Effects of Grazing on Restoration of Southern Mixed Prairie Soils

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Abstract

A comparative analysis of soils and vegetation from cultivated areas reseeded to native grasses and native prairies that have not been cultivated was conducted to evaluate restoration of southern mixed prairie of the Great Plains over the past 30 to 50 years. Restored sites were within large tracts of native prairie and part of long-term grazing intensity treatments (heavy, moderate, and ungrazed), allowing evaluation of the effects of grazing intensity on prairie restoration. Our objective was to evaluate restored and native sites subjected to heavy and moderate grazing regimes to determine if soil nutrients from reseeded cultivated land recovered after 30 years of management similar to the surrounding prairie and to identify the interactive influence of different levels of grazing and history of cultivation on plant functional group composition and soils in mixed prairies. For this mixed prairie, soil nitrogen and soil carbon on previously cultivated sites was 30 to 40% lower than in uncultivated native prairies, indicating that soils from restored sites have not recovered over the past 30 to 50 years. In addition, it appears that grazing alters the extent of recovery of these grassland soils as indicated by the significant interaction between grazing intensity and cultivation history for soil nitrogen and soil carbon. Management of livestock grazing is likely a critical factor in determining the potential restoration of mixed prairies. Heavy grazing on restored prairies reduces the rate of soil nutrient and organic matter accumulation. These effects are largely due to changes in composition (reduced tallgrasses), reduced litter accumulation, and high cover of bare ground in heavily grazed restored prairies. However, it is evident from this study that regardless of grazing intensity, restoration of native prairie soils requires many decades and possibly external inputs to adequately restore organic matter, soil carbon, and soil nitrogen.

Key words: carbon sequestration, nitrogen conservation reserve program.

Introduction

The southern mixed prairie, like most prairies in North America, has become highly fragmented by agricultural practices over the past century. Estimates of land use patterns suggested that of the 24 million ha that existed before European settlement, only 8 to 35% remain (Bragg & Steuter 1995; Licht 1997). Settlement of the Great Plains resulted in highly variable land use patterns with few large uncultivated tracts remaining (Klopatek et al. 1979; Bragg & Steuter 1995). Since the Dust Bowl of the 1930s, much of the marginal cultivated land has been either reseeded or left fallow to proceed through succession (Weaver 1950; Kindscher & Tieszen 1998). Currently, remnant native plant communities are found within a regional matrix of cultivated lands and are typically managed for livestock production. Local reseeded prairies are rarely separated from uncultivated areas and are often managed within larger blocks of native prairie. Comparative analysis of cultivated areas that have been reseeded to native grasses and native prairies that have not been cultivated but managed similarly provide an opportunity to evaluate the effects of long-term management on restoration of mixed prairie.

The Conservation Reserve Program (CRP) was initiated in the United States by the 1985 farm bill that paid farmers to establish permanent cover on marginal cropland. This program was designed to reduce commodity surplus and encourage soil conservation. As of 1992, 36.4 million ha of cropland were converted to perennial vegetation (Licht 1997; Kindscher & Tieszen 1998). In the Great Plains, perennial grasses were reseeded into cultivated areas, and livestock grazing, haying, and other management practices that impact vegetation establishment were excluded for 10 to 15 years. The CRP does not allow livestock grazing on land enrolled in the program; however, many earlier efforts at restoring cultivated lands were done with the intent to graze livestock. Many of the CRP contracts have ended and were not renewed, resulting in the introduction of livestock onto these reseeded areas. Largely because of the CRP program and the increase in atmospheric carbon, there

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has been an increased interest in soil carbon storage, soil fertility, and ecosystem recovery of restored grasslands (Burke et al. 1995). It is important to evaluate the potential implications of livestock grazing on these restored grasslands to determine if exclusion or moderation of grazing after reseeding of native grasses is appropriate.

Management of domestic livestock on rangelands can have variable effects on soil fertility and stability (Milchunas & Lauenroth 1993) and on vegetation structure and composition (Fuhlendorf & Smeins 1997). Therefore, it is likely that grazing intensities can influence the rate of recovery of restored prairies. Several studies have noted that after cultivation, recovery of soil nutrient pools may take decades or even centuries (Burke et al. 1995; Kindscher & Tieszen 1998), but no studies have evaluated the influence of different grazing intensities on the rate of recovery in reseeded grasslands. Our objective was to evaluate restored and native sites that are within long-term heavy and moderate grazing regimes to determine if soil nutrients from reseeded cultivated land have recovered after 30 years of management similar to the surrounding prairie and to identify the interactive influence of different levels of grazing and history of cultivation on plant functional group composition and on soils in mixed prairies.

Study Area

This study was conducted on the Marvin Klemme Range Research Station (35°25′N; 99°05′W)of the Oklahoma Agricultural Experiment Station. The area is located approximately 15 km south of Clinton, Oklahoma in the Rolling Red Plains Resource Area of the southern Great Plains. Average annual precipitation is 76.6 cm, ranging from 51.0 to 81.7 cm (Gillen et al. 2000). Approximately 70% of the rainfall occurs during the primary growing season from April to September. The average date of the last frost is April 8, and the average date of the first frost is October 30. The mean monthly temperature is highest for July (28.4°C) and lowest for January (8.9°C). The 600-ha research station is largely rolling uplands cut by several steep drainages with a mean elevation of 490 m. Rock outcrops and bare areas are common. Soils are highly erosive and primarily classified as a Cordell silty clay loam with a depth of 25 to 36 cm over solid siltstone (Moffatt & Conradi 1979; Gillen et al. 2000).

The vegetation is typical of the southern mixed prairie with variable dominant species dependent on topoedaphic effects and land use. The dominant species are a mixture of perennial grasses with variable statures. Midgrasses are dominant in the area and primarily include *Bouteloua curtipendula* (sideoats grama), *Aristida purpurea* (purple threeawn), and *Bothriochloa laguroides* (silver bluestem). Dominant shortgrasses include *Bouteloua gracilis* (blue grama), *Buchloe dactyloides* (buffalograss), and *Bouteloua hirsuta* (hairy grama). Tallgrasses are less abundant and include *Schizachyrium scoparium* (little bluestem), *Sorghastrum nutans* (yellow indiangrass), and *Andropogon gerardii* (big bluestem). There is also a high diversity of herbaceous dicots that vary with annual fluctuations in precipitation. Woody plant species include *Rhus glabra* (smooth sumac) and *Prunus angustifolia* (chickasaw plum) in isolated portions of the landscape and the widely distributed subshrub *Gutierrezia sarothrae* (broom snakeweed). Taxonomic nomenclature follows Hatch et al. (1990).

In 1989, the research site was divided into 10 pastures to study the importance of variable grazing intensities to livestock production and rangeland condition. These long-term treatments have been adjusted to represent replicated moderate and heavy grazing where livestock are given access to pastures from approximately 1 May until the middle of September. Moderate grazing represents stocking rates that approximate USDA Natural Resource Conservation Service recommendations for the specific site, whereas heavy grazing is nearly twice the moderate stocking rates. In addition, an unreplicated 16-ha area that has not been grazed by domestic livestock for at least 50 years provides an important reference point to evaluate anthropogenic influences. Historical land use on the site has been primarily grazing, with approximately 30% of the area cultivated and reseeded in patches that range from 3 to 27 ha (Gillen et al. 2000). Local areas that were once cultivated occur in almost all pastures and were allowed to naturally revegetate or were reseeded 30 to 50 years ago. Livestock have grazed the entire area since at least 1900 at stocking rates estimated at moderately heavy to heavy since 1965 (Gillen et al. 2000).

Methods

A 100-m grid of permanently marked sample points was established within each of four replicates (40 to 65 ha) of heavy and moderate grazing treatments. Equidistant spacing of 100 m between samples resulted in 28 to 44 sample points in each treatment unit, with variability due to differences in unit size and shape (Fig. 1). Approximately 20% of these sample points were located within areas cultivated until approximately 1950 to 1970 when they were naturally revegetated or reseeded to native grasses (Table 1). Aerial photographs from 1950 and 1984 were used to identify and label the cultivation history as restored (cultivated until 30–50 years ago and then reseeded or left fallow) or native (never cultivated) at each sample point. An additional 12 sample points were randomly established within an unreplicated 16-ha prairie that has never been cultivated and has not been grazed over the past 50 years.

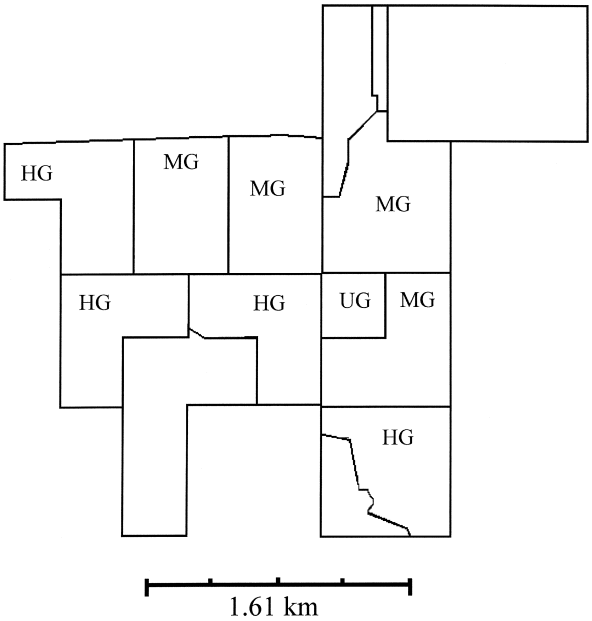

Figure 1. Diagram of the Marvin Klemme Range Research Station (UG, ungrazed; MG, moderately grazed; HG, heavily grazed), which is located approximately 15 km south of Clinton, Oklahoma.

In 1999, five 10-cm deep soil samples were collected with a 2.5-cm diameter soil probe along each 12-m line to the east of each sampling point. The five cores of subsamples were combined to make a single composite soil sample for each sampling point. Soil samples were air dried and ground to pass through a 2-mm sieve. Subsamples were ground to a finer powder using a coffee grinder for soil carbon (C) and total nitrogen (N) analyses. Organic matter contents were determined by loss on-ignition method (Nelson & Sommers 1996) and converted to organic carbon using a factor of 58%. Total N was measured by dry combustion method (LECO Co., St. Joseph, MI, U.S.A.). Soil pH and buffer index were measured by glass electrode in 1:1 soil-to-water suspension and SMP buffer solution, respectively (Sims 1996). Soil NO_3-N was extracted with 0.2% calcium sulfate ($CaSO_4$) solution and quantified by the cadmium-reduction method (Johnson 1992). Plant-available P and K were extracted using Mehlich III solution (Tucker 1992). Phosphorus in solution was determined by colorimetric method, K was determined by inductively coupled plasma emission spectrometry, and both were expressed as an index (Zhang et al. 1998). A random subset of 12 samples from each treatment was further analyzed to determine interactive influences of grazing and historical land use for total N and organic C. This subset resulted in 12 samples from each grazing intensity × land use history combination, including the ungrazed native prairie.

Table 1. Number of soil samples collected and analyzed for properties in each treatment.

	Heavily Grazed		*Moderately Grazed*		*Ungrazed*
	Cultivated	*Native*	*Cultivated*	*Native*	*Native*
Sample Points analyzed for pH, NO_3-N, P, and K	36	80	24	111	12
Subsample for analysis of OC, TN, OM, and C:N	12	12	12	12	12

OC, organic carbon; TN, total nitrogen; OM, organic matter.

The 100-m grid of permanently marked sampling points was established for a long-term study focused on vegetation response to grazing over time. At each point, three 0.10-m^2 evenly spaced quadrats were sampled for vegetation along a 12-m transect to the east initiated at each sampling point. Percent cover of vegetation, bare ground, and litter (Daubenmire 1959) were collected at the end of the growing season in 1998. Plant species were classified as functional groups based on response to grazing, stature, and life history traits (tallgrasses, midgrasses, shortgrasses, perennial forbs, annuals, and shrubs) (Fuhlendorf & Smeins 1998; Gillen et al. 2000).

Analysis of variance (GLM, SAS Institute Inc. 1985) was used to determine statistical differences in plant functional groups and soil parameters among grazing treatment, cultivation history, and their interaction. Analysis of grazing treatments was conducted by using the four replicates of each treatment as experimental units. Patches of cultivated land within each treatment were not uniformly distributed within all grazing experimental units, so land use history effects and the grazing intensity × land use history interaction could not be tested with a traditional split-plot analysis within grazing intensity experimental units. Instead, sampling points (100-m grid) were used as pseudo-replicates and analyzed with analysis of variance to test the interactive influence of grazing and cultivation history on soils and vegetation. Because of the complexity and unbalanced design of the interaction, significance levels throughout this study were defined as $p < 0.10$ for the interaction and $p < 0.05$ for main effects.

Results

Analyses of soil nutrients among grazing treatments ($n = 8$) were only significantly different for NO_3-N, with higher levels in moderate than heavily grazed grasslands (Table 2). Within grazing treatments (see Ta-

Table 2. Soil properties and biotic features (percent cover) in each grazing treatment in native grasslands within the southern mixed prairie of the Great Plains.

	Grazing Treatment		
	Heavy	*Moderate*	*Ungrazed*
Soil properties			
Organic matter (%)	2.94 (0.28)	2.98 (0.12)	3.77
Soil carbon (%)	1.39 (0.18)	1.70 (0.07)	2.15
Soil nitrogen (%)	0.15 (0.02)	0.17 (0.01)	0.22
Carbon:nitrogen	11.33 (0.63)	10.05 (0.51)	10.21
NO_3-N (mg/kg)*	3.30 (0.28)	4.21 (0.28)	4.42
Plant available P index	54.02 (3.30)	49.73 (1.73)	56.17
Plant available K index	592.89 (28.80)	553.14 (18.14)	513.58
PH	7.75 (0.05)	7.56 (0.10)	7.83
Biotic features			
Tallgrasses*	1.44 (0.53)	6.62 (1.37)	19.30
Midgrasses	21.61 (1.44)	20.57 (1.46)	16.47
Shortgrasses	5.31 (0.67)	8.69 (0.98)	8.28
Perennial forbs	2.20 (0.39)	1.37 (0.23)	4.80
Annuals	7.62 (1.10)	5.97 (0.89)	5.49
Shrubs	2.55 (0.99)	2.45 (0.87)	1.00
Litter	13.27 (1.20)	13.24 (1.14)	22.48
Bare*	27.23 (2.27)	21.30 (1.91)	5.42

Values are means; with SE in parentheses.
*Statistical significance between heavy and moderate grazing treatments.

ble 1 for sample numbers), soil carbon, total nitrogen, organic matter, NO_3-N, and K were all significantly higher on sites that had not been cultivated than on sites that had been cultivated and restored (Table 3). Carbon-to-nitrogen ratio and pH were highest in areas with a history of cultivation. For soil carbon and percent total nitrogen, there was a significant interaction between grazing intensity and cultivation history (Fig. 2). The ungrazed native prairie had the highest levels of all nutrients except for K, though significance was not tested because of lack of replication of the ungrazed treatment.

The interaction between grazing and cultivation history was significant for percent cover of tallgrasses and litter. For tallgrass cover (primarily *Schizachyrium scoparium* and *Andropogon gerardii*) the greatest differences occurred among grazing treatments, but within the moderate grazed treatment tallgrasses were more abundant on reseeded sites than native sites (Fig. 2). For litter cover, the interaction was significant because of lower accumulations in the heavily grazed grasslands that had been historically cultivated. Bare ground was primarily influenced by history of cultivation, with more bare ground in restored prairies than native, but there were also differences among grazing treatments with more in heavy than moderate grazing. Grasslands that had a history of cultivation were significantly lower than uncultivated grasslands for cover of shortgrasses, midgrasses, annuals, and litter.

Discussion

Cultivating grasslands can reduce soil organic matter up to 50% within a few years of initial cultivation (Schlesinger 1986; Buyanovsky et al. 1987; Zhang et al.

Table 3. Soil properties and biotic features (percent cover) for native prairie and prairie restored approximately 30 years ago within the southern mixed prairie of the Great Plains.

	Cultivation History	
	Restored	*Native*
Soil properties		
Organic matter (%)*	2.44 (0.11)	3.28 (0.14)
Soil carbon (%)*	1.35 (0.08)	1.87 (0.08)
Soil nitrogen (%)*	0.13 (0.01)	0.20 (0.01)
Carbon:nitrogen*	11.01 (0.41)	9.58 (0.29)
NO_3-N (mg/kg)*	2.80 (0.19)	4.10 (0.15)
Plant available P index	48.22 (2.34)	52.98 (1.79)
Plant available K index*	516.67 (14.41)	591.04 (10.09)
pH*	7.73 (0.05)	7.60 (0.03)
Biotic features		
Tallgrasses	6.71 (1.89)	3.46 (0.86)
Midgrasses*	17.07 (1.66)	21.88 (1.21)
Shortgrasses*	2.79 (0.62)	8.69 (0.78)
Perennial forbs	1.58 (0.33)	1.81 (0.28)
Annuals*	3.84 (0.86)	7.72 (0.88)
Shrubs	0.53 (0.53)	3.19 (0.86)
Litter*	8.36 (1.24)	14.97 (1.00)
Bare*	36.16 (3.05)	20.06 (1.60)

Values are means, with SE in parentheses.
*Statistical differences.

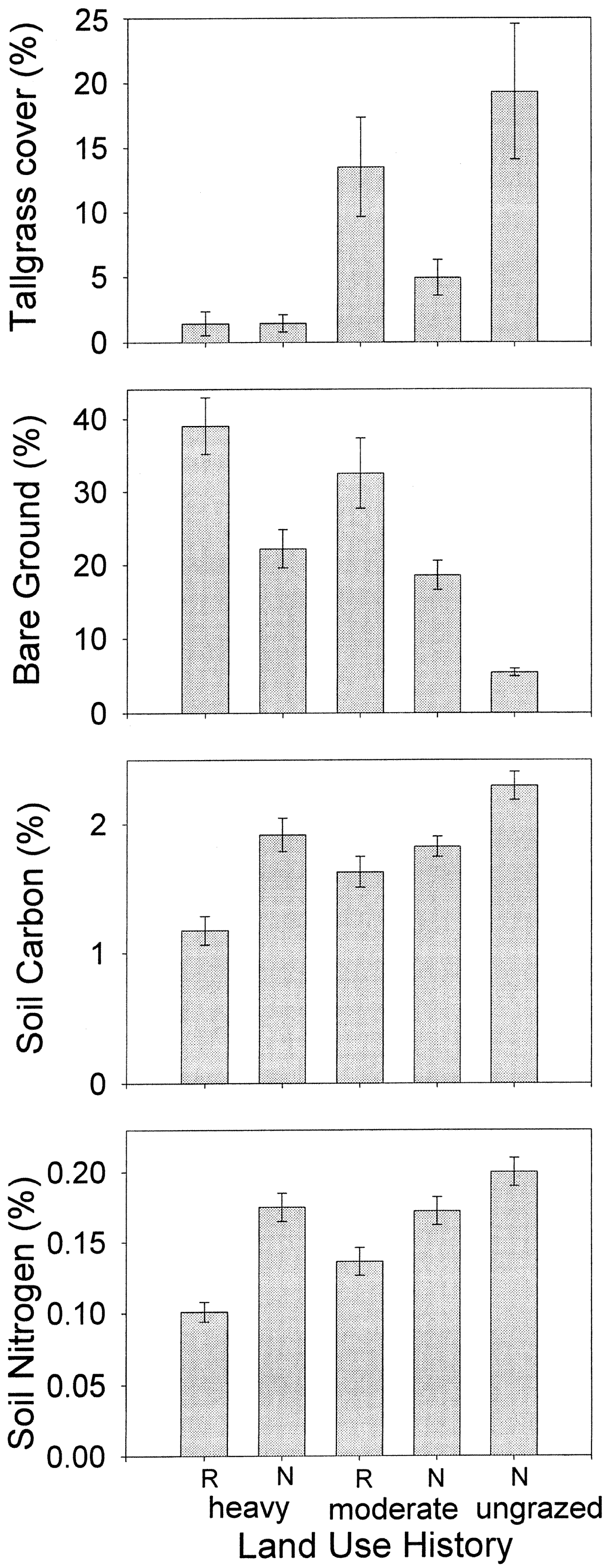

Figure 2. Percent cover of tallgrasses and bare ground and percent soil carbon and soil nitrogen from sites with different grazing histories (heavily grazed, moderately grazed, ungrazed) and cultivation histories (N, native; R, restored or previously cultivated). Vertical bars represent standard errors. Tallgrasses, soil carbon, and soil nitrogen were significant for the interaction between grazing intensity and cultivation history, whereas bare ground was only significant for main effects ($p < 0.10$).

1988; Asner et al. 1997), but only a few studies have quantified the rate of recovery after restoration. A study of restored shortgrass prairie indicated that significant recovery of soil N availability and stability had occurred 50 years after the reintroduction of native perennial grasses (Burke et al. 1995). Yet, carbon capture rates and soil organic matter remained low in these restored prairies. On tallgrass prairie in northeastern Kansas that had been restored for 35 years, soil organic matter remained lower than in native prairie (Kindscher & Tieszen 1998). For this mixed grass prairie, soil nitrogen and soil carbon on previously cultivated sites was 30 to 40% lower than on uncultivated native prairies, which indicates that soils from restored sites have not recovered over the past 30 to 50 years. In addition, grazing intensity alters the extent and rate of recovery of these grassland soils as indicated by the significant interaction between grazing intensity and cultivation history for soil nitrogen and soil carbon.

Livestock grazing can alter amounts, spatial patterns, and composition of nutrient accumulation in soil (Dormaar et al. 1990; Frank et al. 1995; Schuman et al. 1999) and can directly affect species composition and ecosystem structure of grasslands (Ellison 1960; Fuhlendorf & Smeins 1997, 1998). Heavy grazing can increase carbon allocation to leaves, decrease root biomass, and ultimately lower nutrient inputs into the soil (Schuster 1964; Holland & Detling 1990; Schuman et al. 1999). Most of these grazing effects depend on grazing intensity, climate, and topoedaphic variation (Milchunas & Lauenroth 1993; Fuhlendorf & Smeins 1997, 1998). Our study indicates that regardless of cultivation history, soils and vegetation of heavily grazed sites differed significantly from moderately grazed sites (Table 2). However, main grazing effects in this study were confounded as indicated by the interaction between grazing intensity and cultivation history.

The interactive effects of grazing intensity and cultivation history on soil carbon and nitrogen are evident through the variable effects of grazing on restored versus native sites. On restored sites, soil nitrogen and soil carbon were higher with moderate grazing than with heavy grazing, whereas on sites that had never been cultivated grazing minimally influenced soil nutrients (Fig. 2). A primary difference in nutrient cycling and accumulation of soil organic matter between restored and native prairies is expressed by reduced litter accumulation and altered decomposition rates in cultivated systems (Buyanovsky et al. 1987). Grazing has also been shown to alter litter accumulation and decomposition rates, which in turn alters soil carbon and nitrogen contents (Hart et al. 1988; Shariff et al. 1994; Schuman et al. 1999). For this study, heavy grazing reduced litter accumulation and abundance of the most productive species (tallgrasses) and increased bare ground, which led to a reduced accumulation of soil organic matter and soil nutrients. Therefore, heavy livestock grazing interacts with historical cultivation to slow accumulation rates of soil nutrients and organic matter by reducing the organic pool of nutrients associated with high productivity and litter accumulation.

Increased atmospheric carbon over the past century has heightened interest in restoring land unsuited to cultivation (marginal cropland) as a terrestrial carbon sink. Increases in soil nitrogen and carbon levels after prairie restoration from abandoned cropland suggest that the widespread adoption of the CRP could increase soil fertility and stability of some sites and potentially buffer increases in atmospheric carbon (Burke et al. 1995; Knops & Tilman 2000). However, historical cultivation of land unsuited to cultivation has caused considerable erosion in the Great Plains, reducing the production potential and the ability of restored soils to store carbon (Burke et al. 1995). Several conceptual models have suggested that pedogenetic processes are too slow for restored prairie to represent significant global atmospheric carbon capture after the abandonment of cropland (Burke et al. 1997; Schlesinger 1990). Analysis of these restored and native mixed prairie sites indicated that historical cultivation remains a primary factor limiting the ability of many soils to store carbon even more than 30 years after initial restoration efforts. These sites remain lower in carbon than uncultivated sites and can only be considered as a carbon sink in the long term (>100 years) without significant efforts to increase productivity and soil organic matter.

Thirty years after restoration, restored mixed prairies generally had about 30 to 40% lower soil organic carbon and total nitrogen and about 40% higher bare ground than native prairies. Other studies reported that the exclusion of grazing from native mixed grass prairies could, over the long term, reduce soil carbon and nitrogen cycling and potentially the productivity of the system (Schuman et al. 1999). This study suggests that heavy grazing on native mixed prairie has little influence but heavy grazing on restored mixed prairies actually reduces the rate of soil nutrient and organic matter accumulation. Grazing effects on restored prairies are largely due to changes in composition (reduced tallgrasses), reduced litter accumulation, and high cover of bare ground in heavy grazed restored prairies. These data support policies that limit grazing on restored prairies in the CRP, if an objective of this program is restoration of grassland ecosystems or building soil carbon pools. Management of livestock grazing is likely to be a critical factor in determining the potential restoration of mixed prairies. However, it is evident from this study and others that regardless of grazing intensity, restoring native prairie soils requires many decades and possibly external inputs to restore organic matter, soil carbon, and soil nitrogen.

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