Evaluation of Biological Restoration Management of Degraded Native Mixed Grass Prairie

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The greatest detrimental effects that cause degradation of native mixed grass prairie ecosystems occur from long-term nondefoliation management practices that are antagonistic to plant and rhizosphere organism biological requirements and to ecosystem biogeochemical processes resulting in increased shading and increased mulch biomass. Increased shading reduces rate of photosynthesis, reducing carbohydrates supply, causing reduced growth rates of leaves and roots. Increased mulch biomass reduces water infiltration and early season soil temperature causing reduced soil organism biomass and activity, slowed nutrient cycles, and decreased biogeochemical processes resulting in greatly reduced native plant density and in creating larger open spaces for invasion of undesirable introduced plants.

Restoration of degraded native mixed grass prairie ecosystems requires elimination of the shading problem, reduction of the mulch biomass, activation of the ecosystem biogeochemical processes, stimulation of the rhizosphere organisms, and stimulation of the defoliation resistance mechanisms within native grass species. Partial defoliation by grazing graminivores of grass tillers at vegetative growth stages is biologically effective at stimulation of all the restoration processes.

Study Area

The Schnell Recreation Area (SRA), located approximately 2 miles (3.22 kilometers) east of Richardton, North Dakota, in eastern Stark County, is comprised of 1,988 acres (804.5 hectares) that have been managed by the USDI Bureau of Land Management (BLM) since 1993. The area was a working cattle ranch prior to 1993. For 13 years, between 1993 and 2005, cattle grazing was not permitted. As a result of the nondefoliation management by complete rest, the land became severely degraded and dominated with undesirable introduced cool-season domesticated grasses, primarily smooth bromegrass, crested wheatgrass, and Kentucky bluegrass. The SRA shows degradation of two types, each of which has a distinct cause: 1) rangeland with native plant ecosystems that were first degenerated by nondefoliation management practices antagonistic to plant and rhizosphere organism biological requirements and ecosystem biogeochemical processes, then subsequently invaded with undesirable introduced species, and 2) hayland that was seeded with cool-season domesticated grasses after native plant ecosystems were destroyed by tillage. The Bureau of Land Management's identified goals for the Schnell Recreation Area are to restore the native grassland condition and vegetation diversity of the degraded untilled rangeland areas that have been invaded by undesirable species and to convert the seeded cool-season domesticated grasses on the previously tilled haylands to a mixture of native species. This project was developed to evaluate biological restoration of the degraded untilled rangeland areas through implementation of biologically effective grazing management, 2006 to 2011.

Long-Term Regional Weather

The western North Dakota region near Richardton has cold winters and hot summers typical of continental climates. Mean annual temperature is 43.0^{o} F (6.1^{o} C). January is the coldest month, with a mean temperature of 13.5^{o} F (-10.3^{o} C). July and August are the warmest months, with mean temperatures of 70.0^{o} F (21.1^{o} C) and 68.9^{o} F (20.5^{o} C), respectively. Long-term (1971-2000) mean annual precipitation is 17.78 inches (451.61 mm). The precipitation during the perennial plant growing season (April through October) is 14.79 inches (375.67 mm) and is 83.2% of the annual precipitation. June has the greatest monthly precipitation, at 3.39 inches (86.11 mm). The precipitation received in the three month period of May, June, and July is 8.15 inches (207.01 mm) and is 45.8% of the annual precipitation (table 1).

Water stress develops in perennial plants during water deficiency periods when the amount of rainfall is less than evapotranspiration demand. Water deficiency months were identified from historical temperature and precepitaiton data by the ombrothermic diagram technique (Emberger et al.

1963). The long-term (1971-2000) ombrothermic diagram (figure 1) shows near water deficiency conditions during August, September, and October, and favorable water relations during April, May, June, and July. Reoccurrence of water deficiency conditions during April, May, June, and July is 16.9%, 13.6%, 10.2%, and 38.1%, respectively, and during August, September, and October water deficiency reoccurs 52.5%, 50.0%, and 46.6% of the years, respectively. Long-term occurrence of water deficiency conditions is 32.7% of the growing season months, for a mean of 2.0 water deficient months per growing season (Manske et al. 2010).

Growing Season Precipitation

Long-term perennial plant growing season precipitation in the region near Richardton, ND, was 14.79 inches. Long-term April through July precipitation was 9.90 inches and August through October precipitation was 4.89 inches. Growing season precipitation was slightly below normal during 2006 and 2007, and was normal during 2008, 2009, 2010, and 2011.

Growing season precipitation of 2006 was 9.42 inches (63.69% of LTM). April through July precipitation was 43.33% of LTM and August through October precipitation was 104.91% of LTM. Growing season precipitation of 2007 was 10.75 inches (72.68% of LTM). April through July precipitation was 73.43% of LTM and August through October precipitation was 71.17% of LTM. Growing season precipitation of 2008 was 11.45 inches (77.42% of LTM). April through July precipitation was 78.18% of LTM and August through October precipitation was 75.87% of LTM. Growing season precipitation of 2009 was 11.63 inches (78.63% of LTM). April through July precipitation was 74.24% of LTM and August through October precipitation was 87.53% of LTM. Growing season precipitation of 2010 was 13.43 inches (90.80% of LTM). April through July precipitation was 98.69% of LTM and August through October precipitation was 74.85% of LTM. Growing season precipitation of 2011 was 17.15 inches (115.96% of LTM). April through July precipitation was 128.99% of LTM and August through October precipitation was 89.57% of LTM (table 2). Mean growing season precipitation of 2006-2011 was 12.31 inches (83.23% of LTM). Mean April through July precipitation was 82.83% of LTM and mean August through October precipitation was 84.05% of LTM (table 2). Growing season precipitation during the second year to the fourth year, 2007 to 2009, was 76.24% of LTM and was slightly more than 75% of the long-term mean. Growing season precipitation during the fifth and sixth years, 2010 and 2011, was 103.38% of LTM and was greater than 100% of the long-term mean. Growing season precipitation during the second year to the sixth year, 2007 to 2011, was 87.10% of LTM and was slightly less than 90% of the long-term mean.

Table 1. Long-term (1971-2000) mean monthly temperature and monthly precipitation at Richardton, ND.

	º F	º C	in.	mm
Jan	13.50	-10.28	0.45	11.43
Feb	20.40	-6.44	0.48	12.19
Mar	30.30	-0.94	0.86	21.84
Apr	43.40	6.33	1.75	44.45
May	55.70	13.17	2.49	63.25
Jun	64.30	17.94	3.39	86.11
Jul	70.00	21.11	2.27	57.66
Aug	68.90	20.50	1.88	47.75
Sep	57.90	14.39	1.60	40.64
Oct	45.60	7.56	1.41	35.81
Nov	28.80	-1.78	0.75	19.05
Dec	17.40	-8.11	0.45	11.43
	MEAN		**TOTAL**	
	43.00	**6.11**	**17.78**	**451.61**

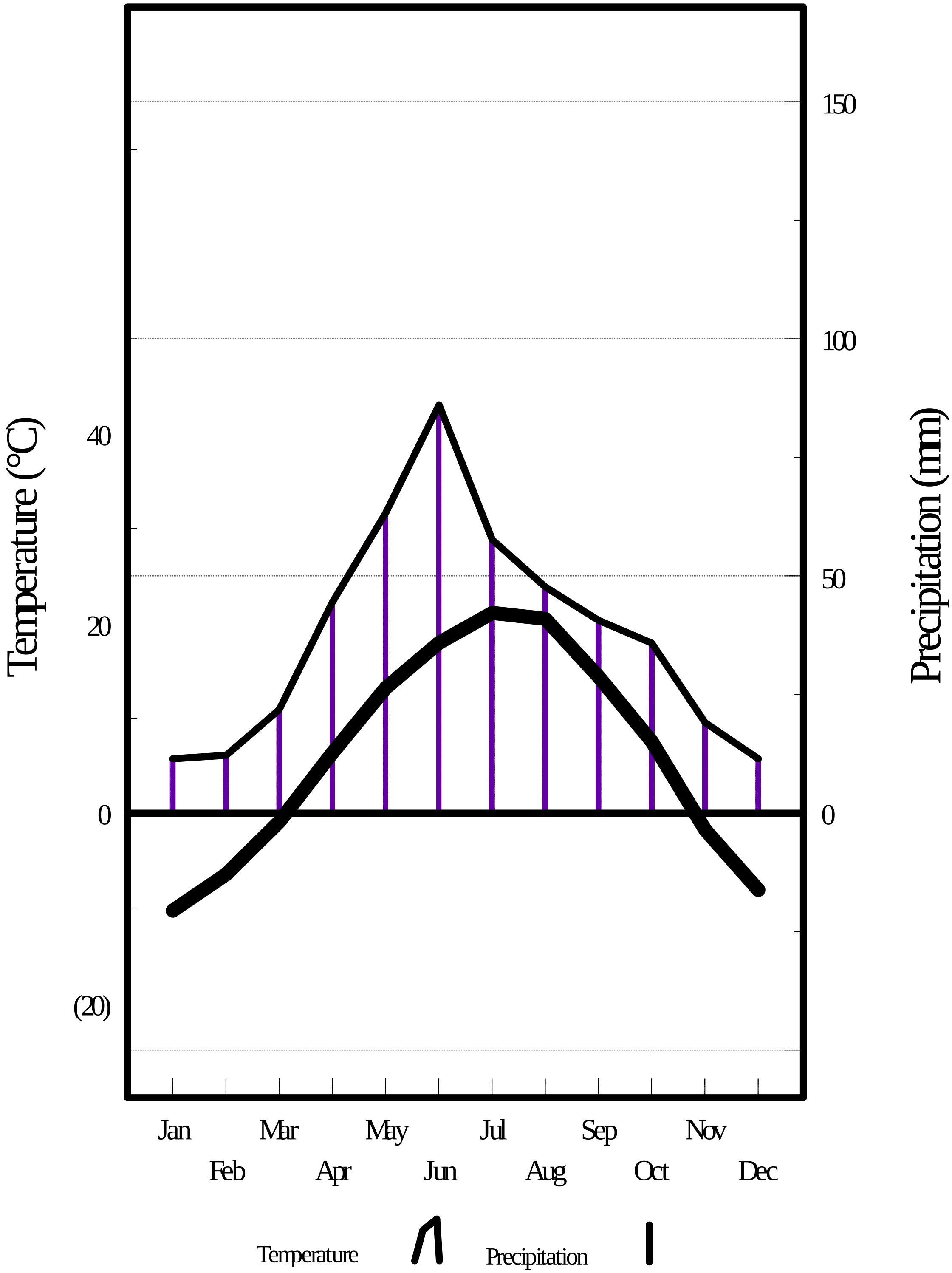

Figure. 1. Ornbrothermic diagram of long-term (1971-2000) mean monthly temperature and monthly precipitation at Richardton, North Dakota.

Table 2. Precipitation in inches for growing season months for 2006-2011, Richardton, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season
Long-term mean (1971-2000)	1.75	2.49	3.39	2.27	1.88	1.60	1.41	14.79
2006	2.53	0.60	0.37	0.79	1.40	2.33	1.40	9.42
% of LTM	144.57	24.10	10.91	34.80	74.47	145.63	99.29	63.69
2007	1.04	3.57	2.22	0.44	1.57	1.29	0.62	10.75
% of LTM	59.43	143.37	65.49	19.38	83.51	80.63	43.97	72.68
2008	0.45	1.32	3.93	2.04	0.56	1.70	1.45	11.45
% of LTM	25.71	53.01	115.93	89.87	29.79	106.25	102.84	77.42
2009	0.59	0.85	3.09	2.82	0.53	1.67	2.08	11.63
% of LTM	33.71	34.14	91.15	124.23	28.19	104.38	147.52	78.63
2010	0.71	3.29	4.35	1.42	0.90	2.30	0.46	13.43
% of LTM	40.57	132.13	128.32	62.56	47.87	143.75	32.62	90.80
2011	2.01	4.94	1.76	4.06	2.07	0.96	1.35	17.15
% of LTM	114.86	198.39	51.92	178.85	110.11	60.00	95.74	115.96
2006-2011	1.22	2.43	2.62	1.93	1.17	1.71	1.23	12.31
% of LTM	69.71	97.59	77.28	85.02	62.23	106.88	87.23	83.23

Procedures

The effects from a biologically effective grazing management strategy in the restoration of native mixed grass prairie plant species composition and grassland ecosystem biogeochemical processes on degraded untilled rangeland were evaluated in four pastures on silty ecological sites with permanent sample plots organized in a paired-plot design. A 16' X 32' (4.88 m X 9.75 m) stock panel exclosure prevented livestock access on an ungrazed plot and a grazed plot on an adjacent area of equal size was accessible by livestock were established at each site for nondestructive data collection. An additional area of similar size accessible by livestock was established at each site for destructive data collection. Ecosystem changes in aboveground herbage biomass, plant species basal cover, forb and shrub density, rhizosphere biomass, and available soil mineral nitrogen were evaluated with data collected from late May through mid October during six growing seasons, 2006 to 2011.

Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986) at each pasture rotation date (seven periods per year). The herbage material from five 0.25 m^2 quadrats (frames) at each destructive sample site outside (grazed) each exclosure was hand clipped to ground level and sorted in the field by biotype categories: domesticated grasses, cool-season grasses, warm-season grasses, sedges, forbs, standing dead, and litter. The herbage of each biotype category from each frame was placed in labeled paper bags of known weight, oven dried at 140° F (60° C), and weighed. Herbage biomass in pounds per acre for each category were determined from the clipping data. Mean herbage biomass for each category were determined for each growing season. Relative composition of herbage biomass biotype categories were determined.

Plant species basal cover was determined by the ten-pin point frame method (Cook and Stubbendieck 1986), with 2000 points collected along permanent transect lines at each nondestructive sample site both inside (ungrazed) and outside (grazed) each exclosure during peak growth between mid July and mid August. The major transect lines were parallel to each other on opposite sides of the exclosure fence. The minor transect lines were perpendicular to the major transect lines and were parallel to each other. Basal cover plant species data were sorted into biotype categories: domesticated grasses, cool-season grasses, warm-season grasses, sedges, forbs, woody species, and litter. Basal cover, relative basal cover, percent frequency, relative percent frequency, and importance value were determined from the ten-pin point frame data. Relative composition of basal cover biotype categories were determined.

Density of forbs and shrubs were determined by counting individual stems of each plant species rooted inside twenty five 0.1 m^2 quadrats placed along permanent transect lines at each nondestructive sample site both inside (ungrazed) and outside (grazed) each exclosure during mid July and mid August. The major transect lines were parallel to each other on opposite sides of the exclosure fence. The minor transect lines were perpendicular to the major transect lines and were parallel to each other. Forb species were categorized as: late succession forbs, mid succession forbs, and early succession forbs. Shrub species were categorized as: woody species. Density per 0.1 m^2 quadrat, relatively density, percent frequency, relative percent frequency, and importance value were determined from the forb and shrub density data. Relative composition of forb and shrub categories were determined.

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

Soil mineral nitrogen, nitrate and ammonium, was sampled at both inside (ungrazed) and outside (grazed) each exclosure by three replicated soil cores with 6 inch (15.2 cm) increments to a 12 inch (30.5 cm) depth collected using a Veihmeyer soil tube with 1 inch (2.5 cm) diameter at the end of the grazing season, 2011. Soil cores were placed on ice immediately and were frozen within 2 to 3 hours of collection. Analysis of soil core samples for available mineral nitrogen (NO_3-NH_4) was conducted by the North Dakota State University Soil Testing Laboratory. Total available mineral nitrogen at a one foot depth was determined from the soil core data and reported as pounds per acre and milligrams per kilogram.

Interpretation of treatment effects on plant community characteristics assumes only minor differences in the vegetation of the grazed area and ungrazed area at the time of exclosure construction on each reference area. A standard t-test was used to analyze differences among means (Mosteller and Rourke 1973). Nomenclature of plant species follows Flora of the Great Plains (1986).

Management Strategy

Restoration of native mixed grass prairie plant species composition and grassland ecosystem biogeochemical processes on degraded untilled rangeland requires implementation of a biologically effective grazing management strategy that stimulates the defoliation resistance mechanisms and related processes (Manske 2011). These mechanisms are: compensatory internal physiological processes, internal vegetative reproduction of secondary tillers from axillary buds, and external symbiotic rhizosphere organism activity (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; Manske 1999). The defoliation resistance mechanisms accelerate growth rates of replacement leaves and shoots, increase photosynthetic capacity of remaining mature leaves, increase allocation of carbon and nitrogen, increase secondary tiller development from axillary buds, and increase conversion of soil organic nitrogen into plant usable mineral nitrogen (Manske 2011).

The twice-over rotation grazing management strategy was the biologically effective management practice implemented at the Schnell Recreation Area (figure 2) to restore the degraded mixed grass prairie plant communities. From 2006 to 2011, three grassland pastures were grazed from early June until mid October, with each pasture grazed for two periods. A fourth pasture was not grazed and was used as a control. Each of the three pastures in the rotation was grazed for 14 to 16 days during the first period, the 45 day interval from 1 June to 15 July, during which the defoliation resistance mechanisms can be activated by partial defoliation by grazing. The length of the first period on each pasture was the same percentage of 45 days as the percentage of the total season's grazeable forage contributed by each pasture (Manske 2000). During the second period, after mid July and before mid October, each pasture was grazed for double the number of days that it was grazed during the first period. The pasture rotation sequence is on table 3. The livestock and stocking rates used to graze the Schnell Recreation Area during 2006 to 2011 are on table 4. Livestock were removed from the grassland pastures in mid October.

The twice-over rotation grazing management strategy coordinates defoliation by grazing with grass phenological growth stages that improves plant health and stimulates biological and ecological processes within grass plants and the ecosystem so that beneficial changes to plant growth, rhizosphere organisms, and biogeochemical cycles in the ecosystem result (Manske 2000). During the first grazing period, grass lead tillers are between the three and a half new leaf stage and the flower (anthesis) stage; these are the stages of tiller development at which partial defoliation by grazing produces beneficial effects by stimulating the defoliation resistance mechanisms that increase compensatory growth rates, increase tillering from axillary buds, and enhance activity of rhizosphere organisms. Increased compensatory growth rates replace leaf and stem material at greater quantities than that removed by grazing. Increased vegetative reproduction by tillering contributes to the development of greater plant basal cover and to the production of greater grass herbage weight. Increased activity of the soil organisms in the rhizosphere supplies the plant with greater quantities of nutrients, primarily mineral nitrogen, to support additional growth (Manske 2000, 2011). Removal of livestock from native rangeland pastures in mid October, during the early fall, allows grass plants to store carbohydrates and nutrients that will maintain plant processes over the winter and to retain the fall vegetative tiller growth that will become next season's tillers (Manske 2003, 2011). The twice-over grazing practice ensures healthy plants in the spring and greater herbage production during the next growing season (Manske 2000, 2011).

Livestock and Stocking Rates

Stocking rate on the Schnell Recreation Area was assessed two times; the first stocking rate assessment was at the start of the study in 2006 using the then current ecological site maps, and the second stocking rate assessment was at the end of the study in 2011 using the recently updated ecological site maps. The 2006 stocking rate assessment determined that a total of 648.14 AUM's of forage was available on pastures 1, 2, and 3. With a grazing season of 4.5 months, 144 AU's with a total herd weight of 144,031 lbs could graze the area at a stocking rate of 2.33 ac/AUM. The 2011 stocking rate assessment determined that a total of 789.90 AUM's of forage was available on pastures 1, 2, and 3. With a grazing season of 4.5 months, 175 AU's with a total herd weight of 175,533 lbs could graze the area at a stocking rate of 1.92 ac/AUM (table 5).

The stocking rate used to graze the Schnell Recreation Area was originally intended to be at 75%, 85%, and 95% of the 2006 assessed stocking rate (table 5) during the first three years and then remain at less than 100% for the duration of the study. The intended stocking rates were not achieved based on the 2006 assessed stocking rate (table 6). Cow-calf pairs grazed the SRA during the first three years, 2006 to 2008 (table 4). The cow weights were heavier than average resulting in the total cow herd weight at 87.6%, 100.3%, and 130.6% of the 2006 assessed stocking rate, respectively (table 6). Heifers grazed the SRA during 2009 and 2010 (table 4). The total heifer herd weights were 96.7% and 105.9% of the 2006 assessed stocking rate, respectively (table 4). Steers grazed the SRA during 2011 (table 4). Less than 52% of the number of steers needed for the intended stocking rate were turned out on the pastures resulting in a total steer herd weight at 45.8% of the 2006 assessed stocking rate (table 6).

A revision of the ecological site stocking rates for the SRA was completed by the NRCS and the second stocking rate assessment was done in 2011 (table 5). The cow-calf pairs were grazed at 72.3%, 82.6%, and 107.5% of the 2011 assessed stocking rate during 2006 to 2008, respectively (table 6). The heifers were grazed at 79.8% and 87.4% of the 2011 assessed stocking rate during 2009 and 2010, respectively (table 6). The actual stocking rates used for the cows and the heifers were closer to the intended stocking rates based on the 2011 assessment (table 6). The steers were grazed at 37.8% of the 2011 assessed stocking rate during 2011 (table 6).

The stocking rate of the cow-calf pairs was increased 15% during the second year, 2007, and increased 30% during the third year, 2008 (table 6). As the cow herd stocking rates increased during the first three years, 2006 to 2008, the relative composition of native grass herbage biomass and basal cover also increased on the grazed pastures (table 7). The heifer herd stocking rates during 2009 and 2010 were lower than the cow-calf stocking rate during 2008 (table 6). With the reduction in stocking rate of the heifers, the relative composition of native grass herbage biomass and basal cover decreased on the grazed pastures (table 7). The steer herd stocking rate during 2011 was the lowest during the study (table 6), the relative composition of native grass herbage biomass decreased to the lowest during the study, and the relative composition of native grass basal cover decreased to near first year values on the grazed pastures (table 7). The three year mean stocking rate of the cow-calf herd was 87.4% of the 2011 assessed stocking rate and the composition of native grass herbage biomass and basal cover on the grazed pastures increased (table 7). The three year mean stocking rate of the heifer and steer herds was 68.3% of the 2011 assessed stocking rate and the composition of native grass herbage biomass and basal cover on the grazed pastures decreased (table 7). The light to moderate stocking rates were not beneficial for improvement of native grass herbage biomass and basal cover.

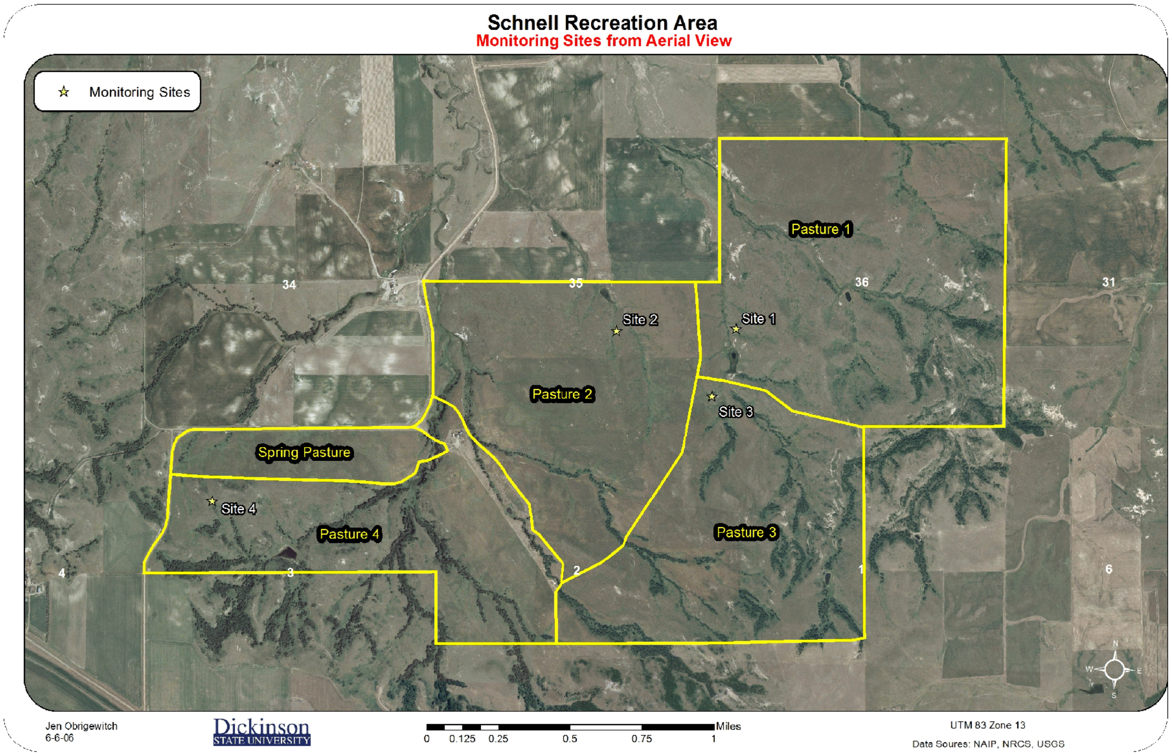

Figure 2. Schnell Recreation Area pastures and study sites.

Table 3. Pasture rotation sequence of the twice-over system at the Schnell Recreation Area, 2006-2011.

	Twice-over Rotation Pasture Sequence					
	First Rotation			Second Rotation		
	1st	2nd	3rd	1st	2nd	3rd
2006	NR 2	NR 1	NR 3	NR 2	NR 1	NR 3
2007	NR 3	NR 2	NR 1	NR 3	NR 2	NR 1
2008	NR 1	NR 3	NR 2	NR 1	NR 3	NR 2
2009	NR 2	NR 1	NR 3	NR 2	NR 1	NR 3
2010	NR 3	NR 2	NR 1	NR 3	NR 2	NR 1
2011	NR 1	NR 3	NR 2	NR 1	NR 3	NR 2

Table 4. Livestock and Stocking Rates used on Schnell Recreation Area, 2006-2011.

Year	#Head	Livestock Type	Mean Weight lbs	AUE	AUM's	Herd Weight lbs	Ac/AUM
2006	84	Cow-Calf pr	1501	113.82	567.51	126114	2.66
2007	103	Cow-Calf pr	1403	132.56	650.08	144462	2.33
2008	130	Cow-Calf pr	1447	171.51	846.43	188095	1.79
2009	167	Heifers	834	145.74	626.99	139332	2.41
2010	162	Heifers	942	154.90	686.52	152561	2.20
2011	101	Steers	654	73.45	297.02	66005	5.09

Table 5. Stocking Rate assessment of Schnell Recreation Area, 2006 and 2011.

	2006 Assessment Using then current Ecological Site Maps			2011 Assessment Using recent updated Ecological Site Maps		
	Acres	AUM's/ac	AUM's	Acres	AUM's/ac	AUM's
Pasture #						
NR 1	628.25	0.3593	225.76	628.30	0.5069	318.47
NR 2	440.19	0.4873	214.51	449.80	0.5067	227.90
NR 3	443.25	0.4690	207.87	441.30	0.5518	243.53
Totals	1511.69	0.4288	648.14	1519.40	0.5199	789.90
Animal Units	4.5 months		144.03 AU's	4.5 months		175.53 AU's
Herd Weight	1000 lbs/AU		144,031 lbs	1000 lbs/AU		175,533 lbs
Stocking Rate	2.33 ac/AUM			1.92 ac/AUM		

Table 6. Livestock numbers and weight and Stocking Rate used 2006 to 2011 compared to 2006 and 2011 assessed values on Schnell Recreation Area.

	Animal Units			Herd Weight			Stocking Rate		
	Used	2006 Assessed 144.03	2011 Assessed 175.53	Used	2006 Assessed 144031	2011 Assessed 175533	Used	2006 Assessed 2.33	2011 Assessed 1.92
Year	#	%	%	lbs	%	%	ac/AUM	%	%
2006	113.82	79.03	64.84	126114	87.56	71.85	2.66	87.66	72.30
2007	132.56	92.04	75.52	144462	100.30	82.30	2.33	100.09	82.55
2008	171.51	119.08	97.71	188095	130.59	107.16	1.79	130.29	107.46
2009	145.74	101.19	83.03	139332	96.74	79.38	2.41	96.76	79.80
2010	154.90	107.55	88.25	152561	105.92	86.91	2.20	105.99	87.42
2011	73.45	50.99	41.84	66005	45.83	37.60	5.09	45.83	37.80

Table 7. Relative composition of native grass herbage biomass and basal cover on the control pasture and on the grazed pastures at the Schnell Recreation Area, 2006-2011.

	Relative Composition (%) Herbage Biomass			Relative Composition (%) Basal Cover	
	Control Pasture	Grazed Pastures	Animal Type	Control Pasture	Grazed Pastures
Pregrazing 2006	2.46	26.21		27.70	69.61
2006	7.46	31.34	Cow-Calf	18.07	66.27
2007	12.18	33.00	Cow-Calf	20.74	77.40
2008	10.78	57.52	Cow-Calf	34.11	80.33
2009	15.74	56.89	Heifers	18.95	74.39
2010	15.54	40.40	Heifers	12.85	67.39
2011	3.14	23.68	Steers	12.61	66.42

Results

Control Pasture NR 4

The mixed grass prairie study area in ungrazed control pasture NR 4 was a degraded silty ecological site dominated by Kentucky bluegrass. Control pasture NR 4 was not grazed during the six years of this study and was not grazed during the 13 years prior to this study. At the start of the study (May 2006), the aboveground vegetation biomass consisted of 72.3% standing dead and litter and 27.7% live herbage. The live herbage biomass was 95.2% domesticated grasses, 2.5% native grasses (2.0% cool season grasses, 0.4% upland sedges, and less than 0.1% warm season grasses), and 2.4% forbs (tables 8 and 9).

The domesticated grass herbage biomass changed little numerically throughout the study (tables 8, 9, and 10). From a starting biomass of 1684.81 lbs/ac in 2006, the weight of the domesticated grasses decreased 364.65 lbs/ac (21.6%) to 1320.16 lbs/ac after 3 years of study, decreased 216.12 lbs/ac (12.8%) to 1468.69 lbs/ac after 5 years of study, and increased 649.17 lbs/ac (38.5%) to 2333.98 lbs/ac after 6 years of study (tables 8 and 10). The domesticated grass basal cover changed little numerically during 2006 to 2009, increased during 2010, then decreased in 2011 (tables 11, 12, and 13). The dominant domesticated grass was Kentucky bluegrass. From a starting basal cover of 10.55% in 2006, the basal cover increased 0.65 percentage points (6.2%) to 11.20% after 3 years of study and increased 4.75 percentage points (45.0%) to 15.30% and 4.80 percentage points (45.5%) to 15.35% during 2009 and 2011, respectively (table 11).

The composition of native cool season grasses in the plant community was low. The cool season grass herbage biomass increased slightly during 2006 to 2009, then decreased in 2010 and 2011 (tables 8, 9, and 10). From a low starting biomass of 35.68 lbs/ac in 2006, the weight of the cool season grasses increased 61.62 lbs/ac (172.7%) to 97.30 lbs/ac after 3 years of study, increased 145.27 lbs/ac (407.2%) to 180.95 lbs/ac after 5 years of study, and decreased to 57.49 lbs/ac after 6 years of study (tables 8 and 10). The native cool season grass basal cover increased slightly during 2006 to 2008, then decreased during 2009 to 2011 (tables 11, 12, and 13). The cool season grasses present were western wheatgrass, needle and thread, and green needlegrass. From a starting basal cover of 1.20% in 2006, the basal cover of the cool season grasses increased 2.35 percentage points (195.8%) to 3.55% after 3 years of study, increased 0.05 percentage points (4.2%) to 1.25% after 5 years of study, and decreased to 0.35% after 6 years of study (tables 11 and 13).

The composition of native warm season grasses in the plant community was low. The warm season grass herbage biomass changed little throughout the study (tables 8, 9, and 10). From an extremely low starting biomass of 0.71 lbs/ac in spring of 2006, the weight of the warm season grasses increased 44.45 lbs/ac (6260.1%) to 45.16 lbs/ac after 3 years of study and increased 102.05 lbs/ac (14373.2%) to 102.76 lbs/ac after 5 years of study (tables 8 and 10). The native warm season grass basal cover increased slightly during 2006 to 2011 (tables 11, 12, and 13). The warm season grass present was a small remnant colony of prairie sandreed. From a extremely low starting basal cover of 0.05% in 2006, the basal cover of warm season grasses increased 0.35 percentage points (700.0%) to 0.40% after 3 years of study, increased 0.60 percentage points (1200.0%) to 0.65% after 5 years of study, and increased to 0.85% after 6 years of study (tables 11 and 13).

The composition of native upland sedges in the plant community was low. The upland sedge herbage biomass changed little throughout the study (tables 8, 9, and 10). From an extremely low starting biomass of 7.14 lbs/ac in 2006, the weight of the upland sedges increased 13.05 lbs/ac (184.2%) to 20.29 lbs/ac after 3 years of study, increased 23.34 lbs/ac (326.9%) to 30.48 lbs/ac after 5 years of study, and decreased to 11.82 lbs/ac after 6 years of study (tables 8 and 10). The native upland sedge basal cover decreased slightly during 2006 to 2011 (tables 11, 12, and 13). The upland sedges present were threadleaf sedge and sun sedge. From a low starting basal cover of 2.85% in 2006, the basal cover of the upland sedges decreased 0.95 percentage points (33.3%) to 1.90% after 3 years of study, decreased 1.10 percentage points (38.6%) to 1.75% after 5 years of study, and decreased to 1.05% after 6 years of study (tables 11 and 13).

The composition of the total native grass population in the plant community was low. The total native grass herbage biomass changed little numerically throughout the study (tables 8, 9, and 10). From a low starting biomass of 43.53 lbs/ac in 2006, the weight of the native grasses increased 119.22 lbs/ac (273.9%) to 162.75 lbs/ac after 3 years of study, increased 270.66 lbs/ac (621.8%) to 314.19 lbs/ac after 5 years of study, and decreased to 223.05 lbs/ac after 6 years of study (tables 8 and 10). The total native grass basal cover increased slightly during 2006 to 2008, then decreased during 2009 to 2011 (tables 11, 12, and 13). From a low starting basal cover of 4.10% in 2006, the basal cover of the native grasses increased 1.75 percentage points (42.7%) to 5.85% after 3 years of study, decreased 0.45 percentage points (11.0%) to 3.65% after 5 years of study, and decreased to 2.25% after 6 years of study (tables 11 and 13).

The composition of the forbs in the plant community was low. The forb herbage biomass decreased slightly during 2006 to 2008, then increased slightly during 2009 to 2011 (tables 8, 9, and 10). From a low starting biomass of 42.10 lbs/ac in 2006, the weight of the forbs decreased 15.08 lbs/ac (35.8%) to 27.02 lbs/ac after 3 years of study, increased 196.55 lbs/ac (466.9%) to 238.65 lbs/ac after 5 years of study, and decreased to 185.43 lbs/ac after 6 years of study (tables 8 and 10). The forb density decreased during 2006 to 2008, then increased during 2009 to 2011 (tables 14 and 15). From a starting density of 5.44 forbs/0.10 m^2 in 2006, was 89.7% lower at 0.56 forbs/0.10 m^2 after 3 years of study, was 52.9% lower at 2.56 forbs/0.10 m^2 after 5 years of study, and was 37.2% lower at 3.56 forbs/0.10 m^2 after 6 years of study (table 14).

Standing dead biomass was 1824.68 lbs/ac in 2006 at the start of the study, decreased 76.3% to 432.54 lbs/ac in 2010 during 5 years of study, and increased to 1229.02 lbs/ac in 2011 at 67.4% of the starting biomass (table 8). Litter biomass was 2785.89 lbs/ac in 2006 at the start of the study, decreased 47.0% to 1476.03 lbs/ac in 2010 during 5 years of study, and increased to 3178.78 lbs/ac in 2011 at 114.1% of the starting biomass (table 8). The litter layer was very thick during each year on the ungrazed control pasture. The biomass of the litter was greater during the sixth year than during the first year. The mean annual litter biomass was 2356.04 lbs/ac and composed 43.4% of the mean annual total biomass. Total dead biomass was 4610.57 lbs/ac in 2006 at the start of the study, decreased 58.6% to 1908.57 lbs/ac in 2010 during 5 years of study, and increased to 4407.80 lbs/ac in 2011 at 95.6% of the starting biomass (table 8). The mean annual biomass of total dead was 3356.59 lbs/ac and composed 61.8% of the mean annual total live and dead biomass.

After 6 growing seasons, the aboveground vegetation biomass consisted of 61.7% standing dead and litter and 38.3% live herbage. The live herbage was 85.1% domesticated grasses, 8.1% native grasses (5.6% warm season grasses, 2.1% cool season grasses, and 0.4% upland sedges), and 6.8% forbs (table 9).

The vegetation on control pasture NR 4 changed during the 6 years of nongrazing management. Domesticated grass herbage biomass increased 38.5% and basal cover increased 45.5%. Native grass herbage biomass increased 412.4% and basal cover decreased 45.1%. Forb herbage biomass increased 340.5% and forb density decreased 34.6%. Total live herbage biomass increased 54.9% and basal cover increased 20.6%. Standing dead herbage biomass decreased 32.6% and litter biomass increased 14.1%.

The rhizosphere weight (table 16) changed little during the first four growing seasons, during which the growing season precipitation was slightly less than 75% of the long-term mean. The rhizosphere weight increased during the fifth and sixth grazing seasons, during which the growing season precipitation was greater than 100% of the long-term mean. From the second grazing season to the sixth grazing season, the rhizosphere weight increased at a mean rate of 13.2 kg/m^3 per year, during which the growing season precipitation was slightly less than 90% of the long-term mean. During the sixth grazing season, the mean rhizosphere weight was 130.56 kg/m^3, which is (32.1%) a low moderate quantity. Mean rhizosphere weights of 406.44 kg/m^3 have been recorded on silty ecological sites managed long-term with a twice-over rotation grazing strategy.

The total available soil mineral nitrogen of nitrate and ammonium was 83.68 lbs/ac on the exclosure and 79.04 lbs/ac on the not grazed area, with a decrease of 5.5% on the not grazed area (table 17). The quantity of total mineral nitrogen on the exclosure and on the not grazed area were not significantly different. The quantity of nitrate was 10.66 lbs/ac on the exclosure and 10.33 lbs/ac on the not grazed area, with a slight decrease of 3.1% on the not grazed area. The quantity of ammonium was 73.02 lbs/ac on the exclosure and was 68.71 lbs/ac on the not grazed area, with a slight decrease of 5.9% on the not grazed area (table 17). The exclosure and the not grazed area had nearly equal quantities of nitrate and similar quantities of ammonium. The amount of nitrate was increased on both the exclosure and not grazed area. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. Both the exclosure and not grazed area had high domesticated grass basal cover. The amount of ammonium was increased on both the exclosure and not grazed area. Both the exclosure and not grazed area had low native grass basal cover and low rhizosphere biomass. However, both the exclosure and not grazed area had high Kentucky bluegrass basal cover. On the ungrazed control pasture NR 4, the high quantities of ammonium appear to be related to easily decomposed labile roots of Kentucky bluegrass and low rhizosphere biomass.

Degradation of the mixed grass prairie communities on the ungrazed control pasture NR 4 resulted in a severe reduction of native grasses, an excessive increase of standing dead and litter, and an extreme increase of domesticated grasses. The severely degraded mixed grass prairie site on control pasture NR 4 was dominated by Kentucky bluegrass at a 95.2% composition. The deterioration of the native prairie communities was a direct result of withholding grazing by large graminivores for nineteen years between 1993 and 2011. Soon after grazing management was removed, native grass live root biomass decreased (Whitman 1974), standing dead leaves accumulated (Brand and Goetz 1986), and ecosystem biogeochemical processes declined (Manske 2011). The reduction of active root surface area caused a decrease in root length for interaction with symbiotic rhizosphere organisms and caused a decrease in absorption of water and nutrients from the soil. The control pasture had no grazing treatments and the changes in the vegetation were due to changes in environmental factors. Native grass growth and development were limited by deficiency levels of sunlight, soil water, and mineral nitrogen.

The accumulation of nondefoliated live and standing dead leaves of grasses reduced light penetration greatly. The mean quantity of domesticated grass and standing dead herbage biomass was 2617.80 lbs/ac and was sufficient to prevent most of the sunlight from reaching the understory native grass leaves. Reduced sunlight caused reduced rates of photosynthesis, decreased rates of herbage production, and increased rates of leaf senescence (Langer 1972, Briske and Richards 1995). Native grasses have high light saturation points and require near full sunlight. The reduced quantity of light reaching the understory leaves was well below the light saturation point of most native grass species. Shading has a greater effect on warm season grasses because they have a higher light saturation point than cool season grasses. Introduced domesticated grasses have lower light saturation points than native grasses, permitting the domesticated grasses to coexist in the low light conditions of the understory of nondefoliated live and dead grass leaves. Native grasses on control pasture NR 4 were inhibited by a severe deficiency of sunlight caused by shading from accumulated domesticated grass and standing dead leaves. The low sunlight intensity caused greatly reduced photosynthetic rates that resulted in a deficiency of available fixed carbon.

The increased quantity of accumulated standing dead material did not make contact with soil and did not decompose through microbial activity. The standing dead material broke down slowly by leaching and weathering, and built up into a thick mulch layer that averaged 2356.04 lbs/ac on the ungrazed control pasture NR 4. The thick mulch modified soil temperatures, inhibited water infiltration, and tied up carbon and nitrogen (Wright and Bailey 1982; Manske 2000, 2011). The litter biomass absorbed a high percentage of the precipitation and the biomass of the thick mulch was sufficient to prevent large quantities of water from infiltrating into the soil. Soil water was greatly reduced in soils covered by thick mulch even though the quantity of growing season precipitation was similar to the regional long-term mean. Native grasses on control pasture NR 4 were inhibited by deficiencies of soil water, cool soil temperatures during spring, and reduced ecosystem nutrients caused by thick mulch.

The amount of precipitation during the first three years, 2006 to 2008, was slightly less than 75% of the long-term mean. The domesticated grasses were under water stress and the herbage biomass decreased 21.6% to 1320.16 lbs/ac. The native grasses were not under water stress and the reduction of domesticated grass herbage biomass permitted the native grasses to increase 273.9% to 162.75 lbs/ac in three years.

The amount of precipitation during the next three years, 2009 to 2011, was slightly more than 95% of the long-term mean. The domesticated grasses were not under water stress and the herbage biomass increased 76.8% to 2333.98 lbs/ac. The increased domesticated grass herbage biomass increased shading for most small native grasses. However, a small remnant colony of prairie sandreed, a tall native grass, was able to grow above the shading of the Kentucky bluegrass leaves and caused the native grass herbage biomass to increase 37.1% to 223.05 lbs/ac.

Precipitation during the six year study was typical of the long-term mean for the region. Domesticated grasses and native grasses responded to water stress at different levels.

The quantity of available soil mineral nitrogen was the difference between the rate of mineralization and the rate of immobilization. Mineralization occurred when organic nitrogen contained in soil organic matter detritus was processed by soil microorganisms to form mineral nitrogen. Immobilization of nitrogen occurred when plants and soil organisms absorbed mineral nitrogen and built essential organic nitrogen compounds from amino acids and nucleotides. The biological modifications to the grassland ecosystem caused the mycorrhizal fungi and other rhizosphere organisms to decrease in biomass and activity levels. Reduced quantities of soil microorganisms decreased the rate mineralization and retarded the nutrient cycles and ecosystem biogeochemical processes, causing severe reductions in the quantities of available mineral nitrogen. After 13 years with nondefoliation management, the rhizosphere biomass on control pasture NR 4 decreased to less than 13% of the potential rhizosphere organism biomass, resulting in greatly reduced quantities of available soil mineral nitrogen and greatly reduced native grass herbage biomass production to 43.53 lbs/ac. Native grasses on control pasture NR 4 were inhibited by a severe deficiency of available soil mineral nitrogen caused by greatly reduced rhizosphere organism biomass and activity.

The decreased supply of soil water, mineral nitrogen, and fixed carbon resulted in a major reduction in assimilation of plant tissue, reducing growth of leaves and roots, and reducing the development of vegetative secondary tillers (Langer 1972, Briske and Richards 1995). Native grass tiller mortality increased and native plant density decreased (Grant et al. 1983), creating large open spaces available for invasion by the undesirable domesticated cool season grasses, Kentucky bluegrass and smooth bromegrass. The increasing live herbage biomass and increasing standing dead biomass of the invading domesticated grasses caused additional shading that resulted in accelerated reductions of the native grasses.

The twice-over rotation grazing strategy was designed to meet the biological requirements of plants and soil organisms and to stimulate activity in the rhizosphere. The annual changes in rhizosphere weight on the ungrazed control pasture NR 4 and on the three grazed pastures NR 1, NR 2, and NR 3 during six grazing seasons were different (table 18). Mean annual rhizosphere weights on the ungrazed control pasture NR 4 and on the grazed pastures NR 1, NR 2, and NR 3 changed little during the first and second grazing seasons, 2006 and 2007. The 2006 rhizosphere weights and the 2007 rhizosphere weights were not significantly different. Rhizosphere weights on the control pasture and on the grazed pastures were not significantly different during the first and second grazing seasons, except the rhizosphere weight on pasture NR 3 during the first year was significantly less than those on grazed pastures NR 1 and NR 2 (table 18).

Mean annual rhizosphere weights on the ungrazed control pasture NR 4 responded differently than those on the grazed pastures. The rhizosphere weights on the control pasture changed little each year from the second year to the fourth year, during which the growing season precipitation was only slightly more than 75% of the long-term mean. Mean change was 2.5 kg/m^3 per year. The control pasture rhizosphere weights increased markedly during the fifth and sixth years, during which the growing season precipitation was greater than 100% of the long-term mean, however, the rhizosphere weights on the control pasture continued to be significantly less than the rhizosphere weights on the grazed pastures (table 18).

Mean annual rhizosphere weights on the grazed pastures NR 1, NR 2, and NR 3 responded differently than those on the ungrazed control pasture and increased substantially each year from the second grazing season to the sixth grazing season, during which the growing season precipitation was slightly less than 90% of the long-term mean. Mean change in rhizosphere weight was 32.0, 29.1, and 23.8 kg/m^3 per year on grazed pastures NR 1, NR 2, and NR 3, respectively.

The increased rhizosphere weights on grazed pastures NR 1 and NR 2 during the third grazing season, 2008, were not significantly different from the other. The rhizosphere weights on grazed pastures NR 1 and NR 2 were significantly greater than those on grazed pasture NR 3 and the control pasture NR 4. Rhizosphere weights on grazed pasture NR 3 were significantly greater than those on the control pasture NR 4 (table 18).

The increased rhizosphere weights on grazed pastures NR 1, NR 2, and NR 3 were not significantly different during the fourth grazing season, 2009, and were not significantly different during the fifth grazing season, 2010. The rhizosphere weights on grazed pastures NR 1, NR 2, and NR 3 were significantly greater than the rhizosphere weights on the ungrazed control pasture NR 4 during the fourth grazing season and during the fifth grazing season (table 18).

The increased rhizosphere weights on grazed pastures NR1 and NR 2 were not significantly different from the other during the sixth grazing season, 2011. The rhizosphere weights on grazed pastures NR 1 and NR 2 were significantly greater than those on grazed pasture NR 3 and on the control pasture NR 4. Rhizosphere weights on grazed pasture NR 3 were significantly greater than those on the control pasture NR 4 during the sixth grazing season (table 18).

The rhizosphere weights on grazed pastures NR 1 and NR 2 were numerically the greatest and were not significantly different from the other during each of the six grazing seasons. The rhizosphere weights on grazed pasture NR 3 were numerically lower than those on pastures NR 1 and NR 2 during each of the six grazing seasons and were significantly lower during the first, third, and sixth grazing seasons. The rhizosphere weights on the ungrazed control pasture NR 4 were numerically lower and were significantly lower than the rhizosphere weights on the grazed pastures NR 1, NR 2, and NR 3 during the third to the sixth grazing seasons (table 18).

Rhizosphere biomass on control pasture NR 4 changed little during the first four years when precipitation was slightly less than 75% of the long-term mean. Rhizosphere biomass increased during the next two years when precipitation was greater than 100% of the long-term mean.

Rhizosphere biomass on grazed pastures NR 1, NR 2, and NR 3 changed little during the first two years when the quantity of exudated carbon would have remained low. Rhizosphere biomass on the grazed pastures increased substantially from the second to the sixth years. The rhizosphere biomass increases on pastures NR 1 and NR 2 were similar to each other and the increases on pasture NR 3 were less than those on pastures NR 1 and NR 2. Most of the rhizosphere biomass increases from the second to the sixth years on the grazed pastures appeared to be related to increases in carbon exudates that resulted from partial defoliation of grass lead tillers by grazing during vegetative growth stages.

Table 8. Mean herbage biomass (lbs/ac) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Domesticated	1684.81	1833.85	1791.31	1320.16	1779.62	1468.69	2333.98
Cool Season	35.68	73.30	110.22	97.30	248.74	180.95	57.49
Warm Season	0.71	59.02	126.59	45.16	56.17	102.76	153.73
Sedges	7.14	25.91	22.27	20.29	49.44	30.48	11.82
Native Grass	43.53	158.23	259.08	162.75	354.35	314.19	223.05
Total Grass	1728.34	1992.08	2050.39	1482.91	2133.97	1782.88	2557.03
Forbs	42.10	128.75	75.97	27.02	116.81	238.65	185.43
Total Live	1770.44	2120.83	2126.36	1509.93	2250.78	2021.53	2742.47
Standing Dead	1824.68	1381.12	708.48	928.70	499.32	432.54	1229.02
Litter	2785.89	2452.03	2131.29	2521.86	1946.39	1476.03	3178.78
Total Dead	4610.57	3833.15	2839.77	3450.56	2445.71	1908.57	4407.80
Total Biomass	6381.01	5953.98	4966.13	4960.49	4696.49	3930.10	7150.27

Table 9. Percent composition of herbage biomass for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Domesticated	95.16	86.47	84.24	87.43	79.07	72.65	85.11
Cool Season	2.02	3.46	5.18	6.44	11.05	8.95	2.10
Warm Season	0.04	2.78	5.95	2.99	2.50	5.08	5.61
Sedges	0.40	1.22	1.05	1.34	2.20	1.51	0.43
Native Grass	2.46	7.46	12.18	10.78	15.74	15.54	8.13
Total Grass	97.62	93.93	96.43	98.21	94.81	88.19	93.24
Forbs	2.38	6.07	3.57	1.79	5.19	11.81	6.76
Total Live	27.75	35.62	42.82	30.44	47.92	51.44	38.35
Standing Dead	28.60	23.20	14.27	18.72	10.63	11.01	17.19
Litter	43.66	41.18	42.92	50.84	41.44	37.56	44.46
Total Dead	72.25	64.38	57.18	69.56	52.08	48.56	61.65
Total Biomass	6381.01	5953.98	4966.13	4960.49	4696.49	3930.10	7150.27

Table 10. Change in herbage biomass (lbs/ac) of grass categories between pregrazing 2006 and not grazed 2008, and not grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	Pregrazing Herbage Biomass 2006	Mean Not Grazed Herbage Biomass 2008	% Difference 2008	Mean Not Grazed Herbage Biomass 2010	% Difference 2010
Domesticated	1684.81	1320.16	-21.64	1468.69	-12.83
Cool Season	35.68	97.30	172.70	180.95	407.15
Warm Season	0.71	45.16	6260.06	102.76	14373.24
Sedges	7.14	20.29	184.17	30.48	326.89
Native Grass	43.53	162.75	273.88	314.19	621.78
Total Grass	1728.34	1482.91	-14.20	1782.88	3.16

Table 11. Basal cover (%) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	2006 Exclosure	2006 Not Grazed	2007 Not Grazed	2008 Not Grazed	2009 Not Grazed	2010 Not Grazed	2011 Not Grazed
Domesticated	10.55	12.35	19.95	11.20	15.30	23.60	15.35
Cool Season	1.20	0.40	2.30	3.55	0.70	1.25	0.35
Warm Season	0.05	0.50	0.80	0.40	0.55	0.65	0.85
Sedges	2.85	2.00	2.20	1.90	2.35	1.75	1.05
Native Grass	4.10	2.90	5.30	5.85	3.60	3.65	2.25
Total Grass	14.65	15.25	25.25	17.05	18.90	27.25	17.60
Forbs	0.05	0.80	0.30	0.10	0.10	1.15	0.20
Woody Species	0.10	0.00	0.00	0.00	0.00	0.00	0.05
Total Live	14.80	16.05	25.55	17.15	19.00	28.40	17.85
Litter	85.20	83.95	74.45	82.85	81.00	71.60	82.15
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 12. Percentage composition (%) of basal cover for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	2006 Exclosure	2006 Not Grazed	2007 Not Grazed	2008 Not Grazed	2009 Not Grazed	2010 Not Grazed	2011 Not Grazed
Domesticated	71.28	76.95	78.08	65.31	80.53	83.10	85.99
Cool Season	8.11	2.49	9.00	20.70	3.68	4.40	1.96
Warm Season	0.34	3.12	3.13	2.33	2.89	2.29	4.76
Sedges	19.26	12.46	8.61	11.08	12.37	6.16	5.88
Native Grass	27.70	18.07	20.74	34.11	18.95	12.85	12.61
Total Grass	98.99	95.02	98.83	99.42	99.47	95.95	98.60
Forbs	0.34	4.98	1.17	0.58	0.53	4.05	1.12
Woody Species	0.68	0.00	0.00	0.00	0.00	0.00	0.28
Total Live	14.80	16.05	25.55	17.15	19.00	28.40	17.85
Litter	85.20	83.95	74.45	82.85	81.00	71.60	82.15
Total							

Table 13. Change in basal cover (%) of grass categories between ungrazed 2006 and not grazed 2008, and not grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	Ungrazed Basal Cover 2006	Not Grazed Basal Cover 2008	% Difference 2008	Not Grazed Basal Cover 2010	% Difference 2010
Domesticated	10.55	11.20	6.16	23.60	123.70
Cool Season	1.20	3.55	195.83	1.25	4.17
Warm Season	0.05	0.40	700.00	0.65	1200.00
Sedges	2.85	1.90	-33.33	1.75	-38.60
Native Grass	4.10	5.85	42.68	3.65	-10.98
Total Grass	14.65	17.05	16.38	27.25	86.01

Table 14. Forb density (#/0.10 m^2) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	2006 Exclosure	2006 Not Grazed	2007 Not Grazed	2008 Not Grazed	2009 Not Grazed	2010 Not Grazed	2011 Not Grazed
Late Succession	4.64	1.12	0.96	0.56	1.20	1.52	2.72
Mid Succession	0.16	0.08	0.24	0.00	0.12	0.60	0.80
Early Succession	0.64	0.36	0.00	0.00	1.00	0.44	0.04
Woody Species	0.48	0.00	0.04	0.00	0.04	0.20	0.16
Total Live	5.92	1.56	1.24	0.56	2.36	2.76	3.72

Table 15. Percent composition (%) of forb density for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 4	2006 Exclosure	2006 Not Grazed	2007 Not Grazed	2008 Not Grazed	2009 Not Grazed	2010 Not Grazed	2011 Not Grazed
Late Succession	78.38	71.79	77.42	100.00	50.85	55.07	73.12
Mid Succession	2.70	5.13	19.35	0.00	5.08	21.74	21.51
Early Succession	10.81	23.08	0.00	0.00	42.37	15.94	1.08
Woody Species	8.11	0.00	3.23	0.00	1.69	7.25	4.30
Total Live							

Table 16. Rhizosphere weight (kg) per cubic meter of soil at the Schnell Recreation Area, 2006-2011.

Pasture NR 4		May	Jul	Oct	Mean
2006	kg/m^3	52.23	74.41	66.09	64.24
2007	kg/m^3	55.20	93.19	85.06	77.82
2008	kg/m^3	69.35	70.62	72.05	70.67
2009	kg/m^3	82.54	83.22	-	82.88
2010	kg/m^3	87.74	96.54	76.27	86.85
2011	kg/m^3	123.07	131.65	136.94	130.56

Table 17. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) at the Schnell Recreation Area, 2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Pasture NR 4	lbs/ac Exclosure	mg/kg Exclosure	lbs/ac Not Grazed	mg/kg Not Grazed	% Difference
Mineral Nitrogen	83.68	25.64	79.04	24.22	-5.54
Nitrate	10.66	3.27	10.33	3.17	-3.10
Ammonium	73.02	22.37	68.71	21.05	-5.90

Table 18. Mean annual rhizosphere weights (kg/m^3) for the control pasture and the three grazed pastures during six years of twice-over rotation management, 2006-2011.

	Grazed NR 1	Grazed NR 2	Grazed NR 3	Control NR 4
2006	91.79ax	74.77ax	54.14ay	64.24axy
2007	93.04ax	91.41ax	71.67abx	77.82abx
2008	129.06abx	116.15bx	94.88bcy	70.67az
2009	138.19bx	142.45bcx	113.05bcx	82.88by
2010	205.65bcx	160.35cdx	139.94cdx	86.85by
2011	221.01cx	207.67dx	167.05dy	130.56cz

Means in the same column and followed by the same letter (a, b, c, d) are not significantly different (P<0.05).

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

Grazed Pasture NR 3

The mixed grass prairie study area in grazed pasture NR 3 was a degraded silty ecological site dominated by smooth bromegrass and Kentucky bluegrass. This site was selected to represent the extreme challenge for grazing defoliation management to convert back to a mixed grass prairie ecosystem. At the start of the study (May 2006), the aboveground vegetation biomass consisted of 68.0% standing dead and litter and 32.0% live herbage. The live herbage biomass was 93.9% domesticated grasses (51.4% smooth bromegrass and 42.5% Kentucky bluegrass), 4.3% native grasses (2.2% upland sedges, 1.8% cool season grasses, and 0.3% warm season grasses), and 1.8% forbs (tables 19 and 20).

The domesticated grass herbage biomass decreased during 2006 to 2010 and increased greatly during 2011 (tables 19, 20, and 21). From a high pregrazing biomass of 1529.96 lbs/ac in 2006, the weight of the domesticated grasses was 52.7% lower at 723.31 lbs/ac after 3 years of grazing, was 19.0% lower at 1238.61 lbs/ac after 5 years, and was 43.3% greater at 2191.98 lbs/ac after 6 years of twice-over rotation grazing (tables 19 and 21). The domesticated grass basal cover increased during 2006 to 2010, then decreased in 2011 (tables 22, 23, and 24). The dominant domesticated grasses were smooth bromegrass and Kentucky bluegrass. Both grasses increased, however, the increase of Kentucky bluegrass was greater. From a pregrazing basal cover of 5.75% in 2006, the basal cover of the domesticated grasses was 118.3% greater at 12.55% after 3 years of grazing, was 276.5% greater at 21.65% after 5 years, and was 176.5% greater at 15.90% after 6 years of twice-over rotation grazing (tables 22 and 24).

The composition of native cool season grasses in the plant community was low (tables 19, 20, and 21). The native cool season grass herbage biomass increased slightly during 2006 to 2008, then decreased slightly during 2009 and 2010, and increased during 2011 (tables 19 and 21). From a pregrazing biomass of 29.97 lbs/ac in 2006, the weight of the cool season grasses was 75.9% greater at 52.71 lbs/ac after 3 years of grazing, was 14.3% lower at 25.69 lbs/ac after 5 years, and was 59.9% greater at 47.91 lbs/ac after 6 years of twice-over rotation grazing (tables 19 and 21). The native cool season grass basal cover decreased slightly during 2006 to 2008, then decreased to zero during 2009 to 2011 (tables 22, 23, and 24). The cool season grasses present were western wheatgrass, needle and thread, and prairie Junegrass. From a high pregrazing basal cover of 0.30% in 2006, the basal cover of the cool season grasses was 33.3% lower at 0.20% after 3 years of grazing and was 100.0% lower after 5 and 6 years of twice-over rotation grazing (tables 22 and 24).

The composition of native warm season grass herbage biomass in the plant community was low throughout the study changing little during 2006 to 2008, then increasing during 2009 to 2011 (tables 19, 20, and 21). From a low pregrazing biomass of 5.00 lbs/ac in 2006, the weight of the warm season grasses was 2.2% lower at 4.89 lbs/ac after 3 years of grazing, increased 25.17 lbs/ac (503.4%) to 30.17 lbs/ac after 5 years, and increased 32.21 lbs/ac (644.2%) to 37.21 lbs/ac after 6 years of twice-over rotation grazing (tables 19 and 21). The native warm season grass basal cover was low and changed little during 2006 to 2008, then decreased to zero during 2009 to 2011 (tables 22, 23, and 24). The warm season grasses present were blue grama and prairie sandreed. From a low pregrazing basal cover of 0.05% in 2006, the basal cover of the warm season grasses did not change at 0.05% after 3 years of grazing and was 100.0% lower after 5 and 6 years of twice-over rotation grazing (tables 22 and 24).

The native upland sedge herbage biomass increased during 2006 to 2009, then decreased during 2010 and 2011 (tables 19, 20, and 21). From a pregrazing biomass of 34.97 lbs/ac in 2006, the weight of the upland sedges increased 35.06 lbs/ac (100.3%) to 70.03 lbs/ac after 3 years of grazing and increased 24.57 lbs/ac (70.3%) to 59.54 lbs/ac after 5 years of twice-over rotation grazing (tables 19 and 21). The upland sedge basal cover decreased during 2006 to 2008, increased during 2009 and 2010, then decreased in 2011 (tables 22, 23, and 24). The upland sedges present were threadleaf sedge and sun sedge. From a pregrazing basal cover of 2.30% in 2006, the basal cover of the upland sedges was 69.6% lower at 0.70% after 3 years of grazing and was 37.0% lower at 1.45% after 5 years of twice-over rotation grazing (tables 22 and 24).

The total native grass herbage biomass increased during 2006 to 2009, then decreased during 2010, and increased during 2011 (tables 19, 20, and 21). From a low pregrazing biomass of 69.94 lbs/ac in 2006, the weight of the native grasses was 82.5% greater at 127.63 lbs/ac after 3 years of grazing, was 65.0% greater at 115.40 lbs/ac after 5 years, and was 92.8% greater at 134.87 lbs/ac after 6 years of twice-over rotation grazing (tables 19 and 21). The herbage weight biomass and basal cover data were collected at different but adjacent areas.

The basal cover of cool season and warm season grasses decreased to zero from 2009 to 2011 on the nondestructive sample site that had tall dense domesticated grasses. The herbage biomass of cool season and warm season grasses continued to be collected on the destructive sample site that had slightly less tall and less dense domesticated grasses which permitted some sunlight to reach the small native grass plants.

The species composition of the forbs was dynamic and remained low throughout the study. The forb herbage biomass increased slightly during 2006 to 2009, then decreased slightly in 2010, and increased greatly in 2011 (tables 19, 20, and 21). From a pregrazing biomass of 29.97 lbs/ac in 2006, the weight of the forbs was 10.2% lower at 26.91 lbs/ac after 3 years of grazing, was 97.3% greater at 59.13 lbs/ac after 5 years, and was 302.1% greater at 120.50 lbs/ac after 6 years of twice-over rotation grazing (tables 19 and 21). The forb density increased slightly during 2006 to 2008, decreased in 2009 and 2010, then increased in 2011 (tables 25 and 26). From a pregrazing density of 1.12 forbs/0.10 m^2 in 2006, the density of the forbs was 121.4% greater at 2.48 forbs/0.10 m^2 after 3 years of grazing, was 53.6% greater at 1.72 forbs/0.10 m^2 after 5 years, and was 242.9% greater at 3.84 forbs/0.10 m^2 after 6 years of twice-over rotation grazing (table 25).

Standing dead biomass was 1361.55 lbs/ac in 2006 at the start of the study, decreased 85.1% to 202.36 lbs/ac in 2009 during 4 years of grazing, and increased to 256.28 lbs/ac in 2011 at 18.8% of the starting biomass (table 19). Litter biomass was 2105.15 lbs/ac in 2006 at the start of the study, decreased 62.3% to 794.03 lbs/ac in 2010 during 5 years of grazing, and increased to 1093.64 lbs/ac in 2011 at 52.0% of the starting biomass (table 19). The litter layer was thick during each year and was less than 1000 lbs/ac only during one growing season, 2010. The mean annual litter biomass was 1675.31 lbs/ac and composed 42.9% of the mean annual total biomass. Total dead biomass was 3466.67 lbs/ac in 2006 at the start of the study, decreased 67.0% to 1144.00 lbs/ac in 2010 during 5 years of grazing, and increased to 1349.93 lbs/ac in 2011 at 38.9% of the starting biomass (table 19). The mean annual total dead biomass was 2318.32 lbs/ac and composed 59.4% of the mean annual total live and dead biomass.

After 6 grazing seasons managed with the twice-over rotation system on pasture three, the aboveground vegetation biomass consisted of 35.6% standing dead and litter and 64.4% live herbage. The live herbage was 89.6% domesticated grasses (62.0% Kentucky bluegrass and 27.6% smooth bromegrass), 5.5% native grasses (2.0% upland sedges, 2.0% cool season grasses, and 1.5% warm season grasses), and 4.9% forbs (table 20).

The vegetation on grazed pasture NR 3 changed during the 6 years of twice-over rotation grazing management. Domesticated grass herbage biomass increased 43.3% and basal cover increased 176.5%. Native grass herbage biomass increased 92.8% and basal cover decreased 66.0%. Forb herbage biomass increased 302.1% and forb density increased 242.9%. Total live herbage biomass increased 50.2% and basal cover increased 101.2%. Standing dead herbage biomass decreased 81.2% and litter biomass decreased 48.1%.

The rhizosphere weight (table 27) did not change during the first two years, and then increased each year from the second grazing season to the sixth grazing season at a mean rate of 23.8 kg/m^3 per year, during which the growing season precipitation was slightly less than 90% of the long-term mean. During the sixth grazing season, the mean rhizosphere weight was 167.05 kg/m^3, which is (41.1%) a low moderate quantity. Mean rhizosphere weights 406.44 kg/m^3 have been recorded on silty ecological sites managed long-term with a twice-over rotation grazing strategy.

The total available soil mineral nitrogen of nitrate and ammonium was 52.05 lbs/ac on the exclosure and 59.85 lbs/ac on the grazed area, with a increase of 15.0% on the grazed area (table 28). The quantity of mineral nitrogen was greater on the grazed area then on the ungrazed exclosure. The quantities of mineral nitrogen were not significantly different on the exclosure and the grazed area. The quantity of nitrate was 6.00 lbs/ac on the exclosure and 7.33 lbs/ac on the grazed area, with an increase of 22.2% on the grazed area. The quantity of ammonium was 46.05 lbs/ac on the exclosure and was 52.52 lbs/ac on the grazed area, with an increase of 14.1% on the grazed area (table 28). The exclosure had lower nitrate and lower ammonium and the grazed area had greater nitrate and greater ammonium. The amount of nitrate was slightly reduced on both the exclosure and grazed area. The reduced quantities of nitrate appear to be related to the reduced quantities of easily decomposed labile roots of smooth bromegrass. The grazed area had greater ammonium. Both the exclosure and grazed area had low native grass basal cover. The greater quantities of ammonium appear to be related to the increased quantities of Kentucky bluegrass roots and greater rhizosphere biomass.

Degradation of the mixed grass prairie communities on the grazed pasture NR 3 resulted in a severe reduction of native grasses, an excessive increase of standing dead and litter, and an extreme increase of domesticated grasses. The untilled silty ecological site was located near a tilled and seeded hayland consisting mostly of smooth bromegrass. The smooth bromegrass had invaded the untilled portions and shaded out nearly all of the native grasses. Kentucky bluegrass was coexisting as an understory member. The deterioration of the native prairie communities was a direct result of withholding grazing by large herbivores for thirteen years between 1993 and 2005. The twice-over rotation grazing management strategy was implemented in 2006 and operated for six years through 2011 with the intended purpose of stimulating the defoliation resistance mechanisms including activation of the compensatory internal physiological processes, activation of the internal vegetative reproduction of secondary tillers from axillary buds, and stimulation of the external symbiotic rhizosphere organism activity.

Native grass herbage biomass changed little and native grass basal cover decreased during the six years of grazing (tables 19 and 22). This indicates that the compensatory internal physiological growth processes and the internal vegetative reproductive processes were not activated by the grazing strategy on pasture NR 3. Activation of the defoliation resistance mechanisms was not accomplished because the understory native grass plants had insufficient quantities of fixed carbon and mineral nitrogen available and had low quantities of sunlight reaching the understory leaves. Native grasses on grazed pasture NR 3 were inhibited by a severe deficiency of sunlight caused by shading from accumulated domesticated grass and standing dead leaves. The low sunlight intensity caused reduced photosynthetic rates that resulted in a deficiency of available fixed carbon. A deficiency of available soil mineral nitrogen was caused by low rhizosphere biomass.

Native grass plants need the essential major elements carbon, hydrogen, and nitrogen in the presence of sunlight for physiological growth processes to produce leaves, stems, roots, and secondary tillers (Manske 2011). The carbon does not come from stored material in the roots (Richards and Caldwell 1985, Coyne et al.1985, Briske and Richards 1995). The carbon allocated for growth comes from atmospheric carbon dioxide which composes about 0.03% of the gasses in the atmosphere and exists at concentrations of around 370 to 385 mg/kg. The carbon dioxide is fixed with hydrogen from soil water during the process of photosynthesis which converts energy from sunlight into chemical energy and assimilates carbohydrates. Atmospheric carbon dioxide is not limiting on rangelands.

The hydrogen comes from soil water absorbed through the roots. Soil water is infiltrated precipitation. Regional long-term mean growing season precipitation was 14.79 inches (375.67 mm). Growing season precipitation averaged 73.1% of the long-term mean during 2006 to 2009, and averaged 103.4% of the long-term mean during 2010 to 2011 (table 2). During the growing seasons of 2006 to 2011, months with water deficiency conditions occurred at a periodicity rate of 34.7%, or 2.1 water deficient months per growing season. In western North Dakota, the long-term period of 118 years, 1892 to 2009, had a periodicity rate of growing season months with water deficiency conditions at 32.7%, for a mean of 2.0 months with water deficiency per growing season (Manske et al. 2010). The growing season precipitation and percent water deficiency conditions during the six years of grazing were near the long-term mean. The quantity of soil water would not have been equal to the quantity of precipitation on the Schnell Recreation Area during 2006 to 2011 because of the build up of the thick mulch layer. Thick mulch intercepts a portion of the precipitation inhibiting infiltration. The thicker the mulch, the greater the quantity of the precipitation absorbed. Native grasses on grazed pasture NR 3 were inhibited by a deficiency of soil water caused by absorption of a high proportion of the precipitation by the thick mulch.

The nitrogen for plant growth comes from the mineral nitrogen converted from soil organic nitrogen by rhizosphere organisms. Low quantities of available soil mineral nitrogen below 100 lbs/ac is the major limiting factor of herbage growth on rangelands (Wight and Black 1979). Mixed grass prairie soils are not deficient of nitrogen. Most of the nitrogen is immobilized in the soil as organic nitrogen. Untilled soils contain about 3 to 8 tons of organic nitrogen per acre. Soil organic nitrogen must be mineralized by rhizosphere organisms to become mineral nitrogen. The quantity of rhizosphere organisms is the limiting factor. Biomass and activity of organisms in the rhizosphere are limited by access to energy from simple carbohydrates which can be exudated from grass plants with partial defoliation by grazing graminivores when the grass lead tillers are at vegetative growth stages between the 3.5 new leaf stage and the flower stage. Nondefoliation management nearly stops exudation of carbohydrates to minuscule leakage causing extreme reductions in rhizosphere biomass resulting in quantities of soil mineral nitrogen well below 100 lbs/ac. Native grasses on grazed pasture NR 3 were inhibited by a deficiency of available soil mineral nitrogen caused by greatly decreased rhizosphere biomass.

Light is radiant energy from the sun and is necessary for photosynthesis. Light varies in duration (length of day) and intensity. Humidity and cloud cover can change light intensity by absorbing and scattering light rays. Intensity of light can also be greatly reduced by shading from other plants. Nondefoliated live and standing dead leaves of grasses reduce light penetration to a similar degree as shrubs, even though shrub leaves are flat and wide and grass leaves are erect and linear (Kochy 1999). The light levels penetrating the leaf canopy can be about 20% of the light levels above the canopy (Peltzer and Kochy 2001).

The severely degraded mixed grass prairie site on pasture NR 3 was dominated by smooth bromegrass and Kentucky bluegrass at a 93.9% composition. During the first three years, 2006 to 2008, cow-calf pairs grazed at 72.3%, 82.6%, and 107.5% of the 2011 assessed stocking rate, respectively. Utilization of the domesticated grass herbage by the cows was around 36.4%. Domesticated grass herbage biomass decreased 52.7% to 723.31 lbs/ac, standing dead biomass decreased 74.2% to 351.40 lbs/ac, litter biomass decreased 10.5% to 1883.70 lbs/ac, and native grass herbage biomass increased 82.5% to 127.63 lbs/ac in three years.

The near full stocking rates of the cow-calf pairs removed enough domesticated grass and standing dead herbage biomass to reduce some of the shading problems and reduced a small amount of the thick mulch problems. Partial defoliation by grazing during vegetative phenological stages stimulated the defoliation resistance mechanisms at some level in the native grasses and activated the rhizosphere organisms and the ecosystem biogeochemical processes as substantiated by the greater rhizosphere biomass and greater available soil mineral nitrogen on the grazed area.

The stocking rate at greater than 100% of assessed value caused more beneficial effects than negative effects. The stocking rate of grazing cow-calf pairs was increased 30.2% from 2007 to 2008 which was 107.5% of the 2011 assessed stocking rate. The growing season of 2008 was the only time that grazing livestock were at sufficient quantities to remove 998.99 lbs/ac of domesticated grass and standing dead biomass. On grazed pasture NR 3, because of the greater than 100% stocking rate, the herbage biomass of domesticated grass decreased 44.3% to 723.31 lbs/ac, standing dead biomass decreased 54.7% to 351.40 lbs/ac, and litter biomass decreased 11.1% to 1883.70 lbs/ac in 2008. Removal of this much herbage biomass opened the grass canopy, reduced the shading effect, and permitted sunlight to reach the understory plants. Native grass herbage biomass increased 64.4% to 127.63 lbs/ac. The beneficial effects of an open canopy carried over into the next growing season. Herbage biomass of native grass increased an additional 34.6% to 171.81 lbs/ac. As a result of the high reduction of domesticated grass herbage biomass in 2008, the biomass of standing dead decreased 42.4% to 202.36 lbs/ac and the biomass of litter decreased 34.0% to 1244.11 lbs/ac in 2009. However, domesticated grass herbage biomass increased 89.0% to 1366.85 lbs/ac; the high stocking rate was not detrimental to smooth bromegrass. Herbage biomass of forbs increased 144.0% to 65.65 lbs/ac in 2009 and weedy forb density increased 200.0% as a result of opening the grass canopy a little and exposing sunlight on small areas of soil causing some weeds to germinate.

During the next two years, 2009 to 2010, heifers grazed at 79.8% and 87.4% of the 2011 assessed stocking rate, respectively. Utilization of the domesticated grass herbage by the heifers was around 19.4%. Standing dead biomass decreased 0.4% to 349.97 lbs/ac, litter biomass decreased 57.8% to 794.03 lbs/ac. However, domesticated grass herbage biomass increased 71.2% to 1238.61 lbs/ac and native grass herbage biomass decreased 9.6% to 115.40 lbs/ac in two years. At stocking rates of 80% and 87% of assessed values, ecosystem restoration of plant communities invaded by smooth bromegrass was reversed with more negative effects than beneficial effects because of the continued shading problem.

During the sixth year, 2011, steers grazed at 37.8% of the assessed stocking rate. Utilization of the domesticated grass herbage by the steers was around 6.1%. Domesticated grass herbage biomass increased 77.0% to 2191.98 lbs/ac, standing dead biomass decreased 26.8% to 256.28 lbs/ac, litter biomass increased 37.7% to 1093.64 lbs/ac, and native grass herbage biomass increased 16.9% to 134.87 lbs/ac in one year. At low stocking rates, ecosystem restoration stopped and degradation advanced with large increases in domesticated grass biomass and litter biomass. Native grass herbage biomass continued to increase as a result of previous beneficial effects from grazing at heavier than 100% stocking rates.

The quantity of aboveground vegetation biomass that included the domesticated grass herbage biomass and standing dead biomass was great throughout each growing season of the six study years on both the ungrazed control pasture NR 4 and the grazed pasture NR 3. The annual mean aboveground vegetation biomass was 1907.85 lbs/ac on pasture NR 3, which was slightly less than but not different from the annual mean aboveground vegetation biomass of 2617.80 lbs/ac on the ungrazed control pasture NR 4 (table 29). These great quantities of aboveground vegetation biomass would prevent most of the sunlight from reaching the smaller native grass plants growing in the understory. Photosynthetic rates in native grass leaves under low sunlight conditions would be extremely low and the quantities of fixed carbon available to native grasses would be far less than that required for normal growth. The native grass herbage biomass on pasture NR 3 was only 138.15 lbs/ac, which was slightly less than but not different from the small amount of 245.28 lbs/ac of native grass herbage biomass on the control pasture NR 4 (table 29).

The lighter stocking rates used during the latter three years, 2009 to 2011, resulted in greater annual mean biomass of domesticated grass and standing dead at 1868.68 lbs/ac, which were sufficient to close the canopy and shade the understory plants. The reduction of sunlight inhibited production of native grass herbage biomass to an annual mean of 140.69 lbs/ac. The relatively light stocking rates used on pasture NR 3 during five of the six years prevented the usual benefits from the twice-over rotation grazing strategy from increasing the native grass herbage biomass and basal cover. The great inhibitory effects from low sunlight intensity caused by shading prevented activation of the beneficial defoliation resistance mechanisms.

The twice-over rotation grazing strategy did, however, increase the rhizosphere weight on pasture NR 3. The rhizosphere weight increase was associated with the increase in Kentucky bluegrass basal cover, not with native grasses or smooth bromegrass.

Smooth bromegrass is considered to be nonmycorrhizal and does not readily develop symbiotic relationships with rhizosphere organisms. During another study, Manske (2007) recorded 32.3% of the root segments of smooth bromegrass from the control (no defoliation) treatment to be infected with endomycorrhizal fungi assessed by a present or absent grid-intersect method. However, nearly all of the fungal infections observed in the biologically active root segment samples were restricted to the root hairs. Almost none of the root segment samples had fungal colonization within the root tissue.

During six years of twice-over rotation grazing, basal cover of native grasses changed little, basal cover of smooth bromegrass increased 63.3%, and basal cover of Kentucky bluegrass increased 511.1% on pasture NR 3. The relative composition in 2006 was 52.2% smooth bromegrass and 31.3% Kentucky bluegrass and the relative composition in 2011 changed to 64.7% Kentucky bluegrass and 28.8% smooth bromegrass (table 30).

Associated with the 106.7% increase in relative composition of Kentucky bluegrass was a 226.0% increase in rhizosphere weight on pasture NR 3 in six years from 2006 to 2011 (table 30). The rhizosphere weight on pasture NR 3 was slightly less than but not significantly different from the rhizosphere weight on control pasture NR 4 during the first two years, 2006 and 2007. The rhizosphere weight on the ungrazed control pasture increased at a mean rate of 13.2 kg/m^3 per year from the second year to the sixth year, during which the growing season precipitation was slightly less than 90% of the long-term mean. The rhizosphere weights increased on the grazed pasture NR 3 from the second year to the sixth year, 2007 to 2011, at a mean rate of 23.8 kg/m^3 per year which was 80.8% greater than the rate of increase on the ungrazed control pasture. The rhizosphere weight on pasture NR 3 increased each year from the second year to the sixth year and was significantly greater than the rhizosphere weight on the ungrazed control pasture NR 4 during each respective year from 2008 to 2011 (table 30).

The mixed grass prairie communities on pasture NR 3 were severely degraded and dominated by smooth bromegrass and Kentucky bluegrass. This site represented the extreme challenge for restoration back to native grass dominated communities. After 6 grazing seasons managed with the twice-over rotation system, the pasture NR 3 site was still dominated by Kentucky bluegrass and smooth bromegrass.

Native grasses annually require partial defoliation by grazing that removes 25% to 33% of the aboveground leaf biomass while the lead tillers are between the 3.5 new leaf stage and the flower stage. This defoliation by grazing is the trigger that stimulates the external rhizosphere organism biomass and activity and that activates the compensatory internal physiological processes and the internal vegetative reproductive processes of the defoliation resistance mechanisms in grass plants.

The external symbiotic rhizosphere organism biomass and activity were stimulated and increased from the second year to the sixth year on pasture NR 3 as a result of the defoliation by grazing managed by the twice-over rotation strategy. However, the native grass herbage biomass and basal cover did not increase as expected because the compensatory internal physiological processes and the internal vegetative reproductive processes failed to activate. The most plausible explanation for nonactivation of the defoliation resistance mechanisms would be a deficiency in the quantity of fixed carbon within the native grasses. A deficiency of sunlight caused by shading would prevent the required rates of photosynthesis from occurring, even though available atmospheric carbon dioxide would not have been deficient. Shaded native grasses do not increase in herbage biomass and basal cover as a result of insufficient activation of the defoliation resistance mechanisms even after the proper defoliation by grazing method triggers the processes.

The deficiency of sunlight attenuated by native grass leaves caused by shading must be corrected through grazing defoliation with relatively high stocking rates managed by the twice-over rotation strategy before degraded mixed grass prairie communities that were subsequently invaded by domesticated grasses can be restored back to native grass communities.

Table 19. Mean herbage biomass (lbs/ac) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	Pregrazin g 2006	2006	2007	2008	2009	2010	2011
Domesticated	1529.96	1488.16	1298.70	723.31	1366.85	1238.61	2191.98
Cool Season	29.97	74.42	36.62	52.71	44.49	25.69	47.91
Warm Season	5.00	47.40	6.93	4.89	29.56	30.17	37.21
Sedges	34.97	79.72	34.10	70.03	97.76	59.54	49.75
Native Grass	69.94	201.54	77.65	127.63	171.81	115.40	134.87
Total Grass	1599.89	1689.70	1376.35	850.94	1538.66	1354.01	2326.85
Forbs	29.97	35.07	40.09	26.91	65.65	59.13	120.50
Total Live	1629.86	1724.77	1416.44	877.85	1604.31	1413.14	2447.34
Standing Dead	1361.55	1204.45	775.00	351.40	202.36	349.97	256.28
Litter	2105.12	2488.83	2117.76	1883.70	1244.11	794.03	1093.64
Total Dead	3466.67	3693.28	2892.76	2235.10	1446.47	1144.00	1349.93
Total Biomass	5096.53	5418.05	4309.20	3112.95	3050.78	2557.14	3797.27

Table 20. Percent composition of herbage biomass for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Domesticated	93.87	86.28	91.69	82.40	85.20	87.65	89.57
Cool Season	1.84	4.31	2.59	6.00	2.77	1.82	1.96
Warm Season	0.31	2.75	0.49	0.55	1.84	2.13	1.52
Sedges	2.15	4.62	2.41	7.98	6.09	4.21	2.03
Native Grass	4.29	11.69	5.48	14.54	10.70	8.17	5.51
Total Grass	98.16	97.97	97.17	96.93	95.91	95.82	95.08
Forbs	1.84	2.03	2.83	3.07	4.09	4.18	4.92
Total Live	31.98	31.83	32.87	28.20	52.59	55.26	64.45
Standing Dead	26.72	22.23	17.98	11.29	6.63	13.69	6.75
Litter	41.30	45.94	49.15	60.51	40.78	31.05	28.80
Total Dead	68.02	68.17	67.13	71.80	47.41	44.74	35.55
Total Biomass	5096.53	5418.05	4309.20	3112.95	3050.78	2557.14	3797.27

Table 21. Change in herbage biomass (lbs/ac) of grass categories between pregrazing 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	Pregrazing Herbage Biomass 2006	Mean Grazed Herbage Biomass 2008	% Difference 2008	Mean Grazed Herbage Biomass 2010	% Difference 2010
Domesticated	1529.96	723.31	-52.72	1238.61	-19.04
Cool Season	29.97	52.71	75.88	25.69	-14.28
Warm Season	5.00	4.89	-2.20	30.17	503.40
Sedges	34.97	70.03	100.26	59.54	70.26
Native Grass	69.94	127.63	82.48	115.40	65.00
Total Grass	1599.89	850.94	-46.81	1354.01	-15.37

Table 22. Basal cover (%) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	5.75	4.80	10.75	12.55	17.30	21.65	15.90
Cool Season	0.30	0.05	0.10	0.20	0.00	0.00	0.00
Warm Season	0.05	0.05	0.60	0.05	0.00	0.00	0.00
Sedges	2.30	0.80	0.70	0.70	1.05	1.45	0.90
Native Grass	2.65	0.90	1.40	0.95	1.05	1.45	0.90
Total Grass	8.40	5.70	12.15	13.50	18.35	23.10	16.80
Forbs	0.05	0.05	0.10	0.40	0.10	0.35	0.20
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	8.45	5.75	12.25	13.90	18.45	23.45	17.00
Litter	91.55	94.20	87.70	86.10	81.55	76.55	83.00
Total	100.00	99.95	99.95	100.00	100.00	100.00	100.00

Table 23. Percentage composition (%) of basal cover for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	68.05	83.48	87.76	90.29	93.77	92.32	93.53
Cool Season	3.55	0.87	0.82	1.44	0.00	0.00	0.00
Warm Season	0.59	0.87	4.90	0.36	0.00	0.00	0.00
Sedges	27.22	13.91	5.71	5.04	5.69	6.18	5.29
Native Grass	31.36	15.65	11.43	6.83	5.69	6.18	5.29
Total Grass	99.41	99.13	99.18	97.13	99.46	98.51	98.82
Forbs	0.59	0.87	0.82	2.88	0.54	1.49	1.18
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	8.45	5.75	12.26	13.90	18.45	23.45	17.00
Litter	91.55	94.25	87.74	86.10	81.55	76.55	83.00
Total							

Table 24. Change in basal cover (%) of grass categories between ungrazed 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	Ungrazed Basal Cover 2006	Grazed Basal Cover 2008	% Difference 2008	Grazed Basal Cover 2010	% Difference 2010
Domesticated	5.75	12.55	118.26	21.65	1590.00
Cool Season	0.30	0.20	-33.33	0.00	-100.00
Warm Season	0.05	0.05	0.00	0.00	-100.00
Sedges	2.30	0.70	-69.57	1.45	-36.96
Native Grass	2.65	0.95	-64.15	1.45	-45.28
Total Grass	8.40	13.50	60.71	23.10	175.00

Table 25. Forb density (#/0.10 m^2) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	0.76	0.56	1.32	2.24	1.40	1.64	2.96
Mid Succession	0.36	0.08	0.00	0.12	0.60	0.04	0.84
Early Succession	0.00	0.04	0.12	0.12	0.36	0.04	0.04
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	1.12	0.68	1.44	2.48	2.36	1.72	3.84

Table 26. Percent composition (%) of forb density for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 3	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	67.86	82.35	91.67	90.32	59.32	95.35	77.08
Mid Succession	32.14	11.76	0.00	4.84	25.42	2.33	21.88
Early Succession	0.00	5.88	8.33	4.84	15.25	2.33	1.04
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live							

Table 27. Rhizosphere weight (kg) per cubic meter of soil at the Schnell Recreation Area, 2006-2011.

Pasture NR 3		May	Jul	Oct	Mean
2006	kg/m^3	51.25	58.51	52.65	54.14
2007	kg/m^3	37.53	84.52	92.96	71.67
2008	kg/m^3	92.89	105.98	85.78	94.88
2009	kg/m^3	128.35	97.74	-	113.05
2010	kg/m^3	107.17	177.92	134.72	139.94
2011	kg/m^3	164.54	167.55	169.06	167.05

Table 28. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) at the Schnell Recreation Area, 2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Pasture NR 3	lbs/ac Exclosure	mg/kg Exclosure	lbs/ac Grazed	mg/kg Grazed	% Difference
Mineral Nitrogen	52.05	15.95	59.85	18.34	14.99
Nitrate	6.00	1.84	7.33	2.25	22.17
Ammonium	46.05	14.11	52.52	16.09	14.05

Table 29. Mean herbage biomass (lbs/ac) and relative composition (%) for the control pasture and grazed pasture NR 3 at the Schnell Recreation Area, 2006-2011.

	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Control Pasture NR 4							
Native Grass	43.53	158.23	259.08	162.75	354.35	314.19	223.05
% Composition	1.21	4.52	9.14	6.67	12.88	12.80	5.62
Domesticated + Standing Dead	3509.49	3214.97	2499.79	2248.86	2278.94	1901.23	3563.00
% Composition	97.62	91.81	88.18	92.22	82.87	77.47	89.71
Grazed Pasture NR 3							
Native Grass	69.94	201.54	77.65	127.63	171.81	115.40	134.87
% Composition	2.34	6.88	3.54	10.38	9.51	6.55	4.99
Domesticated + Standing Dead	2891.51	2692.61	2073.70	1074.71	1569.21	1588.58	2448.26
% Composition	96.66	91.92	94.63	87.43	86.86	90.10	90.55

Table 30. Grass relative composition (%) and rhizosphere weight (kg/m^3) for the control pasture and grazed pasture NR 3 at the Schnell Recreation Area, 2006-2011.

	Grass Basal Cover Relative Composition (%)					
	Control Pasture NR 4			Grazed Pasture NR 3		
	Smooth Bromegrass	Kentucky Bluegrass	% Difference	Smooth Bromegrass	Kentucky Bluegrass	% Difference
2006	0.0	76.95	100.00	52.17	31.30	-40.00
2007	0.0	78.08	100.00	46.94	40.82	-13.04
2008	0.0	65.31	100.00	37.77	52.52	39.05
2009	0.0	80.53	100.00	44.44	49.32	10.98
2010	0.0	83.10	100.00	41.79	50.53	20.91
2011	0.28	85.96	100.00	28.82	64.71	124.53

	Rhizosphere Weight (kg/m^3)		
	Control Pasture NR 4	Grazed Pasture NR 3	% Difference
Pregrazing 2006	52.23	51.25	-1.88
2006	64.24x	54.14x	-15.72
2007	77.82x	71.67x	-7.90
2008	70.67y	94.88x	34.26
2009	82.88y	113.05x	36.40
2010	86.85y	139.94x	61.13
2011	130.56y	167.05x	27.95

Means in the same row and followed by the same letter (x, y) are not significantly different (P<0.05).

Grazed Pasture NR 2

The mixed grass prairie study area in grazed pasture NR 2 was a degraded silty ecological site dominated by Kentucky bluegrass and crested wheatgrass. At the start of the study (May 2006), the aboveground vegetation biomass consisted of 63.3% standing dead and litter and 36.7% live herbage. The live herbage biomass was 53.9% domesticated grasses, (50.2% Kentucky bluegrass and 3.7% crested wheatgrass), 35.5% native grasses (35.2% upland sedges, 0.3% warm season grasses, and less than 0.1% cool season grasses), and 10.6% forbs (tables 31 and 32).

The domesticated grass herbage biomass decreased during 2006 to 2009, increased slightly during 2010, and increased greatly in 2011 (tables 31, 32, and 33). From a pregrazing biomass of 884.86 lbs/ac in 2006, the weight of the domesticated grasses was 63.2% lower at 325.60 lbs/ac after 3 years of grazing and was 56.8% lower at 382.59 lbs/ac after 5 years of twice-over rotation grazing (tables 31 and 33). The domesticated grass basal cover decreased during 2006 to 2008, increased during 2009 and 2010, and decreased during 2011 (tables 34, 35, and 36). The domesticated grass was primarily Kentucky bluegrass with small quantities of crested wheatgrass and smooth bromegrass present. From a pregrazing basal cover of 2.20% in 2006, the basal cover of the domesticated grasses was 61.4% lower at 0.85% after 3 years of grazing, was 27.3% greater at 2.80% after 5 years, and was 52.3% lower at 1.05% after 6 years of twice-over rotation grazing (tables 34 and 36).

The native cool season grass herbage biomass increased during 2006 to 2009, then decreased during 2010, and increased greatly in 2011 (tables 31, 32, and 33). From a low pregrazing biomass of less than l lb/ac in 2006, the weight of the cool season grasses was 100.0% greater at 206.23 lbs/ac after 3 years of grazing, was 100.0% greater at 241.30 lbs/ac after 5 years, and was 111.8% greater than the previous year at 511.14 lbs/ac after 6 years of twice-over rotation grazing (tables 31 and 33). The native cool season grass basal cover increased during 2006 to 2010, then decreased during 2011 (tables 34, 35, and 36). The primary cool season grasses were needle and thread, prairie Junegrass, and western wheatgrass. From a low pregrazing basal cover of 1.35% in 2006, the basal cover of the cool season grasses was 296.3% greater at 5.35% after 3 years of grazing and was 414.8% greater at 6.95% after 5 years of twice-over rotation grazing (tables 34 and 36).

The composition of native warm season grasses in the plant community was low. The native warm season grass herbage biomass increased during 2006 to 2009, then decreased during 2010, and increased greatly in 2011 (tables 31, 32, and 33). From a low pregrazing biomass of 5.00 lbs/ac in 2006, the weight of the warm season grasses increased 14.68 lbs/ac (293.6%) to 19.68 lbs/ac after 3 years of grazing, increased 24.05 lbs/ac (481.0%) to 29.05 lbs/ac after 5 years, and increased 76.15 lbs/ac (1523.0%) to 81.15 lbs/ac after 6 years of twice-over rotation grazing (tables 31 and 33). The native warm season grass basal cover increased during 2006 to 2009, decreased in 2010, and then greatly increased in 2011 (tables 34, 35, and 36). The primary warm season grasses were blue grama, plains muhly, and prairie sandreed. From a pregrazing basal cover of 0.75% in 2006, the basal cover of the warm season grasses increased 2.55 percentage points (340.0%) to 3.30% after 3 years of grazing, increased 1.85 percentage points (246.7%) to 2.60% after 5 years, and increased 4.05 percentage points (540.0%) to 4.80% after 6 years of twice-over rotation grazing (tables 34 and 36).

The native upland sedge herbage biomass increased on the grazed areas during 2006 to 2010 and decreased during 2011 (tables 31, 32, and 33). From a high pregrazing biomass of 576.59 lbs/ac in 2006, the weight of the upland sedges was 39.7% lower at 347.73 lbs/ac after 3 years of grazing, was 2.5% lower at 562.01 lbs/ac after 5 years, and was 35.2% lower at 373.62 lbs/ac after 6 years of twice-over rotation grazing (tables 31 and 33). The upland sedge basal cover increased on the grazed areas during 2006 to 2010, then decreased in 2011 (tables 34, 35, and 36). The upland sedge was threadleaf sedge. From a pregrazing basal cover of 10.65% in 2006, the basal cover of the upland sedges was 16.9% greater at 12.45% after 3 years of grazing and was 45.1% greater at 15.45% after 5 years of twice-over rotation grazing (tables 34 and 36).

The total native grass herbage biomass increased during 2006 to 2009, then decreased during 2010, and increased greatly in 2011 (tables 31, 32, and 33). From a pregrazing biomass of 581.59 lbs/ac in 2006, the weight of the native grasses was 1.4% lower at 573.64 lbs/ac after 3 years of grazing, was 43.1% greater at 832.36 lbs/ac after 5 years, and was 66.1% greater at 965.91 lbs/ac after 6 years of twice-over rotation grazing (tables 31 and 33). The total native grass basal cover increased during 2006 to 2010, then decreased slightly during 2011 (tables 34, 35, and 36). From a pregrazing basal cover of 12.75% in 2006, the basal cover of the native grasses was 65.5% greater at 21.10% after 3 years of grazing and was 96.1% greater at 25.00% after 5 years of twice-over rotation grazing (tables 34 and 36).

The species composition of the forbs was dynamic throughout the study, however, the forb herbage weight and density changed little during 2006 to 2008 (tables 31, 32, and 33). Yellow sweetclover greatly increased on the grazed areas of pasture two during 2009 and 2011. From a pregrazing biomass of 174.12 lbs/ac in 2006, the weight of the forbs was 83.2% lower at 29.26 lbs/ac after 3 years of grazing and was 118.3% greater at 380.04 lbs/ac after 5 years of twice-over rotation grazing (tables 31 and 33). From a pregrazing density of 6.20 forbs/0.10 m^2 in 2006, the forb density was 83.9% lower at 1.00 forbs/0.10 m^2 after 3 years of grazing and was 78.7% and 36.1% greater at 11.08 forbs and 8.44 forbs/0.10 m^2 during 2009 and 2011, respectively (tables 37 and 38).

Standing dead biomass was 1157.46 lbs/ac in 2006 at the start of the study, decreased 93.1% to 80.03 lbs/ac in 2009 during 4 years of grazing, and increased to 471.89 lbs/ac in 2011 at 40.8% of the starting biomass (table 31). Litter biomass was 1669.11 lbs/ac in 2006 at the start of the study, decreased 80.2% to 331.01 lbs/ac in 2010 during 5 years of grazing, and increased to 796.58 lbs/ac in 2011 at 47.7% of the starting biomass (table 31). The litter layer was not thick and the litter biomass averaged only 627.95 lbs/ac after the first growing season. Total dead biomass was 2826.57 lbs/ac in 2006 at the start of the study, decreased 80.3% to 557.73 lbs/ac in 2009 during 4 years of grazing, and increased to 1268.47 lbs/ac in 2011 at 44.9% of the starting biomass (table 31). The mean annual total dead biomass was 1359.60 lbs/ac and composed 46.8% of the mean annual total live and dead biomass.

After 6 grazing seasons managed with the twice-over rotation system on pasture two, the aboveground vegetation biomass consisted of 40.9% standing dead and litter and 59.1% live herbage. The live herbage was 43.0% domesticated grasses, 52.7% native grasses (27.9% cool season grasses, 20.4% upland sedges, and 4.4% warm season grasses), and 4.3% forbs (table 32). The changes in the mixed grass prairie vegetation on pasture two were similar to the changes on pasture one.

The vegetation on grazed pasture NR 2 changed during the 6 years of twice-over rotation grazing management. Domesticated grass herbage biomass decreased 11.0% and basal cover decreased 52.3%. Native grass herbage biomass increased 66.1% and basal cover increased 86.3%. Forb herbage biomass decreased 54.5% and forb density increased 36.1%. Total live herbage biomass increased 11.7% and basal cover increased 59.1%. Standing dead herbage biomass decreased 59.2% and litter biomass decreased 52.3%.

The rhizosphere weight (table 39) did not change during the first two years and then increased each year from the second grazing season to the sixth grazing season at a mean rate of 29.1 kg/m^3 per year, during which the growing season precipitation was slightly less than 90% of the long-term mean. During the sixth grazing season, the mean rhizosphere weight was 207.67 kg/m^3, which is (51.1%) a moderate quantity. Mean rhizosphere weights of 406.44 kg/m^3 have been recorded on silty ecological sites managed long-term with a twice-over rotation grazing strategy.

The total available soil mineral nitrogen of nitrate and ammonium was 47.76 lbs/ac on the exclosure and 49.65 lbs/ac on the grazed area, with an increase of 4.0% on the grazed area (table 40). The quantity of mineral nitrogen was greater on the grazed area than on the ungrazed exclosure. The quantities of mineral nitrogen were not significantly different on the exclosure and the grazed area. The quantity of nitrate was 5.67 lbs/ac on the exclosure and 4.33 lbs/ac on the grazed area, with a decrease of 23.6% on the grazed area. The quantity of ammonium was 42.09 lbs/ac on the exclosure and 45.32 lbs/ac on the grazed area, with an increase of 7.7% on the grazed area (table 40). The exclosure had greater nitrate and lower ammonium and the grazed area had lower nitrate and greater ammonium. The amount of nitrate was greatly reduced on both the exclosure and grazed area. Greatly reduced quantities of nitrate appear to be related to greatly reduced quantities of easily decomposed labile roots of domesticated grasses. Both the exclosure and grazed area had low domesticated grass basal cover. The grazed area had greater ammonium. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

The degraded mixed grass prairie site on pasture NR 2 was dominated by Kentucky bluegrass at a 53.9% composition. During the first three years, 2006 to 2008, cow-calf pairs grazed at 72.3%, 82.6%, and 107.5% of the 2011 assessed stocking rate, respectively. Domesticated grass herbage biomass decreased 63.2% to 325.60 lbs/ac, standing dead biomass decreased 69.6% to 351.91 lbs/ac, litter biomass decreased 53.0% to 784.86 lbs/ac, and native grass herbage biomass decreased 1.4% to 573.64 lbs/ac in three years.

The near full stocking rates of the cow-calf pairs removed sufficient quantities of domesticated grass and standing dead herbage biomass to reduce most of the shading problems and reduced the litter biomass sufficiently to reduce the problems caused by thick mulch. Partial defoliation by grazing during vegetative phenological stages stimulated the defoliation resistance mechanisms at some level in the native grasses and activated the rhizosphere organisms and the ecosystem biogeochemical processes.

The stocking rate at greater than 100% of assessed value caused more beneficial effects than negative effects. The growing season of 2008 was the only time that grazing livestock were at sufficient quantities to remove 825.85 lbs/ac of domesticated grass and standing dead biomass. During the following grazing season, domesticated grass herbage biomass decreased 3.9% to 312.76 lbs/ac, standing dead biomass decreased 77.3% to 80.03 lbs/ac, litter biomass decreased 39.1% to 477.70 lbs/ac, and native grass herbage biomass increased 75.6% to 1007.10 lbs/ac as a result of the greater than 100% stocking rate. However, total forb biomass increased 206.6% to 89.71 lbs/ac and weedy forb density increased 2622.2% as a result of opening the grass leaf canopy excessively and exposing sunlight on large areas of soil causing weed seeds to germinate.

During the next two years, 2009 to 2010, heifers grazed at 79.8% and 87.4% of the 2011 assessed stocking rate, respectively. Standing dead biomass decreased 18.6% to 286.36 lbs/ac, litter biomass decreased 57.8% to 331.01 lbs/ac, and native grass herbage biomass increased 45.1% to 832.36 lbs/ac in two years. However, domesticated grass herbage biomass increased 17.5% to 382.59 lbs/ac. At stocking rates of 80% and 87% of assessed values, ecosystem restoration continued with more beneficial effects than negative effects.

During the sixth year, 2011, steers grazed at 37.8% of the assessed stocking rate. Domesticated grass herbage biomass increased 105.9% to 787.82 lbs/ac, standing dead biomass increased 64.8% to 471.89 lbs/ac, litter biomass increased 140.7% to 796.58 lbs/ac, and native grass herbage biomass increased 16.0% to 965.91 lbs/ac in one year. At low stocking rates, ecosystem restoration stopped and degradation advanced with huge increases in domesticated grass biomass, standing dead biomass, and litter biomass. Native grass herbage biomass continued to increase as a result of previous beneficial effects from grazing at heavier stocking rates.

The mixed grass prairie communities on pasture NR 2 were degraded and dominated by Kentucky bluegrass. Kentucky bluegrass can grow thick and tall enough to shade the basal leaves of needle and thread, prairie Junegrass, blue grama, and plains muhly, and the stalk leaves of young western wheatgrass and prairie sandreed. The deficiency of sunlight attenuated by native grass leaves caused by shading was nearly corrected during the second to the fifth growing seasons through grazing defoliation with relatively high stocking rates greater than 80% of assessed levels managed by the twice-over rotation strategy. Stocking rates at greater than 85% of assessed levels would have removed more of the shading problem.

Table 31. Mean herbage biomass (lbs/ac) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Domesticated	884.86	841.64	1128.21	325.60	312.76	382.59	787.82
Cool Season	0.00	148.23	222.87	206.23	401.76	241.30	511.14
Warm Season	5.00	11.62	25.57	19.68	53.11	29.05	81.15
Sedges	576.59	441.72	395.71	347.73	552.23	562.01	373.62
Native Grass	581.59	601.57	644.15	573.64	1007.10	832.36	965.91
Total Grass	1466.45	1443.21	1772.36	899.24	1319.86	1214.95	1753.72
Forbs	174.12	151.18	53.26	29.26	89.71	380.04	79.31
Total Live	1640.57	1594.39	1825.62	928.50	1409.57	1594.99	1833.03
Standing Dead	1157.46	705.65	375.15	351.91	80.03	286.36	471.89
Litter	1669.11	1279.89	749.58	784.86	477.70	331.01	796.58
Total Dead	2826.57	1985.54	1124.73	1136.77	557.73	617.37	1268.47
Total Biomass	4467.14	3579.93	2950.35	2065.27	1967.30	2212.36	3101.51

Table 32. Percent composition of herbage biomass for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	Pregrazin g 2006	2006	2007	2008	2009	2010	2011
Domesticated	53.94	52.79	61.80	35.07	22.19	23.99	42.98
Cool Season	0.00	9.30	12.21	22.21	28.50	15.13	27.88
Warm Season	0.30	0.73	1.40	2.12	3.77	1.82	4.43
Sedges	35.15	27.70	21.68	37.45	39.18	35.24	20.38
Native Grass	35.45	37.73	35.28	61.78	71.45	52.19	52.69
Total Grass	89.39	90.52	97.08	96.85	93.64	76.17	95.67
Forbs	10.61	9.48	2.92	3.15	6.36	23.83	4.33
Total Live	36.73	44.54	61.88	44.96	71.65	72.09	59.10
Standing Dead	25.91	19.71	12.72	17.04	4.07	12.94	15.21
Litter	37.36	35.75	25.41	38.00	24.28	14.96	25.68
Total Dead	63.27	55.46	38.12	55.04	28.35	27.91	40.90
Total Biomass	4467.14	3579.93	2950.35	2065.27	1967.30	2212.36	3101.51

Table 33. Change in herbage biomass (lbs/ac) of grass categories between pregrazing 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	Pregrazing Herbage Biomass 2006	Mean Grazed Herbage Biomass 2008	% Difference 2008	Mean Grazed Herbage Biomass 2010	% Difference 2010
Domesticated	884.86	325.60	-63.20	382.59	-56.76
Cool Season	0.00	206.23	100.00	241.30	100.00
Warm Season	5.00	19.68	293.60	29.05	481.00
Sedges	576.59	347.73	-39.69	562.04	-2.53
Native Grass	581.59	573.64	-1.37	832.36	43.12
Total Grass	1466.45	899.24	-38.68	1214.95	-17.15

Table 34. Basal cover (%) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	2.20	4.35	0.60	0.85	1.35	2.80	1.05
Cool Season	1.35	2.10	8.95	5.35	5.60	6.95	5.35
Warm Season	0.75	0.55	2.20	3.30	3.70	2.60	4.80
Sedges	10.65	7.90	12.85	12.45	13.50	15.45	13.60
Native Grass	12.75	10.55	24.00	21.10	22.80	25.00	23.75
Total Grass	14.95	14.90	24.60	21.95	24.15	27.80	24.80
Forbs	0.80	0.45	0.30	0.00	0.25	2.15	0.25
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	15.75	15.35	24.90	21.95	24.40	29.95	25.05
Litter	83.90	84.60	75.10	78.05	75.60	70.05	74.95
Total	99.65	99.95	100.00	100.00	100.00	100.00	100.00

Table 35. Percentage composition (%) of basal cover for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	13.97	28.34	2.41	3.87	5.53	9.35	4.19
Cool Season	8.57	13.68	35.94	24.37	22.95	23.21	21.36
Warm Season	4.76	3.58	8.84	15.03	15.16	8.68	19.16
Sedges	67.62	51.47	51.61	56.72	55.33	51.59	54.29
Native Grass	80.95	68.73	96.39	96.13	93.44	83.47	94.81
Total Grass	94.92	97.07	98.80	100.00	98.98	92.82	99.00
Forbs	5.08	2.93	1.20	0.00	1.02	7.18	1.00
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	15.81	15.36	24.90	21.95	24.40	29.95	25.05
Litter	84.19	84.64	75.10	78.05	75.60	70.05	74.95
Total							

Table 36. Change in basal cover (%) of grass categories between ungrazed 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	Ungrazed Basal Cover 2006	Grazed Basal Cover 2008	% Difference 2008	Grazed Basal Cover 2010	% Difference 2010
Domesticated	2.20	0.85	-61.36	2.80	27.27
Cool Season	1.35	5.35	296.30	6.95	414.81
Warm Season	0.75	3.30	340.00	2.60	246.67
Sedges	10.65	12.45	16.90	15.45	45.07
Native Grass	12.75	21.10	65.49	25.00	96.08
Total Grass	14.95	21.95	46.82	27.80	85.95

Table 37. Forb density (#/0.10 m^2) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	1.08	0.28	1.04	0.56	0.92	0.68	1.76
Mid Succession	0.08	0.00	3.76	0.08	0.36	0.08	0.24
Early Succession	5.04	2.28	0.44	0.36	9.80	2.24	6.44
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	6.20	2.54	5.24	1.00	11.08	3.00	8.44

Table 38. Percent composition (%) of forb density for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 2	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	17.42	11.02	19.85	56.00	8.30	22.67	20.85
Mid Succession	1.29	0.00	71.76	8.00	3.25	2.67	2.84
Early Succession	81.29	89.76	8.40	36.00	88.45	74.67	76.30
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live							

Table 39. Rhizosphere weight (kg) per cubic meter of soil at the Schnell Recreation Area, 2006-2011.

Pasture NR 2		May	Jul	Oct	Mean
2006	kg/m^3	73.68	78.26	72.38	74.77
2007	kg/m^3	74.26	96.47	103.49	91.41
2008	kg/m^3	111.77	125.36	111.32	116.15
2009	kg/m^3	159.50	125.40	-	142.45
2010	kg/m^3	133.57	190.09	157.40	160.35
2011	kg/m^3	170.12	219.93	232.95	207.67

Table 40. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) at the Schnell Recreation Area, 2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Pasture NR 2	lbs/ac Exclosure	mg/kg Exclosure	lbs/ac Grazed	mg/kg Grazed	% Difference
Mineral Nitrogen	47.76	14.64	49.65	15.22	3.96
Nitrate	5.67	1.74	4.33	1.33	-23.63
Ammonium	42.09	12.90	45.32	13.89	7.67

Grazed Pasture NR 1

The mixed grass prairie study area in grazed pasture NR 1 was a degraded silty ecological site dominated by Kentucky bluegrass. At the start of the study (May 2006), the aboveground vegetation biomass consisted of 63.9% standing dead and litter and 36.1% live herbage. The live herbage biomass was 75.7% domesticated grasses, 17.0% native grasses (10.8% upland sedges, 5.3% cool season grasses, and 1.0% warm season grasses), and 7.4% forbs (tables 41 and 42).

The domesticated grass herbage biomass decreased during 2006 to 2008, then increased during 2009 to 2011 (tables 41, 42, and 43). From a high pregrazing biomass of 1248.09 lbs/ac in 2006, the weight of the domesticated grasses was 76.3% lower at 295.94 lbs/ac after 3 years of grazing, was 20.8% lower at 988.84 lbs/ac after 5 years, and was 39.0% greater at 1734.66 lbs/ac after 6 years of twice-over rotation grazing (tables 41 and 43). The domesticated grass basal cover increased during 2006 to 2011 (tables 44, 45, and 46). The domesticated grass was primarily Kentucky bluegrass with small quantities of crested wheatgrass and smooth bromegrass present. Kentucky bluegrass increased greatly. From a low pregrazing basal cover of 4.70% in 2006, the basal cover of the domesticated grasses was 55.3% greater at 7.30% after 3 years of grazing, was 133.0% greater at 10.95% after 5 years, and was 170.2% greater at 12.70% after 6 years of twice-over rotation grazing (tables 44 and 46).

The native cool season grass herbage biomass increased during 2006 to 2009, then decreased slightly during 2010 and increased in 2011 (tables 41, 42, and 43). From a low pregrazing biomass of 87.06 lbs/ac in 2006, the weight of the cool season grasses was 97.2% greater at 171.67 lbs/ac after 3 years of grazing, was 329.9% greater at 374.23 lbs/ac after 5 years, and was 503.3% greater at 525.21 lbs/ac after 6 years of twice-over rotation grazing (tables 41 and 43). The native cool season grass basal cover increased during 2006 to 2010, then decreased during 2011 (tables 44, 45, and 46). The primary cool season grasses were western wheatgrass, needle and thread, and prairie Junegrass. From a pregrazing basal cover of 2.35% in 2006, the basal cover of the cool season grasses was 19.2% greater at 2.80% after 3 years of grazing and was 121.3% greater at 5.20% after 5 years of twice-over rotation grazing (tables 44 and 46).

The composition of native warm season grasses in the plant community was low and changed little numerically throughout the study (tables 41, 42, and 43). From a low pregrazing biomass of 14.99 lbs/ac in 2006, the weight of the warm season grasses increased 10.90 lbs/ac (72.7%) to 25.89 lbs/ac after 3 years of grazing and increased 33.94 lbs/ac (226.4%) to 48.93 lbs/ac after 5 years of twice-over rotation grazing (tables 41 and 43). The native warm season grass basal cover was low and increased slightly during 2006 to 2008, then decreased slightly during 2009 to 2011 (tables 44, 45, and 46). The primary warm season grasses were blue grama and prairie sandreed. From a low pregrazing basal cover of 0.10% in 2006, the basal cover of the warm season grasses increased 2.05 percentage points (2050.0%) to 2.15% after 3 years of grazing and increased 0.45 percentage points (450.0%) to 0.55% after 5 years of twice-over rotation grazing (tables 44 and 46).

The native upland sedge herbage biomass increased during 2006 to 2009, then decreased during 2010 and increased slightly in 2011 (tables 41, 42, and 43). From a pregrazing biomass of 177.69 lbs/ac in 2006, the weight of the upland sedges was 4.8% greater at 186.25 lbs/ac after 3 years of grazing and was 39.6% lower at 107.35 lbs/ac after 5 years of twice-over rotation grazing (tables 41 and 43). The upland sedge basal cover increased during 2006 to 2010, then decreased in 2011 (tables 44, 45, and 46). The upland sedge was threadleaf sedge. From a low pregrazing basal cover of 4.60% in 2006, the basal cover of the upland sedges was 96.7% greater at 9.05% after 3 years of grazing and was 116.3% greater at 9.95% after 5 years of twice-over rotation grazing (tables 44 and 46).

The total native grass herbage biomass increased during 2006 to 2009, then decreased slightly during 2010, and increased in 2011 (tables 41, 42, and 43). From a low pregrazing biomass of 279.74 lbs/ac in 2006, the weight of the native grasses was 37.2% greater at 383.81 lbs/ac after 3 years of grazing, was 89.6% greater at 530.51 lbs/ac after 5 years, and was 135.4% greater at 658.55 lbs/ac after 6 years of twice-over rotation grazing (tables 41 and 43). The total native grass basal cover increased during 2006 to 2010, then decreased during 2011 (tables 44, 45, and 46). From a low pregrazing basal cover of 7.05% in 2006, the basal cover of the native grasses was 98.6% greater at 14.00% after 3 years of grazing, was 122.7% greater at 15.70% after 5 years, and was 17.0% greater at 8.25% after 6 years of twice-over rotation grazing (tables 44 and 46).

The species composition of the forbs was dynamic throughout the study, however, the forb herbage weight and density changed little during 2006 to 2008 (tables 41, 42, and 43). Blue wild lettuce and yellow sweetclover greatly increased on the grazed areas of pasture one during 2009 and 2011. From a pregrazing biomass of 121.31 lbs/ac in 2006, the weight of the forbs was 66.1% lower at 41.08 lbs/ac after 3 years of grazing, was 176.7% greater at 335.70 lbs/ac after 5 years, and was back to the pregrazing biomass at 120.91 lbs/ac after 6 years of twice-over rotation grazing (tables 41 and 43). The forb density decreased during 2006 to 2008, and increased in 2009 and 2011. From a pregrazing density of 4.84 forbs/0.10 m^2 in 2006, the forb density was 66.7% lower at 1.64 forbs/0.10 m^2 after 3 years of grazing, and was 157.0% and 190.9% greater at 12.44 forbs and 14.08 forbs/0.10 m^2 during 2009 and 2011, respectively (tables 47 and 48).

Standing dead biomass was 1270.21 lbs/ac in 2006 at the start of the study, decreased 89.4% to 134.77 lbs/ac in 2009 during 4 years of grazing, and increased to 547.64 lbs/ac in 2011 at 43.1% of the starting biomass (table 41). Litter biomass was 1653.41 lbs/ac in 2006 at the start of the study, decreased 62.7% to 616.86 lbs/ac in 2010 during 5 years of grazing, and increased to 999.75 lbs/ac in 2011 at 60.5% of the starting biomass (table 41). The litter layer was not thick and the litter biomass averaged 1023.25 lbs/ac after the first growing season. Total dead biomass was 2923.62 lbs/ac in 2006 at the start of the study, decreased 70.0% to 878.65 lbs/ac in 2009 during 4 years of grazing, and increased to 1547.39 lbs/ac in 2011 at 52.9% of the starting biomass (table 41). The mean annual total dead biomass was 1848.57 lbs/ac and composed 52.6% of the mean annual total live and dead biomass.

After 6 grazing seasons managed with the twice-over rotation system on pasture one, the aboveground vegetation biomass consisted of 38.1% standing dead and litter and 61.9% live herbage. The live herbage was 69.0% domesticated grasses, 26.2% native grasses (20.9% cool season grasses, 4.6% upland sedges, and 0.7% warm season grasses), and 4.8% forbs (table 42). The changes in the mixed grass prairie vegetation on pasture one were similar to the changes on pasture two.

The vegetation on grazed pasture NR 1 changed during the 6 years of twice-over rotation grazing management. Domesticated grass herbage biomass increased 39.0% and basal cover increased 170.2%. Native grass herbage biomass increased 135.4% and basal cover increased 17.0%. Forb herbage biomass decreased 0.3% and forb density increased 190.9%. Total live herbage biomass increased 52.5% and basal cover increased 79.3%. Standing dead herbage biomass decreased 56.9% and litter biomass decreased 39.5%.

The rhizosphere weight (table 49) did not change during the first two years and then increased each year from the second grazing season to the sixth grazing season at a mean rate of 32.0 kg/m^3 per year, during which the growing season precipitation was slightly less than 90% of the long-term mean. During the sixth grazing season, the mean rhizosphere weight was 221.00 kg/m^3, which is (54.4%) a moderate quantity. Mean rhizosphere weights of 406.44 kg/m^3 have been recorded on silty ecological sites managed long-term with a twice-over rotation grazing strategy.

The total available soil mineral nitrogen of nitrate and ammonium was 59.80 lbs/ac on the exclosure and 63.83 lbs/ac on the grazed area, with an increase of 6.7% on the grazed area (table 50). The quantity of mineral nitrogen was greater on the grazed area than on the ungrazed exclosure. The quantities of mineral nitrogen were not significantly different on the exclosure and the grazed area. The quantity of nitrate was 8.00 lbs/ac on the exclosure and 7.00 lbs/ac on the grazed area, with a decrease of 12.5% on the grazed area. The quantity of ammonium was 51.80 lbs/ac on the exclosure and was 56.83 lbs/ac on the grazed area, with an increase of 9.7% on the grazed area (table 50). The amount of nitrate was slightly elevated on both the exclosure and the grazed area. The higher quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. Both the exclosure and grazed area had high domesticated grass basal cover. The grazed area had greater ammonium. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

The degraded mixed grass prairie site on pasture NR 1 was dominated by Kentucky bluegrass at a 75.7% composition. During the first three years, 2006 to 2008, cow-calf pairs grazed at 72.3%, 82.6%, and 107.5% of the 2011 assessed stocking rate, respectively. Domesticated grass herbage biomass decreased 76.3% to 295.94 lbs/ac, standing dead biomass decreased 61.5% to 488.82 lbs/ac, litter biomass decreased 12.6% to 1444.73 lbs/ac, and native grass herbage biomass increased 37.2% to 383.81 lbs/ac in three years.

The near full stocking rates of the cow-calf pairs removed sufficient quantities of domesticated grass and standing dead herbage biomass to reduce most of the shading problems and reduced a small amount of the thick mulch problems. Partial defoliation by grazing during vegetative phenological stages stimulated the defoliation resistance mechanisms at some level in the native grasses and activated the rhizosphere organisms and the ecosystem biogeochemical processes.

The stocking rate at greater than 100% of assessed value caused more beneficial effects than negative effects. The growing season of 2008 was the only time that grazing livestock were at sufficient quantities to remove 1008.01 lbs/ac of domesticated grass and standing dead biomass. During the following grazing season, domesticated grass herbage biomass increased 164.4% to 782.41 lbs/ac, standing dead biomass decreased 72.4% to 134.77 lbs/ac, litter biomass decreased 48.5% to 743.88 lbs/ac, and native grass herbage biomass increased 68.6% to 647.03 lbs/ac as a result of the greater than 100% stocking rate. However, total forb biomass increased 141.7% to 99.29 lbs/ac and weedy forb density increased 6033.3% as a result of opening the grass leaf canopy excessively and exposing sunlight on large areas of soil causing weed seeds to germinate.

During the next two years, 2009 to 2010, heifers grazed at 79.8% and 87.4% of the 2011 assessed stocking rate, respectively. Standing dead biomass decreased 9.8% to 441.00 lbs/ac, litter biomass decreased 57.3% to 616.86 lbs/ac, and native grass herbage biomass increased 38.2% to 530.51 lbs/ac in two years. However, domesticated grass herbage biomass increased 234.1% to 988.84 lbs/ac. At stocking rates of 80% and 87% of assessed values, ecosystem restoration continued with more beneficial effects than negative effects.

During the sixth year, 2011, steers grazed at 37.8% of the assessed stocking rate. Domesticated grass herbage biomass increased 75.4% to 1734.66 lbs/ac, standing dead biomass increased 24.2% to 547.64 lbs/ac, litter biomass increased 62.1% to 999.75 lbs/ac, and native grass herbage biomass increased 24.1% to 658.55 lbs/ac in one year. At low stocking rates, ecosystem restoration stopped and degradation advanced with large increases in domesticated grass biomass, standing dead biomass, and litter biomass. Native grass herbage biomass continued to increase as a result of previous beneficial effects from grazing at heavier stocking rates.

The mixed grass prairie communities on pasture NR 1 were degraded and dominated by Kentucky bluegrass. Kentucky bluegrass can grow thick and tall enough to shade the basal leaves of needle and thread, prairie Junegrass, and blue grama, and the stalk leaves of young western wheatgrass and prairie sandreed. The deficiency of sunlight attenuated by native grass leaves caused by shading was nearly corrected during the second to the fourth growing seasons through grazing defoliation with relatively high stocking rates greater than 80% of assessed levels managed by the twice-over rotation strategy. Stocking rates at greater than 85% of assessed levels would have removed more of the shading problem.

Table 41. Mean herbage biomass (lbs/ac) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	Pregrazin g 2006	2006	2007	2008	2009	2010	2011
Domesticated	1248.09	1067.75	1183.94	295.94	782.41	988.84	1734.66
Cool Season	87.06	207.56	377.50	171.67	389.62	374.23	525.21
Warm Season	14.99	44.75	58.85	25.89	44.04	48.93	16.62
Sedges	177.69	133.44	133.29	186.25	213.37	107.35	116.72
Native Grass	279.74	385.75	569.64	383.81	647.03	530.51	658.55
Total Grass	1527.82	1453.50	1753.58	679.75	1429.44	1519.35	2393.21
Forbs	121.31	93.38	100.85	41.08	99.29	335.70	120.91
Total Live	1649.13	1546.88	1854.43	720.83	1528.73	1855.05	2514.11
Standing Dead	1270.21	1000.47	608.83	488.82	134.77	441.00	547.64
Litter	1653.41	1678.59	1311.04	1444.73	743.88	616.86	999.75
Total Dead	2923.62	2679.06	1919.87	1933.55	878.65	1057.86	1547.39
Total Biomass	4572.95	4225.94	3774.30	2654.38	2407.38	2912.91	4061.51

Table 42. Percent composition of herbage biomass for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	Pregrazin g 2006	2006	2007	2008	2009	2010	2011
Domesticated	75.68	69.03	63.84	41.06	51.18	53.31	69.00
Cool Season	5.28	13.42	20.36	23.82	25.49	20.17	20.89
Warm Season	0.91	2.89	3.17	3.59	2.88	2.64	0.66
Sedges	10.77	8.63	7.19	25.84	13.96	5.79	4.64
Native Grass	16.96	24.94	30.72	53.25	42.33	28.60	26.19
Total Grass	92.64	93.96	94.56	94.30	93.51	81.90	95.19
Forbs	7.36	6.04	5.44	5.70	6.49	18.10	4.81
Total Live	36.06	36.60	49.13	27.16	63.50	63.68	61.90
Standing Dead	27.78	23.67	16.13	18.42	5.60	15.14	13.48
Litter	36.16	39.72	34.74	54.43	30.90	21.18	24.62
Total Dead	63.94	63.40	50.87	72.84	36.50	36.32	38.10
Total Biomass	4572.75	4225.94	3774.30	2654.38	2407.38	2912.91	4061.51

Table 43. Change in herbage biomass (lbs/ac) of grass categories between pregrazing 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	Pregrazing Herbage Biomass 2006	Mean Grazed Herbage Biomass 2008	% Difference 2008	Mean Grazed Herbage Biomass 2010	% Difference 2010
Domesticated	1248.09	295.94	-76.29	988.84	-20.77
Cool Season	87.06	171.67	97.19	374.23	329.85
Warm Season	14.99	25.89	72.72	48.93	226.42
Sedges	177.69	186.25	4.82	107.35	-39.59
Native Grass	279.74	383.81	37.20	530.51	89.64
Total Grass	1527.82	679.75	-55.51	1519.35	-0.55

Table 44. Basal cover (%) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	4.70	5.25	10.10	7.30	11.05	10.95	12.70
Cool Season	2.35	1.60	4.70	2.80	4.35	5.20	2.50
Warm Season	0.10	0.85	1.45	2.15	1.55	0.55	0.25
Sedges	4.60	7.60	8.80	9.05	8.60	9.95	5.50
Native Grass	7.05	10.05	14.95	14.00	14.50	15.70	8.25
Total Grass	11.75	15.30	25.05	21.30	25.55	26.65	20.95
Forbs	0.35	0.45	0.55	0.40	0.65	3.95	0.75
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	12.10	15.75	25.60	21.70	26.20	30.60	21.70
Litter	87.90	84.25	74.40	78.30	73.80	69.40	78.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 45. Percentage composition (%) of basal cover for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Domesticated	38.84	33.33	39.45	33.64	42.18	35.78	58.53
Cool Season	19.42	10.16	18.36	12.90	16.60	16.99	11.52
Warm Season	0.83	5.40	5.66	9.91	5.92	1.80	1.15
Sedges	38.02	48.25	34.38	41.71	32.82	32.52	25.35
Native Grass	58.26	63.81	58.40	64.52	55.34	51.31	38.02
Total Grass	97.11	97.14	97.85	98.16	97.52	87.09	96.54
Forbs	2.89	2.86	2.15	1.84	2.48	12.91	3.46
Woody Species	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Live	12.10	15.75	25.60	21.70	26.20	30.60	21.70
Litter	87.90	84.25	74.40	78.30	73.80	69.40	78.30
Total							

Table 46. Change in basal cover (%) of grass categories between ungrazed 2006 and grazed 2008, and grazed 2010 for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	Ungrazed Basal Cover 2006	Grazed Basal Cover 2008	% Difference 2008	Grazed Basal Cover 2010	% Difference 2010
Domesticated	4.70	7.30	55.32	10.95	132.98
Cool Season	2.35	2.80	19.15	5.20	121.28
Warm Season	0.10	2.15	2050.00	0.55	450.00
Sedges	4.60	9.05	96.74	9.95	116.30
Native Grass	7.05	14.00	98.58	15.70	122.70
Total Grass	11.75	21.30	81.28	26.65	126.81

Table 47. Forb density (#/0.10 m^2) for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	1.88	0.84	1.44	1.64	3.40	0.56	1.44
Mid Succession	0.44	1.12	1.28	0.00	1.68	0.20	1.96
Early Succession	2.52	0.64	0.12	0.00	7.36	2.56	10.68
Woody Species	0.00	0.08	0.00	0.00	0.04	0.00	0.20
Total Live	4.84	2.68	2.84	1.64	12.48	3.32	14.28

Table 48. Percent composition (%) of forb density for silty native rangeland sites at the Schnell Recreation Area, 2006-2011.

Pasture NR 1	2006 Exclosure	2006 Grazed	2007 Grazed	2008 Grazed	2009 Grazed	2010 Grazed	2011 Grazed
Late Succession	38.84	31.34	50.70	100.00	27.24	16.87	10.08
Mid Succession	9.09	41.79	45.07	0.00	13.46	6.02	13.73
Early Succession	52.07	23.88	4.23	0.00	58.97	77.11	74.79
Woody Species	0.00	2.99	0.00	0.00	0.32	0.00	1.40
Total Live							

Table 49. Rhizosphere weight (kg) per cubic meter of soil at the Schnell Recreation Area, 2006-2011.

Pasture NR 1		May	Jul	Oct	Mean
2006	kg/m^3	109.04	93.94	72.38	91.79
2007	kg/m^3	72.26	89.58	117.28	93.04
2008	kg/m^3	106.71	134.08	146.40	129.06
2009	kg/m^3	154.52	121.85	-	138.19
2010	kg/m^3	266.46	197.63	152.86	205.65
2011	kg/m^3	188.38	268.20	206.44	221.00

Table 50. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) at the Schnell Recreation Area, 2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Pasture NR 1	lbs/ac Exclosure	mg/kg Exclosure	lbs/ac Grazed	mg/kg Grazed	% Difference
Mineral Nitrogen	59.80	18.33	63.83	19.56	6.74
Nitrate	8.00	2.45	7.00	2.14	-12.50
Ammonium	51.80	15.87	56.83	17.42	9.71

Changes on the Ungrazed and Grazed Pastures

Cattle grazing was not permitted on the Schnell Recreation Area for thirteen years between 1993 and 2005. The mixed grass prairie communities of the untilled silty ecological sites in ungrazed control pasture NR 4 and in grazed pastures NR 1 and NR 2 degraded as a result of the nondefoliation management by complete rest.

Removal of defoliation by grazing resulted in an accumulation of standing dead leaves. The standing dead leaves did not decompose through microbial activity because the high quantity of standing dead material could not make contact with soil. The standing dead leaves broke down slowly by leaching and weathering, and built up a thick mulch layer. After thirteen years with no cattle grazing on control pasture NR 4, the accumulated standing dead biomass increased to 1824.68 lbs/ac, 28.6% of the total herbage biomass; the accumulated litter biomass increased to 2785.89 lbs/ac, 43.7% of the total herbage biomass; and the total dead biomass increased to 4610.57 lbs/ac, 72.3% of the total herbage biomass (table 51). After thirteen years with no cattle grazing on pastures NR 1 and NR 2, the accumulated standing dead biomass increased to 1213.84 lbs/ac, 26.9% of the total herbage biomass; the accumulated litter biomass increased to 1661.26 lbs/ac, 36.8% of the total herbage biomass; and the total dead biomass increased to 2875.10 lbs/ac, 63.6% of the total herbage biomass (table 52). The large quantity of standing dead biomass reduced the amount of sunlight reaching native grass leaves decreasing photosynthesis resulting in a deficiency of available fixed carbon. The large quantity of litter mulch modified soil temperatures, inhibited water infiltration, and tied up ecosystem nutrients.

The decrease in the supply of soil water, soil nutrients, fixed carbon, and sunlight caused a large decrease in native grass density and herbage biomass production. After thirteen years with no cattle grazing on control pasture NR 4, the total native grass herbage biomass decreased to 43.53 lbs/ac. Cool season grass, warm season grass, and upland sedge herbage biomass decreased to 35.68 lbs/ac, 0.71 lbs/ac, and 7.14 lbs/ac, respectively (table 51). Basal cover of native grasses decreased to 4.10%. Basal cover of cool season grass, warm season grass, and upland sedge decreased to 1.20%, 0.05%, and 2.85%, respectively (table 53). After thirteen years with no cattle grazing on pastures NR 1 and NR 2, the total native grass herbage biomass decreased to 430.67 lbs/ac. Cool season grass, warm season grass, and upland sedge herbage biomass decreased to 43.53 lbs/ac, 10.00 lbs/ac, and 377.14 lbs/ac, respectively (table 52). Basal cover of native grasses decreased to 9.90%. Basal cover of cool season grass, warm season grass, and upland sedge decreased to 1.85%, 0.43%, and 7.63%, respectively (table 54).

The decrease in native grass density and herbage biomass created large open spaces in the plant community which became available for invasion by undesirable domesticated cool season grasses. After thirteen years with no cattle grazing on control pasture NR 4, the domesticated grass herbage biomass increased to 1684.81 lbs/ac, 26.4% of the total herbage biomass (table 51). Basal cover of domesticated grasses increased to 10.55% (table 53). After thirteen years with no cattle grazing on pastures NR 1 and NR 2, the domesticated grass herbage biomass increased to 1066.48 lb/ac, 23.6% of the total herbage biomass (table 52). Basal cover of domesticated grasses increased to 3.45% (table 54). This increase of domesticated grass density and herbage biomass caused additional shading problems for the native grasses.

Mixed grass prairie ecosystems can be degraded more drastically by nondefoliation management than by poor grazing management. Grass plants require partial defoliation by grazing to remain healthy and productive (Manske 1999, 2011). During the early stages of coevolution with grazing mammals (graminivores), grass plants developed several recuperative mechanisms that provided recovery and enhanced vitality, collectively designated as defoliation resistance mechanisms (Briske 1991, Briske and Richards 1995). These adaptive coexistence mechanisms are triggered by partial defoliation by grazing events. When defoliation by grazing is removed from mixed grass prairie ecosystems, the defoliation resistance mechanisms cease and degradation processes commence.

An evolutionary survival mechanism of grass plants to partial defoliation and the loss of leaf area to grazing graminivores, that does not stop upon the removal of grazing, is the production of double the quantity of leaf biomass than needed for normal plant growth and maintenance (Crider 1955, Coyne et al. 1995). With no grazing graminivores to remove half of the herbage production, the surplus leaf material accumulates rapidly. A considerable amount of shade is produced by the accumulating live and standing dead grass leaves reducing the level of understory sunlight below the native grass light saturation point (Peltzer and Kochy 2001). Native grasses have high light saturation points and require near full sunlight. Warm season (C_4) grasses have higher light saturation points than cool season (C_3) 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 grasses to live in low light conditions.

The low amount of sunlight reaching native grass leaves decreases the rate of photosynthesis that reduces the quantity of atmospheric carbon dioxide fixed and the quantity of carbohydrates produced (Coyne et al. 1995). Low quantities of carbohydrates decrease growth of roots, leaves, and stems, and development of secondary tillers. Low quantities of carbohydrates also increase the rates of leaf senescence and tiller mortality that results in reductions of grass plant density and herbage biomass production (Langer 1972, Grant et al. 1983, Briske and Richards 1995).

The accumulating standing dead material not in contact with soil does not decompose through microbial activity. Dead plant material breaks down slowly by leaching and weathering and builds up into a thick mulch layer. Thick mulch modifies soil temperatures, inhibits water infiltration, and ties up nutrients (Wright and Bailey 1982; Manske 2000, 2011). These undesirable modifications to the ecosystem cause decreases in soil microorganism biomass and activity resulting in further reductions in the rates of organic material decomposition (Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990). The ecosystem biogeochemical processes that mineralize nitrogen and cycle essential elements are greatly reduced causing severe decreases in the quantities of available nutrients (Coleman et al. 1983, Curl and Truelove 1986, Klein et al. 1988, Hamilton and Frank 2001).

With continued ecosystem degradation, the impeded native grasses decline further in competitiveness for reduced belowground resources of soil water and nutrients (Li and Wilson 1998, Kochy and Wilson 2000), causing increases in mortality of native grass plants and decreases in native grass density, resulting in the creation of numerous shaded bare spaces in the prairie plant communities (Manske 2006, 2007). Opportunistic introduced cool season domesticated grasses that can exist under low light conditions, like Kentucky bluegrass and smooth bromegrass, invade the bare spaces and procure the remaining belowground resources not being taken up by the small, low vigor native grasses (Kochy and Wilson 2000). As an additional asset, Kentucky bluegrass and smooth bromegrass have labile roots that break down easily making the nutrients contained in dead roots readily available to support continued growth and expansion of those nonnative grasses without assistance from symbiotic rhizosphere organisms. 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.

The degradation of the mixed grass prairie community after thirteen years with no cattle grazing on control pasture NR 4 and on pastures NR 1 and NR 2 resulted in severe reductions of cool season and warm season native grasses, excessive increases of standing dead and litter, and extreme increases of domesticated grasses. At the start of the study (May 2006) on control pasture NR 4, the aboveground vegetation biomass consisted of 72.3% standing dead and litter and 27.7% live herbage. The live herbage biomass was 95.2% domesticated grasses, 2.5% native grasses (2.0% cool season grass, 0.4% upland sedge, and less than 0.1% warm season grass), and 2.4% forbs (table 51). At the start of the study (May 2006) on pastures NR 1 and NR 2, the aboveground vegetation biomass consisted of 63.6% standing dead and litter and 36.4% live herbage. The live herbage biomass was 64.8% domesticated grasses, 26.2% native grasses (22.9% upland sedge, 2.7% cool season grass, and 0.6% warm season grass), and 9.0% forbs (table 52). A similarity index of 52.6% indicated that the degraded plant communities on pastures NR 1 and NR 2 and the plant community on control pasture NR 4 were more similar than dissimilar at the start of the study.

The twice-over rotation grazing management strategy was implemented on pastures NR 1 and NR 2 in 2006 and operated for six years through the growing season of 2011 with the intended purpose to stimulate the defoliation resistance mechanisms and activate compensatory internal physiological processes, internal vegetative reproduction processes, and external symbiotic rhizosphere organism activity. Control pasture NR 4 was not grazed during the six year period from 2006 through 2011.

Cow-calf pairs grazed during 2006 to 2008 at a mean stocking rate 2.20 ac/AUM (87.4% of the 2011 assessed stocking rate). The stocking rates used for the cow-calf pairs were high enough to have beneficial effects on the degraded native mixed grass prairie communities. As a result of three years of grazing with cow-calf pairs on pastures NR 1 and NR 2, native grass herbage biomass increased 11.2% to 478.73 lbs/ac and basal cover increased 77.3% to

17.55%; cool and warm season grass herbage biomass increased 295.6% to 211.74 lbs/ac and basal cover increased 198.7% to 6.81%; and upland sedge herbage biomass decreased 29.2% to 266.99 lbs/ac and basal cover increased 40.9% to 10.75%. Domesticated grass herbage biomass decreased 70.9% to 310.77 lbs/ac and basal cover increased 18.3% to 4.08%. Forb herbage biomass decreased 76.2% to 35.17 lbs/ac and total forb density decreased 76.1% to 1.32 forbs/0.10 m^2, with density of late succession forbs decreasing 25.7% to 1.10 forbs/0.10 m^2 and density of mid and early succession forbs decreasing 94.6% to 0.22 forbs/0.10 m^2. Standing dead biomass decreased 65.4% to 420.37 lbs/ac and litter biomass decreased 32.9% to 1114.80 lbs/ac.

In 2008 after the cow-calf pairs had grazed for 3 years, the degraded native mixed grass prairie communities on pastures NR 1 and NR 2 had improved. Total native grass herbage biomass was 194.2% greater and basal cover was 200.0% greater on the grazed pastures than on the ungrazed control pasture. Cool and warm season grass herbage biomass was 48.6% greater and basal cover was 72.4% greater on the grazed pastures than on the ungrazed control pasture. Native upland sedge herbage biomass was 1215.9% greater and basal cover was 465.8% greater on the grazed pastures than on the ungrazed control pasture. Domesticated grass herbage biomass was 76.5% less and basal cover was 63.6% less on the grazed pastures than on the ungrazed control pasture. Forb herbage biomass was 30.2% greater and forb density was 135.7% greater on the grazed pastures than on the ungrazed control pasture. Standing dead biomass was 54.7% less and litter biomass was 55.8% less on the grazed pastures than on the ungrazed control pasture.

The stocking rate of grazing cow-calf pairs was increased 30.2% from 2007 to 2008 which was 107.2% of the 2011 assessed stocking rate. On grazed pastures NR 1 and NR 2, because of this higher stocking rate, the herbage biomass of domesticated grass and biomass of standing dead decreased 55.6% in 2008. During the growing season of 2008, the greater quantity of livestock removed 916.93 lbs/ac of domesticated grass and standing dead biomass. Removal of this much herbage biomass opened the grass canopy, reduced the shading effect, and permitted sunlight to reach the understory plants. The beneficial effects of an open canopy carried over into the next growing season. Cool and warm season grass herbage biomass increased 109.8% and basal cover increased 11.7%; upland sedge herbage biomass increased 43.4% and basal cover increased 2.8%; and native grass herbage biomass increased 72.8% to 827.07 lbs/ac and basal cover increased 6.3% to 18.65%.

Opening the grass canopy in 2008 also exposed the numerous bare spaces to sunlight. Density of late succession forbs increased 96.4%, furthermore, density of mid and early succession forbs increased 4263.6%. The herbage biomass of forbs increased 168.7% to 94.50 lbs/ac in 2009.

Heifers grazed during 2009 and 2010 at a mean stocking rate of 2.30 ac/AUM (83.4% of the 2011 assessed stocking rate). The mean stocking rate used for the heifers were slightly lower than the mean stocking rate used for the cow-calf pairs. As a result of two years of grazing with heifers on pastures NR 1 and NR 2, the herbage biomass of domesticated grass and standing dead increased 43.5% to 1049.40 lbs/ac and the domesticated grass basal cover increased 68.6% to 6.88%. This increase in herbage biomass was sufficient to thicken the overstory canopy and reduce sunlight reaching the understory native plants. However, the problems with increasing early succession forbs continued. Forb herbage biomass increased 917.5% to 357.87 lbs/ac and total forb density increased 139.4% to 3.16 forbs/0.10 m^2, with density of late succession forbs decreasing 43.6% to 0.62 forbs/0.10 m^2 and density of mid and early succession forbs increasing 1054.6% to 2.54 forbs/0.10 m^2.

The reduction of sunlight inhibited production of the native grasses and effectively reduced the native grass rate of improvement. Cool and warm season grass herbage biomass increased 63.8% to 346.76 lbs/ac and basal cover increased 12.5% to 7.66%; upland sedge herbage biomass increased 25.4% to 334.68 lbs/ac and basal cover increased 18.1% to 12.70%; and total native grass herbage biomass increased 42.3% to 681.44 lbs/ac and basal cover increased 16.0% to 20.35%.

In 2010 after the heifers had grazed for 2 years, the degraded native mixed grass prairie communities on pastures NR 1 and NR 2 had continued to improve. Total native grass herbage biomass was 116.9% greater and basal cover was 457.5% greater on the grazed pastures than on the ungrazed control pasture. Cool and warm season grass herbage biomass was 22.2% greater and basal cover was 303.2% greater on the grazed pastures than on the ungrazed control pasture. Native upland sedge herbage biomass was 998.0% greater and basal cover was 1974.2% greater on the grazed pastures than on the ungrazed control pasture. Domesticated grass herbage biomass was 53.3% less and basal cover was 70.8% less on the grazed pastures than on the ungrazed control pasture. Forb herbage biomass was 50.0% greater and forb density was 23.4% greater on the grazed pastures than on the ungrazed control pasture. Standing dead biomass was 15.9% less and litter biomass was 67.9% less on the grazed pastures than on the ungrazed control pasture.

Steers grazed during 2011 at a stocking rate of 5.09 ac/AUM (37.7% of the 2011 assessed stocking rate). The stocking rate used for the steers was 56.8% less than the mean stocking rate used for the cow-calf pairs. As a result of one growing season of grazing with steers on pastures NR 1 and NR 2, the herbage biomass of domesticated grass and standing dead increased 68.8% to 1771.01 lbs/ac increasing the problems caused by shading; litter biomass increased 89.5% to 898.17 lbs/ac increasing the problems caused by accumulated mulch. Forb density increased greatly. The density of late succession forbs increased 158.1% to 1.60 forbs/0.10 m^2, density of mid and early succession forbs increased 280.3% to 9.66 forbs/0.10 m^2, and total forb density increased 256.3% to 11.26 forbs/0.10 m^2. Forb herbage biomass decreased 72.0% to 100.11 lbs/ac. Native grass basal cover decreased greatly. Cool and warm season grass basal cover decreased 15.7% to 6.46% and herbage biomass increased 63.5% to 567.07 lbs/ac; upland sedge basal cover decreased 24.8% to 9.55% and herbage biomass decreased 26.7% to 245.17 lbs/ac; and native grass basal cover decreased 21.4% to 16.00% and herbage biomass increased 19.2% to 812.23 lbs/ac.

In 2011 after the steers had grazed at a light stocking rate for one growing season, the progress in improvement of the native grasses in the degraded native mixed grass prairie communities on pastures NR 1 and NR 2 was retarded. However, in spite of the setbacks caused by the light stocking rate of the steers, the differences between the grazed plant communities and the ungrazed plant communities continued to expand as a result of the prolonged beneficial effects from the previous grazing by the cow-calf pairs and the heifers. Total native grass herbage biomass was 264.2% greater and basal cover was 611.1% greater on the grazed pastures than on the ungrazed control pasture. Cool and warm season grass herbage biomass was 168.5% greater and basal cover was 438.3% greater on the grazed pastures than on the ungrazed control pasture. Native upland sedge herbage biomass was 1974.2% greater and basal cover was 809.5% greater on the grazed pastures than on the ungrazed control pasture. Domesticated grass herbage biomass was 46.0% less and basal cover was 55.2% less on the grazed pastures than on the ungrazed control pasture. Forb herbage biomass was 46.0% less and forb density was 216.3% greater on the grazed pastures than on the ungrazed control pasture. Standing dead biomass was 58.5% less, litter biomass was 71.7% less, and total dead biomass was 68.1% less on the grazed pastures than on the ungrazed control pasture (tables 57, 58, and 59).

The changes in the vegetation on grazed pastures NR 1 and NR 2 were different from the changes in the vegetation on ungrazed control pasture NR 4. During six years of no grazing on control pasture NR 4, domesticated herbage biomass increased 38.5% from 1684.81 lbs/ac in 2006 to 2333.98 lbs/ac in 2011 (table 51), and domesticated grass basal cover increased 45.5% from 10.55% in 2006 to 15.35% in 2011 (table 53). During six years of grazing on pastures NR 1 and NR 2, domesticated grass herbage biomass increased 18.3% from 1066.48 lbs/ac in 2006 to 1261.24 lbs/ac in 2011 (table 52), and domesticated grass basal cover increased 99.4% from 3.45% in 2006 to 6.88% in 2011 (table 54).

During six years of no grazing on control pasture NR 4, native cool season grass herbage biomass increased 61.1% from 35.68 lbs/ac in 2006 to 57.49 lbs/ac in 2011 (table 51), and native cool season grass basal cover decreased 70.8% from 1.20% in 2006 to 0.35% in 2011 (table 53). During six years of grazing on pastures NR 1 and NR 2, native cool season grass herbage biomass increased 1090.4% from 43.53 lbs/ac in 2006 to 518.18 lbs/ac in 2011 (table 52), and native cool season grass basal cover increased 112.4% from 1.85% in 2006 to 3.93% in 2011 (table 54).

During six years of no grazing on control pasture NR 4, native warm season grass herbage biomass increased 21552.1% from 0.71 lbs/ac in 2006 to 153.73 lbs/ac in 2011 (table 51), and native warm season grass basal cover increased 1600.0% from 0.05% in 2006 to 0.85% in 2011 (table 53). During six years of grazing on pastures NR 1 and NR 2, native warm season grass herbage biomass increased 388.9% from 10.00 lbs/ac in 2006 to 48.89 lbs/ac in 2011 (table 52), and native warm season grass basal cover increased 488.4% from 0.43% in 2006 to 2.53% in 2011 (table 54). A few tillers of prairie sandreed from a remnant colony were growing on the ungrazed control pasture destructive sample site resulting in a raised native warm season grass herbage biomass.

During six years of no grazing on control pasture NR 4, native upland sedge herbage biomass increased 65.6% from 7.14 lbs/ac in 2006 to 11.82

lbs/ac in 2011 (table 51), and native upland sedge basal cover decreased 63.2% from 2.85% in 2006 to 1.05% in 2011 (table 53). During six years of grazing on pastures NR 1 and NR 2, native upland sedge herbage biomass decreased 35.0% from 377.14 lbs/ac in 2006 to 245.17 lbs/ac in 2011 (table 52), and native upland sedge basal cover increased 25.2% from 7.63% in 2006 to 9.55% in 2011 (table 54).

During six years of no grazing on control pasture NR 4, total native grass herbage biomass increased 412.4% from 43.53 lbs/ac in 2006 to 223.05 lbs/ac in 2011 (table 51), and total native grass basal cover decreased 45.1% from 4.10% in 2006 to 2.25% in 2011 (table 53). During six years of grazing on pastures NR 1 and NR 2, total native grass herbage biomass increased 88.6% from 430.67 lbs/ac in 2006 to 812.23 lbs/ac in 2011 (table 52), and total native grass basal cover increased 61.6% from 9.90% in 2006 to 16.00% in 2011 (table 54).

During six years of no grazing on control pasture NR 4, forb herbage biomass increased 340.5% from 42.10 lbs/ac in 2006 to 185.43 lbs/ac in 2011 (table 51), and forb density decreased 34.6% from 5.44 forbs/0.10 m^2 in 2006 to 3.56 forbs/0.10 m^2 in 2011 (table 55). During six years of grazing on pastures NR 1 and NR 2, forb herbage biomass decreased 32.2% from 147.72 lbs/ac in 2006 to 100.11 lbs/ac in 2011 (table 52), and forb density increased 104.0% from 5.52 forbs/0.10 m^2 in 2006 to 11.26 forbs/0.10 m^2 in 2011 (table 56).

During six years of no grazing on control pasture NR 4, standing dead biomass decreased 32.6% from 1824.68 lbs/ac in 2006 to 1229.02 lbs/ac in 2011, litter biomass increased 14.1% from 2785.89 lbs/ac in 2006 to 3178.78 lbs/ac in 2011, and total dead biomass decreased 4.4% from 4610.57 lbs/ac in 2006 to 4407.80 lbs/ac in 2011 (table 51). During six years of grazing on pastures NR 1 and NR 2, standing dead biomass decreased 58.0% from 1213.84 lbs/ac in 2006 to 509.77 lbs/ac in 2011, litter biomass decreased 45.9% from 1661.26 lbs/ac in 2006 to 898.17 lbs/ac in 2011, and total dead biomass decreased 51.0% from 2875.10 lbs/ac in 2006 to 1407.93 lbs/ac in 2011 (table 52).

The mixed grass prairie vegetation in 2011 on grazed pastures NR 1 and NR 2 after six years of twice-over rotation management was different from the vegetation on the ungrazed control pasture NR 4. In 2011 after nineteen years of no grazing on control pasture NR 4, the aboveground vegetation biomass consisted of 61.7% standing dead and litter and 38.3% live herbage. The live herbage biomass was 85.1% domesticated grass, 8.1% native grasses (5.6% warm season grass, 2.1% cool season grass, and 0.4% upland sedge), and 6.8% forbs (table 57). After 6 grazing seasons managed with twice-over rotation strategy on pastures NR 1 and NR 2, the aboveground vegetation biomass in 2011 consisted of 39.3% standing dead and litter and 60.7% live herbage. The live herbage biomass was 58.0% domesticated grass, 37.4% native grasses (23.8% cool season grass, 11.3% upland sedge, and 2.3% warm season grass), and 4.6% forbs (table 57). A similarity index of 37.3% indicated that the improved plant communities on grazed pastures NR 1 and NR 2 and the degraded plant community on ungrazed control pasture NR 4 were more dissimilar than similar after six years of grazing.

The six years of grazing with the twice-over rotation management strategy on pastures NR 1 and NR 2, reduced the standing dead biomass 58.5%, which decreased the problems caused by shading that reduced the rates of photosynthesis and increased the rates of leaf senescence in native grasses, and reduced the litter biomass 71.7%, which decreased the problems caused by thick mulch that modified soil temperatures, inhibited water infiltration, and tied up carbon and nitrogen.

During the six year period from 2006 to 2011, domesticated grass herbage biomass increased 649.17 lbs/ac on the ungrazed control pasture and increased 194.76 lbs/ac on the grazed pastures, and basal cover increased 4.80 percentage points (45.5%) on the control pasture and increased 3.43 percentage points (99.4%) on the grazed pastures. At the end of the study in 2011, domesticated grass herbage biomass was 46.0% less and basal cover was 55.2% less on the grazed pastures than on the ungrazed control pasture. The rate of increase of domesticated grass herbage biomass and basal cover was restricted by the grazing treatment.

The quantity of domesticated grass and standing dead herbage biomass was greater during each of the six growing seasons on the ungrazed control pasture than on the grazed pastures (table 60). The annual mean domesticated grass and standing dead herbage biomass was 2617.80 lbs/ac on the ungrazed control pasture and was significantly greater than that of 1277.06 lbs/ac on the grazed pastures. The great quantity of aboveground vegetation biomass on the ungrazed control pasture prevented most of the sunlight from reaching the smaller native grass plants growing in the understory. Photosynthetic rates in native grass leaves under low sunlight conditions would be extremely low and the quantities of fixed carbon available to native grasses would be far less than that required for normal growth. The annual mean native grass herbage biomass on the ungrazed control pasture was only 245.28 lbs/ac and was significantly less than that of 650.01 lbs/ac on the grazed pastures. The defoliation pressure on the grazed pastures reduced the shading effect of the domesticated grass and standing dead herbage biomass sufficiently to permit greater amounts of sunlight to reach native grass leaves increasing the photosynthetic rates and the growth rates.

During the six year period from 2006 to 2011, native grass herbage biomass increased 179.52 lbs/ac on the ungrazed control pasture and increased 381.56 lbs/ac on the grazed pastures, and basal cover decreased 45.1% on the ungrazed control pasture and increased 61.6% on the grazed pastures. At the end of the study in 2011, native grass herbage biomass was 264.2% greater and basal cover was 611.1% greater on the grazed pastures than on the ungrazed control pasture (tables 57 and 58). The improvements of the native grasses in the degraded native mixed grass prairie communities on the grazed pastures NR 1 and NR 2 indicates that the defoliation resistance mechanisms were activated to some degree by the twice-over rotation grazing management strategy. Increased activity of the compensatory internal physiological growth processes resulted in increased production of native grass herbage biomass. Increased activity of the internal vegetative reproductive processes resulted in increased native grass basal cover.

Removal of cattle grazing from the Schnell Recreation Area for thirteen years from 1993 to 2005 caused degradation of the mixed grass prairie communities on control pasture NR 4 and on pastures NR 1 and NR 2. The transition from plant communities dominated by native grasses to plant communities dominated by domesticated grasses was the visible change but was not the first degrading change. Before the native grass species decreased and the domesticated grass species increased, the rhizosphere biomass decreased. After thirteen years with no cattle grazing, the rhizosphere biomass on control pasture NR 4 decreased to 52.23 kg/m^3, and the rhizosphere biomass on pastures NR 1 and NR 2 decreased to 77.99 kg/m^3. These low quantities of rhizosphere biomass are less than 20% of potential rhizosphere biomass.

When defoliation by grazing is removed from a mixed grass prairie, the native grass live root biomass decreases (Whitman 1974). This decrease in active root surface causes a reduction in root length for interaction with symbiotic rhizosphere organisms and causes a decrease in absorption of water and nutrients from the soil. 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 was, however, the great reduction in the quantity of carbohydrates exuded from the grass roots into the rhizosphere zone. Without defoliation by grazing, only a small quantity of plant material leaks from the grass roots into the rhizosphere; this low amount of carbon compounds is barely enough to sustain a small rhizosphere biomass.

Rhizosphere organism biomass and activity are limited by access to simple carbon chains because the microflora trophic levels lack chlorophyll and have low carbon (energy) content. Partial defoliation of grass plants at vegetative phenological growth stages by large grazing graminivores causes greater quantities of exudates containing simple carbon compounds to be released through the plant roots into the rhizosphere. With the increase in availability of carbon compounds in the rhizosphere, activity of the microorganisms increases. The increase in rhizosphere organism activity causes an increase in rhizosphere volume and biomass.

Grazing on pastures NR 1 and NR 2 was managed with the twice-over rotation strategy for six years from 2006 through 2011, and the rhizosphere weights increased greatly during these six grazing seasons (table 61 and figure 3). Control pasture NR 4 was not grazed during the six year study period.

The rhizosphere weights on grazed pastures NR 1 and NR 2 were not significantly different from the other during each of the six grazing seasons. During the first two years, the rhizosphere weights on the grazed pastures and on the ungrazed control pasture were not significantly different. The 2006 rhizosphere weights and the 2007 rhizosphere weights were not significantly different. The rhizosphere weights on the grazed pastures were numerically greater than the rhizosphere weights on the ungrazed control pasture, but were not significantly different during the first two years, 2006 and 2007 (table 61 and figure 3).

The annual changes of the rhizosphere weights on the ungrazed control pasture responded differently than the annual increases of the rhizosphere weights on the grazed pastures. The rhizosphere weights on the ungrazed control pasture changed little each year from the second year to the fourth year, during which the growing season precipitation was slightly more than 75% of the long-term mean. Mean rhizosphere weight change from the second to the fourth year was 2.5 kg/m^3 per year. The rhizosphere weights on the ungrazed control pasture increased markedly during the fifth and sixth years, 2010 and 2011, during which the growing season precipitation was greater than 100% of the long-term mean. Mean rhizosphere weight change was 23.8 kg/m^3 per year during the fifth and the sixth years. During the period from the second year to the sixth year, during which the growing season precipitation was slightly less than 90% of the long-term mean, the rhizosphere weight increased at a mean rate of 13.2 kg/m^3 per year on the ungrazed control pasture (table 61 and figure 3).

After the second year, rhizosphere weights on the grazed pastures were significantly greater during each year than those on the ungrazed control pasture. The rhizosphere weights on the grazed pastures increased at a mean rate of 27.1 kg/m^3 per year during the second year to the fourth year, during which the growing season precipitation was slightly more than 75% of the long-term mean. The rhizosphere rate of weight increase was 850.1% greater on the grazed pastures than on the ungrazed control pasture during 2007 to 2009. During the fifth and sixth years, 2010 and 2011, during which the growing season precipitation was greater than 100% of the long-term mean, the rhizosphere weight increase on the grazed pastures was 37.0 kg/m^3 per year, which was 55.2% greater than the rhizosphere weight increase on the ungrazed control pasture. The rhizosphere weights on the grazed pastures increased greatly during each grazing season from the second year to the sixth year, 2007 to 2011. When growing season precipitation was slightly less than 90% of the long-term mean from the second year to the sixth year, the rhizosphere weight increased at a mean rate of 30.5 kg/m^3 per year on the grazed pastures which was 131.5% greater than the change in rhizosphere weight on the ungrazed control pasture during the same period. The rhizosphere weights each year during 2008 to 2011 were numerically the greatest on the grazed pastures and were significantly greater than the rhizosphere weights on the ungrazed control pasture during each respective year (table 61 and figure 3). The rhizosphere biomass increases from the second to the sixth years on the grazed pastures NR 1 and NR 2 appeared to be related to increases in carbon exudates that resulted from partial defoliation of grass lead tillers by grazing during vegetative growth stages.

The total available soil mineral nitrogen of nitrate and ammonium on grazed pastures NR 1 and NR 2 was 53.78 lbs/ac on the exclosures and 56.74 lbs/ac on the grazed areas, with an increase of 5.5% on the grazed areas (table 62). The quantity of mineral nitrogen was greater on the grazed areas than on the ungrazed exclosures. The quantities of mineral nitrogen were not significantly different on the exclosures and the grazed areas. The quantity of nitrate was 6.84 lbs/ac on the exclosures and 5.66 lbs/ac on the grazed areas, with a decrease of 17.3% on the grazed areas. The quantity of ammonium was 46.94 lbs/ac on the exclosures and 51.08 lbs/ac on the grazed areas, with an increase of 8.8% on the grazed areas (table 62). The exclosures had greater nitrate and lower ammonium and the grazed areas had lower nitrate and greater ammonium. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

Table 51. Changes in herbage biomass (lbs/ac) and relative composition (%) for ungrazed control pasture at the Schnell Recreation Area, 2006-2011.

	Herbage Biomass (lbs/ac)			Relative Composition (%)		
	Pregrazing 2006	Ungrazed 2011	% Difference	Pregrazing 2006	Ungrazed 2011	% Difference
Domesticated	1684.81	2333.98	38.53	95.16	85.11	-10.56
Cool Season	35.68	57.49	61.13	2.02	2.10	3.96
Warm Season	0.71	153.73	21552.11	0.04	5.61	13925.00
Sedges	7.14	11.82	65.55	0.40	0.43	7.50
Native Grass	43.53	223.05	412.41	2.46	8.13	230.49
Total Grass	1728.34	2557.03	47.95	97.62	93.24	-4.49
Forbs	42.10	185.43	340.45	2.38	6.76	184.03
Total Live	1770.44	2742.47	54.90	27.75	38.35	38.20
Standing Dead	1824.68	1229.02	-32.64	28.60	17.19	-39.90
Litter	2785.89	3178.78	14.10	43.66	44.46	1.83
Total Dead	4610.57	4407.80	-4.40	72.25	61.65	-14.67
Total Biomass	6381.01	7150.27	12.06	6381.01	7150.27	

Table 52. Changes in herbage biomass (lbs/ac) and relative composition (%) for grazed pastures at the Schnell Recreation Area, 2006-2011.

	Herbage Biomass (lbs/ac)			Relative Composition (%)		
	Pregrazing 2006	Grazed 2011	% Difference	Pregrazing 2006	Grazed 2011	% Difference
Domesticated	1066.48	1261.24	18.26	64.84	58.03	-10.50
Cool Season	43.53	518.18	1090.40	2.65	23.84	799.62
Warm Season	10.00	48.89	388.90	0.61	2.25	268.85
Sedges	377.14	245.17	-34.99	22.93	11.28	-50.81
Native Grass	430.67	812.23	88.60	26.18	37.37	42.74
Total Grass	1497.14	2073.47	38.50	91.02	95.39	4.80
Forbs	147.72	100.11	-32.23	8.98	4.61	-48.66
Total Live	1644.85	2173.57	32.14	36.39	60.69	66.78
Standing Dead	1213.84	509.77	-58.00	26.85	14.23	-47.00
Litter	1661.26	898.17	-45.93	36.75	25.08	-31.76
Total Dead	2875.10	1407.93	-51.03	63.61	39.31	-38.20
Total Biomass	4520.05	3581.51	-20.76	4520.05	3581.51	

Table 53. Changes in basal cover (%) and relative composition (%) for ungrazed control pasture at the Schnell Recreation Area, 2006-2011.

	Basal Cover (%)			Relative Composition (%)		
	Exclosure 2006	Ungrazed 2011	% Difference	Exclosure 2006	Ungrazed 2011	% Difference
Domesticated	10.55	15.35	45.50	71.28	85.99	20.64
Cool Season	1.20	0.35	-70.83	8.11	1.96	-75.83
Warm Season	0.05	0.85	1600.00	0.34	4.76	1300.00
Sedges	2.85	1.05	-63.16	19.26	5.88	-69.47
Native Grass	4.10	2.25	-45.12	27.70	12.61	-54.48
Total Grass	14.65	17.60	20.14	98.99	98.60	-0.39
Forbs	0.05	0.20	300.00	0.34	1.12	229.41
Woody Species	0.10	0.05	-50.00	0.68	0.28	-58.82
Total Live	14.80	17.85	20.61	14.80	17.85	20.61
Litter	85.20	82.15	-3.58	85.20	82.15	-3.58
Total	100.00	100.00				

Table 54. Changes in basal cover (%) and relative composition (%) for grazed pastures at the Schnell Recreation Area, 2006-2011.

	Basal Cover (%)			Relative Composition (%)		
	Exclosure 2006	Grazed 2011	% Difference	Exclosure 2006	Grazed 2011	% Difference
Domesticated	3.45	6.88	99.42	24.77	29.43	18.81
Cool Season	1.85	3.93	112.43	13.28	16.81	26.58
Warm Season	0.43	2.53	488.37	3.09	10.82	250.16
Sedges	7.63	9.55	25.16	54.77	40.85	-25.42
Native Grass	9.90	16.00	61.61	71.07	68.43	-3.71
Total Grass	13.35	22.88	71.39	95.84	97.86	2.11
Forbs	0.58	0.50	-13.79	4.16	2.14	-48.56
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	13.93	23.38	67.84	13.93	23.38	67.84
Litter	85.90	76.63	-10.79	85.90	76.63	-10.79
Total	100.00	100.00				

Table 55. Changes in forb density (#/0.10m^2) and relative composition (%) for ungrazed control pasture at the Schnell Recreation Area, 2006-2011.

	Forb Density (#/0.10 m^2)			Relative Composition (%)		
	Exclosure 2006	Ungrazed 2011	% Difference	Exclosure 2006	Ungrazed 2011	% Difference
Late Succession	4.64	2.72	-41.38	78.38	73.12	-6.71
Mid Succession	0.16	0.80	400.00	2.70	21.51	696.67
Early Succession	0.64	0.04	-93.75	10.81	1.08	-90.01
Woody Species	0.48	0.16	-66.67	8.11	4.30	-46.98
Total Live	5.92	3.72	-37.16			

Table 56. Changes in forb density (#/0.10m^2) and relative composition (%) for grazed pastures at the Schnell Recreation Area, 2006-2011.

	Forb Density (#/0.10 m^2)			Relative Composition (%)		
	Exclosure 2006	Grazed 2011	% Difference	Exclosure 2006	Grazed 2011	% Difference
Late Succession	1.48	1.60	8.11	26.81	14.08	-47.48
Mid Succession	0.26	1.10	323.08	4.71	9.68	105.52
Early Succession	3.78	8.56	126.46	68.48	75.35	10.03
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	5.52	11.26	103.99	5.52	11.26	

Table 57. Changes in herbage biomass (lbs/ac) and relative composition (%) for the control pasture and grazed pastures after six years of twice-over rotation management at the Schnell Recreation Area, 2011.

	Herbage Biomass (lbs/ac)			Relative Composition (%)		
	Control Pasture	Grazed Pastures	% Difference	Control Pasture	Grazed Pastures	% Difference
Domesticated	2333.98	1216.24	-45.96	85.11	58.03	-31.82
Cool Season	57.49	518.18	801.34	2.10	23.84	1035.24
Warm Season	153.73	48.89	-68.20	5.61	2.25	-59.89
Sedges	11.82	245.17	1974.20	0.43	11.28	1085.00
Native Grass	223.05	812.23	264.15	8.13	37.37	359.66
Total Grass	2557.03	2073.47	-18.91	93.24	95.39	2.31
Forbs	185.43	100.11	-46.01	6.76	4.61	-31.80
Total Live	2742.47	2173.57	-20.74	38.35	60.69	58.25
Standing Dead	1229.02	509.77	-58.52	17.19	14.23	-17.22
Litter	3178.78	898.17	-71.74	44.46	25.08	-43.59
Total Dead	4407.80	1407.93	-68.06	61.65	39.31	-36.24
Total Biomass	7150.27	3581.51	-49.91	7150.27	3581.51	

Table 58. Changes in basal cover (%) and relative composition (%) for the control pasture and grazed pastures after six years of twice-over rotation management at the Schnell Recreation Area, 2011.

	Basal Cover (%)			Relative Composition (%)		
	Control Pasture	Grazed Pastures	% Difference	Control Pasture	Grazed Pastures	% Difference
Domesticated	15.35	6.88	-55.18	85.99	29.43	-65.78
Cool Season	0.35	3.93	1022.86	1.96	16.81	757.65
Warm Season	0.85	2.53	197.65	4.76	10.82	127.31
Sedges	1.05	9.55	809.52	5.88	40.85	594.73
Native Grass	2.25	16.00	611.11	12.61	68.43	442.66
Total Grass	17.60	22.88	30.00	98.60	97.86	-0.75
Forbs	0.20	0.50	150.00	1.12	2.14	91.07
Woody Species	0.05	0.00	-100.00	0.28	0.00	-100.00
Total Live	17.85	23.38	30.98	17.85	23.38	30.98
Litter	82.15	76.63	-6.72	82.15	76.63	-6.72
Total	100.00	100.00				

Table 59. Changes in forb density (#/0.10m^2) and relative composition (%) for the control pasture and grazed pastures after six years of twice-over rotation management at the Schnell Recreation Area, 2011.

	Forb Density (#/0.10 m^2)			Relative Composition (%)		
	Control Pasture	Grazed Pastures	% Difference	Control Pasture	Grazed Pastures	% Difference
Late Succession	2.72	1.60	-41.18	73.12	14.08	-80.74
Mid Succession	0.80	1.10	37.50	21.51	9.68	-54.99
Early Succession	0.04	8.56	21300.00	1.08	75.35	6876.85
Woody Species	0.16	0.00	-100.00	4.30	0.00	-100.00
Total Live	3.72	11.26	202.69	3.72	11.26	

Table 60. Mean herbage biomass (lbs/ac) and relative composition (%) for the control pasture and grazed pastures at the Schnell Recreation Area, 2006-2011.

	Pregrazing 2006	2006	2007	2008	2009	2010	2011
Control Pasture NR 4							
Native Grass	43.53	158.23	259.08	162.75	354.35	314.19	223.05
% Composition	1.21	4.52	9.14	6.67	12.88	12.80	5.62
Domesticated	1684.81	1833.85	1791.31	1320.16	1779.62	1468.69	2333.98
% Composition	46.86	52.37	63.19	54.14	64.71	59.85	58.77
Standing Dead	1824.68	1381.12	708.48	928.70	499.32	432.54	1229.02
% Composition	50.75	39.44	24.99	38.08	18.16	17.63	30.95
Grazed Pastures NR 1 & NR 2							
Native Grass	430.67	493.66	606.90	478.73	827.07	681.44	812.23
% Composition	15.07	20.37	26.02	38.45	52.46	32.63	30.27
Domesticated	1066.48	954.70	1156.08	310.77	547.59	685.72	1261.24
% Composition	37.31	39.39	49.57	24.96	34.73	32.83	47.00
Standing Dead	1213.84	853.06	491.99	420.37	107.40	363.68	509.77
% Composition	42.46	35.20	21.10	33.76	6.81	17.41	19.00

Table 61. Rhizosphere weight (kg/m^3) for the control pasture and grazed pastures during six years of twice-over rotation management, 2006-2011.

	Control Pasture kg/m^3	Grazed Pastures kg/m^3	% Difference
Pregrazing 2006	52.23	77.99	49.32
2006	64.24x	83.28x	29.64
2007	77.82x	92.22x	18.50
2008	70.67y	122.61x	73.50
2009	82.88y	140.32x	69.31
2010	86.85y	183.00x	110.71
2011	130.56y	214.34x	64.17

Means in the same row and followed by the same letter (x, y) are not significantly different (P<0.05).

Table 62. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) on the grazed pastures at the Schnell Recreation Area, 2011.

Grazed Pastures NR 1 & NR 2	lbs/ac Exclosure	mg/kg Exclosure	lbs/ac Grazed	mg/kg Grazed	% Difference
Mineral Nitrogen	53.78	16.49	56.74	17.39	5.50
Nitrate	6.84	2.10	5.66	1.74	-17.25
Ammonium	46.94	14.39	51.08	15.65	8.82

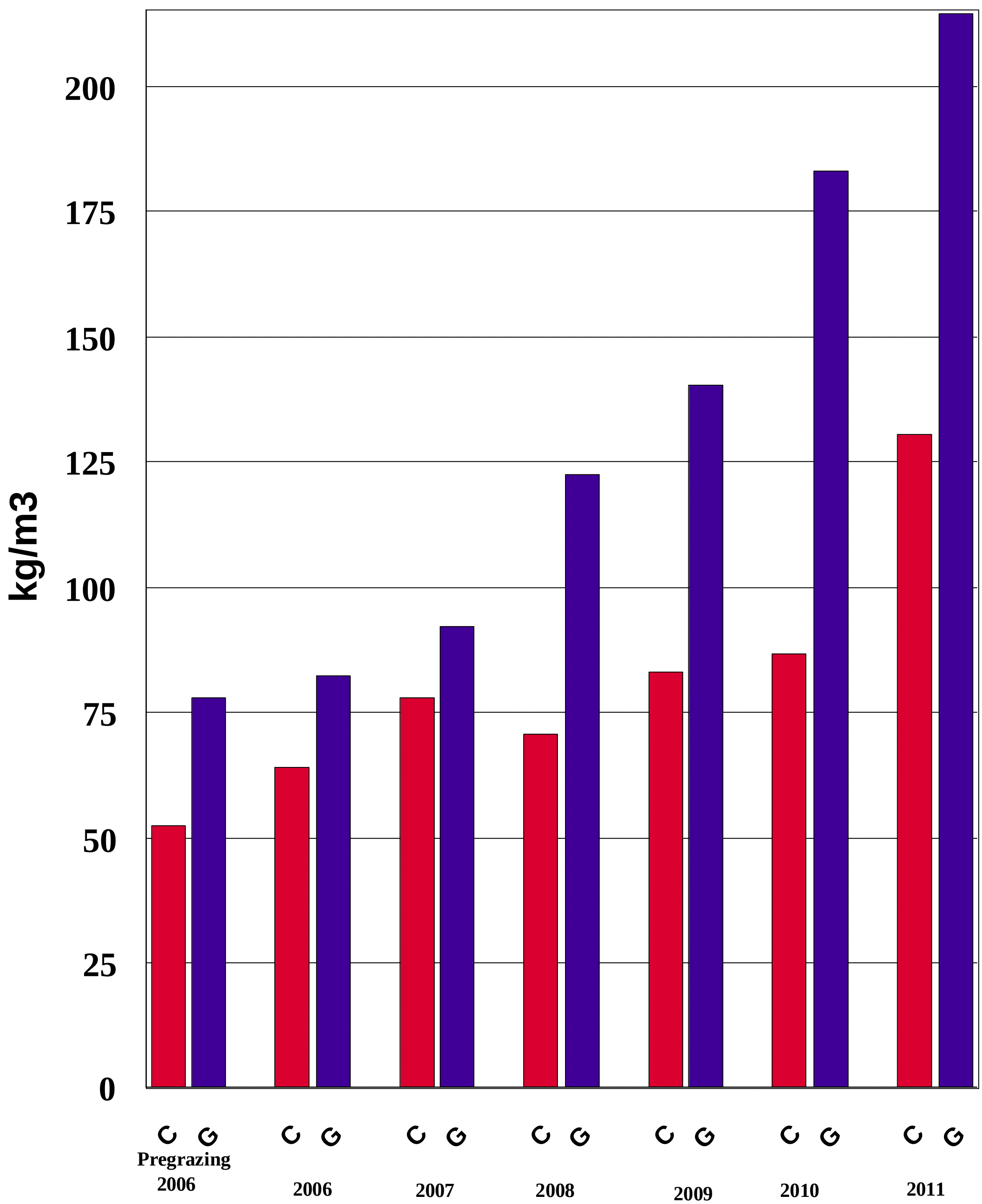

Figure 3. Rhizosphere weight (kg/m3) for the control pasture (red) and grazed pastures (blue) during six years of twice-over rotation management, 2006-2011.

Discussion

Management of grassland ecosystems has customarily been applied from the perspective of the "use" of the grassland. There are grasslands designated for livestock use, other grasslands designated for wildlife use, and some grasslands designated for several uses. The theoretical multiple use of grasslands for watershed, wildlife, recreation, and livestock uses has, in practice, been a process to equate ecosystem impact of the various uses and proportionalize the uses into perceived percentages. Thus, following the concept of management for multiple uses, necessitates reduction of livestock use proportional to the perceived increases in wildlife use, recreation use, etc.

The Schnell Recreation Area was intended, as implied in the name, to be managed for recreation use. Since recreation was considered to occupy 100% of the use, livestock use was reduced proportionally. Cattle grazing was not permitted for 13 years between 1993 and 2005. Placing management priority on the use of a grassland ecosystem imposes antagonistic effects on grassland plants and soil organisms that causes deterioration of biogeochemical processes, and reduction of native grassland productivity. As a result, the mixed grass prairie ecosystems on the SRA were degraded; the desirable native grass species were reduced severely, and the undesirable domesticated grasses were increased extremely.

The cause of degradation of the prairie ecosystems on the Schnell Recreation Area was the antagonistic effects from nondefoliation management that did not meet the biological requirements of the perennial native grass plants and the rhizosphere organisms. Ecosystem deterioration started with management caused reductions in the quantity of plant carbon exudates released into the rhizosphere; reduced carbon exudates caused a decreased in rhizosphere organism biomass and activity; and reduced rhizosphere organism vitality caused a reduction in the quantity of soil organic nitrogen converted into mineral nitrogen. Decreased amounts of available mineral nitrogen below 100 lbs/ac in the ecosystem caused reductions in native grass herbage biomass production and caused decreases in native grass density (basal cover). As degradation continued, numerous large bare spaces between native grass plants were created in the plant communities. These open spaces were ideal habitat for growth of opportunistic domesticated grass species. The composition of grass species changed with decreases in the desirable native species and increases in the less desirable domesticated species. This change in plant composition from desirable to undesirable species was actually the visible symptom of ecosystem degradation; the fundamental cause of the degradation was the reduction of rhizosphere biomass, the reduction of ecosystem biogeochemical processes, and the reduction of available mineral nitrogen below 100 lbs/ac. The degree of plant species change lagged behind the degree of ecosystem function degradation.

There is a major fundamental problem with the traditional concepts of managing renewable natural resources from the perspective of their use or for the product removed. Management of renewable resources for a use narrowly considers only a few elements directly related to that use or product, and neglects to address the needs of all the other components required for the ecosystems to function at potential levels. The renewable natural resources (rangelands, grasslands, croplands, forestlands, and fisheries) have all been managed traditionally for their use. The ecosystems of all of these renewable resources are currently functioning at subpotential levels. The declining production from our nations renewable natural resources is a symptom of degraded ecosystem functions that result from management of renewable resources for a use.

Renewable natural resources are complex ecosystems with several trophic layers of living organisms that have individual biological requirements, and with numerous nonliving components that have changeable characteristics. It is imperative for future progress that management of renewable natural resources be directed away from placing priority on the use and to be focused towards meeting the requirements of all the living and nonliving components of the ecosystem for the purpose of improving ecosystem processes and maintaining production at potential sustainable levels.

In order to achieve continued ecosystem production at potential sustainable levels, the rangeland and grassland renewable natural resources require that management focus on the critical components and meet the biological requirements of the plants and soil organisms. The ecosystem biogeochemical processes and the organism physiological mechanisms that provide the biological requirements for grassland plants and rhizosphere organisms require annual activation from partial defoliation by large graminivores. Grazing animals are a necessity for grassland plants and rhizosphere organisms.

Effectively meeting the biological requirements of grassland plants and soil organisms occurs when the defoliation resistance mechanisms of grass plants and the biogeochemical processes of grassland ecosystems are annually activated by partial defoliation of grass tillers at phenological growth stages between the three and a half new leaf stage and the flower (anthesis) stage. These defoliation resistance mechanisms and biogeochemical processes ensure healthy productive native grass plants, active rhizosphere organisms, and fully functioning mixed grass prairie ecosystems. Full activation of the compensatory internal physiological processes within grass plants accelerates growth rates of replacement roots, leaves, and shoots, increases photosynthetic capacity of remaining mature leaves, increases allocation of carbon and nitrogen, improves water (precipitation) use efficiency, and increases restoration of biological processes enabling rapid and complete recovery of partially defoliated grass tillers. Full activation of the asexual processes of internal vegetative reproduction increases secondary tiller development from axillary buds and increases initiated tiller density during the grazing season. Full activation of the external symbiotic rhizosphere organism activity increases mineralization of mineral nitrogen, increases biogeochemical cycling of essential elements, and improves belowground resource competitiveness (Wight and Black 1972, 1979; 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; Manske 1999, 2011; Kochy and Wilson 2000). Activation of these mechanisms and processes result in increased herbage biomass production, increased plant density, increased available forage nutrients, increased soil aggregation, improved soil quality, increased soil water holding capacity, increased resistance to drought conditions, improved wildlife habitat, improved grassland aesthetics, and improved status of grassland ecosystem health (Manske 2011).

Conclusion

Grass plants, rhizosphere organisms, and grassland ecosystem biogeochemical processes require partial defoliation of grass leaves by grazing graminivores to maintain health and productivity. Grass plants, soil organisms, and graminivores have evolved complex symbiotic relationships. Large grazing graminivores depend on grass plants for nutritious forage. Grass plants depend on rhizosphere organisms for mineralization of essential elements, primarily nitrogen, from the soil organic matter. The main sources of soil organic matter are grazing animal waste and dead plant material. Rhizosphere organisms depend on grass plants for energy in the form of short carbon chains. Sufficient quantities of short carbon chain energy can be exudated from grass plants through the roots into the rhizosphere with removal of 25% to 33% of the aboveground leaf material by large grazing graminivores while grass lead tillers are between the 3.5 new leaf stage and the flower stage. Grass plants produce double the leaf biomass than is needed for existence to counteract the loss of leaf area removed by grazing graminivores.

The grass herbage biomass produced in addition to the necessary herbage biomass has traditionally been allocated as forage for grazing livestock. The primary method used to transfer the additional double the production of grass herbage biomass from use as forage for grazing animals to uses as wildlife habitat and for aesthetically pleasing recreation activities has been implementation of long-term nondefoliation management. However, nondefoliation management starts a complex chain reaction with numerous serious biological problems that create native grassland ecosystem degradation.

Removal of grazing graminivores from grassland ecosystems prevents partial defoliation of grass tillers at vegetative growth stages which results in greatly reducing the quantity of exudated short carbon chain energy from grass tillers through the roots into the rhizosphere reducing the soil organism biomass and activity diminishing mineralization of nitrogen and other essential elements to deficiency quantities.

The additional double the leaf biomass produced by grass plants blocks sunlight from reaching native grass leaves, if not removed annually during the growing season by grazing graminivores, that results in greatly decreased photosynthetic rates diminishing the amounts of fixed carbon to deficiency quantities.

The rapidly accumulating quantities of standing dead biomass decrease slowly by leaching and weathering because the dead litter biomass cannot make contact with the soil surface and decompose more rapidly through microbial activity. The standing dead biomass builds up into a thick mulch layer. Thick mulch effectively blocks sunlight from reaching understory young grass leaves. Thick mulch insulates the soil from warm spring air temperatures preventing heating of cold soil that causes delays in plant and soil organism activity. 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. Thick mulch absorbs and holds precipitation for later evaporation preventing the water from infiltrating into the soil diminishing soil water to deficiency quantities.

Nondefoliation of native grass plants creates critical deficiencies in rhizosphere organisms, mineral nitrogen, essential elements, sunlight, fixed carbon, soil warmth, and soil water. These deficiencies of indispensable component resources prevent grass plants from synthesizing sufficient quantities of vital carbohydrates, proteins, and nucleic acids. With insufficient quantities of vital organic compounds native grass plants cannot maintain production of herbage biomass and tiller numbers.

The defoliation resistance mechanisms are prevented from activation within grass plants as a result of the removal of grazing graminivores from grassland ecosystems. The defoliation resistance mechanisms are a set of physiological, biological, and biogeochemical processes developed by grasses very early during the coevolution with graminivores and are responsible for the remarkable biological success and long survival of grasses in the world. Failure to activate the defoliation resistance mechanisms by annual partial defoliation by grazing graminivores greatly restricts grass plant use of important mechanisms and processes necessary for normal grass growth and development.

Growth and development of undefoliation native grasses are limited by deficiencies of indispensable component resources, inhibited by insufficient quantities of vital organic compounds, and diminished by restricted use of important mechanisms and processes. The resulting progression of decreasing production of herbage biomass and tiller numbers creates substantial bare spaces in the plant community.

Introduced domesticated grasses invade the unoccupied spaces and soon become the dominant vegetation of the degraded grassland ecosystems. The live and standing dead leaves of the domesticated grasses cause additional blockage of sunlight from reaching understory native grass leaves. The accumulation of dead domesticated grass litter enhances the thick mulch problems. As a result of invasion of introduced domesticated grasses into the plant community, the composition of native grasses diminishes greatly. The degree of deterioration of mixed grass prairie ecosystems caused by long-term nondefoliation management is far greater than the degradation caused by poor grazing management.

The reductions in herbage biomass and tiller basal cover and the changes in plant species composition are the observable symptoms of grassland ecosystem degradation. The fundamental cause of degradation, however, is the diminishment of ecosystem biogeochemical processes and the resulting deficiencies in mineral nitrogen, other essential elements, sunlight, fixed carbon, and soil water. The degree of reductions in aboveground plant biomass and the changes in species composition lags behind the degree of belowground ecosystem biogeochemical degradation.

Restoration of mixed grass prairie ecosystems degraded by nondefoliation management and subsequently invaded by introduced domesticated grasses is complex because of several interdependent biological problems. The surviving rhizosphere organisms exist at dangerously small biomass; the composition of the native grass plants remaining in the plant communities is extremely low; the large quantity of surplus standing live and dead domesticated grass herbage biomass causes stifling shading problems for native grasses; and the great quantity of undecomposed litter biomass causes thick mulch problems for ecosystem processes.

Restoration of degraded mixed grass prairie ecosystems depends on the successfulness of recovery of the biogeochemical processes and revival of the indispensable component resources. The rhizosphere organism biomass must be improved initially to increase mineralization of nitrogen and other essential elements. Rhizosphere organisms are limited by access to energy in the form of short carbon chains. Short carbon chain energy is available from grass lead tillers at growth stages between the 3.5 new leaf stage and the flower stage. Exudation of the short carbon chain energy from the grass lead tillers into the rhizosphere can be triggered with removal of 25% to 33% of the aboveground leaf biomass by large grazing graminivores. Two growing seasons using this partial defoliation grazing treatment are required before substantial increases in rhizosphere organism biomass occur. The rate of rhizosphere biomass increase is greater as a result of short carbon chain energy exudated from native grasses than from Kentucky bluegrass.

Increasing sunlight intensities reaching the understory native grass leaves sufficiently to enhance the photosynthetic rates and increase the quantity of fixed carbon requires removal of substantial quantities of the domesticated grass herbage biomass. Removal of large quantities of herbage biomass from the dominating introduced domesticated grasses requires grazing by large graminivores managed with a biologically effective strategy at relatively high stocking rates, around 85% to 100% of assessed levels. Stocking rates greater than 100% can remove great quantities of domesticated grass herbage in a short time period. However, this apparent positive effect causes negative effects that initiate extreme increases in weedy forbs that remain problems for many years. Stocking rates less than 85% do not remove enough domesticated grass herbage to effectively reduce the shading problem which continues to cause insufficient sunlight intensities to reach the understory native grass leaves. Shaded native grasses do not improve but continue to decline. Stocking rates between 85% and 100% remove enough domesticated grass herbage biomass to permit an increased intensity of sunlight to reach the leaves of native grasses that increases the photosynthetic rates and fixes carbon at greater quantities.

Decreasing the ecosystem problems of cold soil temperatures during spring, reduced quantities of biogeochemical cycling essential elements, and reduced quantities of soil water requires reduction in the biomass of thick mulch. Livestock do not preferentially consume old dead litter. Reduction of large quantities of litter biomass requires high animal activity associated with high stocking rates.

Following the successful initial recovery of the biogeochemical processes and the beginning of the revival of the indispensable component resource deficiencies, enhancement of the native grass herbage biomass and basal cover can be initiated through activation of the defoliation resistance mechanisms. Activation of the defoliation resistance mechanisms requires a trigger of partial defoliation by grazing graminivores that removes 25% to 33% of the aboveground leaf biomass from grass lead tillers between the 3.5 new leaf stage and the flower stage. This grazing treatment activates the compensatory internal physiological processes that increase grass herbage biomass production and activates the internal vegetative reproductive processes that increase grass basal cover.

Restoration of mixed grass prairie ecosystems degraded by nondefoliation management and subsequently invaded by introduced domesticated grasses takes several years. The length of time required to reach recovery is related to the severity of degradation.

After the implementation of a biologically effective grazing management strategy and the successful initial recovery of the the biogeochemical processes, the amounts of available mineral nitrogen, essentail elements, fixed carbon, and soil water start increasing from deficient quantities towards functional quantities. With the increasing component resources, native grass plants are able to synthesize increasing quantities of carbohydrates, proteins, and nucleic acids. Activation of the defoliation resistance mechanisms provides important biological and physiological processes permitting native grasses to use the vital organic compounds in increasing quantities for the production of herbage biomass and basal cover. Within a few years, the composition of native grasses increases in the plant community and becomes the dominant vegetation. The native grasses improve in competitiveness for the belowground resources of soil water, mineral nitrogen, and other essential elements which eventually reduces the remaining introduced domesticated grasses to minor composition in the plant community.

Restoration of degraded grassland ecosystems requires partial defoliation by large grazing graminivores that removes 25% to 33% of the aboveground leaf biomass from grass lead tillers at growth stages between 3.5 new leaf stage and the flower (anthesis) stage. Recovered mixed grass prairie ecosystems require the same annual partial defoliation treatment by large grazing graminivores to maintain health and productivity.

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