# Autecology of Kentucky Bluegrass on the Northern Mixed Grass Prairie

Llewellyn L. Manske PhD
Research Professor of Range Science
North Dakota State University
Dickinson Research Extension Center
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The autecology of Kentucky bluegrass, *Poa pratensis*, is one of the prairie plant species included in a long ecological study conducted at the NDSU Dickinson Research Extension Center during 67 growing seasons from 1946 to 2012 that quantitatively describes the changes in growth and development during the annual growing season life history and the changes in abundance through time as affected by management treatments for the intended purpose of 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 2016).

Kentucky bluegrass, *Poa pratensis* L., is a member of the grass family, Poaceae, tribe, Poeae, and is a naturalized (introduced from Europe by early colonists but more probably around the early 1000's), long lived perennial, monocot, cool-season, mid grass, that is intolerant of drought, intolerant of waterlogged soil, intolerant of dense shade but tolerant of slight partial shade, and is a high water user and a high nitrogen user. The first North Dakota record is Bergman 1910. Early aerial growth consists of basal leaves arising from rhizome tiller buds. Basal leaf blades are generally short 1-15 cm (0.4-6.0 in) long, 0.9-3.6 mm wide, keeled, with tip boat prow shaped. The split sheath has thin, translucent margins that overlap for the lower ½. The collar is narrow and continuous. The membranous ligule is 0.51 mm long, continuous with sheath margins, and has a squared off edge. The auricles are absent. The dense rhizome system forms thick mats. The long creeping rhizomes frequently branch producing several tillers at each node at progressive intervals. The dense shallow root system has very fine branching roots arising from stem crowns and rhizome nodes thickly occupying the top 46 to 61 cm (1.5-2.0 ft) of soil with a few long main roots reaching 91 cm (3.0 ft) deep. Most of the roots and rhizomes are in the top 7.6 cm (3 in) of soil that dries out easily. Regeneration is primarily asexual propagation by crown and rhizome tiller buds. Seedlings are somewhat successful where competition from established plants is nonexistent because viable seed production is frequently high. Flower stalks are erect, slender, wiry, 30-60 cm (12-24 in) tall and round in cross section. Inflorescence is a moderately open, somewhat contracted pyramidal panicle, 5-10 cm (2-4 in) long, with 3-5 branches in whorls at each node. Spikelets are laterally compressed with 3 to 6 florets. Flower period is from mid May to late June. Aerial parts are nutritious only before flowering. Forage biomass production is lower than for native grasses because of the high water use and long summer dormancy period. Fire top kills aerial parts and can consume entire crown when soil is dry with a temperature great enough to kill some of the shallow rhizomes and roots. 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 Kentucy bluegrass was based on works of Weaver 1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Uchytil 1993, Wennerberg 2004, Johnson and Larson 2007, and Stubbendieck et al. 2011.

## Procedures

### The 1946-1947 Study

Grass and upland sedge species samples to determine crude protein and phosphorus content were collected weekly during the growing seasons of 1946 and 1947 from two seeded domesticated grasslands and a native rangeland pasture at the Dickinson Research Extension Center located at Dickinson in western North Dakota. Current year's growth of lead tillers of each species was included in the sample; previous year's growth was separated and discarded. Ungrazed samples were collected for each species except for Kentucky bluegrass, which only grew along a watercourse where almost all of the plants had been grazed and remained in an immature vegetative stage, however, a small number of plants escaped grazing and developed normally providing the phenological development data. 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 for each species on sample dates. These data are reported as phenological growth stage in the current report. The grass nutritional quality and phenological growth data were published in Whitman et al. 1951.

**The 1969-1971 Study**

The range of flowering time of grasses and upland sedges was determined by recording daily observations of plants at anthesis on several prairie habitat type collection locations distributed throughout 4,569 square miles of southwestern North Dakota. The daily observed flowering plant data collected during the growing seasons of 1969 to 1971 from April to August were reported as flower sample periods with 7 to 8 day duration in Zaczkowski 1972.

**The 1976-1978 Study**

A study to quantify the phenological development of Kentucky bluegrass on the Dakota Sandhills Region in Ransom and Richland Counties in southeastern North Dakota was conducted during 1976 to 1978 (Manske 1980).

Twelve paired plot study areas were established in five grazing allotments on identical soil series with similar slope and relief. One of the plots excluded grazing with an exclosure constructed of barbed wire fence. The other plots was exposed to grazing. Each paired plot consisted of three plant communities. The mixed grass prairie was located on the upland summit and shoulder slopes, the tall grass prairie was located on the midland back slope and extended into the foot slope, and the wet meadow was located on the lowland foot and toe slopes. Phenological data were collected on a permanent meter wide transect on the slope position of best development on each paired plot. Poa pratensis data was collected on two transects, one in the upland site and the other in the midland site.

Leaf and stalk heights were measured on ten plants in each of the twelve study sites (n = 120) with a meter stick to the nearest 0.1 cm during each biweekly sample period from June through August. The measurements made in the grazed treatment were made on ungrazed plants. Basal leaf heights were measured from ground level to tip of extended leaf. The stalk heights were measured after culms had thickened from ground level to the tip of the stalk or the apex of the top floret. An estimation of the percentage of leaf dryness was recorded as an indication of the degree of senescence. The categories of dryness were; new growth, 0%, <2%, <25%, <50%, <75%, <100%, and 100% dry. The separation between the <2% and <25% dry indicated the start of senescence.

The stages of flower stalk development were recorded as phenophases; flower stalk developing, head emergence, anthesis, seed developing, and seeds being shed. Daily field records were kept from 1 April through 10 September on dates of growth indication, first head emergence, and first flowers at anthesis.

**The 1978-1990 Study**

A study to reduce escaped Kentucky bluegrass in grasslands with fire was part of a larger study to investigate the possibilities of using repeated prescribed burning treatments in the restoration of degraded mixed grass prairie.

The prescribed burning strategy that used an every-other-year burn regime was designed to reduce the invading western snowberry and escaped exotic grasses and to renovate the prairie ecosystem. Annual burn treatments were not possible because of insufficient annual production of plant biomass for fuel (Smith 1985). The study area was divided into 15 prescribed burn management units separated by fire breaks with an average size of 530.5 acres (214.9 ha) and 6 control management units of no burning with an average size of 436.8 acres (176.9 ha). The prescribed burns were conducted during four seasons: early spring (mid-late April), spring (May-mid June), early summer (mid June-July), and mid summer (early-mid August). The number of repeated every-other-year burn treatments was: 1 burn, 2 burns, 3 burns, and 4 burns in a 13 year period. Control treatments of no burns had no wildfires or prescribed burns for over 100 years prior to the start of the study in 1978.

Plant species composition was determined between mid July and mid August during peak growth by the plant shoot cover method (% shoot frequency) (Cook and Stubbendieck 1986), with one hundred 0.1 $m^2$ quadrats placed systematically along designated landscape transects to include summit, shoulder, back, foot, and toe slope plant communities for each management unit and burn treatment recording each plant species present in each frame placement.

Soil microorganism activity was monitored by the quantity of available soil inorganic (mineral) nitrogen, both ammonium $NH_4$ and nitrate $NO_3$, collected during mid June and mid August. Five replicated soil cores 1 inch (2.54 cm) in diameter and 6 inches (15.24) in depth were collected from nearly level loam soils along the permanent landscape transects of each control and prescribed burn treatment and air dried. In the laboratory, subsamples of the five soil cores were evaluated for total incubated mineralizable nitrogen with procedures outlined by Keeney (1982). Inorganic forms of nitrogen, ammonium $NH_4$ and nitrate $NO_3$, were extracted and analyzed by steam distillation (Keeney and Nelson 1982) and reported in pounds per acre.

**The 2006-2011 Study**

A study to reduce escaped Kentucky bluegrass in grasslands with proper grazing management was part of a larger study designed to restore the native grassland ecosystem through implementation of biologically effective grazing management of a degraded untilled mixed grass prairie that had been invaded by undesirable domesticated grasses.

The twice-over rotation grazing management strategy was the biologically effective management practice implemented to restore the degraded mixed grass prairie plant communities. The study area had not been grazed during the previous 13 years. As a result of the nondefoliation management by complete rest, the land became severely degraded and dominated with undesirable introduced cool season domesticated grasses primarily Kentucky bluegrass and smooth bromegrass. The total area was divided into 4 pastures with 3 pastures grazed and 1 pasture ungrazed as the control. The three grassland pastures were grazed from early June until mid October, with each pasture grazed for two periods. Each of the three pastures in the rotation was grazed for 14 to 16 days during the first period, the 45 day interval from 1 June to 15 July, during which the four main defoliation resistance mechanisms can be activated with partial defoliation by grazing. During the second period, the 90 days after mid July and before mid October, each pasture was grazed for double the number of days that it was grazed the first period. Two of the grazed pastures and the control pasture were invaded primarily by Kentucky bluegrass and the third grazed pasture was invaded by smooth bromegrass and Kentucky bluegrass. The effects of the grazing management on Pastures 1 and 2 were compared to the control of no grazing on Pasture 4 from late May through mid October during six growing seasons, 2006 to 2011.

Permanent sample plots were established in each pasture on silty ecological sites and organized in a paired-plot design. A 16' X 32' (4.88 m X 9.75 m) stock panel exclosure prevented livestock access on an ungrazed plot and a grazed plot on an adjacent area of equal size was accessible by livestock. Ecosystem changes in plant species basal cover and % composition, and rhizosphere biomass, were the data evaluated.

Plant species basal cover was determined by the ten-pin point frame method (Cook and Stubbendieck 1986), with 2000 points collected along permanent transect lines at each sample site both inside (ungrazed) and outside (grazed) each exclosure during peak growth between mid July and mid August. Basal cover plant species data were sorted into biotype categories: domesticated Kentucky bluegrass, cool season grasses, warm season grasses, sedges, forbs, and litter. Relative percent composition of basal cover biotype categories were determined.

Rhizosphere biomass was collected at each sample site outside (grazed) each exclosure by three replicated soil cores 3 inches (7.6 cm) in diameter and 4 inches (10.2 cm) in depth during 3 grazing season periods: pregrazing (May), first rotation (July), and second rotation (October), with the mean of 3 used as the annual level, using a humane soil beastie catcher (Manske and Urban 2012). The fresh rhizosphere material, which included the rhizosphere organisms, the active plant roots, and the adhered soil particles, was separated from matrix soil by meticulous excavation with fine hand tools. Both wet and dry rhizosphere weights were collected. Rhizosphere biomass per volume of soil were determined from the soil core rhizosphere weight data and reported as kilograms per cubic meter.

Soil mineral nitrogen, nitrate and ammonium, was sampled at each exclosure by three replicated soil cores at increments to a 24 inch (61 cm) depth collected using a 1 inch (2.5 cm) Veihmeyer soil tube at the end of the grazing season. Soil cores were placed on ice immediately and were frozen within 2 to 3 hours after collection. Analysis of soil core samples for available mineral nitrogen ($NO_3$ & $NH_4$) was conducted by the North Dakota State University Soil Testing Laboratory.

**The 1983-2012 Study**

A long-term change in grass and upland sedges species abundance study was conducted during active plant growth of July and August each growing season of 1983 to 2012 (30 years) on native rangeland pastures at the Dickinson Research

Extension Center ranch located near Manning, North Dakota. Effects from three management treatments were evaluated: 1) long-term nongrazing, 2) traditional seasonlong grazing, and 3) twice-over rotation grazing. Each treatment had two replications, each with data collection sites on sandy, shallow, and silty ecological sites. Each ecological site of the two grazed treatments had matching paired plots, one grazed and the other with an ungrazed exclosure. The sandy, shallow, and silty ecological sites were each replicated two times on the nongrazed treatment, three times on the seasonlong treatment, and six times on the twice-over treatment.

During the initial phase of this study, 1983 to 1986, the long-term nongrazed and seasonlong treatments were at different locations and moved to the permanent study locations in 1987. The data collected on those two treatments during 1983 to 1986 were not included in this report.

Abundance of each grass and upland sedge species was determined with plant species basal cover by the ten-pin point frame method (Cook and Stubbendieck 1986). The point frame method was used to collect data at 2000 points along permanent transect lines at each sample site both inside (ungrazed) and outside (grazed) each exclosure. Basal cover, relative basal cover, percent frequency, relative percent frequency, and importance value were determined from the ten-pin point frame data. Point frame data collection period was 1983 to 2012 on the twice-over treatment and was 1987 to 2012 on the long-term nongrazed and on the seasonlong treatments. However, point frame data was not collected during 1992 on the sandy ecological sites of all three treatments.

During some growing seasons, the point frame method did not document the presence of a particular plant species which was reflected in the data summary tables as a 0.00 or as a blank spot.

The 1983-2012 study attempted to quantify the increasing or decreasing changes in individual plant species abundance during 30 growing seasons by comparing differences in the importance values of individual species during multiple year periods. Importance value is an old technique that combines relative basal cover with relative frequency producing a scale of 0 to 200 that ranks individual species abundance within a plant community relative to the individual abundance of the other species in the community during the growing season. Basal cover importance value ranks the grasses, upland sedges, forbs, and shrubs in a community. The quantity of change in the importance value of an individual species across time indicates the magnitude of the increases or decreases in abundance of that species relative to the changes in abundance of the other species.

**Results**

Carolus Linnaeus (1707-1778) named *Poa pratensis* L. in the 1753 edition of Species Plantarum and did not include a common name nor did he separate European source plant material and North American source plant material. Poa pratensis has traditionally been considered to be indigenous to North America primarily in the Great Lakes Region of the United States and Canada and the Appalachian mountainous regions of eastern United States and has become naturalized in a larger portion of North America by natural dispersal processes and anthropogenic dissemination of seed from North American and European sources (Britton and Brown 1913, Gleason and Cronquist 1963, Morley 1974, Gould 1975, Looman and Best 1987, and Great Plains Flora Association 1986). This assumption was made on the belief that European sources were introduced into North America by early colonist around or before 1700 and would not have had time enough to spread along the Appalachian mountains and the Great Lakes.

However, if European source Poa pratensis plant material was introduced into North America as seeds in livestock forage during the third Viking expedition in 1009, the plant material would have had sufficient time to spread throughout the Appalachian Mountains and Great Lakes region before European settlement would have reached these places.

Thorfinn Karlsefni led the third expedition intended to establish a settlement in North America in 1009. The settlers consisted of 160 or 250 men and women. They had 3 knarr (merchant) ships that could carry their cargo of household items, farm tools, seed, livestock, and forage. They landed at Straumfjord, Vinland on the north shore of Newfoundland along the Strait of Belle Isle in the St. Lawrence Seaway where they spent the first winter. They established trade with the local people, furs for milk or red cloth. The Vikings fermented squashberries, gooseberries, and cranberries to make wine and smelted bog iron to make tools and weapons. Thorfinn's wife, Gudrid Thorbjarnardottir who was beautiful and charismatic, gave birth to a son, Snorri, who was the first documented European person to be born in North America. Gudrid was the widow of Thorvald Eriksson (2nd son of Erik the Red) who was killed during the second expedition in 1005 at Leifsbuoir, Vinland (second campsite of Leif Erikson (1st son of Erik the Red) used during the first expedition, 1000-1002) by local people with an arrow as revenge for his killing of eight local people the previous morning. Sometime during the first year while still at Straumfjord, Thorfinn's bull stormed out of the woods and startled a group of local people coming to trade causing hostile conditions to intensify when the local people returned with a raiding party. The attack was stopped by a desperate pregnant women, Freydis Eriksdottir (a daughter of Erik the Red). She picked up a sword from one of the men that had been killed during first contact, pulled one or both of her breasts out of her bodice, pounded, assumably, the flat side of the sword against her chest, while shouting norse vulgarities at both the local people who were running away and at the fierce Viking warriors who were hiding. Thorfinn came out from his hiding spot and praised her and all celebrated her courage. Freydis remained a life long pagan and never converted to Christianity like most Scandinavians at that time, and made at least one additional voyage back to North America. Soon after the attack, the Vikings packed up and moved south to Straumsoy and hop near Gander Lake on the east side of Newfoundland where their livestock could graze all winter because of the thermal heat. However, after 2 additional years, the local people escalated the number and intensity of attacks on the Viking settlement causing the surviving members to load their Vinland spoils of furs and berries and sailed back to Greenland. Shortly afterward, Thorfinn and his family moved to Iceland for the remainder of their lives at a large turf mansion on a farm near Glaumbaer producing numerous important descendants.

No further attempts to establish a settlement and to transport seed, livestock, and forage to North America from Greenland or Iceland occurred. However, voyages of discovery and to harvest timber and furs, gather berries, and fish for cod requiring a winter stay over continued for more than 350 years until the two settlements on Greenland failed sometime between 1350 and 1400 as a result of the insurmountable hardships caused by the climate change referred to as the Little Ice Age (Chapman n.d., Linden 2004, Short 2017).

Plant material from Europe is *Poa pratensis* var *pratensis* and plant material native to North America is *Poa pratensis var angustifolia.* The common name of Poa pratensis in Europe is smooth meadowgrass or smoothstalk meadowgrass. The common name of Poa pratensis in North America is Kentucky bluegrass which started to be used sometime between 1833 and 1859 as a promotion of thoroughbreds, bourbon, and bluegrass for the state of Kentucky.

Kentucky bluegrass is one of two introduced grasses that have weak lead tillers permitting vegetative tiller development without partial defoliation of the lead tiller at vegetative growth stages. This feature has a cost of double the water use per pound of herbage production. Because of the high water use of Kentucky bluegrass, Denver does not permit Kentucky bluegrass use as lawns. As demand for municipal water increases, more western North American cities will prohibit the use of Kentucky bluegrass as lawn grass.

During the 1946-1947 study, Kentucky bluegrass grew on relatively flat subirrigated lowland areas adjacent to a small permanent watercourse where almost all of the plants had been grazed. A few plants escaped grazing and developed normally.

Kentucky bluegrass starts early greenup in early to mid April (table 1). Early boot stage occurs in late April and stalk emergence occurs in early May (table 1). Early stalks with flowers appear during mid May (table 1). Zaczkowski (1972) determined that escaped Kentucky bluegrass plants had a five week flower period from late May through June (table 2). Seed development occurs after the flower stage and seeds mature during mid June to mid July (table 1) (Whitman et al. 1951, Manske 1999b).

The nutritional quality of ungrazed lead tillers change with the tillers' phenological development. The crude protein content starts to decrease shortly after the flower stage with little forage quality by mid to late June.

Grazed lead tillers remain at an immature vegetative stage. Early season growth stages are high in crude protein and water. The early vegetative leaf stage contain levels of crude protein above 18% during early to mid May (table 1, figure 1). The vegetative lead tillers gradually decrease in crude protein content at 14.9% during early June, 11.7% during early July, and to 9.6% during late July (tables 1 and 3, figure 1). After early August, the Kentucky bluegrass vegetation becomes a complex of senescent lead tillers and the new growth of fall tillers. Phosphorus levels drop below 0.18% during late August (tables 1 and 3).

The 1976-1978 Study of phenological development of Kentucky bluegrass on the Dakota

Sandhills of southeastern North Dakota had perennial plant growing season (April to October) long-term mean precipitation of 16.61 inches which is 84.8% of the long-term mean annual precipitation. Total grass basal cover on the upland mixed grass prairie was 34.1% with the basal cover of Kentucky bluegrass at 7.6% composing 22.2% of the upland community. Total grass basal cover on the midland tall grass prairie was 45.3% with the basal cover of Kentucky bluegrass at 11.6% composing 25.6% of the midland community. Vegetative growth of Kentucky bluegrass occurs very early in the spring. Green carryover leaves can be found during snow melt in mid March. Rapid growth resumes during early April. Ungrazed basal leaves attain a mean maximum mature height of 17.4 cm (6.9 in) during late June on the mixed grass prairie and of 25.1 cm (9.9 in) during mid June on the tall grass prairie (table 4).

The basal leaves of lead tillers on the upland experienced rapid senescence during late June with 42% of the leaves drying (table 5). Leaves of vegetative tillers developed during early and late July which greatly increased the amount of leaves without senescence. Fall tiller growth began in mid August continuing through late August while the aging vegetative tillers increased in senescence (table 5) resulting in decrease in basal leaf height (table 4).

The basal leaves of lead tillers on the midland experienced a gradual increase in percent at stages of senescence from 21% during late June to 48% during mid August (table 5). Distinction between basal leaf growth of lead tillers and vegetative tillers was not possible. Fall tiller growth began in mid August continuing through late August while the aging lead tillers and vegetative tillers increased in senescence (table 5). The basal leaf height changed very little from mid July to late August (table 4).

Phenological growth stage development was similar on the upland mixed grass prairie and the midland tall grass prairie. Flower stalk emergence occurred during mid May. The first flower stalks reached anthesis between 25 May and 5 June. The peak number of stalks at anthesis occurred soon after the first anthesis and most of the plants past through the anthesis phenophase within one week. Seeds developed quickly and mature seeds were easily removed from stalks during mid to late June. The stalks dried and were easily removed by wind by mid July (table 4). Ungrazed flower stalks attain a mean maximum height of 52.2 cm (20.6 in) during late June on the mixed grass prairie and of 52.4 cm (20.6 in) during mid July on the tall grass prairie (table 4).

The growth pattern and phenological development for Kentucky bluegrass were similar on the ungrazed and grazed treatments of the upland and midland plant communities. The basal leaf and stalk heights for the ungrazed plants on the grazed treatments were shorter then the plants on the ungrazed treatments during all biweekly sample periods on both the upland and midland plant communities (table 4).

The 1978-1990 study prescribed burn treatments were intended to decrease and then remove western snowberry and Kentucky bluegrass from degraded mixed grass prairie and restore ecosystem processes.

Western snowberry, *Symphoricarpos occidentalis*, aboveground shoot frequency decreased 68.3% after 1 burn, decreased an average of 40.0% after 2 burns, decreased an average of 67.1% after 3 burns, and decreased an average of 58.4% after 4 burns (table 6). The number of repeated burns caused no additional shoot reduction after one burn. Shoot frequency decreased 91.4% from early spring burns, decreased 83.7% from spring burns, decreased only 32.9% from early summer burns, and decreased 63.1% from mid summer burns (table 6). The greatest reduction in shoot frequency occurred from early spring (mid-late April) burns and significant reductions occurred from spring (May-mid June) burns. Early summer (mid Jun-Jul) and mid summer (early-mid August) burns were less effective at reducing shoot frequency. The aboveground biomass produced by shrubs was greatly reduced after the third and fourth burns.

Kentucky bluegrass, *Poa pratensis*, aboveground shoot frequency decreased 33.4% after 1 burn, decreased 46.8% after 2 burns, decreased 5.6% after 3 burns, and decreased 47.5% after 4 burns (table 6). Additional burns, after the first burn, progressively increased slightly the additional decrease in shoot frequency, except after 3 burns. Shoot frequency increased 21.0% from early spring burns, decreased 58.9% from spring burns, decreased 26.5% from early summer burns, and decreased 37.4% from mid summer burns (table 6). The greatest reduction in shoot frequency occurred from spring (May-mid June) burns and moderate reductions occurred from mid summer (early-mid August) burns.

Burning temporarily reduces the aboveground shoot frequency of Kentucky bluegrass and western snowberry, however, data after thirteen years of burning treatments indicates that prescribed fire does not or cannot remove Kentucky bluegrass and western snowberry from a grassland ecosystem.

Western snowberry and Kentucky bluegrass reproduce vegetatively from buds on rhizomes and crowns. Removal of all or most of the aboveground shoots with fire does not stop the vegetative reproduction processes.

Endomycorrhizal fungi do not colonize the entire root. Fungal infection occurs at the portions of current years' roots that are biologically active. Previous years' roots, mature root portions, and young growing root portions do not host fungal structures. Percent fungal infection of root segments is primarily a factor of the proportion of biologically active root portions to the amount of mature and young growing root portions included in the sample. Identification of biologically active root portions from mature root portions is difficult in the field, with the naked eye or low-power hand lens. The prescribed burning treatments did not affect the fungal infection levels on the roots of western snowberry and Kentucky bluegrass.

Grassland soils have abundant quantities of nitrogen, however, most of this is stored in the organic form and unavailable for direct use by plants. Grassland plants can use nitrogen only in the inorganic (mineral) form. Soil microorganisms of the rhizosphere mineralize soil organic nitrogen into inorganic nitrogen (Ingham et al. 1983). Grassland ecosystems with greater biomass of rhizosphere organisms mineralize greater quantities of organic nitrogen into inorganic nitrogen (Coleman et al. 1983). Measurements of the quantity of available inorganic nitrogen is a proxy indication for the relative quantity of rhizophere organisms. The growing season (June + August) quantity of mineral nitrogen was 31.2 lbs/ac on the no burns, 30.8 lbs/ac on the 1 burn, 32.1 lbs/ac on the 2 burns, 16.8 lbs/ac on the 3 burns, and 20.4 lbs/ac on the 4 burns (table 7) and these quantities are not significantly different. The growing season quantity of mineral nitrogen was 11.9 lbs/ac on the early spring burns, 28.1 lbs/ac on the spring burns, 29.8 lbs/ac on the early summer burns, and 23.1 lbs/ac on the mid summer burns (table 7) and these quantities are not significantly different. The prescribed burning treatments did not affect the quantity of organic nitrogen mineralized into available inorganic nitrogen thus the prescribed burning treatments did not stimulate the biomass and activity of the rhizosphere organisms.

Available soil mineral nitrogen is the major limiting factor of herbage growth on native rangeland ecosystems (Wight and Black 1979). Deficiencies in mineral nitrogen limit herbage production more often than water in temperate grasslands (Tilman 1990). A minimum rate of mineralization that supplies 100 pounds of mineral nitrogen per acre is required to sustain herbage production at biological potential levels on rangelands (Wight and Black 1972). Soil mineral nitrogen available at the threshold quantity of 100 lbs/ac is required for activation of the ecological biogeochemical processes important for rangeland grass production. Wight and Black (1972, 1979) determined that the processes associated with precipitation (water) use efficiency in grass plants were not fully activated unless 100 lbs/ac of mineral nitrogen was available. Manske (2010a, b) found evidence that the other defoliation resistance mechanisms (Manske 1999a, 2011b) had threshold requirements for activation at 100 lbs/ac of mineral nitrogen.

The presence of fire does not prove that grasslands need or are caused by fire (Heady 1975). The existence of a shrub component in a grassland is not an ecologically beneficial relationship as shrubs and grasses are adversarial inhibitive competitors. They compete for sunlight, mineral nitrogen, other essential elements, and soil water. Fire in grasslands cannot prevent the invasion of, or cause the removal of, shrubs, and trees that are able to reproduce by vegetative secondary suckers (Wright and Bailey 1982, Manske 2006a, b). Almost all deciduous woody plants reproduce vegetatively, except big sagebrush (Artemisia tridentata) (Manske 2014). Seedlings of trees, shrubs, weedy forbs, and introduced grasses cannot become established in grasslands containing grasses with full nutrient resource uptake competitiveness (Peltzer and Kochy 2001). Intrusive seedlings can only be established after a grassland has been degraded by poor management practices. Repeated prescribed fire can modify the composition of the aboveground vegetation in degraded grasslands which have been invaded by shrubs. The composition of introduced escaped cool season grasses may change, and early succession and weedy forbs, and shrub aerial stems decrease temporarily after four repeated prescribed fires (Manske 2007, 2011a). However, the fundamental problems of weak nutrient resource uptake, reduced water use efficiency, nonfunctional compensatory physiological mechanisms, impaired vegetative reproduction by tillering, and diminished biogeochemical processes will remain in the degraded grassland ecosystem following repeated fire events. None of the biological, physiological, or asexual mechanisms within grass plants and none of the rhizosphere microbes or biogeochemical processes they perform are activated by fire (Manske 2007, 2011a). Almost all of the essential elements in the aboveground herbage are volatilized when a grassland is burned, and if the soil is dry, some of the belowground essential elements are also lost (Russelle 1992). When the losses of essential elements are greater than the quantity of captured essential elements, the result is degradation of the grassland (McGill and Cole 1981). Fire does not improve grassland ecosystems biologically or ecologically and fire cannot replace the partial defoliation achieved by grazing graminivores in managing healthy and productive grassland ecosystems.

The 2006-2011 study (Manske 2012) evaluates reduction of escaped domesticated Kentucky bluegrass on pastures of degraded mix grass prairie with proper grazing management compared to long-term nongrazed management.

The mixed grass prairie study area in nongrazed control 4 was a degraded silty ecological site dominated by Kentucky bluegrass. Control pasture 4 was not grazed during the six years of the study and was not grazing during the 13 years prior to this study. At the start of the study, the aboveground vegetation biomass consisted of 72.3% standing dead and litter and 27.7% live herbage. The live herbage biomass was 95.2% domesticated grasses and 2.1% native grasses. After 6 growing seasons, the aboveground vegetation biomass consisted of 61.7% standing dead and litter and 38.3% live herbage. The live herbage biomass was 85.1% domesticated grasses and 7.7% native grasses.

Annual herbage biomass production of domesticated grass on nongrazed 4 was not significantly different during the study growing seasons except domesticated grass biomass was significantly less during the third growing season because of water deficiencies during the previous October and current year April and May. Domesticated grass herbage production increased during the sixth growing season as a result of an increase in precipitation during April, May, and July of that year (table 8). Domesticated grass herbage production on nongrazed 4 was significantly greater than that on pastures 1 & 2 during all six growing seasons. Domesticated grass basal cover fluctuated annually during the study (table 9) and the mean basal cover of domesticated grass was 13.0% on nongrazed 4 and was significantly greater than the mean basal cover of 5.7% on grazed pastures 1 & 2.

Native grass herbage production on nongrazed 4 was low and annual herbage biomass production of native grass on nongrazed 4 was not significantly different during the study growing seasons except native grass biomass was reduced during the third growing season because of water deficiencies. Native grass biomass on nongrazed 4 was not significantly different than that produced on grazed pastures 1 & 2 except native grass biomass on pastures 1 & 2 was significantly greater than that on nongrazed 4 during the sixth growing season. Native grass basal cover fluctuated annually during the study (table 9) and native grass basal cover on nongrazed 4 was much reduced during the second to the sixth growing seasons than those on grazed pastures 1 & 2.

The mixed grass prairie study areas of grazed pastures 1 & 2 were degraded silty ecological sites dominated by Kentucky bluegrass. These pastures were not grazed during the 13 years prior to this study and were managed with the Twice-over rotation grazing strategy during the 6 years of the study. At the start of the study, aboveground vegetation biomass consisted of 63.6% standing dead and litter and 36.4% live herbage. The live herbage biomass was 64.8% domesticated grasses and 3.4% native grasses. After 6 grazing seasons, the aboveground vegetation biomass consisted of 39.5% standing dead and litter and 60.5% live herbage. The live herbage biomass was 56.0% domesticated grasses and 27.0% native grasses.

The stocking rates used to grazed pastures 1 & 2 were 80.5% of the assessed rates during the first, second, fourth, and fifth growing seasons, stocking rates were 107% of the assessed rates during the third growing season, and stocking rates were 38% of the assessed rates during the sixth growing season (table 10).

Domesticated grass herbage biomass on pastures 1 & 2 progressively decreased from the second to the fifth growing seasons (table 11) and substantially increased during the sixth growing season because of high rainfall during April, May, and July and because of the 53% reduction in the stocking rate used that year (table 11). Domesticated grass herbage biomass on pastures 1 & 2 was significantly less than that on nongrazed 4 during the six growing seasons. Domesticated grass basal cover fluctuated annually (table 12) and was substantially lower on pastures 1 & 2 than those on nongrazed 4 except for the fourth growing season. The mean basal cover of domesticated grass was 5.7% on pastures 1 & 2 and was significantly lower than the mean basal cover of 13.0% on nongrazed 4.

Native grass herbage production on pastures 1 & 2 increased gradually during the six growing seasons (table 11). Native grass herbage biomass on pastures 1 & 2 was significantly greater than that produced on nongrazed 4 during the sixth growing season. Native grass basal cover fluctuated annually (table 12) and native grass basal cover on pastures 1 & 2 were much greater during the second to the sixth growing seasons than those on nongrazed 4. The mean basal cover of native grass was 6.6% on pastures 1 & 2 and was significantly greater than the mean basal cover of 1.5% on nongrazed 4.

The rhizosphere weight changed very little during the first two growing seasons and were not significantly different on nongrazed 4 and pastures 1 & 2 (table 13, figure 2). After the second growing season through the sixth growing season, the rhizosphere weights increased at different rates resulting in significantly different mean annual rhizosphere weights during growing seasons 3 to 6 on nongrazed 4 and pastures 1 & 2 (tables 13, figure 2).

Rhizosphere weight on nongrazed 4 increased 115.8% during 6 growing seasons from a mean pregrazing rhizosphere weight of 60.49 $kg/m^3$ (14.9% of reference weight) at a mean annual rate of 13.2 $kg/m^2$ reaching a rhizosphere weight of 130.56 $kg/m^3$ (table 13, figure 2) after 6 growing seasons, which was 32.1% of the reference rhizosphere weight of 406.44 $kg/m^3$

Rhizosphere weight on pastures 1 & 2 increased 254.3% during 6 growing seasons from a mean pregrazing rhizosphere weight of 60.49 $kg/m^3$ at a mean annual rate of 30.5 $kg/m^2$ reaching a rhizosphere weight of 214.34 $kg/m^3$ (table 13, figure 2) after 6 growing seasons, which was 52.7% of the reference rhizosphere weight of 406.44 $kg/m^3$

Mean annual rhizosphere weights on nongrazed 4 responded differently than those on grazed pastures 1 & 2. The severely degraded silty ecological site on nongrazed 4 was dominated by Kentucky bluegrass and had no defoliation treatments. The changes in annual rhizosphere weights were related only to changes in growing season precipitation. The first growing season had low precipitation at 63.7% of the long-term mean and four growing season months (May, June, July, and August) had water deficiency conditions. The growing season precipitation during the second to the fourth growing seasons had mean precipitation at 76.2% of the long-term mean. Rhizosphere weight on nongrazed 4 changed little with an increase of 37.0% during the first four growing seasons (table 13, figure 2). The precipitation increased during the fifth and sixth growing seasons at 103.4% of the long-term mean causing the rhizosphere weight to increase 50.3% during the sixth growing season to 130.56 $kg/m^3$ with a total increase of 115.8% during 6 growing seasons (table 13, figure 2).

The rhizosphere weights on pastures 1 & 2 increased with the increase in native grass herbage biomass and basal cover. Domesticated grass herbage biomass on pastures 1 & 2 decreased 23.7% and basal cover increased 55.7% during the first five growing seasons (tables 11 and 12). During the sixth growing season, domesticated grass herbage biomass increased 85.5% above the previous growing season because of increased precipitation and decreased stocking rate. Native grass herbage biomass on pastures 1 & 2 increased 51.6% and basal cover increased 200.4% during the first five growing seasons (tables 11 and 12). During the sixth growing season, native grass herbage biomass increased 73.2% above the previous growing season. The rhizosphere weight on pastures 1 & 2 increased 202.5% during the first five growing seasons and during the sixth growing season increased only 17.1% above the previous growing season because of the decreased stocking rate, reaching 214.34 $kg/m^2$ with a total increase of 254.3% during 6 growing seasons (table 13, figure 2).

After six growing seasons of nongrazing, the rhizosphere weight of 130.56 $kg/m^3$ was 32.1% of the reference weight of 406.44 $kg/m^3$ on nongrazed 4. After six growing seasons of twice-over grazing management, the rhizosphere weight of 214.34 $kg/m^2$ was 52.7% of the reference weight of 406.44 $kg/m^2$ on pastures 1 & 2. The rhizosphere weight on pastures 1 & 2 was 64.2% greater than the rhizosphere weight on nongrazed 4.

Available mineral nitrogen ($NO_3$ + $NH_4$) on nongrazed 4 at 0-24 inch soil depth was 71.24 lbs/ac with 30.69 lbs/ac $NO_3$ and 40.55 lbs/ac $NH_4$ (table 14). Available mineral nitrogen ($NO_3$ + $NH_4$) on pastures 1 & 2 at 0-24 inch soil depth was 99.35 lbs/ac with 50.50 lbs/ac $NO_3$ and 48.85 lbs/ac $NH_4$ (table 14). The rhizosphere microorganisms on pastures 1 & 2 mineralized 64.5% greater $NO_3$, 20.5% greater $NH_4$, and 39.5% greater total available mineral nitrogen ($NO_3$ + $NH_{4)}$ than that mineralized on nongrazed 4.

The quantity of available mineral nitrogen is related to the rhizosphere weight. The rhizosphere microbe biomass and activity are in turn affected by the quantity of exuded short carbon chain compounds. The quantity of exuded carbon in the nongrazed pasture is restricted to plant leakage, while on the grazed pastures it is greater than the quantity of leakage. This is because partial defoliation by graminivores when grass tillers are at the vegetative growth stage causes greater quantities of simple carbon compounds to be exuded from the grass tillers into the rhizosphere (Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990, Hamilton and Frank 2001, Manske 2011b). The grazing treatment removed around 25% of the leaf material of the native grasses when the tillers were between the 3.5 new leaf stage and the flower stage. This progressively decreased the rates of leaf senescence and increased photosynthetic rates, thus increasing both the quantities of fixed carbon available for increasing plant growth and the exudation of simple carbon compounds released through the plant roots into the rhizosphere. During year three, the rhizosphere weight in the grazed pastures increased to 73.5% greater than that in the nongrazed pasture (table 13, figure 2). This in turn increased the mineralization of greater quantities of nitrogen and other essential elements from soil organic matter, resulting in greater activity of compensatory physiological mechanisms and vegetative reproduction by tillering. The end result was an increase in herbage biomass production and basal cover of the cool and warm season native grasses through to year six. Thus, restoration of degraded grasslands slowly builds the ecosystem's biogeochemical processes, and the internal grass mechanism slowly increase native grass composition and the competition from increasingly functional native grasses reduces the composition of the undesirable domesticated grasses.

The 1983-2012 study follows the patterns in the changes of individual grass species abundance for 30 growing seasons on the sandy, shallow, and silty ecological sites of the long-term nongrazed, traditional seasonlong, and twice-over management treatments (tables 15 and 16). Grass species composition in rangeland ecosystems is variable during a growing season and dynamic among growing seasons. The presence of Kentucky bluegrass in rangeland ecosystems indicates that it had escaped, naturalized, and invaded the region.

On the sandy site of the nongrazed treatment, Kentucky bluegrass was present during 20.0% of the years that basal cover data were collected with a mean 0.25% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 20.0% of the years with a mean 0.15% basal cover. Kentucky bluegrass was present during growing seasons with favorable precipitation (tables 15 and 16).

On the sandy site of the ungrazed seasonlong treatment, Kentucky bluegrass was not present during the total 30 year period (tables 15 and 16).

On the sandy site of the grazed seasonlong treatment, Kentucky bluegrass was present during 4.0% of the years that basal cover data were collected with a mean 0.01% basal cover during the total 30 year period. During the early period (1983-1992). Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 6.7% of the years with a mean 0.01% basal cover. Kentucky bluegrass had low abundance on the sandy site of the grazed seasonlong treatment (tables 15 and 16).

On the sandy site of the ungrazed twice-over treatment, Kentucky bluegrass was present during 17.9% of the years that basal cover data were collected with a mean 0.28% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 20.0% of the years with a mean 0.31% basal cover. Kentucky bluegrass was present during growing seasons with favorable precipitation (tables 15 and 16).

On the sandy site of the grazed twice-over treatment, Kentucky bluegrass was present during 10.3% of the years that basal cover data were collected with a mean 0.03% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 13.3% of the years with a mean 0.04% basal cover. Kentucky bluegrass had low abundance on the sandy site of the grazed twice-over treatment (tables 15 and 16).

On the shallow site of the nongrazed treatment, Kentucky bluegrass was present during 3.9% of the years that basal cover data were collected with a mean 0.01% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 6.7% of the years with a mean 0.02% basal cover. Kentucky bluegrass had low abundance on the shallow site of the nongrazed treatment (tables 15 and 16).

On the shallow site of the ungrazed seasonlong treatment, Kentucky bluegrass was not present during the total 30 year period (tables 15 and 16).

On the shallow site of the grazed seasonlong treatment, Kentucky bluegrass was not present during the total 30 year period (tables 15 and 16).

On the shallow site of the ungrazed twice-over treatment, Kentucky bluegrass was present during 6.9% of the years that basal cover data were collected with a mean 0.01% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 6.7% of the years with a mean 0.01% basal cover. Kentucky bluegrass had low abundance on the shallow site of the ungrazed twice-over treatment (tables 15 and 16).

On the shallow site of the grazed twice-over treatment, Kentucky bluegrass was not present during the total 30 year period (tables 15 and 16).

On the silty site of the nongrazed treatment, Kentucky bluegrass was present during 19.2% of the years that basal cover data were collected with a mean 0.19% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 20.0% of the years with a mean 0.34% basal cover. Kentucky bluegrass was present during growing seasons with favorable precipitation (tables 15 and 16).

On the silty site of the ungrazed seasonlong treatment, Kentucky bluegrass was present during 7.7% of the years that basal cover data were collected with a mean 0.11% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was not present. During the later period (1998-2012), Kentucky bluegrass was present during 6.7% of the years with a mean 0.14% basal cover. Kentucky bluegrass had low abundance on the silty site of the ungrazed seasonlong treatment (tables 15 and 16).

On the silty site of the grazed seasonlong treatment, Kentucky bluegrass was present during 3.9% of the years that basal cover data were collected with a mean 0.01% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was present during 16.7% of the years with a mean 0.05% basal cover. During the later period (1998-2012), Kentucky bluegrass was not present. Kentucky bluegrass had low abundance on the silty site of the grazed seasonlong treatment (tables 15 and 16).

On the silty site of the ungrazed twice-over treatment, Kentucky bluegrass was present during 26.7% of the years that basal cover data were collected with a mean 0.34% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was present during 33.3% of the years with a mean 0.10% basal cover. During the later period (1998-2012), Kentucky bluegrass was present during 20.0% of the years with a mean 0.33% basal cover. Kentucky bluegrass was present during growing seasons with favorable precipitation (tables 15 and 16).

On the silty site of the grazed twice-over treatment, Kentucky bluegrass was present during 20.0% of the years that basal cover data were collected with a mean 0.10% basal cover during the total 30 year period. During the early period (1983-1992), Kentucky bluegrass was present during 30.0% of the years with a mean 0.07% basal cover. During the later period (1998-2012), Kentucky bluegrass was present during 13.3% of the years with a mean 0.15% basal cover. Kentucky bluegrass had low abundance on the silty site of the grazed twice-over treatment (tables 15 and 16).

On the not grazed sandy sites, Kentucky bluegrass was present during 12.6% of the years with a mean 0.18% basal cover. On the grazed sandy sites, Kentucky bluegrass was present during 7.2% of the years with a mean 0.02% basal cover.

On the not grazed shallow sites, Kentucky bluegrass was present during 3.6% of the years with a mean 0.01% basal cover. On the grazed shallow sites, Kentucky bluegrass was not present.

On the not grazed silty sites, Kentucky bluegrass was present during 17.9% of the years with a mean 0.21% basal cover. On the grazed silty sites, Kentucky bluegrass was present during 11.9% of the years with a mean 0.06% basal cover.

Kentucky bluegrass was present on the silty and sandy sites of the nongrazed and ungrazed twice-over treatments during growing seasons with favorable precipitation at a mean of 112.0% of the long-term mean at a low 0.20% basal cover. Kentucky bluegrass was present on the silty and sandy sites of the grazed seasonlong and twice-over treatments during the growing seasons with favorable precipitation at a mean of 111.2% of the long-term mean at a very low 0.04% basal cover.

## Discussion

Kentucky bluegrass, *Poa pratensis,* is a naturalized, introduced, long-lived perennial, cool season, mid grass, moncot, of the grass family. Kentucky bluegrass has long been assumed to have been introduced into North America from Europe by early New England colonists around or before 1700. Most early botanists considered Kentucky bluegrass to be native in the regions of the Appalachian Mountains and Great Lakes because Kentucky bluegrass was present when the westward movement of settlers arrived in those areas and introduced plants could not have spread from the New England region west to the Mississippi River that fast. However, if Poa pratensis was introduced into North America when the Vikings attempted to establish a settlement in Newfoundland in 1009 to 1012, the grass would have had time to spread through the Appalachian Mountains and Great Lakes regions before European immigrants settled in those areas.

The dynamic Viking period of expansion from Scandinavia into the North Atlantic Islands during 800 to 1050 was called landnam (land taking or first settlement). This movement of exploration and colonization was amplified when the ruthless pagan Norse King, Harald Finehair (840-933), won a decisive battle at Hafrisfjord in 872 that made him the first sole ruler of Norway. The survivors of the battle and the Norseman who opposed him lost their land and had to make a hasty mass exodus. They emigrated to Scotland, Ireland, and the smaller islands around north Britain. Nordic and Celtic people from North Britain moved to Iceland in 874. The Icelandic population grew to over 20,000 people by 930 and they established a self governing system. In 986, 14 ships and about 300 to 400 people sailed with Erik the Red from Iceland to Greenland, and established 2 settlements and over 400 small farms that continued until sometime between 1350 and 1400. The population of Greenland increased to over 5,000 people by 1000 AD. Between 1009 and 1012, 160 or 250 men and women from Greenland attempted to establish a permanent settlement in North America on Newfoundland, however, it failed after 3 years.

The vegetation of Northern Norway, Northern Britain, subarctic Iceland, and low arctic Greenland was very similar with birch, willow, grasses, and sedges. Poa pratensis was and is a common plant in all of these plant communities. The Nordic and Celtic colonists were familiar with this type of landscape and had long-developed management skills specific to these conditions. They raised cattle for milk, butter, cheese, yogurt, and meat, sheep for wool to weave, goats, pigs, and a small horse. They grew barley for beer and bread. Their pastures and hayfields were fertilized heavily with barnyard manure. We now know from modern research that fertilization of grasslands enhances the dominance of Poa pratensis and eliminates all grass species that are obligate to symbiotic relationships with rhizosphere organisms.

The Greenlandic people who attempted to establish a settlement in Newfoundland brought cattle and most likely sheep. These animal would have required harvested forage for the voyage and during the winter. There is a strong probability that that forage contained Poa pratensis and that soon after those animals were unloaded from the ships that Poa pratensis seeds were deposited on North American soil in 1009.

Phenological development of Kentucky bluegrass is regulated by the changes in the length of daylight and were similar in western and eastern North Dakota. Carryover leaves regreen shortly after snow melt. Early greenup of new basal leaves arising from rhizome tiller buds resumes in early to mid April. Flower stalk emergence occurs during early to mid May. First flower appears during mid to late May with the flower period lasting through June. Seed development occurs during mid to late June and seeds are shed by mid July. Fall tillers develop during mid August, carryover through the winter, and become vegetative tillers the next growing season.

Repeated prescribed burning did not or cannot remove Kentucky bluegrass and any grass or shrub that reproduce vegetatively from buds. Prescribed burning did not affect fungal infection levels. Prescribed burning did not affect the quantity of mineralized inorganic nitrogen and did not stimulate the biomass and activity of rhizosphere organisms. Prescribed burning does not restore degraded grasslands because it does not activate the mechanisms of nutrient resource uptake, water use efficiency, compensatory physiological processes, and vegetative reproduction by tillering and prescribed burning does not stimulate rhizosphere microbes or the biogeochemical processes they perform. Prescribed burning causes increased degradation because almost all of the essential elements in the aboveground herbage are volatilized and lost from the ecosystem and fire has no process to capture and restore essential elements.

Kentucky bluegrass also cannot be removed from a grassland by repeated heavy grazing. Heavy grazing, however, can remove desirable grasses and forbs, which creates open spaces for Kentucky bluegrass to move into. Kentucky bluegrass can only move into a previously healthy grassland after poor management practices have reduced the grass plants nutrient resource uptake competitiveness. Which would indicate the process to remove Kentucky bluegrass would be to restore the ecosystems biogeochemical processes and the main internal grass mechanisms by implementation of the twice-over rotation grazing strategy. This grazing treatment removes around 25% of the leaf material of native grasses when the lead tillers were between the 3.5 new leaf stage and the flower stage. This progressively decreases the rate of leaf senescence and increases the photosynthetic rate, thus increasing both the quantities of fixed carbon available for increased plant growth and for increased exudation of simple carbon compounds released through the grass roots into the rhizosphere. This does not change the rhizosphere weight much during the first two years but greatly increases the rhizosphere weight during the third growing season and all of the consecutive growing seasons. With the greater biomass and activity of the microbes in the rhizosphere, greater quantities of inorganic nitrogen can be mineralized from the soil organic matter. By about the sixth growing season, the biomass and activity levels of the rhizosphere microbes has increased enough to mineralize the threshold quantity of 100 lbs/ac of available mineral nitrogen which will fully activate the water use efficiency, nutrient resource uptake, compensatory physiological processes, and vegetative reproduction by tillering mechanisms. Which results in an increase in herbage biomass production and basal cover of the cool and warm season native grasses. The degraded grassland with Kentucky bluegrass is slowly restored by building the ecosystems' biogeochemical processes and the internal grass mechanisms that increase the composition of the native grasses and decrease the composition of the Kentucky bluegrass.

Kentucky bluegrass grows best east of the Mississippi River in the Appalachian Mountains and Great Lakes regions. It can grow in western North Dakota during April to June, it drys up during July and August, and can grow during late summer during growing seasons with late rains. During the 30 year period of 1983 to 2012, Kentucky bluegrass was documented to be present on the not grazed areas during a mean of 4.3 growing seasons with about 4 hits per year, only during growing seasons with 112% of the long-term mean of 14.1 inches of precipitation (15.8 inches). Kentucky bluegrass was present on the grazed areas during a mean of 1.8 growing seasons with about 0.8 hits per year, only during growing seasons with 111% of the long-term mean of 14.1 inches of precipitation (15.7 inches).

Kentucky bluegrass is not a desirable grass to have in a grassland pasture. It was double the quantity of water per pound of herbage biomass produced. At any amount of growing season precipitation, Kentucky bluegrass would produce half the herbage biomass of native grasses. Unless Kentucky bluegrass is growing on a subirrigated bench near a permanent stream, it provides adequate quality of forage only during the early part of June and then it goes dormant during July and August. It takes several growing seasons, but by implementation of the twice-over rotation grazing strategy, Kentucky bluegrass can be greatly reduced and native grasses greatly increased by restoring the ecosystem biogeochemical processes and the internal grass mechanisms after increasing the biomass and activity of the rhizosphere microbes.

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Table 1. Poa pratensis, Kentucky bluegrass, weekly percent crude protein, percent phosphorus, and phenological growth stages of grazed lead tillers in western North Dakota, 1946-1947.

| Sample Date | Crude Protein % | Phosphorus % | Phenological Growth Satges |
|---|---|---|---|
| Apr 1 | | | |
| 13 | 20.2 | 0.314 | Early leaf greenup |
| 19 | 18.6 | 0.313 | |
| 25 | 19.5 | 0.232 | Flower stalk developing |
| May 4 | 19.8 | 0.299 | Flower stalk emerging |
| 10 | 15.3 | 0.258 | |
| 16 | 18.8 | 0.280 | Flowering (Anthesis) |
| 23 | 15.9 | 0.268 | |
| 28 | 12.8 | 0.264 | |
| Jun 6 | 14.9 | 0.258 | Seed developing |
| 13 | 14.0 | 0.287 | |
| 19 | 13.7 | 0.267 | Seed maturing |
| 26 | 12.2 | 0.231 | Drying |
| Jul 2 | 11.7 | 0.272 | Seed mature |
| 8 | 12.4 | 0.243 | |
| 16 | 11.2 | 0.246 | Seed shedding |
| 24 | 12.6 | 0.238 | |
| 30 | 9.6 | 0.229 | |
| Aug 6 | 11.3 | 0.237 | |
| 13 | 9.7 | 0.255 | Drying |
| 20 | 8.7 | 0.145 | |
| 26 | 10.8 | 0.189 | |
| Sep 3 | - | - | |
| 12 | 8.3 | - | |
| 21 | - | - | |
| 29 | 9.6 | 0.234 | |
| Oct | | | |
| Nov 5 | 7.8 | 0.155 | Drying |

Data from Whitman et al. 1951.

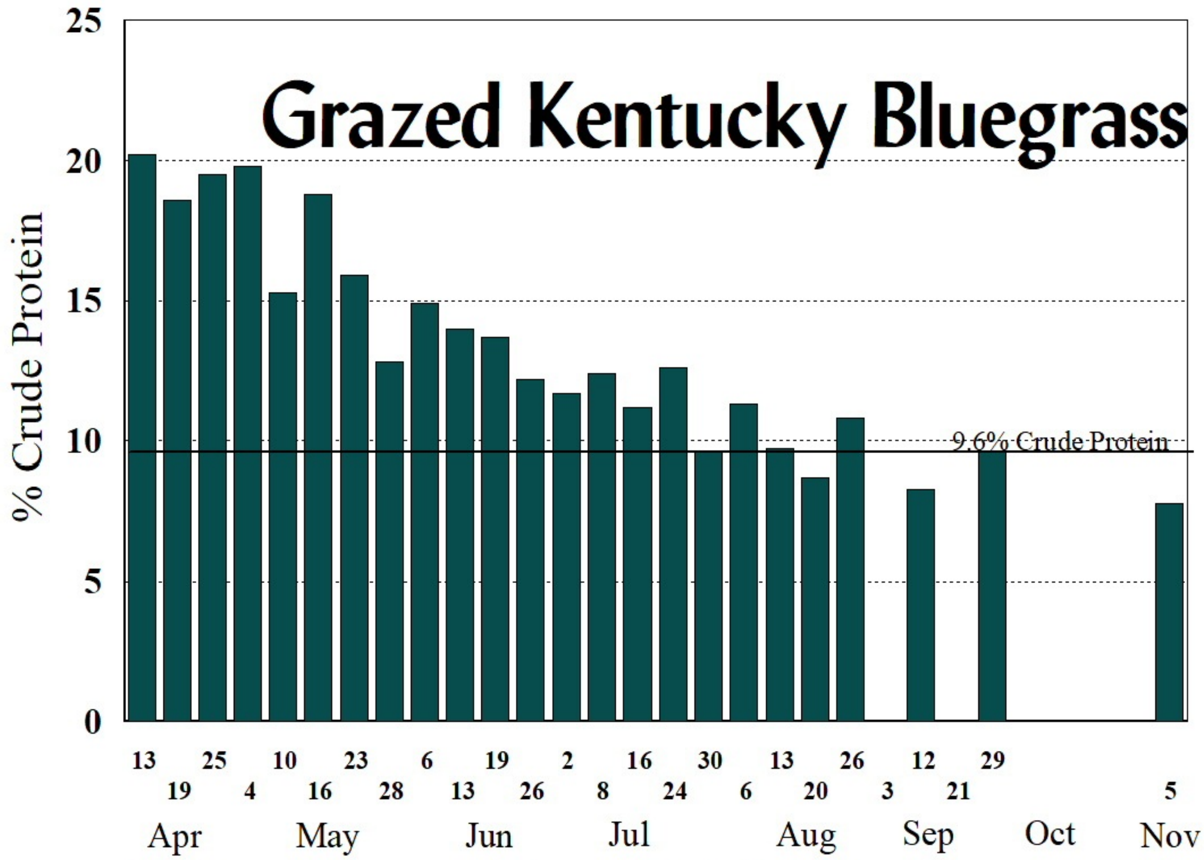


Fig 1. Mean percent crude protein of grazed Kentucky bluegrass in western North Dakota, data from Whitman et al. 1951.

Table 2. First flower and flower period of Poa pratensis, Kentucky bluegrass.

| | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|
| First Flower | | | | | | |
| Mean | | 16 | | | | |
| Flower Period 1969-1971 | | X | XX XX | | | |

First Flower Data from Whitman et al. 1951.
Flower Period Data from Zaczkowski 1972.

Table 3. Intake nutrient requirements as percent of dry matter for range cows with average milk production.

| | Dry Gestation | 3rd Trimester | Early Lactation | Lactation (Spring, Summer, Fall) |
|---|---|---|---|---|
| 1000 lb cows | | | | |
| Dry matter (lbs) | 21 | 21 | 24 | 24 |
| Crude protein (%) | 6.2 | 7.8 | 10.5 | 9.6 |
| Phosphorus (%) | 0.11 | 0.15 | 0.20 | 0.18 |
| 1200 lb cows | | | | |
| Dry matter (lbs) | 24 | 24 | 27 | 27 |
| Crude protein (%) | 6.2 | 7.8 | 10.1 | 9.3 |
| Phosphorus (%) | 0.12 | 0.16 | 0.19 | 0.18 |
| 1400 lb cows | | | | |
| Dry matter (lbs) | 27 | 27 | 30 | 30 |
| Crude protein (%) | 6.2 | 7.9 | 9.8 | 9.0 |
| Phosphorus (%) | 0.12 | 0.17 | 0.19 | 0.18 |

Data from NRC 1996.

Table 4. Leaf and stalk heights of Kentucky bluegrass in centimeters, 1976-1978.

| | Mixed Grass Prairie | | Tall Grass Prairie | |
|---|---|---|---|---|
| Biweekly Sample Period | Ungrazed (cm) | Grazed (cm) | Ungrazed (cm) | Grazed (cm) |
| 13-16 June | | | | |
| Leaf | 16.71 | 9.71 | 25.09 | 18.26 |
| Stalk | 51.12 | 39.70 | 49.03 | 41.39 |
| 26-29 June | | | | |
| Leaf | 17.41 | 11.37 | 22.41 | 17.73 |
| Stalk | 52.23 | 40.65 | 51.78 | 46.19 |
| 11-14 July | | | | |
| Leaf | 16.15 | 10.03 | 20.85 | 14.78 |
| Stalk | 51.21 | 36.06 | 52.43 | 41.39 |
| 24-27 July | | | | |
| Leaf | 15.21 | 11.79 | 19.99 | 13.73 |
| 16-19 August | | | | |
| Leaf | 14.36 | 10.61 | 21.13 | 15.06 |
| 28-31 August | | | | |
| Leaf | 12.49 | 7.73 | 20.99 | 13.71 |

Data from Manske 1980.

Table 5. Leaf percent senescence of Kentucky bluegrass, 1976-1978.

| | Mixed Grass Prairie | | Tall Grass Prairie | |
|---|---|---|---|---|
| Biweekly Sample Period | Ungrazed (%) | Grazed (%) | Ungrazed (%) | Grazed (%) |
| 13-16 June | | | | |
| <2% Dry | 89 | 98 | 93 | 95 |
| Senescent | 11 | 2 | 7 | 5 |
| 26-29 June | | | | |
| <2% Dry | 58 | 52 | 79 | 85 |
| Senescent | 42 | 48 | 21 | 15 |
| 11-14 July | | | | |
| <2% Dry | 75 | 78 | 75 | 88 |
| Senescent | 25 | 22 | 25 | 12 |
| 24-27 July | | | | |
| <2% Dry | 78 | 75 | 65 | 78 |
| Senescent | 22 | 25 | 35 | 22 |
| 16-19 August | | | | |
| New Growth | 12 | 20 | 25 | 28 |
| <2% Dry | 43 | 38 | 27 | 25 |
| Senescent | 45 | 42 | 48 | 47 |
| 28-31 August | | | | |
| New Growth | 38 | 42 | 33 | 38 |
| <2% Dry | 22 | 18 | 22 | 24 |
| Senescent | 40 | 40 | 45 | 38 |

Data from Manske 1980.

Table 6. Effects on % shoot frequency for western snowberry and Kentucy bluegrass for prescribed burning treatments, 1978-1990.

| | Western snowberry | | Kentucky bluegrass | |
|---|---|---|---|---|
| Treatment | % Shoot Frequency | % Difference | % Shoot Frequency | % Difference |
| No Burns | 58.3 | | 59.5 | |
| 1 Burn | | | | |
| Spring | 7.0 | -88.0 | 34.0 | -42.9 |
| Early Summer | 31.5 | -46.0 | 55.0 | -7.6 |
| Mid Summer | 17.0 | -70.8 | 30.0 | -49.6 |
| 2 Burns | | | | |
| Spring | 12.0 | -79.4 | 15.0 | -74.8 |
| Early Summer | 79.0 | 35.5 | 56.0 | -5.9 |
| Mid Summer | 14.0 | -76.0 | 24.0 | -59.7 |
| 3 Burns | | | | |
| Early Spring | 5.0 | -91.4 | 72.0 | 21.0 |
| Early Summer | 31.5 | -46.0 | 40.5 | -31.9 |
| Mid Summer | 21.0 | -64.0 | 56.0 | -5.9 |
| 4 Burns | | | | |
| Early Summer | 14.5 | -75.1 | 23.5 | -60.5 |
| Mid Summer | 34.0 | -41.7 | 39.0 | -64.5 |

Data from Manske 1992.

Table 7. Available mineral nitrogen in lbs/ac during June and August by burn treatment, 1978-1990.

| Treatment | Ammonium $NH_4$ | Nitrate $NO_3$ | Nitrogen $NO_3 + NH_4$ |
|---|---|---|---|
| No Burns | 14.90 | 16.30 | 31.18 |
| 1 Burn | | | |
| Spring | 14.03 | 15.65 | 29.66 |
| Early Summer | 21.24 | 12.26 | 33.50 |
| Mid Summer | 21.33 | 8.05 | 29.35 |
| 2 Burns | | | |
| Spring | 7.08 | 19.53 | 26.61 |
| Early Summer | 21.59 | 15.72 | 37.30 |
| Mid Summer | 14.39 | 17.92 | 32.31 |
| 3 Burns | | | |
| Early Spring | 6.48 | 5.40 | 11.88 |
| Early Summer | 13.77 | 8.13 | 21.90 |
| Mid Summer | 8.91 | 7.75 | 16.66 |
| 4 Burns | | | |
| Early Summer | 14.85 | 11.67 | 26.51 |
| Mid Summer | 10.17 | 4.07 | 14.21 |

Data from Manske 1992.

Table 8. Changes in herbage biomass (lbs/ac) on the nongrazed control pasture 4, 2006-2011.

| Plant Biotype | Year 1 | Year 5 | % Difference | Year 6 | % Difference |
|---|---|---|---|---|---|
| Kentucky bluegrass | 1858.69 | 1534.00 | -17.5 | 2570.98 | 38.3 |
| Cool Season | 79.57 | 182.09 | 128.8 | 50.07 | -37.1 |
| Warm Season | 68.74 | 119.65 | 74.1 | 178.88 | 160.2 |
| Upland Sedges | 28.54 | 38.68 | 35.5 | 9.40 | -67.1 |
| Forbs | 143.20 | 275.93 | 92.7 | 208.02 | 45.3 |

Data from Manske 2012.

Table 9. Changes in basal cover (%) on the nongrazed control pasture 4, 2006-2011.

| Plant Biotype | Year 1 | Year 5 | % Difference | Year 6 | % Difference |
|---|---|---|---|---|---|
| Kentucky bluegrass | 12.35 | 23.60 | 91.1 | 15.30 | 23.9 |
| Cool Season | 0.40 | 1.25 | 212.5 | 0.35 | -12.5 |
| Warm Season | 0.50 | 0.65 | 30.0 | 0.85 | 70.0 |
| Upland Sedges | 2.00 | 1.75 | -12.5 | 1.05 | -47.5 |
| Forbs | 0.80 | 1.15 | 43.8 | 0.20 | -75.0 |

Data from Manske 2012.

Table 10. Stocking Rate Used on Twice-over system 2006 to 2011 and percent of assessed stocking rate (1.92 ac/AUM).

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| Stocking Rate ac/AUM | 2.66 | 2.33 | 1.79 | 2.41 | 2.20 | 5.09 |
| % of Assessed | 72 | 83 | 107 | 80 | 87 | 38 |

Data from Manske 2015.

Table 11. Changes in herbage biomass (lbs/ac) on the grazed twice-over pastures 1 & 2, 2006-2011.

| Plant Biotype | Year 1 | Year 5 | % Difference | Year 6 | % Difference |
|---|---|---|---|---|---|
| Kentucky bluegrass | 936.07 | 713.96 | -23.7 | 1324.45 | 41.5 |
| Cool Season | 200.29 | 310.48 | 55.0 | 560.83 | 180.0 |
| Warm Season | 36.19 | 48.07 | 32.8 | 60.24 | 66.5 |
| Upland Sedges | 273.49 | 315.30 | 15.3 | 262.84 | -3.9 |
| Forbs | 118.05 | 394.74 | 234.4 | 106.27 | -10.0 |

Data from Manske 2012.

Table 12. Changes in basal cover (%) on the grazed twice-over pastures 1 & 2, 2006-2011.

| Plant Biotype | Year 1 | Year 5 | % Difference | Year 6 | % Difference |
|---|---|---|---|---|---|
| Kentucky bluegrass | 4.40 | 6.85 | 55.7 | 6.68 | 51.8 |
| Cool Season | 1.85 | 6.08 | 228.7 | 3.93 | 112.4 |
| Warm Season | 0.70 | 1.58 | 125.7 | 3.65 | 421.4 |
| Upland Sedges | 7.75 | 12.70 | 63.9 | 9.55 | 23.2 |
| Forbs | 0.45 | 3.05 | 577.8 | 0.50 | 11.1 |

Data from Manske 2012.

Table 13. Rhizosphere weight (kg/m$^3$) for the nongrazed control 4 and grazed twice-over pastures 1 & 2 during six years of twice-over rotation management, 2006-2011.

| | Nongrazed Control 4 kg/m$^3$ | Grazed Pastures 1 & 2 kg/m$^3$ | % Difference |
|---|---|---|---|
| Pregrazing 2006 | 60.49 | 60.49 | |
| 2006 | 64.24x | 83.28x | 29.64 |
| 2007 | 77.82x | 92.22x | 18.50 |
| 2008 | 70.67z | 122.61x | 73.50 |
| 2009 | 82.88z | 140.32x | 69.31 |
| 2010 | 86.85z | 183.00x | 110.71 |
| 2011 | 130.56z | 214.34x | 64.17 |

Means in same row followed by the same letter (x, y, z) are not significantly different (P<0.05).
Data from Manske 2015.

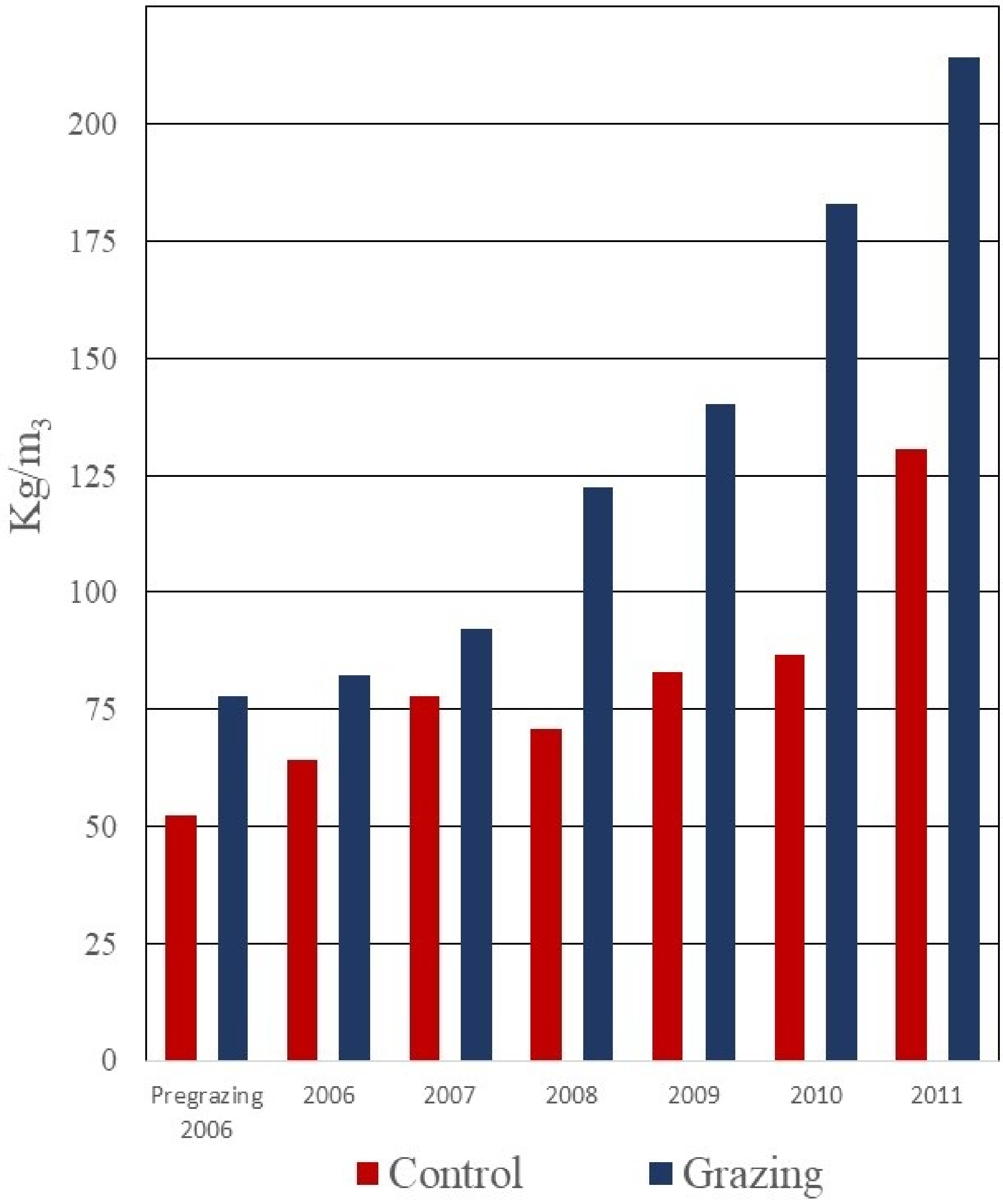


Figure 2. Rhizosphere weight (kg/$m_3$) for control pasture (red) and grazed pastures (blue) during six years of twice-over rotation management, 2006-2011.

Table 14. Available mineral nitrogen, nitrate and ammonium (lbs/ac) during May on the nongrazed control pasture 4 and the grazed twice-over pastures 1 & 2.

| Mineral Nitrogen<br>Soil depth (inches) | Nongrazed Control<br>4 | Grazed Twice-over<br>1 & 2 |
|---|---|---|
| $NO_3$ Nitrate | | |
| 0-6 | 13.25 | 29.63 |
| 6-12 | 9.75 | 11.38 |
| 12-24 | 7.69 | 9.50 |
| 0-24 | 30.69 | 50.50 |
| $NH_4$ Ammonium | | |
| 0-6 | 19.99 | 20.21 |
| 6-12 | 12.32 | 14.20 |
| 12-24 | 8.24 | 14.45 |
| 0-24 | 40.55 | 48.85 |
| $NO_3 + NH_4$ | | |
| 0-6 | 33.24 | 49.83 |
| 6-12 | 22.07 | 25.57 |
| 12-24 | 15.93 | 23.95 |
| 0-24 | 71.24 | 99.35 |

Data from Manske 2015.

| Table 15. Autecology of Poa pratensis, Kentucky bluegrass, with growing season changes in basal cover, 1983-2012. | | | | | |
|---|---|---|---|---|---|
| Ecological Site<br>Year Period | Nongrazed | Seasonlong | | Twice-over | |
| | | Ungrazed | Grazed | Ungrazed | Grazed |
| Sandy | | | | | |
| 1983-1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993-1998 | 0.78 | 0.00 | 0.03 | 0.83 | 0.02 |
| 1999-2003 | 0.27 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 |
| 2010-2012 | 0.10 | 0.00 | 0.00 | 0.93 | 0.18 |
| Shallow | | | | | |
| 1983-1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993-1998 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 |
| 1999-2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010-2012 | 0.12 | 0.00 | 0.00 | 0.07 | 0.00 |
| Silty | | | | | |
| 1983-1987 | 0.00 | 0.00 | 0.30 | 0.18 | 0.13 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 |
| 1993-1998 | 0.13 | 0.49 | 0.00 | 0.71 | 0.06 |
| 1999-2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 0.22 | 0.00 | 0.00 | 0.01 | 0.00 |
| 2010-2012 | 1.23 | 0.00 | 0.00 | 1.51 | 0.70 |

Table 16. Autecology of Poa pratensis, Kentucky bluegrass, with growing season changes in basal cover importance value, 1983-2012.

| Ecological Site Year Period | Nongrazed | Seasonlong | | Twice-over | |
|---|---|---|---|---|---|
| | | Ungrazed | Grazed | Ungrazed | Grazed |
| Sandy | | | | | |
| 1983-1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993-1998 | 7.63 | 0.57 | 0.57 | 6.26 | 0.11 |
| 1999-2003 | 4.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 0.00 | 0.00 | 0.00 | 1.54 | 0.18 |
| 2010-2012 | 0.78 | 0.00 | 0.00 | 11.70 | 1.47 |
| Shallow | | | | | |
| 1983-1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993-1998 | 0.00 | 0.00 | 0.00 | 0.25 | 0.00 |
| 1999-2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010-2012 | 0.92 | 0.00 | 0.00 | 0.50 | 0.00 |
| Silty | | | | | |
| 1983-1987 | 0.00 | 0.00 | 2.22 | 1.45 | 1.11 |
| 1988-1992 | 0.00 | 0.00 | 0.00 | 0.32 | 0.00 |
| 1993-1998 | 1.48 | 9.65 | 0.00 | 4.83 | 0.56 |
| 1999-2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004-2009 | 2.16 | 0.00 | 0.00 | 0.11 | 0.00 |
| 2010-2012 | 10.66 | 0.00 | 0.00 | 15.32 | 7.18 |

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