The Friends of Nachusa Grasslands
2014 Scientific Research Project Grant Report
Due June 30, 2015

Name: Jason E. Willand and Sara G. Baer

2014 grant amount: $2,800.00

Research Project Topic: The influence of land use history on forage quality for the reintroduction of bison.

Research Project Purpose: The purpose of this research project was to quantify the nutrient content in soil and grass forage in prairie restorations and remnants to determine the extent to which forage quality varies across the landscape and is influenced by former agricultural land use.

Research Project Outcomes to Date: The preliminary findings of this study did not show a relationship between soil nitrogen storage and forage quality, as remnant prairies had the lowest stored nitrogen but the greatest forge quality based on crude protein.

Describe how the grant funds you have received from the Friends of Nachusa Grasslands have been used in regard to the above topic, purpose, and/or outcomes:
The funds we received have been used to cover the costs of soil carbon/nitrogen and forage quality analyses, as well as vehicle rental for our sampling trip.

Describe how your project has benefited the work and goals of Nachusa Grasslands:
Our study has provided baseline data that will be valuable in evaluating the potential landscape usage of bison in regards to grazing in the north reintroduction unit.

Describe how your findings can be applied to challenges in management practices for restoration effectiveness and species of concern:
Our findings suggest that current management practices may be effective for maintaining a sustainable environment for bison grazing in both restored and remnant prairies at Nachusa Grasslands through prescribed burning. We found that differences exist in forage quality between different aged restorations and remnant prairie, but that prescribed burning may be able to prolong the nutritional quality of forage to support more heterogeneous usage of the landscape by bison.

The Influence of Agricultural Legacy on Forage Quality: Implications for Bison Introduction in a Landscape Mosaic

A Final Report

Submitted to:

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Introduction

The principle drivers in formation and maintenance of the tallgrass prairie ecosystem were climate, fire, and grazing by large ungulates. Bison, in particular, were the most dominant grazers prior to European settlement and play a "keystone" role in the maintenance of biodiversity through wallowing behavior and preferential grazing on dominant grasses (Knapp et al. 1999; McMillan et al. 2011; Collins and Calabrese 2012). Bison have been reintroduced into a few tallgrass prairie preserves that have never been converted to row-crop agriculture, but in only one other prairie restored from cultivation, Neal Smith National Wildlife Refuge in Iowa (Kagima and Fairbanks 2013). In this refuge containing restored prairie, sexual differences in bison foraging behavior occur, where mixed age and female animals preferentially grazed recently burned areas – selecting forage quality over quantity (Kagima and Fairbanks 2013). Selection for higher quality forage by bison in recently burned area has also been documented in natural prairie, and crude protein decreases exponentially with days since fire (Alfred et al. 2011). Forage quality may also vary between remnant and restored prairie because there is less storage of nutrients (nitrogen) in soil that has been cultivated (McLauchlan et al. 2006; Matamala et al. 2008; Baer et al. 2010) and foliar nitrogen was shown to be higher in a prairie grass growing in remnant prairie compared to restored prairie (Baer et al. 2005). Thus, the forage quality likely varies over the landscape containing restored and remnant prairie at Nachusa Grasslands, with potential consequences for the distribution, localized grazing intensity, and performance of introduced bison.

Cultivating grassland lowers soil organic matter (Anderson and Coleman 1985) that supplies most of the nitrogen (N) to grasses for protein synthesis. Plant proteins account for most of the N transferred to grazers. By this logic, prairie restored from long-term cultivation likely produces grass biomass with lower N content, an important determinant of forage quality.

Previous research at Nachusa Grasslands has demonstrated that N storage in cultivated soil is ~40% that of native prairie remnants and total soil N shows negligible change from cultivated levels following 20 years of prairie restoration (Klopf 2013; Hansen and Gibson 2014). Despite this low storage of N in the soil, aboveground productivity is similar among prairies restored for >4 years (Klopf 2013). Productivity of restored (relative to native) prairie at Nachusa Grasslands likely contains lower N because root biomass increases over time and the amount of N relative to carbon in roots declines as restoration proceeds (Klopf 2013). We are certain that the quality of roots declines as restorations age and becomes lower than native prairie (Klopf 2013). If root nutrient concentrations reflect N in aboveground tissue, then we predict the quality of forage will also decline with restoration age.

The N content of aboveground biomass is known to vary among species, functional groups (cool-season more nutritional than warm-season), management (higher following burning of areas that have not recently burned) and season. Forage quality has been defined as the overall nutritional value of a plant, and how efficiently a grazer can convert forage into mass containing carbohydrates, fats, and proteins (Linn and Martin 1999). Bison preferentially eat grasses, which typically have lower quality forage relative to forbs. Therefore, bison require high quantity low quality food. Knowledge of N content (derived from soil) and caloric content (derived from photosynthesis) of forage will be valuable for understanding the performance of bison on a restored landscape, as crude fiber and protein in forage have been key parameters in explaining the behavior and performance of cattle in grassland (Stejskalová et al. 2013), including restored prairie (Kagima and Fairbanks 2013).

The overall goal of this research was to quantify whether forage quality varies across native prairie remnants, low seeded-diversity older-restored, and high seeded-diversity younger-restored sites and is related to N storage in soil at Nachusa Grasslands. Knowledge of forage quality for bison is needed to predict and explain bison distribution and grazing intensity on the landscape containing a patchwork of restorations and native prairie remnants. We predict there will be lower grass forage quality, with less nitrogen and crude protein, in restored sites relative to remnant prairie, attributed to lower N storage in the soil. We also predict the lowest quantity of forage will be available in the high seeded-diversity younger plantings compared to native prairie remnants and low seeded-diversity older restored prairies.

Materials and Methods

Study site

The study was conducted at Nachusa Grasslands, located in Lee and Ogle counties Illinois. Nachusa is comprised of ~1,900 ha of restored and remnant prairie, oak savanna, and agricultural land managed by the Nature Conservancy. We sampled native prairie remnants (Rem) (n=3), low seeded-diversity older restored prairies (LD) (n=3), and high seeded-diversity younger restored prairies (HD) (n=3) for forage quality in July 2014. Within each field three sampling transects were established along a 50 m baseline transect. The transects were established at random distances along the 50 m baseline. Due to the small size of the remnant prairies, the length of each baseline transect in these fields was modified to fit the widest axis. Five 0.10 m^2 frames were placed 10 m apart along each transect starting from the 10 m point on each transect to sample plant biomass and soil. GPS coordinates were taken at the starting and ending point of each baseline transect and the starting and ending points of each sampling transect (Table 1).

Aboveground biomass and forage quality

All aboveground biomass rooted within the 0.10 m^2 frames along each transect was clipped at ground level and sorted by forbs, graminoids (grasses and sedges) and litter. It should be noted that since our collection was not during the peak of the growing season (late August-September) we did not quantify above net primary productivity (ANPP). Biomass samples were dried at 60^oC, weighed, composited by transect, and later ground. A subsample was analyzed for percent N at SIU and a second subsample was sent to the University of Wisconsin Madison Soil and Forage Laboratory to analyze for acid detergent fiber and neutral detergent fiber, lignin, NDF digestibility, and in vitro dry matter to determine the overall digestibility of the forage, crude protein, and fat content. Acid detergent fiber and neutral detergent fiber analyses represent the digestible and indigestible components of forage (cellulose, hemicellulose, and lignin). Neutral detergent fiber digestibility (NDFD) represents both animal consumption and forage energy content. Dry matter is the percentage of forage that is not water.

Soil carbon and nitrogen

One 2 cm diameter soil core was taken at a depth of 20 cm (separated into 0-10 cm and 10-20 cm to compare to previous studies) following clipping within the area of the frame. Soil cores were composited by depth and transect. In the laboratory soil cores were homogenized through a 4mm sieve. Two 50 g subsamples were dried at 55°C and ground to a fine powder. From each subsample, 50-100 mg was analyzed for percent C and N with a Thermo Scientific Flash 1112 CN Analyzer distributed by CE Elantech Corporation (Lakewood, NJ). Percent C and N were converted to volumetric amounts based on equivalent mass determined from bulk density cores. We measured bulk density of soil from three (1 per transect) 5.5 cm dia. x 20 cm deep (separated into 0-10 cm and 10-20 cm to compare to previous studies) intact soil cores dried to a constant mass at 105°C and weighed.

Statistical analyses

Aboveground biomass, forage quality, and soil carbon and nitrogen were analyzed using an analysis of variance (ANOVA) in SAS (SAS 9.3 2011). Significance was assigned at $\alpha = 0.05$.

Results

Aboveground biomass

There was not a significant difference in graminoid biomass between the three prairie types ($P > 0.05$) (Figure 1a). Although not statistically significant, there was greater graminoid biomass in restored prairies compared to remnant prairies (Figure 1a). Forb biomass differed between the three prairie types ($F_{2,6} = 4.93$, $P = 0.054$) (Figure 1b), with the greatest amount of forb biomass in the high seeded-diversity younger-restored prairies compared to the low seeded-diversity older-restored prairies and remnant prairies. Total biomass also differed between the three prairie types ($F_{2,6} = 64.10$, $P < 0.001$) (Figure 1c). Total biomass in the high seeded-diversity younger-restored prairies was almost twice that of the low seeded-diversity older-restored prairies and more than twice that of the remnant prairies (Figure 1c).

Forage quality

There was not a significant difference in dry matter, neutral and acid detergent fiber, and neutral detergent fiber digestibility between the three prairie types ($P > 0.05$) (Figure 2a-d). The percentage of lignin in dry matter was greatest in the high seeded-diversity younger-restored prairies compared to both the low-seeded-diversity older-restored prairies and remnant prairies ($F_{2,6}$ = 6.06, P = 0.009) (Figure 2e). The percentage of crude protein in dry matter was significantly greater in the remnant prairies compared to both of the restored prairies ($F_{2,6}$ = 11.51, P < 0.001) (Figure 2f). The fat content of forage differed between the three prairie types ($F_{2,6}$ = 5.33, P = 0.015) (Figure 2g), with the greatest fat content available in the high seeded-diversity younger-restored prairies.

Soil carbon and nitrogen

Total soil carbon and nitrogen did not differ between the three prairie types at either the 0-10 cm or 10-20 cm depth. Total soil carbon was similar between the three prairie types at both the 0-10 cm and 10-20 cm depths (P > 0.05) (Figures 3a & c). Total soil nitrogen at the 0-10 cm depth did not significantly differ between the three prairie types (P > 0.05) (Figure 3b), but there was more available nitrogen in the restored prairies compared to the remnant prairies. Total soil nitrogen at the 10-20 cm depth was also not significantly different between the three prairie types (P > 0.05) (Figure 3d), but there was again more nitrogen available in the restored prairies compared to the remnant prairies.

Discussion

Plant diversity and productivity in tallgrass prairie is typically attributed to the availability of nitrogen in the soil (Seastedt and Knapp 1993). Historically, nitrogen availability on prairie landscapes was modulated by the interaction between fire frequency and grazing by native ungulates (Collins 1987). The composition and functioning of tallgrass prairie has been modified by the loss of keystone species (i.e. native grazers), habitat fragmentation, increased atmospheric nitrogen deposition and altered fire frequencies (Samson and Knopf 1994). Bison were considered a vital component of historical tallgrass prairie, but little is known about how bison use restored prairie and their influence on plant community trajectories (Kagima and Fairbanks 2013). Our findings suggest that bison may preferentially use the remnant prairies over the restored prairies in the reintroduction unit at Nachusa Grasslands based on higher crude protein and lower lignin content in the forage.

Contrary to our original prediction, there was greater total aboveground biomass in the restored prairies compared to the remnant prairies. Klopf (2013) found similar results for total aboveground net primary productivity between low and high diversity-seeded prairie restorations at Nachusa Grasslands, whereby total ANPP did not change significantly over time during restoration. It is important to note that while total biomass was higher in the restored prairies, this was driven by greater forb biomass. Bison diet consists of > 90% graminoids (Coppedge et al. 1998), which typically have lower forage quality relative to forbs (Holechek et al. 1982). Since graminoid biomass was similar across the three prairie types, it is plausible to assume that the preferred forage of bison will be available in near equal amounts across the landscape at Nachusa Grasslands. The similarity in graminoid biomass across the study site may be attributed to management history. Restorations are initially seeded with a high diversity of plant species to replicate remnant prairies, and sites are maintained through invasive species removal and prescribed burning (B. Kleiman, personal communication). The application of prescribed burning, particularly in the spring, stimulates the growth of the dominant C_4 grasses (Collins and Calabrese 2012) which comprise the majority of bison diet. Based on our findings, there appears to be little difference between restored and remnant prairies in regards to available graminoid biomass for bison consumption.

While the availability of forage may be similar between the three prairie types sampled during this study, there were differences in the nutritional quality of the graminoid forage. Our findings suggest that graminoid forage quality increases during restoration but do not reach levels equivalent with native prairie. We hypothesized that soils with higher nitrogen storage (i.e. remnant prairie) would also have higher forage quality. Our findings did not find a relationship between soil nitrogen and forage quality, as remnant prairies had lower total nitrogen content but higher forage quality than the restored prairies. This could result from much longer established vegetation in the native prairie accumulating N inputs from atmospheric deposition. While differences exist in the nutritional quality of forage between restored and remnant prairies, this may be alleviated for short time periods by management practices. Previous studies have documented an increase in forage quality (particularly crude protein) following prescribed burning (Biondini et al. 1999; Alfred et al. 2011). The increase in forage quality following prescribed burning can be sustained for several years with moderate grazing (Milchunas et al. 1995), and in some cases upwards of a decade following burning (Ranglack and du Toit 2015). The current prescribed burning regime of 12-18 months in both restored and remnant prairies at Nachusa Grasslands may be sufficient to prevent overexploitation of remnants by bison. This is important because the majority of the landscape in the reintroduction unit is restored prairies that have forage consisting of lower crude protein and higher concentrations of undigestible plant components such as lignin. Prescribed burning may be effective in promoting heterogeneous grazing by bison in the remnants and different aged restorations.

Total carbon and nitrogen did not vary significantly between restored and remnant prairies, although there were slightly larger pools in restored prairies. This is again contrary to our original prediction that remnant prairies would have higher soil carbon and nitrogen than restored prairies. The similarity in total carbon and nitrogen between restored and remnant prairies may be the result of plant species composition more than agricultural legacy. Klopf (2013) found that root biomass and root nitrogen storage increased during restoration to levels comparable to remnant prairie. This may explain why there was little difference in total soil carbon and nitrogen between restored and remnant prairies. Another factor that may have contributed to the similarity in total soil carbon and nitrogen was plant cover. Willand et al. (2013) found that plant cover was similar, or in some cases, greater in restored prairies compared to remnant prairies at Nachusa Grasslands. Plant cover may be correlated with similar or greater soil carbon and nitrogen in restored prairies due to the inputs of carbon and nitrogen from plant biomass and greater root stocks belowground from higher densities of plants in restored prairies compared to remnant prairies.

The preliminary findings of this study suggest that bison grazing within the reintroduction unit at Nachusa Grasslands may be more intensive within prairie remnants compared to restorations. The preferred grazing in remnant prairies by bison may create "hotspots" of excessive nitrogen deposition from bison urea. While it is still too early to tell whether bison will have preferred grazing areas within the reintroduction unit, our findings suggest that forage quality of graminoids is higher in the remnant prairies even though the majority of the reintroduction unit consists of prairie restorations.

Acknowledgements

We thank the Friends of Nachusa Grasslands for funding this research. We also thank Bill Kleiman, Cody Considine and Jeff Walk, the Nature Conservancy, for access to study sites and logistical support. Peter Hoch and Ken McCravy assisted in the field and Nick Loman and Alicia Luebbers assisted with biomass and soil processing in the laboratory. Amanda Rothert, SIUC Core Facility, conducted C and N analyses. Forage quality analyses were conducted by the University of Wisconsin-Madison Soil Testing Laboratory.

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Table 1. GPS coordinates (recorded in latitude and longitude) and date sampled for transects in high diversity-seeded younger-restored (HD), low diversity-seeded older–restored (HD) and remnant (Rem) prairies at Nachusa Grasslands, Illinois. Missing coordinates are represented by ---.

Prairie Type	Transect	Latitude	Longitude	Date Sampled
Rem field 1	Baseline start	N41°53.926'	W89°21.560'	140716
	Baseline end	N41°53.904'	W89°21.560'	140716
	1 start	N41°53.918'	W89°21.564'	140716
	1 end	N41°53.920'	W89°21.586'	140716
	2 start	N41°53.912'	W89°21.568'	140716
	2 end	N41°53.914'	W89°21.590'	140716
	3 start	N41°53.906'	W89°21.573'	140716
	3 end	N41°53.906'	W89°21.596'	140716
Rem field 2	Baseline start	N41°53.920'	W89°21.644'	140715
	Baseline end	N41°53.896'	W89°21.656'	140715
	1 start	N41°53.918'	W89°21.644'	140715
	1 end	---	---	140715
	2 start	N41°53.912'	W89°21.649'	140715
	2 end	---	---	140715
	3 start	N41°53.899'	W89°21.656'	140715
	3 end	---	---	140715
Rem field 3	Baseline start	N41°53.839'	W89°21.677'	140716
	Baseline end	N41°53.829'	W89°21.677'	140716
	1 start	N41°53.839'	W89°21.677'	140716
	1 end	N41°53.839'	W89°21.657'	140716
	2 start	N41°53.833'	W89°21.677'	140716
	2 end	N41°53.833'	W89°21.656'	140716
	3 start	N41°53.829'	W89°21.677'	140716
	3 end	N41°53.827'	W89°21.656'	140716
LD field 1	Baseline start	N41°53.787'	W89°21.801'	140718
	Baseline end	---	---	140718
	1 start	N41°53.787'	W89°21.796'	140718
	1 end	N41°53.760'	W89°21.801'	140718
	2 start	N41°53.787'	W89°21.794'	140718
	2 end	N41°53.760'	W89°21.798'	140718
	3 start	N41°53.787'	W89°21.778'	140718
	3 end	N41°53.759'	W89°21.779'	140718
LD field 2	Baseline start	N41°53.782'	W89°21.461'	140718
	Baseline end	---	---	140718
	1 start	N41°53.774'	W89°21.454'	140718
	1 end	N41°53.768'	W89°21.428'	140718

	2 start	N41°53.771'	W89°21.464'	140718
	2 end	N41°53.767'	W89°21.429'	140718
	3 start	N41°53.765'	W89°21.464'	140718
	3 end	N41°53.756'	W89°21.433'	140718
LD field 3	Baseline start	N41°53.929'	W89°21.225'	140718
	Baseline end	---	---	140718
	1 start	N41°53.929'	W89°21.220'	140718
	1 end	N41°53.904'	W89°21.212'	140718
	2 start	N41°53.929'	W89°21.215'	140718
	2 end	N41°53.906'	W89°21.202'	140718
	3 start	N41°53.929'	W89°21.201'	140718
	3 end	N41°53.908'	W89°21.188'	140718
HD field 1	Baseline start	N41°53.931'	W89°22.009'	140718
	Baseline end	---	---	140718
	1 start	N41°53.931'	W89°22.022'	140718
	1 end	N41°53.959'	W89°22.016'	140718
	2 start	N41°53.931'	W89°22.034'	140718
	2 end	N41°53.961'	W89°22.028'	140718
	3 start	N41°53.931'	W89°22.044'	140718
	3 end	N41°53.962'	W89°22.040'	140718
HD field 2	Baseline start	N41°54.019'	W89°22.014'	140719
	Baseline end	N41°54.026'	W89°22.049'	140719
	1 start	N41°54.021'	W89°22.023'	140719
	1 end	N41°54.047'	W89°22.016'	140719
	2 start	N41°54.022'	W89°22.031'	140719
	2 end	N41°54.049'	W89°22.029'	140719
	3 start	N41°54.026'	W89°22.049'	140719
	3 end	N41°54.053'	W89°22.048'	140719
HD field 3	Baseline start	N41°53.915'	W89°20.764'	140719
	Baseline end	---	---	140719
	1 start	N41°53.910'	W89°20.760'	140719
	1 end	N41°53.927'	W89°20.729'	140719
	2 start	N41°53.907'	W89°20.758'	140719
	2 end	N41°53.917'	W89°20.724'	140719
	3 start	N41°53.896'	W89°20.751'	140719
	3 end	N41°53.904'	W89°20.717'	140719

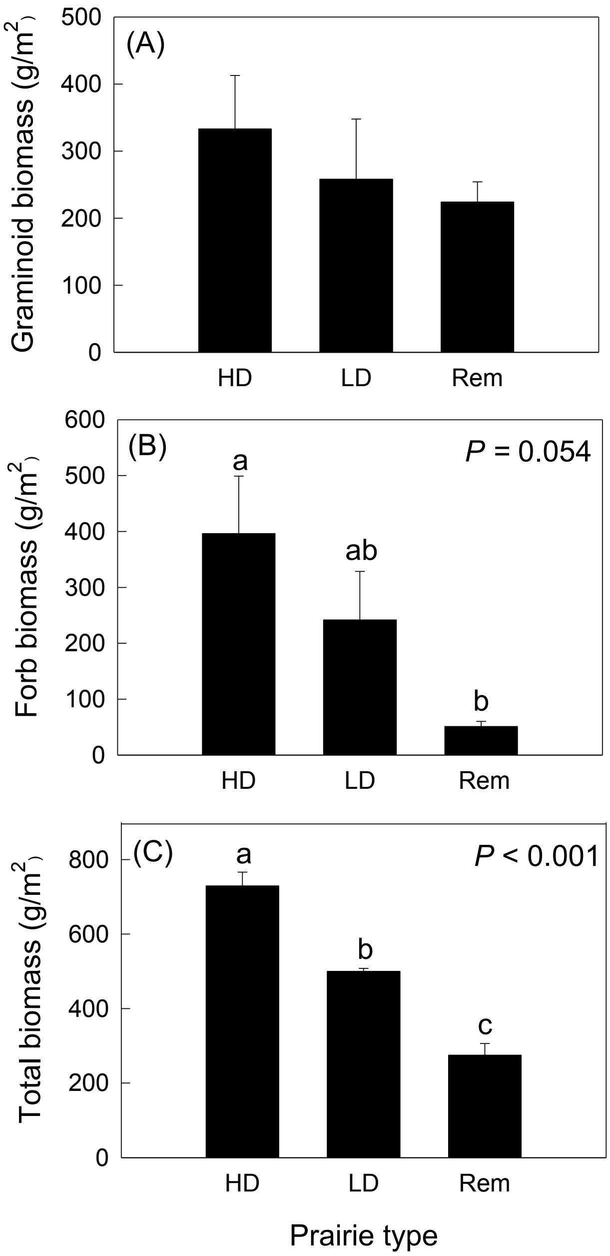

Figure 1. Mean (± standard error) (A) graminoid, (B) forb, and (C) total aboveground net primary productivity (ANPP) from transects sampled in high diversity-seeded younger-restored (HD), low diversity-seeded older –restored (HD) and remnant (Rem) prairies at Nachusa Grasslands, Illinois. Means accompanied by the same letter were not statistically significant ($\alpha = 0.05$).

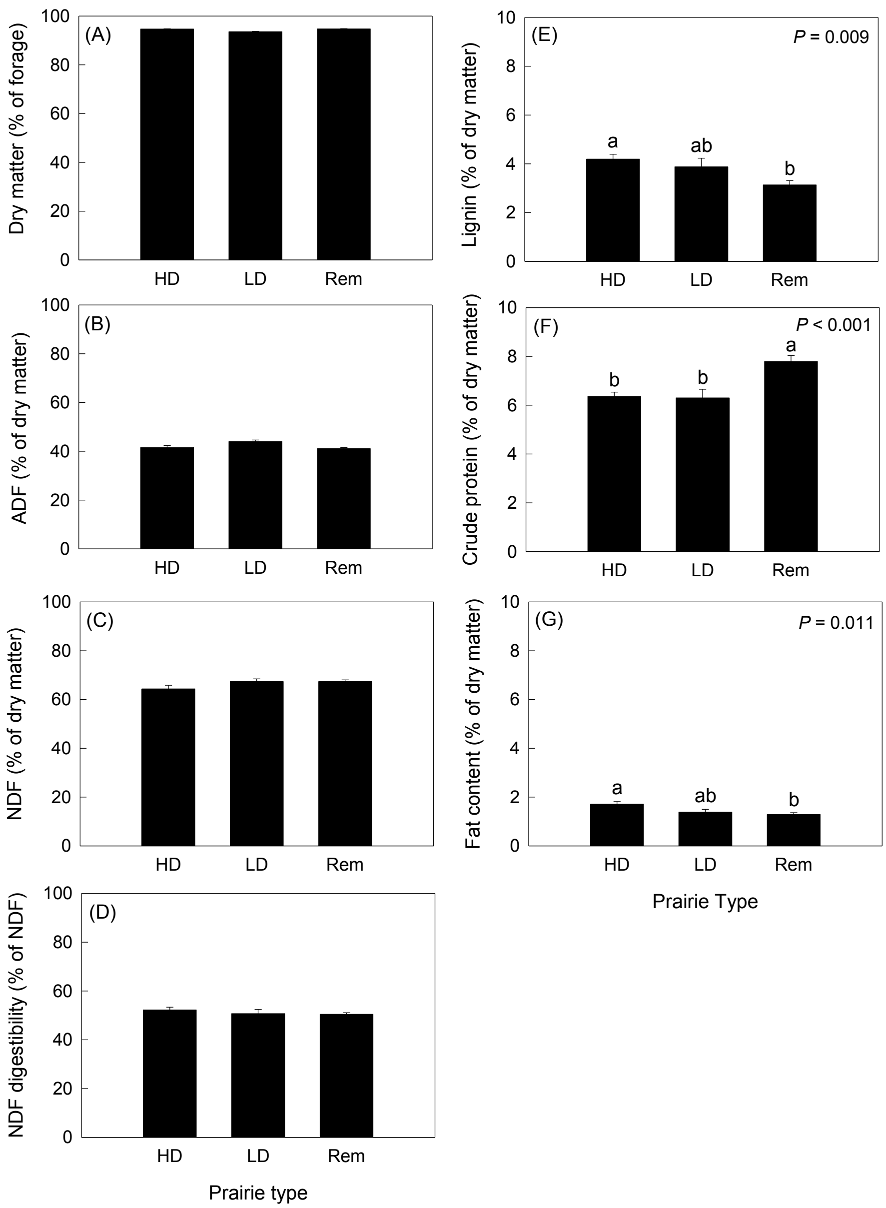

Figure 2. Forage quality as quantified by mean (± standard error) (A) dry matter, (B) acid detergent fiber (ADF), (C) neutral detergent fiber (NDF), (D) NDF digestibility, (E) lignin, (F) crude protein, and (G) fat content from transects sampled in high diversity-seeded younger-restored (HD), low diversity-seeded older–restored (HD) and remnant (Rem) prairies at Nachusa Grasslands, Illinois. Means accompanied by the same letter were not statistically significant (α = 0.05).

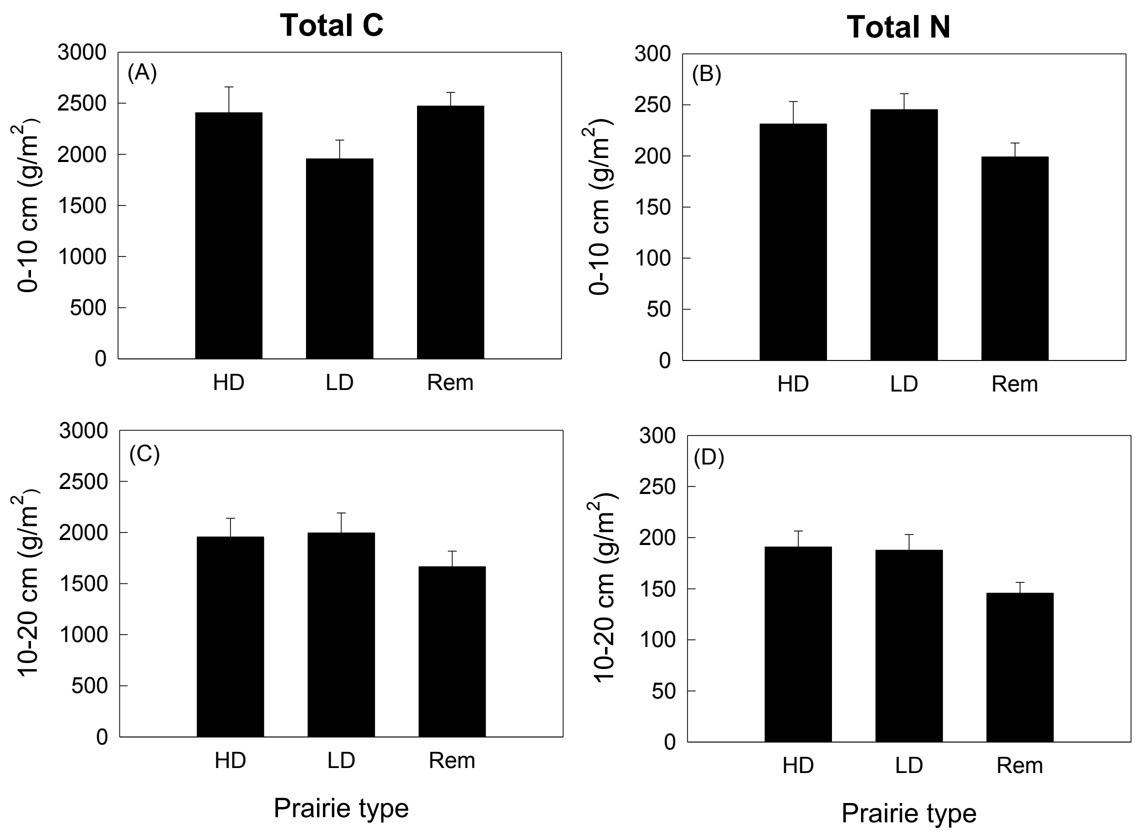

Figure 3. Mean (± standard error) total carbon collected from (A) 0-10 cm and (C) 10-20 cm and total nitrogen collected from (B) 0-10 cm and (D) 10-20 cm depths along transects sampled in high diversity-seeded younger-restored (HD), low diversity-seeded older–restored (HD) and remnant (Rem) prairies at Nachusa Grasslands, Illinois.