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Burning and Mowing Effect on Underground Carbon and Nitrogen in Tallgrass Prairie

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Abstract

As multiple factors influence the biotic processes of prairie ecosystems, it is important to investigate the effects of their interactions. The historical impact of grazing and fire on tallgrass prairies has led to extensive research on their aboveground effects, however little is known about belowground effects. We hoped that further study of the belowground processes would contribute to conservation efforts. However, we worked under the assumption that mowing would produce similar results to grazing. Due to documented morphological differences in plant reactions to burning and grazing we expected that the combined treatments of burning and mowing would also have different effects on root growth and nutrient cycling. Our study examined the effects of different treatment combinations on belowground processes through root productivity, carbon and nitrogen content and the C:N ratio of the roots and soil. We took core samples from a series of plots with combination treatments of burning and mowing. Although previous research suggests that grazing and burning have a significant interactive effect, we found no significant effect of burning or mowing in the majority of our data. We found a significant difference in the percent of carbon in the soil; in the absence of fire, mowing decreased the percent carbon. This may be a result of a combination of many factors.

Introduction

Grazing and fire shaped the tall grass prairie, influencing characteristics such as species diversity and richness, nutrient cycling, and above and belowground processes. Although extensive research explores the effects of each individual factor, a growing body of literature suggests a complex interaction between grazing and burning effects on prairie ecosystems (Johnson and Matchett 2001, Knapp *et al* 1999, Hobbs *et al* 1991). We conducted our research on experimental plots at CERA that combine the treatments of mowing and fire. We hoped to contribute to the understanding of belowground processes.

Our research studied the effects of burning and mowing (under the assumption that mowing simulates grazing) on root-rhizome biomass and the carbon and nitrogen content of soil and roots. Research on grazing indicates reduction in belowground biomass because the plants allocate more of their resources to recovery growth aboveground (Knapp *et al.* 1999, Johnson and Matchett 2001). Spring burning, as used at CERA, has the opposite effect, prompting plants to invest more of their resources in root growth and maintenance (Knapp *et al.* 1999, Johnson and Matchett 2001). We expected mowing to negatively affect root growth, resulting in lower belowground biomass on mowed plots. Based on previous studies regarding the effects of grazing and burning on nitrogen and carbon belowground processes, we hypothesized that mowing would reduce the amount of carbon present in the soil and roots because the plants invest more of their energy in shoot growth in an attempt to recover from the effects of defoliation.

Equating grazing with mowing, we also assumed that mowing would result in increased nitrogen availability. Fire causes loss of nitrogen through combustion whereas mowing, when clippings are retained, preserves system nitrogen. However, mowing does not precisely mimic grazing, since grazing speeds nitrogen processing by returning nitrogen to the soil in the form of urine and feces (Knapp, *et al*. 1999). Mowing can only replicate this effect of grazing with the addition of nitrogen (Hamilton *et al*. 1998), which is not present at CERA.

The proposition that mowing is not equivalent to grazing is important to consider in prairie maintenance and restoration techniques. Small prairie reserves such as CERA may not have room to contain herds of ungulate herbivores and therefore may try to replicate grazing with various mowing practices. In order to best simulate grazing, mowing must be combined with nitrogen addition (Hamilton *et al*. 1998). Fire, grazing and mowing are all used in conservation on prairie reserves to imitate native prairies; an understanding of the interaction

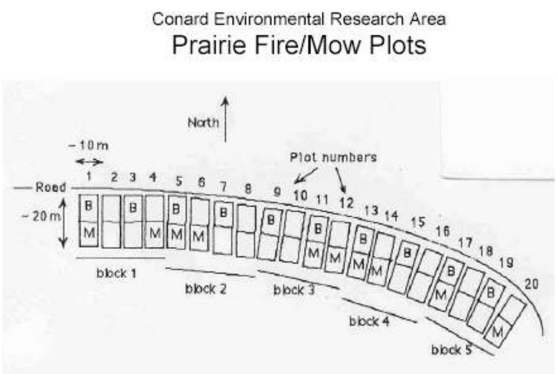

Figure 1: Plot configuration at CERA, courtesy of http://www.grinnell.edu/academic/biology/cera/research/ltexp/includes/PrairieFireMowPlots_03.pdf

between the effects can enhance the application of the techniques. Understanding the effect of each practice, or combination of practices on belowground processes is important to determine which conservation practices should be used, and how they should be used in a given prairie reserve.

Methods

We collected our field data at the Conard Environmental Research Area (CERA) from October 6th, 2004, to October 11th, 2004. We conducted our research on 20, 10m by 10m two-factor plots combining burning and mowing treatments. Alternating plots were burned every spring since 1997, and the mowed plots were mowed in late June from 1999-2002. Plots are arranged into randomized blocks of four, each containing one plot from each combination of treatments (Fig. 1).

We established two transects within each plot, 3 meters from the east and west edges, and took

Table 2: Percent Carbon and Nitrogen in Soil

Source of Variation	Treatment	F Value	P Value
% Nitrogen	Burn	0.09	0.773
	Mow	0.00	0.982
	Burn*Mow	1.19	0.318
	Block	2.05	0.206
% Carbon	Burn	0.32	0.582
	Mow	0.70	0.420
	Burn*Mow	4.48	0.048*
	Block	1.18	0.368
C/N Ratio	Burn	0.32	0.589
	Mow	0.09	0.773
	Burn*Mow	2.23	0.186
	Block	0.41	0.797

Table 1: Analysis of Variance for Root Mass (g)

Treatment	F Value	P Value
Burn	0.00	0.947
Mow	0.07	0.789
Burn*Mow	0.31	0.589
Block Effect	0.55	0.703

two cores at randomly chosen points on each transect, using a 2.5 cm radius corer to a depth of 5 cm (98.17 cm^3). We combined the four cores from each plot to create a homogenous sample and separated roughly 20 mL of soil for C/N analysis. Soaking the cores in water helped to soften them, while filtering the soil through a sieve separated the roots and rhizomes from the soil. After drying at 55°C for 2-14 days, we determined the mass of the root-rhizome samples.

The ratio of Carbon to Nitrogen in the roots and soil was determined from finely ground root samples of 10-20mg and finely ground soil samples of 20-30mg using ThermoFinnegan C/N analyzer. We used an analysis of variance (ANOVA) to test for the effects of burning and mowing treatments on the underground biomass and the ratio of Carbon and Nitrogen in roots and soil.

Results

We found no significant block, treatment, or interaction effects on underground biomass (1.71-7.88g) or percent nitrogen in the soil (0.144-0.246 %) (Tables 1 & 2). However, the treatment interaction is significant ($p = 0.048$) for the percent carbon in the soil: under burning conditions, mowing increases the percent carbon, but in the absence of fire, mowing decreases the percent carbon (Fig 2).

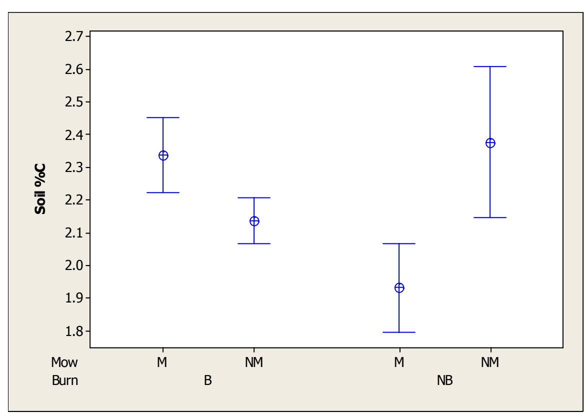

Figure 2: Percent Carbon in the Soil in 2-factor Treatments (bars are one standard error for mean)

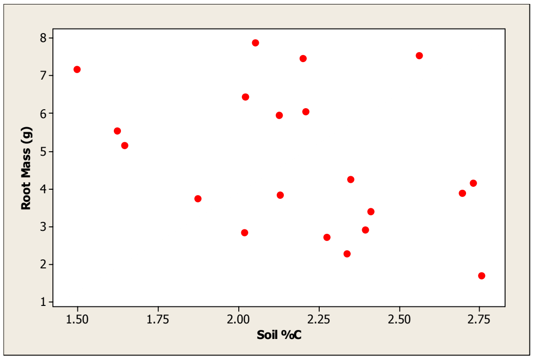

Figure 3: Correlation of soil percent Carbon and root mass

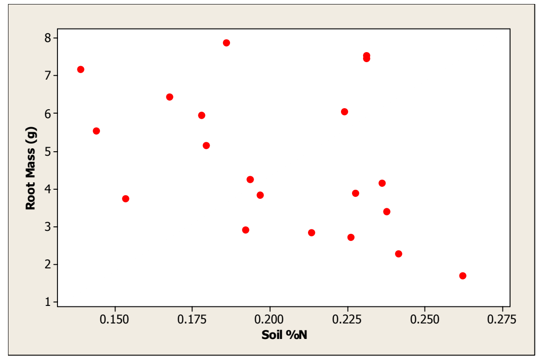

Figure 4: Correlation of soil percent Nitrogen and root mass

There are negative trends in the correlations of root mass to percent nitrogen in soil ($r = -0.410$, $p = .073$) (Fig 3) and root mass to percent carbon in soil ($r = -0.395$, $p = .085$) (Fig 4). There was no significant correlation between root carbon and soil carbon or root nitrogen and soil nitrogen. We also did not find significant treatment effects on root carbon percent (15.820-41.926 %), root nitrogen percent (0.2705-0.586 %), or C:N ratios in soil (10.5095-12.4688) or roots (39.639-114.487) (Table 3). Percent carbon in roots showed a significant block effect ($p = 0.032$).

Discussion

Belowground Biomass- Although our measured effects of fire and mowing on underground biomass were not significant, other studies have indicated that grazing reduces underground biomass (Johnston & Matchett 2001, McNaughton *et al*. 1998) while fire has the opposite effect, increasing root growth and productivity (Johnson and Matchett 2001, Kucera & Dahlman 1968). In a study of belowground processes, Johnston and Matchett concluded that differences in underground responses to fire and grazing are primarily due to the availability of limiting resources (2001). In grazed plots, carbon is the limiting factor, since it is allocated to new shoot growth; in burned plots, nitrogen is the limiting factor when it is lost to fire (Johnson & Matchett 2001). Grazing influences the rate of nitrogen mineralization through the deposition of feces and urine. As mowing fails to replicate this process of fertilization, nitrogen continues to be a limiting resource, retarding root and shoot growth. A study which simulated grazing by combining defoliation with nitrogen fertilization documented significant decreases in root biomass on clipped plants, suggesting that had we fertilized and mowed, we might have observed a significant decrease in the underground biomass (Hamilton *et al*. 1998). However, conflicting research indicates that grazing has no long-term effect on root productivity because plants cannot indefinitely maintain or increase aboveground foliage without returning some of their resources to an extensive root system (McNaughton *et al*. 1998). Variance in our data may also result from our sampling method, which failed to account for the proximity to large plants at the core sampling sites.

Table 3: Percent Carbon and Nitrogen in Roots

Source of Variation	Treatment	F Value	P Value
% Nitrogen	Burn	0.18	0.679
	Mow	1.28	0.283
	Burn*Mow	0.35	0.566
	Block	0.60	0.672
% Carbon	Burn	0.23	0.644
	Mow	1.00	0.337
	Burn*Mow	0.00	0.969
	Block	3.81	0.032*
C/N Ratio	Burn	0.02	0.889
	Mow	2.73	0.127
	Burn*Mow	0.19	0.674
	Block	3.19	0.057

Percent N of Roots and Soil- While burning and mowing effects were non-significant for percent root or soil nitrogen, other studies have shown that grazing reduces the effects of nitrogen lost to combustion and increases the rate of nitrogen cycling and therefore the amount of nitrogen available to plants (Hobbs *et al*. 1991, Frank & Groffman 1998, Knapp *et al*. 1999). Grazing increases the concentration of nitrogen in roots, while reducing root productivity (Johnson & Matchett 2001, Hamilton *et al*. 1998). Although mowing is similar to grazing in reducing standing biomass available to combustion, it does not account for the nitrogen returned to the soil through feces and urination. As we did not simulate this aspect of grazing, we should not expect to see the same significant trends in our results.

Some of the variance in our data can be attributed to errors in the analysis of nitrogen content: the ThermoFinnegan analyzer had significant nitrogen contamination on several runs of samples. We were not able to get uncontaminated data for all of our plots, so the nitrogen data is based on a reduced number of samples for both roots and soil. Between the reduced sample size and the possibility of further contamination, our nitrogen data may be unreliable.

Percent C of Roots and Soil- Since previous studies have noted a decrease in the carbon content of roots under grazing conditions (Knapp *et al*. 1999, Hamilton 1998), we assumed that mowing as a form of defoliation would produce a similar response in plants. However, our results for percent carbon of roots were not statistically conclusive.

The interaction of mowing and burning produced a significant response in the percent carbon of the soil: mowing increased the percent of soil carbon under a fire regime, but decreased the percent of carbon in the absence of fire. An early study of the effects of grazing proposes that a higher organic carbon content in the soil of grazed plots results from an increase in aboveground foliage, and a consequent increase in root mass (Kelting 1954). However, as previously mentioned, other studies note that the removal of aboveground biomass through clipping or grazing reduces belowground biomass (Knapp *et al.* 1999, Hamilton *et al*. 1998), thus suggesting that Kelting's logic may be flawed. Biondindi *et al*. (1998) did not find evidence that grazing significantly affects the carbon content of soil, while Frank and Groffman (1998) found significant but variable effects, leading them to the conclusion that the impact of grazing is secondary to that of topography and climate in soil carbon and nitrogen processes.

It is difficult to trace variations in soil carbon concentration to a single factor because temperature, moisture, nutrient availability, and climatic variations produce complicated and diverse effects (Knapp *et al.* 1998). Our data indicates that mowing combined with fire exclusion results in significantly lower soil carbon levels. The rate of soil respiration, or the amount of carbon lost to the atmosphere in the form of CO2 is one of the dominant factors determining the carbon concentration in soils (Knapp *et al.* 1998). An Australian study of the role of termites in carbon mineralization found a positive relationship between soil moisture and microbial activity (Holt 1987). The accumulation of litter on mowed plots may result in higher moisture levels by reducing the rate of evaporation. Greater microbial activity on mowed plots would increase the rate of soil respiration, thereby decreasing the amount of soil carbon. However, it is difficult to analyze the effects of soil moisture independently of other factors contributing to soil respiration, such as temperature, nutrient availability, and topography.

C:N Ratio roots and soil- Numerous studies have recorded a decrease in the C:N ratio of soil and roots with respect to grazing (Frank & Groffman, 1998, Johnston & Matchett 2001, Knapp *et al*. 1999). Johnson and Matchett (2001) suggest that changes in C:N are largely due to variations in the availability of nitrogen because the percent carbon did not change significantly with treatment or depth while the rate of nitrogen mineralization increased within grazed treatments. By narrowing the C:N ratio, grazing increases the ability of roots to decompose and speeds up N cycling within a system (Johnson & Matchett 2001). The trends in our data contradicted this theory, but were not statistically significant. Again, equating mowing with grazing may not be accurate, as mowing does not return nitrogen to the soil. Errors in the analysis of nitrogen content also may have contributed to the deviations in our results for C:N ratio.

Further studies might investigate the relationship between grazing and mowing, determining the extent and the significance of any differences between the two processes on belowground biomass, carbon and nitrogen content of the roots and soil, and the ratio of C:N. It would also be interesting to pursue the theory that grazing may be secondary to topography and climate in influencing the belowground responses of prairie ecosystems, as suggested by Frank & Groffman (1998). As we conducted our research at the end of the growing season, the plants had already begun the process of translocating resources from aboveground living matter to belowground root systems. It would be informative to conduct a similar study of mowing and burning at a different time in the growing season, perhaps when most plants are beginning to allocate more resources towards shoot growth. The fact that we have very little statistically significant data in a field where most research documents marked differences suggests that mowing as a management technique may not be an adequate substitution for grazing.

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