Advanced Pasture Forage Management Technology for the Northern Mixed Grass Prairie

Llewellyn L. Manske PhD
Research Professor of Range Science
North Dakota State University
Dickinson Research Extension Center
Report DREC 18-4032

Prairie ecosystems are complex; exceedingly more complex than the most complicated machines ever built by humans. The long-standing standard process to understand complex systems is to initially investigate the separate component parts. The gained knowledge of each part combined with the synergistic effects resulting when the parts work together provide the information needed to develop an understanding of the whole ecosystem. This classical concept of biological systems was developed by the Greek philosopher/scientist Aristotle (384-322 BC) who taught that "the whole is greater than the sum of its parts".

The goals of this study were developed by Dr. Warren C. Whitman (c. 1950) and Dr. Harold Goetz (1963) which were to gain quantitative knowledge of each component part and to provide a pathway essential for the understanding of the whole prairie ecosystem that would result in the development and establishment of scientific standards for proper management of native rangelands of the Northern Plains. The introduction to this study can be found in report DREC 16-1093 (Manske 2016b).

The beef production industry has worked for more than half a century to improve the genetic performance of modern beef animals. As a result, the North American beef herd has been transformed into high-performance, fast-growing meat animals with improved genetic potential and increased nutrient demands. Modern high-performance cattle are larger and heavier, gain weight more rapidly, produce more milk, and deposit less fat on their bodies than the traditional low-performance old-style livestock.

The modern high production range cow has greater nutrient demand that is not simply proportional to the cows greater size. A high performance 1200 lb range cow with average milk production at 20 lb/d, is 20% larger than an old style 1000 lb range cow that had milk production at 12 to 6 lb/d, and requires 27% more energy and 41% more crude protein per day during the lactation production periods than the old style range cow. A high performance 1200 lb range cow with high milk production at 30 lb/d requires 43% more energy and 72% more crude protein per day during the lactation periods than the old style range cow (Manske 2014).

Unfortunately, the forage management technology was not improved simultaneously with beef cow performance. Traditional forage management practices are antagonistic to plant growth mechanisms, suppressive to ecosystem biogeochemical processes performed by the soil microorganisms, inefficient at nutrient capture and conversion, and deficient at providing adequate forage quality during the entire grazing period and harvested forage period for modern livestock at low costs.

Improvements in forage management technology are needed that provide the biological and physiological requirements to the forage grass plants, soil microorganisms, and grazing livestock, that can activate and maintain the grass plant growth mechanisms and the ecosystem biogeochemical processes, that can revitalize soil structure and functionality, that can increase forage quantity and nutritional quality, and that can improve livestock growth and weight performance along with the capture of greater wealth per acre from renewable grassland natural resources.

Grazing forage plants is more efficient and effective when the phenological growth stages, the herbage production curves, and the nutrient quality curves of the forage sources match the biological and physiological requirements of the grazing livestock. This action of coordination between the primary producers and the primary consumers is called "seasonality". All of the perennial forage grasses growing in the region of the Northern Mixed Grass Prairie have growth characteristics that can be categorized into three seasonality units. The spring unit from early May to mid June includes the introduced domesticated cool season grasses, such as crested wheatgrass and smooth bromegrass. The summer unit from early June to mid October includes the cool season and warm season native grasses which can be subdivided into four groups; no domesticated grasses are qualified for the summer unit. The fall unit from mid September to mid November includes all of the wildryes, like Altai and Russian.

A sequence of three separate pastures each consisting of grasses from one of the three seasonality units results in a combined grazing period from early May to mid November with a potential duration of 199 days. The combination of a spring unit pasture of domesticated cool season grass and a fall unit pasture of wildrye grass added to a summer unit pasture of native grass forms a simple three pasture complementary grazing system.

Scientists from two research centers, Swift Current Research Branch in southwestern Saskatchewan and NDSU Dickinson Research Extension Center in western North Dakota, have worked extensively on the development of complementary grazing systems for the Northern Plains. Initially, both research centers used a simple three pasture system with crested wheatgrass, native rangeland, and Russian wildrye, and both research centers have also worked with Altai wildrye as the fall pasture.

In the beginning, practically nothing was known about how to graze crested wheatgrass and Russian wildrye, and the same for Altai wildrye when it was initially studied. Stocking rates, start and stop dates, along with all the other basic information had to be determined through trial and error. The stocking rates for native rangeland were recommended at 70% to 80% removal during the 1920's and 1930's. It wasn't known until Crider (1955) reported that root growth stoppage varied proportionally with the percentage of aboveground herbage removal and that removal at 50% herbage or greater was detrimental to future productivity. After the dry period in the 1930's, the recommended starting date for native rangeland was mid June. It wasn't until the early 1980's, that the recommended native rangeland starting date was moved to early June. Grassland ecosystems are complex. It requires a great deal of trial and error research to find the correct answers to simple questions. Research to determine these important answers on how to properly manage complex grassland ecosystems has been conducted at the NDSU Dickinson REC beginning in 1953 continuing through 2018 by Drs. Whitman, Goetz, and Manske.

This report is the synthesis of 66 years of research and will provide the culminated scientific information on the current solutions to the major technological problems that were impeding development of advanced forage management strategies specifically for modern beef livestock on the Northern Mixed Grass Prairie and provide information on the current status of the development of a biologically effective grazing strategy concept with spring and fall domesticated grass pastures complementary to a summer three pasture twice-over rotation system on native rangeland compared to a traditional concept of a simple three pasture complementary grazing system.

Management Treatments

This study evaluates the plant and animal responses to two distinctly different concepts of management of the Spring, Summer, and Fall seasonality pasture units. The Traditional concept managed the grassland resources for their use as forage for livestock. The Biologically Effective concept managed the grassland resources as functional ecosystems and considered the biological requirements of the grass plants, soil microbes, and the livestock.

Spring Complementary Pastures

The traditional spring complementary pasture was crested wheatgrass. Cow and calf pairs grazed one unfertilized pasture of 15 acres (replicated three times) at 2.33 ac/AUM for 28 days (2.14 ac/AU) from early May to early June.

The biologically effective spring complementary pasture was crested wheatgrass. Cow and calf pairs grazed one unfertilized pasture of 26.5 acres split into equal halves with each portion grazed during 2 alternating 7 day periods in a switchback plan (replicated two times) at 1.30 ac/AUM for 28 days (1.20 ac/AU) from early May to early June.

Summer Pastures

The traditional summer rangeland pasture was northern mixed grass prairie. Cow and calf pairs grazed one native rangeland pasture seasonlong (replicated two times) with 7 cows per 80 acres at 2.58 ac/AUM for 135 days (11.43 ac/AU) from early June to mid October.

The biologically effective summer rangeland pastures were northern mixed grass prairie. Cow and calf pairs grazed three native rangeland pastures with a twice-over rotation system (replicated two times) with 8 cows per 80 acres at 2.26 ac/AUM for 135 days (10.22 ac/AU) from early June to mid October.

Fall Complementary Pastures

Four different forage sources for fall complementary pastures have been evaluated that compared two perennial grass forage types and compared two cropland forage types.

The traditional fall complementary perennial grass pasture was native rangeland. Cow and calf pairs grazed one pasture of native rangeland (replicated two times) at 4.11 ac/AUM for 30 days (4.04 ac/AU) from mid October to mid November.

The biologically effective fall complementary perennial grass pasture was Altai wildrye. Cow and calf pairs grazed one pasture of Altai wildrye (replicated two times) at 1.41 ac/AUM for 30 days (1.39 ac/AU) from mid October to mid November.

The traditional fall complementary cropland pasture was cropland aftermath consisting primarily of annual cereal residue of oat and/or barley stubble with some senescent perennial grass on the headlands and waterways. Cow and calf pairs grazed cereal residue forage (replicated two times) at 6.74 ac/AUM for 30 days (6.63 ac/AU) from mid October to mid November.

The biologically effective fall complementary cropland pasture was spring seeded winter cereal. Cow and calf pairs grazed four pastures of spring seeded winter rye with each pasture grazed for one week (replicated two times) at 0.48 ac/AUM for 30 days (0.47 ac/AU) from mid October to mid November.

Commercial crossbred cattle were used on all grazing treatments. Calves were born during March and early April with the average birth date of 16 March and the average birth weight of 95 pounds during the entire study period. The average weight gain between birth and pasture turn out was 95 lbs. Before spring turn out, cow-calf pairs were sorted by cow age and calf age with 50% steers and heifers. At spring turn out, average cow weight was between 1100 lbs and 1200 lbs.

Precipitation

The long-term annual precipitation for DREC ranch in western North Dakota is 17.11 inches (434.56 mm). The perennial plant growing season precipitation (April to October) is 14.47 inches (367.30 mm) and is 84.6% of annual precipitation. The precipitation received in the 3 month period of May, June, and July (8.20 inches) accounts for 47.9% of the annual precipitation. June received the greatest monthly precipitation at 3.19 inches (81.08 mm). Total precipitation received for the 5 month period of November through March averages less than 2.66 inches (15.5% of annual total). Water deficiency conditions occur during 30.6% of the growing season months, this amounts to an average of 2.0 months during every 6.0 month growing season range plants are limited by water stress. Growing seasons with no water deficiency occur during 5.9% of the years. The 3 month periods of May, June, and July experience 31.8% of the water deficient months and August, September, and October experience 64.4% of the water deficient months (table 1) (Manske 2018a).

Procedures

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 with ungrazed and grazed paired plots.

Aboveground herbage biomass was collected from replicated ungrazed and grazed paired plots by the standard clipping method (Cook and Stubbendieck 1986) with five 0.25 m^2 quadrats (frames) at each sample site. On native rangeland sites, clipping occurred monthly from April through October with herbage material sorted in the field by biotype categories: domesticated grasses, cool season, warm season, upland sedge, forbs, standing dead, and litter. On complementary domesticated grass pastures, clipping occurred monthly from April through November with herbage material sorted in the field by biotype categories: domesticated grasses, other grasses, 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.

Crude protein and phosphorus content were determined for 3 domesticated grasses, 1 upland sedge, 5 cool season grasses, and 4 warm season grasses from samples collected weekly during the growing seasons of 1946 and 1947 at the Dickinson Research Extension Center in western North Dakota. Ungrazed current year's growth of lead tillers was included in the sample; previous year's growth was separated and discarded. Crude protein (N X 6.25) content was determined by the procedure outlined in the Official and Tentative Methods of Analysis (A.O.A.C 1945). Phosphorus content was determined by the method outlined by Bolin and Stamberg (1944). Data were reported as percent of oven dried weight. Plant condition by stage of plant development and growth habit was collected on each sample date. These data are reported as phenological growth stages in the current report. The grass nutritional quality and plant growth stage data were published in Whitman et al. 1951.

Rhizosphere volume was determined from diameter and length measurements by a vernier caliper of western wheatgrass roots contained within two replicated soil cores, 3 inches (7.62 cm) in diameter and 4 inches (10.16 cm) in depth, collected monthly from June to September in silty ecological sites reported as total rhizosphere volume per cubic meter of soil published in Gorder, Manske, and Stroh 2004.

Rhizosphere biomass was determined from fresh rhizosphere material weight which included the rhizosphere organisms, the active plant roots, and the adhered soil particles that had been separated from matrix soil by meticulous excavation with fine hand tools from three replicated soil cores on the silty ecological sites of three replicated grazed pastures managed by the twice-over rotation system collected with a humane soil beastie catcher (Manske and Urban 2012).

Soil mineral nitrogen, nitrate (NO_3) and ammonium (NH_4), was determined for replicated soil core samples collected with the 1 inch Veihmeyer soil tube at incremental depths of 0-6, 6-12, and 12-24 inches from silty ecological sites monthly from May to October. Soil samples were frozen soon after collection. Analysis of soil core samples for available mineral nitrogen (NO_3 and NH_4) was conducted by the North Dakota State University Soil Testing Laboratory using wet chemistry methods.

Percent soil organic matter (SOM) was determined by the loss on ignition (% LOI) analysis conducted by the NDSU Soil Testing Laboratory from replicated soil core samples collected during June at silty ecological sites with the 1 inch Veihmeyer soil tube at incremental depths of 0-6, 6-12, and 12-24 inches.

Individual cows and calves were weighed on and off each treatment pasture, at 15-day intervals during the early portion of the grazing season from early May to mid July, and at 30-day intervals during the latter portion of the grazing season from mid July to mid November. Total accumulated weight gain per head, gain per day, and gain per acre were determined.

Pasture costs were determined using pasture rent values of $8.76 per acre calculated from the mean rent values of the 15 counties in southwestern North Dakota reported for 1993 and 1994 (ND Ag Statistics). Total pasture costs and costs per day were determined. Grazing cropland aftermath cost was determined using rent value of $2.00 per acre.

Market value per pound of calf pasture accumulated live weight gain was determined from the low market value of $0.70 per pound occurring during 1993 and 1994. Net returns per cow-calf pair were determined by subtracting pasture costs from calf pasture weight gain value. Net returns per acre were determined by dividing the net returns per cow-calf pair by the number of acres used per Animal Unit (AU) per seasonality unit.

This study used pasture forage production costs and returns after pasture costs to compare and evaluated biological effectiveness of management concepts during three seasonality pasture periods. This study was not economic analysis of total livestock production costs nor was this a study in livestock marketing schemes.

Table 1. Long-term mean precipitation in inches and % frequency of water deficiency conditions for perennial plant growing season months at DREC Ranch, western North Dakota.

		Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term Mean Precipitation	inches	1.46	2.65	3.19	2.36	1.96	1.50	1.35	14.47	17.11
% Frequency water deficiency	%	13.9	11.1	11.1	36.1	47.2	52.8	36.1	30.6	

Data from Manske 2018a.

Spring Complementary Pastures

Crested wheatgrass had been introduced into North America during the early portion of the 20th Century and many agricultural scientists had known of the beneficial potential that crested wheatgrass could achieve. However, little practical use had been made of crested wheatgrass before the late 1930's and early 1940's when it was used to revegetate millions of acres of abandoned cropland that had been turned over with steel moldboard plows in order to fulfill the compliance requirements of the Homestead Acts of the United States and Canada. After the end of World War II, the Northern Plains had millions of acres of crested wheatgrass and we did not know how to best graze these grasslands. This need prompted decades of scientific research (Manske 2012).

Crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., is a member of the grass family, Poaceae, tribe, Triticeae, and is a long lived perennial, monocot, cool-season, mid grass, that is highly drought tolerant and winter hardy. Crested wheatgrass was introduced into the United States in 1906 and into Canada in 1915 from Eurasia and was 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: Crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., (Fairway type); Desert wheatgrass, *Agropyron desertorum* (Fisch. Ex Link) Schultes, (Nordan type and MT Standard type); and Siberian wheatgrass, *Agropyron fragile* (Roth) Candargy, (Siberian type). Even though each species maintained as isolated plant material has distinct characteristics, specific identification of nonsecluded 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. The separation of this resultant mixture of plants into more than one taxon has proven to be impractical. A taxonomic description of most of this material would be more similar to *Agropyron cristatum*. The first North Dakota record is Stevens 1961. Early aerial growth consists of basal leaves from crown and rhizome tiller buds. Basal leaf blades are 10-20 cm (4-8 in) long, 5-10 mm wide, tapering to a point. Leaves roll inward when dry. The split sheath has overlapping margins that open towards the top. The distinct collar is divided. The membranous ligule is 1-2 mm long with a cut like fringed edge. The small auricles are slender, clasping, and clawlike. The rhizomes are traditionally described as short and the plants are categorized as bunches (caespitose), however, the number and length of the rhizomes and the relative quantities of crown tillers and the rhizomes tillers is determined by the timing of the partial defoliation management and having sufficient quantities of viable green leaf area remaining at end of the treatment. Partial defoliation prior to flowering stimulates the number and length of the rhizomes and increases the quantity of rhizome tillers. Partial defoliation following flowering inhibits rhizome development and decreases the quantity of rhizome tillers. The extensive root system has tough main roots arising from stem crowns and rhizome nodes growing vertically downward producing numerous fine branches forming a dense mass in the top 1 m (3.3 ft) of soil. Several long main roots descend to depths of 2.4 m (8 ft) in loose soil. Regeneration is primarily asexual propagation by crown and rhizome tiller buds. Viable seed production is high and seedlings are vigorous, however, seedlings are successful only when competition from established plants is nonexistent. The numerous flower stalks are erect, slender, 30-80 cm (12-32 in) tall, and hairless. Inflorescence is a flattened dense spike, 5-10 cm (2-4 in) long, that has closely spaced overlapping, laterally compressed spikelets of 3 to 8 florets in two opposite rows with one spikelet per node. Flower period is from late May to mid June. Aerial parts are palatable and nutritious during May. Stocking rates greater than proper for native rangeland can be used during early to late May. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reduction in biomass production and tiller density. This summary information on growth development and regeneration of Crested wheatgrass was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Zlatnik 1999a, b, Ogle 2006 a, b, Larson and Johnson 2007, Stubbendieck et al. 2011, and Ogle et al. 2013.

Crested wheatgrass starts early leaf greenup in mid April (table 2). The crested wheatgrass tillers have three and a half new leaves around 22 April which is four to five weeks earlier than native cool season grasses. These early new leaves are highly nutritious forage, however, the available herbage weight is insufficient for grazing until 1 May. Early boot stage occurs in mid May and the first stalks with flowers occurs around 28 May (table 2). 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 2) (Whitman et al. 1951, Manske 1999b).

The nutritional quality of ungrazed lead tillers of crested wheatgrass changes with the tillers' phenological development (table 2). 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. The flower stage is when the greatest weight of crude protein per acre occurs. After the flower stage, crude protein levels remain above 9.6% until late June (table 2, figure 1). As the ungrazed lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility decrease. By early July, crude protein levels drop below 7.8% and below 6.2% in early August (table 2, figure 1). Phosphorus levels drop below 0.18% in late July (table 2). The patterns of change in nutritional quality are similar from year to year because tiller phenological development is regulated primarily by photoperiod (changes in the length of daylight). 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 (from water) for carbohydrate synthesis. Senescence rates increase with high temperatures, precipitation deficiency, and water stress (Whitman et al. 1951, Manske 1999b).

Crested Wheatgrass Management Recommendations

Earlier studies have shown that crested wheatgrass starts growth earlier in the spring than native rangeland and is ready for grazing four weeks earlier than native rangeland. Stocking rates greater than 1.25 ac/AUM are much too heavy. Stocking rates on one pasture strategies can be about 10% heavier than the proper native rangeland stocking rate on the same ecological site. However, grazing periods longer than 32 days on one pasture strategies should use the same stocking rate for native rangeland. Forage utilization greater then 54% and leaving a residual live grass biomass of less than 500 lbs/ac is not enough leaf surface area for plants to fully recover in one growing season causing substantial delays of herbage growth the following spring. Crested wheatgrass plants are hardy but cannot fully recover from double heavy use during one growing season.

Crested wheatgrass alone has adequate crude protein content during the month of May for steers and cow-calf pairs. Grazing studies with 40% to 60% alfalfa showed no clinical signs of bloat in any of the livestock, however, their weight performance was reduced 17%. Weight gains were greater on crested wheatgrass pastures alone than on pastures with alfalfa until the alfalfa was nearly eliminated, then weight gains were the same. Alfalfa has double the water use requirements per pound of dry matter herbage production than grasses. This high water use causes depleted soil water levels to an average of 35% below ambient soil water in a 5 foot radius around each alfalfa plant resulting in water stress conditions and reduced grass herbage production in adjacent grass plants.

Grazing crested wheatgrass pastures for 30 days from mid May to mid June when available crude protein averages 12%, the livestock weight gain is lower than potential. Otherwise, grazing for 30 days from early May to late May when available crude protein averages 17%, the livestock weight gain is much better and close to potential.

Many crested wheatgrass pastures have been seeded into wornout cropland before the organic matter could be replaced with barnyard manure and the soil remains deficient in essential elements. Fertilization of crested wheatgrass pastures can work biologically and economically if 50 lbs N/ac are applied one month (1 April) before the start of grazing (1 May) even if snow remains on the ground; it takes that long of a time period for that treatment to be effective. Fertilization of perennial grasses does not increase total annual production. Fertilization causes tillers of different ages to be synchronized, causing most of the tiller growth to occur together at an earlier but much shorter time span resulting in an apparent greater peak biomass. This also increases the rate of leaf senescence greatly reducing the length of time that the forage has adequate quantities of crude protein. The livestock grazing fertilized pastures have fewer days that the crude protein available meets their requirements than the livestock grazing unfertilized pastures. If cow-calf pairs grazed the fertilized crested wheatgrass pastures, the calves need to be one month old at the start of the grazing period; calves less than one month old cannot gain much more than 1.25 lbs/day. The additional 50 to 60 lbs of weight gain per calf helps pay the fertilizer bill when the annual costs increase. Next time, plan A should be, to increase the organic matter content of the wornout cropland soil before the perennial grass is seeded.

Performance of Grass and Livestock

Crested wheatgrass is an excellent spring (May) complementary pasture. The available herbage biomass provides superior quantity and quality forage from 1 May to the end of May or the first couple of days into June. The crude protein content ranges from 19.0% to 12.1%. Cows with calves one month old on 1 May perform very well while grazing crested wheatgrass; calves less than one month old cannot gain much more than 1.25 lbs/day (Manske 2017b).

The Traditional concept spring strategy used one pasture on unfertilized crested wheatgrass (replicated two times) each with 15 acres grazed for 28 days, stocked at 2.33 ac/AUM (2.14 ac/AU) (table 4).

The Biologically Effective concept spring strategy used a two pasture switchback plan on unfertilized crested wheatgrass (replicated two times) each with 26.5 acres split in half, creating two two pasture switchback systems grazed for 28 days, stocked at 1.30 ac/AUM (1.20 ac/AU) with each half pasture grazed for two periods of 7 days for a total of 14 days on each and 28 days on the 2 halves (table 4). With this simplified version, the pasture switch can always be made during the same day each week i.e. on each Monday morning at 8:00 am. A more complicated version can add four grazing days by making the pasture switch on 8 day periods. Undoubtedly, a system to remind you of the switch days should be developed when using the eight day version.

The one pasture traditional concept provided 1261 lbs/ac herbage during the May grazing period leaving a domesticated grass residual of 797 lbs/ac (table 3, figure 2) which would indicate a utilization rate of 464 lbs/ac. This does not account for a growth rate of about 25 lbs/ac/day. The secondary tiller growth produced 385 lbs/ac between late May and mid July. The basal cover was maintained at a mean of 18.0%.

The two pasture biologically effective concept provided 2183 lbs/ac herbage during the May grazing period, which was 73% greater than that on the one pasture strategy, leaving a domesticated grass residual of 1039 lbs/ac (table 3, figure 2) which would indicate a utilization rate of 1144 lbs/ac. This does not account for a growth rate of greater than 25 lbs/ac/day, with a measured rate of 300 lbs/ac/day during one year between 1 and 28 May. The secondary tiller growth produced 758 lbs/ac between late May and mid July, which was 97% greater than that on the traditional one pasture strategy. The basal cover was maintained at a mean of 22.8% which was 27% greater than the one pasture strategy.

On the switchback strategy, calf weight gain was 2.61 lbs per day, 66.60 lbs per acer, and accumulated weight gain was 76.45 lbs per head. Cow weight gain was 2.60 lbs per day, 65.49 lbs per acer, and accumulated weight gain was 75.43 lbs per head (table 5).

On the one pasture strategy, calf weight gain was 2.57 lbs per day, 32.93 lbs per acer, and accumulated weight gain was 72.67 lbs per head. Cow weight gain was 2.05 per day, 26.67 lbs per acer, and accumulated weight gain was 59.15 lbs per head (table 5).

Cow and calf weight performance on the switchback strategy was greater than those on the one pasture strategy. The calf weight gain per day was 1.6% greater, gain per head was 5.2% greater, and gain per acer was 102.5% greater. The cow weight gain per day was 26.8% greater, gain per head was 27.5% greater, and gain per acre was 145.6% greater (table 5).

Pasture costs were 44.0% lower and cost per day were 43.3% lower on the switchback strategy than those on the one pasture strategy (table 4). The dollar value captured was greater on the switchback strategy, pasture weight gain value was 5.2% greater, net return per cow-calf pair was 33.9% greater, and net return per acre was 138.9% greater, while cost per pound of calf gain was 46.2% lower, than those on the one pasture strategy (table 5).

The two pasture switchback spring crested wheatgrass strategy activated all of the internal grass growth mechanisms yielding greater grass biomass production, greater grass basal cover, and greater development of secondary tillers and fall tillers resulting in greater cow and calf weight gains per head and per day, and remarkably greater weight gains per acre.

Essential Element Absorption

Spring complementary crested wheatgrass pastures should contain a fair amount of standing dead vegetation to slow down the rate of forage passage through the digestive tract of livestock. Management practices that remove 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 tentany while grazing lush spring crested wheatgrass vegetation that contains little standing dead grass. 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. A cows blood serum deficiency of calcium or magnesium is not caused by consuming crested wheatgrass forage deficient in these minerals. Absorption of most essential minerals is by passive diffusion across the intestinal wall; some calcium is transported by 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 the 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 standing 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 in cows grazing crested wheatgrass spring (May) complementary pastures.

Summary

Crested wheatgrass meadows are excellent spring complementary pastures during May. Crested wheatgrass is physiologically ready for grazing in early May. The ability to start grazing a month ahead of the proper grazing start date on native rangeland (1 June) and providing adequate quantities of forage with high nutrient content are the primary biological advantages of crested wheatgrass pastures. The optimum use of crested wheatgrass is grazing during May as spring complementary pastures in conjunction with summer grazing native rangeland rotation systems.

Table 2. Agropyron cristatum, Crested wheatgrass, weekly percent crude protein, percent phosphorus, and phenological growth stages of ungrazed lead tillers in western North Dakota, 1946-1947.

Sample Date	Crude Protein %	Phosphorus %	Phenological Growth Satges
Apr 1			
13	15.5	0.256	Early leaf greenup
19	17.1	0.315	
25	16.2	0.313	
May 4	19.0	0.310	Active leaf growth
10	21.0	0.284	
16	16.2	0.255	Flower stalk developing
23	14.5	0.245	
28	13.5	0.247	Flowering (Anthesis)
Jun 6	12.1	0.232	Seed developing
13	11.5	0.255	
19	10.6	0.225	
26	9.7	0.232	
Jul 2	8.6	0.212	Seed maturing
8	7.5	0.191	
16	7.5	0.181	Seed mature
24	6.4	0.178	Drying
30	6.4	0.183	Drying
Aug 6	5.9	0.148	Drying
13	5.8	0.142	
20	5.8	0.151	
26	5.8	0.147	
Sep 3	4.5	0.148	
12	4.0	0.122	
21	-	-	
29	4.7	0.084	
Oct			
Nov 5	4.2	0.090	Drying

Data from Whitman et al. 1951.

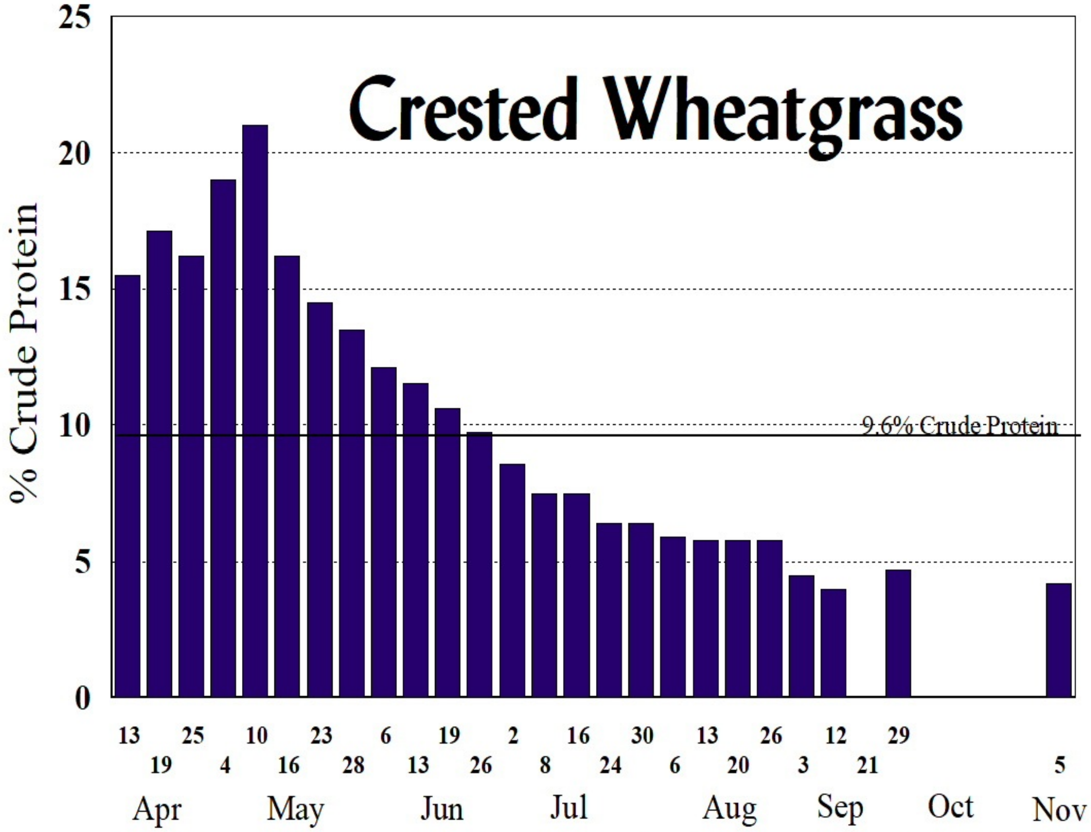

Fig 1. Mean percent crude protein of ungrazed crested wheatgrass in western North Dakota, data from Whitman et al. 1951.

Table 3. Spring herbage biomass (lbs/ac) recovery following May grazing of crested wheatgrass (May) complementary pastures on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Apr	May	Jun	Jul	Aug	Sep
Biologically Effective						
2 Pasture, 1.30 ac/AUM Switchback						
Ungrazed	1330.38	2182.50	2829.06	2570.67	2945.05	2802.96
Grazed		1038.97	1362.88	1796.59	1733.59	1763.57
Traditional						
1 Pasture, 2.33 ac/AUM Unfertilized						
Ungrazed	545.94	1260.70	1265.75	2001.65	1769.43	1992.73
Grazed		797.13	1018.07	1181.96	1101.63	1019.18
% Difference						
Ungrazed	143.7	73.1	123.5	28.4	66.4	40.7
Grazed		30.3	33.9	52.0	57.4	73.0

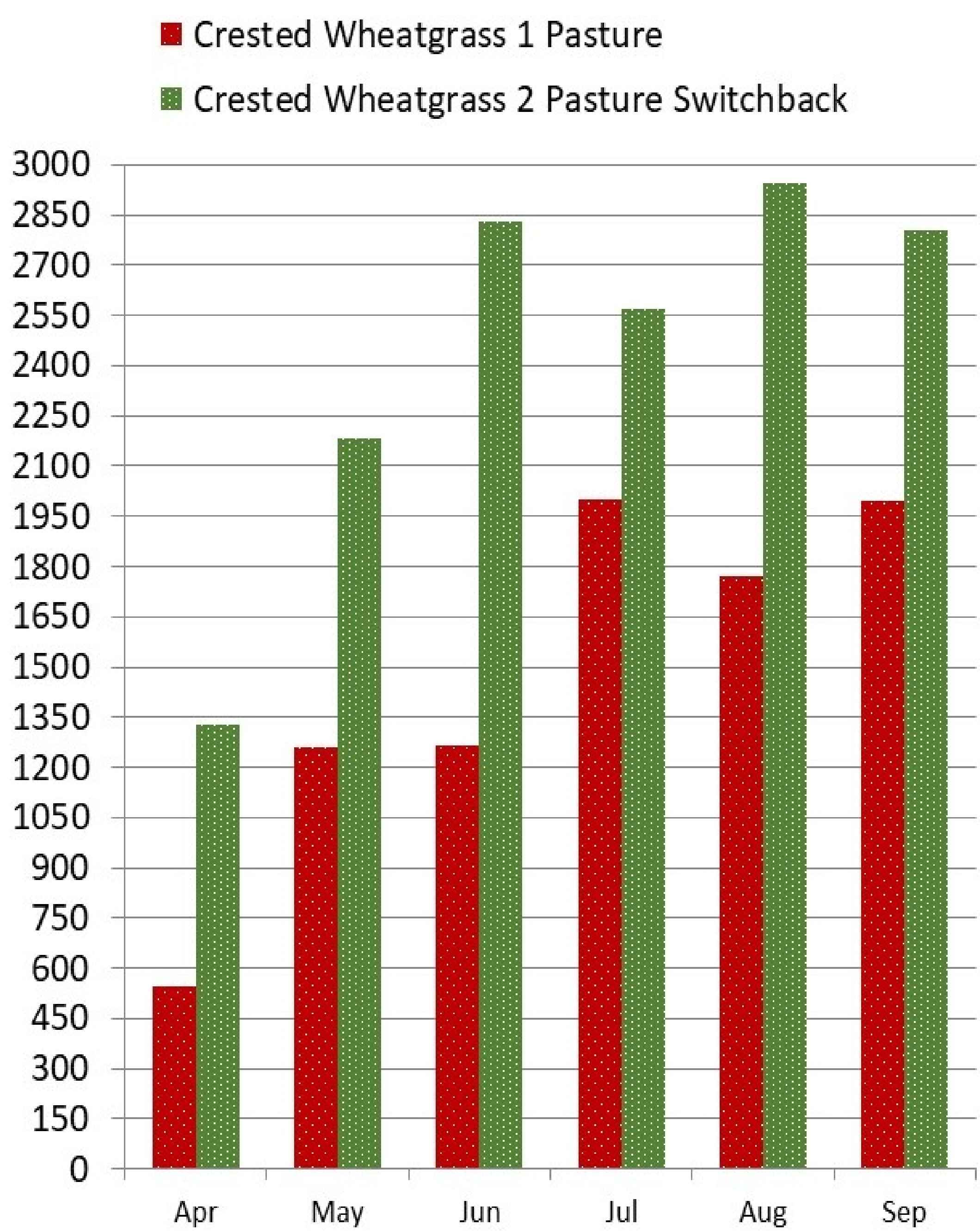

Figure 2. Mean Monthly Crested Wheatgrass Biomass (lbs/ac).

Table 4. Spring grazing period, stocking rate, and pasture cost on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Grazing Period	# Days	# Months	Acres per C-C pr	Acres per AUM	Pasture Cost $	Cost per day $
Biologically Effective	4 May-1 Jun	28	0.92	1.20	1.30	10.51	0.38
Traditional	4 May-1 Jun	28	0.92	2.14	2.33	18.75	0.67
% Difference	same	same	same	-43.93	-44.21	-43.95	-43.28

Table 5. Spring cow and calf weight performance and net returns on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Gain per Head lbs	Gain per Day lbs	Gain per Acre lbs	Pasture Weight Gain Value $	Net Return per C-C pr $	Net Return per Acre $	Cost/lb Calf Gain $
Biologically Effective							
Calf	76.45	2.61	66.60	53.52	43.00	35.84	0.14
Cow	75.43	2.60	65.49				
Traditional							
Calf	72.67	2.57	32.93	50.87	32.12	15.00	0.26
Cow	59.15	2.05	26.67				
% Difference							
Calf	5.20	1.56	102.25	5.21	33.87	138.93	-46.15
Cow	27.52	26.83	145.56				

Summer Unit Pastures

The plant species considered to be native to the Northern Plains originated and developed in other regions. At sometime later these plants migrated into the Northern Plains. None of the living plant species growing in the region are known to have originated in the Northern Plains. The plant communities and vegetation types, however, are relatively young and began development in place about 5000 years ago when the current climate with cycles of wet and dry periods began. The diversity of plant species in these young native plant communities permits the vegetation to respond dynamically to changes in climatic conditions by increasing the plant species favored by any set of conditions. This ability to dynamically adjust to changing climatic factors and the capability to provide adequate quantities of nutritious forage during the entire summer period from 1 June to mid October are ideal characteristics for the summer unit pastures. These plant communities are composed of cool season grasses, warm season grasses, and upland sedges with varying composition.

Major Cool Season Grasses

Prairie Junegrass, *Koeleria macrantha* (Ledeb.) Schult, is a member of the grass family, Poaceae, tribe, Poeae, Syn.: *Koeleria pyramidata* (Lam.) Beauv., *Koeleria cristata* (L.) Pers., and is a native, perennial, monocot, cool-season, mid grass, that is cold and heat tolerant, and drought resistant. The first North Dakota record is Bell 1907. Early aerial growth consists of basal leaves arising from crown tiller buds. Prairie Junegrass consistently reaches the 3.5 new leaf stage by 1 June and is an excellent indicator of physiological grazing readiness of native grasses. Basal leaf blades are 8-18 cm (3-7 in) long, 1-3 mm wide, thick, with broad ribs above and a boat prow shaped tip. The split sheath has overlapping translucent margins with short hairs. The indistinctive collar is continuous. The ligule is membranous, 1.5 mm long, often split, continuous with sheath margins, and fringed with hairs. The auricles are absent. The fibrous root system is primarily shallow, with the greatest concentration in the top 3 cm (1.2 in) of soil. The lateral spread is 20-25 cm (8-10 in) outward from the crown. Most main roots are 0.2 mm thick and remain in the top 46 cm (1.5 ft) of soil, with a few main roots descending down to 76 cm (2.5 ft). Regeneration is primarily asexual propagation by crown tillers. Seedling success is low, primarily because of low seed production, and resulting from poor seedling vigor and high mortality. Flower stalks are erect, 30-60 cm (12-24 in) tall. Inflorescence is a narrow, condensed, panicle, 5-15 cm (2-6 in) long, that opens during flowering becoming plume like, then contracting to narrow spike shape after flowering. Spikelets contain 2 florets. Flowers period is early June to mid July. Leaves are highly palatable to livestock. Fire top kills aerial parts and can consume the entire crown when the soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Prairie Junegrass was based on works of Weaver 1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Simonin 2000, Ogle et al. 2006, Larson and Johnson 2007, and Stubbendieck et al. 2011.

Needle and Thread, *Hesperostipa comata* (Trin. & Rupr.) Barkworth, is a member of the grass family, Poaceae, tribe, Stipeae, Syn.: *Stipa comata* Trin. & Rupr., and is a native, long lived perennial, monocot, cool-season, mid grass, that is highly drought resistant. The first North Dakota record is Bergman 1910. Early aerial growth consists of basal leaves arising from crown tiller buds. Needle and thread consistently reaches the 3.5 (+) new leaf stage by 1 June, however, it rarely retains more than 2 full basal leaves during the early portion of the growing season, eliminating it as an indicator of physiological grazing readiness of native grasses. Basal leaf blades are 10-30 cm (3.9-11.8 in) long, 1-3 mm wide, tapering to a point, with strong ridges on upper surface. Leaves roll inward when dry. The split sheath has overlapping translucent margins. The indistinct collar is continuous and narrow. The ligule is a conspicuous membrane, 3-6 mm long, continuous with sheath margins, often split or frayed. The auricles are absent. This grass is generally considered to be exclusively a bunch grass, however, under proper management, short rhizome tillers can be produced. The extensive fibrous root system is primarily shallow with greater than 50% of the biomass in the top 18 cm (7 in) of soil. The main roots are 1 mm thick and branch profusely with numerous lateral roots. The lateral spread extends 36 cm (14 in) outward from the crown. Several main roots descend down to 91 cm (3 ft) deep with a few main roots extending to 1.8 m (5 ft) deep. Regeneration is primarily asexual propagation by crown tillers. Seedling success is low as a result of poor gemination and competition from established plants. Flower stalks are erect, 30-60 cm(12-24 in) tall. Inflorescence is a narrow panicle with several loosely spreading ascending branches, each with several one flowered spikelets. Flowers are rarely observable because of the prevalence of self fertilization (cleistogamy) within the closed sheath. Floret has a hard sharp pointed base and tip with a 10-

13 cm (4-5 in) long awn that curls as it dries, twisting the seed into the soil. Flower period is late May to late June. The sharp pointed seed with a long awn can cause problems for livestock in hay, however, they rarely cause problems for grazing livestock. Leaves are highly palatable to livestock. Fire top kills aerial parts and fire can consume the entire crown when the soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reductions in biomass and tiller density. This summary information on growth development and regeneration of Needle and thread was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Zlatnik 1999c, Ogle et al. 2006, Larson and Johnson 2007, and Stubbendieck et al. 2011.

Western wheatgrass, *Pascopyrum smithii* (Rydb.) A. Love, is a member of the grass family, Poaceae, tribe, Triticeae, syn., *Elymis smithii*, (Rydb.) Gould, *Agropyron smithii* Rydb., and is a native, long-lived perennial, monocot, cool-season, mid grass, that is tolerant of cold, drought, and periodic flooding, has a high tolerance to alkali and saline soils, and moderately shade tolerant. The first North Dakota record is Potter and Greene 1958. Early aerial growth consists of basal leaves arising from rhizome tiller buds. Leaf blades are 5-25 cm (2-10 in) long, 2-4 mm wide, stiff, thick, deeply ridged on the upper surface, tapering to a point. The split sheath has overlapping margins that open toward the top and has a brown or purplish base. The collar is not well defined, continuous, and medium broad. The ligule is a short flat membrane less than 1 mm long. The auricles are long and clasping, sometimes purplish. The creeping rhizome system is extensive. The aggressive rhizomes are primarily in the top 7.6-10.2 cm(3-4 in) of soil. The frequent branches are 15-91 cm (6-36 in) long, produce single or small groups of aerial stems per node at short progressive intervals. The extensive root system has tough, white or light colored main roots 0.5-1.5 mm thick arising from stem crowns and rhizome nodes growing vertically downward regularly producing profuse quantities of short branches that almost completely occupy the soil. Depth of root penetration varies with soil conditions, usually ranging from 1.2 m (4 ft) to 2.1 m (7 ft) deep. Regeneration is primarily asexual propagation by rhizome tiller buds. Seedling success is low as a result of competition from established plants. Flower stalks are erect, hollow, 30-90 cm(11.8-35 in) tall. Inflorescence is an erect compact spike, 3-16 cm (1.2-6.3 in) long, with overlapping solitary spikelets of 3 to 8 florets. Flower period is June. Aerial parts are highly palatable to livestock. Fire consumes aerial parts halting the process of the four major defoliation resistence mechanisms and causing great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Western wheatgrass was based on works of Weaver 1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Trimenstein 1999, Larson and Johnson 2007, Ogle et al. 2009, and Stubbendieck et al. 2011.

Major Warm Season Grasses

Blue grama, *Bouteloua gracilis* (Kunth) Lag. ex Griffiths, is a member of the grass family, Poaceae, tribe, Cynodonteae, and is a native, long lived perennial, monocot, warm-season, short grass, that is drought tolerant, moderately tolerant of alkaline soils, not tolerant of shading and flooding, and intolerant of acidic and saline soils. The first North Dakota record is Bolley 1891. Early aerial growth consists of basal leaves arising from basal tillers lateral to the crown. Basal leaf blades are 3-10 cm (1.2-3.9 in) long, 1-2 mm wide, tapering to a point. The leaves curl when dry at maturity. The split sheath has translucent margins. The collar is continuous and medium broad with long hairs, at the inside sheath edge. The ligule is a dense fringe of hairs 0.5 mm long. The auricles are absent. The short inconspicuous rhizomes facilitate mat formation. The extensive root system is extremely well developed. The main roots are fine, 0.5-1.0 mm thick, taper to 0.2 mm thick, however, having high tensile strength. The great density is attributed to the abundance of branching. The lateral spread is 20-25 cm (8-10 in) outward from the base of the crown. Most roots grow vertically downward to 91 cm (3 ft) deep with a few main roots extending to 1.8 m (6 ft) deep. Fine lateral roots 1.3-2.5 cm (0.5-1.0 in) long, branched to the 3rd order have a frequency of 1.8 per cm (4.3 per in). The greatest root density occurs in the top 46 cm (4.3 in) of soil permitting rapid response to low precipitation events. Regeneration is primarily asexual propagation by lateral basal tillers. Seedling success is low as a result of competition from established plants. Flower stalks are slender, solid pith filled, 16-50 cm (6-20 in) tall. Inflorescence are 2 (rarely 3) eyebrow shaped spikes 2-5 cm (0.8-2.0 in) long with numerous perfect florets clustered all on one side. Flower period is from early July to August. Aerial parts are highly palatable to livestock. Stevens (1963) claimed that blue grama is our most valuable native pasture grass for drier soil. Fire top kills aerial parts and destroys great proportions of the crown material when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Blue grama was based on works of Weaver 1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Anderson 2003, Larson and Johnson 2007, Wynia 2007, and Stubbendieck et al. 2011.

Little bluestem, *Schizachyrium scoparium* (Michx.) Nash., is a member of the grass family, Poaceae, tribe, Andropogoneae, syn.: *Andropogon scoparius* Michx., and is a native, long lived perennial, monocot, warm-season, mid grass, that is drought tolerant. The first North Dakota record is Bolley 1891. Early aerial growth consists of basal leaves arising from axillary buds of crown tillers and from fall produced tiller buds on short rhizomes. Leaf blades are usually partially folded along mid rib, 5-15 cm (2-6 in) long, 3-6 mm wide, tapering to a point, bluish green with red tinge, constricted at base. The split sheath has nonoverlapping margins, is strongly keeled, and flattened laterally with purplish base. The collar is continuous and broad. The ligule is a fringed membrane, 0.6-2.3 mm long, with a blunt rounded shape, and covered with short hairs. The auricles are absent. The rhizomes are short and can form mats. The extensive root system has numerous tan roots 0.1-1.0 mm thick, branching profusely to the third and fourth order with many branches 76 cm (30 in) long and diverging at various angles. The lateral spread is 30.5-45.7 cm (12-18 in) outward from base of crown then most roots grow vertically downward to 1.4-1.7 m (4.5-5.5 ft) deep. Finely branched rootlets almost completely occupy the top 76 cm (2.5 ft) of soil. Regeneration is primarily asexual propagation by crown tillers and short rhizome tillers. Seedlings are rare and usually have weak vigor. Flower stalks are erect, fine, wiry, flattened towards base, with solid center of pith, 30-80 cm (12-32 in) tall, red to reddish purple, and not grooved. Inflorescence are numerous, single spicate racemes terminal on stem branches, 2.5-7.6 cm (1-3 in) long. Flower period is from early August to September. Leaves are highly palatable to livestock, however, most animals are reluctant to push their nose into the dense concentration of stiff seed heads. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Little bluestem was based on works of Weaver 1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Steinberg 2002, Larson and Johnson 2007, Stubbendieck et al. 2011, and Tober and Jensen 2013.

Prairie sandreed, *Calamovilfa longifolia* (Hook.) Hack. Ex Scribn. & Southw., is a member of the grass family, Poaceae, tribe, Cynodonteae, and is a native, long lived perennial, monocot, warm-season, tall grass, that is drought resistant, tolerant of alkaline soils, not tolerant of salt and susceptible to trampling. The first North Dakota record is Bergman 1911. Early aerial growth consists of basal leaves arising from fall produced tiller buds, that have very sharp tips located at the terminal ends of rhizome branches. Basal leaf blades are 20-30 cm (8-12 in) long, 4-8 mm wide, coarse, firm, leathery, and tapering to a point. The split sheath has overlapping margins with a pinkish base. The distinct inflated collar is broad and continuous with tufts of long fine hairs on the inner margins. The ligule is a dense ring of hairs 1-3 mm long. The auricles are absent. The extensive rhizomes are more than 30 cm (12 in) long, stout, scaly, have a shiny pale whitish color and are terminal with one tiller. The dense fibrous root system has numerous wiry main roots, 2-3 mm thick, arising from stem crowns and rhizome nodes growing vertically and obliquely downward, mostly in the top 46 cm (18 in) of soil, with lateral branches up to 15 cm (6 in) long developing along the full length of the roots, and has a few long main roots that extend down to 1.5 m (60 in) deep, effectively stabilizing deep sandy soils. Regeneration is primarily asexual propagation by large quantities of rhizome tillers. Seedling vigor is only fair and mortality caused by low soil water in the upper layers is high. Flower stalks are robust, 1-2 m (39-79 in) tall, solitary, forming large colonies. Inflorescence is a panicle 10-40 cm (4-16 in) long with whorled ascending branches, that are semi open. Spikelets are 4-7 mm long, and have one floret with a dense basal ring of white hairs. Flower period is from mid July to September. Seed production is low. The leaves are highly palatable and readily eaten by livestock, however, the coarse stems are not eaten, giving the false impression that this grass is undesirable as forage. Fire top kills aerial parts halting the processes of the four major defoliation resistance mechanisms and causing great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Prairie sandreed was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Hauser 2005, Duckwitz and Wynia 2006, Johnson and Larson 2007, and Stubbendieck et al. 2011.

Major Upland Sedges

Threadleaf sedge, *Carex filifolia* Nutt., is a member of the sedge family, Cyperaceae, and is a native, long lived perennial, monocot, cool-season, short graminoid, that is shade tolerant. The first North Dakota record is Bolley 1891. Early aerial growth consists of basal leaves arising from rootstock buds. Basal leaf blades are very fine, thread like, wiry, densely clustered at base with 3 per stem, 7.6-15.2 cm (3-6 in) long, 0.25 mm wide, tapering to a point, usually with edges rolled in, and dark green. Previous years stem and leaf bases are persistent during the following growing season and are chestnut brown. The sheath is papery and squared off at top. The ligule is very a short. The rhizomes are short and black. The extensive fibrous root system has numerous tough, wiry main roots 0.8 mm or less thick, that are resistant to decay as a result of the increased strength from the black pigment, melanin. The lateral spread is from 38 cm (15 in) to 76 cm (30 in) with roots growing obliquely downward, branching profusely, with numerous roots 5 cm (2 in) long. Most main roots descending to 61 cm (24 in) deep and a few long main roots reaching 76 cm (30 in) deep. The terminal ends of the roots are densely appearing broom like (genista). The densest concentration of root mat occurs in the upper 30.5 cm (12 in) of soil. Regeneration is primarily asexual propagation by tiller buds. Flower stalks are erect, triangular in cross section, 10-20 cm (4-8 in) tall. Inflorescence is a solitary terminal narrow spike, 10-25 mm long with male flowers above and a few female flowers below (monoecious). Flower period is from late April to mid June. Aerial parts are highly palatable to livestock. Fire top kills aerial parts and consumes entire crown when soil is dry. This summary information on growth development and regeneration of Threadleaf sedge was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Hauser 2006, and Johnson and Larson 2007.

Needleleaf sedge, *Carex duriuscula* C.A. Mey., is a member of the sedge family, Cyperaceae, syn.: *Carex eleocharis* Bailey, *Carex stenophylla* Wahl., and is a native, long lived perennial, monocot, cool-season, short graminoid, that is drought tolerant. The first North Dakota record is Stevens 1963. Early aerial growth consists of basal leaves arising from rhizome tiller buds. Basal leaf blades are very fine, needle like, stiff, 5-7.6 cm (2-3 in) long, 1-1.5 mm wide, tapering to a point, usually with edges rolled inward. The sheaths are tight and thinning upward. The ligule is wider than long. The dark brown rhizomes are long and slender producing single tillers at 2.5-7.6 cm (1-3 in) progressive intervals. The fibrous root system fans out obliquely downward with numerous main roots that have frequent lateral roots branching to the 2nd and 3rd order forming a dense mat. Regeneration is primarily asexual propagation by rhizome tiller buds. Flower stalks are erect, triangular in cross section, 7.6-20.3 cm (3-8 in) tall. Inflorescence is a solitary, terminal small, spike, 1-2 cm (0.4-0.8 in) long 5-10 mm wide, with male flowers above and few female flowers below (monoecious). Flower period is from May to mid June. Aerial parts are highly palatable to livestock. Fire top kills aerial parts and consumes entire crown when soil is dry. This summary information on growth development and regeneration of Needleleaf sedge was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, and Johnson and Larson 2007.

Nutrient Quality and Phenological Growth

The available nutritional quality of pregrazed lead tillers of native cool and warm season grasses is closely related to the phenological stages of growth and development, which are triggered primarily by the length of daylight (Roberts 1939, Dahl 1995). The length of daylight increases during the growing season between mid April and 21 June and then decreases. All native cool and warm season grasses have adequate levels of energy throughout the growing season.

Native cool season grasses (table 6, figure 3) start early leaf greenup of vegetative carryover tillers in mid April and grow slowly until early May, reaching 59% of the leaf growth in height by mid May with crude protein levels above 16%. Most cool season grasses reach the 3.5 new leaf stage around early June at 73% of the leaf growth in height, contain levels of crude protein above 15% during early to mid June, reach 94% of the leaf growth in height by late June, and 100% of the leaf growth height by late July. Most cool season grasses reach the flower stage before 21 June. After the flower stage, crude protein levels begin to decrease below 15%. During the seed development stage, flower stalks reach 94% of the growth in height by late June and crude protein levels remain above 9.6% until mid July. The growth in height reaches 100% by late July when seeds are maturing and being shed. As the lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility decrease. During late July, crude protein levels drop below 8.0% and below 6.5% in late August (Whitman et al. 1951, Goetz 1963, Manske 2000, 2008b). Crude protein levels of cool season secondary tillers increase above 9.6% during July and August to 13.2% in early September, decrease during September, and drop below 9.6% in early to mid October (Sedivec 1999, Manske 2008b). Phosphorus levels of lead tillers drop below 0.18% in late July, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

Native warm season grasses (table 7, figure 4) start early leaf greenup of vegetative carryover tillers in mid May, have crude protein levels above 15%, reach 44% of the leaf growth in height by early June, containing crude protein above 13% during early to mid June. Most warm season grasses reach the 3.5 new leaf stage around mid June, reaching 85% of the leaf growth in height by late June and reach 100% of height by late July. Seed stalks begin to develop in mid June and reach the flower stage after 21 June with 12.2% crude protein. During the seed development stage, crude protein levels remain above 9.6% until late July when the flower stalks reach 91% of the growth in height. As the lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility decrease. During mid August, crude protein levels drop below 7.0%, seed stalks reach 100% of the growth in height by late August when the seeds are mature and being shed, and drop below 6.0% in crude protein by early September (Whitman et al. 1951, Goetz 1963, Manske 2000, 2008b). Crude protein levels of warm season secondary tillers increase above 9.0% during August to 10.0% in early September, decreases during September, and drop below 9.6% in late September (Sedivec 1999, Manske 2008b). Phosphorus levels of lead tillers drop below 0.18% in late August, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

Crude protein levels of upland sedges (table 8, figure 5) do not follow the same relationship with phenological growth stages as in cool and warm season grasses. Crude protein levels in upland sedges remain high through the flower and seed mature stages. Upland sedges grow very early and produce seed heads in late April to early May and crude protein remains above 9.6% until mid July. Crude protein levels decrease with increases in senescence and drop below 7.8% in early August but do not fall below 6.2% for the remainder of the growing season (Whitman et al. 1951, Manske 2008b). Phosphorus levels drop below 0.18% in mid May when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

The quality of grass forage available to grazing graminivores on grasslands of the Northern Plains is above 9.6% crude protein in the lead tillers of the cool and warm season grasses during mid May to late July. Upland sedges have crude protein levels above 9.6% during early May to mid July. The secondary tillers of the cool and warm season grasses have crude protein levels above 9.6% during mid July to late September or mid October.

The early greenup of rangeland grass in the spring is not from new seedlings but from vegetative carryover tillers that did not produce a seedhead during the previous growing season. Spring growth of carryover tillers depends both on carbohydrate reserves and on photosynthetic products from the portions of previous years leaves that overwintered without cell wall rupture and regreened with chlorophyll. Grass tiller growth and development depend, in part, on some carbohydrate reserves in early spring because the amount of photosynthetic product synthesized by the green carryover leaves and the first couple of early growing new leaves is insufficient to meet the total requirements for leaf growth (Coyne et al. 1995). Grass growth also requires that the tiller maintains adequate leaf area with a combination of carryover leaves and new leaves to provide photosynthetic product for growth of sequential new leaves. The total nonstructural carbohydrates of a grass tiller are at low levels following the huge reduction of reserves during the winter respiration period, and the carbohydrate reserves remaining in the roots and crowns are needed for both root growth and initial leaf growth during early spring. The low quantity of reserve carbohydrates are not adequate to supply the entire amount required to support root growth and also support leaf growth causing a reduction in active growth until sufficient leaf area is produced to provide the photosynthetic assimilates required for plant growth and other processes (Coyne et al. 1995). Removal of aboveground leaf material from grass tillers not yet at the three and a half new leaf stage deprives tillers of foliage needed for photosynthesis and increases the demand upon already low levels of carbohydrate reserves.

Performance of Grass, Livestock, and Rhizosphere Microbes

Native rangeland is the optimum summer pasture selection. There are no other perennial forage plant choices that can perform during the full summer period. The lead tillers of native grasses decrease in nutrient content dropping below a lactating cows requirements during the last two weeks of July. Stimulation of vegetative secondary tillers can provide adequate nutrient quality until late September or mid October when the grazing management strategy activates the ecosystem biogeochemical processes and the internal grass growth mechanisms with coordination of partial defoliation by grazing graminivores that removes 25% to 33% of the leaf material from grass lead tillers at phenological growth stages between the three and a half new leaf stage and the flower stage that occurs during the period from 1 June to 15 July each growing season (Manske 1999, 2011).

The traditional concept summer strategy used one native rangeland pasture (replicated two times) managed with a seasonlong system stocked with 7 cows/80 acres at 11.43 ac/AU and 2.58 ac/AUM from 1 June to 14 October (135 days) (table 12).

The biologically effective concept summer strategy used three native rangeland pastures (replicated two times) managed with a twice-over rotation system stocked with 8 cows/80 acres at 10.22 ac/AU and 2.26 ac/AUM from 1 June to 14 October (135 days) (table 12).

The one pasture traditional concept provided 769.96 lbs/ac of mean total cool and warm season grass herbage per month during the entire 4.4 month grazing period. The three pasture biologically effective concept provided 1010.43 lbs/ac of mean total cool and warm season herbage per month during the grazing period which was 31.2% greater herbage per month than provided on the one pasture system (tables 9 and 10).

The biologically effective strategy greatly stimulated secondary vegetative cool and warm season grass tillers. The cool season grass basal cover was 7.02% producing a great lead tiller herbage peak of 760.51 lbs/ac in July and producing a greater secondary vegetative tiller herbage peak of 826.89 lbs/ac in September. The warm season grass basal cover was 15.95% providing a lead tiller herbage peak of 333.21 lbs/ac in August with secondary vegetative tillers producing herbage biomass greater than 300 lbs/ac during September and October (tables 9 and 11, figure 6).

The traditional strategy stimulated low amounts of secondary vegetative cool and warm season grass tillers. The cool season grass basal cover was 5.85% producing a lead tiller herbage peak of 606.10 lbs/ac in July and producing a small increase in herbage biomass of 33.31 lbs/ac attributed to secondary vegetative tiller growth in September. The warm season grass basal cover was 8.76% providing a lead tiller herbage peak of 287.08 lbs/ac in August with an average decrease of 54.90 lbs/ac in herbage biomass during September and October (tables 10 and 11, figure 7).

The stimulated vegetative cool season grass tillers on the biologically effective strategy had a basal cover that was 20.0% greater, produced a herbage peak biomass in July that was 25.5% greater, and produced a herbage peak biomass in September that was 50.7% greater than those on the traditional strategy. The stimulated vegetative warm season grass tillers on the biologically effective strategy had a basal cover that was 82.1% greater, produced a herbage peak biomass in August that was 16.1% greater, and produced herbage biomass during September and October that was 29.9% greater than those on the traditional strategy.

The mean upland sedge herbage production was 14.2% greater and the mean forb herbage production was 40.0% greater on the traditional concept than those on the biologically effective concept (tables 9 and 10). The increased cool and warm season grass density and herbage production on the twice-over strategy suppressed the upland sedge and forb production.

Native rangeland pastures managed with traditional concepts consistently experience deficiencies in herbage quantity and nutrient quality after mid to late July when the lead tillers are producing seeds. Native rangeland pastures managed with biologically effective concepts consistently experience stimulated secondary vegetative tiller growth that provides additional live grass herbage containing adequate quantities of nutrients to meet the requirements of lactating cows from late July to late September or mid October. The stimulated vegetative tiller growth provides the additional nutrients that improve cow and calf weight performance.

On the biologically effective twice-over rotation strategy, calf weight gain was 2.89 lbs per day, 37.66 lbs per acre, and accumulated weight gain was 380.47 lbs per head. Cow weight gain was 0.66 lbs per day, 8.68 lbs per acre, and accumulated weight gain was 86.92 per head (table 13, figures 8 and 9).

On the traditional seasonlong strategy, calf weight gain was 2.65 lbs per day, 30.61 lbs per acre, and accumulated weight gain was 354.37 lbs per head. Cow weight gain was 0.50 lbs per day, 5.91 lbs per acre, and accumulated weight gain was 67.11 per head (table 13, figures 8 and 9).

Cow and calf weight performance on the biologically effective twice-over rotation strategy was greater than those on the traditional seasonlong strategy. Calf weight was 7.4% greater per head, 9.1% greater per day, and 23.0% greater per acre and cow weight gain was 29.5% greater per head, 32.0% greater per day, and 46.6% greater per acre than those on the traditional strategy (table 13).

Dollar value captured was greater on the biologically effective strategy than those on the traditional strategy. Pasture cost was 10.6% lower and cost per day was 10.8% lower on the biologically effective strategy (table 12). Pasture weight gain value was 7.4% greater, net return per cow-calf pair was 19.5% greater, and net return per acre was 33.7% greater, while cost per pound of calf weight gain was 14.3% lower on the biologically effective strategy (table 13).

Properly functioning grassland ecosystems depend on a large active biomass of rhizosphere microbes. The primary management goal is to increase the rhizosphere microbe biomass to a high level and then to maintain that large biomass each growing season. The fungi, bacteria, and protozoa in the rhizosphere do not have chlorophyll nor direct access to sunlight and, consequently, these microbes are deficient of energy and require an outside source of simple carbon energy. Contrary to common assumptions, there isn't enough short chain carbon energy in recently dead plant material and there isn't enough energy in natural plant leakage to support a large active biomass of soil microbes. The only readily accessible source of large quantities of short chain carbon energy is the surplus fixed carbon energy photosynthesized by grass lead tillers at vegetative phenological growth stages. Grass plants fix a great deal more carbon energy than they use, furthermore, grass plants do not store this surplus fixed energy until the winter hardening period, which starts in mid August. Surplus carbon energy is usually broken down during night respiration. However, grass lead tillers at vegetative growth stages can be manipulated to exudate the surplus carbon energy into the rhizosphere through the roots following removal of 25% to 33% of the aboveground leaf biomass by grazing graminivores. This technique supplies sufficient quantities of short chain carbon energy into the rhizosphere initiating the production of large increases in microbe biomass and activity when 60% to 80% of the lead tiller population are partially defoliated by grazing graminivores during the 45 day stimulation period from 1 June to 15 July.

A rhizosphere volume study with replicated soil cores collected monthly evaluated the effects from three management strategies during study year 20. The management strategies were nongrazed, seasonlong, and twice-over rotation. The third pasture of the twice-over system was grazed during the first grazing period from 1 to 15 July. At that time, surplus carbon energy was exudated from partially defoliated lead tillers through the roots and into the rhizosphere. The rhizosphere microbe biomass increased and the biogeochemical processes that mineralize organic nitrogen into mineral nitrogen greatly increased. By the mid August sample period, the rhizosphere volume had increased 85.7% from the July volume (table 14, figure 10).

Initiation of a twice-over strategy on native rangeland that had previously been managed by nongrazing or traditional seasonlong practices will have a rhizosphere microbe biomass that is low or very low and it will require about three growing seasons to increase the microbe biomass large enough to mineralize 100 lbs/ac of mineral nitrogen. The response from the rhizosphere microbes is not instantaneous. During the first two growing seasons, the increase in rhizosphere biomass is less than 24% change. During the third growing season, the biomass could increase 74%. With the available data, the biomass of mineralized organic nitrogen into mineral nitrogen cannot be determined from the biomass of the rhizosphere, because the relationship between microbe biomass and available mineral nitrogen is not linear. The threshold quantity of mineral nitrogen at 112 kg/ha (100 lbs/ac) must be available in order to fully activate the internal grass growth mechanisms of water use efficiency, vegetative reproduction by tillering, and compensatory physiological processes. The largest rhizosphere biomass measured during this study has been 406 kg/m^3 which apparently mineralized 176 kg/ha (157 lbs/ac) of mineral nitrogen. The quantity of 111 kg/ha (99 lbs/ac) of mineral nitrogen was apparently mineralized by a rhizosphere biomass of 214 kg/m^3 (table 15). In order to provide mineral nitrogen at 112 kg/ha (100 lbs/ac) or greater, the management strategy must maintain a rhizosphere biomass somewhere between 214 kg/m^3 and 406 kg/m^3. The twice-over rotation system is the only management strategy known to be able to maintain a large biomass of rhizosphere microbes.

Native Rangeland Management Recommendations

At the start of this study, the consensus of the experienced range scientists of the Northern Mixed Grass Prairie had concluded that the grazing start date of native rangeland was 15 June based on percent reduction of potential herbage biomass determined by the research of Campbell (1952) and Rogler et al. (1962). Data collected during the early portion of this study showed that native rangeland grass were able to survive and thrive from partial defoliation of 25% to 33% after the 3.5 new leaf stage. This phenological growth stage occurred during early June for most cool season grasses and during mid June for the warm season grasses. This new information changed the recommended grazing start date to 1 June for rotation grazing systems and, ten years later, the grazing start date for seasonlong pastures was moved to 1 June.

Moving the grazing start data of seasonlong management strategies from 15 June to 1 June resulted in an increased cow weight gain per head of 207.8%, gain per day of 163.2%, and gain per acre of 253.9%, and an increased calf weight gain per head of 33.7%, gain per day of 12.8%, and gain per acre of 39.2%; the calf pasture weight gain value increased 33.7%, net return per cow-calf pair increased 85.1%, and net return per acre increased 94.9%.

Moving the grazing start date from 15 June to 1 June and implementing a twice-over rotation management strategy resulted in an increased cow weight gain per head of 298.7%, gain per day of 247.4%, and gain per acre of 419.8%, and increased calf weight gain per head of 43.7%, gain per day of 23.0%, and gain per acre of 71.3%; the calf pasture weight gain value increased 43.5%, net return per cow-calf pair increased 121.3%, and net return per acre increased 160.5%.

The increase in cow and calf weight gain of the seasonlong strategy resulted from trading two weeks of grazing herbage during late October at 5.0% crude protein for two weeks of grazing herbage during early June at 14.3% crude protein. The increased nutrient quality of the herbage during early June also increased cow and calf weight gain on the twice-over rotation strategy. The additional weight gain for cows and calves on the twice-over strategy resulted from the increased herbage biomass and improved nutritional quality provided by the stimulated vegetative secondary tillers during late July to late September or mid October.

Moving the grazing start data to 1 June, add a critical 14 days to the period of time that vegetative secondary tillers can be stimulated for a total period of 45 days from 1 June to 15 July each year.

Crested wheatgrass lead tillers decrease in crude protein content as they develop through the phenological growth stages with the rate of decline increasing after the flower stage on 28 May, by 1 June the crude protein content is at 12.8%. The crude protein content of native rangeland grasses on 1 June is at 15.3% which is 20% greater. This becomes the time (1 June) to move off crested wheatgrass spring pastures unto native rangeland pastures.

The management of grazing livestock on grasslands is much more than just providing grazeable forage to feed growing animals. Grassland renewable natural resources are functioning ecosystems. Grassland ecosystems are operative because of multitudes of biogeochemical processes performed by numerous trophic levels of soil microorganisms. Without the soil microbes, grassland resources would no longer be renewable. These indispensable soil microbes living in the rhizosphere surrounding active perennial grass roots require specific consideration in management practices. In addition, grass plants have numerous internal growth mechanisms that permit grasses to produce herbage and to respond to partial defoliation by replacing removed leaf and stem biomass. This study has determined that four of the grass growth mechanisms are important enough to require specific consideration in management practices.

The basic science of the critical internal grass plant growth mechanisms, the rhizosphere microorganisms, and the major ecosystem biogeochemical processes have been described by physiologists, unfortunately, these descriptions failed to provide instruction on how to apply this critical information to the stewardship of intact grassland ecosystems. The management procedures on how to activate these mechanisms and processes were developed during this study.

The 45 day time period of 1 June to 15 July was determined to be the only period when the internal grass plant growth mechanisms of compensatory physiological mechanisms, vegetative reproduction by tillering, nutrient resource uptake, and water use efficiency could be activated. A threshold of 100 lbs/ac of mineral nitrogen had been previously determined to be necessary to fully activate the water use efficiency mechanisms and the same threshold of a minimum of 100 lbs/ac of mineral nitrogen was determined during this study to also be necessary to fully activate the vegetative reproduction by tillering and the compensatory physiological mechanisms. This same 45 day period was also determined during this study to be the only period when the ecosystem biogeochemical processes performed by the rhizosphere microorganisms could be enhanced by moving surplus short chain carbon energy from grass lead tillers through the roots into the rhizosphere to provide energy to the microbes. This outside source of short chain energy is absolutely necessary to increase the microorganism biomass and activity. During this 45 day time period, native grass lead tillers are at phenological growth stages between the three and a half new leaf stage and the flower stage. At these growth stages, partial defoliation from grazing graminivores that removes 25% to 33% of the aboveground leaf material from 60% to 80% of the lead tillers activates all of these beneficial mechanisms and processes, which are required for grassland ecosystems to function properly at their biological potential.

Management of the Twice-over System

The biologically effective twice-over rotation strategy was designed to coordinate partial defoliation events with grass phenological growth stages, to meet the nutrient requirements of the grazing graminivores, the biological requirements of the grass plants and the rhizosphere microorganisms, to enhance the ecosystem biogeochemical processes, and to activate the internal grass plant growth mechanisms in order for grassland ecosystems to function at the greatest achievable levels.

The twice-over rotation grazing management strategy uses three to six native grassland pastures. Each pasture is grazed for two periods per growing season. The number of grazing periods is determined by the number of sets of tillers: one set of lead tillers and one set of vegetative secondary tillers per growing season. The first grazing period is 45 days long, ideally, from 1 June to 15 July, with each pasture grazed for 7 to 17 days (never less or more). The number of days of the first grazing period on each pasture is the same percentage of 45 days as the percentage of the total season's grazeable forage contributed by each pasture to the complete system. The forage is measured as animal unit months (AUM's). The average grazing season month is 30.5 days long (Manske 2012). The number of days grazed are not counted by calendar dates but by the number of 24-hr periods grazed from the date and time the livestock are turned out to pasture. The second grazing period is 90 days long, ideally from 15 July to 14 October, each pasture is grazed for twice the number of days as in the first period. The length of the total grazing period is best at 135 days; 45 days during the first period plus 90 days during the second period. There is some flexibility in the grazing period dates. The starting date has a variance of plus or minus 3 days with a range of start dates from 29 May to 4 June. This gives an extreme early option to start on 29 May with the first period to 12 July and with the second period to 11 October. The extreme late alternative option can start on 4 June with the first period to 18 July and with the second period to 17 October. There is also the option to add a total of 2 days to the total length of the grazing period. These 2 days can be used when a scheduled rotation date occurs on an inconvenient date by adding one day to each of two rotation dates. The limit of additional days is two per year resulting in a total length of 137 days. If inconvenient rotation dates occur during 3 or more times, an equal number of days greater than two must be subtracted from the grazing season, so total number of days grazed per year does not exceed 137 days. If the start date is later than 4 June, the scheduled rotation dates must remain as if the start date were on 4 June, in order to maintain the coordinated match of the partial defoliation events with the grass phenological growth stages. The total number of days grazed will be 135 days minus the number of days from 4 June to the actual start date. However, it is best to start on 1 June each year.

During the first period, partial defoliation that removes 25% to 33% of the leaf biomass from grass lead tillers between the 3.5 new leaf stage and the flower stage increases the rhizosphere microbe biomass and activity, enhances the ecosystem biogeochemical processes, and activates the internal grass plant growth mechanisms. Manipulation of these processes and mechanisms does not occur at any other time during a growing season. During the second grazing period, the lead tillers are maturing and declining in nutritional quality and defoliation by grazing is only moderately beneficial to grass development. Adequate forage nutritional quality during the second period depends on the activation of sufficient quantities of vegetative secondary tillers from axillary buds during the first period. Livestock are removed from intact grassland pastures in mid October, towards the end of the perennial grass growing season, in order to allow the carryover tillers to store the carbohydrates and nutrients which will maintain plant mechanisms over the winter. Most of the upright vegetative tillers on grassland ecosystems during the autumn will be carryover tillers which will resume growth as lead tillers during the next growing season. Almost all grass tillers live for two growing seasons, the first season as vegetative secondary tillers and the second season as lead tillers. Grazing carryover tillers after mid October causes the termination of a large proportion of the population, resulting in greatly reduced herbage biomass production in subsequent growing seasons. The pasture grazed first in the rotation sequence is the last pasture grazed during the previous year. The last pasture grazed has the greatest live herbage weight on 1 June of the following season (Manske 2018b).

Stocking rates are based on peak herbage biomass on seasonlong grazing practices. The starting stocking rate on the "new" twice-over grazing practice is usually 80% to 100% of the seasonlong stocking rate. It usually requires three grazing seasons with the twice-over strategy stocked at 100% to increase the rhizosphere microbe biomass to be great enough to mineralize 100 lbs/ac of mineral nitrogen (nitrate NO_3 and ammonium NH_4). After the increased rhizosphere microbe biomass can mineralize 100 lbs/ac of mineral nitrogen, the stocking rate can be increased at 10% per year until the system is stocked at 140% of the seasonlong stocking rate. This has been the maximum biological potential reached on North American grasslands from the twice-over rotation strategy.

The amount of mineral nitrogen can be measured. Collect a soil core from silty soil at 0 to 12 and 12 to 24 inch depth during mid May from two or three locations in the entire system. Have a soil laboratory analyze for both nitrate NO_3 and ammonium NH_4. The total mineral nitrogen should equal 100 lbs/ac or greater.

Once a rotation date scheduled has been determined, do not change that schedule greater than one day for any worldly reason. If you do not like your neighbors bull, build a fence that the bull cannot jump. If you have water sources that sometimes go dry, put in a water tank system on a pipeline. Fix the problems that develop with solutions that do not change the rotation schedule.

Table 6. Cool season grasses, weekly percent crude protein, percent phosphorus, and phenological growth stages of ungrazed lead tillers in western North Dakota, 1946-1947.

Sample Date	Crude Protein %	Phosphorus %	Phenological Growth Stages
Apr 1			
13	20.5	0.315	Early leaf greenup
19	23.5	0.346	
25	23.0	0.320	
May 4	21.5	0.301	Active leaf growth
10	18.3	0.303	
16	18.2	0.276	Flower stalk developing
23	16.1	0.239	
28	16.6	0.237	
Jun 6	15.1	0.253	Flower stalk emerging
13	14.4	0.258	
19	15.1	0.244	Flowering (anthesis)
26	12.2	0.232	
Jul 2	11.5	0.228	Seed developing
8	10.3	0.205	Seed maturing
16	10.3	0.203	Seed mature
24	8.3	0.186	Seed shredding
30	8.0	0.177	
Aug 6	6.8	0.149	
13	6.9	0.157	Drying
20	6.7	0.153	
26	6.5	0.141	
Sep 3	5.7	0.124	Drying
12	4.9	0.119	
21	-	-	
29	6.4	0.120	Drying
Oct			
Nov 5	4.9	0.116	Drying

Data from Whitman et al. 1951.

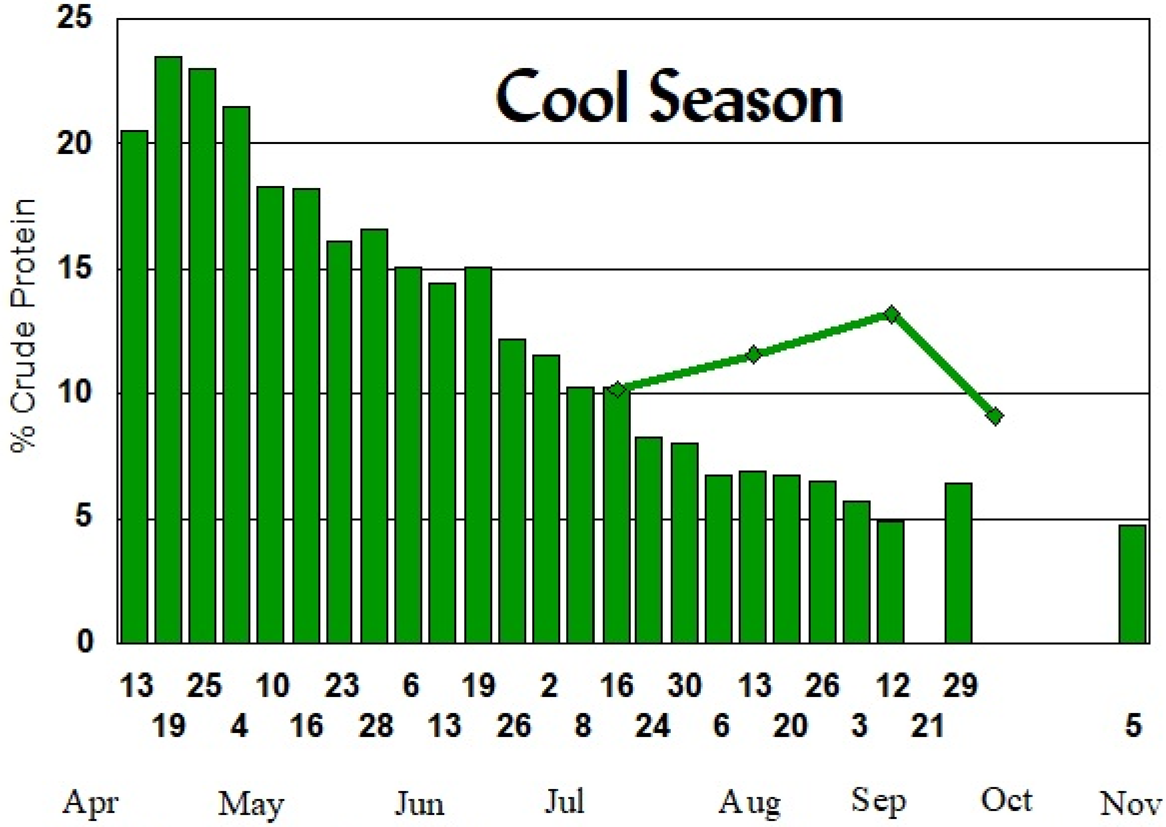

Fig 3. Mean percent crude protein of ungrazed native range cool season grasses in western North Dakota, data from Whitman et al. 1951 and secondary tiller data from Sedivec 1999.

Table 7. Warm season grasses, weekly percent crude protein, percent phosphorus, and phenological growth stages of ungrazed lead tillers in western North Dakota, 1946-1947.

Sample Date	Crude Protein %	Phosphorus %	Phenological Growth Stages
Apr 1			
13			
19			
25			
May 4			
10	15.5	0.267	Early leaf greenup
16	14.7	0.226	
23	15.7	0.232	
28	15.5	0.264	
Jun 6	13.9	0.299	Active leaf growth
13	13.9	0.286	
19	12.3	0.286	
26	12.2	0.275	
Jul 2	11.3	0.245	Flower stalk developing
8	10.4	0.245	Flower stalk emerging
16	9.6	0.222	Flowering (anthesis)
24	9.7	0.226	
30	7.2	0.208	
Aug 6	7.1	0.175	Seed developing
13	7.4	0.186	
20	6.9	0.194	Seed maturing
26	6.2	0.150	
Sep 3	6.4	0.153	Seed mature
12	5.7	0.121	
21	4.8	0.189	Drying
29	4.1	0.076	
Oct			
Nov 5	4.7	0.085	Drying

Data from Whitman et al. 1951.

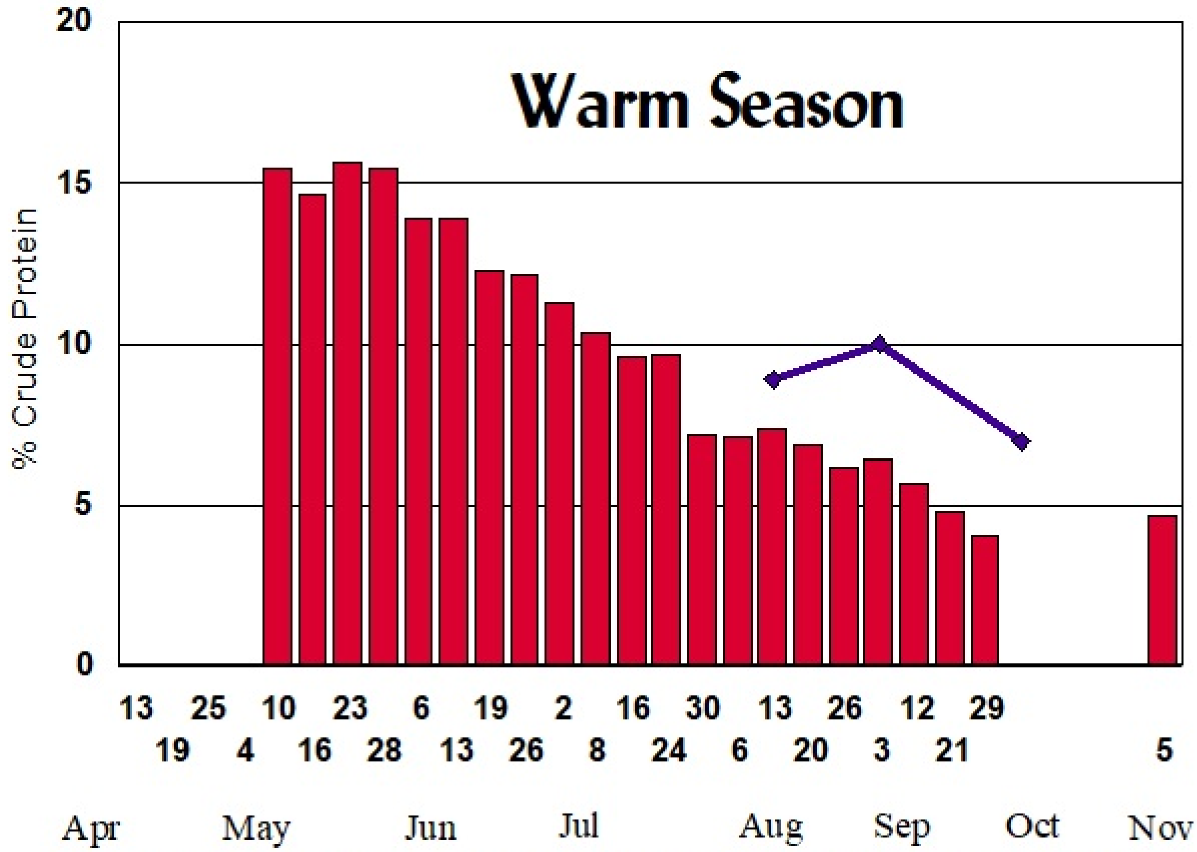

Fig 4. Mean percent crude protein of ungrazed native range warm season grasses in western North Dakota, data from Whitman et al. 1951 and secondary tiller data from Sedivec 1999.

Table 8. Upland sedges, weekly percent crude protein, percent phosphorus, and phenological growth stages of ungrazed lead tillers in western North Dakota, 1946-1947.

Sample Date	Crude Protein %	Phosphorus %	Phenological Growth Stages
Apr 1			
13	14.6	0.270	Flower stalk developing
19	22.2	0.317	
25	15.1	0.210	Flowering (Anthesis)
May 4	15.3	0.210	Seed developing
10	13.2	0.185	
16	15.0	0.170	
23	13.7	0.176	
28	13.8	0.162	Seed maturing
Jun 6	12.9	0.160	
13	14.2	0.160	Seed mature
19	11.3	0.179	
26	12.1	0.152	
Jul 2	11.0	0.153	Drying
8	9.7	0.155	
16	9.8	0.128	
24	8.4	0.122	
30	8.4	0.115	
Aug 6	8.0	0.097	Drying
13	7.5	0.109	
20	7.1	0.118	
26	8.0	0.091	
Sep 3	9.6	0.135	Drying
12	6.3	0.085	
21	-	-	
29	6.8	0.083	
Oct			
Nov 5	6.9	0.096	Drying

Data from Whitman et al. 1951.

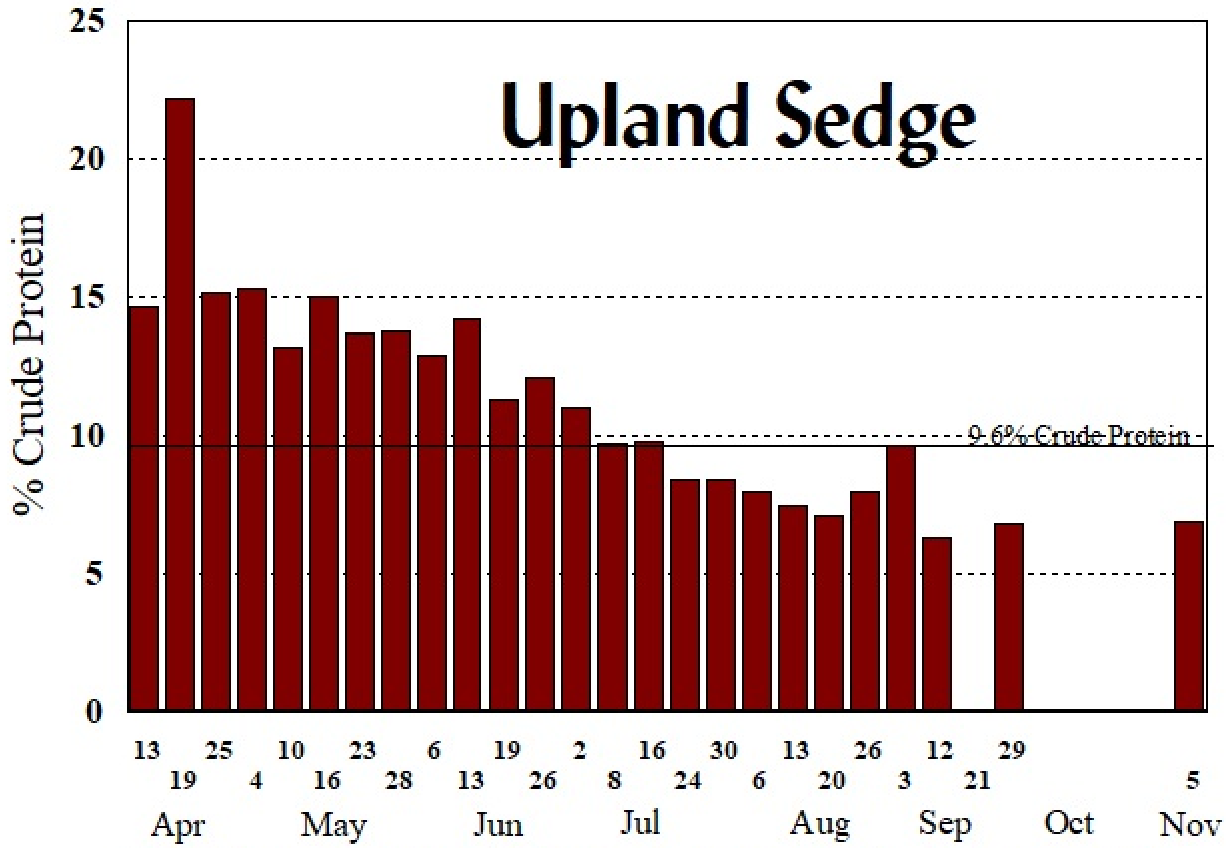

Fig 5. Mean percent crude protein of ungrazed native range upland sedges in western North Dakota, data from Whitman et al. 1951.

Table 9. Mean monthly herbage biomass (lbs/ac) by biotype categories on the silty ecological sites of the Biologically Effective concept, 1983-2012.

Silty Site	May	Jun	Jul	Aug	Sep	Oct
Cool Season	397.73	637.66	760.51	670.20	826.89	698.80
Warm Season	179.90	217.06	304.43	333.21	300.86	302.53
Upland Sedge	165.99	199.29	204.99	175.74	127.28	137.21
Forbs	145.26	146.55	193.27	187.79	164.72	159.88
Grasses	577.63	854.72	1064.94	1003.41	1127.75	1001.33
Graminoids	743.62	1054.01	1269.93	1179.15	1255.03	1138.54
Total	888.88	1200.56	1463.20	1366.94	1419.75	1298.42

Table 10. Mean monthly herbage biomass (lbs/ac) by biotype categories on the silty ecological sites of the Traditional concept, 1983-2012.

Silty Site	May	Jun	Jul	Aug	Sep	Oct
Cool Season	308.46	483.96	606.10	515.39	548.70	542.12
Warm Season	123.98	157.64	244.45	287.08	222.68	241.69
Upland Sedge	168.26	226.16	237.83	222.50	151.45	126.55
Forbs	166.47	218.24	293.73	253.01	212.18	216.13
Grasses	432.44	641.60	850.55	802.47	771.38	783.81
Graminoids	600.70	867.76	1088.38	1024.97	922.83	910.36
Total	767.17	1086.00	1382.11	1277.98	1135.01	1126.49

Table 11. Basal cover (%) of graminoids on the silty sites of the Biologically Effective and Traditional concepts, 1983-2012.

	Biologically Effective		Traditional		
Silty Site	Basal Cover %	Composition %	Basal Cover %	Composition %	Difference %
Cool Season	7.02	24.6	5.85	28.5	20.0
Warm Season	15.95	55.9	8.76	42.6	82.1
Upland Sedge	5.55	19.5	5.95	28.9	-6.7
Grasses	22.97	80.5	14.61	71.1	57.2
Graminoids	28.52		20.56		38.7

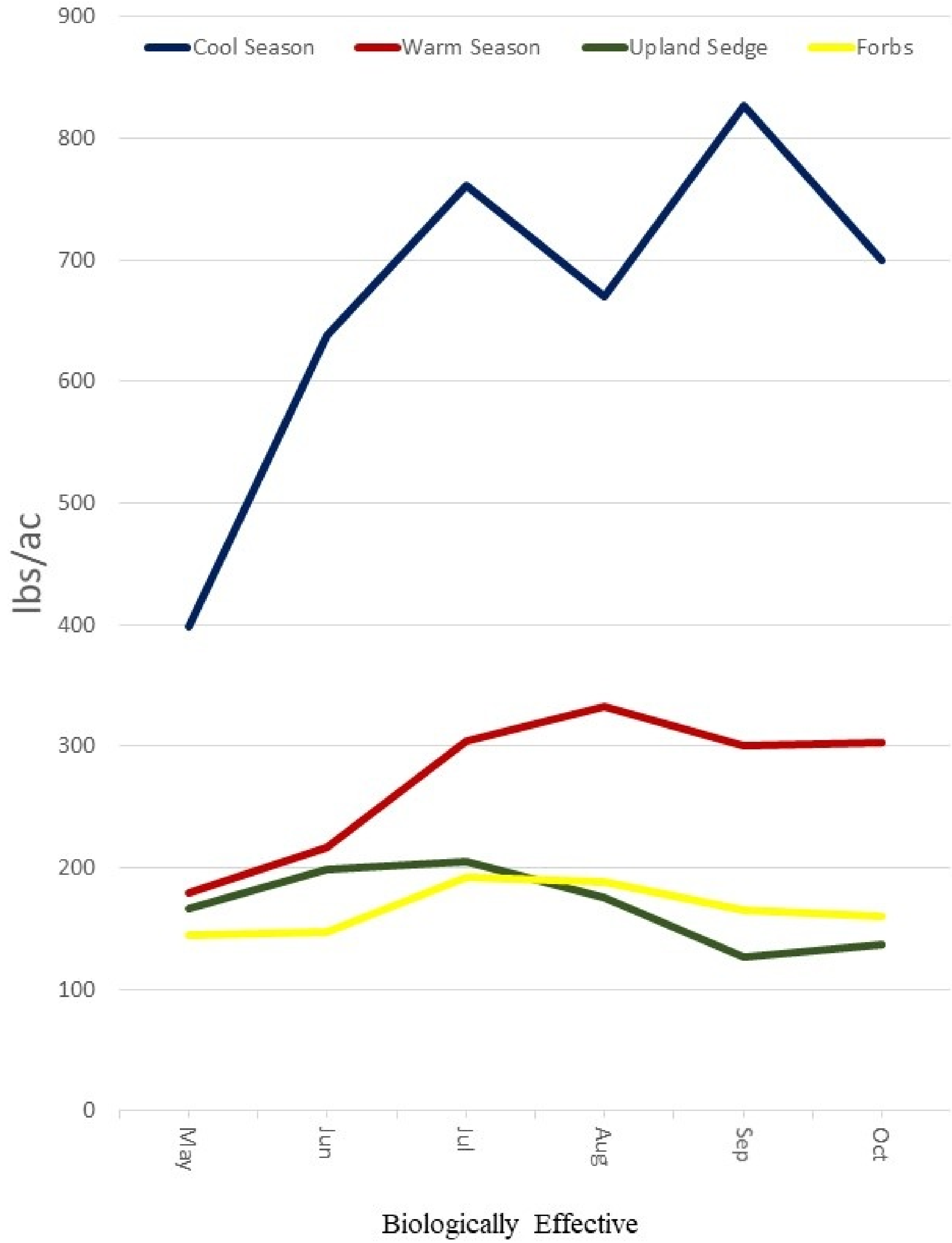

Figure 6. Mean monthly herbage biomass (lbs/ac) by biotypes on the silty site of the Biologically Effective concept, 1983-2012.

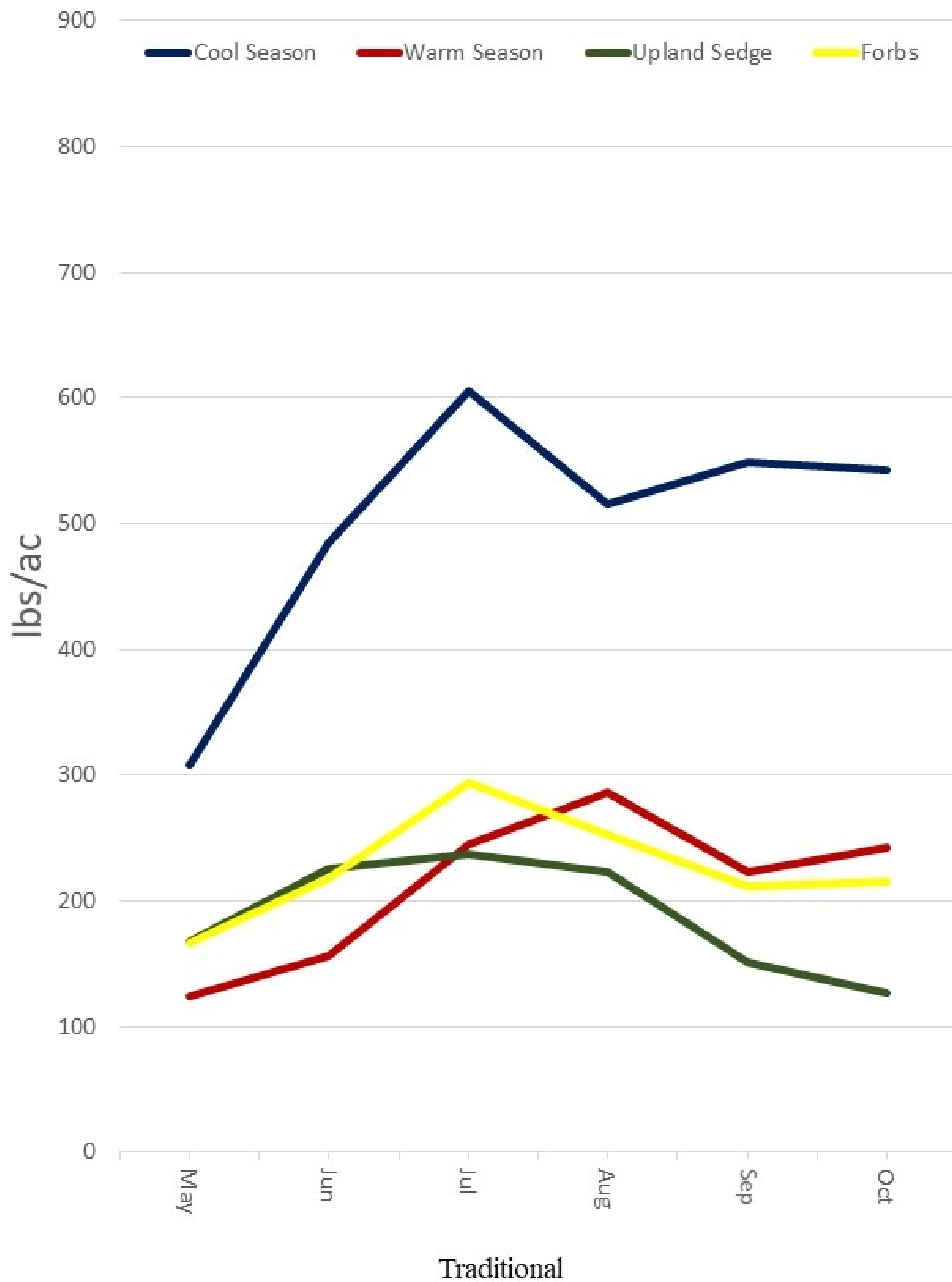

Figure 7. Mean monthly herbage biomass (lbs/ac) by biotypes on the silty site of the Traditional concept, 1983-2012.

Table 12. Summer grazing period, stocking rate, and pasture cost on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Grazing Period	# Days	# Months	Acres per C-C pr	Acres per AUM	Pasture Cost $	Cost per day $
Biologically Effective	1 Jun-14 Oct	135	4.43	10.22	2.26	89.53	0.66
Traditional	1 Jun-14 Oct	135	4.43	11.43	2.58	100.13	0.74
% Difference	same	same	same	-10.59	-12.40	-10.59	-10.81

Table 13. Summer cow and calf weight performance and net returns on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Gain per Head lbs	Gain per Day lbs	Gain per Acre lbs	Pasture Weight Gain Value $	Net Return per C-C pr $	Net Return per Acre $	Cost/lb Calf Gain $
Biologically Effective							
Calf	380.47	2.89	37.66	266.33	176.80	17.30	0.24
Cow	86.92	0.66	8.68				
Traditional							
Calf	354.37	2.65	30.61	248.06	147.93	12.94	0.28
Cow	67.11	0.50	5.91				
% Difference							
Calf	7.37	9.06	23.03	7.37	19.52	33.69	-14.29
Cow	29.52	32.00	46.87				

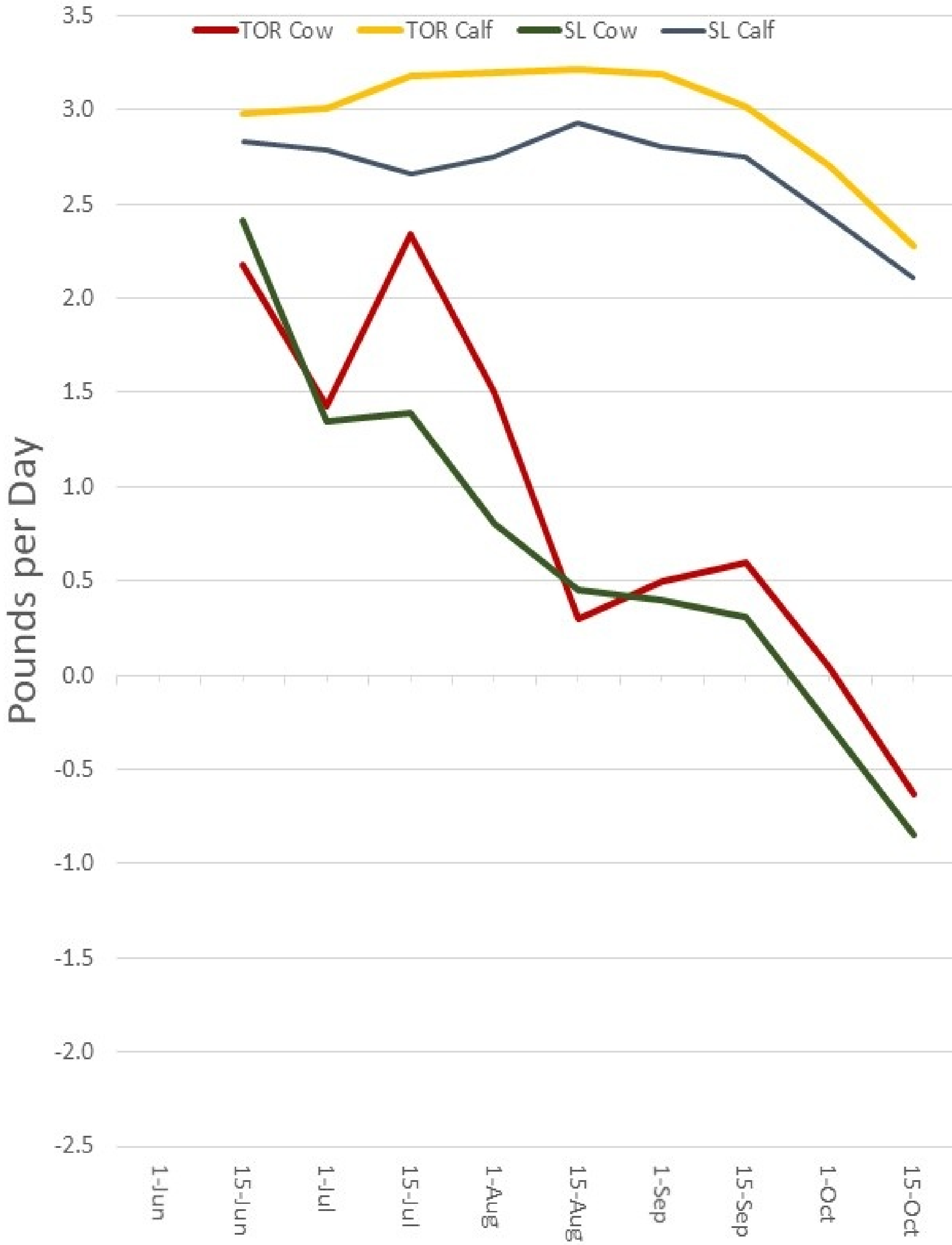

Figure 8. Cow and calf daily gain on the seasonlong and twice-over grazing systems.

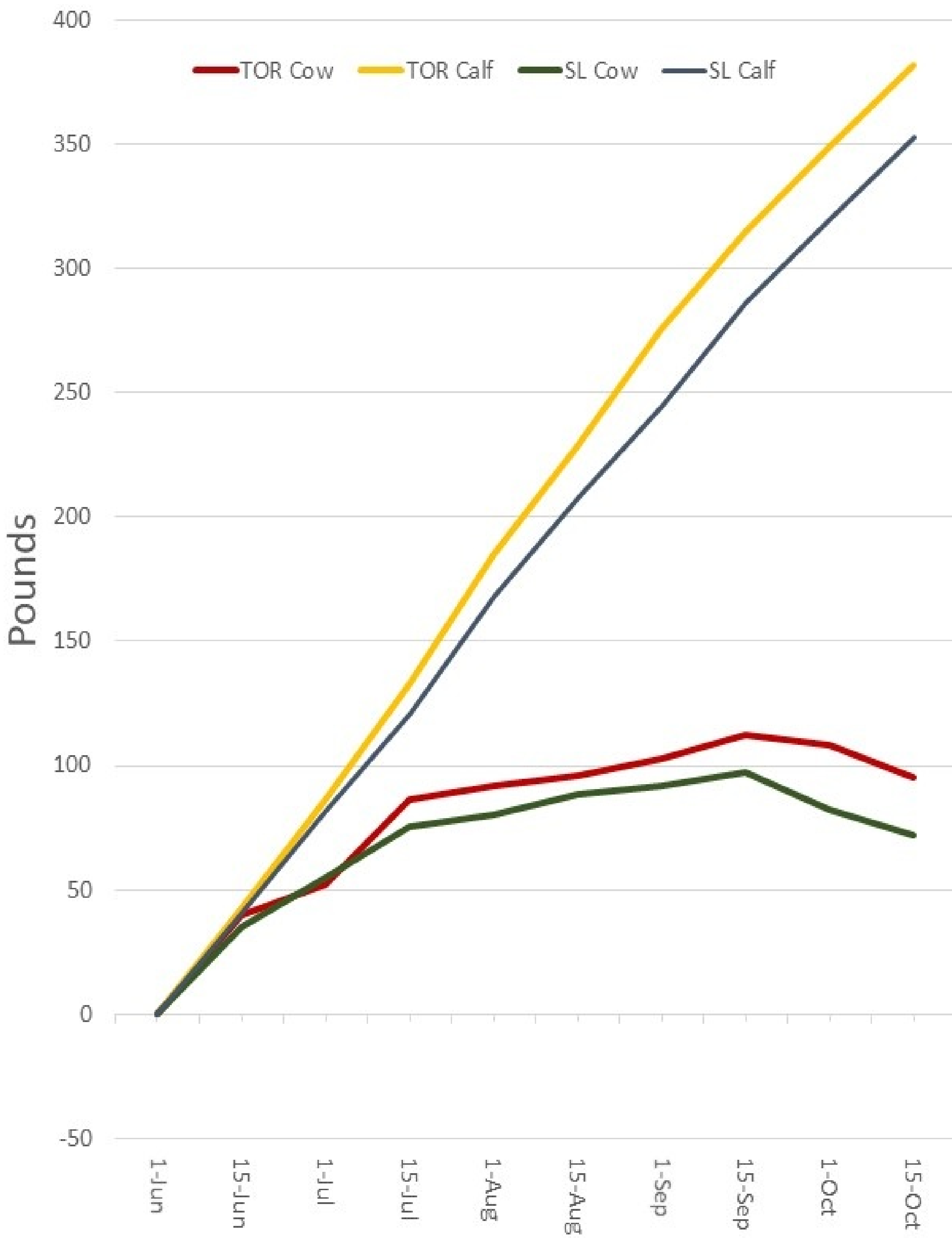

Figure 9. Cow and calf accumulated weight gain on the seasonlong and twice-over grazing systems.

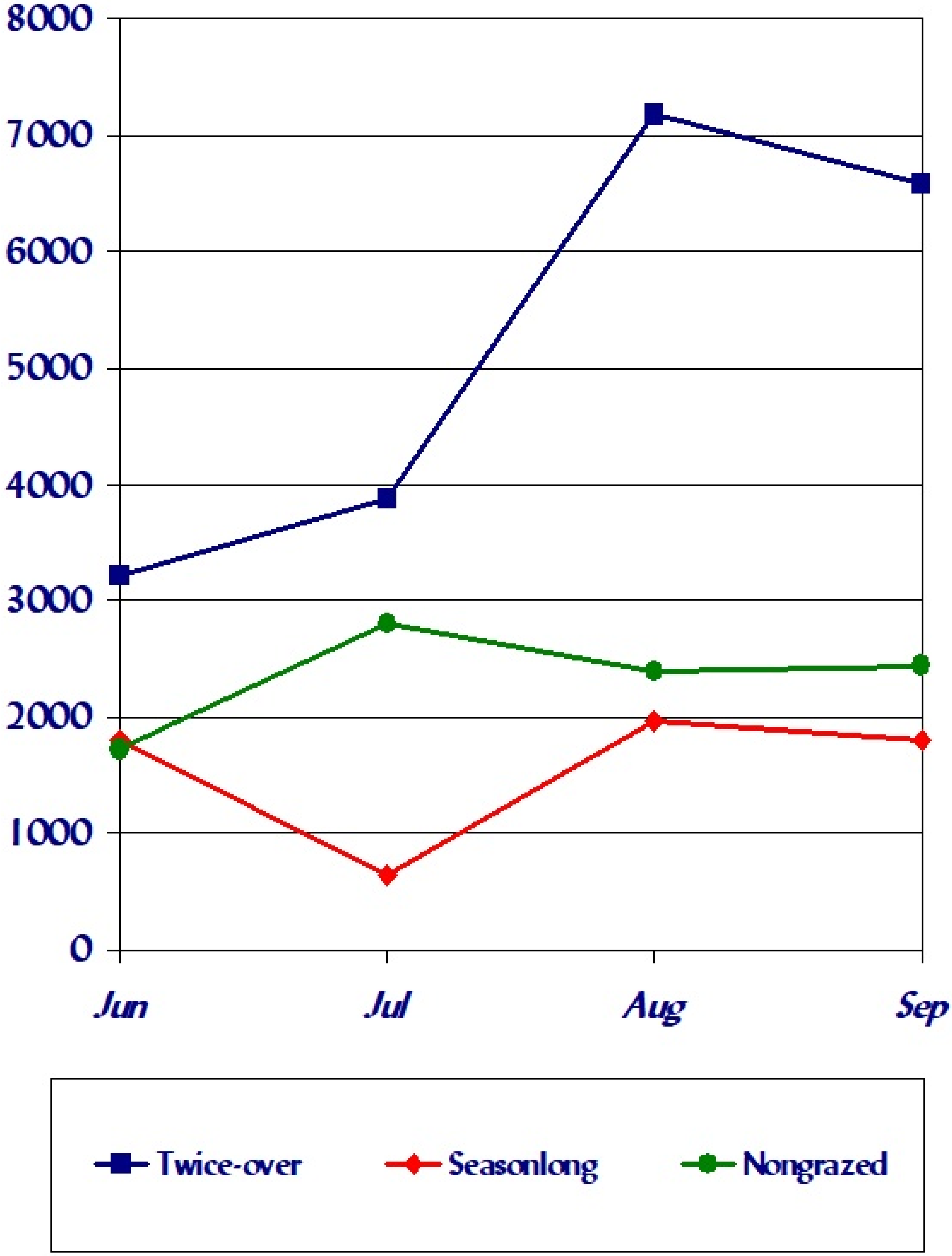

Figure 10. Rhizosphere volume (cm^3) per cubic meter of soil

Table 14. Rhizosphere volume in cubic centimeters per cubic meter of soil (cm^3/m^3), 2002.

Grazing Management	May	Jun	Jul	Aug	Sep	Oct
Nongrazed		1725.24a	2804.61a	2391.97b	2438.47b	
Seasonlong		1800.93a	642.21b	1963.02b	1802.97b	
Twice-over		3214.75a	3867.54a	7183.27a	6586.06a	

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Gorder, Manske, and Stroh, 2004.

Table 15. Rhizosphere biomass categories associated with mineral nitrogen biomass categories,

Management Strategy Concept	Biomass Category	Rhizosphere Biomass (microbes, roots, adhered soil)	Mineral Nitrogen Biomass (threshold at 112 kg/ha (100 lbs/ac)	
		kg/m^3	kg/ha	(lbs/ac)
Nongrazed	Very low	52 to 118	15.1 to 27.0	(13.5 to 24.1)
Traditional	Low	104 to 171	26.3 to 65.2	(23.5 to 58.2)
Biologically Effective	High	214 to 406	111.3 to 176.3	(99.4 to 157.4)

Rhizosphere Biomass Not Linearly Related to Mineral Nitrogen Biomass.

Fall Complementary Pastures

The wildryes are the only perennial grass type that retains adequate nutritional quality to meet a lactating cows requirements during fall grazing from mid October to mid November. Despite these unique important characteristics, wildryes are not a popular fall pasture in the Northern Plains. The problem isn't the grasses. The problem is the management. The wildryes do not grow and behave like native grasses of the Northern Mixed Grass Prairie and cannot be managed with the same techniques that the native grasses are managed. The native grasses plus crested wheatgrass and smooth bromegrass grow and behave as if they were types of perennial spring wheat. The wildrye grasses grow and behave as if they were types of perennial winter wheat. Proper management of wildrye fall pastures must be adjusted to accommodate these differences in growth and behavior.

There are numerous types of wildryes in the world. The two common types in the Northern Plains are Altai and Russian Wildryes.

Altai wildrye, *Leymus angustus* (Trin.) Pilg., is a member of the grass family, Poaceae, tribe, Triticeae, syn.: *Elymus angustus* Trin., and is a long lived perennial, monocot, cool-season, mid grass, that is drought tolerant, very winter hardy, highly tolerant of saline soils nearly at the level of tall wheatgrass, and fairly tolerant of alkaline soils. Altai wildrye was introduced into Canada as two seed lots. The first seed lot arrived in 1934 from Voronezh, USSR, located in the far western European Russian Steppe. The second seed lot arrived in 1939 from the Steppe of Kustanay located in the northern region of Kazakhstan. Three synthetic strains were developed from seed increase plots started in 1950 at the Swift Current Research Station followed by more sites at seven research stations in Alberta, Manitoba, and Saskatchewan, which produced the first released cultivar, Prairieland, in 1976. Seed from the increase fields at Swift Current was used to establish 60 acres of Altai wildrye monoculture at the NDSU Dickinson Research Extension Center for a replicated study of late season grazing during mid October to mid November conducted from 1983 to 2005 for 23 years. Early aerial growth consists of basal leaves from crown tiller buds. Basal leaf blades are 15-25 cm (6-10 in) long, 0.5-0.7 cm wide, erect, coarse, light green to bluegreen to blue, and can remain upright under deep wet snow. The leaf sheath is usually shorter than the internodes and grayish green. The membrane ligule is 0.5-1.0 mm long with an obtuse apex. Some early specimens of introduced strains showed vigorous rhizome charateristics and aggressive spreading which was considered to be undesirable. The available released plant material are generally weakly rhizomatous with short rhizomes. Unfortunately, fields seeded with plant material that has nonaggressive short rhizomes is limited by around a 20 to 25 year life expectancy. However, the uniquely deep extensive fibrous root system that can penetrate to depths of 3-4 m (9.8-13.1 ft) and efficiently absorb available soil water was retained. Regeneration is primarily asexual propagation by crown and short rhizome tiller buds. Seedlings have slow, weak growth and are successful only when competition from established plants is nonexistant. Flower stalks are erect, 60-100 cm (24-39 in) tall, mostly leafless and few in numbers. Inflorescence is a terminal spike 15-20 cm (6-8 in) long, 1 cm in diameter, that has closely spread overlapping spikelets of 2 or 3 florets, with 2 or 3 spikelets per node. Basal leaves are palatable to livestock and seed stalks are not. Wildryes maintain slightly higher levels of protein and digestibility with advancing maturity better than other species of perennial grasses. Wildryes are best used for late season grazing from mid October to mid November. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reduction in biomass production and tiller density. This summary information on growth development and regeneration of Altai wildrye was based on works of Lawrence 1976, and St. John et al. 2010.

Russian wildrye, *Psothyrostachys juncea* (Fisch.) Nevski., is a member of the grass family, Poaceae, tribe, Triticeae, syn.: *Elymus junceus* Fisch., and is a long lived perennial, monocot, cool-season, mid grass, that is exceptionally drought tolerant, tolerant of extremely cold temperatures, highly tolerant of saline soils, fairly tolerant of alkaline soils, intolerant of spring flooding or high water tables, and does not perform well on sandy soils. Russian wildrye was introduced into the United States from Siberia. It was brought to North Dakota in 1907, grown at the Dickinson Research Extension Center in 1913, and grown at the USDA-ARS at Mandan, ND. in 1927. It was introduced into Canada from Siberia in 1926. Early aerial growth consists of basal leaves from crown tiller buds. Basal leaf blades are 7-40 cm (3-16 in) long, 2-6 mm wide, soft, lax, numerous and dense. The split sheath has overlapping margins and open at the top. Previous years sheath bases are persistent and shredded into fibers. The collar is broad and continuous. The membrane ligule is 1 mm long with a blunt flat edge that has numerous small irregular cuts. The small auricles are 2 mm long, clasping, and clawlike. Some plants form no rhizomes, while other plants have several short rhizomes, while other plants have several short rhizomes that form clumps 20-30 cm (8-12 in) wide. Unfortunately, fields seeded with plant material that has nonaggressive short rhizomes is limited by around a 20 to 25 year life expectancy. All bunches have an extensive network of dense, fibrous roots with a lateral spread of 1.2-1.5 m (4-5 ft) that descend downward to 2.5-3.0 m (8-10 ft) deep. About 75% of the root biomass is in the top 15-61 cm (6-24 in) of soil that provides high plant competition to most other species. Regeneration is primarily asexual propagation by crown and short rhizome tiller buds. Seedlings are weak, develop slowly and are successful only when competition from established plants is nonexistant. Flower stalks are erect, hollow, 60-100 cm (24-39 in) tall, mostly leafless and few in number. Inflorescence is a terminal spike 6-11 cm (2.4-4.3 in) long, 5-9 mm wide, that has closely spaced overlapping spikelets of 1 to 4 florets, with 2 or 3 spikelets per node. Flower period in the Great Plains is May and June. Basal leaves are palatable to livestock and seed stalks are not. Wildryes maintain slightly higher levels of protein and digestibility with advancing maturity better than other species of perennial grasses. Wildryes are best used for late season grazing from mid October to mid November. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reduction in biomass production and tiller density. This summary information on growth development and regeneration of Russian wildrye was based on works of Stevens 1963, Dodds 1979, Great Plains Flora Association 1986, Ogle et al. 2005, Taylor 2005, and Johnson and Larson 2007.

Wildryes Require Different Management Practices

Growth characteristics of Altai wildrye is quite different from native cool season grasses. Grazing cool season native grasses during vegetative growth stage prior to the flower stage activates vegetative tiller development from axillary buds. Lightly grazing of Altai wildrye prior to the flower stage did not activate vegetative tillers. Early season grazing actually decreased tiller basal cover. However, fall grazing during mid October to mid November that removed 50% or less of the standing leaf biomass greatly increased vegetative secondary tillers and fall tillers that develop during the following summer and early fall.

During early spring, the carryover tillers that survived the winter in the 50% residual herbage biomass of Altai wildrye tussocks regreened providing most of the carbohydrates and energy used for growth of the current leaves of the new seasons lead tillers. Removal of most of the herbage biomass during the fall grazing period causes termination of a major portion of the living crown tillers with greatly reduced active lead tiller growth and critical reductions in herbage biomass and nutritional quality the following growing season.

Lead tillers produce 3.5 new leaves around early June. The seed stalks develop early and are visible before 21 June. The carryover leaves senescence during June. Most of the aboveground herbage biomass weight in June (1668.80 lbs/ac) is the new leaves and stalks of the current lead tillers (figure 11). After the flower stage, the crude protein content of the lead tillers starts to decrease slowly. The vegetative tillers, that have been activated during the previous fall grazing period, begin visible growth shortly after the lead tillers reach the flower stage. The aboveground herbage biomass during July (2210.59 lbs/ac) and August (2291.83 lbs/ac) is the slowly senescent lead tillers and the rapidly growing vegetative tillers. From mid August to about mid October, the fall tillers develop and produce the additional herbage biomass during September (3021.91 lbs/ac) and October (3140.89 lbs/ac). By mid October, the fall tillers should have around 10% to 12% crude protein, the vegetative tillers should have around 10% to 8% crude protein, and the lead tillers should have 8% to 6% crude protein. The ratio of the three tiller types would effect the mean crude protein level of the Altai wildrye forage during the fall grazing period from mid October to mid November (table 16, figure 11).

The lead tillers terminate at the end of their second growing season, the year they produce a seed head. The vegetative tillers carryover during the winter and become the next seasons lead tillers. The fall tillers carryover during the winter and become the next seasons vegetative tillers, a few well developed fall tillers may become lead tillers. The survival of the carryover vegetative tillers and fall tillers depends on the amount of leaf area they retain at the end of the fall grazing period. When 50% or more of the aboveground herbage remains on mid November (1500.00 lbs/ac), most of the vegetative tillers and fall tillers survive to the next spring. However, when greater than 50% of the aboveground herbage is removed by mid November or during an injudicious longer grazing period after mid November, most of the vegetative tillers and fall tillers will have lost greater leaf biomass than they can recover from, resulting in an extremely low survival rate and a rapidly degrading wildrye stand. This devastating reduction in herbage biomass has been incorrectly blamed unto the grass, not on the management practice that truly caused the reductions.

The wildryes do not increase vegetative tiller growth by light grazing during the early vegetative growth stages of lead tillers before the flower stage. So do not graze wildryes during May or June. Vegetative secondary tillers and fall tillers are stimulated by fall grazing from mid October to mid November. There is no data of grazing stimulation during mid September to mid October. We know that grazing from mid October to mid November works when 1500 lbs/ac residual herbage remain from mid November to spring. That seems like a lot of herbage to leave. Remember that at least 1500 lbs/ac of forage is available to be removed. If the 50% quantity of residual is not remaining at the end of the fall grazing period, the quantity of herbage produced for the next fall grazing period will be much less than the potential 3000 lbs/ac, plus a loss of a potential 1000 lbs/ac to 2000 lbs/ac in additional herbage that could be produced when the grasses remain healthy. The residual of 1500 lbs/ac must remain or your management will fail the vegetation, the stand will deteriorate in 20 to 25 years, and the grass receives the blame. By leaving 50% residual annually, the wildrye stand life expectancy could be perpetual. This will require another long-term research study.

Performance of Grass and Livestock

Altai wildrye is an excellent fall pasture during mid October to mid November. The wildryes have been considered to be difficult to grow because they respond differently than the native grasses and common domesticated grasses to standard grassland practices. The wildryes are different and require different management practices. The wildryes are not the problem. The standard management practices are the problem. With 27 years of research, the problems with the standard practices can be corrected.

Four different forage sources for fall complementary pastures have been evaluated that compared two perennial grass forage types and compared two cropland forage types. Two biologically effective fall complementary pastures are Altai wildrye (perennial grass) and Spring Seeded Winter Cereal (cropland). Two traditional fall pastures are Native Rangeland (perennial grass) and Cropland Aftermath (cropland).

The biologically effective fall complementary perennial grass pasture was Altai wildrye. Cow and calf pairs grazed one pasture of Altai wildrye (replicated two times) at 1.41 ac/AUM for 30 days (1.39 ac/AU) from mid October to mid November (table 17).

The traditional fall complementary perennial grass pasture was native rangeland. Cow and calf pairs grazed one pasture of native rangeland (replicated two times) at 4.11 ac/AUM for 30 days (4.04 ac/AU) from mid October to mid November (table 17).

The one pasture traditional concept of native rangeland provided 891 lbs/ac herbage during the mid October to mid November grazing period leaving a residual of 668 lbs/ac, which would indicate a utilization rate of 223 lbs/ac. There is no new growth of native rangeland after mid October and leaf senescence is greatly accelerated, with nutritional quality below a lactating cows crude protein requirements.

The one pasture biologically effective concept of Altai wildrye provided 3141 lbs/ac herbage during the mid October to mid November grazing period leaving a residual of 1496 lbs/ac, which would indicate a utilization rate of 1645 lbs/ac. The residual herbage would include highly senescent lead tiller leaves that would contain 8% to 6% crude protein, secondary vegetative tiller leaves that would contain 10% to 8% crude protein, and fall tiller leaves that would contain 12% to 10% crude protein. Some of the residual would contain the totally senescent seed heads of which the cows do not consume.

On the Altai wildrye strategy, calf weight gain was 1.82 lbs per day, 37.12 lbs per acre, and accumulated weight gain was 50.34 lbs per head. Cow weight gain was 1.62 lbs per day, 32.22 lbs per acre, and accumulated weight gain was 42.60 lbs per head (table 18).

On the native rangeland strategy, calf weight gain was 0.59 lbs per day, 4.38 lbs per acre, and accumulated weight gain was 17.73 lbs per head. Cow weight loss was 1.74 lbs per day, 12.90 lbs per acre, and accumulated weight loss was 52.20 lbs per head (table 18).

Cow and calf weight performance on the Altai wildrye strategy was greater than those on the native range strategy. The calf weight gain per day was 208.47% greater, gain per head was 183.93% greater, and gain per acre was 747.49% greater. The cow weight gain per day was 193.10% greater, gain per head was 181.61% greater, and gain per acre was 349.77% greater (table 18).

Pasture costs were 65.58% lower and cost per day were 65.25% lower on the Altai wildrye strategy than those on the native range strategy (table 17). The dollar value captured was greater on the Altai wildrye strategy, pasture weight gain value was 183.96% greater, net return per cow-calf pair was 200.35% greater, and net return per acre was 391.56% greater, while cost per pound of calf gain was 87.94% lower, than those on the native range strategy (table 18).

The biologically effective fall complementary cropland pasture was spring seeded winter cereal. Cow and calf pairs grazed four pastures of spring seeded winter rye with each pasture grazed for one week (replicated two times) at 0.48 ac/AUM for 30 days (0.47 ac/AU) from mid October to mid November (table 19).

The traditional fall complementary cropland pasture was cropland aftermath of annual cereal residue of oat and/or barley stubble. Cow and calf pairs grazed one pasture of cereal residue forage (replicated two times) at 6.74 ac/AUM for 30 days (6.63 ac/AU) from mid October to mid November (table 19).

The one pasture traditional concept of cropland aftermath provided 270 lbs/ac herbage during the mid October to mid November grazing period leaving a residual of 135 lbs/ac, which would indicate a utilization rate of 135 lbs/ac. The nutrient content of stubble from annual cereal harvested for grain is almost nonexistent and lactating cows cannot find forage that meets their crude protein requirements.

The four pasture biologically effective concept of spring seeded winter cereal provided 1908 lbs/ac forage during the mid October to mid November grazing period leaving no standing residual vegetation. The livestock had access to one fresh pasture per week with reuse of previous pastures.

On the spring seeded winter cereal strategy, calf weight gain was 2.00 lbs per day, 127.66 lbs per acre, and accumulated weight gain was 60.00 lbs per head. Cow weight gain was 1.05 lbs per day, 67.02 lbs per acre, and accumulated weight gain was 31.50 lbs per head (table 20).

On the cropland aftermath strategy, calf weight gain was 0.42 lbs per day, 1.90 lbs per acre, and accumulated weight gain was 12.57 lbs per head. Cow weight loss was 1.61 lbs per day, 7.27 lbs per acre, and accumulated weight loss was 48.17 lbs per head (table 20).

Cow and calf weight performance on the spring seeded winter cereal strategy was greater than those on the cropland aftermath strategy. The calf weight gain per day was 376.19% greater, gain per head was 377.33% greater, and gain per acre was 6618.95% greater. The cow weight gain per day was 165.22% greater, gain per head was 165.39% greater, and gain per acre was 1021.87% greater (table 20).

Pasture costs were 48.57% greater and cost per day were 50.00% greater on the spring seeded winter cereal strategy than those on the cropland aftermath strategy (table 19). Even though the pasture costs were higher, the dollar value captured was greater on the spring seeded winter cereal strategy, pasture weight gain value was 377.27% greater, net return per cow-calf pair was 600.00% greater, and net return per acre was 7182.09% greater, while cost per pound of calf gain was 68.57% lower, than those on the cropland aftermath strategy (table 20).

Grazing native rangeland after mid October and grazing cropland aftermath of annual cereal residue stubble are old style traditional forage management practices previously used with low-performance livestock that do not work biologically nor economically with modern high-performance livestock. Both practices are deficient at providing adequate forage quality and inefficient at nutrient capture. The cows lose considerable weight and the calf weight gain is diminutive resulting in negative net returns (tables 18 and 20).

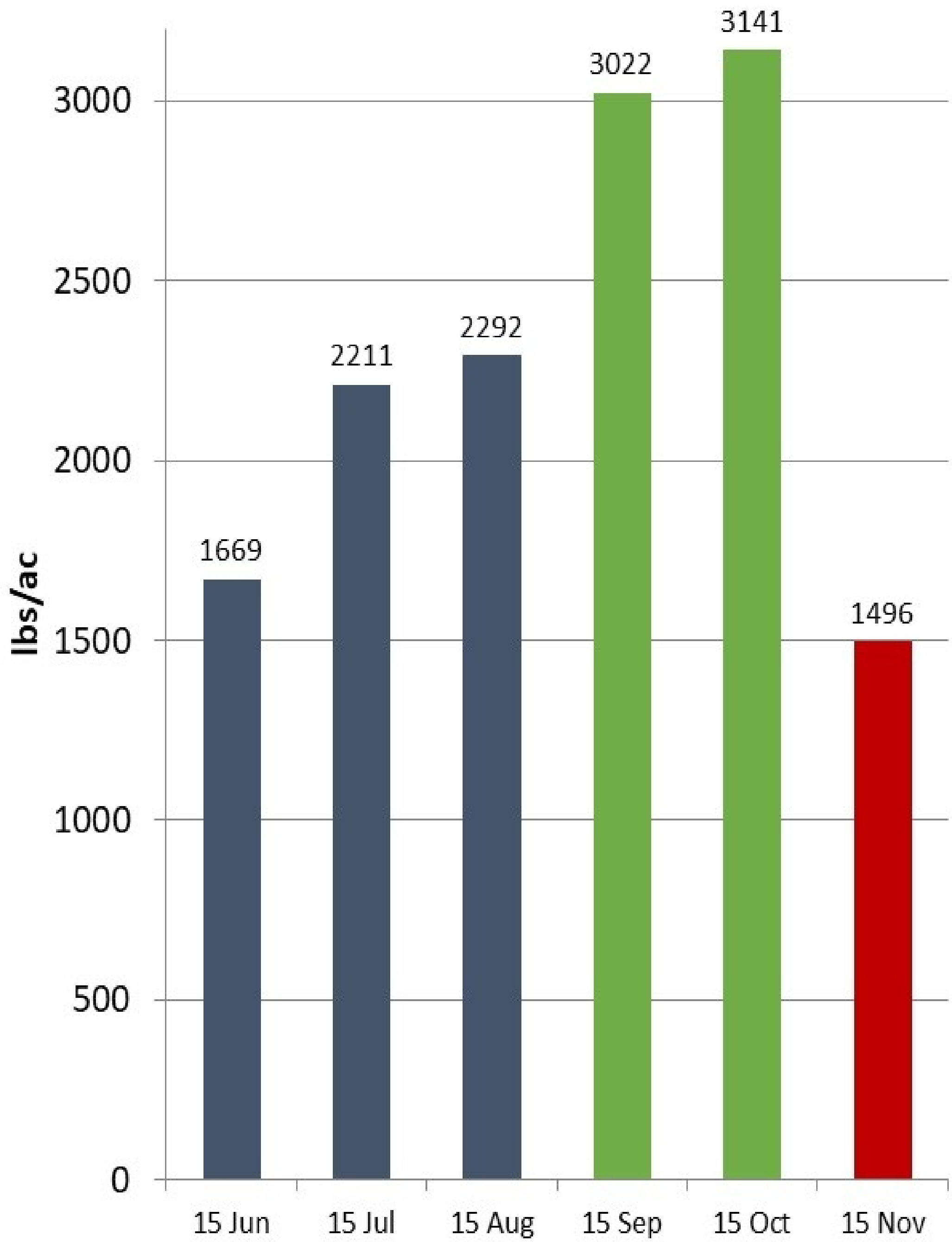

Figure 11. Altai wildrye mean monthly herbage biomass (lbs/ac) on two pastures fall grazed during mid October to mid November, 1984-2002.

Table 16. Conjectural contributions of weight/acre in pounds (lbs) and percentage (%) by the tiller types to total herbage biomass during monthly periods and percent (%) and pounds (lbs) of crude protein from tiller types during the mid October to mid November grazing period.

						Grazing Period	
Tiller Type	Jun	Jul	Aug	Sep	Oct	% CP	lbs CP
Lead Tillers							
lbs/ac	1669	1335	1068	855	684	8%	54.7
%	100.0	60.4	46.6	28.3	21.8		
Secondary Tillers							
lbs/ac		876	1224	1591	1432	10%	143.2
%		39.6	53.4	52.6	45.6		
Fall Tillers							
lbs/ac				576	1025	12%	123.0
%				19.1	32.6		
Total Herbage							
lbs/ac	1669	2211	2292	3022	3141	10.2%	320.9

Table 17. Fall grazing period, stocking rate, and pasture cost on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Grazing Period	# Days	# Months	Acres per C-C pr	Acres per AUM	Pasture Cost $	Cost per day $
Biologically Effective Altai wildrye	14 Oct to 13 Nov	30	0.98	1.39	1.41	12.18	0.41
Traditional Native Rangeland	14 Oct to 13 Nov	30	0.98	4.04	4.11	35.39	1.18
% Difference	same	same	same	-65.59	-65.69	-65.58	-65.25

Table 18. Fall cow and calf weight performance and net returns on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Gain per Head lbs	Gain per Day lbs	Gain per Acre lbs	Pasture Weight Gain Value $	Net Return per C-C pr $	Net Return per Acre $	Cost/lb Calf Gain $
Biologically Effective							
Calf	50.34	1.82	37.12	35.24	23.06	16.59	0.24
Cow	42.60	1.62	32.22				
Traditional							
Calf	17.73	0.59	4.38	12.41	-22.98	-5.69	1.99
Cow	-52.20	-1.74	-12.90				
% Difference							
Calf	183.93	208.47	747.49	183.96	200.35	391.56	-87.94
Cow	181.61	193.10	349.77				

Table 19. Fall grazing period, stocking rate, and pasture cost on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Grazing Period	# Days	# Months	Acres per C-C pr	Acres per AUM	Pasture Cost $	Cost per day $
Biologically Effective Spring Seeded Winter Cereal	14 Oct to 13 Nov	30	0.98	0.47	0.48	19.70	0.66
Traditional Cropland Aftermath	14 Oct to 13 Nov	30	0.98	6.63	6.74	13.26	0.44
% Difference	same	same	same	-92.91	-92.88	48.57	50.00

Table 20. Fall cow and calf weight performance and net returns on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept	Gain per Head lbs	Gain per Day lbs	Gain per Acre lbs	Pasture Weight Gain Value $	Net Return per C-C pr $	Net Return per Acre $	Cost/lb Calf Gain $
Biologically Effective							
Calf	60.00	2.00	127.66	42.00	22.30	47.45	0.33
Cow	31.50	1.05	67.02				
Traditional							
Calf	12.57	0.42	1.90	8.80	-4.46	-0.67	1.05
Cow	-48.17	-1.61	-7.27				
% Difference							
Calf	377.33	376.19	6618.95	377.27	600.00	7182.09	-68.57
Cow	165.39	165.22	1021.87				

Total Pasture Performance of Livestock

The total complementary system evaluated cow and calf weight performance on spring, summer, and fall seasonality pastures managed by two distinctly different concepts; the old style traditional and the modern biologically effective.

On the old style traditional concept, cow and calf pairs grazed one crested wheatgrass spring pasture at 2.14 ac/AU for 28 days during 4 May to 1 June, grazed one summer native rangeland pasture seasonlong at 11.43 ac/AU for 135 days during 1 June to 14 October, and grazed one fall native rangeland pasture at 4.04 ac/AU for 30 days during 14 October to 13 November (table 21). The total complementary system consisted of 17.61 ac/AU grazed for 193 days (6.33 months) from 4 May to 13 November. The total pasture cost was $154.27 per cow-calf pair at a cost per day of $0.80 (table 23). Calf weight gain was 444.77 lbs per head, 2.30 lbs per day, and 25.26 lbs per acre (table 22). Cow weight gain was 74.06 lbs per head, 0.38 lbs per day, and 4.21 lbs per acre (table 22). The gross dollar value captured from calf pasture weight gain was $311.34, net return per cow-calf pair was $157.07, and net return per acre was $8.92, with cost of calf weight gain at $0.50 per lb (table 23).

On the modern biologically effective concept, cow and calf pairs grazed two crested wheatgrass spring pastures in a switchback plan at 1.20 ac/AU for 28 days with each pasture grazed for two alternating 7 day periods during 4 May to 1 June, grazed three summer native rangeland pastures with a twice-over rotation system at 10.22 ac/AU for 135 days with each pasture grazed for two periods per year during 1 June to 14 October, and grazed one Altai wildrye fall pasture at 1.39 ac/AU for 30 days during 14 October to 13 November (table 21). The total complementary system consisted of 12.81 ac/AU grazed for 193 days (6.33 months) from 4 May to 13 November. The total pasture cost was $112.22 per cow-calf pair at a cost per day of $0.58 (table 23). Calf weight gain was 507.26 lbs per head, 2.63 lbs per day, and 39.88 lbs per acre (table 22). Cow weight gain was 204.95 lbs per head, 1.06 lbs per day, and 16.11 lbs per acre (table 22). The gross dollar value captured from calf pasture weight gain was $355.08, net return per cow-calf pair was $242.86, and net return per acre was $18.96, with cost of calf weight gain at $0.22 per lb (table 23).

The spring, summer, and fall grazing periods occurred at the same time, the number of days grazed and the number of months grazed were the same on both concept complementary systems (table 21). The Biologically Effective complementary system grazed 4.8 fewer acres, at $42.05 lower pasture cost per cow-calf pair, and at $0.22 lower cost per day (table 23). On the Biologically Effective concept system, calf weight gain was 62.5 lbs per head greater, at 0.33 lbs per day greater, and at 14.62 lbs per acre greater. Cow weight gain was 130.89 lbs per head greater, at 0.68 lbs per day greater, and at 11.90 lbs per acre greater (table 22). The gross dollar value captured from calf pasture weight gain was $43.74 greater, net return per cow-calf pair was $85.79 greater, and net return per acre was $10.04 greater, with cost of calf weight gain at $0.28 per lb lower (table 23).

A hardworking rancher has 6 sections of land with typical Northern Plains soils and 3840 acres of perennial grass pastures. This rancher firmly believes that the improved genetics of his livestock will enhance the ranches profit margin. He continues to standby the old style traditional management concepts taught to him by his father and grandfather that had pulled the family through many hard times. This land has historically been able to graze 218 cow-calf pairs during a 193 day grazing season on 467 acres of crested wheatgrass in one spring pasture, 2492 acres of summer native rangeland with a seasonlong system, and 881 acres of reserved fall native rangeland in one pasture. The herd gross dollar value captured from the average of 444.77 lbs per calf was $67,872, minus a total pasture cost of $33,631, yields a pasture net return from 218 cow-calf pairs of $34,241.

A neighboring ranch family has 6 sections of land with typical Northern Plains soils and 3840 acres of perennial grass pastures. This two generation ranch family had attended Manske's 3-day grazing workshop in January three years earlier. They now have their pasture land fully implemented with the biologically effective management concept. They have determined that they are able to graze 300 cow-calf pairs during a 193 day grazing season on 360 acres of spring crested wheatgrass with a two pasture switchback plan, 3064 acres of summer native rangeland with a three pasture twice-over system, and 416 acres of fall Altai wildrye in one pasture. The herd gross dollar value captured from the average of 507.26 lbs per calf was $106,524, minus a total pasture cost of $33,666, yields a pasture net return from 300 cow-calf pairs of $72,858. This pasture net return is $38,617 (112.8%) greater than the pasture net returns received from the same type land managed by old style traditional concepts and grazed by identical high-performance modern cow-calf pairs.

Biologically Effective Forage Management Matching Modern Beef Cattle Requirements

Both the old-style traditional concept and the modern biologically effective concept used the same high-performance beef cattle on the same Northern Plains soil types. However, these modern beef cattle did not perform at their genetic potentials when they grazed grassland pastures managed with old style traditional technology that had originally been designed for old-style livestock. Grass lead tillers during the seed development stage drop below the crude protein requirements of lactating cows. This stage occurs during late June for crested wheatgrass, during mid July for native cool season grass, and during late July for native warm season grass and they remain deficient of crude protein during the remainder of the grazing season. Traditional management practices do not stimulate secondary tiller development for herbage growth after mid July. The old-style cows would graze native rangeland during June and early July, put on considerable body fat, and then be able to milk about 6 to 7 lbs/d from that body fat during mid July to mid October. Modern high-performance cows have had the ability to deposit large quantities of body fat genetically removed. The typical quantity of body fat on modern cows can produce milk for about one week. In order for modern cows to perform at their genetic potential, the require quantities of crude protein and energy need to be met everyday.

During each of the three seasonality periods of the spring, summer, and fall pastures of the biologically effective complementary system, the four major grass growth mechanisms and the ecosystem biogeochemical processes were all fully activated by properly coordinated partial defoliation by grazing graminivores.

Full activation of the compensatory physiological mechanisms within grass plants requires the availability of a threshold quantity of 100 lbs/ac of mineral nitrogen, thereafter it, accelerates growth rates of replacement leaves and shoots, increases photosynthetic capacity of remaining mature leaves that increase the quantity of available fixed carbon, increases the uptake of rhizosphere mineralized nitrogen, and increases restoration of biological and physiological processes enabling rapid and complete recovery of partially defoliated grass tillers at a replacement biomass rate of 140% of the grass biomass removed by grazing.

Full activation of the asexual mechanisms of vegetative reproduction by tillering requires the availability of a threshold quantity of 100 lbs/ac of mineral nitrogen, thereafter it, increases secondary tiller development from axillary buds, increased initiated tiller density during the growing season, and increases herbage biomass production, and improves herbage nutritional quality that meets the modern cows crude protein requirements to late September 100% of the years and to mid October 64% of the years.

Full activation of the precipitation (water) use efficiency mechanisms requires the availability of a threshold quantity of 100 lbs/ac of mineral nitrogen, thereafter it, increases herbage biomass production 50.4% per inch of rainfall received and greatly reduces the detrimental effects to grass herbage production during water deficiency periods and during drought conditions.

Full activation of the nutrient resource uptake mechanisms increases root absorption of soil water and the major and minor essential elements, improves the robustness of grass growth and development, increases competitiveness and dominance of healthy grasses, and increases suppression of undesirable grass, weedy forb, and shrub seedlings or rhizome shoots from encroachment and establishment within grassland communities.

A large active biomass from 214 kg/m^3 to 406 kg/m^3 of rhizosphere microorganisms is required to perform the ecosystem biogeochemical processes at potential rates. Biogeochemical processes renew the nutrient flow activities in ecosystem soils of renewable natural resources. Biogeochemical processes transform stored essential elements from organic forms into plant usable inorganic forms. Biogeochemical processes also capture replacement quantities of lost or removed major essential elements of carbon, hydrogen, nitrogen, and oxygen, with assistance from active live plants, and transform the captured major essential elements into storage as organic forms for later use. Biogeochemical processes decompose complex unusable organic material into compounds and then into reusable essential elements.

With the grass growth mechanisms and ecosystem biogeochemical processes functioning at biological potentials, the three indispensable biotic grassland ecosystem components, grass plants, soil microbes, and grazing graminivores have the opportunity to produce at their biological potentials. The biologically effective management of crested wheatgrass produced 73.1% greater herbage biomass during the grazing period than the traditionally managed crested wheatgrass. The biologically effective management of cool season grass produced basal cover at 20.0% greater, July peak herbage at

25.5% greater, and September peak herbage at 50.7% greater than the traditionally managed cool season grass. The biologically effective management of warm season grass produced basal cover at 82.1% greater, August peak herbage at 16.1% greater, and September and October herbage biomass at 29.9% greater than the traditionally managed warm season grass. The biologically effective management of Altai wildrye produced 252.5% greater herbage during the grazing period than the traditionally managed fall native rangeland pasture.

The biologically effective complementary system produced calf weight gain at 14.1% greater per head, 14.4% greater per day, and 57.9% greater per acre, produced cow weight gain at 176.7% greater per head, 179.0% greater per day, and 282.7% greater per acre than that produced on the traditional complementary system. The biologically effective complementary system produced gross dollar value of calf pasture weight gain at 14.1% greater, net return per cow-calf pair at 54.6% greater, and net return per acre at 112.6% greater, with cost of calf weight gain at 56.0% lower per pound than that produced on the traditional complementary system.

Total Complementary Grazing System

The North American beef production industry guided a major effort to improve beef animal genetic productivity resulting in high-performance beef livestock with greater nutrient demand. Imprudently, the forage management technology to meet these higher nutrient requirements at low cost was not simultaneously improved.

Unfortunately, modern beef cattle do not perform at their genetic potentials on pasture forage managed by old style traditional technology. Which has been clearly illuminated by the results of this study (tables 21, 22, and 23). Traditional forage management practices are deficient at providing adequate forage quality during the entire grazing period, inefficient at nutrient capture and conversion, antagonistic to plant growth mechanisms, and suppressive to ecosystem biogeochemical processes performed by the soil microorganisms.

Biologically effective forage management technology has been developed for high-performance beef livestock and is able to provide the biological and physiological requirements to the forage grass plants, soil microorganisms, and grazing livestock, able to activate and maintain the grass plant growth mechanisms and the ecosystem biogeochemical processes, able to revitalize soil structure and functionality, able to increase forage quantity and nutritional quality, and able to improve livestock growth and performance along with the capture of greater wealth per acre from renewable grassland natural resources.

Acknowledgment

I am grateful to Sheri Schneider for assistance in the production of this manuscript and for development of the tables and figures.

Table 21. Total grazing periods, and stocking rates on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept Seasonality Units	Grazing Periods	# Days	# Months	ac/AU	ac/AUM
Biologically Effective					
Spring	4 May-1 Jun	28	0.92	1.20	1.30
Summer	1 Jun-14 Oct	135	4.43	10.22	2.26
Fall	14 Oct-13 Nov	30	0.98	1.39	1.41
Total	4 May-13 Nov	193	6.33	12.81	2.02
Traditional					
Spring	4 May-1 Jun	28	0.92	2.14	2.33
Summer	1 Jun-14 Oct	135	4.43	11.43	2.58
Fall	14 Oct-13 Nov	30	0.98	4.04	4.11
Total	4 May-13 Nov	193	6.33	17.61	2.78
% Difference					
Spring	same	same	same	-43.93	-44.21
Summer	same	same	same	-10.59	-12.40
Fall	same	same	same	-65.59	-65.69
Total	same	same	same	-27.26	-27.34

Table 22. Total cow and calf weight performance on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept Seasonality Units	Gain per Head lbs	Cow Gain per Day lbs	Gain per Acre lbs	Gain per Head lbs	Calf Gain per Day lbs	Gain per Acre lbs
Biologically Effective						
Spring	75.43	2.60	65.49	76.45	2.61	66.60
Summer	86.92	0.66	8.68	380.47	2.89	37.66
Fall	42.60	1.62	32.22	50.34	1.82	37.12
Total	204.95	1.06	16.11	507.26	2.63	39.88
Traditional						
Spring	59.15	2.05	26.67	72.67	2.57	32.93
Summer	67.11	0.50	5.91	354.37	2.65	30.61
Fall	-52.20	-1.74	-12.90	17.73	0.59	4.38
Total	74.06	0.38	4.21	444.77	2.30	25.26
% Difference						
Spring	27.52	26.83	145.56	5.20	1.56	102.25
Summer	29.52	32.00	46.87	7.37	9.06	23.03
Fall	181.61	193.10	349.77	183.93	208.47	747.49
Total	176.74	178.95	282.66	14.05	14.35	57.88

Table 23. Total pasture costs and net returns on the Biologically Effective concept compared to those on the Traditional concept.

Management Strategy Concept Seasonality Units	Pasture Cost $	Cost per Day $	Accumulated Weight lbs	Weight Gain Value $	Net Return per C-C pr $	Net Return per Acre $	Cost/lb Weight Gain $
Biologically Effective							
Spring	10.51	0.38	76.45	53.52	43.00	35.84	0.14
Summer	89.53	0.66	380.47	266.33	176.80	17.30	0.24
Fall	12.18	0.41	50.34	35.24	23.06	16.59	0.24
Total	112.22	0.58	507.26	355.08	242.86	18.96	0.22
Traditional							
Spring	18.75	0.67	72.67	50.87	32.12	15.00	0.26
Summer	100.13	0.74	354.37	248.06	147.93	12.94	0.28
Fall	35.39	1.18	17.73	12.41	-22.98	-5.69	1.99
Total	154.27	0.80	444.77	311.34	157.07	8.92	0.50
% Difference							
Spring	-43.95	-43.28	5.20	5.21	33.87	138.93	-46.15
Summer	-10.59	-10.81	7.37	7.37	19.52	33.69	-14.29
Fall	-65.58	-65.25	183.93	183.96	200.35	391.56	-87.94
Total	-27.26	-27.50	14.05	14.05	54.62	112.56	-56.00

Literature Cited

Anderson, M.C. 2003. Boutelona gracilis. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Association of Official Agricultural Chemists. 1945. Official and tentative methods of analysis. Ed. 6. Washington, DC. 932pp.

Bolin, D.W. and O.E. Stamberg. 1944. Rapid digestion method for determination of phosphorus. Ind. and Eng. Chem. 16:345.

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Crider, F.J. 1955. Root-growth stoppage resulting from defoliation of grass. USDA Technical Bulletin 1102. 23p.

Dahl, B.E. 1995. Developmental morphology of plants. p. 22-58. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Dodds, D.L. 1979. Common grasses and sedges in North Dakota. NDSU Extension Service R-658. Fargo, ND.

Duckwitz, W. and R. Wynia. 2006. Calamovilfa longifolia. Scribn. Plant Database. USDA. Natural Resources Conservation Service. Bismarck, ND. and Manhattan, KS. http://plants.usda.gov/

Great Plains Flora Association. 1986. Flora of the Great Plains. University of Kansas, Lawrence, KS.

Goetz, H. 1963. Growth and development of native range plants in the mixed prairie of western North Dakota. M. S. Thesis, North Dakota State University, Fargo, ND. 165p.

Gorder, M.M., L.L. Manske, and T.L. Stroh. 2004. Grazing treatment effects on vegetative tillering and soil rhizospheres of western wheatgrass. NDSU Dickinson Research Extension Center. Range Research Report DREC 04-1056. Dickinson, ND. 13p.

Hauser A.S. 2005. Calamovilfa longifolia. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Hauser A.S. 2006. Carex filifolia. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Johnson, J.R., and G.E. Larson. 2007. Grassland plants of South Dakota and the Northern Great Plains. South Dakota University. B 566 (rev.). Brookings, SD.

Larson, G.E., and J.R. Johnson. 2007. Plants of the Black Hills and Bear Lodge Mountains. 2nd Edition. South Dakota State University, Fargo, ND. 219p.

Lawrence, T. 1976. Prairieland, Altai wildryegrass. Canadian Journal of Plant Science 56:991-992.

Manske, L.L. 1994. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings - Leafy Spurge Strategic Planning Workshop. USDI National Park Service, Dickinson, ND. p. 3-16.

Manske, L.L. 1999a. Can native prairie be sustained under livestock grazing? Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, AB. p. 99-108.

Manske, L.L. 1999b. Annual nutritional quality curves for domesticated cool season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1024. Dickinson, ND. 13p.

Manske, L.L. 2000. Grass growth in height. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 00-3020. Dickinson, ND. 4p.

Manske, L.L. 2008a. Annual mineral quality curves for graminoids in the Northern Plains. NDSU Dickinson Research Extension Center. Range Management Report DREC 08-1030b. Dickinson, ND. 15p

Manske, L.L. 2008b. Annual nutritional quality curves for graminoids in the Northern Plains. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 08-3014c. Dickinson, ND. 15p.

Manske, L.L. 2011. Biology of defoliation by grazing. NDSU Dickinson Research Extension Center. Range Management Report DREC 11-1067b. Dickinson, ND. 25p.

Manske, L.L., and J.A. Urban. 2012. Humane soil beastie catcher: Its fabrication and use. NDSU Dickinson Research Extension Center. Range Research Report DREC 12-1079. Dickinson, ND. 9p.

Manske, L.L. 2012. Length of the average grazing season month. NDSU Dickinson Research Extension Center. Range Management Report DREC 12-1021c. Dickinson, ND. 2p.

Manske, L.L. 2014. The modern range cow has greater nutrient demand than the old style range cow. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 14-3063. Dickinson, ND. 6p.

Manske, L.L. 2016a. The renewability of grazingland ecosystems. NDSU Dickinson Research Extension Center. Range Research Report DREC 16-1092b. Dickinson, ND. 14p.

Manske, L.L. 2016b. Autecology of prairie plants on the Northern Mixed Grass Prairie. NDSU Dickinson Research Extension Center. Range Research Report DREC 16-1093. Dickinson, ND. 38p.

Manske, L.L. 2018a. Range plant growth related to climate factors of Western North Dakota, 1982-2017. NDSU Dickinson Research Extension Center. Range Research Report DREC 18-1078g. Dickinson, ND. 19p.

Manske, L.L. 2018b. Restoring degraded grasslands. pp. 325-351. in A. Marshall and R. Collins (ed.). Improving grassland and pasture management in temperate agriculture. Burleigh Dodds Science Publishing, Cambridge, UK.

National Research Council (NRC). 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

North Dakota Agricultural Statistics Service. 1993. North Dakota Agricultural Statistics 1993. North Dakota State University and U.S. Department of Agriculture. Fargo, ND. 112p.

North Dakota Agricultural Statistics Service. 1994. North Dakota Agricultural Statistics 1994. North Dakota State University and U.S. Department of Agriculture. Fargo, ND. 112p.

Ogle, D., L. St. John, J. Cornwell, L. Holzworth, M. Majerus, D. Tober, K.B. Jensen, and K. Sanders. 2005. Psothyrostachys juncea (Fisch.) Nevski. Plant Database. USDA. Natural Resources Conservation Services. Boise, ID. http://plants.usda.gov/

Ogle, D.G., L. St. John, M. Majens, D. Tilley, T.A. Jones, S. Parr. 2006. Koeleria macrantha (Ledeb) J.A. Schultes. Plant Database. USDA. Natural Resources Conservation Service. Boise, ID. http://plants/usda.gov/

Ogle, D.G., M. Majens, L. St. John, D. Tilley, T.A. Jones, S. Parr. 2006. Hesperostripa comata (Trin. & Rupr.) Barkworth. Plant Database. USDA. Natural Resources Conservation Service. Boise, ID. http://plants/usda.gov/

Ogle, D.G. 2006a. Agropyron desertorum (Fisch. ex Link) J.H. Schultes. Plant Database. USDA. Natural Resources Conservation Service. Boise, ID. http://plants.usda.gov/

Ogle, D.G. 2006b. Agropyron cristatum (L.) Gaertn. Plant Database. USDA. Natural Resources Conservation Service. Boise, ID. http://plants.usda.gov/

Ogle, D.G., L. St. John, and S.R. Winslow. 2009. Plant guide for western wheatgrass (Pascopyrum smithii). USDA. Natural Resources Conservation Service. Boise, ID. http://plants.usda.gov/

Ogle, D.G., L. St. John, and K. Jensen. 2013. Plant Guide for Siberian wheatgrass (Agropyron fragile). USDA. Natural Resources Conservation Service. Aberdeen, ID. http://plants.usda.gov/

Roberts, R.M. 1939. Further studies of the effects of temperature and other environmental factors upon the photoperiodic response of plants. Journal of Agricultural Research 59:699-709.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. North Dakota Agricultural Experiment Station. Bulletin 439. 15p.

St. John, L., D.G. Ogle, W. Duckwitz, and D. Tober. 2010. Plant Guide for Altai wildrye (Leymus angustus). USDA. Natural Resources Conservation Service. Aberdeen, ID. http://plants.usda.gov/

Sedivec, K. 1999. Nutritional quality of selected rangeland plants. Summary Report. NDSU Animal and Range Sciences Department. Research Report. Fargo, ND.

Simionin, K. 2000. Koeleria macrantha. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Steinberg, P.D. 2002. Schizachyrium scoparium**.** Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Stevens, O.A. 1963. Handbook of North Dakota plants. North Dakota Institute for Regional Studies. Fargo, ND.

Stubbendieck, J., S.L. Hatch, and N.M. Bryan. 2011. North American wildland plants. 2nd Ed. University of Nebraska Press. Lincoln, NE.

Taylor, J.E. 2005. Psothyrostachys juncea. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Tober, D. and N. Jensen. 2013. Plant guide for little bluestem (Schizachyrium scoparium). USDA. Natural Resources Conservation Service. Bismarck, ND. http://plants.usda.gov/

Trimenstein D. 1999. Pascopyrum smithii. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database/feis/

Weaver, J.E. 1954. North American Prairie. Johnsen Publishing Co. Lincoln, NE. 348p.

Whitman, W.C. c. 1950. Native range plants-their growth and development in relation to the establishment of standards for their proper utilization. Hatch Project 9-5.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Wynia, R. 2007. Boutelona gracilis (Kunth) Lag. Ex Griffiths. Plant Database. USDA. Natural Resources Conservation Service. Manhattan, KS. http://plants.usda.gov/

Zaczkowski, N.K. 1972. Vascular flora of Billings, Bowman, Golden Valley, and Slope Counties, North Dakota. PhD. Thesis. North Dakota State University, Fargo, ND. 219 p.

Zlatnik, E. 1999a. Agropyron desertorum. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database.feis/

Zlatnik, E. 1999b. Agropyron cristatum. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us/database.feis/

Zlatnik, E. 1999c. Hesperostripa comata. Fire Effects Information System. USDA. Forest Service. http://www.fs.fed.us.database/feis/