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Effect of Snowpack on Biomass, Soil and Microbial Activity in Restored Prairies in Southeastern Minnesota

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Abstract:

Predicting the effects of climate change on all ecosystems is important to quantify before they are realized, in order to create proper management tools. Weather fluctuations are likely to occur, resulting in reduced snow cover amount and duration in many locations. To see how lack of snow through a winter affects biomass, soil, microbial activity, four plots in a restored prairie in southeastern Minnesota were removed of snow during the winter of 2008-2009. The following autumn, I measured the CO_2 flux (a proxy for microbial activity), soil moisture, soil organic matter, biomass dry weight, and biomass carbon to nitrogen mass ratios (C:N) in the exposed and covered soils from the previous winter. Of the four plots, two were restored to native prairie in 1993 and two in 1998. I found CO_2 flux to be significantly higher in the 1993 prairie and in the covered plots while soil was significantly moister in the 1998 prairie. When prairie is restored from agricultural land, it takes many years to regain soil nutrients and microbial activity, making CO_2 higher in the older prairie. There was sustained difference in microbial activity between the two snowpack treatments as there had been in winter, possibly because both sample times were during a stable weather period. Biomass C:N was significantly higher in the covered plots, since nitrification rates are higher, making N readily available in the soil, resulting in more N in biomass grown the following season. As variations in snow cover are predicted with increasing climate change, more nitrate will be present in the soil, resulting in higher N loss, possibly in the form of N leaching or increased denitrification (nitrous oxide). Also, lower microbial activity in exposed soils will result in lower CO_2 emissions from soil. It will be important to quantify the amount of denitrification and carbon debt from snowpack treatments.

Introduction:

Microbial activity determines the carbon and nitrogen cycling in soil (Edwards et al., 2007). These nutrients, in turn, influence production. Plant species produced also determine the future nutrients of the soil by influencing root chemistry, root biomass, and in their litter decomposition (Fornara et al., 2009). Soil microbial activity and communities are consistently changing with the shifting environmental conditions and are especially sensitive to soil thaw timing and duration. The soil processes that occur during the freeze-thaw cycles of the winter months will determine the nutrient composition of the system and thus the subsequent growing season (Edwards et al., 2007). The seasonal timing and duration of these cyclical soil thawing and freezing processes, snow cover specifically, are changing with the warming climate, making it important to study the ecological effects of these changes (Brown and Mote, 2009).

Another threat to soil quality, biodiversity, and ecosystem structure as a whole is agriculture. Conventional agriculture strips soil of carbon and microbial biomass while often overwhelming the soil with nitrogen when fertilizers are used. Restoration projects aim to return these lands to native grassland and regain the soil quality, which could take 55-75 years for some soil components such as organic matter (McLauchlan et al., 2006).

The natural lands of St. Olaf College in southeastern Minnesota provide a unique opportunity for students to research restored prairie ecosystems. Previously agricultural land, the 350-acres of natural lands began being converted back to native prairie in 1989, with more patches converted every few years until the present day and maintained with periodic fire disturbances (Smith, 2008).

A recent study in the winter of 2008-2009 aimed to find the effects of snow cover on spatial heterogeneity of nutrients, and soil microbial activity. Two different plots in three prairies restored in different years, making for six plots total, were studied. On the inside of each plot, the snow was shoveled off and the ground was exposed for the remainder of the winter, while the exterior stayed covered in snow. There was a significantly higher CO_2 flux in the covered soil of each plot, which meant that there was higher soil respiration from increased microbial activity due to the increased soil temperature from snow insulation. There was a negative mineralization rate in the snow covered patches, likely from more organisms in this patch converting the available ammonium back to nitrate. The positive nitrate mineralization rate of the exposed patch meant there was more available N in the soil at the end of the winter (Carpenter et al., 2009)

The exposed and snow covered patches have not been studied since last winter and it is useful to find out how those two different snowpack treatments influence microbial activity, soil, and biomass during the following fall, in order to extrapolate these results to ecosystem changes from global warming's predicted effects on snowpack. Earlier snowmelt may result in a higher productivity in the following season, which in this study would result in more aboveground biomass from the exposed patches (Liptzin et al., 2009). Microbial immobilization, caused by increased ammonium in soil, has been found to be the most important process leading to reduction in nitrogen uptake by plants, which would likely result in a lower C:N ratio of biomass in this study (Vitousek and Matson, 1984). It is difficult to predict the effects on soil moisture, soil organic matter, and CO_2 flux that the snowpack treatment will have the following autumn, although since there was a lack of effect on CO_2 flux in April, I would not predict an effect in other non-snow cover months.

While the snow pack from the previous winter may have an effect on soil, microbes, and production, the number of years since prairie restoration may also have an effect. Smith (2008) found no significant difference in soil organic matter between the prairies. Average CO_2 flux, microbial biomass, and carbon to nitrogen mass ratios (C:N) of biomass have been found to increase as the years since restoration increases (Manning et al., 2008). Aboveground biomass was reduced in more recently burned prairies , and in older prairies (Smith, 2008; Manning et al., 2008).

I aimed to find the effects of prairie age and lack of snow cover on microbial activity, soil, and biomass. This study can be used for future predictions of weather fluctuations and the subsequent ecosystem changes as well as for future studies in the natural lands.

Methods:

This study was conducted on the St. Olaf College Natural Lands, in Southeastern Minnesota. The land was formerly used for agriculture, but was restored into native prairie in 1993 and 1998, respectively, for the two prairies I studied. The seeds used to plant the prairie grasses were from Prairie Restoration Inc., a company that sells seeds from the area. The prairies have been managed with periodic fire disturbance, and were last burned in 2006 and 2005 for the 1993 and 1998 prairies respectively (Smith, 2008). There were two plots in each prairie, each plot with an exposed and covered area in the winter of 2008-2009, making for eight different areas of sampling. In each plot a snow fence was put up to separate the exposed center of the plot from the regular snowpack exterior of the plot. After every snowfall that winter the snow was shoveled off the exposed plot within 24 hours.

CO_2 Flux

CO_2 flux was measured using a machine made by PP systems and measurements were made according to the EGM model's instructions. Measurements were taken on two separate days, one in mid-October, the other in mid-November. On both sampling days the weather was between 55-65 degrees Fahrenheit and no snow had accumulated on the ground. Four CO_2 flux readings were taken in the inside of each plot (the exposed area from the previous winter) and four readings were taken in the outside of the plot (in the snow covered area). In the exposed area the four readings were taken approx. 0.5-1 meter away from the center, in the four corners of the quadrat. In the covered area the four readings were taken approx. 1 meter from the exposed area, on the four sides of the square.

Soil Analysis

In order to assess soil quality, three soil cores were taken from the exposed and covered areas of each plot, on two sampling days (beginning of October and mid-November), making six soil cores for each area, 48 samples total. Soil cores were placed in pre-weighed marked tins and massed for a fresh weight. Samples were put in a drying oven at 105 degrees Celsius for 48 hours and massed for a dry weight. Soil moisture was calculated with the following equation:

$$\% \text{ Moisture} = [(\text{Fresh weight} - \text{Dry weight})/\text{Dry weight}] \times 100\%$$

A sample of the soil between 10-20g in weight was taken from the dry amount, crushed into a sand like form, and poured through a sieve of 1.19mm. This sample was placed in a pre-weighed crucible and placed in a muffle furnace at 500 degrees Celsius for 4 hours. The soil was then massed to calculate percent soil organic matter with the following equation:

$$\%\text{SOM} = [(\text{Dry weight} - \text{Ashed weight})/\text{Dry weight}] \times 100\%$$

Biomass Analysis

In order to assess biomass quality, one 0.25 m2 quadrat was sampled in each area, making for eight biomass samples total. Aboveground biomass was harvested with large shears to cut down all of the biomass that had roots within the quadrat. Biomass was cut at approximately 4-6 inches above the ground and placed into marked paper bags. Once brought back to lab the biomass was air dried.

Biomass samples were then sorted into grasses and forbs and treated as separate samples for the remainder of the analysis. All of the biomass was massed in pre-weighed aluminum boats to obtain a total air-dried weight. The biomass was placed back into its respective paper bags and a small sample of the total biomass in each sample, was pre-weighed in an aluminum boat before being placed in a drying oven at 105 degrees Celsius for 24 hours. The samples were massed again after coming out of the oven. A total oven-dried weight for each biomass sample was calculated with the following equations:

Total oven-dried biomass = (small sample post-oven weight/small sample pre-oven weight)* total air dry weight

In order to analyze the biomass samples for carbon and nitrogen content, small samples were taken from the air-dried biomass in the bags and ground into a powder. These ground samples were then placed in small pre-weighed aluminum packets and crushed into a spherical shape before being massed again. The final mass of these balls was between 2.5-3.5 grams. Six standard amounts of nitrogen were also made into balls to create a nitrogen calibration curve. These samples and standards were run through the Costech elemental combustion machine.

Statistical Analysis

Stata version 9.0 was used for all statistical analyses. One-way ANOVA tests were used to determine if there were any significant relationships between each of the two independent variables (prairie age and snowpack treatment) and the measured dependent variables: CO_2 flux, percent soil moisture, percent soil organic matter, oven-dried grass weight, oven-dried forb weight, C/N of grass, and C/N of forbs. A p-value of 0.05 determined significance and mean values were also used for comparisons.

Results:

CO_2 Flux

Mean CO_2 Flux was significantly higher in the 1993 plots than in the 1998 plots (P= 0.0269) (Table 1). This shows a relationship between age of prairie and CO_2 flux, a proxy for microbial activity. Mean CO_2 flux was significantly higher in the area of each plot that had been covered by snow during the previous winter than in the exposed area (P= 0.0114) (Table 2). This shows a relationship between snowpack treatment and microbial activity.

Soil parameters

The percent soil moisture was significantly higher in the 1998 plots than in the 1993 plots (P= 0.0131) (Table 3). There was not a significant relationship between percent soil moisture and snowpack treatment (Table 4).

There were no significant relationships between soil percent organic matter and prairie age or snowpack treatment (Tables 5 and 6).

Biomass parameters

There were no significant relationships between oven-dry grass or forb weight and prairie age or snowpack treatment (Tables 7, 8 9, and 10). However, oven-dry grass weight was noticeably greater in the 1998 prairie than the 1993 prairie, although the p-value was not significant (p= 0.1377) (Table 7).

There was not a significant relationship between prairie age and grass C:N (Table 11). With the snowpack treatments there was a significantly higher mean grass C:N in the areas of the plots that had been covered by snowpack compared to areas that had been exposed (P= 0.0031) (Table 12). There were no significant relationships between prairie age or snowpack treatment with forb C:N (Tables 13 and 14).

Discussion:

Prairie age and soil quality

Agriculture has destroyed soils over the past century to such an extent that it takes years before converted prairie land has nutrient-rich soil once again. Soil carbon increases at a constant rate for the first 40 years after it is converted from agricultural land to grassland (McLauchlan et al., 2006). When comparing prairies that have recently been converted to those that have been established for a longer time, soil microbial C and N biomass has been found to increase by 141% and 33%, respectively (Baer et al., 2000). Another study found total C, microbial biomass

C, and C mineralization to increase as a function of time in a 12-year time horizon (Baer et al., 2002). My results follows previous research in the natural lands where average CO_2 flux was found to be higher in older prairies (Manning et al., 2008).

It is difficult to explain the soil moisture difference between the two prairies, but there could be a connection with biomass. Since plants require water for growth, a higher moisture in the 1998 prairie could explain the higher production in the 1998 prairie. The biomass trend follows the results of Smith (2008) where biomass was negatively related to prairie age. Also, the 1993 prairie was burned more recently, in 2006, than the 1998 prairie, burned in 2005. Previous studies have found biomass to be reduced in more recently burned prairies (Manning et al., 2008; Smith, 2008).

Smith (2008) also found no significant difference in soil organic matter between the prairies as was found in this study.

Snowpack, nitrogen availability, and microbial activity

Previous analysis on soil N processes during the winter of 2008-2009 found the covered soil to have negative rates of N mineralization and increased rates of nitrification, resulting in immobilization of nitrogen in the predominate ammonium form under soil covered in snow (Carpenter et al., 2009; Vitousek and Matson, 1984). In the exposed soil the processes were just the opposite with positive rates of N mineralization and decreased rates of nitrification, resulting in mobilization of N in the nitrate form. The higher mineralization of N in the exposed soil allowed for more nitrogen availability in the spring (Carpenter et al, 2009). This could have been predicted to show higher biomass production in the exposed sites, but that was not found in this study. Another study found that a reduction in N availability in soil (as was found in the covered plots) did not result in a decrease in net productivity and attributed this to shifts in nitrogen-use efficiency and functional group composition. More specifically, it was hypothesized that there were more C4 grasses with better nutrient-use efficiency in the less nutrient soils (Baer and Blair, 2008).

Instead of increased biomass in exposed plots, higher N content was found in the grass in these sites. Microbial immobilization has been found to be the most important process leading to reduction in N uptake by plants (Vitousek and Matson, 1984). The grasses with higher N content also had a lower C:N, following results of previous studies (Pastor et al., 1984; Wedin and Tilman, 1996).

Microbial activity determines the C and N cycling in the soil, setting the soil nutrients before plants begin to grow in the spring (Edwards et al., 2007). The previous winter had shown higher CO_2 flux values in the covered sites in the March data, but once the snow had melted in April the snowpack treatment had hardly any effect on CO_2 flux values. I found higher CO_2 flux values in this study for the previously covered sites and there had been no snowpack on the ground since the previous winter. The lack of a relationship between CO_2 flux and snowpack treatment from April and the presence of one in the autumn could be representing different microbial communities depending on the climate conditions and the time of year. Microbial activity is extremely sensitive to soil thaw timing and duration (Edwards et al., 2007). In the spring the soil was rapidly thawing and waterlogged, and the microbial communities that thrived in the frozen soil could have been dying out as new species grew in numbers. The CO_2 flux was in a transition phase, not as stable as the communities became throughout the summer and into the fall. The stable conditions in the fall made it easier to see the effect of snowpack effect on microbial activity.

Since CO_2 flux is a proxy for microbial activity, I hypothesize that there may be a relationship between increased soil N availability and decreased microbial activity. Wallenstein et al. (2006) found decreased organic soil microbial biomass in hardwood and pine stands with high N fertilization. One hypothesis for this result is that soil C:N will decrease with increased soil N and bacteria with a smaller C:N than fungi will be able to use organic substrates with lower C:N. Another hypothesis proposed was soil acidification from increased soil nitrification resulting in nitrate leaching.

Implications for future ecosystem shifts from climate change

It is widely known that snow cover will decrease in amount and duration with increasing global temperatures, however, coastal areas will sooner be affected by climate change in terms of reduced snow cover than inland prairies, such as the area in this study (Brown and Mote, 2009). The results obtained from the exposed sites should aid in projections for ecosystem shifts from predicted decreased snow cover.

Negative trends have been found between N availability in soils and plant diversity, hinting that long-term increases in soil N availability, as was seen in exposed winter soils, will decrease biodiversity (Baer and Blair, 2008). Supporting this hypothesis is the similarity in effects from increased N deposition and N availability in soil. Increased soil nitrogen deposition has been shown to decrease plant diversity, decrease native grass species (C4 grasses), increase non-native grass species (C3 grasses), decrease the C:N ratio in prairie biomass, and increase soil nitrate and mineralization rates. A decrease in plant diversity is also a decrease in the capacity of carbon sequestration, resulting in a positive feedback for climate change (Fornara and Tilman, 2008).

The increase in soil nitrate decreases total N retention in soil (Wedin and Tilman, 1996). Faster rates of N cycling makes a more active N pool, which ultimately allows the soil to remain productive with increasing C and N deposition. Since the added nutrients will be taken up by the plant biomass instead of in the soil in this more active system, less carbon will be sequestered (Fornara et al., 2009).

One hypothesis for the effects of high N loss from soils due to increased mineralization could result in higher N concentrations in runoff and thus nutrient additions to nearby water bodies, which could ultimately result in eutrophication (Vitousek and Matson, 1984). A second hypothesis is that increased soil nitrate could likely result in higher denitrification rates, especially during spring snowmelt when soil water content is high and oxygen is limited. Increased microbial activity also contributes to increased nitrous oxide flux. Therefore, the exposed soil could produce nitrous oxide from denitrification, but the covered soil will produce nitrous oxide with increased microbial activity (Filippa et al., 2009). More work should be done to quantify the denitrification rates and thus nitrous oxide emissions from both the covered and exposed soil, during winter and throughout the following year. While nitrous oxide is an important part of the nitrogen cycle, it is a greenhouse gas (Filippa et al., 2009).

CO_2 emissions due to soil respiration are greater from deeper snowpacks, due to the increased microbial activity (Edwards et al., 2007). Although exposed soils will provide a smaller carbon sink, they might be a smaller carbon source as well. Quantifying the carbon processes in exposed as compared to covered soils could help settle the debate on which snowpack treatment would produce the most carbon debt.

Decreased snow cover will certainly change soil nutrients, microbial activity, and biomass species composition, even in the short-term time frame.

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Literature Cited:

Baer, S.G., C.W. Rice, and J.M Blair. 2000. Assessment of soil quality in fields with short and long term enrollment in the CRP. Journal of Soil and Water Conservation 55:142-146.

Baer, S.G., D.J. Kitchen, J.M. Blair, and C.W. Rice. 2002. Changes in ecosystem structure and function along a chronosequence of restored grasslands. Ecological Applications 6:1688-1701.

Baer, S.G. and J.M. Blair. 2008. Grassland establishment under varying resource availablity: a test of positive and negative feedback. Ecology 7:1859-1871.

Brown, R.D. and P.W. Mote. 2009. The response of northern hemisphere snow cover to a changing climate. Journal of Climate 22: 2124-2145.

Brye, K.R., S.T. Gower, J.M Norman, and L.G. Bundy. 2002. Carbon budgets for a prairie and agroecosystems Effects of land use and interannual variability. Ecological Applications 12:962-979.

Cahill, K.N., C.J. Kucharik, and J.A. Foley. 2009. Prairie restoration and carbon sequestration: difficulties quantifying C sources and sinks using a biometric approach. Ecological Applications 8:2185-2201.

Carpenter, L.M., E.C. Seybold, G.M. Wilkinson, D.W.P. Manning, and J. Schade. 2009. Winter snowpack effects on biogeochemical processes in a restored tallgrass prairie. Biology Independent Research 398, St. Olaf College.

Edwards, A.C., R. Scalenghe, and M. Freppaz. 2007. Changes in the seasonal snow cover of alpine regions and its effect on soil processes: A review. Quaternary International 162-163:172-181.

Filippa, G., M. Freppaz, M.W. Williams, D. Helmig, D. Liptzin, B. Seok, B. Hall, and K. Chowanski. 2009. Winter and summer nitrous oxide and nitrogen oxides fluxes from a seasonally snow-covered subalpine meadow at Niwot Ridge, Colorado. Biogeochemistry 95:131-149.

Fornara, D.A. and D. Tilman. 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology 96:314-322.

Fornara, D.A., D. Tilman, and S.E. Hobbie. 2009. Linkages between plant functional composition, fine root processes, and potential soil N mineralization rates. Journal of Ecology 97:48-56.

Liptzin, D., M. W. Williams, D. Helmig, B. Seok, G. Filippa, K. Chowanski, J. Hueber. 2009. Process-level controls on CO_2 fluxes from a seasonally snow-covered subalpine meadow soil, Niwot Ridge, Colorado. Biogeochemistry 95: 151-166.

Manning, D.W.P, B. Clifford, E.C. Mulder, C. Baustian, J. Brandell, R. G. Johnson, B. McCafferty, A. Suginaka, H. Wadell, and J.D. Schade. 2008. Effects of restoration on biogeochemical processes in restored tallgrass prairies. Biology Independent Research 398, St. Olaf College .

McLauchlan, K.K., S.E. Hobbie, and W.M. Post. 2006. Conversion from agriculture to grassland builds soil organic matter in decadal timescales. Ecological Applications 1:143-153.

Pastor, J., J.D. Aber, C.A. McClaugherty, and J. M. Melillo. 1984. Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. Ecology 65:256-268.

Smith, E. 2008. Biomass Production and Soil Nutrient Analysis in Restored Prairies. Biology Independent Research 398, St. Olaf College.

Vitousek, PM and PA Matson. 1984. Mechanisms of nitrogen retention in forest ecosystems: a field experiment. Science 225:51-52.

Wallenstein, M.D., S. McNulty, I.J. Fernandez, J. Boggs, and W.H. Schlesinger. 2006. Nitrogen fertilization decreases forest soil fungal and bacterial biomass in three long-term experiments. Forest Ecology and Management 222:459-468.

Wedin, D.A. and D. Tilman. 1996. Influence of nitrogen loading and species composition on the carbon balance of grasslands. Science 274:1720-1723.