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Seasonal response of herbage production and its nutrient and mineral contents to long-term cattle grazing on a Rough Fescue grassland

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ABSTRACT

This study investigated the effect of long-term cattle grazing on herbage production and its nutrient and mineral concentrations over the grazing season. The grazing experiment was conducted on a Rough Fescue (*Festuca campestris* Rydb.) grassland established in 1949. The three grazing treatments were moderate grazing (MG), heavy grazing (HG), and a non-grazed exclosure (CK) with corresponding stocking rates of 2.4, 4.8, and 0 animal unit months (AUM) ha^{-1}, respectively. Within each of these three treatments four sampling locations were selected as four replications. Herbage biomass (green standing crop [current years' production] and litter biomass [previous years' production]) and its nutrient and mineral concentrations were determined monthly from May to September 2007. The green standing crop increased but litter biomass decreased with grazing and peak green standing crop for MG and HG occurred one month earlier than in the CK. For the green standing crop, total nitrogen (TN) concentration increased with grazing from 28.2 g kg^{-1} in the CK to 39.9 g kg^{-1} in the HG treatment in May while increases (12.4–15.7%) in other months were not significant. Total phosphorus (TP) (16.4%) and $\delta^{15}N$ were higher in the HG than in the CK. For the litter, TN and Ca concentrations decreased with grazing, but TP, $\delta^{15}N$, K and Mg concentrations increased. The herbage feed quality also varied over the grazing season with TN, TP, K, and Mg concentrations decreasing over the grazing season while Ca concentration was lowest in spring (3.07 g kg^{-1}) and late fall (4.08 g kg^{-1}). Grazing appeared to accelerate nutrient cycling and improved herbage quality. These grasslands require disturbance for optimal performance but heavy grazing pressure could severely reduce their health.

1. Introduction

Herbage biomass (green standing crop and litter biomass) is affected by defoliation from animal grazing (Bilotta et al., 2007). Grazing may decrease herbage biomass (Kooijman and Smit, 2001; Donaphy and Fulkerson, 2002), have no effect on herbage biomass (Hart et al., 1988) as plants compensate for tissue removal (Langlands and Bennett, 1973), or increase herbage biomass (Cluzeau et al., 1992) when overcompensation occurs (McNaughton, 1983). Different herbage responses to grazing can be attributed in part to stocking rates and other grazing management practices that determine the frequency and severity of vegetation removal (Dowling et al., 2006).

Livestock grazing affects the flow of nutrients in the grassland ecosystem by stimulating their turnover. Animals use only a small proportion of nutrients and minerals they ingest, with 60–99% returned to the soil in the form of dung or urine (Haynes and Williams, 1993). Nutrients and minerals in animal excreta are more readily available to plants than those in soil (McNaughton et al., 1988). Grazing accelerates mineralization of organic N providing a more readily available form for plant growth (Risser and Parton, 1982), leading to higher herbage N, P and K concentrations in grazed (or defoliated) than ungrazed grassland (Dormaar and Willms, 1998).

Nitrogen concentrations of different plant tissues can range from 0.03 to 7.0% with the highest occurring in young and actively growing tissue or in storage tissue such as seeds (Mattson, 1980). Nutrient and mineral concentrations generally decline during the course of the growing season until tissue senescence (Johnston and Bezeau, 1962) occurs. The rate of change in nutrient and mineral concentration varies with different plant types and species (Johnston and Bezeau, 1962). However, relatively little is known

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Abbreviations: AUM, animal unit months; HG, heavy grazing; MG, moderate grazing; TN, total nitrogen; TP, total phosphorus.

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about how grazing management, which influences herbage production and nutrient cycling, affects seasonal nutrient and mineral concentrations (Bilotta et al., 2007). The objective of this study was to elucidate the role of livestock grazing on nutrient cycling. Specifically, we tested the response of the plant community in a Rough Fescue grassland ecosystem to long-term protection or cattle grazing to study how these treatments influenced the seasonal variability in herbage nutrient and mineral contents.

2. Materials and methods

2.1. Site description and grazing treatments

The experiment utilized a long-term cattle grazing study initiated in 1949 with four non-replicated treatments as reported by Dormaar and Willms (1998). Briefly, the study site was located at the Agriculture and Agri-Food Canada Research Centre, Stavely Substation, Stavely, Alberta (50°12′N, 113°54′W). The topography is undulating, varying in elevation from 1280 to 1420 m above sea level. Three of the four grazing treatments were selected for investigation in 2007: moderate grazing (MG), heavy grazing (HG), and a non-grazed exclosure (CK) that were stocked at 2.4, 4.8, and 0 animal unit months (AUM) ha^{-1} with total areas of 32.0, 16.0, and 0.76 ha, respectively. The same number, type and breed of animal (mostly lactating Heifer-continental cross cows with calves) have been assigned to the MG and HG paddocks and grazed from around 15 May to 15 November in each year since 1949. The calves were typically born in March and weaned in October.

From 1997–2007 (the period for which monthly weather data is available), the mean annual and growing season (April to August) precipitation was 494 and 358 mm, respectively and the mean annual and growing season air temperature was 5.6 and 11.8 °C, respectively. The 2007 growing season precipitation of 249 mm was lower and temperature of 12.3 °C was higher than the 11-yr average. The 2007 growing season was characterized by a wet (102 mm, 148% of 11-yr average) May and dry (0.6 mm, 1.3% of 11-yr average) and hot (3.1 °C higher than 11-yr average) July. Monthly precipitation over the rest of the 2007 growing season varied from 46 to 108% of the 11-yr average, while 2007 average monthly temperatures were close to the 11-yr average.

Vegetation is Fescue Grassland (*Festuca campestris*, Rydb.) as described by Coupland and Brayshaw (1953). Rough Fescue is the dominant species with *Danthonia parryi* Scribn. co-dominant while grazed areas were dominated by *Poa pratensis*. The soil is an Orthic Black Chernozemic (Typic Haplustolls in US taxonomy) with a clay–loam to loam texture, and soil total nitrogen (TN), total phosphorus (TP) and organic C (OC) concentrations (0–30 cm) were 5.1, 0.87 and 55.2 g kg^{-1}, respectively (Li et al., 2009).

2.2. Herbage sampling and analysis

An exclosure (7 m × 11 m) was installed in each grazing treatment in spring 2007 before new growth began and prior to cattle grazing. Each exclosure was located at the top of a hill within the gently undulating landscape. Herbage was sampled on 10 May 2007 prior to the start of grazing and monthly from June to September during the grazing season. During sampling, four 50 cm × 50 cm quadrats were randomly placed inside the exclosure of each grazing treatment and treated as four replications. The herbage samples in each quadrat were harvested at ground level, brought back to the laboratory, separated into green standing crop and litter biomass (standing and fallen), dried for 48 h at 60 °C and weighed. The green standing crop was produced in the current year while the litter biomass was produced in previous years.

The green standing crop and litter samples were first coarsely ground (<2 mm) and sub-samples were finely ground to pass a 0.150 mm sieve. Fine ground samples were used in all analysis. The TN and $\delta^{15}N$ concentrations were determined using a GC–MS CNS analyzer (Carla Erba, Italy). The TP was determined by digesting with 18 M H_2SO_4 following the method of Parkinson and Allen (1975) and the P concentration in the digesting solution was determined using an Astoria auto-analyzer (Clackamas, Oregon). For mineral concentration analysis, samples were digested using HNO_3 acid and the Na, K, Mg and Ca concentration in the digested solution were determined using a flame atomic absorption machine (Varian Model AA240, Palo Alto, CA).

2.3. Dung sampling and analysis

When herbage samples were collected, three fresh cattle dung samples excreted on the sampling day close to the exclosure or water point were collected (June to September) from each of the two grazed treatments. Fresh dung samples were first extracted with water. Concentrations of soluble NO_3^- and NH_4^+ were determined using a Bran + Luebbe AutoAnalyzer III (Bran + Luebbe, Germany), PO_4^{3-} using an Astoria auto-analyzer (Clackamas, Oregon), Na^+, K^+, Ca^{2+} and Mg^{2+} using a flame atomic absorption machine (Varian Model AA240, Palo Alto, CA) and Cl^- and SO_4^{2-} using a Dionex ion chromatograph (Dionex, Model Dx-600, Sunnyvale, CA). The TN, $\delta^{15}N$ and TP concentrations in dung were determined using oven-dried samples (60 °C) following the methods for herbage described above.

2.4. Statistical analysis

The study was unreplicated and we made the assumption that the sub-sampling error was representative of the experimental error. We believe this was reasonable under the circumstances because the exclosures were located at a similar topographic location within each paddock and the primary factor dictating the effect on vegetation was grazing. We appreciate the risk of employing an unreplicated experiment but the site provides a unique opportunity where the long-term history of grazing is known. Therefore, GLM procedure of SAS (SAS Institute Inc., 2005) was used to analyze the data as a randomized complete block design with grazing, sampling time and their interactions in the model as fixed effects. Sampling time was treated as a repeated measure to account for potential correlations. Various types of variance–covariance structures were fitted and the one with the lowest AIC value was used for the final analysis. The LSD test was used for all mean comparisons, which were considered significant only at $P < 0.05$. Correlation analyses among various parameters of vegetation and dung were also conducted and reported only when significant at $P < 0.05$.

3. Results

3.1. Production, nitrogen, $\delta^{15}N$, phosphorus and minerals level in green standing crop

The green standing crop production and its TN and $\delta^{15}N$ concentrations were affected by grazing, sampling time and their interactions. There were no differences in green standing crop production among grazing treatments in May prior to the start of grazing. Production was higher with grazing (MG and HG) than the CK in June, July and September, but lower with grazing (MG and HG) than the CK in August. There were no differences between MG and HG except in August. Peak green standing crop was obtained in August for the CK but in July for both MG and HG treatments (Table 1).