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To,

My Mother, Hosnieh:

for being the flicker of a candle in dark pathways, guiding me through the right path, praying for my wishes to come true

and

in loving memory of My Father, Abbas:

who regretfully did not live to see my achievements
To,

My Husband, Mostafa:

for his endless support and constant encouragement, helping me to go through this journey,

for enormous patience, living 6215 miles far away from me,

for his constant long calls, giving me a sense of love and connection,

I am thankful every moment of my life for having him beside me.
Abstract

Ongoing climate change has emerged as a major scientific challenge in the current century. Grassland ecosystems are considered net carbon (C) sinks to mitigate climate change. However, they are in turn, influenced by climate change and management practices, providing feedback to climate change via soil microbial community and biogeochemical fluxes. In this thesis, I examined the impact of warming, altered precipitation, and defoliation on soil microbial composition and function, C and N dynamics, and fluxes in soil respiration (CO₂), nitrous oxide (N₂O) and methane (CH₄), together with other belowground ecosystem functions, within two ecosites in a northern native temperate grassland in central Alberta, Canada, over a two-year period.

Fungi-to-bacteria ratio was not affected by climatic parameters or defoliation, indicating a high degree of resistance in the below ground community to the treatments imposed. However, C substrate utilization was influenced by warming and defoliation, as was soil microbial biomass. In contrast, soil respiration (or C loss) was not. Soil respiration acclimatized rather quickly to warming, and N₂O and CH₄ effluxes showed minor responses to warming at both ecosites, regardless of defoliation. These results suggest warming is unlikely to lead to positive climate change feedback due to soil-based responses, regardless of ongoing land use. However, altered precipitation (± 50%) demonstrated greater impacts on C and N fluxes relative to warming and defoliation. Increased precipitation stimulated soil C loss to the atmosphere, potentially generating positive feedback for climatic warming in this northern temperate grassland.
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Chapter 1 Introduction, background and research overview

Introduction

"With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century."

~IPCC (2007)

While the original concerns over climate change targeted the North Atlantic, climate change has now become a global issue with increases in global average temperature evident worldwide (Biello, 2007). Associated with temperature changes are variation in precipitation pattern. Evidence for precipitation increases (eastern part of North and South America, northern Europe and northern and central Asia) and decreases (subtropical land region) are evident in various regions of the globe (IPCC, 2007). Warming may cause change in precipitation via two basic physical mechanisms: (i) warmer air is capable of holding greater amount of moisture, and (ii) warmer weather leads to greater evaporation and associated drying of the land surface (Easterling et al., 2000; Huntington, 2006).

Today, one of the main concerns is the consequence of climate change both locally and globally. To reduce the rate of CO$_2$ increase in the atmosphere, global efforts are underway to develop mitigation strategies to both enhance potential sinks and decrease potential sources of greenhouse gases (CO$_2$, N$_2$O, CH$_4$) (IPCC,
One major strategy is to sequester atmospheric carbon dioxide (CO$_2$) into biomass and soil organic matter of terrestrial ecosystems (Izaurralde et al., 2001; IPCC, 2007).

Within the biosphere, rangeland ecosystems cover up to 80% of terrestrial lands (Lund, 2004), and hence hold significant potential to sequester atmospheric CO$_2$. Considering the fact that 20 to 73% of global rangelands have been degraded (Lund, 2007), the current rate of C sequestration of 0.5 Pg C year$^{-1}$ (Schlesinger, 1997) might be below the maximum potential of many ecosystems. Improved management of degraded rangelands would therefore enhance the rate of C sequestration globally, and thereby mitigate the effects of climate change (Schimel et al., 1990; Conant et al., 2001). Despite the importance of rangelands, their role in C sequestration has been overlooked relative to studies in forested areas, leaving great uncertainty about the C storage potential in rangeland ecosystems.

Rates of soil C sequestration in rangeland ecosystems are sensitive to both climate (Conant et al., 2001) and grazing management (Jones & Donnelly, 2004). As one of the most common management practices in rangeland ecosystems (Derner & Schuman, 2007), grazing is of crucial importance in C sequestration and in affecting soil C storage in such ecosystems (Bruce et al., 1999). However, grazing impacts are variable among ecosystems, and thus local research is needed to understand the relationship between grazing and C budgets. Therefore, understanding the impacts of grazing strategies on the potential for (and
limitations in) C sequestration within rangeland ecosystems under the context of climate change has scientific merit.

The soil’s capacity to sequester C is finite. In rangeland ecosystems, where nitrogen (N) often limits primary productivity (Derner & Schuman, 2007), N availability is one of the limitations to C sequestration (Reich et al., 2006). In addition, global C and N are known to co-cycle via biomass accumulation, decomposition, and storage (Asner et al., 1997). As a result, it is important to incorporate both C and N dynamics into climate change studies conducted within these ecosystems. More specifically, soil microbial processes and communities should be investigated as the soil microbial community drives biogeochemical cycles, particularly C and N cycling, as well as storage in the soil. Soil microbial properties such as size, activity and composition play key roles in nutrient cycling, carbon sequestration and in general, all biogeochemical reactions in the soil. Ultimately, the microbial community can reflect soil-plant responses to climate change and grazing management (Fig. 1-1). Consequently, predictions of global C sequestration, emerging land use policy, and routine public decisions on land management, are inextricably tied to the assemblage of both soil C and N dynamics and microbial communities found in rangeland ecosystems, as well as their response to climate change factors (e.g., warming and precipitation).
2. Background

2.1. Linkage between climatic and biogeochemical cycles

Based on existing field-based climate change studies, soil belowground functions such as C and N dynamics may regulate global climate change via the influence of end-products of greenhouse gas (GHG) emissions, known as “feedback” (Cao & Woodward, 1998). Feedback associated from climatic parameters on GHG emissions may accelerate or dampen global warming, respectively, creating positive or negative feedbacks. Increased CO$_2$ concentration

Figure 1-1. A conceptual model showing climate-grazing consequences on soil biogeochemical and microbial processes. The cause and effect relationship between soil C and N pools and turnover/transformation processes are indicated by arrows. Red colors indicate the treatments applied and the pathways they are likely to impact.
or environmental warming received early attention from researchers investigating the effects of climate change in natural ecosystems (Makarov, 1959; Bazzaz, 1990). Rustad et al. (2001) in a meta-analysis study of 32 research sites demonstrated that 2-9 years of experimental warming with the range of 0.3-6.0°C increased soil CO$_2$ emission by 20% (with a 95% confidence interval of 18-22%). Beier et al. (2008) found that warming also increased soil CO$_2$ respiration in shrublands. This implies that microbial aerobic respiration may be enhanced in a warmer climate within well drained soils due to the higher level of oxygen, in turn resulting in a net loss of C via CO$_2$, a process potentially enhances positive feedback under climatic warming (Foley & Ramankutty, 2004; Pendall et al., 2004). Changes in this large soil C flux at the global scope (e.g. $75 \times 10^{15}$ gC/yr) can simultaneously affect C storage in the soil matrix (Schlesinger & Andrews, 2000), and hence the potential for C sequestration in the system.

In contrast, temperature sensitivity of soil CO$_2$ efflux may decline over time as observed by Luo et al. (2001) in a tall grass prairie and Strömgren (2001) in a boreal spruce stand. Regardless of whether it is acclimatization of soil microbial activity to climatic warming (Luo et al., 2001; Strömgren, 2001) or depletion of readily decomposable substrate (Kirschbaum, 2004) that is the cause of such observations, these phenomena may weaken the positive feedback to climatic warming. Inconsistent responses have also been observed in microbial responses to warming. While soil microorganisms serve to sequester carbon in the system (Bradford et al., 2002), they are in turn influenced by climatic parameters. Increased temperature may change the source of C utilization by the soil
microbial community towards either old or new carbon substrates (Zogg et al.,
1997; Andrews et al., 2000). Furthermore, soil microbial characteristics (e.g.
composition and function) also displayed contrasting responses to experimental
warming (e.g., Zhang et al., 2005; Rinnan et al., 2007; Frey et al., 2008; Rinnan
et al., 2009). For instance, warming shifted soil microbial community
composition towards dominance by bacteria in subarctic heath (Rinnan et al.,
2007; Frey et al., 2008) and dominance by fungi in tall grass prairie (Zhang et al.,
2005).

Contradictory responses of nitrogen dynamics to climatic warming have also
been reported. Rustad et al. (2001) reported an average increase of 46% (with a
95% confidence interval of 30-64%) in net N mineralization due to 0.3-6.0°C
warming during 2-9 years. In contrast, N mineralization was relatively
insensitive to experimental warming in the study by Beier et al. (2008). Wan et al.
(2005) found that net N mineralization increased under experimental warming in
the first year, but decreased during the second year of study. This change may be
caused by differences in site characteristics such as aboveground community
composition and available moisture. Moisture as well as vegetation composition
can directly impact nitrogen mineralization responses to soil warming (Shaw &
Harte, 2001).

Although the majority of previous global climate change studies have
emphasized warming, the effects of precipitation have been the focus in more
recent climate change studies (i.e., Weltzin et al., 2003). Precipitation and soil
water conditions influence photosynthesis, plant growth, and litter decomposition
(Coughenour & Chen, 1997), and as a result, change the potential for C sequestration in the system. Positive relationships between precipitation and soil CO$_2$ respiration (Wiant, 1967; Tylor et al., 2004), and N$_2$O emission (Xu et al., 2002) have been reported in several terrestrial systems. Based on this relationship, increases in the amount of precipitation may create positive feedback to global climate change via trace gas emissions. However, the prediction of feedback is difficult and dependent on the impacts of precipitation on various soil C and N pools. Precipitation regimes may influence total soil C and N pools (Walter, 2004) via changes in soil microbial biomass carbon (Singh et al., 2009), soil organic C (Wichern & Joergensen, 2009), decomposer community composition (Tylor et al., 2004), net N mineralization (Coughenour & Chen, 1997), and N nitrification (Wang et al., 2006). A summary of other research reporting on the impacts of climate change on soil parameters is provided in Table 1-1.

Asymmetrical responses of soil C and N pools to climatic parameters provide no straightforward prediction of C sequestration in rangeland ecosystems. Despite this, the facilitation of atmospheric C sequestration in rangeland ecosystems via modified land use management has been set as a future goal (Lal, 2004; Jones & Donnelly, 2004). Moreover, the breakdown between net sources and sinks of carbon in terrestrial ecosystems remains unclear (Foley & Ramankutty, 2004). Recent reviews have recommended a need to further understand biogeochemical cycles and soil microorganisms as underlying mechanisms for the potential to influence C sources or sinks in terrestrial ecosystems (Foley & Ramankutty, 2004; Pendall et al., 2004). Thus, in rangeland
ecosystems, it is fundamentally important that we understand the impacts of land use management (i.e., grazing strategies) on soil microbial communities as well as C and N dynamics under ongoing climate change.

2.2. Linkage between grazing strategies and biogeochemical cycles

Grazing strategies can influence plant communities in rangeland ecosystems. Inappropriate grazing such as high stocking rates can reduce desirable productive forage plants while increasing woody plants together with unpalatable grasses and forbs (Cingolani, 2005; Zhou et al., 2006). Carbon and nitrogen dynamics in rangeland ecosystems are regulated through plant tissue quality and quantity, as well as the intensity and nature of disturbance. Disturbances such as defoliation may have importance consequences on C and N flows at the plant-soil interface (McGill et al., 1986; Howe 1994), and hence determine the potential for C sequestration (Derner & Schuman, 2007). Thus far, varied effects of grazing or defoliation have been reported on microbial communities and nutrient cycling (Table 1-2).

Several studies have proposed biogeochemical cycling models with positive feedback of disturbances such as grazing in plant-soil nutrient flows in rangeland ecosystems (Wedin, 1995, 1996; Pastor & Cohen, 1997). There is some experimental evidence to support the grazing- or defoliation-positive outcomes on soil organic C (Shuman et al., 2002; Pineiro et al., 2009) and N availability (Seagle et al., 1992) in rangeland ecosystems. In a mixed grassland ecosystem, clipping caused an increase in soil microbial C: N ratio (Harris et al., 2008).