lorenz 1986). However, crested wheatgrass hay fields and pastures have the potential to provide suitable habitat for pestiferous rangeland grasshopper population development. Crested wheatgrass stands persist after several years of heavy use as widely spaced large bunches or widely spaced single tillers and small bunches. These growth characteristics of open canopy provide favorable habitat for several pest grasshopper species (Onsager 1995, and pers. comm.). The majority of grasshopper "hot spots" in the Northern Plains are found on double used or poorly used crested wheatgrass hay fields and pastures. Management of crested wheatgrass favorable for pest grasshoppers needs to be terminated and management of crested wheatgrass favorable for livestock production and unfavorable for pest grasshopper production needs to be evaluated and implemented.

Study Areas

The objectives of this research project were to quantitatively describe the changes to vegetation structure during the growing season caused by mowing and grazing management practices on crested wheatgrass meadows and to document changes to grasshopper population abundance and composition that resulted from the management caused changes to grasshopper habitat. This collaborative project was conducted from the Range Research Laboratory at the NDSU Dickinson Research Extension Center (DREC), Dickinson, North Dakota, directed by Dr. Llewellyn L. Manske and was responsible for the vegetation data, and conducted from the Rangeland Insect Laboratory at the USDA Agricultural Research Service (ARS), Bozeman, Montana, that was moved mid study to Sidney, Montana, directed by Dr. Jerome A. Onsager and was responsible for the grasshopper data.

The initial study sites were located in the North Dakota Grasshopper IPM Demonstration Project Site within the McKenzie County Grazing District of the Little Missouri Grasslands, 21 miles (34 km) west of Watford City between 47° 35' and

47° 50' N. latitude and 104° 00' and 103° 45' W. longitude, North Dakota. The study sites were provided with the cooperation of the USDA Forest Service and the McKenzie County Grazing Association. The project was funded by the USDA Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ), Cooperative Grasshopper Integrated Pest Management (GHIPM) Project during the 1993 and 1994 field seasons. The two research units agreed to continue research project data collection for the field seasons of 1995 to 1998 as separate but cooperative entities. The grasshopper data collection was continued from the USDA-ARS, Sidney, Montana, laboratory on the initial study sites. The vegetation data collection was continued on similar sites located a short distance east in Dunn County at the NDSU Dickinson Research Extension Center ranch, at 46° 48' N. latitude and 102° 48' W. longitude, near Manning, North Dakota.

Long-Term Regional Weather

The western North Dakota region has cold winters and hot summers typical of continental climates. Mean annual temperature is 40.9º F (4.9º C). January is the coldest month, with a mean temperature of 11.5º F (-11.4º C). July and August are the warmest months, with mean temperatures of 68.7º F (20.4º C) and 67.0º F (19.5º C), respectively. Long-term (1892-2010) mean annual precipitation is 16.03 inches (407.15 mm). The precipitation during the perennial plant growing season (April through October) is 13.54 inches (343.76 mm) and is 84.5% of the annual precipitation. June has the greatest monthly precipitation, at 3.55 inches (90.14 mm). The precipitation received in the three month period of May, June, and July is 8.13 inches (206.50 mm) and is 50.7% of the annual precipitation (Manske 2011f).

Water stress develops in perennial plants during water deficiency periods when the amount of rainfall is less than evapotranspiration demand. Water deficiency months were identified from historical temperature and precipitation data by the ombrothermic diagram technique (Emberger et al. 1963). The long-term (1892-2010) ombrothermic diagram shows near water deficiency conditions during August, September, and October, and favorable water relations during April, May, June, and July. Reoccurrence of water deficiency conditions during April, May, June, and July is 16.9%, 13.6%, 10.2%, and 38.1%, respectively, and during August, September, and October water deficiency reoccurs 52.5%, 50.0%, and 46.6% of the years, respectively. Long-term occurrence of water deficiency conditions is 32.7% of the growing season months, for a mean of 2.0 water deficient months per growing season (Manske et al. 2010).

Growing Season Precipitation

Growing season (April to September) precipitation for the McKenzie County study sites was taken from the Watford City ndawn weather station and reported by Onsager (2000) (table 13). Long-term (31 years) annual precipitation for the area was 14.41 inches (366.01 mm). Growing season precipitation for 1993 and 1995 was above normal. Growing season precipitation for 1994 and 1996 was below normal and for 1997 and 1998 conditions were dry with perennial plants under water stress some of the time. The growing season conditions progressively became warmer and dryer during the six years of data collection at the McKenzie County study sites.

Precipitation for the perennial plant growing season months (April through October) for the Dunn County study sites was taken from the DREC ranch weather station and reported by Manske (2013) (table 14). Long-term (31 years) annual precipitation for the area was 16.91 inches (429.51 mm). Growing season precipitation for 1993 to 1997 was normal each year and was above normal for 1998. Water deficiency conditions occurred during August, September, and October in 1993; July, August, and September in 1994; June and September in 1995; April and October in 1996; August in 1997; and April and September in 1998.

Management Treatments

Three crested wheatgrass management treatments were established at the McKenzie County location and each of the separate defoliation treatment areas were designed with two replicated vegetation sample sites. The crested wheatgrass mowing treatment was established on an existing crested wheatgrass hay field. The large area had been fenced separately and had not been grazed. Prior to 1989, the crested wheatgrass vegetation had been swathed for hay annually during early to mid July. The hay field consisted of large crested wheatgrass wolf plants widely spaced with greater than 50% bareground. After 1989, the cutting time was moved earlier to mid or late June, after the flower stage and before the seeds had matured. The mowing treatment plots were cut for hay during late June in 1993 and 1994. No grasshopper population data was collected on the crested wheatgrass mowing treatment study plots.

The crested wheatgrass seasonlong grazing treatment study plots were located on two large replicated areas that had been seeded with crested wheatgrass shortly after 1936. The crested wheatgrass plots were interspersed among native rangeland that had been managed as one extremely large pasture grazed seasonlong annually from 1 June to 31 October since the McKenzie County Grazing Association had been organized. The pasture was grazed during this same time period in 1993 and 1994, and from 1995 to 1998. One of the seeded crested wheatgrass areas was sampled for grasshopper population data during 1993 to 1998.

The crested wheatgrass spring grazing treatment study plots were in adjacent replicated pastures traditionally grazed during May after the calves had been branded. Prior to 1989, these two crested wheatgrass pastures had also been grazed during the fall after mid October for a month or so. After 1989, the fall grazing period was intended to have been terminated. The crested wheatgrass pastures were spring grazed at relatively high stocking rates during 1 to 31 May 1993 and from 28 April to 1 June 1994, and the pastures were fall grazed for a "short" period in 1993 after mid October. The spring grazing treatment was conducted during the May time period from 1995 to 1998 without any fall grazing periods. The spring grazing crested wheatgrass treatment pastures were sampled for grasshopper population data at two replicated study sites during 1993 to 1998.

Research activity on the grasshopper habitat study continued at two locations during 1995 to 1998. The grasshopper population data was collected at the initial study sites on the seasonlong grazing and spring grazing of crested wheatgrass treatments at the McKenzie County locations. The vegetation data was collected on similar study sites with two spring grazing crested wheatgrass during May management treatments at the Dunn County locations.

The spring grazing crested wheatgrass during May on a one pasture treatment was designed with two replicated pastures each with four vegetation sample sites. Each pasture was grazed for 30 or 31 days from early May stocked at 1.82 acres per cow-calf pair per month.

The spring grazing crested wheatgrass during May on a two pasture treatment was designed with two replicated pastures split in half creating two two pasture switchback systems with two grazing periods of 7 or 8 days each per half pasture. Each half pasture with two vegetation sample sites was grazed for a total of 15 or 16 days during May. The half pasture grazed first one year was grazed second the next year. Each two pasture twice-over switchback system was grazed for 30 or 31 days from early May stocked at 0.75 acres per cow-calf pair per month. After this study, the stocking rate was reduced to 1.0 acre per cow-calf pair per month and the management was simplified by grazing during 28 days in May with each half pasture grazed for two 7 day periods.

Procedures

Changes in residuum vegetation structure during the growing season caused by management practices on crested wheatgrass meadows were evaluated by aboveground herbage biomass, plant species basal cover, and bareground area collected at the McKenzie County sites during the growing seasons of 1993 and 1994 and by aboveground herbage biomass and plant species basal cover collected at the Dunn County sites during the growing seasons of 1995 to 1998.

Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986). All herbage biomass clipping sites were partially defoliated by the selected management treatment. The reported herbage biomass values represent the residuum vegetation and the regrowth vegetation resulting from the treatment. This study did not establish nondefoliated sample sites that show the vegetation response without the treatment. Clipped herbage material was collected monthly (May, June, July, and August) from five 0.25 m^2 quadrats (frames) during 1993 and from four 0.25 m^2 quadrats during 1994 at each replicated vegetation sample site on the mowing treatment, the seasonlong grazing treatment, and the spring grazing treatment at the McKenzie County research study sites. Clipped herbage material was collected monthly (May, June, July, August, and September) from five 0.25 m^2 quadrats (frames) during 1995 to 1998 at each replicated vegetation sample site on the spring grazing during May on the one pasture system and on the two pasture switchback system at the Dunn County research study sites. The herbage material in each frame was hand clipped to ground level and sorted in the field by biotype categories: domesticated grass, native grass, forbs, standing dead, and litter. The herbage of each biotype category from each frame was placed in labeled paper bags of known weight, oven dried at 140° F (60° C), and weighed. Herbage biomass in pounds per acre and relative composition for each biotype category was determined from the clipping data. Mean monthly herbage biomass for each biotype category was determined for each growing season.

Plant species basal cover was determined by the ten-pin point frame method (Cook and Stubbendieck 1986) with 2000 points collected along transect lines at each replicated vegetation sample site during peak growth between mid July and mid August each year. Basal cover plant species data were sorted into biotype categories: domesticated grass, native grass, sedges, forbs, litter, and bare soil. The bare soil category was the percent mineral soil not covered by live plants or litter. Basal cover and relative composition of biotype categories were determined from the ten-pin point frame data collected at the McKenzie County research study sites during 1993 and 1994, and at the Dunn County research study sites during 1995 to 1998.

Bareground area was determined with the line intercept method (Canfield 1941, Cook and Stubbendieck 1986) that was modified to measure linear length of intercepted open areas not covered by vegetation canopy. Ten 2000 cm (787.4 in) transect lines were established at each vegetation sample site at the McKenzie County research study sites. Bareground area percentage and combined bareground length of each transect were means of four readings per growing season conducted between June and August of 1993.

Vegetation structure during the growing season resulting from management treatments were evaluated with herbage biomass and basal cover data. The vegetation structure caused by the spring grazing treatment was compared to the vegetation structure caused by the seasonlong grazing treatment by percent difference data at the McKenzie County research study sites. The vegetation structure caused by the spring grazing during May on the two pasture switchback system was compared to the vegetation structure caused by the one pasture system by percent difference data at the Dunn County research study sites.

Grasshopper population density data was collected during 1993 to 1998 at the initial McKenzie County reseach study sites by a team of entomologists directed by Dr. Onsager using methods described by Onsager and Henry (1977). Each grasshopper study site was provided with a set of 40 aluminum wire rings, each 0.1 m^2, affixed to the ground in a 4 X 10 array with 8 meters between rings. Grasshopper populations were sampled at 7 to 10 day intervals during 1993, 1995, and 1998, and at 2 to 3 day intervals during 1994 and 1997. Sampling began as soon as the grasshopper study sites were accessible in the spring and terminated after killing frost in the fall. Total density was estimated by counting grasshoppers within each ring of the 40 wire ring array that had a total area of 4 m^2. The field data was converted into grasshopper days (GD) per m^2 which is an index of seasonal abundance for 3rd instar and older stages. The concept of grasshopper days (GD) is similar to that of animal unit months (AUM). A sweep net collection was taken along the perimeter of the 40 wire ring array each sampling period to establish composition of the population by species and by stage of development (Onsager 2000).

Results

The growing season residuum vegetation structure expected to negatively affect pestiferous rangeland grasshopper populations was greater plant herbage biomass, greater live plant basal cover, and reduced bareground areas with open vegetation canopy cover.

McKenzie County Study Sites

Effects from mowing treatments on crested wheatgrass meadows were evaluated. The growing season residuum vegetation structure resulting from the June mowing crested wheatgrass treatment at the McKenzie County study sites was described from monthly herbage biomass and mean monthly herbage biomass of the domesticated grass, total live, and standing biomass biotype categories, from basal cover of the domesticated grass and total live biotype categories, and from the bareground area percentage and combined bareground length per 2000 cm transect data.

The June mowing crested wheatgrass treatment was swathed during late June 1993; the hay yield was 414.77 lbs/ac leaving a residual biomass of 595.33 lbs/ac. The crested wheatgrass plants grew slowly during June and July reaching peak monthly biomass in August at 1142.83 lbs/ac (table 15). During the growing season of 1993, the aboveground vegetation biomass on the June mowing treatment consisted of 42.9% standing dead and litter and 57.1% live herbage. The live herbage biomass was 93.7% domesticated grass, 2.8% native grass, and 3.5% forbs including a small amount of alfalfa (table 16).

The 1993 growing season was the fifth year that the crested wheatgrass hay field had been swathed early in mid to late June and the area still consisted of large widely spaced crested wheatgrass wolf plants. The monthly herbage biomass of the domesticated grass, total live, and standing biomass biotype categories was moderate during June and July with peak biomass occurring in August. The mean monthly herbage biomass during the 1993 growing season for the domesticated grass, total live, and standing biomass biotype categories was 889.37 lbs/ac, 948.74 lbs/ac, and 1169.95 lbs/ac, respectively (table 15). The 1993 growing season basal cover of the domesticated grass and total live biotypes were extremely low at 12.3% and 19.6%, respectively, with 80.4% of the area without live plants (table 19).

The June mowing crested wheatgrass treatment was swathed during late June 1994; the hay yield was 618.22 lbs/ac leaving a residual biomass of 525.20 lbs/ac. The crested wheatgrass plants decreased in herbage weight during June, July, and August reaching a low monthly biomass of 427.80 lbs/ac (table 17). During the growing season of 1994, the aboveground vegetation biomass on the June mowing treatment consisted of 48.4% standing dead and litter and 51.6% live herbage. The live herbage biomass was 85.7% domesticated grass, 2.2% native grass, and 12.1% forbs (table 18).

The 1994 growing season was the sixth year that the crested wheatgrass hay field had been swathed early in mid to late June and showed little improvement. The monthly herbage biomass of the domesticated grass, total live, and standing biomass biotypes changed little during June, July, and August. The mean monthly herbage biomass during the 1994 growing season for the domesticated grass, total live, and standing biomass biotypes was 633.26 lbs/ac, 738.78 lbs/ac, and 1054.26 lbs/ac, respectively (table 17). The 1994 growing season basal cover of the domesticated grass and total live biotypes were remarkably low at 9.1% and 13.5%, respectively, with a 25.7% and 31.3% reduction in basal cover from the 1993 growing season, respectively (table 19).

Bare soil, or mineral soil not covered by live plants or litter, percentages measured with the ten-pin point frame method were extremely great at 53.8% and 68.0%, with a mean of 60.9%, on the June mowing treatment during the 1993 and 1994 growing seasons, respectively (table 19).

Bareground, or open canopy, area measured with the line intercept method was 74.5%, 1490 cm/2000 cm transect, on the June mowing treatment. The great reduction in plant cover was caused by a long history of mowing late during July. Six years of mowing earlier in late June had not yet turned the problem around (table 20).

Grasshopper population density data was not collected on the crested wheatgrass June mowing treatment plots. This hay field provided excellent pest grasshopper habitat consisting of widely spaced large bunches of crested wheatgrass having low herbage biomass, remarkably low live plant basal cover, and expansive bareground areas with abundant open vegetation canopy cover.

Effects from grazing treatments on crested wheatgrass meadows were evaluated. The residuum vegetation structure of crested wheatgrass meadows during the growing season on spring grazing treatments were compared with that on seasonlong grazing treatments at the McKenzie County study sites. Comparisons of the growing season residuum vegetation structure was evaluated using percent difference data for monthly herbage biomass and mean herbage biomass of the domesticated grass, total live, and standing biomass biotype categories and percent difference data for basal cover of the domesticated grass and total live biotype categories, and the bareground area percentage and combined bareground length per 2000 cm transects were evaluated from the grazing treatments at the McKenzie County study sites.

The seasonlong grazing crested wheatgrass treatment was lightly grazed during the period of 1 June to 31 October 1993 at moderate stocking rates leaving a mean residual standing biomass of 840.56 lbs/ac (table 21). Crested wheatgrass was at late phenological growth stages and decreasing in crude protein content during June. Cattle consumed little mature crested wheatgrass herbage after early June. During the growing season of 1993, the aboveground vegetation biomass on the seasonlong grazing treatment consisted of 54.0% standing dead and litter and 46.0% live herbage. The live herbage biomass was 98.5% domesticated grass, 1.1% native grass, and 0.4% forbs (table 22).

The spring grazing crested wheatgrass treatment was heavily grazed for 31 days during May 1993 leaving a residual biomass of 331.11 lbs/ac. The crested wheatgrass plants grew slowly during June and July reaching peak monthly herbage biomass in August at 1807.55 lbs/ac (table 23). During the growing season of 1993, the aboveground vegetation biomass on the spring grazing treatment consisted of 35.0% standing dead and litter and 65.0% live herbage. The live herbage biomass was

97.5% domesticated grass, 2.4% native grass, and 0.2% forbs (table 24).

The monthly herbage biomass of the domesticated grass, total live, and standing biomass biotypes were lower on the spring grazing treatment during May, June, and July than those on the seasonlong grazing treatment during the 1993 growing season (tables 21 and 23). The domesticated grass herbage production greatly increased in August on the spring grazing treatment causing the monthly herbage biomass of the domesticated grass, total live, and standing biomass biotypes to increase with monthly biomass at 189.0%, 192.5%, and 128.5% greater than those on the seasonlong grazing treatment, respectively. As a result, the mean monthly herbage biomass for the domesticated grass, total live, and standing biomass biotypes were 28.0%, 29.5%, and 10.6% greater on the spring grazing treatment than those on the seasonlong grazing treatment, respectively (table 25). The 1993 growing season basal cover on the seasonlong grazing and spring grazing treatments of the domesticated grass biotype was 29.0% and 36.0% and of the total live biotype was 37.9% and 39.4%, respectively (tables 31 and 32). The basal cover of the domesticated grass biotype was 24.0% greater and of the total live biotype was 3.9% greater on the spring grazing treatment than those on the seasonlong grazing treatment, respectively (table 33).

The seasonlong grazing crested wheatgrass treatment areas were lightly grazed during the period of 1 June to 31 October 1994 at moderate stocking rates leaving a mean residual standing biomass of 968.94 lbs/ac (table 26). During the growing season of 1994, the aboveground vegetation biomass on the seasonlong grazing treatment consisted of 36.4% standing dead and litter and 63.6% live herbage. The live herbage biomass was 95.9% domesticated grass, 1.8% native grass, and 2.3% forbs (table 27). The light grazing during two growing seasons caused changes in herbage biomass production during the 1994 growing season compared to the 1993 growing season with a 27.2% increase in live herbage biomass and a 37.9% decrease in dead herbage (tables 21 and 26).

The spring grazing crested wheatgrass pastures were grazed for a month or so during the fall of 1993 after mid October and were heavily grazed for 35 days during late April to early June 1994 leaving a residual biomass of only 253.51 lbs/ac (table 28). The crested wheatgrass plants grew slowly during the growing season and never produced greater than 200 lbs/ac of new growth. During the growing season of 1994, the aboveground vegetation biomass on the spring grazing treatment consisted of 37.2% standing dead and litter and 62.8% live herbage. The live herbage biomass was 93.0% domesticated grass, 1.0% native grass, and 6.0% forbs (table 29). The late season fall grazing, heavy spring grazing, and less than normal growing season precipitation caused reductions in herbage biomass during the 1994 growing season compared to the 1993 growing season with a 49.5% decrease in live herbage biomass and a 44.5% decrease in dead herbage (tables 23 and 28).

The double use of fall grazing and heavy spring grazing on the spring grazing treatment was detrimental to the crested wheatgrass plants resulting in little herbage biomass production occurring during the 1994 growing season. The domesticated grass, total live, and standing biomass biotypes monthly herbage biomass were much lower on the spring grazing treatment during the 1994 growing season than those on the seasonlong grazing treatment. The mean monthly herbage biomass for the domesticated grass, total live, and standing biomass biotypes were 50.2%, 48.6%, and 48.1% lower on the spring grazing treatment than those on the seasonlong grazing treatment, respectively (table 30). The 1994 growing season basal cover of the domesticated grass biotype was 17.9% and 23.6% and of the total live biotype was 26.4% and 25.1% on the seasonlong grazing and spring grazing treatments, respectively (table 31 and 32). The basal cover of the domesticated grass biotype was 32.2% greater and the total live biotype was 4.7% lower on the spring grazing treatment than those on the seasonlong grazing treatment, respectively (table 33). The native grass decreased 42.8% and the total forbs decreased 62.8% during 1994 on the spring grazing treatment causing the decrease in total live basal cover (table 32).

Bare soil, or mineral soil not covered by live plants or litter, percentages measured with the ten-pin point point frame method was 6.6% and 7.3%, with a mean of 7.0%, on the seasonlong grazing treatment during the 1993 and 1994 growing seasons, respectively (table 31) and were 7.8% and 6.8%, with a mean of 7.3%, on the spring grazing treatment during the 1993 and 1994 growing seasons, respectively (table 32). Little difference in bare soil percentages were measured with the ten-pin point frame method on the seasonlong grazing and spring grazing treatments.

Bareground, or open canopy, area measured with the line intercept method was 30.9%, 618 cm/2000 cm transect, on the seasonlong grazing treatment (table 34) and was 19.3%, 386 cm/2000 cm transect, on the spring grazing treatment (table 35). The line intercept method measured 60.1% greater bareground area on the seasonlong grazing treatment than on the spring grazing treatment.

The lightly grazed seasonlong grazing crested wheatgrass treatment had greater dead herbage biomass during the 1993 and the 1994 growing seasons, had greater live herbage biomass in May, June, and July during the 1993 growing season, had greater live herbage biomass during the 1994 growing season, and had greater bareground area than that on the heavily grazed spring grazing treatment.

The heavily grazed spring grazing crested wheatgrass treatment had greater domesticated grass basal cover during the 1993 and 1994 growing seasons, had greater total live basal cover during the 1993 growing season, and had greater live herbage biomass in August and September during the 1993 growing season than that on the seasonlong grazing treatment.

In summary, the residuum vegetation structure resulting from the seasonlong grazing treatment and from the spring grazing treatment after two growing seasons was different.

The seasonlong grazing treatment had 71.8% greater standing dead biomass and 78.3% greater dead litter biomass than that on the spring grazing treatment. The seasonlong grazing treatment was lightly grazed with little herbage removal by cattle because the crested wheatgrass plants were at mature phenological growth stages and contained low nutrient quality during the summer grazing period causing most of the herbage that grew on the plots to die and remain on the plots.

The seasonlong grazing treatment had lower vegetation canopy cover with 21.3% lower domesticated grass basal cover and 60.1% greater bareground area than that on the spring grazing treatment. The seasonlong grazing treatment lacked grazing in May for stimulation of vegetative secondary tiller development between the 3.5 new leaf stage and the flower stage resulting in fewer new tillers produced each year.

The spring grazing treatment had 27.1% greater domesticated grass basal cover than that on the seasonlong grazing treatment. The increased tiller basal cover resulted from the grazing in May that stimulated vegetative secondary tiller development. Because of the greater domesticated grass basal cover on the spring grazing treatment, the domesticated grass herbage biomass should have also been greater. The herbage biomass of the domesticated grass biotype was not greater as a result of the heavy spring grazing that removed great quantities of plant biomass leaving insufficient leaf area to supply the needed photosynthetic products used for growth of additional leaf and stem biomass. The fall grazing removed great quantities of plant biomass from fall tillers and carryover tillers that later caused further reductions in the quantities of herbage biomass produced during the following growing season.

The plants on the seasonlong grazing treatment produced less herbage biomass than the plants on the spring grazing treatment, however, because of the heavy herbage biomass removal during the fall grazing and the spring grazing on the spring grazing treatment, the seasonlong grazing treatment had 18.0% greater domesticated grass herbage biomass, 16.6% greater total live herbage biomass, and 26.3% greater standing biomass than that on the spring grazing treatment.

The growing season vegetation structure on both the seasonlong grazing treatment and spring grazing treatment of crested wheatgrass meadows was highly desirable for grasshoppers. Mean annual grasshopper days (GD) per m^2 were great on both the seasonlong grazing treatment and the spring grazing treatment during each year of the study (Onsager 2000). The seasonlong grazing treatment had an annual mean of 1011 GD for the 9 pestiferous rangeland grasshoppers and had an annual mean of 1569 GD for the total of all grasshopper species. The spring grazing treatment had an annual mean of 978 GD for the 9 pestiferous rangeland grasshoppers and had an annual mean of 1645 GD for the total of all grasshopper species (table 36).

The same three grasshopper species, Mel sanguinipes, Mel infantilis, and Mel gladstoni, had great annual mean grasshopper days per m^2 on both grazing treatments with a combined total of 852 GD on the seasonlong grazing treatment and 706 GD on the spring grazing treatment (table 36). These three grasshopper species preferred crested wheatgrass meadows (Onsager 2000).

Population abundance of Pho nebrascensis increased to an annual mean of 126 GD on the seasonlong grazing treatment but remained at a low mean abundance of 16 GD on the spring grazing treatment (table 36). On the other hand, population abundance of three grasshopper species, Tra kiowa, Age deorum, and Mel femurrubrum, increased to annual means of 98 GD, 88 GD, and 35 GD, respectively, on the spring grazing treatment while remaining at low annual means of 14 GD, 4 GD, and 2 GD, respectively, on the seasonlong grazing treatment (table 36). One grasshopper species, Mel gladstoni, had similar mean annual grasshopper days per m^2 on both the seasonlong grazing treatment (52 GD) and the spring grazing treatment (53 GD) (table 36), however, the main increases in population abundance occurred during different years. The major increase in Mel gladstoni population abundance occurred in 1994 on the spring grazing treatment and occurred in 1995 on the seasonlong grazing treatment (Onsager 2000).

One of the abundant grasshopper species, Ope obscura, was considered to be primarily a pest on short grass prairie areas and preferred blue grama as its food plant (Pfadt 1994) was identified as a major pest on native rangeland managed with seasonlong grazing during this study (Onsager 2000), however, it was not abundant in the grasshopper populations on the two crested wheatgrass management treatments (table 36).

Grasshopper population infestations on both the seasonlong grazing treatment and spring grazing treatment had remarkable single season outbreak spikes during 1994 (figure 2). The same two grasshopper species, Mel sanguinipes and Mel infantilis, were the most prevalent grasshoppers involved in the 1994 outbreaks on both grazing treatments (Onsager 2000), however, the primary changes in vegetation structure on the two grazing treatments in 1994 compared to that in 1993 were different. In 1994, the basal cover of the domesticated grass biotype decreased 38.5% and the bareground area was 60.1% greater at 30.9% on the seasonlong grazing treatment, and, in 1994, the herbage biomass of the standing biomass biotype decreased 45.9% on the spring grazing treatment.

Grasshopper population assemblages again increased to outbreak levels in 1997 and 1998 on both the seasonlong grazing treatment and the spring grazing treatment (figure 2) (Onsager 2000), however, the main grasshopper species with the greatest increases in grasshopper days per m^2 were different on the two grazing treatments. Two grasshopper species, Mel sanguinipes and Age deorum, accounted for most of the outbreak increase in 1997 and 1998 on the spring grazing treatment with increases in abundance by Mel gladstoni contributing to the large outbreak population (Onsager 2000). One grasshopper species, Pho nebrascensis, accounted for most of the outbreak increase on the seasonlong grazing treatment with dramatic increases in abundance by Mel gladstoni and Enc costalis contributing to the large outbreak population (Onsager 2000).

Generally, the growing season residuum vegetation structure, thus the grasshopper habitat, on crested wheatgrass meadows resulting from the seasonlong grazing treatment and the spring grazing treatment were quite different. The standing herbage biomass was greater, except during August and September 1993; the basal cover was less; and the bareground area was much larger on the seasonlong grazing treatment than those on the spring grazing treatment. The standing herbage biomass was less, except during August and September 1993; the basal cover was greater; and the bareground area was much smaller on the spring grazing treatment than those on the seasonlong grazing treatment. It can reasonably be assumed that as long as the management of the grazing treatments continue without change, the differences in residuum vegetation structure resulting from the grazing treatments will also continue without change.

The primary changes in vegetation structure resulting from the seasonlong grazing treatment were reduced basal cover and larger bareground area; the grasshopper species that increased in abundance as a result of these habitat changes were: Mel sanguinipes with an annual mean of 547 GD increased during 1994; Mel infantilis with an annual mean of 253 GD increased during 1994; Pho nebrascensis with an annual mean of 126 GD increased during 1997 and 1998; Mel gladstoni with an annual mean of 52 GD increased during 1995 and 1998; and Enc costalis with an annual mean of 11 GD increased during 1997 and 1998 (table 36) (Onsager 2000).

The primary change in vegetation structure resulting from the spring grazing treatment was reduced standing herbage biomass; the grasshopper species that increased in abundance as a result of this habitat change were: Mel sanguinipes with an annual mean of 415 GD increased during 1994, 1997, and 1998; Mel infantilis with an annual mean of 238 GD increased during 1994; Tra kiowa with an annual mean of 98 GD increased during the study; Age deorum with an annual mean of 88 GD increased during 1997 and 1998; Mel gladstoni with an annual mean of 53 GD increased during 1994, 1997, and 1998; and Mel femurrubrum with an annual mean of 35 GD increased during the study (table 36) (Onsager 2000). Pestiferous rangeland grasshopper species increase in abundance when the vegetation structure of the habitat decreases in basal cover, increases in bareground area, and/or decreases in standing herbage biomass.

Dunn County Study Sites

Effects from grazing treatments on crested wheatgrass meadows were evaluated. The residuum vegetation structure during the growing season on spring grazing crested wheatgrass during May on a two pasture switchback system were compared with that on a one pasture system at the Dunn County study sites. Comparisons of the growing season residuum vegetation structure was evaluated using percent difference data for monthly herbage biomass and mean herbage biomass of the domesticated grass, total live, and standing biomass biotype categories and percent difference data for basal cover of the domesticated grass and total live biotype categories from the grazing treatments at the Dunn County study sites.

Spring grazing of crested wheatgrass during May is an ideal match between grass phenological growth stages and partial defoliation by large grazing graminivores to activate beneficial plant mechanisms and ecological processes. The majority of the crested wheatgrass lead tillers produce three and a half new leaves prior to 1 May and at that stage the tillers are physiologically ready for partial defoliation of less than 50% of the leaf biomass. A healthy dense stand of crested wheatgrass is capable of producing rapid rates of growth of herbage biomass during May. Some of the advanced lead tillers reach the flower stage by 28 May slowing the growth rate of those tillers. The remaining lead tillers would reach the flower stage before the second or third week in June if they were ungrazed. Partial defoliation after the 3.5 new leaf stage and before the flower stage activates mechanisms for vegetative production of secondary tillers. The secondary tillers grow rapidly reaching peak growth in early to mid July. After mid August the grass plants start the 2.5 month process to prepare for the winter low activity period. During that preparation period, cool season grasses, including crested wheatgrass, produce fall tillers that become next growing seasons vegetative tillers. The current seasons vegetative tillers that did not produce a seed head become carryover tillers; they will be able to survive the winter and grow during the following growing season as lead tillers that are destined to produce flowering seed heads.

The spring grazing crested wheatgrass during May on a one pasture system was grazed 30 or 31 days at a stocking rate of 1.82 ac per AUM during the 1995 to 1998 growing seasons leaving a mean domesticated grass lead tiller residual of 751.61 lbs/ac after the May grazing period, the mean secondary tiller regrowth in July was 337.52 lbs/ac (44.9% of the June residual lead tiller biomass), and the mean fall tiller growth in September was 144.58 lbs/ac (14.8% of the fully developed secondary tiller biomass in August) producing a mean monthly domesticated grass biomass of 912.09 lbs/ac (14.5% less than that on the two pasture system) (table 37). During the growing seasons of 1995 to 1998, the aboveground vegetation biomass of the spring grazing on a one pasture system consisted of 38.4% standing dead and litter and 61.6% live herbage. The live herbage biomass was 86.4% domesticated grass, 7.4% native grass, and 5.9% forbs (table 38).

The spring grazing crested wheatgrass during May on a two pasture switchback system was grazed 30 or 31 days at a stocking rate of 0.75 ac per AUM during the 1995 to 1998 growing seasons leaving a mean domesticated grass lead tiller residual of 721.04 lbs/ac after the May grazing period, the mean secondary tiller regrowth in July was 544.82 lbs/ac (75.6% of the June residual lead tiller biomass), and the mean fall tiller growth in September was 159.33 lbs/ac (14.5% of the fully developed secondary tiller biomass in August) producing a mean monthly domesticated grass biomass of 1066.16 lbs/ac (16.9% greater than that on the one pasture system) (table 39). During the growing seasons of 1995 to 1998, the aboveground vegetation biomass of the spring grazing on a two pasture switchback system consisted of 32.0% standing dead and litter and 68.0% live herbage. The live herbage biomass was 91.1% domesticated grass, 6.5% native grass, and 2.5% forbs (table 40).

The spring grazing on a two pasture twice-over switchback system activated greater vegetative tiller growth than the spring grazing on a one pasture system. The two pasture system produced 61.4% greater secondary tiller biomass and 10.2% greater fall tiller biomass than that produced on the one pasture system.

The mean monthly herbage biomass of the domesticated grass, total live, standing dead, and standing biomass biotypes on the spring grazing on a one pasture system was 912.09 lbs/ac, 1055.50 lbs/ac, 235.55 lbs/ac, and 1291.05 lbs/ac, respectively (table 37), and on the spring grazing on a two pasture system, the mean monthly herbage biomass of these biotypes was 1066.16 lbs/ac, 1170.75 lbs/ac, 106.73 lbs/ac, and 1277.48 lbs/ac, respectively (table 39). The two pasture system produced greater live residual herbage biomass than the one pasture system. The two pasture system produced 16.9% greater domesticated grass biomass and 10.9% greater total live biomass than that produced on the one pasture system (table 41). The one pasture system retained 120.7% greater standing dead biomass than that on the two pasture system as a result of the lighter stocking rate. The herbage biomass of the standing biomass biotype was nearly the same on both the one pasture system and the two pasture system (table 41). The standing biomass biotype on the one pasture system consisted of 70.7% domesticated grass, 10.9% native grass and forbs, and 18.2% standing dead herbage. On the two pasture system, the standing biomass biotype consisted of 83.5% domesticated grass, 8.2% native grass and forbs, and 8.4% standing dead herbage.

Basal cover during the 1995 to 1998 growing seasons of the domesticated grass biotype was 18.2% and 21.7% and of the total live biotype was 20.7% and 26.2% on the one pasture system and on the two pasture system, respectively (table 42). The basal cover of the domesticated grass biotype was 19.6% greater and of the total live biotype was 26.5% greater on the two pasture system than those on the one pasture system (table 43). The greater basal cover on the two pasture system indicated greater activation of the vegetative tiller producing mechanisms.

Bare soil, or mineral soil not covered by live plants or litter, percentages measured with the ten-pin point frame method was small at 3.0% and 2.4% on the one pasture system and on the two pasture system, respectively (table 42). The bare soil area on the one pasture system was 24.7% greater than that on the two pasture system.

The residuum vegetation structure resulting from spring grazing crested wheatgrass during May on a one pasture system and on a two pasture system were not desirable as habitat for pestiferous rangeland grasshoppers. Except during May and early June, the crested wheatgrass tillers were tall and dense through the entire growing season. The long shoot tillers had numerous senescent and live stem leaves that formed a dense canopy nearly covering the entire ground surface.

Grasshopper population density data were not collected on these Dunn County research study sites. However, during vegetation data collection, very few grasshoppers were observed. The small quantity of grasshoppers present were not a problem. The growing season residuum vegetation structure on the crested wheatgrass two pasture switchback spring grazing system had 16.9% greater domesticated grass biomass, 10.9% greater total live plant biomass, 19.6% greater domesticated grass basal cover, 26.5% greater total live plant basal cover, 61.4% greater secondary tiller biomass, and 10.2% greater fall tiller biomass than the residuum vegetation structure on the crested wheatgrass one pasture spring grazing system.

Greater activation of the plant defoliation resistance mechanisms and the ecosystem biogeochemical processes on the two pasture system resulted in greater livestock weight gain than on the one pasture system. During May, cows and calves gained 111 lbs/ac and 90 lbs/ac, respectively, on the two pasture system, and cows and calves gained 32 lbs/ac and 31 lbs/ac, respectively, on the one pasture system. Cow gains were 244.5% greater and calf gains were 186.2% greater per acre on the two pasture system than on the one pasture system. The great cow and calf weight performance on spring grazing of crested wheatgrass during May occurs only when the calves are one month old or older on 1 May.

Discussion

Crested wheatgrass starts early leaf greenup in mid April. The crested wheatgrass tillers have three and a half new leaves around 22 April that are highly nutritious forage for the very early and early hatching grasshoppers, which is four to five weeks earlier than native cool season grasses. Early boot stage occurs in mid May and the first stalks with flowers occurs around 28 May. Most of the lead tillers reach the flower stage during the following 10 to 14 days. The late flowering lead tillers should flower by 10 June. Seed development occurs after the flower stage and seeds reach maturity during the following 5 to 8 weeks (table 44) (Whitman et al. 1951, Manske 1999b).

The nutritional quality of ungrazed lead tillers of crested wheatgrass changes with the tillers' phenological development. Early season growth stages are high in crude protein and water. The early vegetative leaf stages contain levels of crude protein above 15% during early to mid May. As seed stalks begin to develop in mid May, crude protein levels begin to decrease. At the flower stage, lead tillers contain 13.5% crude protein. After the flower stage and during the seed development stage, crude protein levels remain above 9.6% until late June. As the ungrazed lead tillers mature, the fiber content increases and percent crude protein, water, and digestability decrease. By early July, crude protein levels drop below 7.8% and below 6.2% in early

August (figure 3, table 44). Phosphorous levels drop below 0.18% in late July. The patterns of change in nutritional quality are similar from year to year because tiller phenological development is regulated primarily by photoperiod. Slight variations in nutritional quality result from annual variations in temperature, evaporation, and water stress. Nutritional quality can also be slightly altered by changes in rates of tiller growth and plant senescence. Growth rates are affected by the level of photosynthetic activity, which is affected by air and soil temperature, cloud cover, and availability of hydrogen for carbohydrate synthesis. Senescence rates increase with high temperatures, precipitaiton deficiency, and water stress (Whitman et al. 1951, Manske 1999b).

Crested wheatgrass meadows can be used one time per year without detrimental effects as hay fields, spring pastures, or summer pastures. Double heavy use of crested wheatgrass causes biological degradation. Even though this is a fact long-known, many crested wheatgrass pastures have two heavy uses per growing season with intense grazing occurring during the spring and fall. Some crested wheatgrass meadows are grazed in the spring and hayed during the summer, and others are hayed during the summer and grazed in the fall. Crested wheatgrass plants are hardy but they do not fully recover from two heavy uses during one growing season. Numerous biological problems develop in crested wheatgrass plants that are used heavy two times each year. Double heavy use decreases plant health with accompanying decreases in herbage production and plant density. Repeated double heavy use results in a depauperated stand that can have greater than 50% bare ground, while a properly managed stand with one use per year would be healthy and productive and would have no more than about 6% or 12% bare ground.

Double use of crested wheatgrass meadows that removes most of the standing dead vegetation has the potential to cause serious mineral deficiencies in the grazing cows blood. Mature lactating cows can develop milk fever or grass tetany while grazing lush spring crested wheatgrass vegetation. Milk fever is caused by a blood deficiency of calcium (Ca) and grass tetany is caused by a blood deficiency of magnesium (Mg). Crested wheatgrass herbage, however, is rarely deficient in calcium or magnesium during the growing season. Absorption of most minerals is by passive diffusion across the intestinal wall; some calcium is transported with a protein carrier. Only about half of the ingested minerals are absorbed through the intestinal wall into the cows blood system under normal conditions. During the early spring, the rate of forage passage through the cows digestive tract is accelerated when lush vegetation high in water and crude protein is consumed; greatly reducing the quantity of dietary minerals absorbed through the intestinal wall and potentially resulting in deficiencies of calcium or magnesium in the cows blood. Cattle grazing crested wheatgrass pastures containing sufficient amounts of dry carryover residual vegetation can maintain normal slow rates of forage passage through the digestive tract and normal rates of mineral absorption; which in effect, prevents the occurrence of mineral deficiencies in the blood and thus preventing the development of milk fever or grass tetany.

Hay Field

Cutting crested wheatgrass hay during mid to late July to maximize the dry matter yield also causes problems that decrease herbage production and plant density. Cutting the lead tillers after they have flowered and started to develop seeds prevents activation of the compensatory physiological processes and the vegetative reproduction by tillering processes. Removal of greater than 50% of the leaf material from mature lead tillers results in insufficient leaf area retained on the tiller for even partial foliage recovery using current photosynthetic assimilates. Tillers with 50% or more of the aboveground leaf material removed reduce root growth, root respiration, and root nutrient absorption (Crider 1955). Root mortality and decomposition begin within 2 days of haying mature tillers (Oswalt et al. 1959). Mature tillers must depend upon stored carbohydrates for replacement leaf growth (Briske and Richards 1995). There is a high biological cost to the tiller when the photosynthetic system needs to be replaced from stored carbohydrates. This implied reduction in efficiency results in reduced root growth, decreased tiller development, and low growth rates causing decreased tiller numbers, reduced total basal cover, and reduced quantities of herbage biomass produced (Coyne et al. 1995) and promotes the development of widely spaced wolf plants. Repeated late season haying of crested wheatgrass progressively reduces the quantities of stored carbohydrates.

Late cut mature crested wheatgrass hay has low crude protein content of around 6.4%. The nutrient content of late cut mature hay meets the dietary requirements of range cows only during the dry gestation prodution period. This is the only range cow production period that late cut mature hay has lower cost, by a few cents, than crested wheatgrass cut at the boot stage during mid May to early June (16 May to 10 June). Cutting crested wheatgrass hay at the boot stage reduces the dry matter yield by 300 lbs/ac (19%) and increases the crude protein yield by 87 lbs/ac (85%) (table 45). The forage feed costs per day from feeding late cut mature crested wheatgrass to range cows during the third trimester and early lactation production periods was 16% greater and 50% greater, respectively, compared the feed costs per day from feeding early cut at the boot stage hay. Feeding early cut boot stage hay has lower forage feed costs because the greater crude protein yield per acre reduces the crude protein cost per pound and thus reducing the feed cost per day (table 45) (Manske 2002).

Cutting crested wheatgrass hay during mid to late June did not improve herbage biomass production or tiller density after six years of treatment. Cutting crested wheatgrass hay early between the boot stage and the flower stage captures greater weight of crude protein per acre and activates the vegetative reproduction by tillering processes that increases tiller density and promotes development of rhizome tillers that fill in the space between bunches.

Spring Pasture

Crested wheatgrass meadows are excellent spring pastures during May. Crested wheatgrass is physiologically ready for grazing in early May. The three and a half new leaves are produced around 22 April, however, the leaf weight is not great enough to start grazing during late April. It is important to wait until 1 May when the herbage biomass quantity is sufficient for grazing. The ability to start grazing a month ahead of the proper grazing start date on native rangeland is the primary biological advantage of crested wheatgrass pastures and their priority use should be grazing during May as spring complementary pastures in conjunction with summer grazing native rangeland rotation systems.

The stocking rate for grazing crested wheatgrass during May can be relatively heavy because of the similar lead tiller rapid growth during the early portion of the growing season. Average stocking rates of crested wheatgrass May pastures in good to fair condition range from 0.60 to 1.00 acres/AUM in the drift prairie, from 1.00 to 1.50 acres/AUM in the Missouri coteau, and from 1.50 to 2.00 acres/AUM in the west river regions of the mixed grass prairie. The one spring pasture treatment in very good condition was stocked at 1.82 acres/AUM. The two spring pasture switchback system in excellent condition was stocked at 0.75 acres/AUM for four years then reduced to 1.00 acres/AUM during the following years. A high stocking rate can be repeated annually on spring complementary crested wheatgrass pastures when the grazing occurs during the period that the quantity of herbage biomass is increasing towards the peak level during late May. Vegetative tillers on a healthy dense stand of crested wheatgrass can produce 300 pounds of herbage biomass per acre per day until the lead tillers reach the flower stage starting around 28 May and lasting to about 10 June. This level of production can be maintained year after year if the stubble left after grazing at the end of May is three inches or taller and the pasture is not used again until next spring. Heavy use of crested wheatgrass plants one time during May require the remainder of the growing season to recover biologically.

The two pasture switchback spring grazing system activated greater compensatory physiological processes and greater vegetative tiller growth than the one pasture spring grazing system yielding greater domesticated grass and total live plant biomass production, greater domesticated grass and total live plant basal cover, and greater development of secondary tillers and fall tillers resulting in a residuum vegetation structure unfavorable for pestiferous rangeland grasshoppers.

Summer Pasture

Many beef production operations have greater land area planted with crested wheatgrass than can be used during May as spring complementary pastures for the main range cow herd. These beef operations are in need of additional summer grazingland for heifer development or for stocker steers. The crested wheatgrass acreage in excess of May complementary pastures can be used in a summer grazing system by implementation of twice-over grazing technology (Manske 1999a, 2011b).

There are two biological problems that need resolution in order for summer grazing of crested wheatgrass pastures to work and to be sustainable as a long-term practice. First, the high stocking rate used on the spring grazing treatment during May cannot be the stocking rate used during summer grazing of crested wheatgrass, and second, crested wheatgrass lead tiller forage drops below 9.6% crude protein during the third week in June and livestock lose weight shortly after.

The proper stocking rate used during summer grazing of crested wheatgrass should be the same stocking rate used to graze native rangeland on identical soil types. The total net primary production of crested wheatgrass herbage biomass during an entire growing season is about the same as that produced on native rangeland. Crested wheatgrass monocultures appear to produce greater herbage than native rangeland because ungrazed crested wheatgrass has one major growth period with most of the lead tillers growing together at a similar time and at a similar rate resulting in a high peak herbage biomass early in the growing season with little new growth occurring after mid to late June. Native rangeland, on the other hand, is a mixture of numerous cool season and warm season species with several growth periods not occurring together but spread throughout the early portion of the growing season resulting in a lower peak herbage biomass extended over a longer period of time, and producing about the same quantity of total new growth material as crested wheatgrass per acre in a year. Crested wheatgrass grazed only during May can support the higher spring stocking rate. The spring stocking rate used to graze summer crested wheatgrass pastures would be expected to produce negative effects on plant health similar to that of double heavy use. Stocking summer grazed crested wheatgrass pastures at the same rate used to graze native rangeland should be perpetually sustainable.

Maintaining nutritional quality of crested wheatgrass forage at or above livestock nutritional requirements for 120 days from early May to late August requires activation of the vegetative reproduction by tillering processes. Seasonlong grazing management of crested wheatgrass meadows provided adequate crude protein for lactating cows until the third week in June. At that time, cattle stop utilizing crested wheatgrass. The nutritional quality of crested wheatgrass lead tiller forage drops below 9.6% crude protein soon after the flower stage when the seeds are being filled (table 44, figure 3) (Whitman et al. 1951, Manske 1999b). Stimulation of vegetative secondary tillers, that have a crude protein content greater than 9.6%, would be able to extend the length of time for an additional two to two and a half months that the forage quality on crested wheatgrass summer pastures would meet the dietary requirements of lactating cows until late August.

The physiological processes for activation of vegetative reproduction of secondary tillers from axillary buds in crested wheatgrass is the same as in native range grasses. Secondary tiller development from axillary buds is regulated by lead tillers, through a process of lead tiller dominance. The lead tillers produce an inhibitory hormone that prevents the growth hormone from activating growth within axillary buds. Grazing that removes a small amount (25% to 33%) of leaf tissue from the aboveground portion of lead tillers after the three and a half new leaf stage and before the flower stage rapidly reduces the amount of inhibitory hormone in the tiller. With the inhibitory hormone reduced, the growth hormone stimulates vegetative reproduction and several secondary tillers develop from the axillary buds (Manske 2011b).

If no defoliation occurs before the flower stage, the lead tiller inhibits vegetative tiller development until the inhibitory hormone production naturally declines during the flower stage. This gradual hormone reduction permits one axillary bud to grow and develop into a secondary tiller, which in turn produces inhibitory hormones that prevent growth of the other axillary buds. Single tiller development after the flower stage on crested wheatgrass plants is, by default, primarily as crown tillers producing bunches, while multiple tiller development following biologically effective stimulation by grazing is mainly as rhizome tillers producing dense sod.

The period of activation of vegetative development of multiple secondary tillers in crested wheatgrass is between the three and a half new leaf stage and the flower stage. These phenological growth stages are the same in all grass species. However, the seasonal period when these phenological growth stages occur are different for the various grass species. For crested wheatgrass, these growth stages when activation of vegetative reproduction can occur develop between 1 May and 10 June each year. This 40 day stimulation period is then the duration of the first grazing period. The second grazing period is double the number of days of the first period and would be 80 days in duration. A summer twice-over rotation grazing system on crested wheatgrass pastures would be from 1 May until 29 August, with a duration of 120 days.

The most successful strategy for grazing crested wheatgrass during the summer has been with four equal sized pastures. Each pasture would be grazed for 10 days in succession during the first grazing period between 1 May and 10 June. Then during the second grazing period, each pasture would be grazed again for double the number of days it was grazed during the first grazing period. The second period would occur between 10 June and 29 August and each of the four equal sized pastures would be grazed for 20 days in the same sequence. The first pasture grazed in the sequence during one year was the last pasture grazed the previous year.

The number of days grazed are not counted by calendar dates; days grazed are counted by the number of 24 hour periods grazed from the date and time the cattle are turned into a pasture. If cattle are turned into pasture A at 9:00 am on 1 May, 10 days of grazing occurs at 9:00 am on 11 May, not on 10 May.

The summer grazed crested wheatgrass pastures must leave 50% of the leaf biomass at the end of the grazing season in order for biological recovery of the plants. That amount of leaf area is required to store enough carbohydrates for respiration during the winter dormancy and for healthy productive leaf growth the following growing season.

Management of Crested Wheatgrass Meadows

Crested wheatgrass plants are extremely hardy and persistent. However, crested wheatgrass plants can be degraded and productivity and plant density can be diminished in only a few years of unsuitable management.

Some of the management treatments evaluated in this study resulted in degradation of the crested wheatgrass plants. Crested wheatgrass cut annually for hay at the mature stage during early to mid July yielded a reduced quantity of dry matter with very low nutrient quality. This late cut treatment caused reductions in plant density and herbage biomass production. The resulting residuum habitat had widely spaced wolf plants with greater than 50% bareground and was highly desirable for pest grasshopper population increase. Crested wheatgrass cut annually for hay at the seed development stage during mid to late June yielded low quantities of dry matter weight and low to moderate nutrient quality. This haying treatment did not improve the thin plant density of medium sized bunches. The resulting residuum habitat consisted of 656.12 lbs/ac of crested wheatgrass at 10.7% basal cover with 74.5% bareground and was favorable for pest grasshopper population increase. Crested wheatgrass pastures grazed seasonlong at moderate stocking rates from early June to late October was at late phenological growth stages with low nutritional quality and had extremely low livestock utilization. The resulting residuum habitat consisted of 667.99 lbs/ac of crested wheatgrass at 23.4% basal cover with 30.9% bareground and was favorable for pest grasshopper population increase. Crested wheatgrass spring pastures grazed at excessively heavy stocking rates during May and frequently grazed a second time after mid October for a month or so had too much leaf area removed and replaced only a small portion of the leaf material grazed. The resulting residuum habitat consisted of 566.10 lbs/ac of crested wheatgrass at 29.8% basal cover with 19.3% bareground and was favorable for pest grasshopper population increase.

These four examples of crested wheatgrass meadows poorly managed with traditional concepts all developed the typical characteristics of open canopies with low herbage biomass, low plant basal cover, and large bare areas that are ideal habitats favorable for pestiferous rangeland grasshopper population development. Large quantities of pest grasshoppers are produced in the Northern Plains on similarly managed degraded crested wheatgrass meadows with characteristic open canopy and bare areas. Management of these degraded crested wheatgrass meadows should be changed.

Crested wheatgrass meadows can be managed to be favorable for livestock production and unfavorable for pest grasshopper production as early cut hay fields, as spring pastures grazed during May, and as summer pastures grazed from early May to late August.

Crested wheatgrass meadows in the Northern Plains can produce sufficient herbage biomass and nutritional quality to be used as hay fields. The timing of cutting is critical to activate the beneficial plant mechanisms, to capture the greatest quantity of nutrients per acre, and to develop the residuum vegetation structure to be unfavorable for pestiferous rangeland grasshoppers. Crested wheatgrass cut early between the boot stage and the flower stage during mid May to early June yielded 19% less dry matter and 85% greater nutrient quality than hay cut late at the mature stage. This early cut treatment caused increased plant density from rhizome tillers and increased herbage biomass production. The resulting residuum habitat was unfavorable for pest grasshopper population increase.

The priority use of crested wheatgrass meadows should be as spring complementary pastures grazed during May. Crested wheatgrass grazed in the spring between the three and a half new leaf stage and the peak flower stage during May increased plant density from rhizome tillers and increased herbage biomass production on a one pasture treatment or on the improved two pasture twice-over switchback system. Crested wheatgrass tillers develop through vegetative phenological growth stages from the three and a half new leaf stage to the flower stage during early to late May. The compensatory physiological processes and the vegetative reproduction by tillering processes can be activated during these phenological growth stages. Activation of the compensatory physiological processes within grass plants accelerate growth rates of replacement roots, leaves, and shoots, increases photosynthetic capacity of remaining mature leaves, increases allocation of carbon and nitrogen, improves water (precipitation) use effciency, and increases restoration of biological processes enabling rapid and complete recovery of partially defoliated grass tillers. Activation of the asexual processes of vegetative reproduction increases secondary tiller development from axillary buds and increases tiller density during the growing season. The spring grazing crested wheatgrass during May on the two pasture twice-over switchback system activates the compensatory physiological processes and the vegetative reproduction processes at greater levels than the activation of these processes by the one pasture treatment. As a result, the two pasture system produces greater domesticated grass biomass and basal cover, greater total live plant biomass and basal cover, and greater secondary tiller and fall tiller biomass resulting in greater cow and calf weight gain performance and greater growing season residuum vegetation structure that is unfavorable habitat for pestiferous rangeland grasshopper population development. The livestock are removed from the crested wheatgrass pastures at the end of May and moved to native rangeland rotation pastures. The quantity of leaf area remaining at the end of May must be sufficient to photosynthesize adequate quantities of carbohydrates to support the secondary tiller growth from nearly all of the activated axillary buds.

Summer grazing of crested wheatgrass meadows does not improve the plants to the highest biological status, does not return the greatest quantity of wealth per acre, and does not produce the most unfavorable habitat for pest grasshoppers as does spring grazing during May. However, summer grazing on four equal sized crested wheatgrass pastures for 120 days from early May to late August managed with the twice-over rotation technology based on a 40 day stimulation period is the most acceptable plan B use for crested wheatgrass meadows.

The poorly managed crested wheatgrass meadows in the Northern Plains that have the characteristic open canopy, low herbage biomass, low plant basal cover, and large bareground areas can produce grasshopper populations of 8 per square yard. Eight grasshoppers per square yard over an acre use 109.6 pounds of grass herbage per month. During a 5.5 month growing season, 8 grasshoppers per square yard over an acre use 602.8 pounds of grass herbage. On one million acres of poorly managed crested wheatgrass in the Northern Plains, 8 grasshoppers per square yard use 602,800,000 pounds of grass herbage in one growing season. If the weight of herbage used by eight grasshoppers per square yard were converted to tons, it would be 301,400 tons of grass herbage. If one ton of crested wheatgrass hay cut early at the boot stage with 14.5% crude protein were worth $100.00, eight grasshoppers per square yard over an acre, during a 5.5 month growing season, on one million acres, would use $30,140,000.00 of hay.

The amount of this lost revenue that was contributed for pest grasshopper herbage use from your land can be determined by multiplying the acreage of poorly managed crested wheatgrass meadows with $30.14 per acre. The lost income resulting from grasshopper use of herbage on poorly managed crested wheatgrass meadows can be changed into increased net returns per acre by managing the crested wheatgrass meadows as hay fields cut early between the boot stage and the flower stage during mid May to early June, as spring pastures grazed between the three and a half new leaf stage and the peak flower stage during early to late May, or as four equal sized summer pastures grazed for 120 days from early May to late August managed with the twice-over rotation technology with the first grazing period of 40 days.

Table 13. Precipitation during growing season months (April-September), Watford City, ND.

	1993	1994	1995	1996	1997	1998
mm	456.56	266.67	322.22	233.33	194.44	227.78
inches	17.94	10.50	12.69	9.19	7.66	8.97

Data from Onsager 2000.

Table 14. Precipitation in inches and percent of long-term mean for perennial plant growing season months, western North Dakota, 1993-1998.

Years	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1993	1.41	1.71	4.57	5.10	1.24	0.18	0.05	14.26	17.36
% of LTM	97.92	66.80	139.76	209.88	72.94	12.68	3.82	100.92	102.66
1994	0.86	1.46	4.51	1.07	0.31	1.08	4.58	13.87	16.14
% of LTM	59.72	57.03	137.92	44.03	18.24	76.06	349.62	98.16	95.45
1995	1.01	4.32	0.68	4.62	3.16	0.00	0.67	14.46	16.24
% of LTM	70.14	168.75	20.80	190.12	185.88	0.00	51.15	102.34	96.04
1996	0.14	3.07	1.86	2.55	1.72	2.51	0.09	11.94	15.97
% of LTM	9.72	119.92	56.88	104.94	101.18	176.76	6.87	84.50	94.44
1997	2.89	0.95	5.02	5.41	0.76	1.75	0.78	17.56	18.61
% of LTM	200.69	37.11	153.52	222.63	44.71	123.24	59.54	124.27	110.05
1998	0.40	1.51	5.98	2.11	4.60	0.71	4.38	19.69	22.42
% of LTM	27.78	58.98	182.87	86.83	270.59	50.00	334.35	139.35	132.58
1993-1998	1.12	2.17	3.77	3.48	1.97	1.04	1.75	15.30	17.79
% of LTM	77.78	84.77	115.29	143.21	115.88	73.24	133.59	108.28	105.20

Table 15. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with June mowing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	1010.10	595.33	809.22	1142.83	889.37
Native Grass	0.00	101.16	0.00	3.93	26.27
Total Forbs	8.21	6.42	19.62	98.12	33.09
Total Live	1018.31	702.91	828.84	1244.88	948.74
Standing Dead	289.01	169.48	256.90	169.48	221.11
Standing Biomass	1307.32	872.39	1085.74	1414.36	1169.95
Litter	432.37	561.25	577.30	391.77	490.67
Total Dead	721.38	730.73	834.20	561.25	711.89
Total Biomass	1739.69	1433.64	1663.04	1806.13	1660.63

Table 16. Monthly composition (%) of herbage biomass for crested wheatgrass managed with June mowing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	99.19	84.70	97.63	91.81	93.74
Native Grass	0.00	14.39	0.00	0.32	2.77
Total Forbs	0.81	0.91	2.37	7.88	3.49
Total Live	58.53	49.03	49.84	68.93	57.13
Standing Dead	16.61	11.82	15.45	9.38	13.31
Standing Biomass	75.15	60.85	65.29	78.31	70.45
Litter	24.85	39.15	34.71	21.69	29.55
Total Dead	41.47	50.97	50.16	31.07	42.87
Total Biomass	1739.69	1433.64	1663.04	1806.13	1660.63

Table 17. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with June mowing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	1143.72	525.50	436.01	427.80	633.26
Native Grass	9.77	23.14	3.21	28.29	16.10
Total Forbs	285.62	26.16	30.33	15.56	89.42
Total Live	1439.11	574.80	469.55	471.65	738.78
Standing Dead	590.24	280.27	170.56	220.86	315.48
Standing Biomass	2029.35	855.07	640.11	692.51	1054.26
Litter	496.58	147.00	273.31	595.50	378.10
Total Dead	1086.82	427.27	443.87	816.36	693.58
Total Biomass	2525.93	1002.07	913.42	1288.01	1432.36

Table 18. Monthly composition (%) of herbage biomass for crested wheatgrass managed with June mowing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	79.47	91.42	92.86	90.70	85.72
Native Grass	0.68	4.03	0.68	6.00	2.18
Total Forbs	19.85	4.55	6.46	3.30	12.10
Total Live	56.97	57.36	51.41	36.62	51.58
Standing Dead	23.37	27.97	18.67	17.15	22.03
Standing Biomass	80.34	85.33	70.08	53.77	73.60
Litter	19.66	14.67	29.92	46.23	26.40
Total Dead	43.03	42.64	48.59	63.38	48.42
Total Biomass	2525.93	1002.07	913.42	1288.01	1432.36

Table 19. Basal cover (%) and composition (%) for crested wheatgrass managed with June mowing.

Plant Biotype	Basal Cover %		Composition %	
	1993	1994	1993	1994
Domesticated	12.25	9.10	62.50	67.56
Native Grass	3.75	0.78	19.13	5.79
Alfalfa	1.85	1.38	9.44	10.24
Total Forbs	1.75	2.21	8.93	16.41
Total Live	19.60	13.47		
Litter	26.60	18.55		
Bare Soil	53.80	67.98		

Table 20. Bareground area on crested wheatgrass managed with June mowing as mean of ten 2000 cm (787.4 in) transects.

Bareground Size		Percent Area	Bareground Combined Length	
cm	in	%	cm	in
0-5	0-2	25.5	510	200.9
6-10	2-4	23.4	467	184.0
11-20	4-8	23.0	460	180.9
21-30	8-12	14.9	298	117.2
31-40	12-16	7.9	157	61.8
41-50	16-20	3.7	74	29.2
51-90	20-35	1.7	34	13.3

Table 21. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with seasonlong grazing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated		548.40	616.91	625.47	596.93
Native Grass		2.14	11.42	6.78	6.78
Total Forbs		1.78	4.28	0.71	2.26
Total Live		552.32	632.61	632.96	605.96
Standing Dead		200.88	311.84	191.07	234.60
Standing Biomass		753.20	944.45	824.03	840.56
Litter		411.03	458.85	560.89	476.92
Total Dead		611.91	770.69	751.96	711.52
Total Biomass		1164.23	1403.30	1384.92	1317.48

Table 22. Monthly composition (%) of herbage biomass for crested wheatgrass managed with seasonlong grazing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated		99.29	97.52	98.82	98.51
Native Grass		0.39	1.81	1.07	1.12
Total Forbs		0.32	0.68	0.11	0.37
Total Live		47.44	45.08	45.70	45.99
Standing Dead		17.25	22.22	13.80	17.81
Standing Biomass		64.70	67.30	59.50	63.80
Litter		35.30	32.70	40.50	36.20
Total Dead		52.56	54.92	54.30	54.01
Total Biomass		1164.23	1403.30	1384.92	1317.48

Table 23. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with spring grazing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	331.11	400.69	517.36	1807.55	764.18
Native Grass	7.85	2.14	21.76	43.53	18.82
Total Forbs	2.85	1.07	2.14	0.00	1.52
Total Live	341.81	403.90	541.26	1851.08	784.51
Standing Dead	364.65	122.38	60.30	31.40	144.68
Standing Biomass	706.46	526.28	601.56	1882.48	929.20
Litter	408.54	208.73	257.61	234.77	277.41
Total Dead	773.19	331.11	317.91	266.17	422.10
Total Biomass	1115.00	735.01	859.17	2117.25	1206.61

Table 24. Monthly composition (%) of herbage biomass for crested wheatgrass managed with spring grazing, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	96.87	99.21	95.58	97.65	97.47
Native Grass	2.30	0.53	4.02	2.35	2.40
Total Forbs	0.83	0.26	0.40	0.00	0.19
Total Live	30.66	54.95	63.00	87.43	65.02
Standing Dead	32.70	16.65	7.02	1.48	11.99
Standing Biomass	63.36	71.60	70.02	90.78	77.01
Litter	36.64	28.40	29.98	11.09	23.00
Total Dead	69.34	45.05	37.00	12.57	35.00
Total Biomass	1115.00	735.01	839.17	2117.25	1206.61

Table 25. Percent difference of monthly herbage biomass on the spring grazing compared to the seasonlong grazing of crested wheatgrass, 1993.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated		-26.93	-16.14	188.99	28.02
Native Grass		0.00	90.54	542.04	177.58
Total Forbs		-39.89	-50.00	-100.00	-32.74
Total Live		-26.87	-14.44	192.45	29.47
Standing Dead		-39.08	-80.66	-83.57	-38.33
Standing Biomass		-30.13	-36.31	128.45	10.55
Litter		-49.22	-43.86	-58.14	-41.83
Total Dead		-45.89	-58.75	-64.60	-40.68
Total Biomass		-36.87	-38.78	52.88	-8.42

Table 26. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with seasonlong grazing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	848.47	916.71	659.72	531.28	739.05
Native Grass	2.81	0.00	29.61	22.69	13.78
Total Forbs	20.87	29.70	18.91	2.00	17.87
Total Live	872.15	946.41	708.24	555.97	770.69
Standing Dead	336.02	175.46	131.30	150.21	198.25
Standing Biomass	1208.17	1121.87	839.54	706.18	968.94
Litter	220.95	284.73	219.79	249.05	243.63
Total Dead	556.97	460.19	351.09	399.26	441.88
Total Biomass	1429.12	1406.60	1059.33	955.23	1212.57

Table 27. Monthly composition (%) of herbage biomass for crested wheatgrass managed with seasonlong grazing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	97.28	96.86	93.15	95.56	95.89
Native Grass	0.32	0.00	4.18	4.08	1.79
Total Forbs	2.39	3.14	2.67	0.36	2.32
Total Live	61.03	67.28	66.86	58.20	63.56
Standing Dead	23.51	12.47	12.39	15.73	16.35
Standing Biomass	84.54	79.76	79.25	73.93	79.90
Litter	15.46	20.24	20.75	26.07	20.09
Total Dead	38.97	32.72	33.14	41.80	36.44
Total Biomass	1429.12	1406.60	1059.33	955.23	1212.57

Table 28. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with spring grazing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	253.51	438.60	389.27	390.70	368.02
Native Grass	15.70	0.00	0.00	0.00	3.93
Total Forbs	11.69	31.40	29.61	22.87	23.89
Total Live	280.90	470.00	418.88	413.57	395.84
Standing Dead	232.28	39.78	44.24	112.74	107.26
Standing Biomass	513.18	509.78	463.12	526.31	503.10
Litter	90.72	128.72	66.01	221.82	126.82
Total Dead	323.00	168.50	111.25	334.56	234.08
Total Biomass	603.90	638.50	529.13	748.13	629.92

Table 29. Monthly composition (%) of herbage biomass for crested wheatgrass managed with spring grazing, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	90.25	93.32	92.93	94.47	92.97
Native Grass	5.59	0.00	0.00	0.00	0.99
Total Forbs	4.16	6.68	7.07	5.53	6.04
Total Live	46.51	73.61	79.16	55.28	62.84
Standing Dead	38.46	6.23	8.36	15.07	17.03
Standing Biomass	84.98	79.84	87.52	70.35	79.87
Litter	15.02	20.16	12.48	29.65	20.13
Total Dead	53.49	26.39	20.84	44.72	37.16
Total Biomass	603.90	638.50	529.13	748.13	629.92

Table 30. Percent difference of monthly herbage biomass on the spring grazing compared to the seasonlong grazing of crested wheatgrass, 1994.

Plant Biotype	May	Jun	Jul	Aug	Mean Monthly
Domesticated	-70.12	-52.15	-40.99	-26.46	-50.20
Native Grass	458.72	0.00	-100.00	-100.00	-71.48
Total Forbs	-43.99	5.72	56.58	1043.50	33.69
Total Live	-67.79	-50.34	-40.86	-25.61	-48.64
Standing Dead	-30.87	-77.33	-66.31	-24.95	-45.90
Standing Biomass	-57.52	-54.56	-44.84	-25.47	-48.08
Litter	-58.94	-54.79	-69.97	-10.93	-47.95
Total Dead	-42.01	-63.38	-68.31	-16.20	-47.03
Total Biomass	-57.74	-54.61	-50.05	-21.68	-48.05

Table 31. Basal cover (%) and composition (%) for crested wheatgrass managed with seasonlong grazing.

Plant Biotype	Basal Cover %		Composition %	
	1993	1994	1993	1994
Domesticated	29.04	17.85	76.62	67.72
Native Grass	5.88	6.00	15.51	22.76
Sedges	0.25	0.00	0.66	0.00
Total Forbs	2.73	2.51	7.20	9.52
Total Live	37.90	26.36		
Litter	55.47	66.34		
Bare Soil	6.63	7.30		

Table 32. Basal cover (%) and composition (%) for crested wheatgrass managed with spring grazing.

Plant Biotype	Basal Cover %		Composition %	
	1993	1994	1993	1994
Domesticated	36.00	23.60	91.42	93.99
Native Grass	1.45	0.83	3.68	3.31
Sedges	0.10	0.00	0.25	0.00
Total Forbs	1.83	0.68	4.65	2.71
Total Live	39.38	25.11		
Litter	52.83	68.09		
Bare Soil	7.79	6.80		

Table 33. Percent difference of basal cover on the spring grazing compared to the seasonlong grazing of crested wheatgrass, 1993-1994.

Plant Biotype	Difference %	
	1993	1994
Domesticated	23.97	32.21
Native Grass	-75.34	-86.17
Sedges	-60.00	0.00
Total Forbs	-32.97	-72.91
Total Live	3.91	-4.74
Litter	-4.76	2.64

Table 34. Bareground area on crested wheatgrass managed with seasonlong grazing as mean of ten 2000 cm (787.4 in) transects.

Bareground Size		Percent Area	Bareground Combined Length	
cm	in	%	cm	in
0-5	0-2	69.1	1382	544.1
6-10	2-4	18.7	374	147.2
11-20	4-8	7.5	150	59.1
21-30	8-12	1.6	32	12.6
31-40	12-16	3.1	62	24.4

Table 35. Bareground area on crested wheatgrass managed with spring grazing as mean of ten 2000 cm (787.4 in) transects.

Bareground Size		Percent Area	Bareground Combined Length	
cm	in	%	cm	in
0-5	0-2	80.7	1614	635.4
6-10	2-4	15.2	304	119.7
11-20	4-8	4.1	82	32.3
21-30	8-12	0.0	0	0
31-40	12-16	0.0	0	0

Table 36. Mean cumulative grasshopper days (GD) per m^2 and primary habitat use for pestiferous grasshoppers on crested wheatgrass managed with spring grazing and seasonlong grazing, 1993-1998.

					Mean Cumulative Grasshopper days per m^2	
Pestiferous Rangeland Grasshoppers	Hatch Group	Egg Pod Site	Basking Site	Daily Activity Site	Spring Grazing	Seasonlong Grazing
Mel san	Early	Bareground	Grd/Veg	Bareground	415	547
Mel inf	Early	Bareground	Bareground	Grd/Veg	238	253
Pho neb	Late	Bareground	Veg/Grd	Veg/Grd	16	126*
Tra kio	Intermediate	Bareground	Bareground	Bareground	98*	14
Age deo	Early	Bareground	Bareground	Bareground	88*	4
Mel gla	Late	Bareground	Bareground	Bareground	53	52
Mel fem	Intermediate	Bareground	Bareground	Grd/Veg	35*	2
Enc cos	Intermediate	Bareground	Bareground	Bareground	9	11
Ope obs	Late	Bareground	Veg/Grd	Veg/Grd	6	2
Total cumulative GD for the 9 pestiferous grasshoppers					978	1011
Total cumulative GD for the other 21 nonpestiferous grasshoppers					667	558
Total cumulative GD for all grasshoppers					1645	1569

Habitat use information from Cushing 1993, Pfadt 1994.
Grasshopper days per m^2 data from Onsager 2000.

Mean value is significantly greater than its complement*.

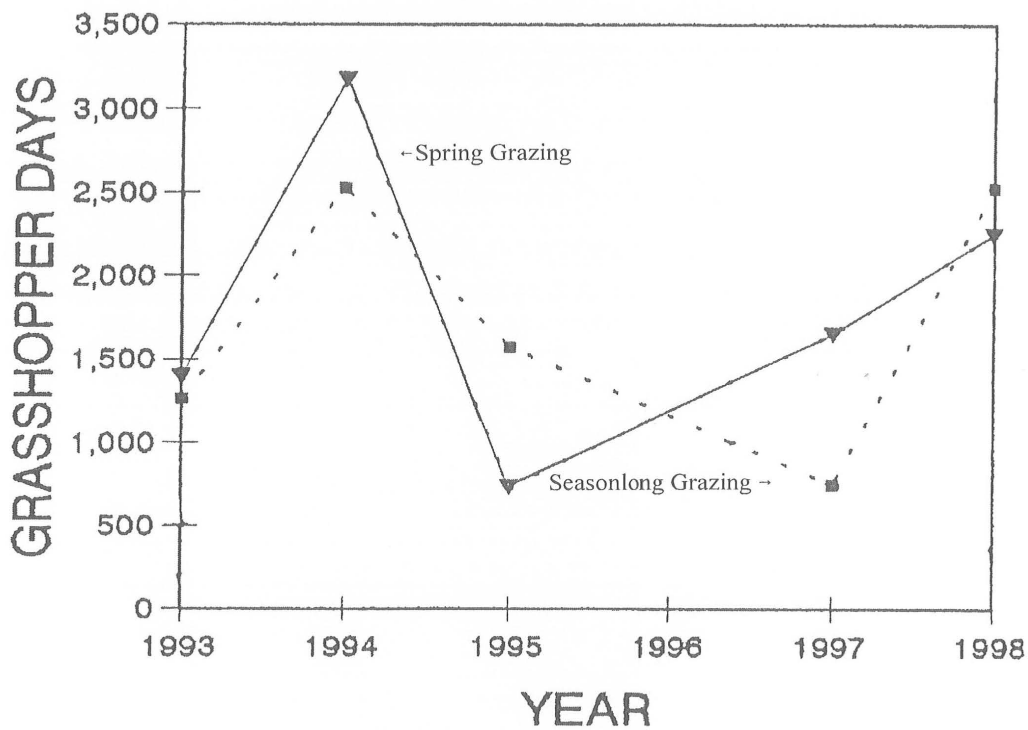

Figure 2. Grasshopper population abundance reported as grasshopper days per square meter on crested wheatgrass managed with spring grazing and seasonlong grazing. Data from Onsager 2000.

Table 37. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with spring grazing on one pasture system, 1995-1998.

Plant Biotype	May	Jun	Jul	Aug	Sep	Mean Monthly
Domesticated	625.13	751.61	1089.13	975.00	1119.58	912.09
Native Grass	69.28	58.72	79.19	76.37	107.86	78.28
Total Forbs	46.99	36.59	105.91	44.15	77.16	62.16
Total Live	741.40	861.74	1274.23	1095.52	1304.60	1055.50
Standing Dead	511.74	205.90	183.01	139.65	137.45	235.55
Standing Biomass	1253.14	1067.64	1457.24	1235.17	1442.05	1291.05
Litter	415.21	398.00	296.24	322.61	678.30	422.07
Total Dead	926.95	603.90	479.25	462.26	815.75	657.62
Total Biomass	1668.35	1465.64	1753.48	1557.78	2120.35	1713.12

Table 38. Monthly composition (%) of herbage biomass for crested wheatgrass managed with spring grazing on one pasture system, 1995-1998.

Plant Biotype	May	Jun	Jul	Aug	Sep	Mean Monthly
Domesticated	84.32	87.22	85.47	89.00	85.82	86.41
Native Grass	9.34	6.81	6.21	6.97	8.27	7.42
Total Forbs	6.34	4.25	8.31	4.03	5.91	5.89
Total Live	44.44	58.80	72.67	70.33	61.53	61.61
Standing Dead	30.67	14.05	10.44	8.96	6.48	13.75
Standing Biomass	75.11	72.84	83.11	79.29	68.00	75.36
Litter	24.89	27.16	16.89	20.71	31.99	24.64
Total Dead	55.56	41.20	27.33	29.67	38.47	38.38
Total Biomass	1668.35	1465.64	1753.48	1557.78	2120.35	1713.12

Table 39. Monthly herbage biomass (lbs/ac) for crested wheatgrass managed with spring grazing on two pasture twice-over switchback system, 1995-1998.

Plant Biotype	May	Jun	Jul	Aug	Sep	Mean Monthly
Domesticated	991.59	721.04	1265.86	1096.50	1255.83	1066.16
Native Grass	54.08	73.09	99.10	67.62	85.10	75.80
Total Forbs	8.36	21.20	45.51	33.61	35.28	28.79
Total Live	1054.03	815.33	1410.47	1197.73	1376.21	1170.75
Standing Dead	314.16	81.20	40.18	49.74	48.36	106.73
Standing Biomass	1368.19	896.53	1450.65	1247.47	1424.57	1277.48
Litter	524.53	433.34	297.89	339.92	628.32	444.80
Total Dead	838.69	514.54	338.07	389.66	676.68	551.53
Total Biomass	1892.72	1329.87	1748.54	1587.39	2052.89	1722.28

Table 40. Monthly composition (%) of herbage biomass for crested wheatgrass managed with spring grazing on two pasture twice-over switchback system, 1995-1998.

Plant Biotype	May	Jun	Jul	Aug	Sep	Mean Monthly
Domesticated	94.08	88.44	89.75	91.55	91.25	91.07
Native Grass	5.13	8.96	7.03	5.65	6.18	6.47
Total Forbs	0.79	2.60	3.23	2.81	2.56	2.46
Total Live	55.69	61.31	80.67	75.45	67.04	67.98
Standing Dead	16.60	6.11	2.30	3.13	2.36	6.20
Standing Biomass	72.29	67.41	82.96	78.59	69.39	74.17
Litter	27.71	32.59	17.04	21.41	30.61	25.83
Total Dead	44.31	38.69	19.33	24.55	32.96	32.02
Total Biomass	1892.72	1329.87	1748.54	1587.39	2052.89	1722.28

Table 41. Percentage difference of monthly herbage biomass on the two pasture system compared to the one pasture system of spring grazing crested wheatgrass, 1995-1998.

Plant Biotype	May	Jun	Jul	Aug	Sep	Mean Monthly
Domesticated	58.62	-4.07	16.23	12.46	12.17	16.89
Native Grass	-21.94	24.47	25.14	-11.46	-21.10	-3.17
Total Forbs	-82.21	-42.06	-57.03	-23.87	-54.28	-53.68
Total Live	42.17	-5.39	10.69	9.33	5.49	10.92
Standing Dead	-38.61	-60.56	-78.04	-64.38	-64.82	-54.69
Standing Biomass	9.18	-16.03	-0.45	1.00	-1.21	-1.05
Litter	26.33	8.88	0.56	5.37	-7.37	5.39
Total Dead	-9.52	-14.80	-29.46	-15.71	-17.05	-16.13
Total Biomass	13.45	-9.26	-0.28	1.90	-3.18	0.53

Table 42. Basal cover (%) and composition (%) for crested wheatgrass managed with spring grazing on two pastures and one pasture systems, 1995-1998.

Plant Biotype	Two Pasture System		One Pasture System	
	Basal Cover %	Composition %	Basal Cover %	Composition %
Domesticated	21.72	82.77	18.16	87.56
Native Grass	3.79	14.44	1.76	8.49
Sedges	0.24	0.91	0.20	0.96
Total Forbs	0.48	1.83	0.63	3.04
Total Live	26.24		20.74	
Litter	71.37		76.29	
Bare Soil	2.39		2.98	

Table 43. Percent difference of basal cover on the two pasture system compared to the one pasture system of spring grazing crested wheatgrass, 1995-1998.

Plant Biotype	Difference % 1995-1998
Domesticated	19.60
Native Grass	115.34
Sedges	20.00
Total Forbs	-23.81
Total Live	26.52
Litter	-6.45

Table 44. Crested wheatgrass weekly percent crude protein and phenological growth stages of ungrazed lead tillers.

Sample Date	Percent Crude Protein	Phenological Growth Stages
Apr 1		
13	15.5	Early leaf greenup
19	17.1	
25	16.2	Three and a half new leaves
May 4	19.0	Active leaf growth
10	21.0	
16	16.2	Flower stalk developing
23	14.5	
28	13.5	Flowering (anthesis)
Jun 6	12.1	
13	11.5	Seed developing
19	10.6	
26	9.7	
Jul 2	8.6	Seed maturing
8	7.5	
16	7.5	Seed mature
24	6.4	
30	6.4	Tiller drying
Aug 6	5.9	
13	5.8	
20	5.8	
26	5.8	
Sep 3	4.5	

Data from Whitman et al. 1951

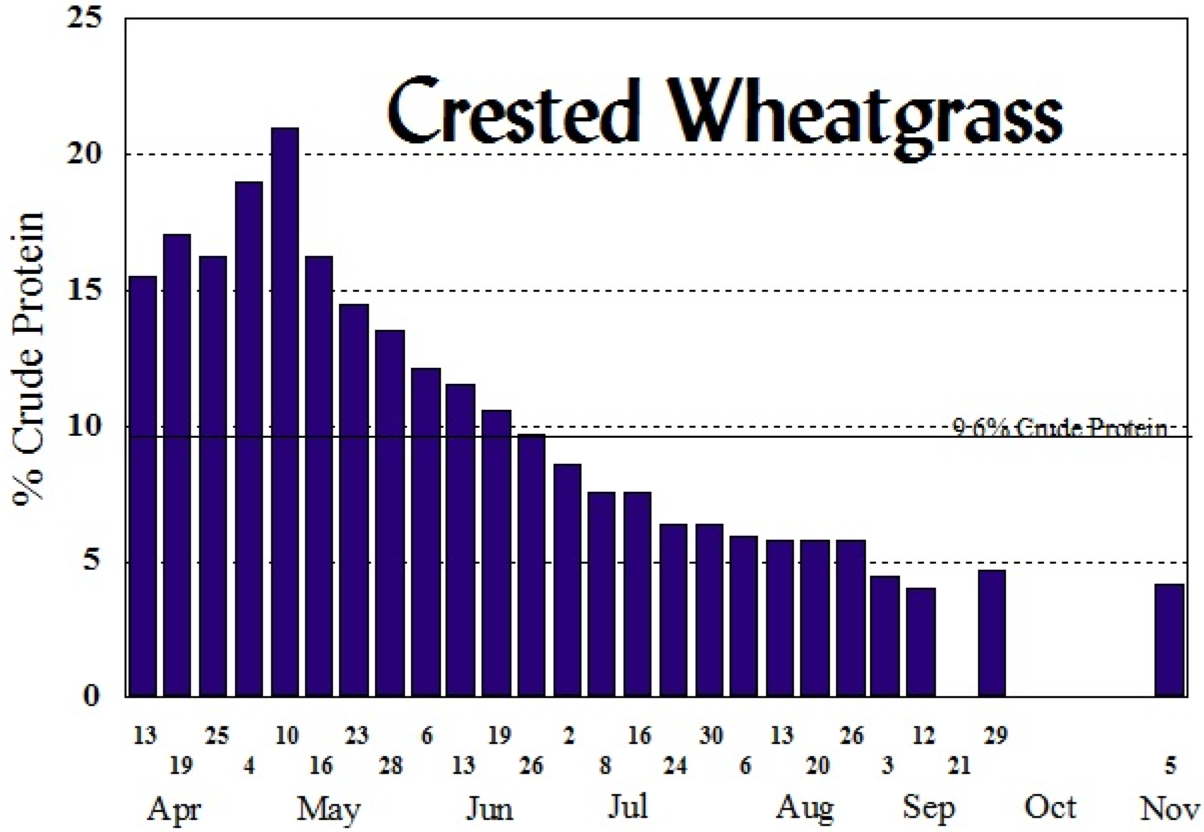

Fig 3. Mean percent crude protein of ungrazed crested wheatgrass in western North Dakota, data from Whitman et al. 1951.

Table 45. Forage dry matter biomass and crude protein yield and costs for crested wheatgrass hay cut at two growth stages.

	Costs/acre								
	Land Rent	Custom Work	Baling Costs	Production Costs $/ac	Forage Biomass Yield lb/ac	Forage Biomass Costs $/ton	Crude Protein %	Crude Protein Yield lb/ac	Crude Protein Costs $/lb
Crested Wheatgrass									
Mature	14.22	5.31	8.58	28.11	1600	34.80	6.4	102	0.28
Boot stage	14.22	5.31	6.97	26.50	1300	40.80	14.5	189	0.14

Data from Manske 2002.