EFFECTS OF SUGAR BEET PULP ON CHEATGRASS AND BLUEBUNCH WHEATGRASS GROWTH UNDER CONTROLLED CONDITIONS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

ABSTRACT

Cheatgrass (*Bromus tectorum* L.,) an invasive, annual grass species, degrades range and pasture lands by out competing and replacing preferred native grass species resulting in economic and ecological losses. Current control strategies are costly and ecological risky. Soil nitrogen depletion by promoting microbial nitrogen utilization by application of a carbohydrate energy source such as sucrose may decrease cheatgrass's competiveness and permit seedling establishment of preferred native species. Review of the literature reveals attempts at restoration of native grasses and elimination of cheatgrass by nitrogen depletion with sucrose applications have failed or at best achieved limited success. We believe one reason for failure is that soil microbes utilize applied simple carbohydrates such as sucrose too rapidly resulting in only short periods of nitrogen depletion, and that application of sugar beet pulp may promote a longer state of nitrogen depletion. We hypothesize the growth of nitrogen dependent invasive grasses will be inhibited by nitrogen deprivation produced by mulch application of coarse granulated sugar beet pulp, and that the inhibition of growth is not related to a passive mulch effect.

In a four armed green house study, we compared cheatgrass and bluebunch wheatgrass growth after application of ground sugar beet pulp at rates of 0.0, 0.5, 1.0 2.0 and 4.0 tons per acre. As a control, granite chicken grit was similarly applied in equal volumes to rule out a passive mulch effect. At 35 days, there was a negative linear relationship between rate of sugar beet pulp application and cheatgrass growth ($p < 0.001$) and BBW growth ($p<0.002$). The negative effect of sugar beet pulp on cheatgrass growth was twice the negative effect on blue bunch growth. Granite grit application did not decrease growth of either species. We conclude that sugar beet pulp application depresses cheatgrass growth and that the cause is not a passive mulch effect. Our data indicates that longer duration nitrogen deprivation may aid in promoting restoration of cheatgrass dominated acreages, and treatments such as sugar beet pulp application may permit native grass seedling emergence and establishment.

EFFECTS OF SUGAR BEET PULP ON CHEATGRASS AND BLUEBUNCH WHEATGRASS GROWTH UNDER CONTROLLED CONDITIONS

Introduction

Cheatgrass (*Bromus tectorum* L.) is an invasive, annual grass species that currently dominates more than 22 million ha (Vasquez et al. 2008) and may be the most common plant in the western United States (Meyer and Leger 2010). Cheatgrass invasion decreases rangeland productivity, produces major changes in species richness and composition, increases fire frequency, degrades ecosystems and alters wildlife habitats (Vasquez et al. 2008). In agricultural systems such as winter wheat production, cheatgrass invasion significantly reduces crop quality and yields (Menalled et al. 2008). Cheatgrass control attempts have achieved only limited success and have high capital and labor costs (Young and Clements 2009). We believe that if control methods are not based upon scientifically obtained, ecological data documenting individual plant responses to treatment modalities, they will fail. We have designed our current investigation in an effort to increase cheatgrass control effectiveness utilizing the concept of soil nitrogen reduction by carbohydrate stimulation of soil microbial denitrification. Our investigation documents altered cheatgrass growth response resulting from application of an agricultural waste by product, sugar beet pulp.

Literature Review

Cheatgrass

By 1938, cheatgrass a non-native winter annual grass had dominated range and pasturelands in the plains, foot hills and intermountain valleys of eleven western United States (U. S. Forest Service 2005, Meyer, S. E and E. A. Leger 2010). One of the most successful and wide spread invasive species in North American landscapes, cheatgrass was introduced as a seed contaminant from Eurasia and the Mediterranean less than one hundred seventy five years ago. (Harris 1967, Upadhyaya et al. 1986, Meyer and Leger 2010). As an annual plant, cheatgrass expansion violates two major concepts of seral succession proposed by Clements: 1.) As an annual grass species, Clements classified cheatgrass as either a colonizer or early seral state species (Clements 1936, Weaver and Clements 1938); 2.) Although cheatgrass invades and dominates only as a consequence of disturbance such as heavy grazing, cheatgrass remains a dominant species long after the disturbance is removed (Harris 1967). However, more recent ecologists would classify cheatgrass as a climax species (Young and Clements 2009,) in that cheatgrass invasion supports the more recent concept of State and Transition Theory. Once establishment occurs, the ecological threshold is extremely difficult to reverse (Stringham et al. 2003). Cheatgrass dominance is related to its ability to:

1. "…exploit disturbance at multiple spatial scales to become established …".
2. Produce large amounts of seed.
3. "… be highly competitive for below ground resources with an extensive fine root system that usurps available water and nutrients from the soil…"

4. Self pollinate; one seed can produce a stable, dominant population (Meyer and Leger 2010).

Once domination occurs, cheatgrass eliminates other botanical species either by its innate ability to compete or by its positive co-existence with fire.

Competition amongst species occurs when two organisms in close proximity utilize a factor present in quantities less than the combined needs of both organisms (Weaver and Clements 1938). As a winter annual, cheatgrass establishes in autumn, survives over winter and resumes growth early in the spring at lower soil temperatures than its neighbors (Harris 1967, Young and Clements 2009). Cheatgrass utilizes water and thereby water soluble nutrients before slower growing native grass species initiate spring growth (Harris 1967). Cheatgrass seedling survival is greater than native seedling survival because of better ability to extract water from soil (Warg 1938). In greenhouse studies, crested wheat grass (*Agropyron cristatum* (L.) Gaertn.) seedling tiller growth was shown to be inversely proportional to density of cheatgrass seedlings due to increased soil water depletion associated with increasing cheatgrass density (Figure 1), (Evans 1961). Additionally once established, the increased shoot height of cheatgrass seedlings compared to crested wheatgrass seedlings may enable cheatgrass to successfully compete for light (Evans 1961).

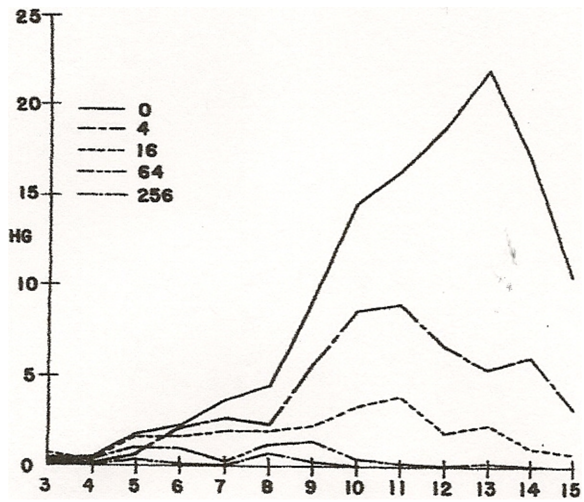


Figure 1. Weekly height of crested wheat grass as a function of cheatgrass density of 0, 4, 16, 64, and 256 plants per sq. ft. (Evans 1961).

Bluebunch wheatgrass (*Agropyron spicatum* (Pursh) A. Love forma spicata) was the original successional climax species of the northern intermountain region (Harris 1967), and was probably capable of limiting cheatgrass growth in the absence of disturbance (Harris 1967, Meyer and Leger 2010). Dominance of cheatgrass over bluebunch wheatgrass occurs only as a result of disturbance such as fire, overgrazing, plowing, trampling or fertilizer application (Harris 1967). Once cheatgrass dominance over bluebunch wheatgrass is achieved, reversal is either limited (Daubenmire 1942), or occurs extremely slowly (Harris 1967). Although cheatgrass prefers coarse, granular soil (Upadhyaya et al. 1986), it is capable of dominance in most western environments and habitats (Hubert 1955). This ability is a function of genetic plasticity and the existence of various ecotypes (Meyer, S. E and E. A. Leger 2010).

Cheatgrass has considerable morphological plasticity relative to site of growth (Hubert 1955). In adverse arid conditions, a plant may have one 5-10cm culm with an inflorescence consisting of one spikelet; whereas in favorable moist conditions, a single plant may have 12-15 culms of 50-70cm height with hundreds of spikelets (Harris 1967, Young and Clements 2009). Although cheatgrass is usually classified as a winter annual, some plants in low density habitats can persist for two winters and flower the following summer (Harris 1967). Production of two sets of inflorescences in a single season is common (Harris 1967, Sloane and Marlow 2011). As mentioned, the perennial bunchgrass, crested wheatgrass exhibits depressed culm height with increasing cheatgrass density (Evans 1961). Conversely, in cheatgrass dominated communities, cheatgrass shoot height increases with increasing conspecific density (Evans 1961) (Figure 2).

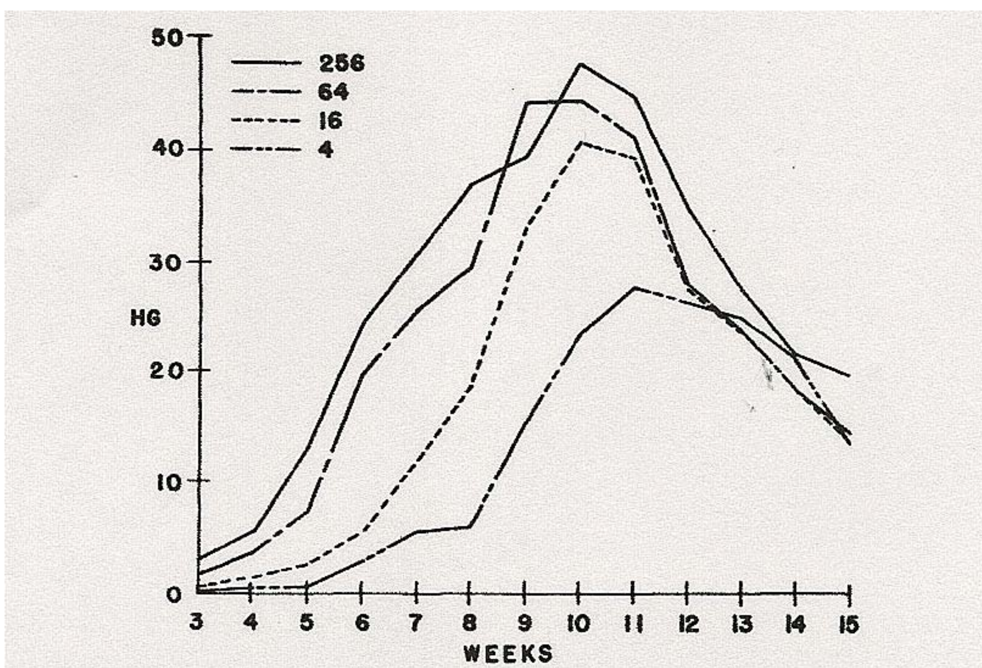


Figure 2. Cheatgrass shoot height as a function of week at 4,16, 64, and 256 plants per sq. ft. (Evans 1961).

These results conflict with the accepted concepts that individual plant growth should decrease as competition increases. This response could possibly be caused by the individual plant competing for light. If biomass increases, one would expect root mass to also increase resulting in increasing cheatgrass domination of the above and below ground growth site.

After seed drop, cheatgrass seeds are consider to remain dormant as long as hot, dry weather persists, usually a period of six to eight weeks (Harris 1967). Since cheatgrass is a winter annual, germination and emergence occur with onset of cooler weather and autumn precipitation. Seedlings grow in a basilar fashion on the soil surface through the winter. In the absence of snow cover, I have observed winter growth in a basal fashion manifested as surface greening whenever several warm sunny winter days occur. Cheatgrass root growth continues throughout the winter (Harris 1977). Seedlings are primed and ready for the onset of warmer days in early spring when growth rate accelerates at soil temperatures that are too low for native grass growth (Harris 1967, Young and Clements 2009). Cheatgrass seedlings prevent establishment of other grasses by monopolizing soil moisture, nitrogen and space prior to physiologic "wake-up" of its competitors (Evans 1961). Competition for and utilization of nitrogen may be as relevant to cheatgrass competiveness as water use and low temperature germinability. Cheatgrass seedling growth rate has been shown to correlate mostly with soil temperatures early in springtime and subsequently tissue nitrogen levels later on in spring when adequate soil moisture is present, and to a lesser extent with soil moisture alone (Uresk et al. 1979).

Concept of Nitrogen Deprivation as a Treatment Modality

Workers at the Agricultural Research Station in Reno postulated that limiting cheatgrass's access to soil nitrogen including its own replacement nitrogen may limit cheatgrass's ability to compete with and maintain its dominance over native grasses (Young et al. 1998). Specifically, application of carbohydrate in the form of sucrose as an energy source for soil microbes may increase denitrification and lower soil nitrogen content. These researchers employed this concept in an eight armed study of the effects of nitrogen on invasive grass growth incorporating sucrose application and nitrapyrin, an agent that blocks organic nitrogen breakdown. In three of the arms, sucrose and nitrapyrin were applied individually and combined (Young, J. A. et al. 1998). However, in this study medusahead, an invasive annual similar to cheatgrass, was the dominant invasive grass. Both nitrapyrin and sucrose application decreased medusahead density and there was an additive effect when both treatments were simultaneously applied (Young et al. 1998).

Besides introducing the concept of nitrogen deprivation as a control modality, this review uncovers another aspect of this topic. The target invasive species and the desired restorative species frequently differ from study to study sometimes even at the same location and with the same group of investigators, but conclusions are frequently generalized from individual species responses.

There are reports of multiple studies employing the concept of nitrogen deprivation of invasive grasses in attempts to restore native or desired species (Mangold and Sheley 2008, Alpert, P. 2010). Review of the literature reveals studies differ in location, methods and results, but in general these trials are either unsuccessful or demonstrate limited effects (Alpert 2010). In my review of the literature, most do not investigate the underlying science involved nor do they measure individual plant parameters. Rather they are focused on producing a desired restoration result. The actual carbohydrate applied, method of carbohydrate application and number of applications vary significantly amongst studies suggesting that the nature and source of carbohydrate may be an important factor.

In early studies, finely ground wheat straw and saw dust did not inhibit long term cheatgrass growth. Although there was depression with sawdust noted in the first year, there was increased cheatgrass growth in subsequent years compared to control areas (Smoliak 1965). Subsequently, saw dust was thought to have some depressive effects (Alpert 2000). In tall grass Canadian prairie, a mixture of sawdust and sucrose was employed in 1992 (Morgan 1994). One of three sites showed a significant decrease in weed growth (species not specified) lasting more than one year, but there was no increase in seeded native grass or forb growth. The other two sites manifested no changes (Morgan 1994). Nitrogen content of these two sites was thought to be higher than the initial site. Carbohydrate was raked in to the soil by an unspecified method. Morgan (1994) describes his technique as "Soil Impoverishment" and includes a list of suggested implementation methods for range restoration utilizing nitrogen depletion which other investigators then cite (McClendon and Redente 1991, Morghan et al. 1999, Seastadt et al. 1996).

1. Choose site with non-native invasion.
2. Perform a soil sample analysis including nitrogen level.

3. Utilize equal size representative experimental and control plots.
4. Consult soil scientists to determine amount of carbohydrate required to lower soil nitrogen for at least one growing season.
5. Apply recommended amounts of carbohydrate.
6. Identically seed experimental and control plots
7. Monitor plots for species density and cover for at least one growing season. (Morgan 1994)

At a site in central Colorado, restoration of an area disturbed by utility placement resulted in peppergrass (*Lepidium densiflorum* Schrad.) and diffuse knapweed (*Centaurea diffusa* Lam.) invasion (Seastadt et al . 1996). Initial attempts to restore the site involved planting of four warm season grasses and western wheat grass (*Pascopyroum smithii* (Rydb.) Barkworth & D.R. Dewey) but only the western wheatgrass established to any extent (Morghan et al. 1999). A mixture of sucrose and saw dust (amounts not provided), was applied three times in 1994 and twice in the spring of 1995. There was a decrease in the density of peppergrass in the carbon amended plot, (p-value 0.04), but there was no effect on densities of knapweed or western wheat grass (Seatstadt et al. 1996). These authors did note an increase in all three species in the carbon amended plot the following year (p-value 0.001), and an increase in peppergrass with a decrease in western wheatgrass in the control plots. Nitrogen measurements were not included in this report. In a follow up report, the authors found that nitrogen analysis revealed decreased soil inorganic nitrogen one month after treatment, but did not differ from control areas two months after treatment (Morghan et al. 1999). These authors commented that sucrose may be the most costly carbon source, and that consideration of other industrial waste carbon sources such as saw dust or sugar beet pulp should be considered. They suggested the nature and type of carbohydrate energy source seemed to be important factors.

Current Study

We believe the failure of non-sugar carbohydrate to uniformly depress invasive species growth and restore native species may be related to the fact that plants evolved with "natural" organic fiber litter on and in the ground. Most of this litter is composed of more complex carbohydrates, cellulose and lignin, which decompose slowly and thereby limit the rate of microbial energy utilization and ensuing nitrogen depletion. Sucrose application may result in high concentrations of readily usable carbohydrate energy sources allowing for a fast microbial "consumption" and subsequent depletion of soil nitrogen by denitrifying microbes. Continued viability of these denitrifying microbes may be important so that they sequester nitrogen nutrients that would be released by microbe death (Jonasson et al. 1996, Schmidt et al. 1997). The reported failures may be caused by microbial utilization of sucrose that is too fast resulting in only transient nitrogen depletion of insufficient duration to inhibit invasive plant growth long enough to establish native species. Soil impoverishment by nitrogen depletion may require a different type of carbohydrate. A carbohydrate source that releases sucrose over a longer time period could extend nitrogen depletion enough to inhibit invasive species growth and "open a window" in which native species can recover or be established. We believe that sugar beet pulp may provide this slower, more prolonged release of basic carbohydrate while being utilized by microbes faster than cellulose or lignin.

Objectives

The goal of our experiment was to determine if we could inhibit cheatgrass growth by the application of sugar beet pulp to the soil surface in a greenhouse environment. Secondly, we wanted to determine, if cheatgrass growth was inhibited, whether such inhibition relates to sugar beet pulp application or to a passive mulch effect. Thirdly, we wanted to determine if sugar beet pulp application will also inhibit a native grass such as bluebunch wheatgrass. Lastly, as an indirect measure of nitrogen depletion, we wanted to determine if inert mulch with no carbohydrate content would produce similar inhibition. If similar inhibition occurred with the inert mulch, this would indicate a physical rather than a nutritive cause.

Hypothesis

We hypothesized that the growth of nitrogen dependent invasive grasses will be inhibited by application of a mulch of coarse granulated sugar beet pulp, and that the inhibition of growth is not related to a passive mulch effect. Our null hypothesis was that the growth of nitrogen dependent invasive grasses will not be inhibited by application of a mulch of coarse granulated sugar beet pulp, and that any inhibition of growth is caused by the passive presence of mulch.

Materials and Methods

The study was performed in the west greenhouse of the Montana State University Plant Growth Center, Bozeman, Montana. Standard pasteurized Plant Growth Center planting medium consisting of equal parts of loam soil, concrete sand and sphagnum peat moss was used. Cheatgrass seed was harvested in the summer of 2009 by hand clipping from random sites in a 10.4 hectare cheatgrass dominated pasture in the Paradise Valley, 24 kilometers south of Livingston Montana. Care was taken to avoid harvesting any cheatgrass seed that showed evidence of *Ustiago bullata* smut infestation since such infestation would presumably affect germination and growth. The seed was stored in an unheated garage over winter. Bluebunch wheatgrass seed was purchased in 2009 from Wind River Seed Company (Manderson, WY). Once sowing was complete, watering was performed twice daily in five minute intervals using an automated timer and spray equipment produced by Orbit Irrigation Products, Inc.(Bountiful, UT). Sugar beet mulch was created by grinding pelleted sugar beet pulp (Lakeland Feed, Hamilton, MT.) three times through a un-meshed feed grinder to a flakey / granular consistency at the Montana State University Nutrition Laboratory, Bozeman, MT. Commercially available untreated, washed, Poultry Grit, Insoluble Crushed Granite (Manna Pro, St. Louis Missouri) was used as the non-carbohydrate mulch.

Two hundred seventy, four inch square plastic pots were filled with growing medium to 1cm below the rim and placed in 18 trays of 15 pots. Cheatgrass and bluebunch wheatgrass were used as representative invasive and native grass species. Two trays of 15 pots were used as untreated controls for each grass species. Sugar beet pulp application rates equivalent to 0.0, 0.5, 1.0, 2.0 and 4.0 tons per acre were used (0.0, 1.1, 2.2, 4.4 and 8.8 grams per pot). We chose these application rates because they could be adapted to future field applications. Because granite grit mass was 2.13 times the mass of the sugar beet pulp, equal volumes (0.0, 2.3, 4.7, 9.4, and 18.8 grams per pot) of grit were calculated, measured and applied. There were four trays of 15 pots of each treatment for each grass species. On 1/17/2011, seeds were individually planted on the same day in the center of the pot just below the surface using a forceps. Sugar beet pulp and granite were evenly dispersed on the soil in the center area of each pot after planting the seeds. Each pot was labeled prior to planting with species, group number and application rate. A random sample of 270 numbers was generated with a statistical program (R 2.11.1), and prior to watering, each pot was assigned and labeled with a second identification number (1:270). Pots were then rearranged in trays in the numerical order of the random sequence. Trays were arranged on a standard greenhouse table in three rows of six and were randomly rotated several times during the course of the experiment. Daily watering commenced on 1/22/2011 and consisted of an automated fine spray for two five minutes periods at 6 AM and 4 PM (Figure 3).

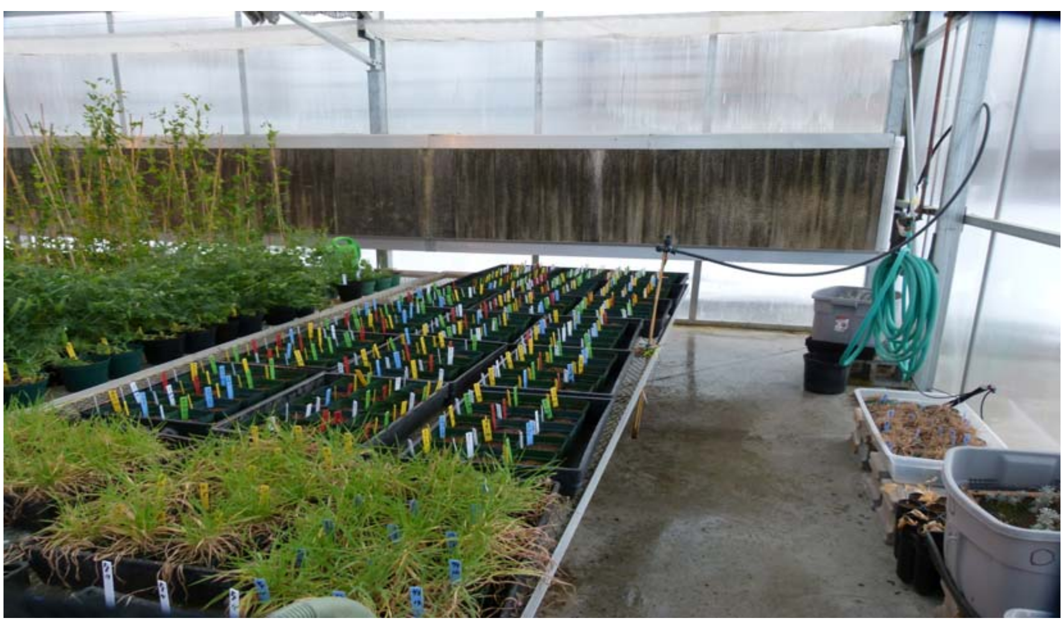


Figure 3. Seeded pots main experiment prior to watering. Trial plants are in foreground.

Measurements of total number of tillers per plant, total number of leaves per plant, total length of each leaf from tip to crown were performed on day 35. Measuring was performed using a narrow metal ruler with minimal vegetative manipulation to limit plant reaction previously documented in other cheatgrass studies in an effort to minimize handling effects on future measurements. All measurements were performed by one individual with data recording by a second individual to minimize error.

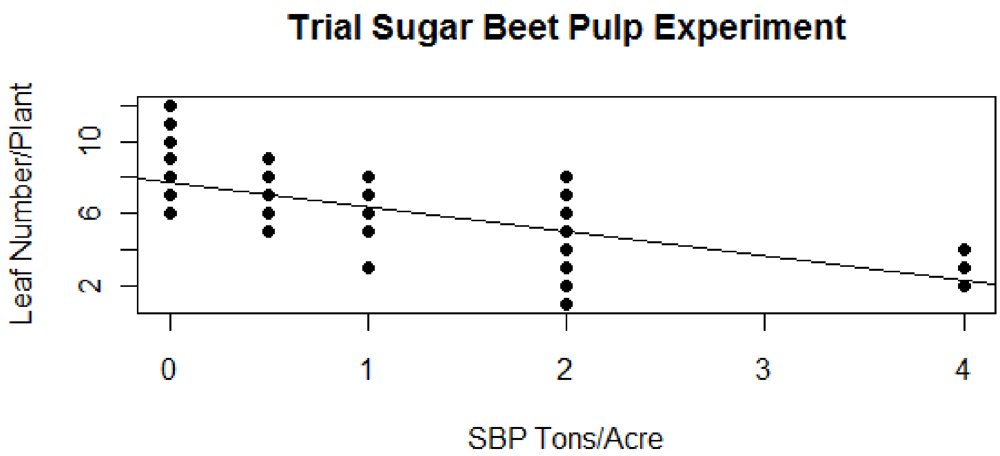
Analysis of variance and linear regression analysis using R 2.11.1 and R 2.12.2 was performed using treatment level as an explanatory variable and total leaf number as a response variable to determine if a quantifiable relationship existed between sugar beet pulp application levels and grass responses.

Prior to performing the main experiment, a preliminary experiment tested the effects of the same sugar beet pulp application levels on cheatgrass growth. A similar format was used consisting of a control group and 4 treatment levels of 15 pots each. All other parameters were identical to the main trial except that measurements were made on day 24. Linear regression analyses and model fitting were performed using treatment rate as an explanatory variable and total leaf length or leaf number per plant as a response variables.

Results

Trial Experiment

There was a negative linear relationship between growth rate as measured by total leaf number and the rate of sugar beet pulp application (p value <.001 on seventy two degrees of freedom). For each unit increase in tons per acre of sugar beet pulp application, there was an associated decrease in total leaf number of each cheatgrass plant on Day 24 of 1.34 (95% C.I. -1.6,-1.0). There was also a negative linear relationship of growth as measured by total leaf length per cheatgrass plant and the rate of sugar beet pulp application with a similar slope ($p<.001$). For each unit increase in tons per acre of sugar beet pulp application, there was an associated decrease in total leaf length of each cheatgrass plant of 180mm (95% C.I. -214mm,-146mm). A.I.C. analysis favored the fit of the leaf number model (280, 1004). Therefore, we used an analysis model utilizing only leaf number for the main experiment. Plots of the models are provided (Figure 4). A bar graph of the leaf number data is provided (Figure 5).



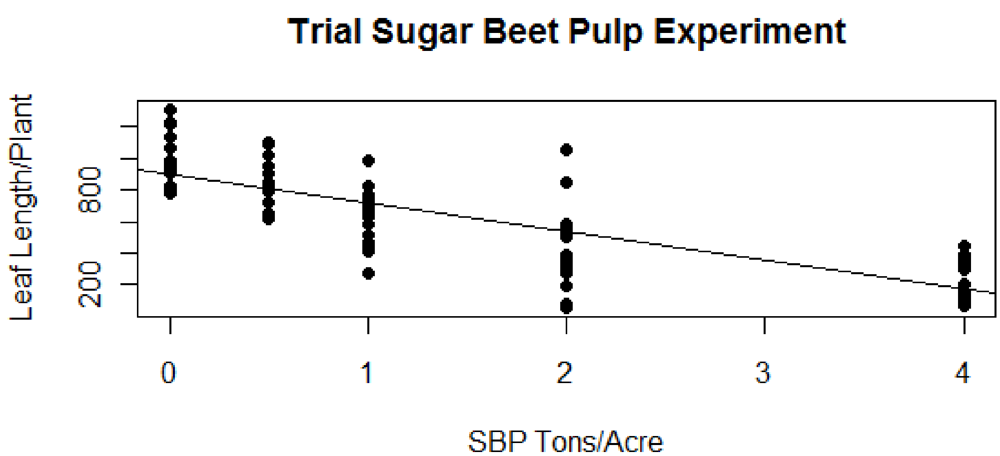


Figure 4. Plots of trial experiment regression models: SBP = sugar beet pulp, 0 = control.

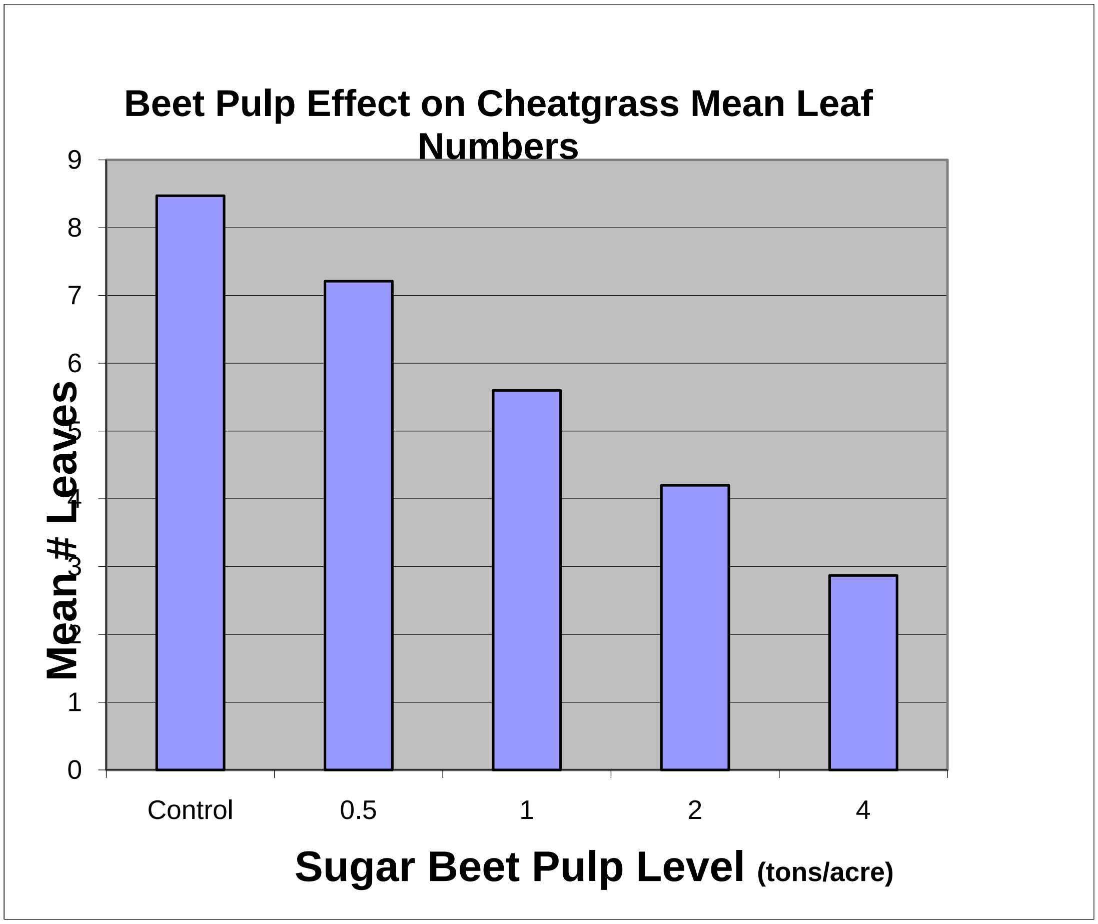


Figure 5. Trial Experiment: Total leaf number per plant ~Application level of sugar beet pulp

Main experiment

Our plants grew nicely (Figure 6).

Figure 6. Plant growth of both species on Day 51.

<u>Cheatgrass</u>: At 35 days, there was a negative linear relationship between the level of sugar beet pulp application and cheatgrass growth as manifested by total number of leaves per plant (p-value of <0.001 on 64 df.). As sugar beet pulp application increased by one ton per acre, there was a 72% decrease in total number of leaves (95% C. I. -1.12, -0.31). In contrast, there was a positive linear relationship between level of granite grit application and cheatgrass growth as manifested by total number of leaves per plant (p-value of <0.009 on 73 df.). As granite grit application increased by one ton per acre, there was a 45% increase in total number of leaves (95% C.I. 0.11, 0.79).

Bluebunch Wheatgrass: At 35 days, there was a negative linear relationship between the level of sugar beet pulp application and bluebunch wheatgrass growth as manifested by total number of leaves per plant (p-value of <0.002 on 73 df.). As sugar beet pulp application increased by one ton per acre, there was 35% decrease in total number of leaves (95% C. I. -0.56, -0.13). There was a no linear relationship between rate of granite grit application and bluebunch wheatgrass growth as manifested by total number of leaves per plant (p-value of 0.97 on 73 df.).

Our results demonstrated negative linear relationships between growth of cheatgrass and bluebunch wheatgrass and levels of sugar beet pulp application. The cheatgrass growth coefficient was approximately twice as negative as the bluebunch wheatgrass growth coefficient. This is confirmed by analysis of variance in which the mean number of leaves between species differed with a F value of 113.9 ($p < 0.001$) (Appendix A) and confirmed by multiple linear regression analysis in which in the β-1 coefficients differed with a t-value of 3.7 ($p < 0.001$) (Appendix B). In contrast, there was a positive linear relationship between cheatgrass growth and levels of granite grit while bluebunch wheatgrass growth had no relationship (Figure 7).

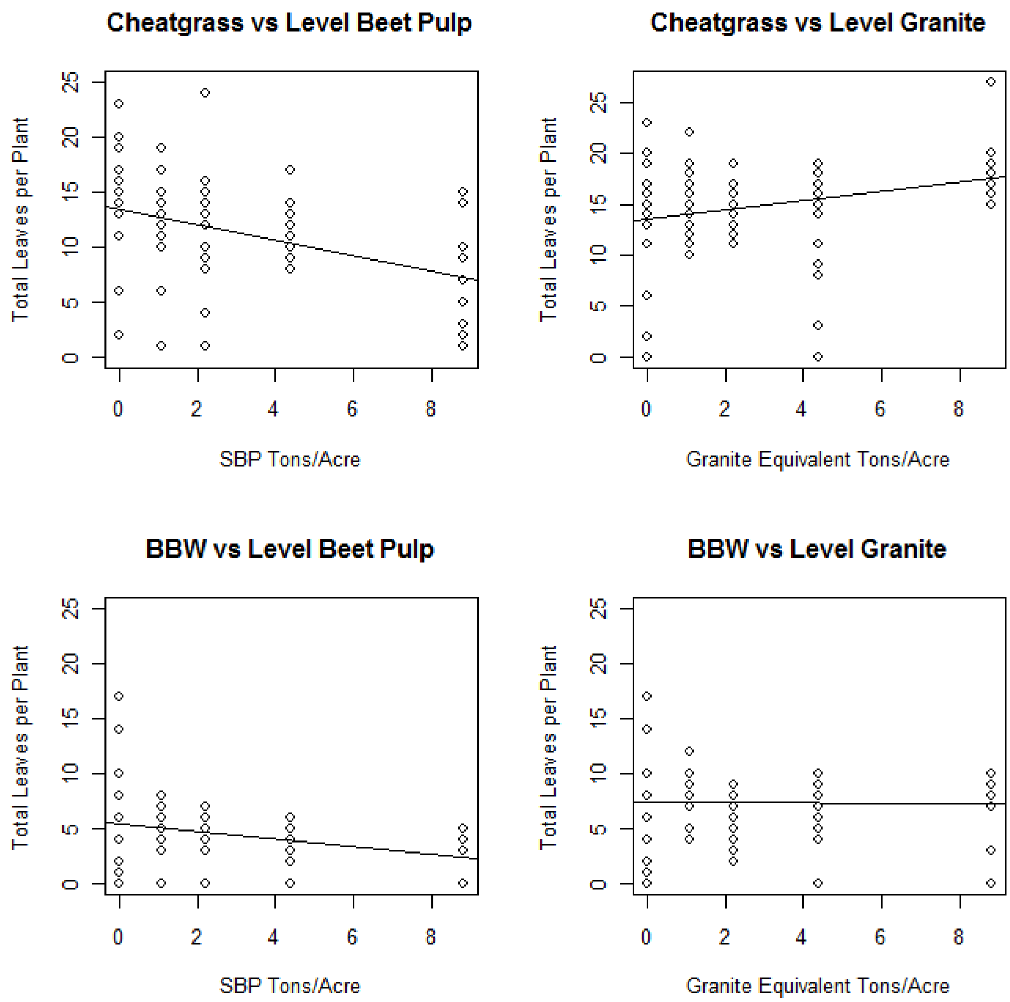


Figure 7. Regression plots of total leaf number ~ treatment application level.

Discussion

We observed that the application of sugar beet pulp depresses the greenhouse growth of cheatgrass seedlings to a greater degree than it depresses the growth of bluebunch wheatgrass seedlings. Analysis using total leaf length per plant for the main experiment (not provided) produces similar results with similar significance values. Cheatgrass seed germination and emergence was 93% and essentially was not different from other studies performed with this seed harvest (Table 1). Blue bunch viability on Day 35 was 88%. We had not previously documented bluebunch wheatgrass germination rates of this seed batch, but we estimated that germination and emergence were approximately 85% in other green house studies. In our current experiments, germination and emergence rates are high implying that the application of the sugar beet pulp affects growth and not germination or emergence. Essentially almost all seeds of both species germinated and emerged within two weeks of initial watering. Seedling attrition after emergence in the trial and main experiment approached zero. We have not produced inflorescences in either species in any of our green house trials, possibly because continued watering prevents vernalization.

Species	Living Plants Day 35, N=135
Cheatgrass	93%
Bluebunch wheatgrass	88%

Table 1: Viable plants on Day 35.

Although our data support our hypothesis and demonstrate a negative linear relationship between sugar beet pulp application and cheatgrass growth, we have not demonstrated that nitrogen depletion is the causative factor. Similarly, there is a possibility that the sugar beet pulp fostered some form of pathological growth depression. We are, however, unaware of any other study that quantitatively documents individual plant growth parameters of native or invasive grass species as an outcome of carbohydrate application to soil surfaces. Furthermore, although we have no indication to suggest that the cheatgrass present in the harvest location differs from cheatgrass in general, various ecotypes of cheatgrass are known to exist (Upadhyaya et al. 1986), so our data is only valid for cheatgrass harvested at this location during the summer of 2009. Similarly, our data is valid only for seeds harvested in 2009. We currently have a trial in progress using cheatgrass seeds harvested in 2010 from the same location.

The differences in the relationship of sugar beet pulp application between cheatgrass and bluebunch wheatgrass is consistent with the previously explained concepts that native grass growth is less dependent on soil inorganic nitrogen content than nitrogen dependent invasive grass growth. All grasses tested so far are cool season C-3 grasses. Based on an extensive literature review, response of warm season grasses to carbohydrate related nitrogen depletion has not been documented. Preparation is underway to test the response of side oats grama (*Bouteloua curtipendula* (Michx.) Torr.), a middle height warm season C-4 grass and little bluestem (*Schizachyrium scoparium* (Michx.) Nash), a tall warm season C-4 grass, to sugar beet pulp application.

At the current time, we cannot explain the positive relationship of the granite grit on cheatgrass growth. In addition to the statistical documentation, this relationship was easily documented by casual visual inspection in the greenhouse. Despite randomization, the tallest cheatgrass plants were almost always those emerging through the granite mulch. Bluebunch wheatgrass also emerged through the granite. Neither species seemed to have any difficulty with the granite. Observers have previously noted that cheatgrass avoids clayey soils and prefers coarse growing mediums (Upadhyaya et al. 1986). Granite chicken grit enhancement may be related to increased soil coarseness. Studies are needed to determine if “beneficial” ions leaching off the granite are a causative factor, but since a similar effect on bluebunch wheatgrass was not noticed, this seems unlikely. Since the regression analysis of bluebunch leaf number per plant yielded a β-1 coefficient approaching zero, a granite common mulch or ion effect does not seem likely. Possible explanations may relate to moisture trapped under the granite or temperature effects of granite warmed by sun that are more efficiently utilized by cheatgrass.

Although it is tempting to statistically compare growth parameters of the two grass species utilized in our experiment, I believe such comparisons may not be appropriate. We have observed these grass seedlings are markedly structurally different from each other in the number of leaves, number of tillers, leaf length, surface cover, root configuration, root diameter and root depth. Bluebunch wheatgrass seedlings reach to the sky in a thin column of a few long leaves, with the last, youngest leaf, usually being the longest. Cheatgrass seedlings produce larger numbers of tillers that grow laterally from a quickly developing crown before extending upwards. The first and second blades of each tiller are usually the longest. Bluebunch wheat grass sequesters a vertical column of space similar to warm season perennial grasses noted by Weaver (1968). Cheatgrass grows laterally from the crown and sequesters basal soil surface area in a dish like fashion.

Implications for Management

Cheatgrass invasion is responsible for ongoing degradation of residential properties, dry land pastures, agricultural acreage and rangelands with major financial consequences in all 4 categories (Young and Clements 2009). We as well as other observers have noticed that established grasses in pastures and rangelands can successfully compete with cheatgrass as long as there is no disturbance such as fire, over grazing, or damage by construction equipment, but once such a disturbance occurs, cheat grass domination occurs. Once cheatgrass domination is present, cheatgrass becomes a formable adversary because it is able to consistently compete with almost all vegetation (Harris 1967, Hubert 1955). Two different groups of investigators at the Agricultural Research Station at Burns, Oregon and the University of Nevada-Reno presented information at the recent SRM Meeting in Billings that below ground germination rates of native grasses in annual invasive grass dominated grasslands are very high, similar to those in our greenhouses studies. However, seedling emergence in cheatgrass dominated sites is virtually nonexistent (James et al. 2011, Ledger et al. 2011). However, if native seedlings emerge and live a short period of time, they are capable of establishing viable populations (Clements 2011). These presenters concluded that growth of invasive grasses such as cheatgrass and medusahead needed to be depressed long enough with sufficient magnitude to “open a window” that permitted native grass establishment.

I have observed a stable 50m by 15 m area of established bluebunch wheat grass growing alongside 15ha of a cheatgrass dominated pasture (Figure 8). The bluebunch wheatgrass is situated on the top edge of a bench and separated from a road by a standard barb wire fence. The fence protects the bluebunch wheatgrass from well intended, twice yearly mowing of the adjacent cheat grass dominated roadside. Although the road side berm and the surrounding pasture are dominated by cheatgrass, the bluebunch wheatgrass maintains its presence even though deer traverse this fence repeatedly on a daily basis and undoubtedly transfer cheatgrass seed into the bluebunch area. Some of the bluebunch islands show evidence of grazing. These examples demonstrate that if disturbances are controlled and if windows of opportunity are provided, native grasses can compete with cheatgrass invasion. Carbohydrate application as described in this report may be a method of creating such a window of opportunity.

Figure 8. Stable but grazed bluebunch wheatgrass (background right) growing along cheatgrass dominated roadside on left side of fence and foreground.

Creation of opportunity windows is only one aspect of successful restoration. Restoration efforts must take into account the ecological effects of all aspects of the restoration efforts. All such efforts must limit the amount of disturbance they create, because the beneficial energies of the restoration cannot be outweighed by the disturbance energies. Young and Clements (2009) have reviewed data that implies control and restoration efforts with well intended herbicide use and subsequent tillage may actually increase soil nitrate concentrations that promote ongoing cheatgrass dominance. We believe impeding cheatgrass growth without simultaneously establishing desired native species to compete with cheatgrass for space, nutrients and water will be a waste of time and finances. Similarly, we believe that it will not be possible to restore every native species of a given site. Scientifically obtained ecological data is required to avoid blindly restoring a species that has no chance of survival. This is our reason for including bluebunch wheatgrass in our experiments, and why further trials will involve desirable warm season grasses such as side-oats grama and little bluestem as well as other cool season grasses. We believe that single or multiple sugar beet pulp applications with subsequent nitrogen depletion may open a window for native grass establishment, but will only do so if all other activities that promote invasive growth are minimized or avoided, and the entire restoration effort is based on documented ecological fact.

We believe that any site preparation should be practical and cost effective. Many cheatgrass invaded rangelands are not amenable to mechanical manipulation such as tilling or raking never mind drilling. The detrimental effects of rangeland restoration on agricultural equipment are discussed in detail by Young and Clements (2009). Methods of application of carbohydrate source and site preparation techniques require comment. Sucrose saw dust application by raking has been mentioned in our literature review. Our experience is that this is not feasible. In a frequently cited publication, bulldozing a site was performed to remove the seed bed of undesired species followed by two years of weeding and subsequent mechanical tilling to document nitrogen effect on succession stage (McLendon and Redente 1991). Such efforts are too costly even if they are necessary. Seed must be sufficiently covered to allow germination and establishment in semi-arid environments, but coverage techniques must be ecologically and financially feasible.

The original medusahead field trials as previously discussed employed surface broad cast application of sucrose. We have commented that sucrose is considered to be expensive (Morghan and Seastadt 1999). Financial aspects will require an effective low cost carbohydrate source that can be applied evenly with minimal labor and diesel fuel expense. Broadcast application of beet pulp seems to be the least expensive application method of achieving our goal of discovering a method to promote native species establishment with as little disturbance and cost as possible.

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APPENDICES

APPENDIX A

ANALYSIS OF VARIANCE TABLE

```
lm(formula = Total Leaves ~ Grass * Type * Rate)


Response: Totleaves
                 Df Sum Sq Mean Sq  F value    Pr(>F)    
Grass             1 3060.3 3060.30 113.9140 < 2.2e-16 ***
Type              2 1579.4  789.68  29.3942 3.099e-12 ***
Rate              1   80.0   80.01   2.9781  0.085585 .  
Grass:Type        2   93.9   46.95   1.7476  0.176227    
Grass:Rate        1    3.0    2.96   0.1103  0.740053    
Type:Rate         1  272.4  272.41  10.1400  0.001628 ** 
Grass:Type:Rate   1  198.1  198.05   7.3721  0.007068 ** 
Residuals       260 6984.9   26.86                      
---
```

APPENDIX B

MULTIPLE LINEAR REGRESSION TABLE

```
lm(formula = Total leaves ~ Grass * Type * Rate)

Residuals:
    Min      1Q  Median      3Q     Max 
-15.637  -1.952   0.271   2.075  53.479 

Coefficients: (2 not defined because of singularities)
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)            6.6002     1.3383   4.932 1.45e-06
***
GrassCG                6.8674     1.8926   3.628 0.000343
***
TypeGR                 1.3824     1.7649   0.783 0.434173
TypeSBP               -2.0118     1.7648  -1.140 0.255339
Rate                  -0.2113     0.2269  -0.931 0.352522
GrassCG:TypeGR        -1.1311     2.4959  -0.453 0.650788
GrassCG:TypeSBP        1.4515     2.4957   0.582 0.561351
GrassCG:Rate          -0.6914     0.3209  -2.155 0.032098 *
TypeGR:Rate            0.1065     0.3209   0.332 0.740341
TypeSBP:Rate               NA         NA      NA       NA
GrassCG:TypeGR:Rate    1.2321     0.4538   2.715 0.007068
**
GrassCG:TypeSBP:Rate       NA         NA      NA       NA
---

Residual standard error: 5.183 on 260 degrees of freedom
Multiple R-squared: 0.4308,     Adjusted R-squared: 0.4111 
F-statistic: 21.87 on 9 and 260 DF,  p-value: < 2.2e-16
```