Carbon addition in the Form of Sucrose and Sawdust as a Method of Restoring Native Perennial Grasses in Two Coastal California Prairies

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Abstract The extensive conversion of California’s grasslands into communities occupied by Mediterranean annual grasses, and the nitrogen enrichment of areas in which native remnant populations still remain, have created a strong interest in employing labile carbon addition as a method of restoring and preserving the native perennial bunchgrasses that once dominated California’s landscape. Nitrogen enrichment has been shown to favor invasions of grasslands by annual species. Carbon addition to the soil may be used to temporarily decrease soil nitrogen availability, which in turn may decrease the competitiveness of exotic annual grasses, and thereby give native seedlings a greater chance of survival. This study examined whether the addition of labile carbon (in the form of sucrose and sawdust) reduced plant available nitrogen and increased native establishment in two coastal California prairies. In March 2006, sawdust and sucrose (400 g C/ m^2) were added to plot that contained both native and exotic seedlings and measures of soil moisture and nitrogen levels were taken. I expect to find that carbon amended plots have lower net nitrogen mineralization and nitrification rates and lower ammonium and nitrate concentrations than umamended plots. At both sites, there was no significant difference in soil moisture levels between the two treatments. This implies that any differences in species composition can be attributed to differences in soil nitrogen levels rather than differences in soil moisture.

Introduction

Invasions by exotic species have been acknowledged as critical components of human-induced ecosystem change and pose a serious threat to global biodiversity (Mack et al. 2000, Borer et al. 2003, Corbin and D'Antonio 2004). The transformation of nearly all of the 10 million hectares of California grasslands from native perennial bunchgrass communities into annual Mediterranean grass communities is one of the most dramatic examples of a large-scale invasion in the world (Corbin et al. 2004, Borer et al. 2003). There are currently many ongoing attempts to restore native California bunchgrasses to grasslands that are dominated by annual exotic species (Corbin et al. 2004).

Among the methods being tested is the lowering of soil nitrogen (N) levels through the addition of organic carbon (C), most often in the form of sucrose and/or sawdust, to the soil (Zink and Allen 1998, Reever Morghan and Seastedt 1999, Torok et al. 2000, Cione et al. 2002, Blumenthal et al. 2003, Averett et al. 2004, Corbin et al. 2004). Today, the spread of invasive N-fixing species into many ecosystems around the world (Vitousek et al. 1987, Maron and Connors 1996, Maron and Jefferies 1999, Mack et al. 2000, Corbin et al. 2004) combined with the impact of human activities, such as the use of nitrogen fertilizer, fossil fuel combustion, the planting of N-fixing crops in agriculture, and the mobilization of N from long-term biological storage pools (Vitousek et al. 1997, Bobbink et al. 1998, Corbin et al. 2004), have caused a large increase in the amount of N available for use by species in all environments.

Historically, N has been a limiting nutrient in most ecosystems, and native species in these systems are adapted to these low N conditions (Vitousek et al. 1997, Blumenthal et al. 2003). In contrast, many invasive species have a life strategy of growing quickly and producing large amounts of seed. This strategy is dependent on the wide availability of N (Huenneke et al. 1990, McLendon and Redente 1992, Rothrock and Squiers 2003). When the pool of available N decreases, these species lose their competitive advantage, and native species, which are accustomed to competing for N, are better able to compete against the invaders (McLendon and Redente 1992, Blumenthal et al. 2003, Rothrock and Squiers 2003). Higher available soil N in many ecosystems, including grasslands, has consequently been found to promote and sustain the presence of invasive weeds (Huenneke et al. 1990, McLendon and Redente 1992, Redente et al. 1992, Maron and Connors 1996, Vitousek et al. 1997, Bobbink et al. 1998, Maron and Jefferies 1999, Paschke et al. 2000, Rothrock and Squiers 2003, Corbin et al. 2004), and recent research indicates that lowering levels of soil N can shift the community composition back towards native species (Zink and Allen 1998, Blumenthal et al. 2003, Averett et al. 2004).

Studies have shown that soil N levels can be lowered through the addition of organic C into the soil, which stimulates soil microbe immobilization of N (Killham 1994, Corbeels et al. 2000). This decreases the amount of ammonium and nitrate available to plants and thereby lowers plant growth (Reever Morghan and Seastedt 1999, Blumenthal et al. 2003, Averett et al. 2004, Corbin et al. 2004). Although both native and exotic growth decreases with C addition, it is expected that native species will be better able to compete against nitrophilic exotics in lower N conditions (Corbin et al. 2004). The results of experiments on the effects of C addition on soil N availability and plant growth have varied however (Zink and Allen 1998, Reever Morghan and Seastedt 1999, Cione et al. 2002, Blumenthal et al. 2003, Averett et al. 2004, Corbin and D'Antonio 2004), and this area needs further investigation.

Because the effects of C addition are temporary, repeated additions of C to the soil over the course of a year influence community composition more strongly then the application of only a single treatment (Morghan and Seastedt 1999, Torok et al. 2000, Cione et al. 2002). The application of C in the spring, during the peak growing season, is especially important because this is the time period in which plants take up the most nutrients (Morghan and Seastedt 1999, Cione et al. 2002). Sucrose supplies a large amount C in a form that is readily exploited by microbes, so its effects are seen more quickly, but they last for a shorter period of time then the effects of sawdust addition (Torok et al. 2000). Sawdust supplies C in a form that must be broken down, and it is therefore not as quickly utilized by microbes, but its effects on soil N last longer then the effects of sucrose addition (Torok et al. 2000). Many studies incorporate the use of both sucrose and sawdust in their treatments as a way of generating a quick and long lasting effect on soil N levels (Reever Morghan and Seastedt 1999, Blumenthal et al. 2003, Corbin and D'Antonio 2004).

The length and magnitude of the effect of carbon addition on soil N and on plant community composition varies with the type of C added (sawdust vs sucrose) and with the climate and soil properties of the ecosystem (Torok et al. 2000). Results of past studies can be used to indicate a general idea of the length of the C addition effect on soil N levels. Torok et al. (2000) found that the sucrose effect lasted for about one month, while sawdust effects have been found to last from 2 months (Reever Morghan and Seastedt 1999) to 4 months (Cione et al. 2002). Once soil N is decreased by a treatment, it may retain lower N levels for longer than a year, possibly as a result of the initial steep decline in N from the original C application (Torok et al. 2000, Blumenthal et al. 2003).

C addition has also been found to increase soil moisture levels (Blumenthal et al. 2003, Averett et al. 2004). Water is an important limiting resource for native grasses, and water scarcity has been shown to prevent their successful competition against exotic species (Hamilton et al. 1999). By increasing soil moisture, C addition may therefore provide yet another benefit to native grass species.

Currently research involving various combinations of different restoration methods is being carried out by Jeffrey D. Corbin in two coastal California prairies located at Tom's Point and at Point Reyes National Seashore. Corbin's research is focused on the success of seed addition in combination with a treatment meant to decrease exotic species' ability to compete. The three treatments being tested are mowing, the removal of Residual Dry Matter (RDM) through raking, and labile carbon addition in the form of sawdust and sucrose. The success of these methods will be determined by comparing the percent cover of native species in each plot.

This study will build on Corbin's experiments by testing whether the addition of labile carbon (as sugar and sawdust) will reduce plant-available nitrogen and increase native establishment. C addition is meant to temporarily decrease soil N availability and thereby decrease exotic productivity, giving native seedlings a greater chance of survival and establishment.

The hypotheses being tested are: (1) ammonium and nitrate concentrations and net nitrification and N mineralization rates will be lower in the carbon amended plots. (2) soil moisture levels will be higher for C amended plots (3) native establishment will be higher in the carbon amended plots. Due to the time constraints of this project, the data presented and analyzed in this paper will not include the information on native establishment (hypothesis 3) or the information on soil nitrogen levels (hypothesis 1).

Methods

Study Sites Point Reyes and Tom's Point are both characterized by a Mediterranean climate, with germination occurring around October and the peak growth for annual species being reached around March. Both sites have been invaded by exotic annual grasses from the

Mediterranean, but remnant native populations are still present in these areas. The two sites have also been periodically invaded by yellow bush lupine (*Lupinus arboreas*), a short lived, N-fixing shrub that has been shown to facilitate invasion by exotic weeds through N enrichment of the soil (Maron and Connors 1996, Maron and Jefferies 1999). The presence of *L. arboreas* in these two sites implies that the soil has been enriched by N, and this makes C addition an especially promising restoration treatment for these areas.

Experimental Design In October 2005, Corbin established 128, 5m x 5m plots. 64 plots are located at Tom's Point and 64 plots are located at Point Reyes National Seashore. 8 of the plots at each site were randomly assigned one of 8 treatments. The two treatments for which GWC and ammonium and nitrate information were collected are the seed addition and raking treatment (control) and the seed addition, raking, and labile carbon addition treatment. Native perennial seeds were added to the plots at a rate of 100 seeds/ m^2 in October 2005. Sawdust and sucrose were added to the site in October 2005 and then again during the growing season in March 2005 (200g C / m^2 sawdust, 200g C / m^2 sucrose). One week after the March 2005 carbon application, three 15cm deep x 2cm wide cores were collected from the plots, and the soil collected from each plot was bulked. A subsample of soil was weighed, dried in a >100 ?C oven for 2 days, and weighed again in order to determine Gravimetric Water Content, which is calculated as [(wet weight – dry weight)/ (wet weight – tin weight)]. Another subsample was immediately extracted with 50mL of 2M KCl. A final subsample was incubated at 25 ?C for 2 weeks and then extracted with 50mL of 2M KCl. The extracted solutions were sent to the ANR Analytical Laboratory in UC Davis for analysis. The laboratory uses the Flow Injection Analyzer Method to determine ammonium and nitrate concentrations.

The ANR Analytical Laboratory will provide the results in units of [mg N / L]. This information will be transformed to units of [mg N / kg soil] using the following equations:

dry weight factor = wet weight/(1+GWC)

[mg N / kg soil] = [sample concentration *(volume of extractant +(dry weight factor * GWC))]

Net N mineralization rates will be calculated as:

(incubated NO_3 + incubated NH_4) - (initial NO_3 + NH_4 concentrations)

Net nitrifications rates will be calculated as:

(incubated NO_3 -initial NO_3)

Statistical Analysis A 2-tailed t-test will be used to compare ammonium concentrations, nitrate concentrations, net N mineralization rates, net nitrification rates, and GWC between the 8 carbon amended plots and the 8 control plots at each site.

Results

There was no significant difference in the Gravimetric Water Content (GWC) measured in March 2006 between the control and carbon addition treatments at either Point Reyes ($t = 0.3668$, $P = 0.7233$) or Tom's Point ($t = -0.6147$, $P = 0.5503$) (Fig 1). This indicates that the sucrose and sawdust addition did not influence soil moisture levels.

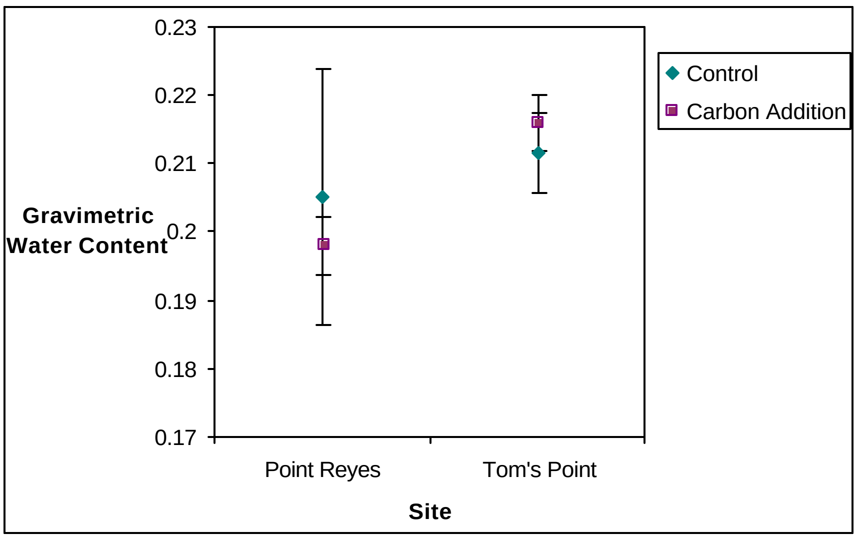

Figure 1: Mean Gravimetric Water Content (GWC) in carbon addition and control plots at both sites. Points represent mean ± standard error.

Discussion

The reason that a difference in soil GWC was not detected between control and carbon addition plots could be a result of the large amount of rainfall that occurred in the spring. It is likely that the soil in all plots was saturated with water, and the addition of sawdust under such conditions could only make a very small impact, if any, on the soil moisture in the carbon amended plots. The lack of a significant difference in soil moisture content between the two treatments implies that any detectable affect that C addition has on species composition can be attributed to the influence of soil nitrogen differences rather than soil moisture differences.

In the use of carbon addition as a restoration method, the feasibility of applying this technique must be considered. If a very large amount of carbon addition is needed in order to influence soil nitrogen levels and thereby influence plant community composition, then this may not be a realistic method for land managers to apply for reasons of both finance and practicality of use.

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