Effects of nitrogen reduction on invasive plants in restored grasslands

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Disclaimer: This is only a rough draft -- the final thesis will not be ready until November of 1997. The numerical data itself is complete and will not change, but the text will change greatly and will be expanded to include the results of previous years.

Abstract

Control of invasive plant species is a problem facing ecosystem management officials, especially for disturbed ecosystems and ecosystems with elevated nutrient levels. Disturbed grasslands with elevated nitrogen levels tend to have low species diversity and high numbers of invasive species. I studied the effects of carbon amendments on disturbed grassland with elevated nitrogen levels to see if carbon amendments could lower soil nitrogen levels and control invasive species invasion.

A combination of sugar and sawdust was added to the soil of the disturbed plots. This addition of carbon to the soil stimulates soil microbe growth which binds soil nitrogen and makes it unavailable to plants. I analyzed soil nitrogen levels during treatment, one month after treatment, and two months after treatment and compared control plot levels to treatment plot levels to study both the effectiveness of this treatment in lowering nitrogen and the duration of that effect. I also measured the response of plant biomass and invasive species number to this treatment. I found a significant decrease in soil nitrogen levels both during the treatment period and one month after. I also found a significant decrease in the

overall biomass of the treatment plots and in the biomass of the most problematic invader, diffuse knapweed. These results indicate that carbon amendment treatments can be effective at decreasing soil nitrogen levels which can help control invasive species.

Introduction

One of the largest problems facing land management and land restoration agencies is the invasion of ecosystems by non-native species (Hobbs and Humphries 1994; Morgan 1994; Westman 1990). To find a way to protect areas against invasion, we must first understand the processes that make an area susceptible to invasion. Two processes that contribute to such susceptibility are disturbance and nutrient additions (Hobbs and Huenneke 1992; Hobbs 1989; Huenneke et al. 1990; Hobbs and Humphries 1994; Lodge 1993; Westman 1990; Cowie and Werner 1993). While each is quite powerful at enabling invasion on its own, the combination of the two processes makes invasion even more likely (Hobbs 1989). Disturbance leading to secondary succession is often characterized by a rapid increase in soil nitrogen followed by a gradual decrease (Vitousek et al. 1989). So, to combat invasion, we must focus on strategies that lower elevated nutrient levels and speed the process of recovery from disturbance.

One technique that can be used to lower soil nitrogen levels and favor later seral species is addition of carbon amendments to the soil. Carbon amendment treatment involves the addition of organic matter -- such as sugar, sawdust, straw or grain hulls -- that is high in carbon and low in nitrogen to the soil of an experimental site (Morgan 1994). The addition of carbon stimulates soil microbe growth, and the soil microbes accumulate soil nitrogen in their biomass which makes it unavailable to plants (Vitousek 1982; Morgan 1994; McLendon and Redente 1992; Hunt et al. 1988). Because native plants and late seral species are more able to out-compete invasive species and early seral species in the resulting low nitrogen environment (Redente et al. 1992; Wedin and Tilman 1990), the nitrogen-lowering effects of carbon amendment treatment can help speed the rate of succession in disturbed areas by countering the nutrient increases due to disturbance and by favoring late seral species.

The soil nitrogen-lowering effects of carbon amendments can help fight invasion by countering the effects of increased nutrient levels due to disturbance or nutrient inputs and slowing the growth rates of invasive and early seral species. As a result, carbon amendments can favor the growth of late seral species and speed the rate of succession in disturbed areas. Finally, carbon amendments can lower soil nitrogen levels, resulting in a gradual increase in plant species which decreases the likelihood of invasion. I propose that carbon amendments can be used as a tool to lower soil nitrogen levels and help grasslands fend off invasion by speeding the process of succession and increasing their species diversity.

Materials and Methods

Plots and Treatment

Eighteen experimental plots are located in Boulder Open Space land, south of the city of Boulder, Colorado. These plots measure 3 m by 1.5 m and are divided into a control half and a treatment half. Twelve of these plots are on the site of a 1991 disturbance, and six are on the site of a 1993 disturbance. Burial of utility cables was responsible for both disturbances. All plots have large populations of invasive species. These plots were also used in carbon amendment studies conducted in 1994 and 1995 by Seastedt et al. (1996). I hand sprinkled carbon amendments onto the soil surface in the center square meter of the treatment plots at regular intervals. The total amount of carbon added during the experiment was 1000g of sucrose (table sugar) and 650g of sawdust. I added about 200 g of sucrose each month from February to June and 325 g of sawdust in March and May only.

Soil Analyses

I analyzed the soil at three dates -- during treatment, one month after, and two months after -- to see how long the effects of treatment lasted. In May, during the carbon amendment addition period, I analyzed the soil in both halves of the eighteen plots. I analyzed both halves of twelve of the paired plots in July, one month after I had stopped adding carbon amendments to the plots. I analyzed the soil in both halves of the remaining six paired plots in August. Each sample consisted of two 10 cm soil cores from one half of the paired plots. I sifted each sample through 2 mm mesh, weighed the soil, dried the soil in a 60° C baking oven, and re-weighed the soil to find its moisture content. I prepared each soil sample by adding 5 g of soil to 50 ml of 2N KCl, shaking the sample for 1 hour, and allowing it to sit for 19 hours. The solution was filtered, and this filtered solution was analyzed on a Lachet analyzer for nitrogen in both its nitrate (NO_3^-) and ammonium (NH_4^+) forms.

Plant Census and Biomass

I identified the native and invasive plants in the plots in July. I counted the total number of alyssum and Western wheat within a 0.1 m^2 quadrat and the total number of diffuse knapweed within the full 1 m^2 plot. Flowering knapweed biomass was collected separately from the rest of the plant biomass, so the knapweed could be left in the field until its seed matured which allowed seed harvesting for knapweed seed production estimates. The first biomass harvest occurred in mid-July. All non-knapweed biomass was clipped at the soil surface in an 0.1 m^2 section of each plot. The previous season's standing dead plants and litter were also not collected because any biomass from this material would not reflect biomass changes during this treatment period. This harvest underestimates the annual productivity because many of the early season plants had already senesced, but I assumed that this bias would not affect treatment comparisons. All biomass was air dried for five days, then dried in a 60° oven to constant weight. The second harvest occurred in late August and consisted of all the mature knapweed in the entire 1 m^2 plot. All knapweed was air-dried to constant weight. I estimated knapweed seed production by harvesting and counting the number of seeds per ten random seed heads from the knapweed plants in each plot.

Statistical Tests

All data was analyzed with a standard paired plot comparison except the mature knapweed density, which showed no correlation between plots. The knapweed data was analyzed with a log-transform because the variance was larger than the mean.

Results

The treatment significantly decreased soil inorganic nitrogen levels during treatment and one month after the treatment had ceased (Table 1, Figures 1 and 2). The soil organic nitrogen levels were not significantly different from the levels in the control plots after two months. This decrease in soil nitrogen resulted in a decrease in plant biomass in the treated plots. Both the non-knapweed biomass and the mature knapweed biomass were significantly lower in the treated plots than in the control plots (Table 2); ($P < 0.05$ for both). Knapweed was present in nine of the treatment plots and five of the control plots and weighed an average of 81.72 g/m^2 in each of the nine treatment plots compared to an average of 236.26 g/m^2 in each of the five control plots. There was no significant difference between the percentage of invasive species in the treated plots and the percentage of invasive species in the control plots. The knapweed seed count showed no significant difference in seed production between the knapweed in the control plots and that in the treatment plots ($P > 0.05$). The average number of seeds per seed head in the treated plots was 6.2 while the average number in the control plots was 8.2. Larvae of the knapweed biocontrol agent *Urophora affinis* was present in some of the seed heads and may account for any decrease in seed production between the knapweed in the test plots and knapweed in other sites.

Average Amounts of Ammonium and Nitrate per Analysis Date

		Analysis 1	Analysis 2	Analysis 3
Ammonium	Control:	3.53	4.62	2.60
	Treatment:	0.62	1.55	1.63
	P > T:	P = 0.0001	P = 0.0003	P = 0.1320
Nitrate	Control:	2.31	1.52	1.43
	Treatment:	0.56	0.55	1.11
	P > T:	P = 0.0002	P = 0.0002	P = 0.2778

Table 1: Average values for ammonium and nitrate in the control and treatment plots during all three soil analyses and values for probability. All amounts given in $\mu g/g$ (micrograms of nitrogen per gram of soil).

Average Biomass - Treatment Plots and Control Plots

Non-knapweed biomass	Control plots	311.83 g/m^2
	Treatment plots	178.36 g/m^2
Mature knapweed biomass	Control plots	65.63 g/m^2
	Treatment plots	40.86 g/m^2
Total biomass	Control plots	377.46 g/m^2
	Treatment plots	219.22 g/m^2

Table 2: Comparison of average biomass amounts for control and treatment plots. Biomass is broken down into three categories: non-knapweed biomass, mature knapweed biomass, and the total biomass. The amounts listed reflect the average biomass of all eighteen treatment or control plots. The biomass of the knapweed plots with knapweed (nine treatment plots and five control plots) was averaged over all eighteen plots. All are significantly different ($P < 0.05$).

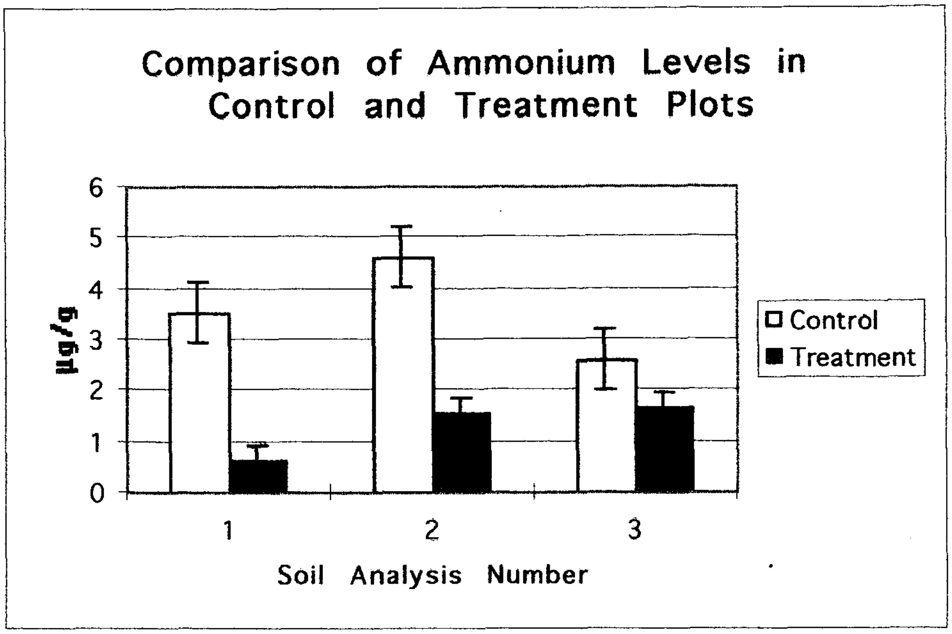

Figure 1: Comparison of ammonium levels between control and treatment plots and changes in these levels over the course of the experiment. Each pair of bars represents one analysis date. All amounts given in $\mu g/g$ (micrograms of nitrogen per gram of soil).

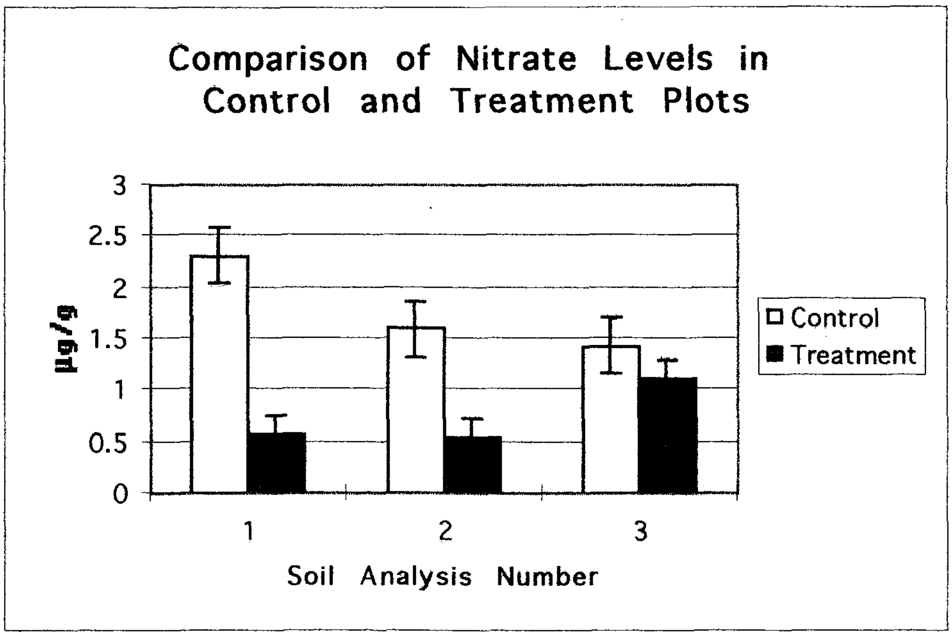

Figure 2: Comparison of nitrate levels between control and treatment plots and changes in these levels over the course of the experiment. Each pair of bars represents one analysis date. All amounts given in $\mu g/g$ (micrograms of nitrogen per gram of soil).

Discussion

The carbon amendment treatment lowered nitrogen levels in my treated plots substantially below the levels found in control plots (Table 1). Unfortunately, the soil nitrogen-lowering effects did not last long after the treatment (Figures 1 and 2). In order to continuously lower soil nitrogen levels, one must continue to add carbon amendments at regular intervals. There was no significant increase in native species density in the treated plots and no significant decrease in the density of the invasive species. There was a significant decrease in plant biomass, including knapweed biomass (Table 2). Knapweed seed production appears to be proportional to biomass so this decrease in biomass may have had an additional effect on the number of seeds produced by the knapweed in the treated plots. Comparisons of number of seeds per seed head showed no significant difference between treated and control plots.

Problems with this experiment included the small size of the plots in relation to sources of seed rain and the inability to keep cows out of the plots. These plots are surrounded by a large amount of invaded grassland, so seed rain from outside the plots potentially lessened the effectiveness of the treatment. While the treatment may have reduced seed sources of annual and biannual weeds in the treatment plots, seeds from the surrounding areas undoubtedly reached the plots. The experiment was also potentially affected by the cattle that accidentally were allowed to graze the plot for three days in mid-June. This accidental grazing of the plots added nitrogen, in the form of urea, randomly to the plots, and it would be difficult to know exactly what effect the nitrogen addition may have had. At a minimum, the background variation in soil inorganic nitrogen was undoubtedly affected. The treatment effect may have persisted longer had the cattle not increased nitrogen levels. I would propose that a better idea of carbon amendments effectiveness would be gained by conducting a more controlled experiment in an area less accessible to invasive plant seeds and rogue cattle.

In conclusion, my study confirms that carbon amendment treatment is an effective treatment for lowering soil nitrogen levels and plant biomass. While this study was not able to give any further insight into the effectiveness of carbon amendments on invasive species populations or plant species diversity, the nitrogen-lowering effects of this treatment may help control invasive species and plant diversity in a longer study. In addition, the soil analyses revealed information about the duration of the soil nitrogen-lowering effect which will be useful in formulating a land restoration plan focused around carbon amendments. Carbon amendments will be most effective in areas of short-term disturbance with temporary increases in soil nitrogen.

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