Agriculture, Ecosystems and Environment 255 (2018) 12–19

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Sustainable livestock production in sub-arctic Alaska: Plant and soil responses to simulated intensively managed grazing

Laura Starr*, Steven Seefeldt, Mingchu Zhang, Janice Rowell

School of Natural Resources and Extension, University of Alaska Fairbanks P.O. Box 757140 Fairbanks, AK, USA

ARTICLE INFO

Keywords:
Sub-arctic agriculture
Simulated grazing
Nutrient cycling
Pasture ecology

ABSTRACT

Managing a robust pasture ecosystem and optimizing available forage under sub-arctic conditions in interior Alaska is a challenge. The region is characterized by a short growing season, slow residue decomposition rates and undeveloped soils that are vulnerable to compaction and erosion. The goal of this research was to examine the relative and combined role of grazing mechanisms; herbivory, trampling, and manure/urine deposition on forage yield and soil health in sub-arctic pastures within a simulated intensively managed rotational grazing (IMRG) framework.

A full factorial experiment of muskox (*Ovibos moschatus*) manure/urine deposition (M), simulated trampling (T), and herbivory (forage clipping) (H), and control (C) mimicking IMRG timing and intensity, was conducted at the Robert G. White Large Animal Research Station, University of Alaska, Fairbanks. The simulations were conducted on 48–1 m^2 plots on hilltop and hill bottom pastures with different vegetation and soil types, over the 2014 and 2015 grazing seasons. The control represented a pasture absent of grazing and served as a comparison of the treatments to restorative rest of grazing land.

Grazing treatments MH and MTH had a positive impact on forage yield, while T and MT had a negative impact compared to C ($p < 0.05$) in both pastures. Bare ground was reduced under all treatments in both locations compared to baseline measurements ($p < 0.05$) but was no different to control ($p < 0.16$). Differences were documented in soil parameters in both pastures with the hilltop pasture demonstrating the greatest change; MT had 93% more total water soluble nitrogen (N) and 287% more H3A extracted inorganic N than C ($p < 0.05$). In the hill bottom pasture, MTH had 28.5% more total water soluble N than C ($p < 0.05$). These findings suggest that trampling had a negative impact on forage yield if not combined with herbivory, while it had a positive impact on soil parameters if combined with manure. While grazing impact factors such as manure, trampling and herbivory have the potential to both benefit and harm pasture health, the study documented an improvement to both forage yield, and certain soil aspects of soil health and nutrients when applied in combination under the IMRG paradigm in the Alaskan sub-arctic.

1. Introduction

Many ecosystems in Alaska are well suited to grazing. The North American subarctic supports some of the largest wild herds of grazing ungulates on the continent yet livestock production in Alaska remains relatively undeveloped. In 2012, it was estimated that there were less than 17,000 head of livestock in the state. Despite the enormous size of Alaska, the land area currently in pasture is small at less than 299,000 ha (Dinkel and Czapla, 2012). This constraint of space, along with extreme climactic conditions, a short growing season, expensive imported farm inputs, and competition from other markets, makes maximizing land resources and understanding the potential impacts of grazing livestock in the subarctic environment crucial. With a growing global population, the demand for livestock products is expected to increase exponentially (Pica-Ciamarra et al., 2014). This increased demand coupled with the impacts of climate change and increased pressure on natural resources, makes the question of efficient and sustainable livestock grazing critical (Joyce et al., 2013).

Ungulates impact the ecosystem via three mechanisms: waste deposition, trampling, and herbivory. These mechanisms affect plant and soil biota, nutrient cycling, hydrologic cycling, and soil physical properties in a complex web of interactions (Coughenour, 1985; Teague et al., 2011). As with other disturbances, grazing can have positive or negative impacts on the ecosystem depending on the timing, frequency, and intensity (Wang et al., 2006).

Grazing regimes vary from unfettered access to large areas over the

* Corresponding author.
E-mail addresses: lmstarr@ksu.edu (L. Starr), seefeldt@wsu.edu (S. Seefeldt), mzhang3@alaska.edu (M. Zhang), jan.rowell@alaska.edu (J. Rowell).

https://doi.org/10.1016/j.agee.2017.12.015
Received 10 July 2017; Received in revised form 13 December 2017; Accepted 15 December 2017

course of years to the daily rotation of a herd into different paddocks. Grazing is spatially heterogeneous due to livestock, vegetation, and environmental factors (Briske et al., 2008). This heterogeneous pattern creates areas that are subject to deleterious grazing pressure even under light stocking rates (Barnes et al., 2008; Teague et al., 2011). Over-utilized patches can spiral into a positive feedback loop, where desirable plant communities, soil structure, soil biota, nutrient cycling and hydrological function are compromised and the area deteriorates (Norton, 1998; Teague et al., 2011).

Many regions, including Alaska grasslands and tundra, evolved with large, dense herds of ungulates that play a vital role in ecosystem function. Some practitioners and researchers have demonstrated that domesticated livestock can be used to fill that role with carefully managed grazing (Briske et al., 2008; Teague et al., 2013). Intensively managed rotational grazing (IMRG) is a management regime that proposes to improve pasture usage and ecosystem function by increasing intensity and decreasing duration of grazing events in response to pasture indicators such as plant growth (Savory, 1983; Norton, 1998; Jacobo et al., 2006; Teague et al., 2011). The frequent livestock movement of IMRG can prevent over grazing and over trampling, and distributes dung and urine more evenly (Savory, 1983).

Forage is thought to benefit from less selective grazing and increased recovery periods (Manske, 2003; Barnes et al., 2008). An optimal residual leaf area is critical to recovery of the plant and resilience of the pasture while a regulated amount of grazing on plant species prevents plant maturation and consequent decline in palatability for livestock (Teague et al., 2011). Healthy soil processes ensure efficient recycling of nutrients, regulate hydrological systems, maintain soil structure and ultimately provide vigorous plant growth for livestock forage (Wang et al., 2006; Schmaltz et al., 2013). IMRG theory maintains that partially decomposed organic matter is incorporated into the soil profile from brief but intense trampling. Increased organic matter and improved incorporation is thought to increase soil biota activity and encourage decomposition, thus enhancing nutrient cycling and water storage capacity (Savory, 1983; Donkor et al., 2002; Kohler et al., 2005; Teague et al., 2011). Incorporated organic matter lends resilience and stability to soil structure. Increased stability in soil structure could mitigate adverse effects from trampling and soil compaction (Barnes et al., 2008; Briske et al., 2008; Teague et al., 2011). Academic research has had mixed results on the efficacy of IMRG and has not conclusively demonstrated the outcomes of these ecological assumptions (Donkor et al., 2002; Briske et al., 2008; Teague et al., 2013).

Several studies have demonstrated that subarctic and arctic ecosystems benefit from intensive grazing pressure because of more rapid nutrient cycling from ungulate digestion. Grazing research has documented increased primary productivity due to heavy grazing by muskoxen on a sub-arctic farm and in the high arctic wilds (McKendrick et al., 1980, McKendrick, 1981). Olofsson et al. (2001) measured a beneficial increase in primary productivity and nitrogen cycling as a result of heavy reindeer grazing, while primary productivity decreased under moderate grazing. A simulated study in northern Sweden detailed an increased abundance of soil bacteria and bacteria feeding nematodes only in plots that received trampling and fertilization, compared to plots that received fertilization alone, demonstrating the impact of trampling on soil biota in subarctic soils (Sorensen et al., 2009). These studies suggest that increased grazing pressure and trampling in grazing management may have potential to improve pasture ecosystem function while optimizing available forage in subarctic environments.

The knowledge gap addressed in this research refers to whether the theories that underpin IMRG benefit vegetation and soil in the unique subarctic environment of interior Alaska. We designed a simulation study on related factors, separate, and in combination, to evaluate their relative role and interaction under the prescribed intensity and frequency of the IMRG regime. We measured changes in forage yield, percentage of bare ground, soil nutrients, organic matter, microbial respiration, and microbial biomass to document grazing impacts on pasture health. Our objective was to gain insight into these processes to better predict the impact of IMRG on sub-arctic soil health and plant productivity and take the first steps towards developing sustainable grazing practices for the region.

2. Materials and methods

2.1. Research site

This research was conducted at the Robert G. White Large Animal Research Station (LARS), with an elevation of 210 MASL, at the University of Alaska, Fairbanks, in central Alaska, USA (64.84° N, 147.72 °W). The Fairbanks area has a mean annual temperature of −2.5 °C, 27.5 cm mean annual precipitation, and 80 to 120 frost-free days. LARS is a 54.23 ha research farm facility that is sown with smooth bromegrass (*Bromus inermis),* kentucky bluegrass *(Poa pratensis)*, and red fescue (*Festuca rubra)*. Soils at the research site are a silt loam with less than 10% clay content and poorly incorporated organic material. The site has been continuously grazed by muskoxen (*Ovibos moschatus)* and reindeer (*Rangifer tarandus)* since 1980. These animals were excluded from the study plots for the duration of the simulated trial.

Treatments were applied during the 2014 and 2015 growing season (approximately 110 days for each year). Summer temperature (12.9 °C in 2014, 12.7 °C in 2015) and summer precipitation (7.4 cm in 2014, 5.3 cm in 2015) was above average in both years, compared to 30 year averages (Table 1). The experiment was conducted in two, south facing pastures with different soil types, moisture regimes, and dominant plant species. The hilltop pasture was dominated by Kentucky bluegrass and had well-drained, Fairbanks silt loam soil with loess parent material (NRCS, 2016). Bulk density, a measure of compaction, was 1.4 g/cm^3. The hill bottom pasture was predominantly smooth bromegrass (*Bromus inermis*) and common quackgrass *(Elymus repens*), and had Minto silt loam soil with a colluvium and loess parent material (NRCS, 2016). Bulk density was 1.05 g/cm^3. The hill bottom site was on average 2.9 °C cooler (4.8 °C cooler in June) on the soil surface and 1.6 °C cooler, 5 cm below ground than the hilltop pasture. The hilltop pasture was also drier (approx. 10% less soil moisture than the hill bottom) and more degraded of the two sites (28% bare ground compared to 11% on the hill bottom site pretreatment). Both soils types are described as a coarse-silty, mixed, super active, Eutrocryepts, to a depth of more than 203 cm based on US Soil Taxonomy (NRCS, 2016). While both soils share similar physical and chemical characteristics, the Minto silt loam has a slightly slower drainage rate, deeper surface organic layer, and shallower depth to the water table (NRCS, 2016).

2.2. Research design

Experimental design consisted of fully factorial combinations of grazing impact factors; manure and urine application (M), simulated herbivory (H), and trampling (T) using a completely randomized block design (Fig. 1). A control plot (no treatment) was present in each block to represent a pasture taken out of the grazing rotation. This factorial combination gave eight treatment types including the control (C),

Table 1
Temperature and precipitation averages for growing season over the two years of the study, at Fairbanks, AK (Alaska Climate Research Center, 2017).

Month	*30-yr monthly mean temp (°C)*	*2014*	*2015*	*30-yr monthly mean precip (cm)*	*2014*	*2015*
May	9.67	10.73	12.92	1.52	0.15	0.74
June	15.78	14.68	15.42	3.48	9.04	2.62
July	16.94	16.11	16.78	5.49	14.68	7.06
August	13.39	15.04	12.53	4.78	5.82	6.55
September	7.17	7.98	5.78	2.79	7.34	9.5