Using Prairie Restoration to Evaluate the Age of Respired Carbon

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Abstract:

As the world's climate warms due to increasing levels of CO2 in the atmosphere, there has been increased interest in the role of soil as a carbon store. Typically, carbon is sequestered in aboveground biomass and then is incorporated as litter into the soil, where microbes process it and release carbon back into the atmosphere via soil respiration. Yet the impacts of aboveground factors, like plant diversity and herbivory, on belowground processes is poorly understood. In this study, we analyzed soil respiration rates and carbon isotope emissions in a restoration prairie under differing conditions of herbivory and plant diversity. The prairie was restored in 2012 from agricultural fields in a soy-corn rotation. We found that respiration rates remained unchanged with either treatment. We did, however, find a significant difference in carbon isotope emissions. Areas with greater C3 cover also had significantly more C3 associated carbon respired from the soil. We found that within 5 years, respired carbon significantly reflected a change in cover, illustrating that soil microbes are processing newer carbon inputs rather than carbon associated with the previous land use. This is noteworthy because it shows that the carbon being releases into the atmosphere is affected by the current plant cover.

Introduction

Approximately 80% (2500 gigatons) of all terrestrial carbon is found in soil (Lal, 2008), which is almost twice as much carbon as found in the atmosphere (Eswaran et al, 1993). Soil respiration is one of the major players in the global carbon cycle, with even small changes in respiration rates having potential feedback implications for the global climate (Rustad et al, 2000). Knowing how much carbon is in soil is insufficient to fully understand this dynamic interplay of above- and belowground responses. One key component to gaining a greater understanding is to comprehend the age of soil carbon and when it is processed and released into the atmosphere.

Carbon (C) is not all processed within the same timeframe. This phenomena can be understood by defining operational C pools with different turnover times. These C pools are relatively accurate in estimating soil C dynamics. Terrestrial carbon dynamics are understood by the using a several-pool submodel (Kelly et al, 1997). The three main pools consist of “fast” carbon (i.e. months to years old), “slow” carbon (i.e. years to decades old), and “passive” carbon (i.e. decades to centuries old) (Parton et al, 1993). In some prairies, fast carbon is estimated to make up very little of total soil carbon (~5%) while slow carbon composes closer to ~45% and passive carbon comprises roughly half, as shown in Figure 1 (Bandaranayake et al, 2003). Although this pool system is widely used, it is not always accurate in its predictions and can overestimate carbon inputs (Álvaro-Fuentes et al, 2009; Izaurralde, et al, 2006).

Carbon is processed in these pools when carbon dioxide is released from soil via soil respiration (Figure 2). Soil respiration is the process of carbon dioxide release from roots and the decomposition of organic material by microbes; this can be an important indicator of ecosystem productivity (Lou et al, 2006). About 75×10^{15}gC/year is released into the

atmosphere by this process (Schlesinger et al, 2000). This amount of carbon dioxide could significantly affect the global climate by increasing global temperatures.

Respiration rates have been found to increase due to herbivory. Herbivory has been shown to alter soil through various mechanisms (Bardgett et al., 2001). Positive effects have been associated with grazing, benefiting organic and inorganic soil components by way of plant growth overcompensation and nutrient inputs by herbivores through urine and dung (Augustine et al, 1998). These increased nutrient cycling rates have been shown to increase soil respiration and microbial metabolic activity (Lou et al, 2006). Negative effects have also been observed, due to selective foraging on nutrient rich plants. Foraging of this nature can lead to the dominance of less nutrient-rich species, resulting in fewer nutrients being returned to the soil through litter (Ritchie et al., 1998). A major component of soil respiration is from microbial decomposition of litter and soil organic matter (Lou et al, 2006). This is most prominent if the herbivores remove more nutrients that they return to the soil.

The types of plants aboveground have also shown to affect respiration rates. Plants can affect belowground respiration by changing microclimates and the quality and amount of litter produced (Raich et al, 2000). Each plant species is unique and contributes to the productivity of the belowground system (Eisenhauer et al, 2010). Plant diversity has been shown to increase some nutrient availability and soil respiration rates, most likely attributed to an increase in productivity (Zak et al, 2003).

One way to measure the age of respired carbon is to look at a system that has undergone a change in vegetation, transferring from C3 to C4 plants or vis versa. These two groups of plants have different ways of possessing carbon and have different affinities for carbon isotopes (Schönwitz et al, 1986). By analyzing respired carbon isotopes, it is possible to determine if the

carbon originated from a C3 or C4 plant and consequently the approximate age of the respired carbon. Very little work has been done using this method. The closest analog is the analysis of solid phase d13C, which is less sensitive to short term changes in carbon inputs (Balesdent et al, 1987; Gregorich et al, 1995).

In this study, we analyzed soil respiration rates and carbon isotope emissions in a restoration prairie under differing conditions of herbivory and plant diversity. We hypothesized that higher diversity areas and areas with herbivory would have higher respiration rates. We also hypothesized that the isotopes of the respired carbon would reflect the older agriculture carbon (carbon primarily associated with C4 plants), indicating that the soil microbes are still processing primarily older carbon rather than the carbon from the new prairie cover (C3 plant associated carbon).

Material and Methods:

Study Site: Soil samples were taken from Oakridge Prairie located in Story County, Ames Iowa (Figure 3). This prairie was originally an agricultural field growing corn and soybeans in yearly rotation. In 2012 it was converted into a restoration prairie. It was divided into eight plots 32 by 32 meters, four of which had electric fences and vole fences to limit herbivory. Each plot also consisted of an inner circle with a diameter of 19.2 m that was seeded with 58 plant species and the rest of the square was seeded with 14 plant species. Both areas were seeded with 519 seeds per m^2. The total area of the high diversity region is 289.5 m^2 and the area of low diversity was 662.47m^2.

Sample handling: Soil samples were collected on October 7 and 9 of 2016. Samples were taken in groups of four from three areas of each diversity in each plot, totaling 12 samples in each diversity region for each plot. Sites were chosen from previous cover plot measurement sites. A

meter squared transect was used, place in the area of previous cover measurements. Samples were taken 6 inches away from each corner of the transect at an angle of 135° from the sides. A two inch in diameter pipe was hammered 10 cm into the ground to extract the sample. Samples were stored in plastic Ziploc bags in coolers while in the field and then transferred to a -20°C until testing.

Seven days before testing, samples were removed from the freezer, placed in a glass jar, and allowed to incubate at room temperature (approximately 21°C) in a dark area. Samples were tested 10 at a time using a tunable diode laser absorption spectrometer to measure respiration and carbon isotope emission. To test for leaks, the connected jars were exposed to concentrated carbon dioxide.

Analysis: A mixing model was used to partition respiration sources. All analyses were conducted in R. To determine the effect of herbivory and diversity on respiration rate, we used a general linear model and assumed a Gaussian error distribution. The same was done for analyzing how herbivory and diversity affected the proportion of C3 associated carbon respired. Random effects included plot and "group" (the cluster of four samples taken within a meter squared). Plant cover was also analyzed by using a general linear model and assumed a Gaussian error distribution.

Results:

Neither herbivory ($p=0.7876$; Figure 4) nor diversity also had no significant effect on respiration, ($p=0.0704$; Figure 4). High diversity treatments had a higher proportion of C3 species aboveground ($p < 0.001$ - Figure 5), however, herbivory did not significantly affect the portion of C3 cover ($p=0.07$; Figure 5). Herbivory also did not significantly affect the proportion of respired carbon associated with C3 plants, ($p= 0.7533$; Figure 6). Treatments with higher

diversity contained a greater proportion of respired carbon derived from C3 plant, ($p < 0.001$; Figure 6).

Discussion:

We found that carbon isotope emissions reflect the plant cover from the recently restored prairie rather than the agricultural sources that dominated the land cover for the last few decades. This illustrates that soil microbes are processing the new carbon inputs rather than carbon from the long standing carbon pool (Trumbore, 2000). Other studies looking at respired isotopes in relation to C3 and C4 plants have similar findings with respired carbon closely reflecting cover within six to seven years (Schönwitz et al, 1986; Allen et al, 2000; Trumbore, 2000).). There does appear to be a temporal lag in carbon processing. C3 cover and respired C3 are not are not identical, which suggests that there is still a legacy effect from the previous agricultural regime.

These findings support other results in different systems implying that respiration responds to newer carbon inputs much faster than other soil properties (Schönwitz et al, 1986; Allen et al, 2000; Trumbore, 2000). Our results reemphasize the importance of the aboveground community on belowground processes.

Contrary to our hypothesis, herbivory and diversity did not significantly affect soil respiration rates (Figure 4). This suggests that, in this system, the influence of herbivory was not translated to the belowground system. Little is understood about how herbivory affects the living components of soil (Bardgett et al, 2001). Some studies have shown that herbivory increased both soil and root respiration (Holland et al, 1996). Soil respiration did not differ between areas with high and low plant diversity. Although respiration rates did not change with either treatment, sources of the respired carbon did. We have shown that within 5 years, respired

carbon significantly reflects a change in cover, illustrating that soil microbes are processing newer carbon inputs.

The world's soil contains almost twice as much carbon as the atmosphere (Eswaran et al, 1993). The release of this carbon could have devastating consequences for the global climate. By understanding the origin and age of the carbon that is being released, we are closer to understanding the dynamic interplay of soil and climate change. The next step is to further analyze which plant communities may have the largest carbon-storing ability and use these communities to help mitigate atmospheric carbon dioxide.

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Figures:

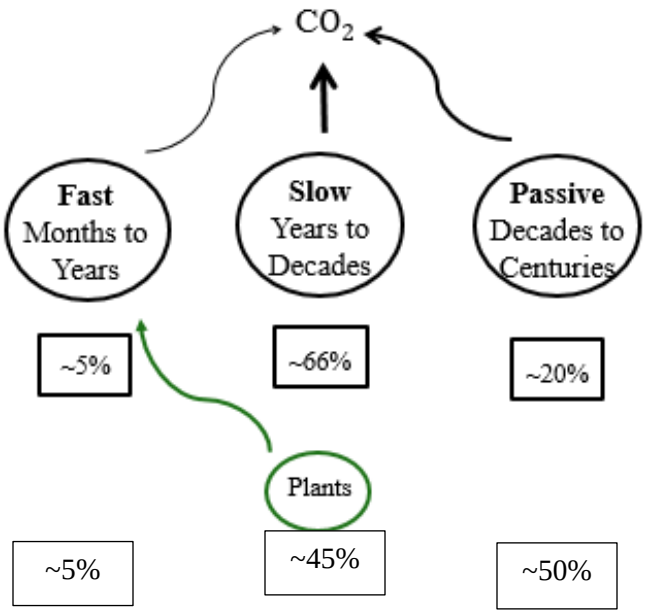

Figure 1 The estimated age of each carbon pool and its contribution to the carbon produced by the soil (Bandaranayake et al, 2003)

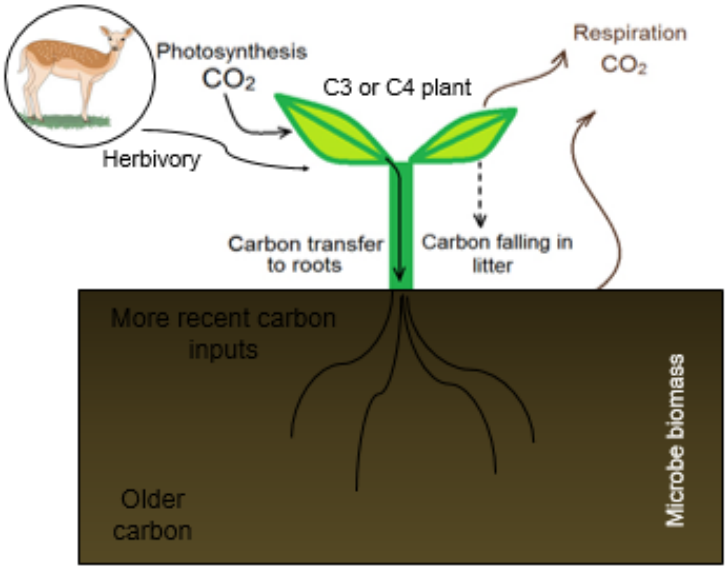

Figure 2. Dynamics interplay of vegetation and soil (Aberystwyth University).

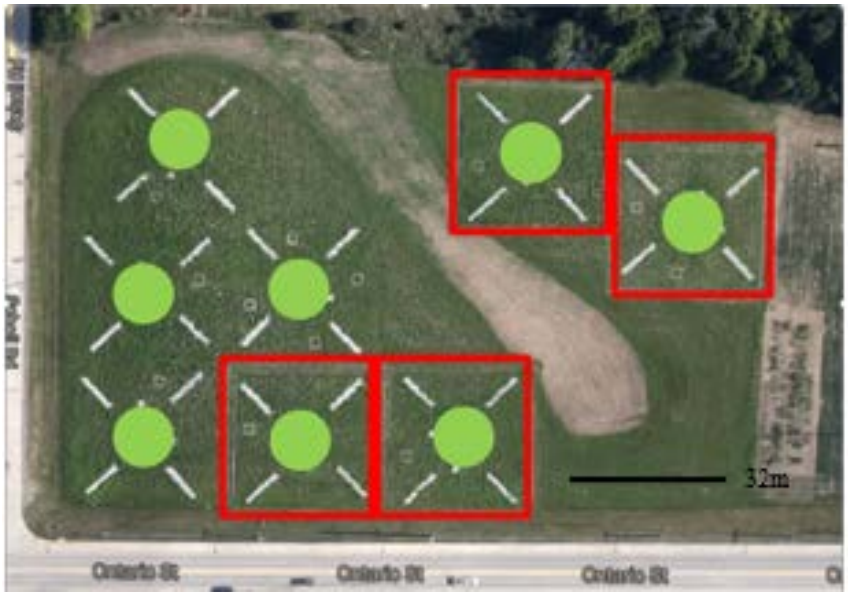

Figure 3. Oakridge study site. The red outline marks the herbivory enclosures. The light green circles mark the high diversity area (seeded with a seed mix of 58 species), while the remaining area was seeded with 14 species. Plots are 32m x32m and interior circle has a diameter of 19.2m.

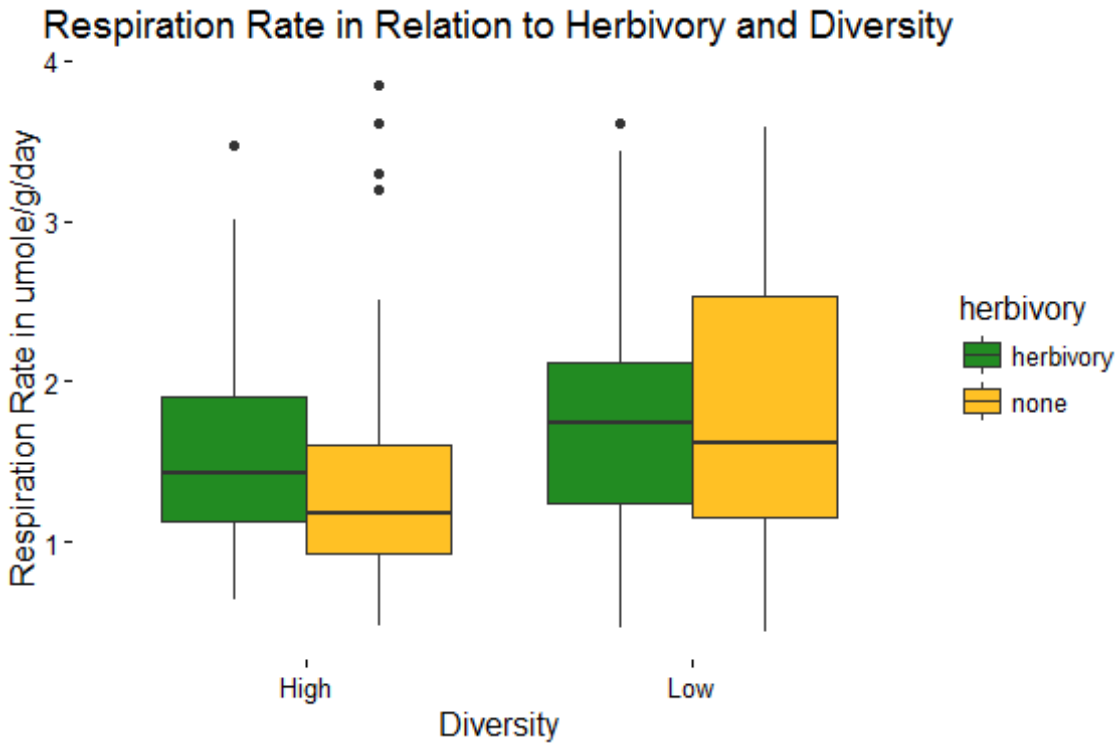

Figure 4. Soil respiration rates across herbivory and diversity treatments did not significantly differ (diversity: p = 0.07; herbivory: p=0.79.)

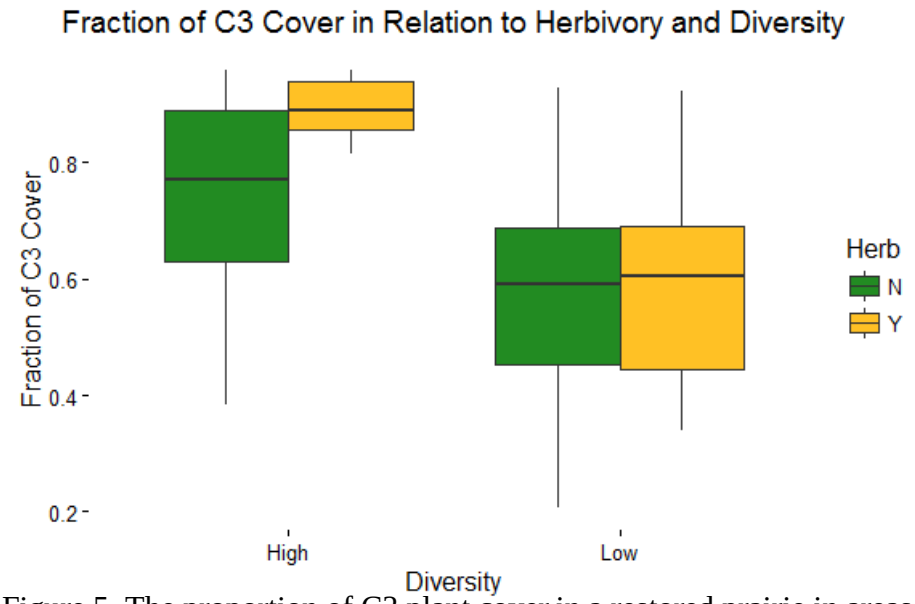

Figure 5. The proportion of C3 plant cover in a restored prairie in areas seeded with high or low diversity seed mixes and areas open to herbivory compared to herbivore enclosures. C3 cover was significantly greater in high diversity plots ($p < 0.001$) but did not significantly differ between herbivory treatments ($p = 0.07$)

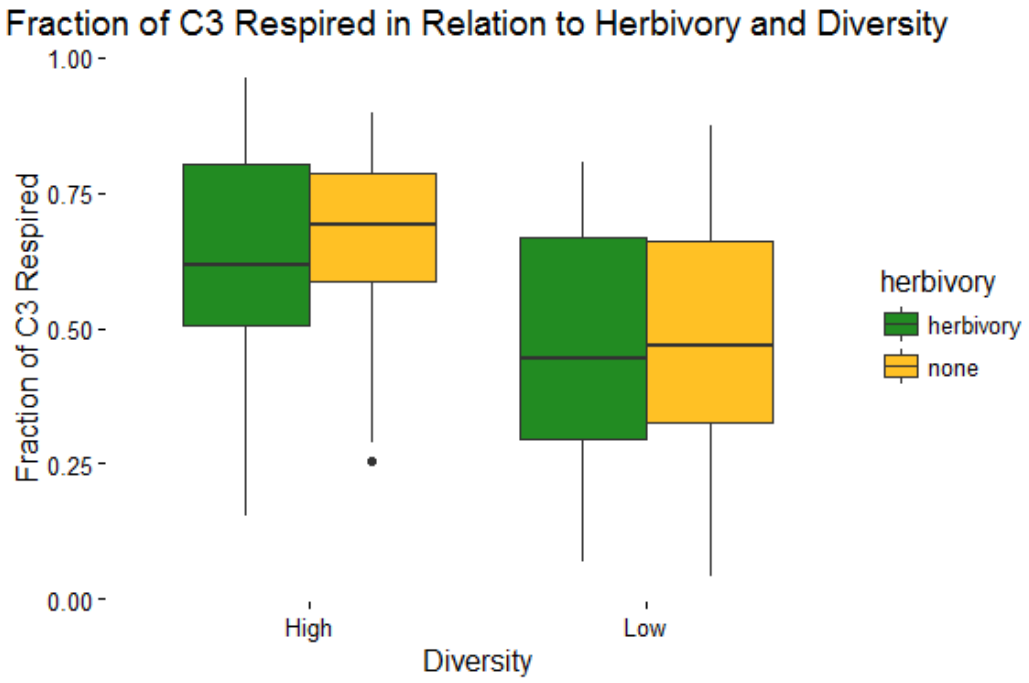

Figure 6. The proportion of respiration associated with C3 carbon sources in a restoration prairie either open to herbivores or within herbivore enclosures and in areas seeds with high or low diversity mixes. There was no significant effect of herbivory ($p=0.7533$). There was a significant difference between high and low diversity prairie plots ($p<0.001$).

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