CARBON AND NITROGEN CYCLING IN HIGH-ELEVATION HAY MEADOWS: UNDERSTANDING PROCESSES FOR IMPROVED AGROECOSYSTEM PRODUCTIVITY

D.M. Adamson, and J.B.Norton
University of Wyoming, Laramie, WY
jnorton4@uwyo.edu (307) 766-5082

ABSTRACT

Irrigated hay meadows are an integral, but often under-performing component of livestock operations in western rangeland ecosystems. Flood irrigation resulting in seasonal saturation, high elevation, and cool temperatures common to these systems result in concentration of organic materials near the soil surface, constraining nitrogen cycling, forage productivity and diversity. Improved understanding of nutrient cycling, soil organic matter processes, and ecosystem services of irrigated hay meadows, as impacted by management, is necessary for improving long-term sustainable production. The goal of this study is to develop process-level understanding in support of management that improves soil health, biodiversity, and productivity of irrigated meadows by sampling four meadow systems in Wyoming and Colorado. At each site, three management scenarios are being compared: fertilized and irrigated meadows, unfertilized and irrigated meadows, and unfertilized and unirrigated rangeland, all on the same soil series. Carbon and nitrogen dynamics are being monitored by sampling the O and A horizons of meadow soils, and the A horizon of rangeland soils. Samples taken in spring and summer of 2021 were analyzed for potentially mineralizable carbon, potentially mineralizable nitrogen, total organic carbon, total nitrogen, microbial biomass carbon, and microbial biomass nitrogen. Results support the hypothesis that carbon and nitrogen dynamics predominate in the O-horizon, with relatively little activity in the A-horizon directly below. Although meadow soils store large amounts of carbon and nitrogen in the O-horizon, this does not translate to mineralization levels that support adequate forage yields in the field, due to limited microbial activity during periods of continuous saturation.

INTRODUCTION

High-elevation hay meadows are integral to the success of ranching operations in the Intermountain West, as they provide critical winter forage for livestock production. Stockpiling adequate stores of hay to overwinter breeding stock and reduce risk of future drought requires ranchers to make management decisions to balance productivity with input costs and productive acres (Taylor et al., 1985). Traditionally, use of nitrogen fertilizer has been one tactic to produce adequate yields in a system where water management and shortened growing season limit productive capacity.

The dependence on nitrogen fertilizer in meadows is somewhat paradoxical considering meadows have an O-horizon at the soil surface containing as much as 1,120-2,464 kg N/ha (Siemer, 1979). This O-horizon develops in meadows as a result of repeated low-efficiency flood-irrigation methods that leave the soil saturated for 6-8 weeks in the growing season (Peck and Lovvorn, 2001). Combined with this, the cold, high-elevation climate in which meadows are found means the soil microbial community has reduced ability to mineralize organic matter for forage production.

With the reoccurrence of drought, increased forage prices, and recently doubled fertilizer prices, ranchers must utilize sustainable management practices to increase productivity of meadow forage systems. Therefore, the objective of this study is to describe soil properties and soil organic matter (SOM) processes that affect nitrogen availability in order to leverage management tactics that make nitrogen more available for sustainable forage production in meadows.

MATERIALS AND METHODS

In spring of 2021, we identified four meadow systems in southern Wyoming and northern Colorado that met the requirements of flood irrigation and elevation greater than 1,980 m. At each meadow system, we further identified three management areas, all on the same soil series: 1) long-term fertilized, irrigated meadow, 2) long-term unfertilized, irrigated meadow, and 3) unfertilized, unirrigated natural rangeland. Three plots were randomly established at each management area for repeated sampling.

Samples were taken in spring 2021, following thaw, and summer 2021, one week prior to hay harvest. In meadows, samples were taken from both the O-horizon (0-5 cm) and the A-horizon directly below (5-15 cm). Because an O-horizon does not exist in the rangeland soils, only the A-horizon was sampled (0-10 cm). Samples were put on ice and transferred to the lab where they were analyzed for potentially mineralizable nitrogen (PMN), potentially mineralizable carbon (PMC), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), total organic carbon (TOC), and total nitrogen (TN). PMN was analyzed using a 2-week anaerobic incubation followed by colorimetric NH4+ analysis (Waring and Bremner, 1964). PMC was analyzed using a 2-week aerobic incubation analyzed for CO2 evolution (Zibilski, 1994). MBC and MBN were determined using the fumigation method followed by extraction in 0.5M K2SO4 and combustion analysis (Horwath and Paul, 1994). TOC and TN were determined using combustion analysis.

Statistical analysis was performed using R 4.1.1. For all soil analyses, an ANOVA was performed with soil horizon, management area, ranch, and sampling date as factors. If sampling date was a significant factor, it was removed from the model and sampling times were analyzed separately. Significance was set at α=0.1, as this is an observational study. Following a significant factor or interaction in the ANOVA, means were separated using Tukey's HSD.

RESULTS AND DISCUSSION

Decades of continuous flood irrigation has resulted in the development of a 3-5 cm O-horizon at the surface of meadow soils (Lewis, 1957). Statistical analysis confirms that the O-horizon significantly affects C and N cycling in meadows, as horizon was a highly significant ($P<0.0001$) model factor for all soil analyses for both spring and summer samplings (Table 1). Meadow soils store large amounts of C and N in the O-horizon, with relatively little C and N in the A-horizon directly below (Table 2, spring sampling & Table 3, summer sampling). This is also true for labile C, N, and microbial biomass (MBC & MBN), where a majority of C and N cycling appears to be occurring in the O-horizon with relatively little activity in the A-horizon for both spring and summer samplings (Table 2 & 3). A potential reason for the lack of activity in the A-horizon is the effect of flood-irrigation on species composition. Long periods of soil saturation common to meadows have been shown to favor rhizomatous grasses with shallow root systems, reducing the amount of organic matter in the A-horizon compared with unirrigated rangeland soils (Table 2 & 3) (Rumburg and Sawyer, 1965).

Table 1: ANOVA p-values for six soil properties on meadow and rangeland soils with soil horizon (O or A for meadow, A for rangeland) as the main factor, and management (fertilized meadow, unfertilized meadow, rangeland) as the sub-factor.

	Horizon		Management		Horizon x Treatment	
	Spring	Summer	Spring	Summer	Spring	Summer
TOC	<0.0001	<0.0001	<0.01	<0.0001	0.09	0.10
TN	<0.0001	<0.0001	<0.01	<0.0001	0.09	0.52
PMC	<0.0001	<0.0001	<0.001	<0.01	<0.01	0.02
PMN	<0.0001	<0.0001	<0.0001	<0.0001	0.41	0.03
MBC	<0.0001	<0.0001	0.54	<0.001	0.63	<0.01
MBN	<0.0001	<0.0001	0.06	<0.01	0.61	<0.01

In the field, it appears mineralization of C and N is limited, as unfertilized forage yields in meadows are commonly low, ranging from 1,700-2,800 kg/ha annually (Rumburg and Siemer, 1975). This is somewhat surprising, considering the C:N ratio of the O-horizon does not exceed 15:1. Our results support that, in ideal conditions, the microbial community is never limited by substrate quality and can mineralize large amounts of C and N in the lab. The reason for the disconnect in meadow nutrient cycling appears to be a result of soil climate. Meadows commonly exist at elevations > 1,980-m, where growing seasons are short and soils remain cold or frozen for long periods of time. When temperatures increase in spring and summer, saturated conditions, as a result of continuous flood irrigation, reduce the ability of the microbial community to mineralize OM (Bossio and Scow, 1995). Considering the need for increased sustainability of western forage systems, ranchers would benefit from improved nitrogen mineralization to support yields without excess dependence on synthetic fertilizer. Research that examines methods to stimulate N mineralization in the field will be critical for improved sustainability of meadows in the future.

Table 2: Average response of meadow and rangeland soils for six soil properties sampled in spring 2021. Different letters within columns denote significant differences at α=0.10

			Analysis					
Location	Management	Horizon	TOC (%)	TN (%)	PMC (mg/kg)	PMN (mg/kg)	MBC (mg/kg)	MBN (mg/kg)
Meadow	Fertilized	O-Horizon	14.77 a	1.13 a	4071 a	61.10 a	3158 a	157 a
Meadow	Unfertilized	O-Horizon	12.75 a	0.94 a	2819 a	31.10 a	3368 a	168 a
Meadow	Fertilized	A-Horizon	1.28 c	0.11 b	172 c	1.22 a	376 a	10 a
Meadow	Unfertilized	A-Horizon	1.47 bc	0.11 c	205 c	1.43 a	359 a	10 a
Rangeland	Unfertilized	A-Horizon	2.34 b	0.17 b	343 b	9.86 a	442 a	18 a

Table 3: Average response of meadow and rangeland soils for six soil properties sampled in summer 2021. Different letters within columns denote significant differences at α=0.10

			Analysis					
Location	Management	Horizon	TOC (%)	TN (%)	PMC (mg/kg)	PMN (mg/kg)	MBC (mg/kg)	MBN (mg/kg)
Meadow	Fertilized	O-Horizon	17.05 a	1.28 a	4216 a	51.93 a	9031 a	290 a
Meadow	Unfertilized	O-Horizon	18.47 a	1.31 a	3243 b	29.06 ab	5424 b	185 b
Meadow	Fertilized	A-Horizon	1.23 c	0.12 a	200 c	1.90 c	408 c	14 c
Meadow	Unfertilized	A-Horizon	2.03 b	0.14 a	222 c	5.26 c	348 c	14 c
Rangeland	Unfertilized	A-Horizon	2.89 b	0.22 a	406 c	19.89 b	580 c	29 c

REFERENCES

Bossio, D.A., and K.M. Scow. 1995. Impact of carbon and flooding on the metabolic diversity of microbial communities in soils. Appl. Environ. Microbiol. 61(11): 4043–4050. doi: 10.1128/aem.61.11.4043-4050.1995.

Horwath, W.R., and E.A. Paul. 1994. Microbial Biomass. In: Bigham, J.. and Mickelson, S.H., editors, Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties. Soil Science Society of America, Madison, WI. p. 753–774

Lewis, R. 1957. Mountain meadow improvement in Wyoming. Univ. Wyoming Ext. Bulletin 3.

Peck, D.E., and J.R. Lovvorn. 2001. The importance of flood irrigation in water supply to wetlands in the Laramie Basin, Wyoming, USA. Wetlands 21(3): 370–378.

Rumburg, C., and W. Sawyer. 1965. Response of wet-meadow vegetation to length and depth of surface water from wild-flood irrigation. Agron. J. 57: 245–247.

Rumburg, C., and E. Siemer. 1975. Forage production and quality. In: Rumburg, C., editor, Alternative Meadow and Livestock Management Systems. Bulletin 5. Colorado Agricultural Exp. Station, Fort Collins, CO. p. 4–6.

Siemer, E. 1979. Mountain Meadow Management Problems and Research Needs. Proc. from Manag. Intermt. Meadows Meet. Jackson WY 1(1): 176–211.

Taylor, D., W. Seamands, D. Menkhaus, J. Jacobs, and R. Delaney. 1985. An economic analysis of n fertilization of intermountain hay meadows. Agron. J. 77(1): 17–20.

Waring, S.A., and J.M. Bremner. 1964. Ammonium Production in Soil under Waterlogged Conditions as an Index of Nitrogen Availability. Nature 201: 951–952.

Zibilski, L.M. 1994. Carbon Mineralization. In: Bigham, J.M. and Mickelson, S.H., editors, Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties. Soil Science Society of America, Madison, WI. p. 835–864