to cable with swivels. The cable-chain drag was pulled between two tow vehicles to survey suitable nest habitat. Nests were located by the sites of flushed hens and marked with a flag placed fifteen paces to the north. The cable-chain drag was used to survey 2,640 acres (1068 ha). Trained bird dogs were also used to locate prairie grouse nest sites with the observer on foot. The dogs were used to survey 2,903 acres (1175 ha).

Data collected at each nest site located was the number of eggs, major plant species, dimensions of the nest site, distance from the nest site to short (< 1 dm) vegetation, topographic relief, percent slope, and aspect. Nest location was marked on a map and the distance to the nearest display ground was measured. When nest was no longer used, the nest cover was evaluated by the height-density pole, with one set in center of nest, four sets two meters out, and four sets four meters out with a total of 36 readings.

### Procedures for Brooding Activity

Determination of successful brooding habitat required to know the location of representative brood sites. Two methods were used to locate brood rearing sites. Trained bird dogs were used to locate prairie grouse broods with two observers on horse back. The dogs were used to survey 41,633 acres (16,849 ha). Vehicle transects with a total of 50 miles (80.5 km) long that dissected all habitat types of the Hummocky Sandhills and Deltaic Plain Habitat Associations were traversed 3 times every two weeks during the growing season. Data collected at each site that broods were located was the number of chicks, estimated age, habitat type, dominant plants, the cadastral description, and allotment and pasture. Representative brood habitat quality was measured by the height-density pole.

### Procedure for Sharptailed Grouse Habitat Usage

This habitat usage study was conducted to determine which habitats were being used by sharptailed grouse during their annual seasonal activities. The four seasonal periods were: Spring 1 April to 15 June, Summer 16 June to 31 August, Fall 1 September to 15 November, and Winter 16 November to 31 March.

The landscape of the Sandhills region was separated into eleven habitat types based on vegetation composition, topography, and soil characteristics. The vegetation map was a composite developed from homogeneous reflectance of two sets of Landsat-2 images, from May and August, and one set of Skylab photographs, from June. The soil map was developed from homogeneous regions of similar soil texture in General Soils Maps of Ransom and Richland Counties. The topographic map was developed from homogeneous physiographic regions of nine US Geological Survey Topographic Quadrangle Maps. These three developed maps were field checked and then the homogeneous physiographic sites with closely related distribution were grouped into four mappable complexes of habitat associations. Acreages of each habitat type and habitat association were determined by 3 replications of electronic planimeter and dot grid techniques. The resulting information was reported by Manske (2020) in Sandhill Habitats (figure 2 and table 18).

Observations of sharptailed grouse performing annual seasonal activities were made during foot transects with bird dogs and during vehicle transects. The data collected at each sharptailed grouse observation was: cadastral description, allotment and pasture location, land use, habitat type, dominant plant species, date, time of day, general weather conditions, the species and sex of each prairie grouse if it could be determined, and behavioral activity of the bird.

The sharptailed grouse habitat use index developed by Robel et al. (1970b) (% of bird locations/% of study area) was used to indicate relative habitat use by sharptailed grouse during four seasonal periods. A habitat use index greater than 1.0 indicates selection of that habitat was greater than expected by chance use. Index values less than 1.0 indicate selection at less than the availability of that habitat. An index of zero indicates avoidance of that habitat type.

### Results for Courtship Activity

Sharptailed grouse gather every spring on communal display dancing grounds, for the purpose of courtship and mating. A few older male sharptailed grouse form on the dancing grounds around 15 to 20 March followed soon afterward by the younger males.

During the early period, the males determine the pecking order and the boundaries of their display territories by intense skirmishes. The mechanism that triggers this ritualistic activity is a change in the balance of two hormones in the pituitary gland that is activated by the increase of day length in early spring. The change of hormones in the pituitary gland causes the male testes and female ovaries to enlarge and produce complimentary hormones that strongly influence the behavior of the birds. The auditory and visual signals of male sharptailed grouse in full courtship display further stimulates breeding behavior.

The male sharptailed grouse census indicates a low population during 1961 to 1970. During the first census efforts in 1961 no sharptailed grouse dancing grounds were located but several scattered birds were observed. A hybrid was active on one booming ground which indicates that a breeding male or female sharptailed grouse was active during a past mating season. During 1963, the first dancing ground was located audially but not counted. During 1970, a second dancing ground was located and counted with 11 male sharptailed grouse. This ground was located and counted in 1961 and 1962 with one male prairie chicken each year.

During 1961 to 1967, all 56 allotments were grazed 6 months seasonlong from mid May to mid November, providing little adequate concealment habitat for the sharptailed grouse. During 1968 to 1970, a few allotments were cross fenced and some multiple pastures were grazed one time per year with one of the pastures deferred until late season. In 1971, 18 pastures from 15 allotments, about 10% of the land were grazed two times per year.

The spring prairie grouse census reflects the grazing management practice of the previous season or two. The spring census of 1971 found three dancing grounds with 25 male sharptailed grouse, and 1 booming ground had 4 male sharptailed grouse; these 4 display grounds had 29 male sharptailed grouse. The spring census of 1972 found that 3 dancing grounds had 32 males, 2 mixed grounds had 19 males, and 2 booming grounds had 5 males; these 7 display grounds had a huge increase of 56 male sharptailed grouse. The spring census of 1973 found that 5 dancing grounds had 40 males, 1 mixed ground had 6 males, and 3 booming grounds had 6 males; these 9 display grounds had 52 male sharptailed grouse (tables 1, 2, 3, and 4).

In 1974, 14 allotments, 26% of the land, had all pastures grazed 2 times per year. The number of pastures with two grazing periods per year increased each grazing season until the peak in 1978 when 54% of the land was managed with two grazing periods per year.

The spring census of 1975, found that 5 dancing grounds had 46 males, 1 mixed ground had 4 males, and 2 booming grounds had 3 males; these 8 display grounds had 53 male sharptailed grouse. The spring census of 1977, found that 6 dancing grounds had 35 males, 3 mixed grounds had 15 males, and 1 booming ground had 1 male; these 10 display grounds had 51 male sharptailed grouse. There had not been an increase in the number of male sharptailed grouse active on the display grounds censused from 1972 to 1978 (tables 1, 2, 3, and 4).

The spring census of 1979, found that 12 dancing grounds had 104 males, 10 mixed grounds had 45 males, and 3 booming grounds had 7 males; these 25 display grounds had a huge increase to 156 male sharptailed grouse. The spring census of 1980, found that 12 dancing grounds had 110 males, 8 mixed grounds had 65 males, and 7 booming grounds had 15 males; these 27 display grounds had an increase to 190 male sharptailed grouse (tables 1, 2, 3, and 4).

The display ground activity levels are assumed to be similar in male and female sharptailed grouse. The male birds start courtship activity on dancing grounds around 15 to 20 March. The female birds are visible on dancing grounds about a week later. Male birds arrive 1 hour to ½ hour before sunrise and most vocal activity occurs from dawn until ½ hour to 1 hour after sunrise, display activity slows down but continues until 8 or 9 o'clock depending on weather conditions or presence of female birds. Intense levels of courtship display occurs from 7 to 28 April with peak activity from 14 to 20 April. Activity continues after 28 April at low intensity but has renewed activity during late May to mid June when renesting females return to the dancing grounds (figure 1).

Male hybrid activity on display grounds was extremely erratic, they come and go, even during peak display periods (table 5). Very few female hybrids were identified showing interest on display grounds and only during peak display periods.

The male sharptailed grouse breakup into small groups after mid June but remain in the vicinity of the display ground all summer.

The distance from the center of the display ground to the nearest livestock watering facility was measured for 87 dancing grounds with active male sharptailed grouse. Most, 48 grounds (55%), were located near a livestock water facility with vegetation grazed shorter than the typical level and had a mean distance of 569 ft (173 m). The other display grounds, 39 grounds (45%), were greater than 1500 ft (457 m) from a livestock watering facility. 23

grounds (26%) were restricted to the upland mixed grass prairie community with short stature vegetation. 11 grounds (12.6%) had been mowed during the previous year. Only 5 grounds (5.7%) had male sharptailed grouse displaying on the midland tall grass prairie community that had not been mowed the previous year and was greater than 1500 ft (457 m) from livestock water. No sharptailed grouse males displayed on unmowed lowland sedge meadow community. The vegetation height stature had been reduced by grazing or mowing management on the sites of 59 grounds (68%) selected by male sharptailed grouse and the sites selected for only 28 grounds (32%) had vegetation at typical level.

The quality of concealment cover adjacent or very near spring display grounds was determined for 87 dancing grounds by the height-density pole method. The concealment cover was very good with mean 100% VOM at greater than 1.5 dm (5.9 in) on 70 grounds (80.5%). The concealment cover was good with mean 100% VOM near 1.5 dm (5.9 in) on 11 grounds (12.6%). The concealment cover was poor with mean 100% VOM at less than 1.5 dm (5.9 in) on 6 grounds (6.9%). Most dancing grounds, 81 grounds (93.1%), had good or very good concealment cover adjacent or very near with mean 100% VOM at or greater than 1.5 dm (5.9 in).

Prairie grouse census started in 1961 that located 6 display grounds. The first dancing ground was located in 1963. The second dancing ground was located in 1970 which had changed from being a booming ground in 1961 and 1962.

By 1980 (year 20), the location of 13 dancing grounds was known (table 6). Four dancing grounds had been known for only one or two years and had not yet moved. Nine (69.2%) of the dancing grounds had changed locations. These dancing grounds had been active for an average of 5.6 years, moved an average of 3.7 times, at a rate of movement during 78.8% of their active years. The mean distance moved was 0.57 miles (0.92 km). The mobility of each display ground was limited to a territory or movement zone of varying size with a mean of 0.68 X 0.39 miles (1.1 X 0.63 km) with 195 acres (79 ha) (table 6).

The sharptailed grouse population congregate into three major districts (figure 2). During the period of 1971 to 1980, the number of male sharptailed grouse, the number of dancing grounds, and mixed display grounds, and the quantity of occupied habitat greatly increased on each of the population districts.

The West Central District was located west of McLeod (tables 7 and 10). In 1975, it had 2 dancing grounds with 14 male sharptailed grouses. During the consecutive five years, 1 dancing ground remained active, 1 dancing grounds changed to a mixed ground, 5 new dancing grounds were added, and 5 new mixed grounds were added. During 1980, there were 6 dancing grounds and 6 mixed grounds with 111 male sharptailed grouse and 6 hybrids (table 7 and figure 2).

The South East District was located south and east of McLeod (tables 8 and 10). In 1975, it had 1 dancing ground with 15 male sharptailed grouse and 1 hybrid. During the consecutive five years, the 1 dancing ground remained active, 1 new dancing grounds was added, and 4 new mixed grounds were added. During 1980, there were 2 dancing grounds and 4 mixed grounds with 37 male sharptailed grouse (table 8 and figure 2).

The North East District was located north and east of McLeod (tables 9 and 10). In 1975, it had 2 dancing grounds and 1 mixed ground with 24 male sharptailed grouse and 3 hybrids. During the consecutive five years, 2 dancing grounds remained active, 1 mixed ground was active during 4 of the 6 years, and 1 new dancing ground was added. During 1980, there were 3 dancing grounds with 36 male sharptailed grouse and 1 hybrid (table 9 and figure 2).

Unfortunately, in 1979, the grazing management was drastically changed to multiple pastures grazed one time and one of the pastures deferred until late season. The number of pastures grazed two times per year were rapidly reduced to zero shortly after 1979. This major change in grazing management practices terminated the 10 year (1971 to 1980) period with encouraging increases in sharptailed grouse population. After these changes in grazing management, the sharptailed grouse has had wide irregular fluctuations with a greatly decreased number.

## Results for Nesting Activity

Female sharptailed grouse visit the dancing ground several times before she submits to copulate with the male of her choosing, which is not always the dominant male. The hen had previously selected a nest site with good visual obstruction cover. After mating, she finishes building the ground nest. The first egg is laid in about 3 days (1 to 5 days), followed by one egg per day, until a full clutch with a mean of 13 eggs (12 to 15 eggs) (table 11). Incubation starts after all the eggs are laid and usually takes 25 days

(23 to 27 days). The hen leaves the nest for brief periods to feed but spends most of the time on the nest, the male does not help.

Three nests were located by the cable-chain drag, 1 nest was located during a prescribed burn, 4 nests were located by the dogs, and a dog was used to relocate 2 nests that the marker flag had been removed by curious deer.

The mean distance of the nest sites to the nearest display grounds was 0.75 miles (table 11). However, the hen may not have mated on the nearest display ground. All eight of the nest sites were located in native vegetation of the midland tall grass prairie community. Switchgrass was the dominant species at all of the nest sites except, one nest was located near a white spiraea shrub with Kentucky bluegrass the dominant grass and switchgrass was a subdominant. The immediate nest sites were characteristically completely covered by vegetation. The sides and top were very dense residual and growing vegetation. The mean 100% VOM at nest center was 2.58 dm (10.2 in). Some nest sites had a definable hole in the vegetation for the hen to pass in or out. Most of the nest sites had an elliptical shape with the mean dimensions of 1.9 X 2.3 ft and an area of 3.11 $ft^2$. All of the nest sites were located on relatively level topography, with slopes of 1% to 5%, and the aspect was mostly north or south (table 12).

The surrounding nest cover had a mean 100% VOM of 2.4 dm (9.5 in). The distance to short vegetation of less than 1 dm (3.9 in) was categorized into narrow (<10 ft) (<3.0 m), medium (to 50 ft) (to 15.2 m), and wide (>50 ft) (>1.5.2 m) cover (table 12). Two nest sites were in narrow cover with a mean of 4.5 ft (1.4 m) to short vegetation. One of these nests were lost to high soil moisture and the other nest was believed to have been successful because it was in some of the best cover measured with a 100% VOM at 3.1 dm (12.2 in). Four nest sites were in medium cover with a mean of 20.8 ft (6.3 in) to short vegetation. Two of the nests had been located during the early stages of egg laying and were abandoned, 1 nest was lost during a prescribed burn, the hen escaped, and on the fourth nest, 9 of 10 eggs hatched. Two nest sites were in wide cover with a mean of 150 ft (45.8 in) to short vegetation. One of the nests had partial success with 12 of the 14 eggs hatched, and the other nest had 13 eggs hatch (tables 11 and 12).

**Results for Brooding Activity**

Sharptailed grouse chicks have an “egg tooth” which is a hard white growth on the end of their bill to help them break the eggshell from inside. It disappears soon after hatching. The chicks are precocial, they are covered with down, the eyes are open, they can walk and feed themselves as soon as they are dry. Most of the first day is spent on or near the nest site. The chicks eat a high protein diet of mostly insects and grow very fast. They are capable of short flights at 7 to 10 days old. At 90 days old, the young cannot easily by distinguished from adult plumage, except the chicks are still lighter weight.

The estimated age of the chicks was based on the relative body size in relation to an adult bird and the stage of plumage development (table 13). At the time, the research to identify the stages for aging young prairie grouse were for birds in the hand, not for field observations.

The sharptailed grouse brood search was conducted for 6 years from mid June to mid September. The trained bird dogs located 13 broods and 15 broods were located by vehicle transects. Two broods of hybrid chicks with sharptailed grouse hens were located (table 15).

The sharptailed grouse brood size tended to decrease with time. The mean sharptailed grouse completed clutch size was 13 ± 1.79 eggs. About 50% of the nests hatch some eggs. The mean number of eggs that hatched from successful nests was 12 ± 1.63 eggs. The brood size in late June was 9.7 chicks, by late July the brood size was 9.2 chicks and by late August the brood size had decreased to 7.0 chicks (table 14). The higher percent of losses appears to occur early after hatch. From a full clutch of eggs in a nest to late August, the hens had been able to save about 50% of their chicks, which seems to be a remarkable accomplishment. During a biweekly period, the age of young birds had a wide spread in age of about 26 days from youngest to oldest.

Sharptailed grouse broods were located in a wide variety of habitats with 54% in shrubs and 46% in grass (table 15). Thirteen (46%) broods were located in the upland mixed grass prairie communities with 85% in shrubs of lead plant, buckbrush, green sage, oak saplings, rose, and willow, and 15% in blue grama. Six (21%) broods were located in the midland tall grass prairie communities with 67% in shrubs of spiraea, lead plant, buckbrush, and wild licorice, and

33% in grass of switchgrass and Kentucky bluegrass. Nine (32%) broods were located in the lowland sedge meadow with sedge and grasses of woolly sedge, Kentucky bluegrass, and northern reed.

Sharptailed grouse broods were very mobile and travel over a large area and use several habitat types. Areas of shorter vegetation that had been mowed or grazed were used as feeding areas. The adjacent areas of dense residual and growing vegetation were used for escape cover and loafing. Broods usually used areas that had a high amount of shrubs and forbs. These areas usually provided good canopy cover and relatively open understories.

The height-density pole was used to evaluate the quality of six prairie grouse brood habitat sites (tables 16 and 17). The upland shrub site had a mean 100% VOM of 1.6 dm (6.3 in) with 65% of the reading at or above 1.5 dm. The two midland grass sites had mean 100% VOM of 1.9 dm (7.5 in) and 2.3 dm (9.1 in) with 97% and 100% of the readings at or above 1.5 dm. The midland grass-shrub site had a mean 100% VOM of 2.4 dm (9.5 in) with 95% of the readings at or above 1.5 dm. The lowland sedge-grass site had a mean 100% VOM of 1.8 dm (7.1 in) with 85% of the readings at or above 1.5 dm. The lowland sedge-shrub site had a mean 100% VOM of 1.9 dm (7.5 in) with 95% of the readings at or above 1.5 dm (tables 16 and 17). Prairie grouse hens selected very good concealment cover for their broods.

**Results for Sharptailed Grouse Habitat Usage**

The Sandhills region was comprised of eleven habitat types grouped into four habitat associations (table 18). The largest habitat association was the Hummocky Sandhills that consisted of 65,494 acres, and was 50.16% of the Sandhills region. It was comprised of the Upland mixed grass prairie habitat type that consisted of 34,389 acres, 26.34%, with blue grama, needle and thread, and upland sedge; the Midland tall grass prairie habitat type that consisted of 16,558 acres, 12.68% with little bluestem, big bluestem, and switchgrass; the Lowland sedge meadow habitat type that consisted of 12,737 acres, 9.76% with woolly sedge, northern reed, and baltic rush; and the Cropland habitat type that consisted of 1,810 acres, 1.39% with replacement vegetation.

The second habitat association was the Deltaic Plain that consisted of 38,761 acres, and was 29.69% of the Sandhills region. It was comprised of the Midland tall grass prairie habitat type that consisted of 14,476 acres, 11.09%, with little bluestem, big bluestem, and Indian grass; the Lowland sedge meadow habitat type that consisted of 5,387 acres, 4.13% with woolly sedge, northern reed, and lowland sedge; and the Cropland habitat type that consisted of 18,898 acres, 14.47% with replacement vegetation.

The third habitat association was the Choppy Sandhills that consisted of 19,170 acres, and was 14.68% of the Sandhills region. It was comprised of the Upland Woodland grove and savanna habitat type that consisted of 12,269 acres, 9.40%, with bur oak, quaking aspen, and green ash; and the Open Grassland thin mixed grass prairie habitat type that consisted of 6,901 acres, 5.29% with blue grama, upland sedge, and sand dropseed.

The smallest habitat association was the River Terrace that consisted of 7,135 acres, and was 5.46% of the Sandhills region. It was comprised of the Riparian Forest habitat type that consisted of 5,710 acres, 4.37% with basswood, American elm, green ash, and box elder; and the Cropland habitat type that consisted of 1,425 acres, 1.09% with replacement vegetation.

Transportation Routes have been constructed across the Sandhills region. Gravel Roads have a total length of 112 miles with 679 acres of right of way, 0.52%; Railroads have a total of 17.5 miles of track with 106 acres of right of way, 0.08%; and Asphalt Roads have a total length of 13 miles with 79 acres of right of way, 0.06%.

Habitat usage by sharptailed grouse during four seasonal periods was determined by the habitat use index (% of bird locations/% of study area). The spring activity period occurred over 2.5 months from 1 April to 15 June with 958 observations of sharptailed grouse performing seasonal activities. The habitat use index for the Hummocky Sandhills was high at 1.98, for the Deltaic Plain was zero; for the Choppy Sandhills was very low at 0.06, and for the River Terrace was zero. The habitat use index for the Upland mixed grass prairie was at 2.48, for the Midland tall grass prairie was at 2.33, for the Lowland sedge meadow was at 0.34, and for the Cropland area was at 0.61 of the Hummocky Sandhills. The Upland Woodland was at 0.09 of the Choppy Sandhills. The habitat types of the Deltaic Plain and River Terrace had habitat use index at zero (table 19).

The summer activity period occurred over 2.5 months from 16 June to 31 August with 350 observations of sharptailed grouse performing seasonal activities. The habitat use index for the Hummocky Sandhills was high at 1.79, for the Deltaic Plain was at 0.08, for the Choppy Sandhills was at 0.53, and for the River Terrace was at zero. The habitat use index for the Upland mixed grass prairie was at 1.36, for the Midland tall grass prairie was at 2.57, for the Lowland sedge meadow was at 1.96, and for the cropland was at 1.89 of the Hummocky Sandhills, which were used for concealment cover and protection from the hot sun by the males and for nest and brood cover by the hens. The Lowland sedge meadow was at 0.48, and the Midland tall grass prairie was at 0.03 for the Deltaic Plain which were used for concealment, protection from the hot sun, and brood cover and feeding areas (table 19).

The Fall activity period occurred over 2.5 months from 1 September to 15 November with 210 observations of sharptailed grouse performing seasonal activities. The habitat use index for the Hummocky Sandhills was at 1.62, for the Deltaic Plain was at 0.53, for the Choppy Sandhills was at 0.06, and for the River Terrace was at zero. The Fall period had several changes with a shift from grassland habitats to cropland habitats, the hens leave her brood which brake up and disperse, and adult and juvenile birds gather at fall display grounds forming small winter flocks. The greatest habitat use index for the Upland mixed grass prairie was at 190.48, the Lowland sedge meadow was at 3.11, and the Midland tall grass prairie was at 0.09 of the Deltaic Plain primarily because of the large quantity of buckbrush on the Upland which was used by males and broods for concealment cover, shade, and the ripe berries for food. The Midland tall grass prairie was at 4.62, the Upland mixed grass prairie was at 0.76, the Cropland was at 0.70, and the Lowland sedge meadow was at 0.20 of the Hummocky Sandhills, and the Open Grassland was at 0.18 of the Choppy Sandhills which were used for shade and concealment cover (table 19).

The gravel roads had a high use index during the fall at 3.66 which were used for grit, for spilled grain moved from field to storage, and for dust baths. Rose hip seeds were used for grit during every month of the year.

The Winter activity period occurred over a long 4.5 months from 16 November to 31 March with 1,248 observations of sharptailed grouse performing seasonal activities. The habitat use index for the Deltaic Plain was high at 2.16, for the Choppy Sandhills was at 0.39, for the Hummocky Sandhills was at 0.34, and for the River Terrace was at zero. The shift from grassland habitat to cropland habitat and adjacent tree shelterbelts had been completed. The high index for cropland area was at 5.07 and for shelterbelts was at 32.05 for the Hummocky Sandhills and for cropland was at 4.28 and shelterbelts was at 3.51 for the Deltaic Plain which indicates the importance of agricultural food sources during the winter. The Open Grassland was at 1.01, and the Upland Woodland was at 0.03, of the Choppy Sandhills, the Midland tall grass prairie was at 0.42, of the Deltaic Plain, and the Upland mixed grass prairie was at 0.31, the Midland tall grass prairie was at 0.03, and the Lowland sedge meadow was at 0.08 of the Hummocky Sandhills which were used for loafing areas between the morning and evening feeding periods (table 19).

Sharptailed grouse used the grassland habitats of the Hummocky Sandhills during the spring, summer, and fall and moved to the cropland habitat and adjacent planted tree shelterbelts of the Hummocky Sandhills and Deltaic Plain during winter. Sharptailed grouse used the grassland habitat and short shrub and sapling tree zone at the edge of mature tree groves and savanna of the Choppy Sandhills. They did not use the mature tree areas of the Choppy Sandhills and River Terrace.

Habitat usage by sharptailed grouse during three critical activities of courtship, nesting, and brood rearing were determined by the habitat use index (% of bird locations/% of study area). The critical courtship and mating activity is performed on communal display grounds (dancing grounds) had 88 observations. Each display ground is anchored on the Upland mixed grass prairie with an habitat use index of 2.76 and for the Midland tall grass prairie was at 2.15 of the Hummocky Sandhills. The Upland mixed grass prairie was grazed. The Midland tall grass prairie was used by males as courtship territories if mowed the previous year and used as concealment cover by males and females if not mowed the previous year. No sharptailed grouse used habitats of the Deltaic Plain for display grounds (table 20).

The critical nesting activity was performed solely by the females with no help from the males had 8 observations. Each nest site is placed in very good concealment cover with high visual obstruction. The habitat use index value was high at 7.88 for the switchgrass portion of the Midland tall grass prairie of the Hummocky Sandhills. The switchgrass community was the only habitat found to be used by sharptailed grouse for nesting (table 20).

The critical brood rearing activity was performed solely by the females with no help from the males had 28 observations. All broods that were accompanied by a hen used a wide variety of habitats for concealment cover and feeding. Usually the brooding habitat had an abundance of short shrubs and forbs that provided good canopy cover and open understory. The habitat use index for the Midland tall grass prairie was at 2.34, for the Lowland sedge meadow was at 1.58, and for the Upland mixed grass prairie was at 1.56 of the Hummocky Sandhills; for the Lowland sedge meadow was at 0.69 of the Deltaic Plain; and for the Upland Woodland was at 1.17 of the Choppy Sandhills. Mature woodland areas were not used by sharptailed grouse (table 20).

## Discussion

Long term survival of sharptailed grouse in the Sandhills region depends on the availability of short stature habitat for courtship activities, good concealment cover for nesting, brooding, roosting, and escaping activities, and agricultural commodities for winter food. The quality of the grassland habitats is greatly affected by the type of grazing management implemented.

The 6 month seasonlong treatment resulted in a mean 100% VOM of the switchgrass zone at 1.3 dm (5.1 in) with 43% readings at or above 1.5 dm during spring, 13% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plant species composition significantly increased with Kentucky bluegrass, and decreased with cool and warm season native grasses.

The deferred grazing treatment resulted in a mean 100% VOM of the switchgrass zone at 1.6 dm (6.3 in) with 62% readings at or above 1.5 dm during spring, 20% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plant species composition significantly increased with Kentucky bluegrass, and decreased with switchgrass, warm and cool season native grasses, and upland sedges.

The two pasture switchback strategy resulted in a mean 100% VOM of the switchgrass zone at 1.7 dm (6.7 in) with 63% readings at or above 1.5 dm during spring, 30% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plant species composition significantly decreased with switchgrass, warm and cool season native grasses, and upland sedges.

The allotments with multiple pastures grazed two times per year resulted in a mean 100% VOM of the switchgrass zone at 2.0 dm (7.9 in) with 78% readings at or above 1.5 dm during spring, 32% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plant species composition significantly increased with switchgrass, lowland sedge, warm and cool season native grasses, upland sedges, and total basal cover.

During the 28 year period that all 56 allotments were grazed with 8 month or 6 month seasonlong, the male sharptailed grouse population remained very low with probably no more than 5 or 6 males. During the 3 year period that 39% of the land was managed with multiple pastures grazed one time per year with one pasture deferred to late season, the census documented 11 male sharptailed grouse on the spring of the third year. During the next 3 years, 10% of the land was grazed two times per year, by the spring of the third year, the number of male sharptailed grouse increased to 52. During the next 5 years the quantity of land managed with grazing two times increased from 26% to 54% of the land and the male sharptailed grouse census increased to 156 with the increase continuing for one additional year, with a peak sharptailed grouse census at 190 males. Then the grazing management was changed back to multiple pastures grazed one time per year with one pasture deferred to late season and the pastures grazed two times per year were decreased to zero causing the sharptailed grouse population to have wide irregular fluctuations with a declining trend. This drastic change in grazing management effectively terminated the expansion in the sharptailed grouse population.

During this 10 year improvement period, the sharptailed grouse population increased from 29 to 190 males, the quantity of land managed with two grazing periods per year increased from 10% to 54%, which greatly increased the quantity and quality of the available concealment cover. The mean 100% VOM at 1.5 dm (5.9 in) was considered to be the minimum for good concealment cover.

During the period of increasing sharptailed grouse population, the concealment cover used for nesting activities had a mean 100% VOM at 2.4 dm (9.5 in). The concealment cover used for brooding activities with upland shrubs had a 100% VOM at 1.6 dm (6.3 in), with midland grass had 100% VOM at 1.9 dm (7.5 in) and 2.3 dm (9.1 in), with midland shrubs had a 100% VOM at 2.4 dm (9.5 in), with lowland grass had a 100% VOM at 1.8 dm (7.1 in). The concealment cover used for night roosting activities had a mean 100% VOM at 1.6 dm (6.3 in) during spring and at 2.0 dm (7.9 in) during fall.

During the period with declining sharptailed grouse population, the available concealment cover would have decreasing quantity and quality that resulted after the drastic change to grazing management practices with multiple pastures grazed one time per year and one pastures deferred until late season. The type of grazing management implemented affects the quality of grassland habitat available to grassland wildlife.

## Acknowledgment

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Sharp-tailed Grouse, Male. Photo by Al Smith

Hybrid (Prairie Chicken X Sharp-tailed Grouse), Male. Photo by Ed Bry

Table 1. Active male spring census of Sharptailed Grouse on Dancing Grounds.

| Dancing Ground Number | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | 11 | | 9 | 8 | 8 | 11 | 10 | 4 | 2 | 3 | 3 |
| 4 S | | | 7 | | | | 1 | 1 | 3 | | 6 | 10 |
| 10 | | | 13 | 19 | 5 | 4 | 4 | | 11 | 14 | 11 | 15 |
| 14 | | | 5 | 4 | 5 | 12 | 15 | 7 | 15 | 7 | 10 | 8 |
| 18 | | | | | 17 | 16 | 15 | | 1 | 2 | 6 | 9 |
| 20 | | | | | 5 | 2 | | | | | | 14 |
| 31 | | | | | | | | | | | 16 | 16 |
| 32 | | | | | | | | 2 | | | 3 | 2 |
| 33 | | | | | | | | | | | 24 | 12 |
| 38 | | | | | | | | 3 | 1 | | 10 | 10 |
| 41 N | | | | | | | | | | | 7 | 6 |
| 41 S | | | | | | | | | | | 2 | |
| 47 | | | | | | | | | | | 6 | 5 |
| ST Males | | 11 | 25 | 32 | 40 | 42 | 46 | 23 | 35 | 25 | 104 | 110 |

Table 2. Active male spring census of Sharptailed Grouse on Mixed Display Grounds.

| Mixed Ground Number | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | | | | | | | | | 7 | 1 | 2 | 4 |
| 13 E | | | | 17 | 6 | | | 3 | 4 | 7 | 1 | 1 |
| 13 W | | | | | | | | | | | 8 | 8 |
| 15 | | | | 2 | | | | | | | 2 | 2 |
| 26 | | | | | | 1 | 4 | 1 | | 3 | 1 | |
| 28 | | | | | | | | 3 | 4 | 1 | 2 | |
| 30 N | | | | | | | | | | | | 17 |
| 30 S | | | | | | | | | | | 2 | 3 |
| 42 | | | | | | | | | | | 12 | 16 |
| 44 | | | | | | | | | | | 6 | |
| 45 | | | | | | | | | | 2 | 9 | 14 |
| ST Males | | | | 19 | 6 | 1 | 4 | 7 | 15 | 14 | 45 | 65 |

Table 3. Active male spring census of Sharptailed Grouse on Booming Grounds.

| Booming Ground Number | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 1 | | | 1 | | | | | 1 |
| 8 E | | | | | | | | | 1 | | 1 | 2 |
| 11 | | | | | | | 2 | | | | | |
| 12 | | | 4 | 4 | 2 | | | | | | | |
| 17 | | | | | 3 | | | | | | | |
| 19 | | | | | 1 | | | | | | | |
| 21 | | | | | | | | | | | 1 | 1 |
| 22 | | | | | | 1 | | | | | | |
| 24 | | | | | | 4 | | | | | | 2 |
| 27 | | | | | | | | | | | 5 | 3 |
| 29 | | | | | | | | | | | | 4 |
| 43 | | | | | | | | | | | | 2 |
| ST Males | | | 4 | 5 | 6 | 5 | 3 | | 1 | | 7 | 15 |

Table 4. Total active male spring census of Sharptailed Grouse.

| Type Display Ground | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dancing | | 11 | 25 | 32 | 40 | 42 | 46 | 23 | 35 | 25 | 104 | 110 |
| Mixed | | | | 19 | 6 | 1 | 4 | 7 | 15 | 14 | 45 | 65 |
| Booming | | | 4 | 5 | 6 | 5 | 3 | | 1 | | 7 | 15 |
| Total ST Males | | 11 | 29 | 56 | 52 | 48 | 53 | 30 | 51 | 39 | 156 | 190 |

Table 5. Active male spring census of Hybrid Grouse with Sharptailed Grouse on Display Grounds.

| Display Ground Number | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | | | 1 | 1 | | | | | | |
| 4 S | | | | | | | | | | | | 1 |
| 10 | | | | 1 | | | 1 | | | 1 | 1 | |
| 13 E | | | | 3 | 5 | | | | 1 | | | |
| 13 W | | | | | | | | | | | | 2 |
| 14 | | | | | | | 2 | | | | 2 | 1 |
| 18 | | | | | | | 1 | | | | | |
| 20 | | | | | | 1 | | | | | | 1 |
| 33 | | | | | | | | | | | 1 | 1 |
| 38 | | | | | | | | | | | | 1 |
| 45 | | | | | | | | | | 1 | 2 | |
| Hybrid Males | | | | 4 | 6 | 2 | 4 | | 1 | 2 | 6 | 7 |

Figure 1. Daily and weekly percentage of male [♂] and female [♀] sharp-tailed grouse [ST] present on the display grounds - 1975-1980.

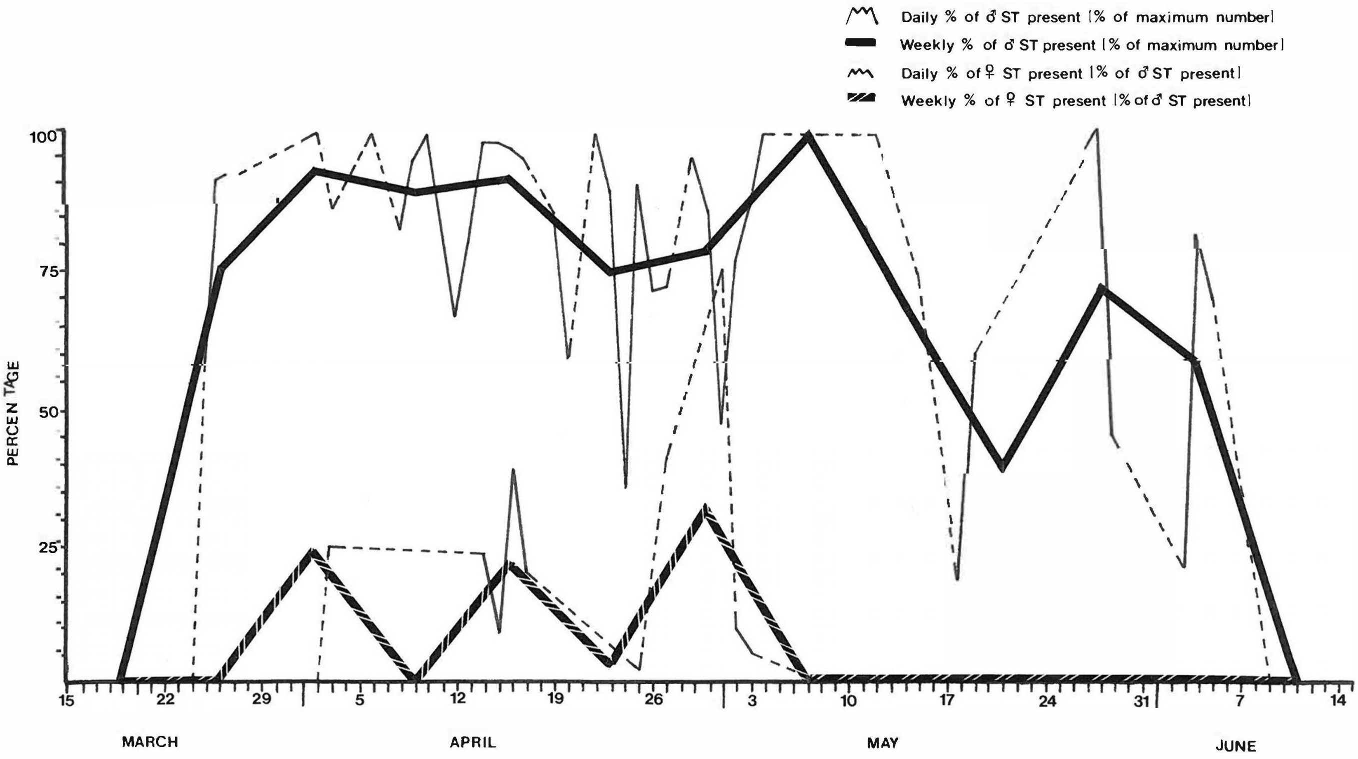

FIGURE 2. PRAIRIE GROUSE DISPLAY GROUNDS ON THE SHEYENNE NATIONAL GRASSLANDS-1980

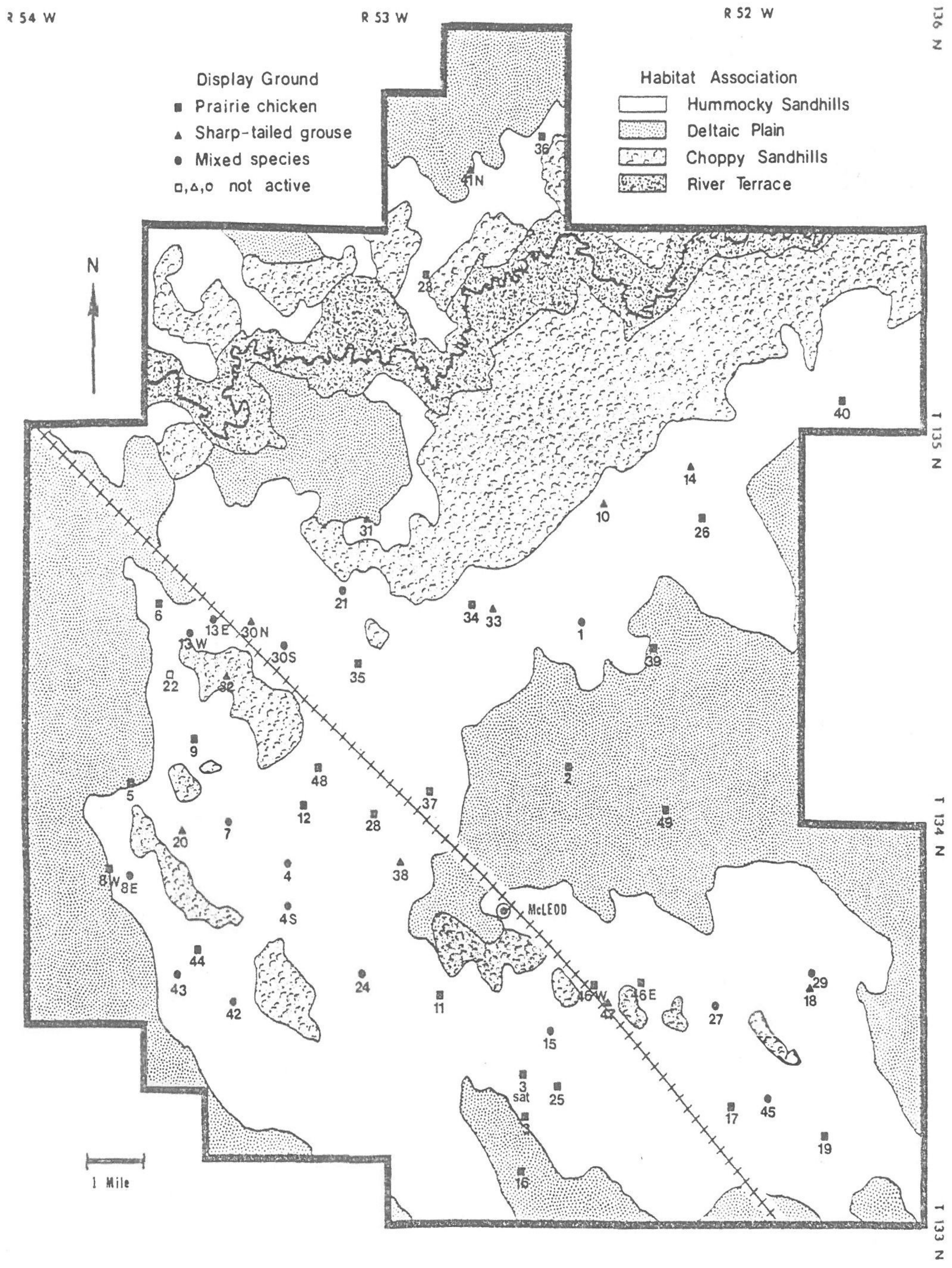

Table 6. Movement rate of spring Sharptailed Grouse Dancing Grounds

| Dancing Ground Number | Years Censused # | Different Locations # | Movement Rate % | Distance Moved mi | Size Movement Zone mi X mi | Area Movement Zone acre |
|---|---|---|---|---|---|---|
| 4 | 8 | 5 | 87.5 | 0.64 | 0.79 X 0.42 | 211 |
| 4 S | 5 | 5 | 100.0 | 0.77 | 0.79 X 0.62 | 314 |
| 10 | 8 | 4 | 50.0 | 0.46 | 0.77 X0.41 | 205 |
| 14 | 10 | 4 | 40.0 | 0.13 | 0.26 X 0.13 | 19 |
| 18 | 7 | 4 | 57.1 | 1.13 | 1.61 X 0.66 | 678 |
| 20 | 3 | 3 | 100.0 | 0.32 | 0.33 X0.32 | 70 |
| 31 | 2 | 1 | 0.0 | 0.0 | | |
| 32 | 3 | 3 | 100.0 | 0.76 | 0.77 X 0.16 | 77 |
| 33 | 2 | 1 | 0.0 | 0.0 | | |
| 38 | 4 | 3 | 75.0 | 0.18 | 0.16 X 0.15 | 13 |
| 41 N | 2 | 1 | 0.0 | 0.0 | | |
| 41 S | 1 | 1 | 0.0 | 0.0 | | |
| 47 | 2 | 2 | 100.0 | 0.73 | 0.65 X 0.40 | 166 |
| Mean N=9 | 5.6 | 3.7 | 78.8 | 0.57 | 0.68 X 0.39 | 195 |

Table 7. Population expansion of Sharptailed Grouse on the West Central District.

| | Active Display Grounds | | Active Males | |
|---|---|---|---|---|
| Year | ST | Mixed | ST | Hy |
| 1970-1974 | 3 | 3 | 17 | 1 |
| 1975 | 2 | 0 | 14 | |
| 1976 | 5 | 1 | 22 | |
| 1977 | 3 | 3 | 24 | 1 |
| 1978 | 1 | 3 | 11 | |
| 1979 | 6 | 6 | 73 | 3 |
| 1980 | 6 | 6 | 111 | 6 |

Table 8. Population expansion of Sharptailed Grouse on the South East District.

| | Active Display Grounds | | Active Males | |
|---|---|---|---|---|
| Year | ST | Mixed | ST | Hy |
| 1970-1974 | 1 | 1 | 7 | |
| 1975 | 1 | 0 | 15 | 1 |
| 1976 | 0 | 0 | 0 | |
| 1977 | 1 | 0 | 1 | |
| 1978 | 1 | 1 | 4 | 1 |
| 1979 | 3 | 2 | 28 | |
| 1980 | 2 | 4 | 37 | |

Table 9. Population expansion of Sharptsiled Grouse on the North East District.

| | Active Display Grounds | | Active Males | |
|---|---|---|---|---|
| Year | ST | Mixed | ST | Hy |
| 1970-1974 | 2 | 1 | 14 | |
| 1975 | 2 | 1 | 24 | 3 |
| 1976 | 1 | 0 | 8 | |
| 1977 | 2 | 0 | 26 | |
| 1978 | 2 | 1 | 24 | 1 |
| 1979 | 3 | 1 | 46 | 3 |
| 1980 | 3 | 0 | 36 | 1 |

Table 10. Change in number of active display grounds with male Sharptailed Grouse on three districts between 1975 and 1980.

| West Central | | | South East | | | North East | | |
|---|---|---|---|---|---|---|---|---|
| 1975 | 1980 | | 1975 | 1980 | | 1975 | | 1980 |
| ST | ST | Mix | ST | ST | Mix | ST | Mix | ST |
| 4 | 4 S | 4 | 18 | 18 | 15 | 10 | 26 | 10 |
| 4 S | 20 | 7 | | 47 | 27 | 14 | | 14 |
| | 30 N | 8 E | | | 29 | | | 33 |
| | 31 | 13 W | | | 45 | | | |
| | 32 | 30 S | | | | | | |
| | 38 | 42 | | | | | | |

Table 11. Sharp-Tailed Grouse (ST) nest site and outcome.

| | | | | Outcome | |
|---|---|---|---|---|---|
| # of Nest Site | Date First Located | # of Eggs | Display Ground | Success | Failure |
| 1 | 14 May | 12 | .50 mi. | ? Hatched | |
| 2 | 22 May | 1 | 1.13 mi. | | Site Abandoned |
| 3 | 22 May | 5+ | 1.13 mi. | | Site Abandoned |
| 4 | 25 May | 14 | .75 mi. | Hen Escaped | Site Burned |
| 5 | 2 Jun | 15 | .75 mi. | | High Moisture, 11 Eggs Remained |
| 6 | 4 Jun | 13 | .88 mi. | 13 Hatched | |
| 7 | 6 Jun | 14 | .38 mi. | 12 Hatched | 2 Eggs Missing |
| 8 | 19 Jun | 10 | .50 mi. | 9 Hatched | |

Table 12. Sharp-Tailed Grouse (ST) nest site habitat description.

| # of Nest Site | Habitat Type | Dominant Plants | Nest Site Size ft | Nest Site Area ft$^2$ | Slope % | Aspect | Cover in dm 100% V.O.M. | Feet to Short Cover of ≤ 1.0 dm 100% V.O.M. |
|---|---|---|---|---|---|---|---|---|
| 1 | Midland | switchgrass | 2 X 3 | 4.71 | 5% | N | 3.1 | 3 |
| 2 | Midland | switchgrass | 1.5 X 1.5 | 1.77 | 2% | S | 1.6 | 20 |
| 3 | Midland | switchgrass | 1.5 X 1.5 | 1.77 | 2% | S | 1.7 | 15 |
| 4 | Midland | switchgrass | 2 X 2 | 3.14 | 2% | NE | 2.2 | 18 |
| 5 | Midland | switchgrass | 1 X 1.5 | 1.18 | 5% | N | 2.5 | 6 |
| 6 | Midland | switchgrass | 3 X 3 | 7.07 | 1% | E | 3.0 | 150 |
| 7 | Midland | switchgrass | 2 X 3 | 4.71 | 1% | S | 2.7 | 150 |
| 8 | Midland | spiraea, K. bluegrass | 2 X 2.5 | 3.93 | 3% | N | 2.2 | 30 |

Table 13. Criteria used to help estimate age of Sharptailed Grouse chicks in broods observed in the field.

| Age in Weeks | Age in Days | Body Size in Relation to Adult | General Plumage Characteristics |
|---|---|---|---|
| 1 | 7 | | Downy appearance, cannot fly |
| 1.5 | 10 | | Wing feathers appear, can fly 50ft |
| 3 | 21 | <1/3 | Juvenal breast feathers appear, can fly 100 yds |
| 4 | 28 | 1/3 | Breast fully feathered |
| 5 | 35 | <1/2 | Juvenal plumage nearly complete |
| 6 | 42 | 1/2 | Juvenal plumage nearly complete |
| 7-8 | 49-56 | >1/2 | Juvenal plumage complete |
| 9 | 63 | <3/4 | Immature plumage appearing |
| 10 | 70 | 3/4 | Immature plumage appearing |
| 11-12 | 77-84 | >3/4 | V-shaped markings on breast |
| 13 | 91 | <Full | Not easily distinguished from adult |
| 14 | 98 | Full | Immature plumage nearly complete<br>Weight less than adult |

Table 14. Number of chicks in Sharptailed Grouse broods with complete counts and estimated age in days for biweekly periods.

| Biweekly Period | Brood Size n=19 | Age in Days n=26 |
|---|---|---|
| 15-30 Jun | 9.7 | 21 |
| 1-15 Jul | 10.7 | 35 |
| 16-31 Jul | 9.2 | 47 |
| 1-15 Aug | 7.8 | 69 |
| 16-31 Aug | 7.0 | 79 |
| 1-15 Sep | - | - |
| Mean | 8.8 ± 3.3 | |

Table 15. Sharptailed Grouse (ST) brood and habitat description.

| Brood Number | Date Located | # of Chicks | Estimated age in days | Habitat Type | Dominant Plants |
|---|---|---|---|---|---|
| 1 | 25 Jun | 21 | 21 | Midland | spiraea |
| 2 | 28 Jun | 8 | 21 | Upland | lead plant-green sage |
| 3 | 6 Jul | 11 | 35 | Midland | switchgrass-K. bluegrass |
| 4 | 7 Jul | 11 | 25 | Upland | lead plant-buckbrush |
| 5 | 14 Jul | 10 | 28 | Upland | oak-cottonwood |
| 6 | 15 Jul | 15 | 50 | Upland | oak |
| 7 | 17 Jul | 4 | 45 | Lowland | sedge |
| 8 | 18 Jul | 3 | ? | Midland | switchgrass |
| 9 | 20 Jul | 13 | 60 | Upland | buckbrush-green sage |
| 10 | 23 Jul | 3 Hy | 42 | Lowland | sedge |
| 11 | 23 Jul | 6 Hy | 20 | Lowland | K. bluegrass-northern reed |
| 12 | 25 Jul | ? | 14 | Lowland | sedge |
| 13 | 26 Jul | ? |  | Lowland | sedge |
| 14 | 28 Jul | 8 | 70 | Upland | blue grama (hayed) |
| 15 | 28 Jul | 6 | 60 | Upland | lead plant-rose |
| 16 | 29 Jul | 4 | 70 | Midland | spiraea |
| 17 | 31 Jul | 4 | 42 | Upland | lead plant |
| 18 | 31 Jul | 1 | 42 | Upland | blue grama-green sage |
| 19 | 4 Aug | 12 | 70 | Upland | blue grama |
| 20 | 6 Aug | 1 | 70 | Lowland | sedge |
| 21 | 8 Aug | 10 | 70 | Upland | willow |
| 22 | 10 Aug | 9 | 70 | Lowland | sedge |
| 23 | 10 Aug | 5 | 70 | Lowland | sedge |
| 24 | 13 Aug | 3 | 63 | Midland | wild licorice-K. bluegrass |
| 25 | 17 Aug | 1 | 80 | Upland | buckbrush |
| 26 | 17 Aug | 4 | 75 | Midland | buckbrush-big bluestem |
| 27 | 17 Aug | 10 | 80 | Upland | buckbrush-blue grama |
| 28 | 27 Aug | 7 | 80 | Lowland | sedge (mowed) |

Table 16. Prairie grouse brood habitat quality of six representative sites.

| | | Height-Density in decimaters | | |
|---|---|---|---|---|
| Brood Habitat Site Number | Habitat Type | 100% VOM | 0% VOM | Dominant Plants |
| 1 | Upland | 1.6 | 3.6 | lead plant-rose |
| 2 | Midland | 1.9 | 6.4 | switchgrass |
| 3 | Midland | 2.3 | 6.0 | switchgrass-northern reed |
| 4 | Midland | 2.4 | 6.6 | switchgrass-willow |
| 5 | Lowland | 1.8 | 5.0 | sedge-switchgrass-northern reed |
| 6 | Lowland | 1.9 | 6.3 | sedge-willow |

Table 17. Percent of readings at half decimeter of height-density pole 100% VOM at six representative brood habitat sites.

| | Brood Habitat Sites | | | | | |
|---|---|---|---|---|---|---|
| Half Decimeter | #1 Upland | #2 Midland | #3 Midland | #4 Midland | #5 Lowland | #6 Lowland |
| 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 5 | 0 | 0 | 0 | 0 | 0 |
| 1.0 | 30 | 3 | 0 | 5 | 15 | 5 |
| 1.5 | 25 | 30 | 9 | 12 | 27 | 30 |
| 2.0 | 25 | 52 | 44 | 25 | 42 | 55 |
| 2.5 | 12 | 10 | 31 | 30 | 12 | 10 |
| 3.0 | 3 | 5 | 16 | 20 | 4 | |
| 3.5 | | | | 5 | | |
| 4.0 | | | | 3 | | |
| % at 1.5 dm or above | 65 | 97 | 100 | 95 | 85 | |

1 dm=3.94

Table 18. Surface area of Habitat Types and Habitat Complexes.

| Habitat Complex<br>Habitat Type | Hectare | Acre | $mi^2$ | Percentage |
|---|---|---|---|---|
| Hummocky Sandhills | 26,505.4 | 65,494 | | 50.16 |
| Upland Grassland | 13,917.2 | 34,389 | 53.7 | 26.34 |
| Midland Grassland | 6,701.0 | 16,558 | 25.9 | 12.68 |
| Lowland Grassland | 5,154.7 | 12,737 | 19.9 | 9.76 |
| Cropland | 732.5 | 1,810 | 2.8 | 1.39 |
| Deltaic Plain | 15,686.6 | 38,761 | | 29.69 |
| Midland Grassland | 5,858.4 | 14,476 | 22.6 | 11.09 |
| Lowland Grassland | 2,180.1 | 5,387 | 8.4 | 4.13 |
| Cropland | 7,648.0 | 18,898 | 29.5 | 14.47 |
| Choppy Sandhills | 7,758.1 | 19,170 | | 14.68 |
| Upland Woodland | 4,967.3 | 12,269 | 19.2 | 9.40 |
| Open Grassland | 2,792.8 | 6,901 | 10.8 | 5.29 |
| River Terrace | 2,887.5 | 7,135 | | 5.46 |
| Riparian Forest | 2,310.8 | 5,710 | 8.9 | 4.37 |
| Cropland | 576.7 | 1,425 | 2.2 | 1.09 |

Data from Manske 1980.

Table 19. Habitat Use Index (% of bird locations/% of study area) for Sharptailed Grouse during annual phenological activities.

| Habitat Complex<br>Habitat Type | % of Sandhills | Spring<br>1 Apr-15 Jun | Summer<br>16 Jun-31 Aug | Fall<br>1 Sep-15 Nov | Winter<br>16 Nov-31 Mar |
|---|---|---|---|---|---|
| Hummocky Sandhills | 50.16 | 1.98 | 1.79 | 1.62 | 0.34 |
| Upland Grasslands | 26.34 | 2.48 | 1.36 | 0.76 | 0.31 |
| Midland Grasslands | 12.68 | 2.33 | 2.57 | 4.62 | 0.03 |
| Lowland Grasslands | 9.76 | 0.34 | 1.96 | 0.20 | 0.08 |
| Cropland | 1.36 | 0.61 | 1.89 | 0.70 | 5.07 |
| Shelterbelts | 0.03 | 0.00 | 0.00 | 0.00 | 32.05 |
| Deltaic Plain | 29.69 | 0.00 | 0.08 | 0.53 | 2.16 |
| Upland Grasslands | 0.01 | 0.00 | 0.00 | 190.48 | 0.00 |
| Midland Grasslands | 11.09 | 0.00 | 0.03 | 0.09 | 0.42 |
| Lowland Grasslands | 4.13 | 0.00 | 0.48 | 3.11 | 0.00 |
| Cropland | 11.39 | 0.00 | 0.00 | 0.00 | 4.28 |
| Shelterbelts | 3.08 | 0.00 | 0.00 | 0.00 | 3.51 |
| Choppy Sandhills | 14.68 | 0.06 | 0.53 | 0.06 | 0.39 |
| Upland Woodland | 9.40 | 0.09 | 0.82 | 0.00 | 0.03 |
| Open Grassland | 5.29 | 0.00 | 0.00 | 0.18 | 1.01 |
| River Terrace | 5.46 | 0.00 | 0.00 | 0.00 | 0.00 |
| Riparian Forest | 4.37 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cropland | 1.09 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transportation Routes | | | | | |
| Gravel Roads | 0.52 | 0.00 | 0.00 | 3.66 | 0.00 |
| (N)= | | 958 | 350 | 210 | 1248 |

Table 20. Habitat Use Index (% of activity sites/% of study area) for Sharptailed Grouse during annual phenological activities.

| Habitat Complex<br>Habitat Type | % of Sandhills | Display Ground Habitat | Nest Habitat | Brood Habitat |
|---|---|---|---|---|
| Hummocky Sandhills | 50.16 | | | |
| Upland Grasslands | 26.34 | 2.76 | 0.00 | 1.56 |
| Midland Grasslands | 12.68 | 2.15 | 7.88 | 2.34 |
| Lowland Grasslands | 9.76 | 0.00 | 0.00 | 1.58 |
| Cropland | 1.36 | 0.00 | 0.00 | 0.00 |
| Shelterbelts | 0.03 | 0.00 | 0.00 | 0.00 |
| Deltaic Plain | 29.69 | | | |
| Upland Grasslands | 0.01 | 0.00 | 0.00 | 0.00 |
| Midland Grasslands | 11.09 | 0.00 | 0.00 | 0.00 |
| Lowland Grasslands | 4.13 | 0.00 | 0.00 | 0.69 |
| Cropland | 11.39 | 0.00 | 0.00 | 0.00 |
| Shelterbelts | 3.08 | 0.00 | 0.00 | 0.00 |
| Choppy Sandhills | 14.68 | | | |
| Upland Woodland | 9.40 | 0.00 | 0.00 | 1.17 |
| Open Grassland | 5.29 | 0.00 | 0.00 | 0.00 |
| (N)= | | 88 | 8 | 28 |

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# Visual Obstruction of Prairie Grouse Habitat Following Summer Mowing and Spring Burning

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center

Report DREC 20-1193

Vegetation on the highly productive subirrigated zone with the switchgrass community on the foot slope and the sedge meadow community on the toe slope grow very rapidly, produce a high density of seed heads, reach senescent growth stages early in the growing season, and these wet meadow graminoids deposit silicon crystals in their leaf epidermis which greatly increases the rate of wear on livestock teeth. These growth characteristics discourage livestock from grazing wet meadow vegetation during mid and late season which effectively transfers the grazing pressure to the upland mixed grass prairie and midland tall grass prairie communities resulting in under utilization on the lowland and heavier utilization on the upland and midland vegetation which is responsible for the great density of Kentucky bluegrass.

Manipulations of the wet meadow vegetation with summer mowing or spring prescribed burning returns the plants to early growth stages during the mid and late portions of the growing season. These early growth stages are highly nutritious (Erickson et al. 1978), low in epidermal silicon crystals, and readily selected for by livestock. Moving some of the grazing pressure back to the wet meadow returns grazing levels on the upland mixed grass prairie and the midland tall grass of big bluestem and little bluestem back to standard stocking rates.

Prairie grouse depend on the switchgrass community for nesting habitat and they use the switchgrass and the sedge meadow communities for roosting habitat and concealment cover.

## Procedure

The effects of summer mowing and spring prescribed burning was evaluated for visual obstruction by the height-density pole method developed by Robel et al. (1970a) and modified by Kirsch (1974). A mean 100% VOM at 1.5 dm (5.9 in) was considered to be the minimum for good concealment cover (Manske 1981, Higgins and Barker 1982).

The summer mowing trail was conducted on wide areas of homogeneous switchgrass vegetation with the mowing treatments conducted during July and the height-density measurements read during May while the treatment was 1 to 6 years old.

The spring prescribed burn trial was conducted on two replicated areas of homogeneous switchgrass vegetation with the burns occurring during May. A control of unburned identical vegetation was adjacent to each burned area. The height-density measurements were read during May and October for 2 years post treatment.

## Results

### Summer Mowing Trial

The first spring following a summer mow treatment, the vegetation had a low 100% VOM at only 0.5 dm (2.0 in) (table 1) which was inadequate for concealment cover but if the mowed areas were adjacent to an existing upland display ground, some male birds could use the mowed area as courtship territories. During the second spring, the vegetation had already improved to a 100% VOM at 1.5 dm (5.9 in) which was at the minimum for good concealment cover and would most likely be used for day roosts, loafing areas, and brood travel routes. The third and fourth spring vegetation had good 100% VOM at 2.3 dm (9.1 in) and 2.7 dm (10.6 in) which would provide excellent concealment cover for nesting, night roosting, and escape cover for the prairie grouse. The fifth and sixth spring vegetation had greatly decreased to a 100% VOM at 1.8 dm (7.1 in) and 1.7 dm (6.7 in) which would still provide good concealment cover, just not as good as the vegetation during the third and fourth springs. The control area of unmowed and ungrazed had very similar 100% VOM during the fourth and fifth springs as the mowed treatment (table 1). Unmanipulated vegetation does not remain stagnant. It deteriorates. Undisturbed management is not a valid grassland management practice.

### Spring Prescribed Burn Trial

The vegetation growth following a spring burn was slow to recover. During the first and second growing seasons, the 100% VOM remained below the minimum of a mean of 1.5 dm (5.9 in) and was well below the preburn 100% VOM at 1.9 dm, (7.5 in) and the level of the unburned control (table 2). The second year vegetation also would not provide the minimum for concealment cover and would most likely be used for day roosts, loafing areas, and brood travel routes, and would not be expected to be used for nesting, night roosting, or escape cover by prairie grouse.

## Discussion

The treatments of summer mowing and spring prescribed burning did not effectively activate the four grass internal physiological growth mechanisms nor the ecosystem biogeochemical processes. Each of the treatments remove too much leaf area resulting in insufficient quantities of currently photosynthesized fixed carbon that would have supported new graminoid tiller growth. Counter to common assumptions, stored carbohydrates are not used for biomass growth to replace the leaf area removed during defoliation treatments (Richards and Caldwell 1985, Briske and Richards 1995). The benefit from the summer mowing and spring burning treatments for new regrowth biomass comes from the removal of standing old growth and senescent current years growth resulting in the reduction of shading which permits sunlight to reach the soil.

Removal of great proportions of the leaf area, causes both the summer mowing and spring burning treatments to reduce live graminoid tiller density. Coordination of these treatments with the grazing rotation schedule so that livestock will not have access to the treated vegetation until the grass tillers have developed to the 3.5 new leaf stage. At that growth stage, partial removal of leaf area by grazing can activate the four grass internal physiological growth mechanisms and the ecosystem biogeochemical processes that will increase graminoid tiller density.

Summer mowing attracts livestock to the wet meadow vegetation for one grazing season following treatment. Spring burning attracts livestock to the wet meadow vegetation for two grazing seasons following treatment. This difference of attracting livestock grazing of the wet meadow vegetation for one additional grazing season has been incorrectly used for the promotion of spring burning as being more effective than summer mowing. However, the biological reason why the spring burning treatment attracts livestock grazing for two growing seasons is that burning causes greater degradation to the vegetation. This level of damage required two growing seasons for the plants to recover. The wet meadow vegetation treated with summer mowing was damaged less than that treated with spring burning and required only one growing season for the plants to recover.

## Management Implications

Grazing graminivores have difficulty in properly defoliating the grassland communities that grow on subirrigated soils. The grasses and sedges that grow in the wet meadow community deposit silicate crystals in the leaf tissue, which cause excessive wear on livestock teeth. The mature wet meadow forage is usually consumed at only around a 10% rate. The ungrazed standing plant biomass restricts growth of young grass plants and this old material needs to be removed by summer mowing or spring burning on repeated cycles. However, the wet meadow experiences unpredictable wet and dry conditions of the subirrigated soils mandating a flexible treatment schedule. A simple strategy would be to organize the wet meadow areas into three groups. With each group containing wet meadow sites from each pasture of a grazing system. All of the wet meadow sites in the same group would receive treatment during the same year. All of the wet meadow sites in each group would receive a mowing or burning treatment one time in a cycle of three to five years as conditions permit. The sedge meadow can receive more frequent treatment than the switchgrass community.

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Table 1. Mean visual obstruction during May for 6 years after summer mowing of Midland switchgrass community and control of no treatment.

| | Mowed Once Grazed Each Year | | | | Unmowed Ungrazed | | | |
|---|---|---|---|---|---|---|---|---|
| | 0% VOM | | 100% VOM | | 0% VOM | | 100% VOM | |
| Years Post Treatment | dm | in | dm | in | dm | in | dm | in |
| 1st | 2.1 | 8.3 | 0.5 | 2.0 | - | | - | |
| 2nd | 4.9 | 19.3 | 1.5 | 5.9 | - | | - | |
| 3rd | 5.2 | 20.5 | 2.3 | 9.1 | - | | - | |
| 4th | 6.3 | 24.8 | 2.7 | 10.6 | 7.5 | 29.6 | 2.6 | 10.2 |
| 5th | 5.8 | 22.9 | 1.8 | 7.1 | 5.9 | 23.2 | 1.8 | 7.1 |
| 6th | 5.7 | 22.5 | 1.7 | 6.7 | - | | - | |

1dm=3.94 in

Table 2. Mean visual obstruction during spring and fall for two years after prescribed burn of Midland switchgrass community and control of no burn.

| | Spring Burn | | | | No Burn | | | |
|---|---|---|---|---|---|---|---|---|
| | 0% VOM | | 100% VOM | | 0% VOM | | 100% VOM | |
| Years Post Treatment | dm | in | dm | in | dm | in | dm | in |
| 1st Spring | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 17.7 | 1.9 | 7.5 |
| 1st Fall | 5.7 | 22.5 | 1.5 | 5.9 | 6.5 | 25.6 | 2.3 | 9.1 |
| 2nd Spring | 5.2 | 20.5 | 1.4 | 5.5 | 6.2 | 24.4 | 1.9 | 7.5 |
| 2nd Fall | 4.5 | 17.7 | 1.7 | 6.7 | 5.6 | 22.1 | 2.0 | 7.9 |

1 dm=3.94 in

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# Undisturbed Management of Grassland Habitat Is Not A Biologically Sustainable Treatment

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center
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The standard go to recommended grassland habitat management for wildlife, scarce plants, and precarious insects is the undisturbed treatment. This report scientifically explains why the undisturbed treatment of grassland habitat is not biologically sustainable in the Northen Plains.

Often times, livestock grazing is removed to protect a grassland ecosystem based on naive presumptions that livestock grazing causes damage to a grassland ecosystem or that they interfere with the life cycle of wildlife, scarce plants, and precarious insects. Livestock grazing is not what causes damage to grasslands; poor management of grazing livestock can cause serious damage to grasslands. The greatest antagonistic effects to a grassland ecosystem occur from undisturbed management concepts that rest grasslands from grazing defoliation. The term “rest” is a misnomer; resting a grassland does not cause revitalizations of crucial biological and ecological processes. Resting a grassland by withholding partial defoliation by grazing results in regression of ecosystem processes and biological growth mechanisms. Several negative changes occur relatively soon after grazing graminivores are removed from grasslands; the live root biomass of grasses decrease (Whitman 1974), standing dead leaves and litter accumulate (Brand and Goetz 1986), and ecosystem biogeochemical processes diminish (Manske 2011b).

The reduction of live root surface area causes a decrease in active root length for interaction with symbiotic rhizosphere organisms and causes a decrease in absorption of water and nutrients from the soil. Reduction of active root biomass and diminishment of grass plant health vigor result in a loss of resource uptake efficiency and a suppression of competitiveness of grass plants to take up mineral nitrogen, essential elements, and soil water (Kochy 1999, Kochy and Wilson 2000).

Grass plants produce double the quantity of leaf biomass than needed for normal plant growth and maintentance (Crider 1955, Coyne et al. 1995). Without grazing graminivores to remove the surplus herbage production, the standing leaf material accumulates rapidly and changes from an asset to a detriment. The accumulation of nondefoliated live and standing dead leaves of grasses reduce light penetration below native grass light saturation points (Peltzer and Kochy 2001). Native grasses have high light saturation points and require near full sunlight. Warm season grasses have higher light saturation points than cool season grasses (Kochy 1999, Kochy and Wilson 2000). Shading reduces native warm season grasses more than native cool season grasses. Introduced cool season domesticated grasses have lower light saturation points than native grasses, permitting domesticated grass to live in low light conditions. The accumulating standing dead leaves shade the lower leaves, increasing the rate of leaf senescence and reducing the rate of photosynthesis, causing a decrease in the supply of carbohydrates (Coyne et al. 1995) that results in a reduction in growth of leaves and roots (Langer 1972, Briske and Richards 1995). Grass leaves grown under shaded conditions become longer but narrower, thinner, and lower in weight (Langer 1972) than leaves in sunlight. Shaded grass plants shift to erect growth forms with a small number of tillers (Briske and Richards 1995). Lack of grazing reduces grass tiller densities by decreasing tiller development and increasing tiller mortality through shading (Manske 2013). After a few years, shading reduces the composition of native grass species in the ecosystem and increases the composition of shade-tolerant or shade-adapted replacement species, like smooth bromegrass and Kentucky bluegrass.

Standing dead material not in contact with soil does not decompose through microbial activity. Dead plant material on nongrazed treatments breaks down slowly over several years by leaching and weathering and builds up into a thick mulch layer. Thick mulch effectively blocks sunlight from reaching understory young grass leaves. Thick mulch modifies soil temperatures. Thick mulch ties up and holds organic nutrients above the soil surface preventing accession to the soil organic matter which limits nutrient cycling through biogeochemical processes increasing the deficiencies of essential elements causing great reductions in grass growth of leaves and roots. Thick mulch absorbs and holds precipitation for later evaporation preventing the water from infiltrating into the soil diminishing soil water to deficiency quantities (Wright and Bailey 1982, Manske 2000, 2011a).

The loss of active root length is a contributing factor in the reduction of rhizosphere biomass. The primary cause for the reduction in rhizosphere biomass is, however, the great reduction in the quantity of carbohydrate energy exudated from the grass roots into the rhizosphere zone. Without partial defoliation by grazing, only a small quantity of short carbon chain energy leaks from the grass roots into the rhizosphere; this low amount of simple carbon compounds is barely enough to sustain a very small rhizosphere microbe biomass. A small biomass of rhizosphere organisms function at greatly reduced rates of organic material decomposition, and can mineralize only small quantities of nitrogen and other essential elements (Anderson et al. 1981, Coleman et al. 1983, Curl and Truelove 1986, Klein et al. 1988, Whipps 1990).

Removal of partial defoliation for 13 years resulted in an increase of standing dead and litter, an increase of introduced domesticated grasses, a great decrease of native grasses, and an increase of all forbs with a decrease in desirable forbs (Manske 2012). The total dead biomass was 63.6% of the total herbage biomass (an increase of 300.3%), with standing dead at 26.9% and litter at 36.7%. Live herbage biomass was 36.4% of the total herbage biomass, with domesticated grass at 64.8% (an increase of 94.8%), cool season grasses at 2.7% (a decrease of 89.0%), warm season grasses at 0.6% (a decrease of 79.4%), upland sedges at 22.9% (a slight decrease of 1.5%), and all types of forbs at 9.0% (an increase of 56.3%). The rhizosphere biomass had decreased to 52.2 kg/m$^3$ which can mineralize less than 20% of the minimum quantity of mineral nitrogen needed at 100 lbs/ac (112 kg/ha).

Removal of partial defoliation by grazing for 75 years resulted in an excessive increase of standing dead and litter, a remarkable increase of woody shrubs and trees, an increase of introduced domesticated grasses, a severe reduction of native grasses, and a considerable decrease of desirable forbs (Manske 2013). The total dead biomass was 59.7% of the total herbage biomass (an increase of 263.6%), with standing dead at 11.1% and litter at 48.6%. Live herbage biomass was 40.3% of total herbage biomass, with domesticated grass at 79.6% (an increase of 106.1%), cool season grasses at 5.7% (a decrease of 80.0%), warm season grasses at 0.04% (a decrease of 99.7%), upland sedges at 6.3% (a decrease of 23.9%), and all types of forbs at 8.4% (an increase of 20.0%). The woody shrubs and trees had increased 500.0% and occupied 53.8% of the land area. The grass root biomass had decreased 32.6%. The available mineral nitrogen was only at 42.0 lbs/ac (47.0 kg/ha) which is greatly below the needed minimum of 100 lbs/ac (112 kh/ha).

The huge increase of woody shrubs and trees was not caused by the lack of fire. It was caused by the lack of biologically effective grazing management that resulted in the great reduction of the grass plant mechanism of competitive nutrient and water resource uptake. When grass plants are managed biologically they become healthy and have the full competitive resource uptake mechanism working, seedlings of trees, shrubs, forbs, and introduced grasses cannot become established in mixed grass prairie communities (Li and Wilson 1998, Kochy and Wilson 2000, Peltzer and Kochy 2001).

With continued ecosystem degradation, the impeded native grasses declined further in their ability to be competitive in uptake of belowground resources of soil water and nutrients (Li and Wilson 1998, Kochy and Wilson 2001), causing additional mortality of native grasses and decreased density, resulting in the creation of numerous shaded bare spaces in the previously closed prairie plant communities (Manske 2013).

Opportunistic introduced cool season domesticated grasses, like Kentuck bluegrass and smooth bromegrass can exist under low light conditions and invade the shaded bare spaces by procuring the remaining belowground resources not being taken up by the diminutive, low vigor native grasses (Kochy and Wilson 2000). These domesticated grasses also have labile roots that breakdown easily making the nutrients contained in dead material readily available to support continued growth and expansion of these nonnative grasses without assistance from soil microorganisms. In a short period of time, the introduced domesticated grasses increase in density and herbage biomass creating greater shading problems for the suppressed native grasses, escalating degradation of an already devastated ecosystem.

With the removal of partial defoliation by grazing there is a great reduction in the quantity of carbohydrates exuded from the grass roots into the rhizosphere zone. The rhizosphere microorganism biomass and activity are dependent on access to outside sources of simple carbon chains from the grasses. The rhizosphere microflora trophic levels lack chlorophyll and have low carbon (energy) content. Partial defoliation of grass plants at vegetative phenological growth stages by large graminivores cause great quantities of exudates containing simple carbon compounds to be released through the plant roots into the rhizosphere zone. When that source of carbon stops, the small amount of carbon compounds in the plant material that leaks from grass roots is barely enough to sustain a very small rhizosphere biomass that cannot mineralize the minimum quantity of 100 lbs/ac of mineral nitrogen causing great reductions in herbage biomass production.

Grazing graminivores perform several indispensable functions for grassland ecosystems. Partial defoliation by grazing graminivores activate the four major internal grass plant growth mechanisms, enhance rhizosphere microorganisms activity and increase their biomass large enough to perform the ecosystem biogeochemical processes and to mineralize greater than 100 lbs/ac of mineral nitrogen plus the other essential elements, and they remove the surplus grass leaf biomass produced by grass plants before it can become a detriment to the ecosystem each growing season.

Grazing graminivores is biologically beneficial for grass plants and for grassland ecosystems when grazing periods are coordinated with grass phenological growth stages. The four primary physiological growth mechanisms within grass plants that perform the herbage replacement processes are activated with partial defoliation by grazing graminivores when 25% to 33% of leaf weight is removed from 60% to 80% of lead tillers during vegetative phenological growth stages between the three and a half new leaf and the flower stage when a threshold quantity of 100 lbs/ac of mineral nitrogen is available. Unavailable soil organic nitrogen must be mineralized by soil microbes in order for nitrogen to be usable by grass plants. A large biomass of rhizosphere microorganisms is required to mineralize a large quantity of nitrogen yielding 100 lbs/ac. Grassland microbes are achlorphyllous and cannot fix their own carbon energy. Large quantities of surplus short chain carbon energy are produced by healthy vegetative lead tillers that can be exudated into the microbial rhizosphere when 25% to 33% of the leaf weight is removed with partial defoliation by grazing graminivores while lead tillers are between the three and a half new leaf stage and the flower stage. The four primary physiological growth mechanisms are not functional when less than 100 lbs/ac of mineral nitrogen is available and are not activated when zero % or greater than 33% of the leaf weight of lead tillers is removed during vegetative growth stages.

Grazing graminivores receive nutritious forage from healthy grass plants. However, providing forage for graminivores is not the only purpose for grazing grasslands. Grass plants have biological requirements and have four primary physiological growth mechanisms that must be activated by partial defoliation by grazing. Rhizosphere microorganisms are needed in large quantities to perform all of the ecosystem biogeochemical processes, but are unable to fix carbon energy and require exudated short chain carbon energy that can be provided by partial defoliation by grazing. The three indispensable biotic components of grasslands; grass vegetation, rhizosphere organisms, and large graminivores; must have their biological requirements provided with partial defoliation by grazing graminivores in order for grassland ecosystems to function at achievable levels.

The successful sustainability of grassland ecosystems depends upon the implementation of biologically effective management strategies that can provide the biological and physiological requirements of the forage grass plants, soil microorganisms, and grazing graminivores, 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 growth and nutritional quality, and that can improve livestock growth and weight performance along with the capture of greater wealth per acre.

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# Deferred-Rotation: An Obsolete Grazing Practice

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center
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The current science of rangeland management has been built by countless, hardworking, dedicated scientists that have inspired deeper investigations into how rangeland ecosystems work. The concept of deferred and rotation grazing was developed on an early hypothesis that considered the only process to improve degraded native rangeland was to reseed the land by mechanical methods or by letting the grass plants produce seeds and trample the seeds into the ground with livestock (Jardine 1916). Modern more profound hypothesis consider improvement of degraded native rangeland by activating the processes of vegetative reproduction of secondary tillers from axillary buds and by increasing the biomass of the symbiotic rhizosphere microorganisms that perform the ecosystem biogeochemical processes (Manske 2018) making the deferred-rotation grazing practices obsolete.

Vegetative tiller growth is the dominant form of reproduction in semiarid and mesic grasslands (Belsky 1992, Chapman and Peat 1992, Briske and Richards 1995, Chapman 1996, Manske 1999a) not sexual reproduction and the development of seedlings. Recruitment of new grass plants developed from seedlings is negligible in grassland ecosystems. The frequency of true seedlings is extremely low in functioning grasslands, and establishment of seedlings occurs only during years with favorable moisture and temperature conditions (Wilson and Briske 1979, Briske and Richards 1995), in areas of reduced competition from vegetative tillers, and when resources are readily available to the growing seedling.

The deferred-rotation grazing system was developed by Arthur Sampson from research conducted in the Blue Mountains of Oregon. The first version was a two pasture system with one pasture grazed early and one pasture deferred until late season, then rotated the order on a one or two year cycle (Sampson 1913). The second version was a three pasture system with grazing separated into spring, summer, and fall. The sequence was followed for two years, during the rotation cycle, the fall pasture became the spring pasture, the previous spring pasture became the summer pasture, and the previous summer pasture became the fall pasture (Sampson 1923). The intended purpose of deferment was to gain plant vigor, increase seed production, storage of carbohydrates in roots and stems, and improve the health of rangeland. Grazing after seed maturity would scatter and trample the seeds into the soil in order to promote seedling establishment. The second year of deferment was intended to improve development of young seedlings.

Two years of deferment was explained by Sampson (1914), “The grazing has been deferred until the fall for two years. This is done to allow any seedlings that might start from the previous year’s seeding a chance to become more firmly established before the division (pasture) is grazed.”

Sampson (1913, 1914) and Jardine (1916) knew that grass seed that drops from the grass head and germinate have an extremely low survival rate because they do not get enough root material into the soil before they dry out. So the late season trampling by cattle seemed to be the only logical way to get the dropped seeds too the soil. They did not think one year would be enough, so they extended the process to two years.

The Blue Mountains of Oregon where Sampson collected data is spectacular country, however, the seasonal precipitation distribution is the Pacific Pattern with most of the precipitation occurring during fall and winter. The fall rains begin in late September and increase with a peak in November or December and decrease to March, with July, August, and early September receiving very little precipitation. This pattern greatly limits available soil moisture for developing grass roots during the growing season. Sampson would have experienced very little grass growth and nearly no grass regrowth during the summer months. The grasses of Oregon produce vegetation tillers, but because of the lack of rainfall during summer, they are usually inhibited by low soil water to grow during that growing season. The grazing activated vegetative secondary tillers appear the next spring, a month or more ahead of normal lead tiller development. Sampson did not recognize these early spring tillers as last grazing season stimulated vegetative tillers. At that time, pasture scientists, were trained as agronomists, knew that some grasses produced vegetative tillers. However, the importance of vegetative tillers was dismissed. Grass seed production and seedling establishment was far more important for the improvement of pasture forage production according to the agronomic based scientific concepts of the time.

A deferred and rotation grazing treatment was investigated at the Northern Great Plains Field Station at Mandan, North Dakota (Sarvis 1923, 1941). The experimental plan followed closely, with modifications, to the grazing order of a three pasture deferred and rotation practice described in the 1915 Agricultural Yearbook (Jardine 1916). This deferred-rotation treatment was added to the two year old stocking rate on seasonlong grazed pastures study that had four rates of grazing intensities. These grazing investigations were conducted by J.T. Sarvis for 23 years from 1918 to 1940. The modifications made by Sarvis (1923) was the change in the pasture sequence of the pasture with the fall deferred treatment moved to the summer period, which was different than Sampson's plan which moved the fall deferred treatment to the spring period (Sampson 1923).

Sarvis (1941) believed that undergrazing caused slight deterioration to plant communities by the accumulation of old vegetation that steers would not eat and by the increase of coarseness of weeds. Sarvis (1941) also knew that continued removal of the maximum quantity (100%) of the annual forage produced would sooner or later cause a sharp decline in grazing capacity. As a result, Sarvis developed grazing guidelines that required that 15% to 25% of the annual forage production to remain standing at the end of the grazing season. However in practice, the reported mean forage use on the deferred pastures was 92% removed and the mean forage use on the standard seasonlong pasture was 77% removed (Sarvis 1923).

The grazing investigations conducted by J.T. Sarvis (1923, 1941) at the Mandan, North Dakota, Northern Great Plains Field Station studied the three pasture deferred and rotation grazing treatment that was developed by Sampson (1913, 1923), and adapted and put into practice by the US. Forest Service (Jardine 1916), in order to determine the performance of its direct application in the northern Great Plains. The study area was a large section of flat land with very good soil and uniform mixed grass prairie in excellent condition, 3.5 miles south of Mandan. Seventy acres were divided into three equal pastures to be grazed during spring, summer, and fall periods. A comparable control treatment was seventy acres in one pasture grazed seasonlong. The intended grazing season was 150 days from mid May to mid October (table 1). The research animals were two years old grade steers of standard beef breeds of Angus, Herefords, and Shorthorns that were furnished by the North Dakota Agricultural Experiment Station with the mean initial weight of 750 pounds.

When the steers on the grazing treatments appeared to have lost weight, they were weighed at 5 or 10 day intervals and when the weight loss was documented the steers on the seasonlong treatments were removed from the study pastures and moved to the reserve pasture. When forage on the fall pasture of the deferred treatment became short and inferior and the steers began to lose weight, the steers were moved to the spring pasture that had new secondary growth (Sarvis 1941). This new secondary growth was not recognized as vegetative reproduction of tillers from axillary buds.

During the first two years of the deferred treatment, 10 steers grazed the deferred and seasonlong treatments at the same stocking rate. However, the steers on the deferred treatment gained a mean of only 260 pounds which was much less weight than the steers on the seasonlong treatment that gained a mean of 309 pounds. The number of steers placed on the deferred treatment was increased to an average of 14 head and the number of steers on the seasonlong treatment remained at 10 head. However, after 17 years the mean weight gain per head on the deferred treatment reached 266.1 pounds and the gain per head on the seasonlong treatment dropped to 308.3 pounds (table 2).

The lower weight gain for the steers on the deferred treatment (table 3) were explained by Sarvis (1923), "The deferred and rotation pastures show either light gains or losses for the month of October and somewhat reduced gains during September. The lower gains during the latter part of the season do not necessarily condemn fall grazing. This is the time when cattle put on the "finish" so often referred to by stockmen, which is apparently a hardening process brought about through a reduction in the quantity of water that they drink, as well as a change in the condition of their flesh. Therefore, when cattle are without feed or water for 24 hours in the fall they will "shrink" less than they would during the same length of time earlier in the season. The autumn also represents the transition or adjustment period of the cattle between summer and winter. The cooler weather of autumn always causes shrinkage of the cattle, which is recorded as a loss in weight."

Sarvis failed to explain why the steers on the seasonlong treatment did not experience the same degree of "finish" as the steers on the deferred pasture (table 3).

Sarvis (1923) explained the purpose of the deferment, "This deferred and rotation grazing system is designed to allow each division of the pasture to mature a crop of seeds for two successive years before it is harvested by the cattle in the fall of each year. Grazing on each division is deferred and rotated, so that each unit has an equal chance to produce a maximum crop of seeds normally before it is distributed by grazing. The seeds of the grasses which are scattered on the ground are aided in their planting by trampling of the cattle.

Sarvis (1941 p.80) concluded, "So far as it has been possible to determine, there has been no significant benefit from reseeding of the grasses under this deferred and rotation grazing system during this experiment after 23 years."

Sampson knew very early in his studies that cattle produced very low weight gains on the deferred pastures, he knew that some grasses reproduced vegetatively, and he did not have documentation that the production of seeds resulted in greater numbers of seedlings.

The US Forest Service knew that cattle produced very low weight gains on the deferred pastures, and they did not have documentation that the production of seeds resulted in greater numbers of seedlings.

Sarvis knew in the first two years of study that two year old steers produced very low weight gains on the deferred pastures, he documented that the number of seedlings did not increase on the deferred treatment, and he documented a large reduction in grass density that he attributed to the severe drought frequency during the study period with 4 of the driest years recorded including 1934 and 1936. Sarvis did not consider the high forage use at 85% to 75% to be a factor in grass density reduction.

Despite the lack of supporting scientific data, these pasture agronomists still continued to promote the use of the deferred-rotation grazing practice to livestock producers west of the Mississippi River.

The deferred-rotation grazing practice was included in a study of the effects of grazing management practices on grassland vegetation and on the quantity of prairie grouse concealment cover of the Sandhills region in southeastern North Dakota that evaluated for visual obstruction by the height-density pole, herbage biomass by hand clipping, and basal cover by the ten pin point frame conducted by Manske, 1975 to 1980.

The seasonlong grazing treatment resulted in a mean 100% VOM of the switchgrass zone at 1.5 dm (5.9 in) with 55% readings at or above 1.5 dm during spring, 13% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plant species composition significantly increased with Kentucky bluegrass, and decreased with warm and cool season native grasses.

The deferred grazing treatment resulted in a mean 100% VOM of the switchgrass zone at 1.6 dm (6.3 in) with 62% readings at or above 1.5 dm during spring, 20% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and the plants species composition significantly increased with Kentucky bluegrass, and decreased with switchgrass, warm and cool season native grasses, and upland sedges.

The twice-over rotation grazing strategy resulted in a mean 100% VOM of the switchgrass zone at 2.0 dm (7.9 in) with 78% readings at or above 1.5 dm during spring, 32% of the herbage biomass samples from the Upland and Midland communities were greater on the grazed area than on the ungrazed area, and plant species composition significantly increased with switchgrass, lowland sedges, warm and cool season native grasses, upland sedges, and total basal cover.

Grassland ecosystems of the Sandhills region were negatively affected by the deferred grazing practice from the significant yearly increase in Kentucky bluegrass and a decrease in native warm and cool season grass basal cover, total grass density, herbage biomass production, and low quality of prairie grouse concealment cover. The grassland ecosystems received a huge loss of significant energy and resources which were used for the increased useless grass seed production that could have been supplied for an increase of vegetative secondary tiller production with adequate crude protein for lactating cows to graze until mid October.

Deferring the starting date of grazing on native rangeland until after the grass lead tillers have flowered and developed seeds prevents stimulation of compensatory physiological mechanisms, vegetative reproduction by tillering, competitive nutrient resource uptake, and water use efficiency mechanisms within grass plants, and rhizosphere organism activity that perform all of the ecosystem biogeochemical processes. The herbage biomass available to grazing livestock on deferred grazing practices is below the potential quantities (Manske 2000b) and the nutritional quality is below the crude protein requirements of lactating cows (Whitman et al. 1951, Manske 1999b) because of leaf senescence and translocation of cell constituents from leaf structures (Langer 1972, Beard 1973, Leopold and Kriedemann 1975). The intended biological purpose of deferred grazing was to increase grass density by promoting seedling development from increased seed stalk quantities and to use trampling by livestock to scatter and plant the produced seeds. However, grassland ecosystem processes do not function in accordance with the obsolete deferred grazing hypothesis.

Effects on cow and calf weight performance from three grazing management strategy concepts were evaluated for five years (1983-1987) in western North Dakota on native rangeland mixed grass prairie conducted by Manske.

The old management concept of deferred grazing until after seed set was stocked heavily at 8.88 ac/AU and 2.22 ac/AUM for 4.0 months from 16 Jul to 15 Nov (122 days) (table 4).

The traditional concept of seasonlong grazing was stocked at 12.31 ac/AU and 2.80 ac/AUM for 4.39 months from 18 Jun to 30 Oct (134 days) (table 4).

The biologically effective concept of three pasture twice-over rotation strategy was stocked at 10.22 ac/AU and 2.28 ac/AUM for 4.49 months from 1 Jun to 16 Oct (137 days) (table 4).

On the deferred treatment, calf weight gain was only at 1.80 lbs per day, 24.73 lbs per acre, and accumulated weight gain was low at 219.60 lbs per head. Cow weight gain was extremely low at 0.06 lbs per day, 0.82 lbs per acre, and accumulated weight gain was 7.24 lbs per head (tables 5 and 6).

On the traditional seasonlong treatment, calf weight gain was 2.18 lbs per day, 23.77 lbs per acre, and accumulated weight gain was 292.12 lbs per head. Cow weight gain was 0.40 lbs per day, 4.35 lbs per acre, and accumulated weight gain was 53.60 lbs per head (tables 5 and 6).

On the biologically effective twice-over strategy, calf weight gain was 2.21 lbs per day, 29.63 lbs per acre, and accumulated weight gain was 302.80 lbs per head. Cow weight gain was 0.62 lbs per day, 8.31 lbs per acre, and accumulated weight gain was 84.91 lbs per head (tables 5 and 6).

Dollar value captured on the deferred treatment was the lowest. Pasture cost was low at $77.79 and cost per day was low at $0.64 because of the very heavy stocking rate (table 4). Pasture weight gain value was low at $153.72, net return per cow-calf pair was very low at $75.93 because of the low calf weight gain, net return per acre was moderate at $8.55 because of the heavy stocking rate, and the cost per pound of calf weight gain was high at $0.51 per lb because of the low calf gains (tables 5 and 6).

Dollar value captured on the traditional seasonlong treatment was moderate. Pasture cost was high at $107.84 and cost per day was high at $0.80 because of the low stocking rate (table 4). Pasture weight gain value was high at $204.48, net return per cow-calf pair was high at $96.64, net return per acre was low at $7.85 because of the low stocking rate, and the cost per pound of calf weight gain was low at $0.37 per lb because of the good calf gains (tables 5 and 6).

Dollar value captured on the biologically effective twice-over strategy was good. Pasture cost was moderate at $89.53 and cost per day was low at $0.65 (table 4). Pasture weight gain value was high at $211.96, net return per cow-calf pair was very high at $122.43, and net return per acre was very high at $11.98, and the cost per pound of calf weight gain was very low at $0.30 per lb (tables 5 and 6).

The crude protein content of grass lead tillers drops below the requirements of a lactating cow during the last two weeks of July (Whitman et al. 1951, Manske 1999b). The cow weight gain per day begins to decrease during early August on the deferred and seasonlong grazing practices (table 6) and those cows lose weight after mid September. The calf weight gain per day begins to decrease two week after their cows decrease in weight gain on the deferred and seasonlong grazing practices (table 6).

The grazing cows on the twice-over rotation strategy stimulate vegetative reproduction of secondary tiller development from the axillary buds during the first grazing period from 1 June to 15 July.

These secondary tillers provide adequate crude protein to meet the lactating cows requirements through September on table 6. During these early years of development of the twice-over system, it was hypothesized that the tiller stimulation period lasted until the end of July. It did not, it lasts until mid July. As a result the third pasture did not grow secondary tillers and the cows lost weight during early October (table 6). When the stimulation period was adjusted to mid July, the third pasture produced secondary vegetative tillers high in crude protein, and the cows gained weight until mid October. Mid October is the latest that grass plants can be pushed to maintain adequate levels of crude protein that meets lactating cow requirements. Notice the jump in cow and calf weight gain on the twice-over practice in early August when the old second grazing period previously started. With the adjustment in the stimulation period, the first grazing period on all pastures is 45 days long from 1 June to 15 July and the second period is 90 days long from 15 July to 14 October. The grassland ecosystem improves and cow and calf weight gains increase because of the grazing stimulated vegetative reproduction of secondary tillers from axillary buds that contain adequate quantities of crude protein to meet the requirements of lactating cows until mid October.

Biologically effective management of native rangeland meets the biological and physiological requirements of the grass plants, soil organisms, and grazing animals, and cycles the essential elements. The biologically effective twice-over rotation grazing management strategy coordinates defoliation events with grass phenological growth stages and activates the compensatory physiological mechanisms, the vegetative reproduction by tillering mechanisms, the nutrient resource uptake mechanisms, and the water use efficiency mechanisms within grass plants, and elevates the soil rhizosphere microorganism biomass that perform all of the ecosystem biogeochemical processes.

An early hypothesis that had a biologically incomplete concept of how grassland ecosystems function required reseeding to restore degraded grasslands was used to develop the deferred-rotation grazing practice. However, the concept that recruitment of new plants on grassland ecosystems comes from seedlings was obsolete. New grass plants develop from vegetative secondary tillers. Because of the early pasture scientists dismissed the importance of vegetative tillers, the deferred grazing practices caused further ecosystem degradation and poor livestock weight gains. The deferred practices does not increase grass seedling establishment, and vegetative tillers are inhibited, causing a decrease in native grass density, providing spaces for Kentucky bluegrass and other weeds to increase. The resulting available late season forage is senescent lead tillers, dried Kentucky bluegrass, and coarse mature weeds that contain crude protein at levels well below the requirements of lactating cows causing extremely poor weight gain performances from cows and calves.

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Table 1. Summer grazing period, stocking rate, and pasture costs (rent at $8.76/ac) on the deferred and seasonlong treatments conducted by J.T. Sarvis, 1918-1934.

| Management Strategy Concept | Grazing Period | # Days | # Months | Acres per 2 yr Steer | Acres per Month | Pasture Cost $ | Cost per day $ |
|---|---|---|---|---|---|---|---|
| Deferred | 16 May-8 Oct | 146 | 4.79 | 5.0 | 1.04 | 43.80 | 0.30 |
| Seasonlong | 16 May-10 Oct | 148 | 4.85 | 7.0 | 1.44 | 61.32 | 0.41 |

Based on Data from Sarvis 1941.

Table 2. Summer two year old steer weight performance and net returns (at market value of $0.70/lb) on the deferred and seasonlong treatments conducted by J.T. Sarvis, 1918-1934.

| Management Strategy Concept | Gain per Head lbs | Gain per Day lbs | Gain per Acre lbs | Pasture Weight Gain Value $ | Net Return per Steer $ | Net Return per Acre $ | Cost/lb Steer Gain $ |
|---|---|---|---|---|---|---|---|
| Deferred | | | | | | | |
| Steer | 266.1 | 1.82 | 53.2 | 186.27 | 142.47 | 28.49 | 0.17 |
| Seasonlong | | | | | | | |
| Steer | 308.3 | 2.08 | 44.0 | 215.81 | 154.49 | 22.07 | 0.20 |

Based on Data from Sarvis 1941.

Table 3. Two year old steer gain per head and gain per day during grazing season on native rangeland managed by deferred and seasonlong treatments conducted by J.T. Sarvis, 1918-1934.

| 2 yr Steer | 16 May-30 Jun Spring | 1 Jul-31 Aug Summer | 1 Sep-15 Oct Fall | 16 May-15 Oct Season |
|---|---|---|---|---|
| Deferred | | | | |
| Gain/Head | 135.8 | 110.5 | 19.8 | 266.1 |
| Gain/Day | 2.95 | 1.78 | 0.44 | 1.82 |
| Seasonlong | | | | |
| Gain/Head | 154.5 | 119.2 | 34.6 | 308.3 |
| Gain/Day | 3.36 | 1.92 | 0.77 | 2.08 |

Data from Sarvis 1941.

Table 4. Summer grazing period, stocking rate, and pasture costs (rent at $8.76/ac) on the deferred, seasonlong, and twice-over treatments in western North Dakota conducted by L.L. Manske, 1983-1987.

| Management Strategy Concept | Grazing Period | # Days | # Months | Acres per C-C pr | Acres per AUM | Pasture Cost $ | Cost per Day $ |
|---|---|---|---|---|---|---|---|
| Deferred | 16 Jul-15 Nov | 122 | 4.0 | 8.88 | 2.22 | 77.79 | 0.64 |
| Seasonlong | 18 Jun-30 Oct | 134 | 4.39 | 12.31 | 2.80 | 107.84 | 0.80 |
| Twice-over | 1 Jun-16 Oct | 137 | 4.49 | 10.22 | 2.28 | 89.53 | 0.65 |

Table 5. Summer calf and cow weight performance and net returns (at market value of $0.70/lb) on the deferred, seasonlong, and twice-over treatments in western North Dakota conducted by L.L. Manske, 1983-1987.

| 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 $ |
|---|---|---|---|---|---|---|---|
| Deferred | | | | | | | |
| Calf | 219.60 | 1.80 | 24.73 | 153.72 | 75.93 | 8.55 | 0.51 |
| Cow | 7.24 | 0.06 | 0.82 | | | | |
| Seasonlong | | | | | | | |
| Calf | 292.12 | 2.18 | 23.73 | 204.48 | 96.64 | 7.85 | 0.37 |
| Cow | 53.60 | 0.40 | 4.35 | | | | |
| Twice-over | | | | | | | |
| Calf | 302.80 | 2.21 | 29.63 | 211.96 | 122.43 | 11.98 | 0.30 |
| Cow | 84.91 | 0.62 | 8.31 | | | | |

Table 6. Calf and cow gain per day during biweekly periods grazing native rangeland managed by three systems in western North Dakota conducted by L.L. Manske, 1983-1987.

| Calf | Jun | | Jul | | Aug | | Sep | | Oct | | Nov | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deferred | | | | 2.39 | 2.39 | 2.23 | 2.09 | 2.09 | 1.04 | 0.77 | 0.77 | |
| Seasonlong | | 2.52 | 2.50 | 2.22 | 2.34 | 2.44 | 2.30 | 1.87 | 1.61 | 1.40 | | |
| Twice-over | 2.61 | 2.06 | 2.25 | 2.27 | 2.55 | 2.50 | 2.18 | 2.06 | 1.44 | | | |

| Cow | Jun | | Jul | | Aug | | Sep | | Oct | | Nov | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deferred | | | | 1.52 | 1.49 | 0.71 | 0.15 | -0.19 | -0.55 | -0.74 | -1.01 | |
| Seasonlong | | 1.97 | 1.78 | 1.10 | 0.95 | 0.20 | 0.07 | -0.38 | -0.81 | -0.74 | | |
| Twice-over | 3.04 | 2.17 | 0.70 | 0.52 | 0.79 | 0.89 | 0.84 | 0.54 | -1.68 | | | |

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# Grassland Wildlife Habitat Management Compatible with Livestock Production in the Northern Plains

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center
Report DREC 20-1187

Traditionally, livestock grazing and wildlife habitat were considered to be competing uses of grasslands. But that was when management practices focused only on the aboveground component of grass.

Fortunately, the long needed basic science of the critical grass physiological growth mechanisms and the essential grassland ecosystem biogeochemical processes performed by soil microbes were described in detail during a concentrated effort in the late 1970's through the 1990's. These important research findings were not reported on the 6 o'clock news nor in the popular farm magazines and the general public has remained unaware of the existence of this paradigm changing breakthrough science. Knowledge of the grass growth mechanisms and ecosystem biogeochemical processes permits development of management strategies that consider all the above - and belowground components while meeting the biological requirements of the grass plants and soil microbes and enhancing the functionality of the ecosystem resulting in grassland productivity at biological potential levels. Biologically effective management strategies that are designed to activate the grass physiological growth mechanisms and promote the ecosystem biogeochemical processes is also sound livestock grazing management and beneficial wildlife habitat management.

Grasslands are complex ecosystems; exceedingly more complex than the most complicated machines ever built by humans. Grassland ecosystems are comprised of biotic and abiotic components. The indispensable biotic components are grass vegetation, rhizosphere organisms, and domesticated graminivores which have biological and physiological requirements (Manske 2018b, c, d). The abiotic components include radiant energy from sunlight, the major essential elements of carbon, hydrogen, nitrogen, and oxygen, and the minor essential elements of macro - and micro - nutrients required by living organisms, and the environmental conditions. Grass plants, rhizosphere organisms, and grazing graminivores have developed complex symbiotic relationships. Grazing graminivores depend on grass plants for nutritious forage. Grass plants depend on rhizosphere organisms for mineralization of essential elements from the soil organic matter. Rhizosphere organisms, which are achlorophyllous, depend on grass plants for short chain carbon energy that is exudated through the roots of lead tillers at vegetative growth stages following partial defoliation by grazing graminivores. Grass plants produce double the leaf biomass than is needed for photosynthesis in order to attract the vital partial defoliation by grazing graminivores on which they depend.

The indispensable grass vegetation provides nutritious forage to large grazing graminivores and habitat to wildlife. Grass plants use the major and minor essential elements in the inorganic form to synthesize vital organic components of carbohydrates, proteins, and nucleotides for growth. Grass plants have four primary internal plant growth mechanisms that help grass tillers withstand and recover from partial defoliation by grazing graminivores. The primary mechanisms are: compensatory physiological mechanisms (McNaughton 1979, 1983; Briske 1991); vegetative reproduction by tillering (Mueller and Richards 1986, Richards et al. 1988, Murphy and Briske 1992, Briske and Richards 1994, 1995); nutrient resource uptake (Crider 1955, Li and Wilson 1998, Kochy and Wilson 2000, Peltzer and Kochy 2001); and water use efficiency (Wight and Black 1972, 1979).

Compensatory physiological mechanisms give grass plants the capability to replace lost leaf and shoot biomass following partial grazing defoliation by increasing meristematic tissue activity, increasing photosynthetic capacity, and increasing allocation of carbon and nitrogen. Fully activated mechanisms can produce replacement foliage at 140% of the herbage weight that was removed during grazing (Manske 2000a, b, 2010a, b, 2014a, b). The growth rates of replacement leaves and shoots increase after partial defoliation by grazing. The enhanced activity of meristematic tissue produces larger leaves with greater mass (Langer 1972, Briske and Richards 1995). Developing leaf primordia not fully expanded at time of defoliation have increased growth rates and tend to grow larger than leaves on undefoliated tillers (Langer 1972). Partial defoliated tillers increase photosynthetic rates of remaining mature leaves and rejuvenated portions of older leaves not completely senescent (Atkinson 1986, Briske and Richards 1995). Changes in cytokinin levels and other signals produced as a result of the increase in the root-shoot ratio rejuvenate the photosynthetic apparatus, inhibit or reduce the rate of senescence, and increase the life span and leaf mass of remaining mature leaves (Briske and Richards 1995). Activation of the compensatory physiological mechanisms after partial defoliation of grass tillers by grazing require alternative sources of abundant carbon and nitrogen (Coyne et al. 1995). Carbon fixed during current photosynthesis in remaining mature leaf and shoot tissue and rejuvenated portions of older leaves is preferentially allocated to areas of active meristematic tissue (Ryle and Powell 1975, Richards and Caldwell 1985, Briske and Richards 1995, Coyne et al. 1995). The quantity of leaf area required to fix adequate quantities of carbon is 67% to 75% of the predefoliated leaf area (Manske 1999, 2011b, 2014c). Very little, if any, of the carbon and nitrogen stored in the root system is remobilized to support compensatory growth (Briske and Richards 1995). The mobilizable nitrogen pools in the shoot tissue are reduced following partial defoliation. This loss in nitrogen from the shoot increases preferential use of the quantities of mineral nitrogen available in the media around the roots (Millard et al. 1990, Ourry et al. 1990). This available soil mineral nitrogen has been converted from soil organic nitrogen by active rhizosphere organisms, absorbed though the roots, and moved to areas of active meristematic tissue.

Vegetative secondary tillers are shoots that develop on lead tillers from growth of axillary buds by the process of tillering (Dahl 1995). Meristematic activity in axillary buds and the subsequent development of vegetative tillers is regulated by auxin, a growth-inhibiting hormone produced in the apical meristem and young developing leaves (Briske and Richards 1995). Tiller growth from axillary buds is inhibited indirectly by auxin interference with the metabolic function of cytokinin, a growth hormone (Briske and Richrds 1995). Partial defoliation of young leaf material at vegetative growth stages temporarily reduces the production of the blockage hormone, auxin (Briske and Richards 1994). The abrupt reduction of plant auxin in the lead tiller allows for cytokinin synthesis or utilization in multiple axillary buds, stimulating the development of vegetative secondary tillers (Murphy and Briske 1992, Briske and Richards 1994).

If no defoliation occurs before the flower (anthesis) stage, the lead tiller continues to hormonally inhibit secondary tiller development from axillary buds. Production of the inhibitory hormone, auxin, declines gradationally as the lead tiller reaches the flower stage. The natural reduction of auxin in the lead tiller usually permits only one secondary tiller to develop. This developing secondary tiller produces auxin that hormonally suppresses development of additional axillary buds (Briske and Richards 1995). Vegetative tiller growth is the dominant form of reproduction in semiarid and mesic grasslands (Belsky 1992, Chapman and Peat 1972, Briske and Richards 1995, Chapman 1996, Manske 1999) not sexual reproduction and the development of seedlings. Recruitment of new grass plants developed from seedlings is negligible in healthy grassland ecosystems. The frequency of true seedlings is extremely low in functioning grasslands, and establishment of seedlings occurs only during years with favorable moisture and temperature conditions (Wilson and Briske 1979, Briske and Richards 1995), in areas of reduced competition from vegetative tillers, and when resources are readily available to the growing seedling.

Grass plant dominance within a grassland community is related to the plants competitiveness at nutrient and water resource uptake. Crider (1955) found that grass tillers with 50% or more of the aboveground leaf material removed reduce root growth, root respiration, and root nutrient absorption resulting in reduced functionality of these grass plants. Reduction of active root biomass caused diminishment of grass plant health and vigor (Whitman 1974) that resulted in a loss of resource uptake efficiency and a suppression of the competitiveness of grass plants to take up mineral nitrogen, essential elements, and soil water (Li and Wilson 1998, Kochy 1999, Kochy and Wilson 2000, Peltzer and Kochy 2001). The loss of active root length contributed to the reduction of rhizosphere biomass and the decline of ecosystem biogeochemical processes (Coleman et al. 1983, Klein et al. 1988). The nutrient resource uptake competitiveness of healthy grasses is able to suppress the expansion of shrubs and prevent successful establishment of grass, forb, and shrub seedlings into grasslands (Peltzer and Kochy 2001). The grass growth form has competitive advantages of nutrient uptake over the shrub growth form (Kochy and Wilson 2000). Grass aboveground biomass is primarily productive photosynthetic leaves resulting in a high resource uptake efficiency. Grasses are good competitors for belowground nutrient resources and superior competitors for mineral nitrogen because of a high root: shoot ratio and no woody stems to maintain. Shrubs have a great reduction in resource uptake efficiency because a large portion of the photosynthates produced in the leaves must be used to build and maintain their unproductive woody stems. However, the taller woody stems make shrubs superior competitors for aboveground sunlight resources (Kochy and Wilson 2000). Competition for belowground nutrient resources from healthy grasses reduce the growth rates of shrub rhizomes and cause high mortality rates of young sucker (Li and Wilson 1998).

Shrubs can compete for some of the belowground resources only after the grass plants have been degraded by ineffective management. Following the reduction in grass plant resource uptake competitiveness, the belowground resources no longer consumed by the smaller, less vigorous degraded grasses, are taken up by the shrub plants resulting in proportional increases of biomass production (Kochy and Wilson 2000). With greater nutrient resources, shrub rhizome suckers are able to establish a faster growth rate and a higher survival rate (Li and Wilson 1998). The resulting greater shrub stem density increases the competition for the aboveground resources of light causing strong suppression of the grasses (Kochy and Wilson 2000). Traditionally, the observation of increasing woody shrubs and trees into grasslands would have been explained as a result of fire suppression (Humphrey 1962, Stroddart, Smith, and Box 1975, Wright and Bailey 1982). The invasion of the cool season exotic grasses, Kentucky bluegrass, and smooth bromegrass, into much of the northern mixed grass prairie was presumed to be caused by the absence of fire (Kirsch and Kruse 1972). Seedlings of trees, shrubs, weedy forbs, and introduced grasses cannot become established in healthy functioning grassland ecosystems with grasses that have retained full resource uptake competitiveness (Peltzer and Kochy 2001, Manske 2019).

Grasslands of the Northern Plains managed with traditional practices are notorious for their inhibitory deficiency in available soil mineral nitrogen (Goetz et al. 1978) which has been determined to cause the observed low herbage production. Deficiencies in mineral nitrogen limit herbage production more often than water deficiencies in temperate grasslands (Tilman 1990). Total herbage biomass production on grassland ecosystems has been shown to increase with increases in the quantity of available soil mineral nitrogen (Rogler and Lorenz 1957; Whitman 1957, 1963, 1976; Smika et al. 1965; Goetz 1969, 1975; Power and Alessi 1971; Lorenz and Rogler 1972; Taylor 1976; Wight and Black 1979). Greater quantities of available soil mineral nitrogen has been shown to also cause the soil water use efficiency to improve in grassland plants (Smika et al. 1965, Wight and Black 1972, Whitman 1976, 1978). Using a proxy method, Wight and Black (1972) found that precipitation (water) use efficiency of grass plants improved when soil mineral nitrogen was available at threshold quantities of 100 lbs/ac (112 kg/ha) and greater. The inhibitory deficiencies of mineral nitrogen on grasslands that had less than 100 lbs/ac of available soil mineral nitrogen caused the weight of herbage production per inch of precipitation received to be reduced an average of 49.6% below the weight of herbage produced per inch of precipitation on the grassland ecosystem that had greater than 100 lbs/ac of mineral nitrogen and did not have mineral nitrogen deficiencies (Wight and Black 1979). The efficiency of water use in grass plants function at low levels when mineral nitrogen is deficient, and function at high levels when mineral nitrogen is available at threshold quantities of 100 lbs/ac or greater (Manske 2009d). The level of water use efficiency determines the level of herbage biomass productivity on grasslands. Manske (2010a, b) found that the threshold quantity of 100 lbs/ac of available mineral nitrogen was also critical for functionality for two internal grass plant growth mechanisms of the vegetative reproduction by tillering and the compensatory physiological mechanisms. Both of these mechanisms function at high potential levels on grasslands that have 100 lbs/ac or greater available soil mineral nitrogen and do not function or function at extremely low levels on grasslands that have mineral nitrogen deficiencies (Manske 2009c, 2010a, b, c, 2011c).

The indispensable rhizosphere microorganisms are responsible for the performance of the ecosystem biogeochemical processes that determine grassland ecosystem productivity and functionality. Biogeochemical processes transform stored essential elements from organic forms or ionic forms into plant usable mineral forms. Biogeochemcial processes 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 replacement essential elements into storage as soil organic matter for later use. Biogeochemical processes decompose complex unusable organic material into compounds and then into reusable major and minor essential elements (McNaughton 1979, 1983; Coleman et al. 1983; Ingham et al. 1985; Mueller and Richards 1986; Richards et al. 1988;

Briske 1991; Murphy and Briske 1992; Briske and Richards 1994, 1995).

The quantity of ecosystem biogeochemical processes conducted is dependent on the quantity of rhizosphere microorganism biomass (Coleman et al. 1983). The greater the microbial biomass, the greater the grassland ecosystem productivity. The greater the productivity, the greater the annual increase in soil organic matter. Increases in the organic matter content of a soil improves the stability of soil aggregates, improves the physical and chemical properties, improves soil air and water infiltration and water holding capacity, improves soil fertility, and increases cation exchange capacity (Schimel, Coleman, and Horton 1985, Six et al. 1998, 2004). Rhizosphere organism biomass and activity are limited by access to simple carbon chain energy (Curl and Truelove 1986) because the microflora trophic levels lack chlorophyll and have low carbon (energy) content.

Partial defoliation by large indispensable grazing graminivores that removes 25% to 33% of the aboveground leaf and shoot weight from grass lead tillers in vegetative phenological growth between the three and a half new leaf stage and the flower stage (Manske 1999) causes large quantities of exudates containing simple carbon compounds to be released through the plant roots into the rhizosphere (Hamilton and Frank 2001). With the increase in availability of energy from simple carbon compounds in the rhizosphere, microorganism activity (Elliot 1978, Anderson et al. 1981, Whipps 1990) and biomass (Gorder, Manske, and Stroh 2004) greatly increase. The elevated biomass and activity of the microfauna trophic levels results in heavy consumption of the low carbon, high nitrogen content microflora trophic levels resulting in ingestion of greater quantities of nitrogen than the microfauna organisms need for a balanced diet based on energy (carbon); the excess nitrogen is excreted as ammonium ($NH_4$). As a result of the increase in availability of energy from the exudated simple carbon chains, the biomass and activity of rhizosphere organisms greatly increased, transforming greater quantities of organic nitrogen into mineral nitrogen (Coleman et al. 1983, Klein et al. 1988, Burrows and Pfleger 2002, Rillig et al. 2002, Bird et al. 2002, Driver et al. 2005).

The increased available mineral nitrogen is absorbed into grass plant roots and through complex processes, the plant combines the mineral nitrogen with carbon, hydrogen, and oxygen to synthesize different kinds of amino acids which are combined into large organic compounds to produce various types of proteins, nucleotides, and chlorophyll, resulting in greatly increased herbage biomass production at or near potential biological levels (Manske 1999, 2003). As a result of the great increase in ecosystem net primary productivity, much greater quantities of organic nitrogen are returned annually back to the grassland ecosystem pool of soil organic matter which will raise the ecosystem functionality.

Production of herbage biomass on grassland ecosystems at potential biological levels requires mineral nitrogen to be available at the threshold amount of 100 lbs/ac or greater. The biogeochemical processes of the nitrogen cycle in grassland ecosystems that convert organic nitrogen into mineral nitrogen are a function of the complex symbiotic interactions among rhizosphere organisms, grass plants, and large grazing graminivores. Soil organic matter in grassland ecosystems generally contains about three to eight tons of organic nitrogen per acre. Organic nitrogen is a form of nitrogen not directly usable by grass plants. Organic nitrogen must be transformed into inorganic (mineral) nitrogen in order to be usable by plants. In grassland ecosystems, the transformation of plant usable mineral nitrogen from soil organic nitrogen requires active rhizosphere organisms comprised of several trophic levels of microbes existing in the narrow zone of soil around active roots of perennial grass plants (Harley and Smith 1983, Campbell and Greaves 1990, Caesar-TonThat et al. 2001b).

The nitrogen cycle within grassland soils functions with two major biogeochemical processes. Immobilization is the process of assimilation of mineral nitrogen into organic forms of living organisms. Mineralization is the process of converting organic nitrogen into mineral (inorganic) nitrogen. Mineralization is a complex biogeochemical process conducted by saprotrophic and heterotrophic soil microorganisms that convert immobilized organic nitrogen from soil organic matter detritus into mineral (inorganic) nitrogen (Power 1972). Ammonium salts are the first inorganic nitrogen compounds produced by microbial digestion. Complex proteins and other organic nitrogen compounds are simplified by enzymatic digestion that hydrolyze the peptide bonds and liberate and degrade the amino acids by deamination to produce ammonia ($NH_3$) and carbon dioxide, or other low molecular weight carbon compounds (Power 1972, Brady 1974). Most of the ammonia released is readily hydrolyzed into stable ammonium ($NH_4$). The ammonium ions are fairly immoble and some can be oxidized during nitrification producing nitrite ($NO_2$) and then nitrate ($NO_3$) (Brady 1974, Legg 1975, Coyne et al. 1975). The quantity of available nitrate in soil increases when the soil moisture content is abundant (Brady 1974). Mineral nitrogen ($NH_4$ and $NO_3$) have several optional biological and chemical pathways and are not available for very long. The quantity of available mineral nitrogen varies with changes in soil microorganism biomass and plant phenological growth and development during the growing season (Whitman 1975) and is the net difference between the total quantity of organic nitrogen mineralized by soil microorganisms and the quantity of mineral nitrogen immobilized into organic forms by plants and soil microbes (Brady 1974, Legg 1975). Maintaining available mineral nitrogen at the threshold quantity of 100 lbs/ac or greater requires a very large biomass of soil microorganisms.

Perpetuation of life on earth requires that the abiotic major and minor essential elements be reused over and over. Recycling of the essential elements is also performed by rhizosphere microorganisms. The essential elements are required for life to exist by ensuring growth and development of organisms and the maintenance of all life functions (table 1). Animals require twenty one elements and plants require seventeen elements. Sixteen of the same essential elements are required by both animals and plants. The four major essential elements: carbon (C), hydrogen (H), nitrogen (N), and oxygen (O) are required in very large amounts by animals and plants. A portion of the major essential elements is lost annually from grassland ecosystems by natural processes and a portion is removed from grassland ecosystems as weight biomass produced by insects and wildlife and as animal growth from essential elements transferred from grass plants to grazing livestock. When greater quantities of major essential elements are lost and removed than the quantities accumulated, the ecosystem degrades (declines). When greater quantities of major essential elements are accumulated than the quantities removed, the ecosystem aggrades (improves). Biologically effective management strategies can replenish the quantity of lost or removed major essential elements by capturing input essential elements from the surrounding environment through ecosystem biogeochemical processes performed by the indispensable rhizosphere microorganisms.

Animals and plants require large amounts of the same five macronutrients: potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), and sulfur (S). Animals require one additional macronutrient: sodium (Na) and require chlorine (Cl) as a macronutrient. Warm season plants and cacti use some sodium (Na). Animals and plants require very small amounts of the same seven micronutrients or trace elements: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and nickel (Ni). Animals require four additional micronutrients: iodine (I), cobalt (Co), selenium (Se), and chromium (Cr). Plants require one additional micronutrient: boron (B), and require chlorine (Cl) as a micronutrient. A few plants and rhizobia use some cobalt (Co).

The ecosystem source for all of the minor essential elements required by animals and plants is weathered parent material. The elemental content of the parent material greatly influences the quantity of macro - and micronutrients in the soil. The minor essential elements are stored in the soil organic matter as unavailable organic forms or as ions adsorbed by colloidal complexes and are biologically and chemically immobilized, respectively. While in these stable forms, the minor essential elements are not subjected to potential losses through volatilization or leaching movement (Legg 1975, Gibson 2009). The immobilized minor essential elements are made available through the ecosystem biogeochemical cycles performed by rhizosphere microorganisms (McGill and Cole 1981, Cheng and Johnson 1998, Manske 2012b, 2014c). The quantity of available minor essential elements is determined by the recycling rates of soil organic matter decomposition and mineralization that are directly regulated by the biomass of active rhizosphere microorganisms. Without the stimulation from the partial defoliation of grass lead tillers by the indispensable grazing graminivores none of the ecosystem biogeochemical processes and the internal grass plant mechanisms are activated and do not function.

Prescribed burning and mowing grass hay cannot activate the grass plant growth mechanisms or the ecosystem biogeochemical processes because these practices remove too much of the leaf area preventing adequate quantities of carbon energy to be fixed through leaf photosynthesis. Stored carbohydrates are not mobilized for complementary replacement growth following defoliation events (Richards and Caldwell 1985, Briske and Richards 1995).

Repeated prescribed burning can modify the composition of the aboveground vegetation in degraded grasslands which have been invaded by shrubs. The composition of introduced cool season grasses may change, and early succession and weedy forbs, and shrub aerial stems decrease temporarily after four repeated prescribed burns (Manske 2007a, 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 ecosystem biogeochemcial processes will remain in the degraded grassland ecosystem following repeated burning events. None of the biological, physiological, or asexual mechanisms within grass plants and none of the rhizosphere microbes or biogeochemcial processes they perform are activated by fire (Manske 2007a, 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 ecological and fire cannot replace the partial defoliation achieved by grazing graminivores in managing healthy and productive grassland ecosystems (Manske 2018a).

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Table 1. Essential Elements Required by Animals and Plants.

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Major Essential Elements required by animals and plants

Carbon (C), Hydrogen (H), Nitrogen (N), Oxygen (O)

Minor Essential Elements

Macronutrients required by animals and plants

Potassium (K), Calcium (Ca), Phosphorus (P), Magnesium (Mg), Sulfur (S)

Macronutrients required by animals

Sodium (Na), Chlorine (Cl)

Micronutrients required by animals and plants

Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu)

Molybdenum (Mo), Nickel (Ni)

Micronutrients required by animals

Iodine (I), Cobalt (Co), Selenium (Se), Chromium (Cr)

Micronutrients required by plants

Boron (B), Chlorine (Cl)

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Blue elements required by both animals and plants, Red elements required by animals, Green elements required by plants.

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# Attaining Full Functionality of Grassland Ecosystems with the Twice-over Rotation Grazing Management Strategy

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center
Report DREC 20-1196

Functionality of grassland ecosystems at full biological potential requires recycling adequate quantities of essential elements through the biogeochemical processes performed by the belowground soil microbes in order to replace removed aboveground leaf and stem biomass of grass plants through the primary physiological growth mechanisms, all of which must be activated annually by partial defoliation by grazing graminivores during vegetative growth stages of grass lead tillers.

Grasslands of the Northern Plains managed by traditional practices are low in available mineral nitrogen. This low nitrogen availability has long been known to be responsible for the reduced herbage productivity and below genetic potential calf weight gains per acre. However, intact grasslands have adequate nitrogen, usually at 5 to 6 tons of organic nitrogen per acre, which is not available to plants. Organic nitrogen must be mineralized by soil microorganisms in order for it to be available for plant use in the inorganic form. Unfortunately, traditional and gimmick grazing management practices do not elevate the soil microorganism biomass high enough to support mineralization of organic nitrogen at a level that can yield a supply at the threshold quantity of 100 lbs/ac or greater (Wight and Black 1972, 1979), which will permit the four primary grass plant growth mechanisms and all of the ecosystem biogeochemical processes to function at potential biological levels.

Intact grassland ecosystems that are low in available mineral nitrogen cannot be improved with some quick fix agronomic practice. The application of nitrogen fertilizer to grassland ecosystems does not solve the complex problems related to the cause of low soil mineral nitrogen (Manske 2014). It was found that nitrogen fertilization of native grasslands caused a synchronization of grass tiller growth stage development, resulting in a small increase in herbage biomass which later produced a high rate of leaf senescence and an early season decrease in forage nutritional quality compared to nonfertilized grasslands (Manske 2014). It also caused a short term shift in plant species composition, with an increase in mid cool season grass (e.g. western wheatgrass) and a decrease in short warm season grasses (e.g. blue grama) (Manske 2009a, 2014). Initially, these changes were considered by most observers to be beneficial (Manske 2009d). However, close examination of the data showed that the costs of the additional herbage weight were excessive (Manske 2009b), and that the long term disruptions of ecosystem biogeochemical processes were detrimental to desirable plant composition (Manske 2010). The reduction of short warm season grasses caused a decrease in total live plant basal cover, thus exposing greater amounts of soil to higher levels of solar radiation and erosion (Goetz et al. 1978). These large areas of open space became ideal invasion sites for undesirable plants, resulting in a long term plant species compositional shift towards a replacement community of domesticated and introduced mid cool season grasses (e.g. Kentucky bluegrass, Smooth bromegrass), and in the removal of nearly all the native plant species (Manske 2009c, 2010, 2018a).

Implementation of the strategy to interseed alfalfa into intact semiarid native grassland does not solve the complex problems related to the cause of low soil mineral nitrogen (Manske 2005). The introduction of alfalfa increased demand on the existing low levels of soil mineral nitrogen because almost all of the alfalfa plants' nitrogen requirements had to be taken from the soil. The interseeded alfalfa plants had extremely low levels of nodulation of rhizobium bacteria on the roots and, consequently, almost no nitrogen fixation. The inoculated rhizobium had been consumed by the resident soil microbes before the alfalfa seedlings had grown sufficient root material to permit infection (Manske 2004). The low amounts of mineral nitrogen available in the soil resulted in slower rates of growth and higher rates of mortality for the interseeded alfalfa plants than those for alfalfa plants solid seeded into cropland (Manske 2005). In addition, the high water use of the interseeded alfalfa plants depleted soil water levels within a 5 foot radius from each crown to an average of 35% below ambient soil water levels, causing drought stress conditions in the adjacent grass plants and, subsequently, further reducing grass herbage production (Manske 2004, 2005). Agronomic strategies implemented on grassland ecosystems slowly stifled grass internal growth mechanisms and ecosystem biogeochemical processes to ineffectiveness (Manske 2018a).

Grassland ecosystems should be managed with sound ecological principles. The ecological method to increase the quantity of available mineral nitrogen to 100 lbs/ac or greater in grassland ecosystems is to increase the biomass of the rhizosphere microorganisms. The rhizosphere is the narrow zone of soil bonded by extracellular adhesive polysaccharides around active roots of perennial grassland plants. The primary biologically active rhizosphere microbes are the endomycorrhizal fungi, ectomycorrhizal fungi, low carbon: high nitrogen bacteria, and normal carbon: nitrogen protozoa. The rhizosphere microbes do not possess chlorophyll nor do they have direct access to sunlight, as a consequence, 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 grass material and there isn’t enough energy from 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 the surplus fixed energy until during the winter hardening period, which starts in mid August and lasts to hard frost. Surplus carbon energy not programed for use, is broken down during night respiration. However, grass lead tillers at vegetative growth stages, between the three and a half new leaf stage and the flower (anthesis) stage, can be manipulated to exudate most of the surplus carbon energy into the rhizosphere through the roots following partial 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 grass lead tiller population are partially defoliated by grazing graminivores over a period of 7 to 17 days on each pasture during the 45 day stimulation period from 1 June to 15 July.

Initiation of a twice-over strategy on native grassland that had previously been managed by nongrazing or traditional seasonlong practices will have a rhizosphere microbe biomass that is low to 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 and rhizosphere weight changes respond differently to different management treatments (Manske 2018b).

Management of grassland ecosystems without large grazing graminivores is not sustainable. Forty-five years of research have been devoted to the development of a biologically effective grazing management strategy that can improve and maintain grassland ecosystems at their potential biological levels.

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 2012a). 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 2018a).

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 (Manske 2012b). 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.

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.

Implementation of a twice-over rotation strategy will activate functionality of the four primary grass physiological growth mechanisms at much higher rates during the summer grazing period of 1 June to 14 October with the availability of 100 lbs/ac mineral nitrogen than the lower grass growth rates on traditional seasonlong practices with inadequate quantities of mineral nitrogen. On the twice-over rotation strategy, the greater than 100 lbs/ac mineral nitrogen result in higher functioning rates of the grass growth mechanisms causing cool season grass lead tiller biomass to be 25.5% greater during the July peak and causing a secondary vegetative tiller biomass to be 50.7% greater during the second peak in September, and causing warm season grass lead tiller biomass to be 29.9% greater during the peak in September and October, which causes total native grass herbage biomass to be 31.2% greater than those on the seasonlong treatment during the growing season. The increased grass biomass and improved nutrient content result in greater stocking rates, with calf weight gain per acre to be 23.0% greater, and cow weight gain per acre to be 46.9% greater than the productivity on traditional seasonlong grazing practices (Manske 2018c).

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