Grazing Management, Season, and Drought Contributions to Soil Property Dynamics and Greenhouse Gas Flux in Semiarid Rangeland

Mark Liebig[1*], Scott Kronberg[1], John Hendrickson[1], and Jason Gross[2]
[1]USDA-ARS, Mandan, ND; [2]USDA-FS, Silt, CO

RATIONALE AND OBJECTIVE

Semiarid rangelands provide an array of ecosystem services, yet the role of grazing management and environmental conditions to affect rangeland soil function is poorly understood.

The objective of this study was to assess effects of grazing management, season, and drought on soil property dynamics and greenhouse gas flux within semiarid rangeland.

METHODS

Site and Treatment Description

The research site was located at the USDA-ARS, Northern Great Plains Research Laboratory near Mandan, ND, USA (46° 46′ 12″ N, 100° 55′ 59″ W). The site is characterized by a semiarid continental climate, with long-term (90 yr) mean annual precipitation and temperature of 410 mm and 4°C, respectively. The site is situated on a gently rolling landscape (0-3% slope). The soil possesses a silty loess mantle overlying Wisconsin age till, and is categorized as a blend of Temvik and Wilton silt loams (Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls).

Grazing treatments included two native vegetation pastures and one seeded forage pasture. The two native vegetation pastures included a moderately grazed pasture (2.6 ha steer^{-1}) and heavily grazed pasture (0.9 ha steer^{-1}), both of which were established in 1916. A crested wheatgrass pasture represented the seeded forage, which was planted in 1932 into plowed native range and grazed at 0.4 ha steer^{-1} in late-spring/early-summer and 0.9 ha steer^{-1} for the remainder of the grazing season. To increase production, CWP was fertilized in the fall of each year since 1963 with NH_4NO_3 at 45 kg N ha^{-1}.

Measurements and Data Analyses

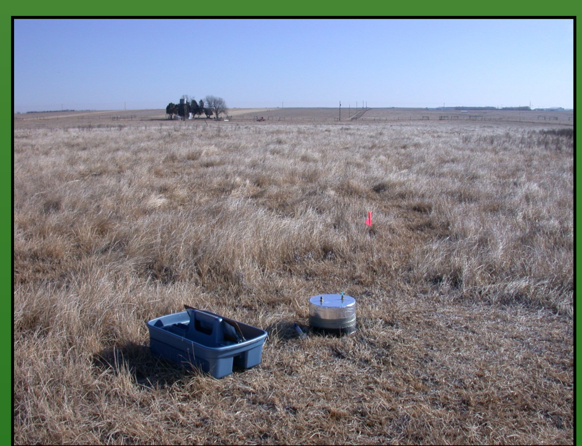
Soil bulk density, electrical conductivity, soil pH, extractable NO_3-N and NH_4-N, and microbial biomass C were evaluated in the grazing treatments in 2004, 2005, and 2006. Soil samples were collected three times per year (mid-April, late-July, early-October) in four randomly selected locations near the center of each treatment with a hand probe at depths of 0-5 and 5-10 cm. Standard laboratory analyses were used. Microbial biomass C was evaluated in late-July only.

Soil-atmosphere CO_2, CH_4, and N_2O fluxes were measured in the grazing treatments from 21 October 2003 to 24 October 2006 using static chamber methodology with six two-part chambers per treatment. Change in gas concentration in chamber headspace was assessed by gas chromatography. Gas flux measurements were made one to two times per week when near-surface soil depths were unfrozen or during mid-winter thawing periods. Otherwise, gas fluxes were measured every other week.

Due to a lack of treatment replication, sampling locations and anchors served as pseudo-replicates in each treatment for soil properties and gas flux measurements, respectively. A mixed repeated measures model was used to analyze the effects of grazing treatment, year, and season on soil properties and gas flux. To evaluate the contribution of soil properties to CO_2, CH_4, and N_2O flux, stepwise regression was employed using a significance criterion of $P \leq 0.1$.

Moderately grazed pasture

Heavily grazed pasture



Crested wheatgrass pasture

FINDINGS AND IMPLICATIONS

Soil Condition

Effect (0-5 cm)	Soil bulk density (Mg m^{-3})	Electrical conductivity (dS m^{-1})	Soil pH (-log[H$^+$])	Soil NO_3-N (kg N ha^{-1})	Soil NH_4-N (kg N ha^{-1})	Microbial biomass C (kg C ha^{-1})
Grazing treatment						
Crested wheatgrass	0.82 (0.01)	0.26 (0.02)	4.83 (0.03)	10.1 (1.1)	9.2 (0.5)	169 (20)
Heavily grazed	0.76 (0.01)	0.29 (0.01)	6.59 (0.02)	2.6 (0.5)	2.6 (0.2)	640 (58)
Moderately grazed	0.72 (0.01)	0.28 (0.01)	6.17 (0.02)	2.6 (0.4)	3.2 (0.5)	534 (42)
P value	*<0.0001*	*0.2638*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Year						
1	0.81 (0.01)	0.25 (0.01)	5.85 (0.11)	3.7 (0.7)	4.0 (0.8)	391 (56)
2	0.74 (0.01)	0.31 (0.01)	5.90 (0.14)	3.7 (0.7)	3.7 (0.8)	434 (82)
3	0.76 (0.01)	0.27 (0.01)	5.84 (0.14)	7.9 (1.2)	7.4 (1.3)	517 (78)
P value	*<0.0001*	*0.0017*	*0.1332*	*<0.0001*	*0.0039*	*0.0700*
Season						
Spring (Mar-May)	0.76 (0.01)	0.22 (0.01)	5.91 (0.13)	3.5 (0.6)	8.3 (1.4)	--
Summer (Jun-Aug)	0.79 (0.01)	0.33 (0.01)	5.79 (0.13)	8.6 (1.1)	4.2 (0.8)	--
Fall (Sep-Nov)	0.76 (0.01)	0.28 (0.01)	5.90 (0.12)	3.2 (0.7)	2.5 (0.4)	--
P value	*0.0586*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	--

Values in parentheses reflect standard error of the mean.

- High stocking rate and fertilizer N application within the crested wheatgrass pasture contributed to increased soil bulk density and extractable N, and decreased soil pH and microbial biomass C compared to native vegetation pastures.
- Seasonal dynamics in soil properties were expressed through significantly lower soil pH in summer compared to spring and fall, elevated soil NO_3-N in summer, and decreasing soil NH_4-N from spring to fall.
- Drought conditions during the third year of the study contributed to approximately two-fold increases in extractable N.
- **Near-surface soil properties exhibited strong responses to not just grazing management, but year and season as well.**

Associations Identified through Stepwise Regression

Variable / Depth	Soil bulk density	Electrical conductivity	Soil pH	Soil NO_3-N	Soil NH_4-N	Microbial biomass C
Carbon dioxide efflux						
0-5 cm		0.23	0.07	0.16		
5-10 cm	0.03	0.36		0.37		
Methane flux						
0-5 cm	0.33				0.10	
5-10 cm		0.26				
Nitrous oxide flux						
0-5 cm	0.09					
5-10 cm		0.43	0.06		0.06	

- Stepwise regression found select soil properties to be moderately-related to soil-atmosphere greenhouse gas fluxes, with model R^2 ranging from 0.09 to 0.76.
- Electrical conductivity was included most frequently in stepwise regressions.
- **Easily measured soil properties (e.g., electrical conductivity) may serve as useful indicators for identifying greenhouse gas hotspots in rangeland.**

ACKNOWLEDGEMENTS

The authors gratefully acknowledge David Brandt, Patrick Kilzer, Angela Renner, Gail Sage, and Becky Wald for their assistance with sample collection and laboratory analyses. This work contributes to the USDA Agricultural Research Service GRACEnet Project.