USE OF SOIL CARBON AMENDMENTS ON A MARTHA'S VINEYARD GRASSLAND RESTORATION SITE

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Abstract

Old agricultural fields often are characterized by high soil N, which benefits many non-native species but prevents native species' re-establishment. The competition between non-native and native species often delays or prevents restoration efforts. One technique used in experiments focused on reducing plant-available N is the use of C amendments. This study investigated the possibility of using soil C amendments on a post-agricultural site on Martha's Vineyard. On Herring Creek Farm, ecologists are currently trying to find a way to re-establish the rare native sandplain grass ecosystem. In this experiment, soil was collected from the farm field, amended with various quantities of different amendments, incubated, and then analyzed for NO_3^- and NH_4^+ at time steps. The net mineralization and nitrification fluxes were calculated using these pools. Non-native grass was also grown in control and amended soil samples. It was shown that sucrose and sawdust were effective in reducing the inorganic N pools and decreasing non-native grass biomass. Woodchip-amended samples were able to show a reduction in the inorganic N pools but did not show any apparent effect on non-native biomass. Because several levels of each amendment were used, this study was able to show a correlation between increased added soil labile C and reduced inorganic N pools. Furthermore, it was also able to show that very significant reductions in inorganic N can occur at low levels of amendment.

Keywords: carbon addition, grassland restoration, invasive competition, labile carbon, mineralization, nitrification, sawdust, sucrose, woodchips.

Introduction

One of the main goals in restoration ecology is the re-establishment of native species, and old agricultural fields are frequently in need of such restoration. Post-agricultural soils are often left with a high N content from years of fertilizer use in combination with acid deposition (Tiffney Jr., 1997). These high soil N levels benefit faster-growing non-native species. However, the successful growth of non-natives can then cause a competition problem for slower-growing native species (Motzkin and Foster, 2002). Furthermore, the typical lack of diversity in most invasive-dominated areas lowers the overall productivity of the ecosystem, leading to lower plant N uptake, and, in effect, slower natural recovery (Tilman et al., 1996). Several studies have aimed to decrease soil N by increasing the C:N ratio through the use of soil C amendments. By giving microbes additional sources of C, the demand for N, in order to maintain a steady C:N ratio, increases. By increasing the rate of microbial N immobilization, plant-available N tends to decrease.

Several different C amendments have been tried in other studies, including sucrose (McLendon & Redente 1992), sawdust (Alpert & Maron, 2000), bark mulch, leaf litter (Cione et al., 2002), and different combinations of each. Besides deciding which amendment(s) to apply, another consideration is how much additive is needed to yield conclusive results. Thus far, studies' results have been somewhat contradictory. In 2003, Blumenthal et al. reported very positive results using a high sawdust (94%), low sucrose (6.0%) mix. Though the change in NH_4^+ was relatively minor, NO_3^- was dramatically altered and native biomass increased. This study concluded that sawdust may be beneficial in inhibiting the growth of invasive species. However, another study in 2004 by Corbin et al. concluded that sawdust addition yielded no long-term reduction in non-native growth, despite a reduction in net mineralization and an increase in microbial biomass. The difference in studies' results merits further investigation.

In 2001, The Nature Conservancy purchased 215 acres of Herring Creek Farm on Martha's Vineyard, with the goal of re-establishing 62 acres of the sandplain grass ecosystem, a rare landscape unique to this region (TNC, 2005) and invaluable due to its ability to support a number of rare species (Motzkin and Foster, 2002). The farm is adjacent to Katama Air Field, which already has some sandplain grass presence, so the restoration of the Herring Creek Farm portion would be important in expanding and connecting this ecosystem. However, high N, a result from years of fertilization and N deposition, has stymied efforts to re-establish native species presence. Soil amendments might be able to ameliorate this problem.

This experiment attempted to decrease the N content of soil collected from Herring Creek Farm by adding various amendments, each at different levels, to soil samples. The NO_3^- and NH_4^+ pools were measured, and mineralization and nitrification were calculated at different time steps. The goal was to determine if C amendments do, indeed, affect soil N, and if so, which amendment in what amount yields results and when. In addition to this, non-native fescue grass was grown in control soil samples and soil samples treated with different amendments, again in several levels. The goal of this experiment was to determine if non-native species' growth would be decreased by the addition of C.

It was hypothesized that the sawdust- and sucrose-amended soil would produce measurable trends within the study period, while the woodchips would take longer to homogenize with the soil. Mineralization and nitrification rates, as well as NH_4^+ and NO_3^- contents, were expected to decrease as amendment level increased. Lastly, it was conjectured that non-native growth would react negatively to the C amendments, in terms of germination success and biomass.

The Herring Creek Farm study was conducted with the intention of being able to provide conclusive results, if any were shown, to restoration ecologists. While this particular investigation was performed in a laboratory setting, positive results from this experiment might encourage further field investigations.

Methods

Study Site: This study focused on 62 acres of Herring Creek Farm, on which the Nature Conservancy aims to re-establish the sandplain grass ecosystem. The farm is located in the Edgartown, MA, on the southeast section Martha's Vineyard. It is presently considered to be agricultural grassland surrounded by neighboring sandplain grass systems (Figure 1). Dominant vegetation include tall fescue (*Festuca arundinacea*) Queen Anne's Lace *(Daucus carota),* orchard grass (*Dactylis glomerata* L), various clover species (*Trifolium*), and Crownvetch (*Coronilla varia* L.). The soil is composed heavily of sand and has distinctive Ap and E horizons (Kleese, 2003). The field has a significant plow layer, reaching up to 60 cm in depth. Information on soil C, N, and pH were obtained as part of the study.

Soil Analyses: In order to make a composite soil sample to use for the soil analyses and growth experiment, one shovelful of soil was collected from each of 2 random locations in each of 7 equidistant transects across the 62 acre field, making 14 field samples total. Plants were removed and then each shovelful was taken about 10 cm in depth. Roots were also precluded as best as possible from these collections.

Equal masses of each of the 14 soil samples were combined into one homogenized composite soil sample. Eight 100.0 g soil samples were dried at 60ºC for 48 hours for a dry-wet mass conversion. For the NO_3^- and NH_4^+ analyses, 100.0 g of wet soil were added to each of 186 sealed plastic cups. Six of these cups were designated as "initial control" and tested for pH, NO_3^-, and NH_4^+ immediately. For each time step thereafter (weeks 1, 2 and 3) there were 6 control cups and 18 cups for each of the 3 treatments, or 60 cups per week total.. For better manageability, the addition of the treatments was scheduled over a three day time period.

For the treatments, sucrose ($C_{12}H_{22}O_{11}$), sawdust (predominantly cedar and spruce), and woodchips (softwood mix) were used. Nine different levels were used for each treatment, ranging from 0.10-800% of the estimated soil labile C. The fraction of soil labile C was estimated by assuming that 10.0% of the total soil C is labile. Since soil C and N could not be analyzed until towards the end of the study, the total soil C content of 3.18%, based off of a previous study of Herring Creek Farm, was used for the amendment calculations. Therefore, the percentage of soil that was assumed to be labile C was estimated to be 0.318% The number of grams of soil labile C per 100 g wet weight (74.3 g dry weight) of soil could then be estimated. The grams of labile C per 100 g wet soil were then multiplied by the percentage, or level, of soil labile C that was to be added (0.10-800%). This value represented the grams of soil labile C that were to be added by the sucrose, sawdust, or woodchips. The value was then divided by the fraction of the amendment that was labile C, which were estimated to be 40.0%, 8.0%, and 3.0%, for sucrose, sawdust, and woodchips, respectively. This final value represented the grams of amendment that were to be added. Doing this division helped to correct for the difference in labile C between the amendments (Table 1).

Once the actual soil composite used in this experiment was analyzed for C and N , the range of soil C added was actually found to be 0.13 - 1038.37% of the estimated soil labile C.

For each of the three weeks following the start of incubation, 2 replicates of each of the 9 levels in each of the 3 treatments (i.e., 18 cups per treatment or 54 amended samples total), 6 control samples, and 6 blanks were measured for NO_3^-, NH_4^+, and pH. To do the NO_3^- and NH_4^+ analyses each week, 15.0 g wet sub-sample was combined with 50.0 mL of 1 uM KCl, and these mixtures were placed on a shaker table for 2 hours, after which, each cup was set to decant for 30 minutes. Gravity extractions were done using 125.0 mm filters that had been pre-treated with KCl. About 20.0 mL of each sample's KCl extract was collected in two sterile 25.0 mL scintillation vials, one for each of the analyses. Due to the translucency of the KCl extractions in week 3, these extracts were filtered through 25.0 mm Swinnex filters. Because of the number of extractions, the gravity filtrations were scheduled over a 3-day time period. Two KCl blanks were filtered during each of the day's extractions (6 blanks/week). Extractions were kept frozen until analyzed.

Nitrate was analyzed using a Lachat auto analyzer. A 0.0-50.0 uM NO_3^- standard curve was run, and any samples that fell out of range were re-run using a 3:1 KCl dilution. Ammonium was analyzed using a Shimadzu 1601 Spectrophotometer. A 0.0-100.0 uM NH_4^+ standard curve was run, and any samples that out of range were also re-run using a 3:1 KCl dilution.

The NO_3^- and NH_4^+ data were used to calculate mineralization and nitrification rates. The initial concentrations were subtracted from the final concentrations and then divided the days incubated.

In addition to these analyses, each sample was tested for pH at its designated time step to see if there were any observable trends in acidity. This was done by mixing 10.0 wet soil with 50 mL deionized water. Lastly, C and N content for the control soil (20.0-30.0 mg) was measured using 6 replicates in the CHN analyzer**.** As the exact composition of the sawdust and woodchips were unknown, C and N contents were based on estimated contents for newly cut Northern softwoods (Blumenthal et al. 2003) (Table 2). Being from the same lumber yard, they are assumed to be from similarly aged stands.

Plant Growth Experiment: In addition to the soil analyses, a plant growth experiment was conducted using non-native fescue grass (*Festuca arundinacea*). To do this, 300.0 g wet soil was added to 50 pots and,. Five of these pots were designated as control. The others received one of the 3 treatments (sucrose, sawdust, or woodchips). In this experiment, however, 5 different levels of each treatment were used, ranging from 0.13 to 32.34 % of the estimated soil labile C. This was done to better simulate a realistic application. Three replicates were used for each level within each treatment (i.e. 15 cups per treatment). Once the treatments were well mixed into the soil, 100 fescue grass seeds (0.2443 g) were added to each pot and hand-tilled into the topsoil for a few seconds. The pots were placed in a growth chamber for 4 weeks at 20 ºC, under ambient light and CO_2 conditions and received about 50 mL of water each day. After this period, grass blades were counted and cut at soil level. They were then dried at 60ºC for 24 hours and weighed to provide dry biomass per pot.

Results

Soil C, N, and pH: The average of the CHN analyses showed that the soil used in this study had a C content of 2.45% and an N content of 0.194% (Table 2). The pH analyses done during each of the time steps provided another observable trend. The initial pH was found to be 6.31. The control soils became more acidic throughout the study period. The sucrose-amended samples showed less of an overall increase in acidity over the time periods, but the highly amended samples were always much more acidic than the low level amendments. By the end of the three week incubation period, sucrose level 1 (0.13% soil labile C) had a pH of 5.75, while sucrose level 9 (1038.37% soil labile C) had a pH of 4.03. The sawdust amended samples, contrarily, yielded no significant trends in acidity and fluctuated throughout. In the woodchip samples, though there was no noticeable trend in pH in relation to amendment level, it does seem that by the end of the study period, most of the samples within each level had become more basic. Woodchip levels 1 and 2 ended the incubation period with pH levels of about 6.89.

Soil NH_4^+ and NO_3^- Pools: All treatments showed a sharp decrease in NH_4^+ pool size (mg/m^2) with increased amendment level. After the first week of incubation, sucrose showed the lowest NH_4^+ pool in relation to the highest treatment level, while woodchips had highest pool (Figure 2). It is interesting to note that at only the 6.49% added soil labile C level, all of the treatments' NH_4^+ pool sized leveled for the most part, thereafter decreasing in small increments. The week 2 analyses yielded more variation, with the NH_4^+ pool size fluctuating slightly as amendment level increased. This time step showed sawdust with the smallest pool size and sugar with the largest, contradictory to the previous time step. Again, however, it seems that after 6.49% soil labile C was added, the pool sizes decreased less significantly with increasing amendment amount (Figure 3). For the final time step, little had changed from the week 2 measurements except that the fluctuation between amendment level and pool size evened and showed a clearer trend. However, the woodchip samples had the lowest pool size in most of the levels (Figure 4). Overall, it appeared that while NH_4^+ decreased with increased amendment level, the most significant decreases occurred at low levels of amendments.

The NO_3^- analyses also showed a sharp decrease in pool size (mg/m^2) in all treatments as amendment level increased. There was some fluctuation in the first time step, in terms of pool size versus amendment level, though the pool size generally seemed to reach a steady low level once 32.45% soil labile C was added. Sucrose seemed to maintain the largest pool, and sawdust had a very low pool size (Figure 5). The week 2 time step showed much higher NO_3^- pools for both sucrose and woodchips, though sawdust remained very low (Figure 6). After 3 weeks of incubation, however, NO_3^- in sucrose-amended samples dropped to very low levels similar to those of the sawdust-amended samples (Figure 7). As with NH_4^+, it seemed to be a general trend that while NO_3^- generally decreased with increased amendment level, significant decreases occurred at the low levels of amendments.

Adding NH_4^+ and NO_3^- together and comparing these values among treatments and treatment levels showed that the total pool increased dramatically over the course of the three weeks for the lightly amended soils, but remained steadily low for the highly amended samples. The highest amended sucrose and sawdust samples, however, decreased very slightly (Figure 8abc).

Overall, through the course of the incubation weeks, both the NO_3^- and NH_4^+ pool sizes generally increased in the lightly amended, but decreased in the highly amended samples. Also, for the most part, pool size decreased inversely with the amount of amendment added, with dramatic decreases in low amendment levels.

Net Mineralization and Nitrification: The trends of sucrose, sawdust, and woodchips by treatment level in terms of the calculated Net Mineralization (Figure 9) and Net Nitrification (Figure 10), showed mineralization and nitrification decreasing sharply as amendment was added until the level of 6.49% soil labile C, after which it decreased slightly for sucrose and sawdust and fluctuated for woodchips. Overall, it seemed that sucrose and sawdust had very similar trends. Total Net Mineralization decreased, albeit slightly, throughout the range of percent soil labile C added, but Net Nitrification remained relatively unchanged after 259.59% soil labile C was added (level 7).

In the highly amended samples of sucrose and sawdust, the mineralization and nitrification fluxes were negative, while the high woodchip samples, despite having low fluxes, remained positive.

Plant Growth Analyses: The stem density yielded no correlation to the amendment added or to the amendment level added. Therefore, the per-stem biomass is somewhat difficult to compare between treatments and treatment levels. However, the average per stem dry biomass as well as the total biomass did relate to the amount of amendment added for the sucrose and sawdust treatments. For sucrose, the trends for total dry biomass and average stem biomass were very similar. There was a sharp decrease in the low amendment samples, but this decrease became gradual after the 1.30% soil labile C level, or level 3 (Figure 11ab). For sawdust, the trends between total dry biomass, and average stem biomass differed in that the average stem biomass was slightly more variable. However, like sucrose, the total dry biomass decreased as the percent of added soil labile C increased, as was the case for the average stem biomass. As seen with the sucrose samples, the decrease in both total dry biomass and average stem biomass became quite gradual after 1.30% soil labile C was added (Figure 12ab).

The woodchip samples did not show clear trends in either the total dry biomass or the average stem biomass. There was also a lot more variation between the replicates (Figure 13ab).

Compared to each other, it seems that the sucrose and sawdust samples yielded very similar total dry biomass values, as well as average stem biomass values. Using the woodchips samples highest levels as a basis comparison, however, shows that the woodchip samples had the highest total dry biomass and the highest average stem biomass when compared to the sucrose and sawdust highly amended samples.

Discussion

Soil Analyses: Looking at NO_3^- and NH_4^+ pools by time step in the control samples alone helps to better illustrate the NO_3^- and NH_4^+ trends in the amended sample. While control soil samples showed a sharp increase in NO_3^- and a slight increase in NH_4^+ by the time the incubation steps were done (Figure 14), sawdust level 8, a representative example of an amended sample, showed a decrease to very low levels in both inorganic N pools (Figure 15). In general, the overall trends in amended samples' NO_3^- and NH_4^+ pools were very different from control samples' pools. This suggests that in an incubation experiment with the absence of plants, NO_3^- and NH_4^+ pools will generally increase because there is no plant uptake, but if amendments are included, the NO_3^- and NH_4^+ pools will generally decrease, likely due to increased microbial immobilization and nitrification.

Another important observation that can be drawn from the soil analyses for all 3 treatments is that the lower levels of C amended seemed to create the largest decreases in NO_3^- and NH_4^+, while the decreases thereafter were minor. The results on Figures 8a, 8b, and 8c, suggest that when the percent of soil labile C is increased by less than 10%, there are still huge reductions in the total inorganic N pool, which was often several times smaller than the control inorganic N pool.

There were noticeable differences between the treatments, as well. Throughout the total incubation, sawdust consistently had the lowest inorganic N pool throughout most of the levels (Figures 8abc). This was contradictory to what might be expected considering nearly all of the C in sucrose in labile and can be readily used by microbes. However, one explanation for this could be that organisms in the soil simply prefer sawdust as a C source over sucrose, since processed sugar is a foreign substance to soil while wood is plant material. The greater surface area in sawdust might also be advantageous to microbes. Another difference between the treatments is that, while sucrose and sawdust maintain fairly even regressions by the end of the incubation periods, the woodchip samples showed a lot of variability, especially in the high levels of amendments. This could be attributable to the fact that the woodchips were a harder amendment to homogenize with the soil (Figures 7, 8c). The woodchip samples also consistently had the highest N mineralization and nitrification fluxes. While it is true that, in each amendment level, sucrose, sawdust, and woodchips contributed the same amount of labile C, perhaps the size of the woodchips made some labile C inaccessible to microbes over a short time period (Figures 9, 10).

Plant Growth Experiment: For the plant growth experiment, it is interesting that in the sucrose and sawdust samples, the total dry biomass and individual stem dry biomass values corresponded to the percentage of soil labile C added, in the same way the NH_4^+ and NO_3^- pools (and the total inorganic N) corresponded to the level of amendment (Figures 11ab and 12ab).

The woodchip samples showed no such trend, but unlike the sucrose and sawdust samples, the woodchip samples generally maintained positive net mineralization and nitrification fluxes (Figures 9, 10). The week 3 total inorganic N was also higher in the woodchips than the sucrose and sawdust, and it is possible that the positive mineralization and nitrification and a slightly higher inorganic N could account for the difference in plant development (Figure 8c).

Another important thing to take into consideration with the growth experiment is that the amendments did not seem to prevent germination. Sprouting success was variable among all of the treatments and treatment levels. Therefore, perhaps higher levels are needed to prevent germination. In this study, however, sucrose and sawdust did seem to stymie the development of the fescue grass. Before cutting the blades, a few sucrose amended pots appeared to have stunted growth. This would have provided a lower total dry biomass and individual stem biomass than fully grown blades, despite a lack of difference in how many stems there were.

Relating the general observations of the soil analyses to the growth experiment suggests that the amendments decreased NO_3^- and NH_4^+ enough to see noticeable reductions in plant dry biomass and stem dry biomass. Furthermore, the combined results suggest that even low levels of amendments reduced NH_4^+ and NO_3^- enough to affect the growth of the non-native species in the sucrose and sawdust samples.

This same relationship between decreased NO_3^- and NH_4^+ pools and decreased non-native development was seen in other studies. In a study at the University of Oregon, C addition negatively affected the dry biomass of non-native species, reducing it by about 64% (Miriti & Curtis, 2002). Another experiment by Paschke, et al. (2000) was able to reduce the N available to exotic annual grass in a way that actually changed the plant community structure to resemble that of a late-seral community, which was thought to be the original vegetative structure of the study area. Additionally, the reduced inorganic N pools corresponded to decreased invasive weed biomass. As stated, the Blumenthal et al. (2003) study saw dramatic differences in NO_3^- in combination with a decrease in non-native biomass. Several other studies have documented seeing a change in weedy biomass in response to C addition (Reever et al., 1999, Alpert and Maron 2000, Paschke et al., 2000), but thus far there have been far fewer studies that have observed a benefit to native species from a reduced N content. Therefore, the effects of N reduction on native species would benefit from further investigation.

Restoration Implications

The NH_4^+ + NO_3^- data from week 3 (Figure 8c), provides some interesting insight as to what a necessary application would be if one wanted to reduce NO_3^- and NH_4^+ pools. For sucrose, it seems that as more soil labile C is added, the greater the decrease is in NO_3^- and NH_4^+. The lowest pool can be achieved by adding 1038.37% of the soil labile C, or, in application, 6195.9 g of sucrose per m^2. However, this leaves a lot of question as to whether or not the decrease in inorganic N would be worth the amount of sucrose needed, especially taking into considering the risk of fermentation, which occurred in the study at sucrose levels 7, 8, and 9. Therefore, it might be best, in a realistic scenario, to apply 32.45-129.80% soil labile C, or 193.62 to 774.48 g sucrose / m^2. This addition would also be beneficial in terms of what was seen with the plant growth data. While germination was not stymied, it did seem that non-native plant hardiness decreased, possibly giving native plants a better opportunity to compete for resources, as well as possibly benefiting from a reduced N content in itself.

Sawdust seemed to work best when it was applied as 6.49 to 32.45% of the soil labile C, or 193.62 to 968.10 g sawdust / m^2. In the plant growth experiment, 32.45% also yielded the smallest total dry biomass and individual stem dry biomass. Application in any greater amount only shows very insignificant changes so the decrease in inorganic nitrogen seen after 32.45% is likely not worth the amount of sawdust that would be needed to yield the small decrease.

For woodchip application, it might be beneficial to add the same percentage of soil labile C, 32.45%, or 2,581.6 g woodchips / m^2 but no more. After this point, there does not seem to be any decrease in NO_3^- + NH_4^+, only variability. However, in terms of usefulness, the plant growth experiment suggests that woodchips were not useful in affecting the growth of non-native species. Therefore, it might be more useful to consider either sucrose or sawdust as an amendment, or a combination of each (Table 3).

Conclusion

It is important to note that a controlled laboratory exercise might produce results far different from what might be produced in the experiment. However, a controlled experiment of this type can be a useful first step in restoration efforts. This study was able to conclude that, at least in a controlled setting, C amendments can decrease NO_3^- and NH_4^+ pools enough to show a noticeable change in invasive plant development. Now that this has been shown, perhaps the next step is to test whether or not native species would be affected by the amendments. Just because the non-native species' development was hindered by the amendments, does not necessarily mean that native growth would benefit. In the Corbin et al. study (2004), both native and non-native plants were negatively affected by the addition of sawdust. However, in another study, non-native biomass decreased while native biomass increased (Blumenthal et al., 2003). In addition to growing native species in a controlled setting, growing native and non-native species together might be an interesting way to look at the competitiveness of native versus non-native species. Lastly, it would also be important to test the effectiveness and longevity of amendments in the field, where the soil would be exposed to varied weather patterns and numerous means of N export and import.

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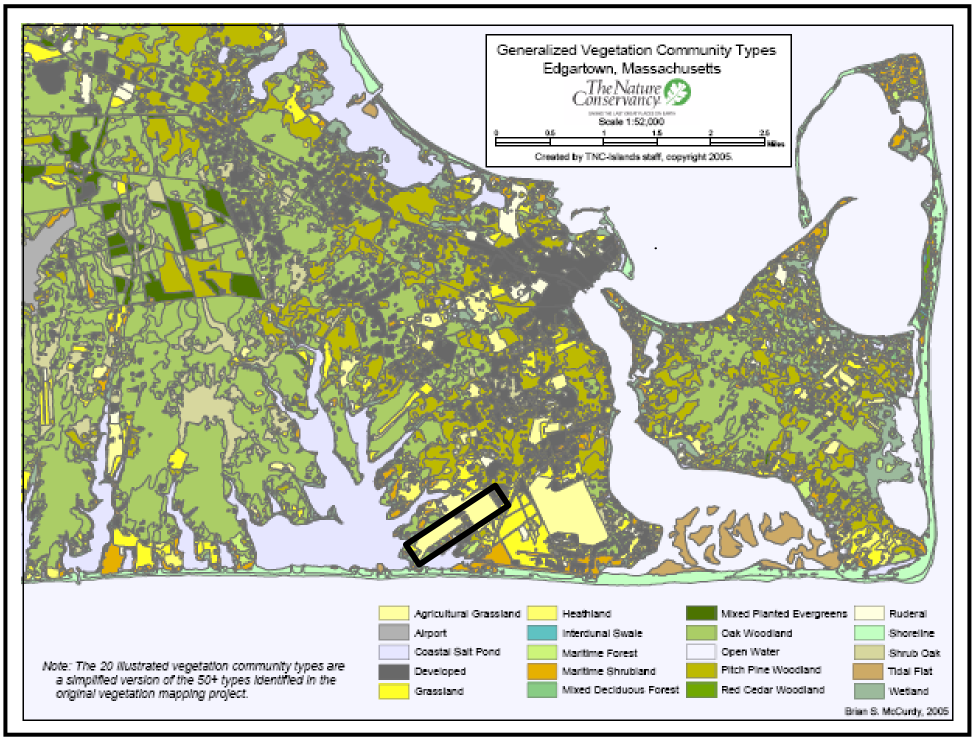


Figure 1. Vegetation map of Edgartown, Massachusetts, located on Martha's Vineyard. Herring Creek Farm is located next to the Katama Air Field. Map courtesy of The Nature Conservancy.

Treatment Types and Quantities		
Treatment	**Range of g C/m^2 Added**	**Range of g Labile C/m^2***
	Nine Levels in Each Range	
Sucrose	0.33 – 2,602	0.31 – 2,478
Sawdust	1.51 – 12,082	0.31 – 2,478
Woodchips	4.03 – 32,219	0.31 – 2,478

Table 1. * The added soil labile C was estimated as a percentage of the initial soil's estimated labile C divided by the treatment's estimated labile C. Therefore, the labile C added from each treatment was the same and adjusted by the mass of the amendment used. Two replicates were used in each of the nine levels for each treatment type. Measurements were taken at 1, 2, and 3 week incubation periods.

Carbon and Nitrogen Contents of Soil and Treatments				
	C (%)	**N (%)**	**C:N Ratio**	**Estimated Labile C (%)**
Soil	2.45	0.20	~ 12.3:1	10.0
Sucrose	42.0	0.0	-	40.0
Sawdust*	40.0	0.21	~ 190.5:1	8.0
Woodchips *	40.0	0.21	~ 190.5.1	3.0

Table 2. Carbon and nitrogen contents for the soil used for all treatment levels as well as the treatment C and N contents themselves. *Sawdust and woodchip C and N contents were based on estimated values for northern softwoods (Blumenthal et al. 2003).

Recommended Amendment Amounts According to Study Data to Achieve Maximum Decrease in (NO_3^- + NH_4^+)

Amendment	Addition Amount (g/m^2)	% of Soil Labile C Added
Sucrose	193.62 – 774.48	32.45 – 129.80
Sawdust	193.62 – 968.10	6.49 - 32.45
Woodchips	2,581.61	32.45

Table 3. Recommended amendment amounts (g/m^2) needed to minimize the added NO_3^- and NH_4^+ according to the study data from week 3.

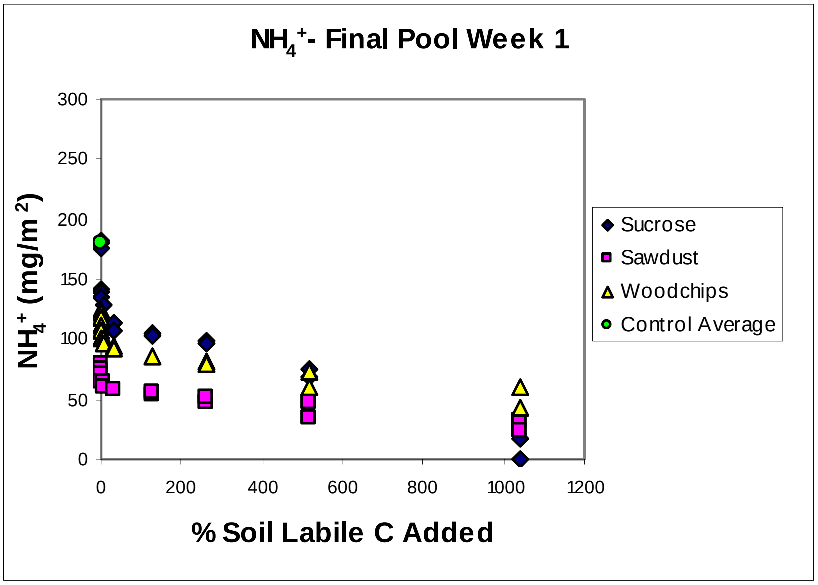


Figure 2. Final NH_4^+ Pool for Week 1 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).

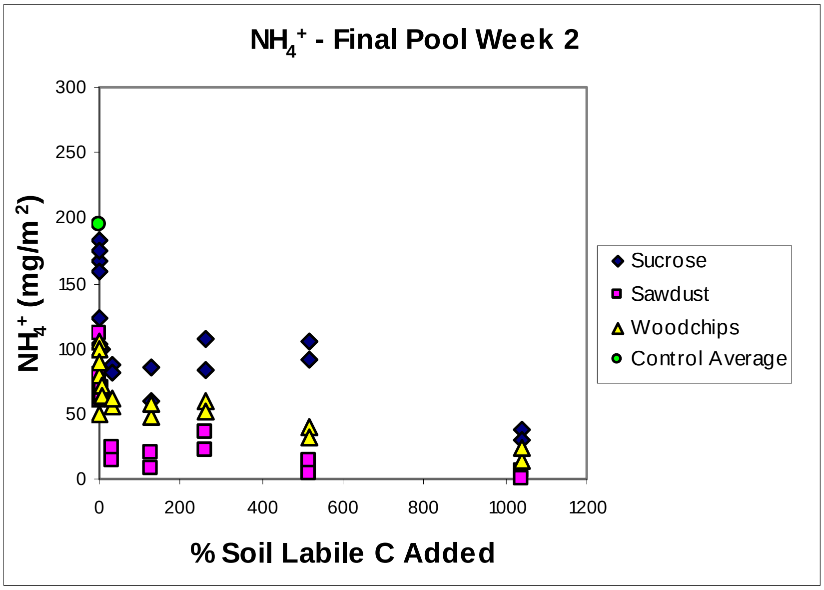


Figure 3. Final NH_4^+ Pool for Week 2 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).

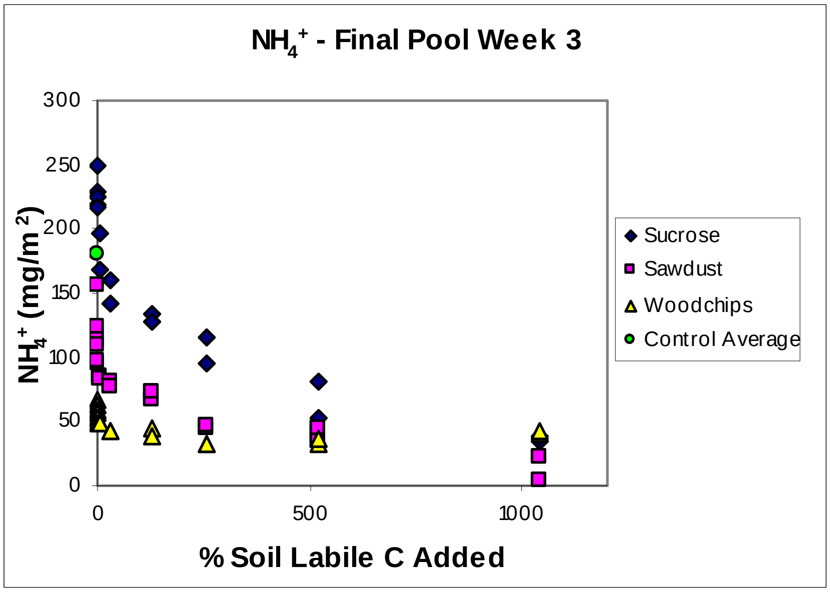


Figure 4. Final NH_4^+ Pool for Week 3 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).

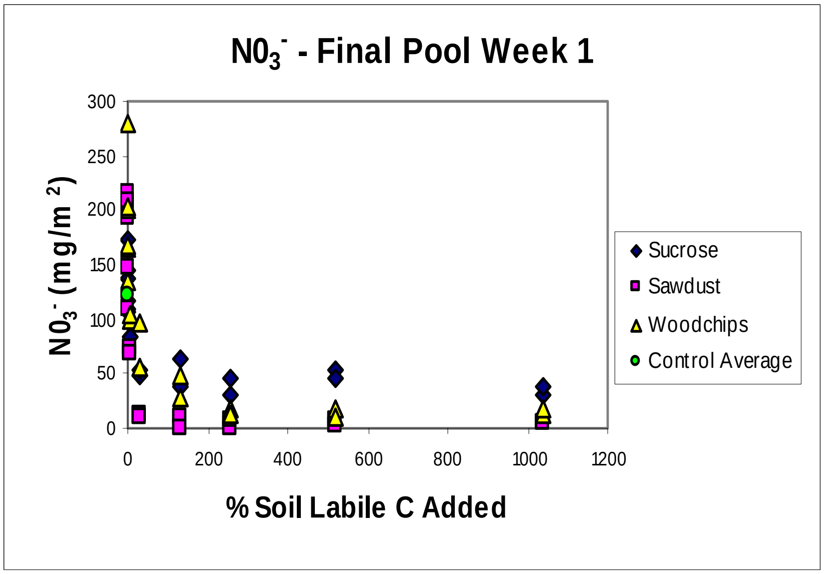


Figure 5. Final NO_3^- Pool for Week 1 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).

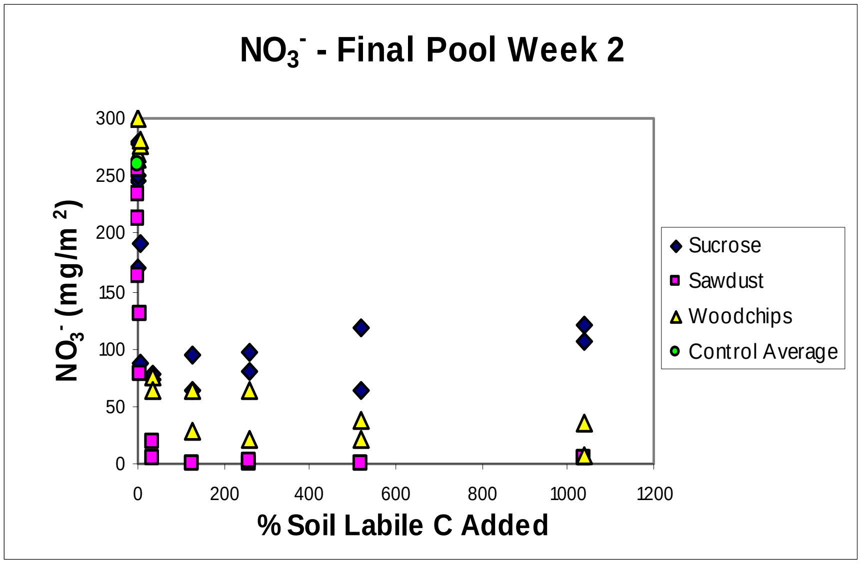


Figure 6. Final NO_3^- Pool for Week 2 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).

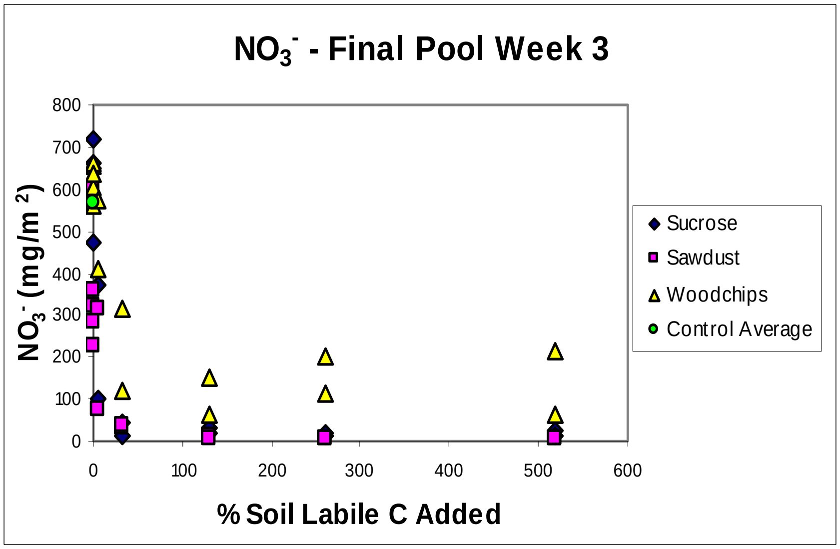
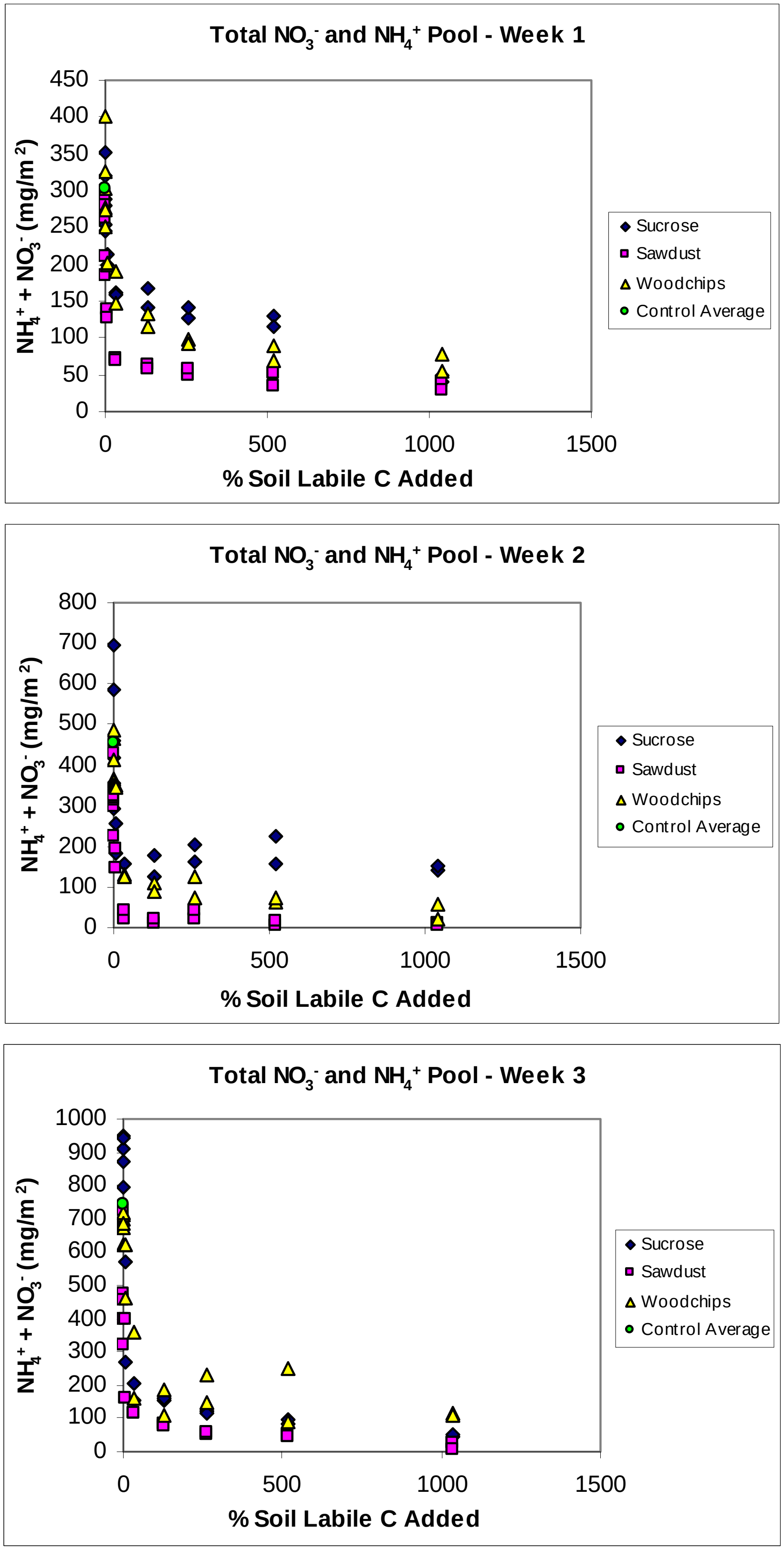


Figure 7. Final NO_3^- Pool for Week 3 for 10 levels (including 0) for sucrose, sawdust, and woodchips, plotted as % soil labile C added versus pool (mg/m^2).



Tables 8abc. Total NO_3^- and NH_4^+ added for the 10 levels (including 0) for sucrose, sawdust, and woodchips. Plotted as NH_4^+ plus NO_3^- against % soil labile C Added.

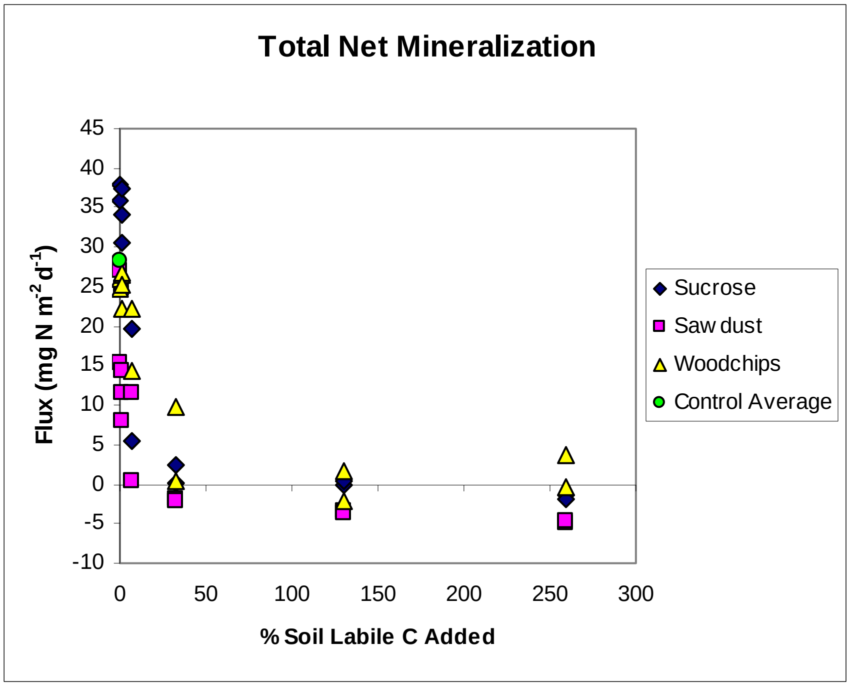


Figure 9. Total Net Nitrification for Sucrose, Sawdust and Woodchips, and their respective 10 levels (including 0). Plotted at Flux (mg N m^{-2} d^{-1}) versus % soil labile C added.

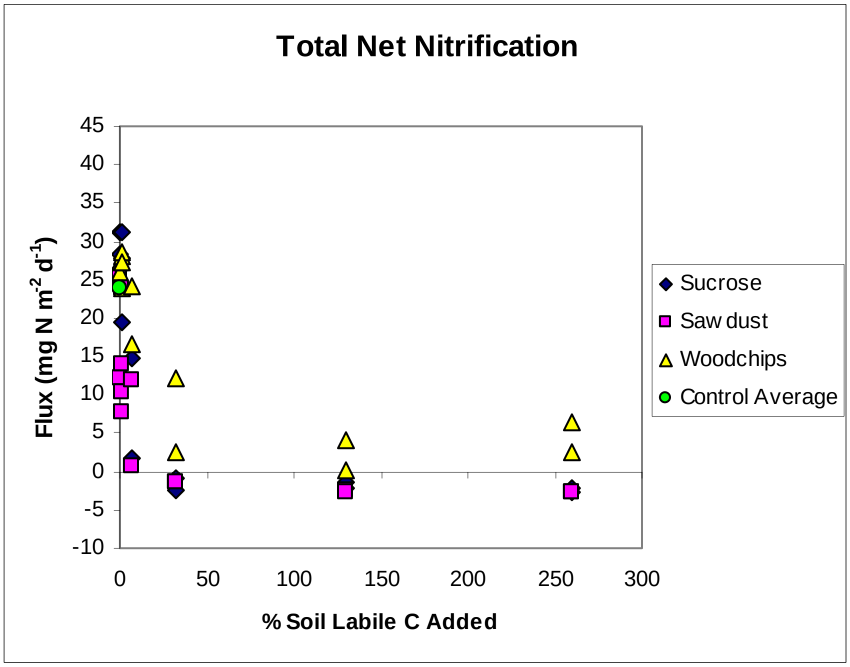
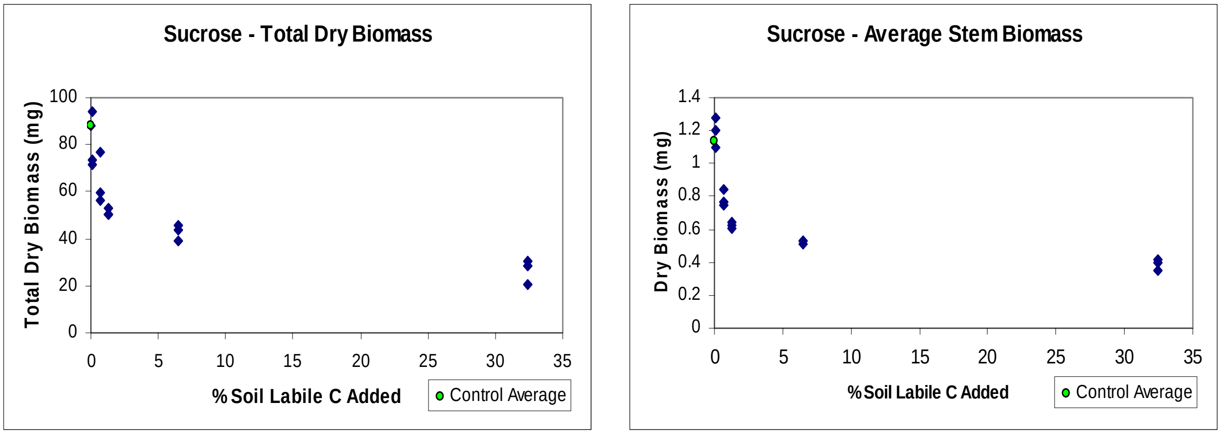
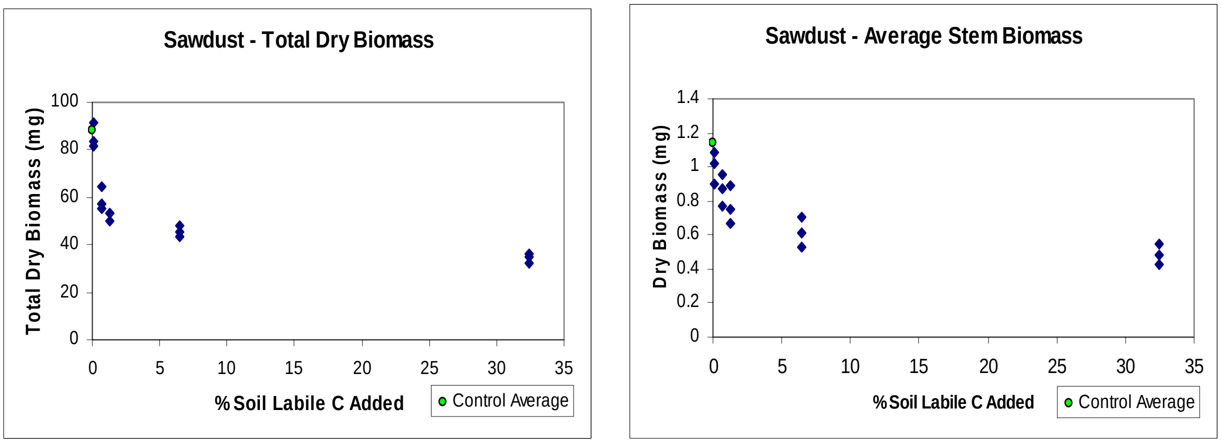


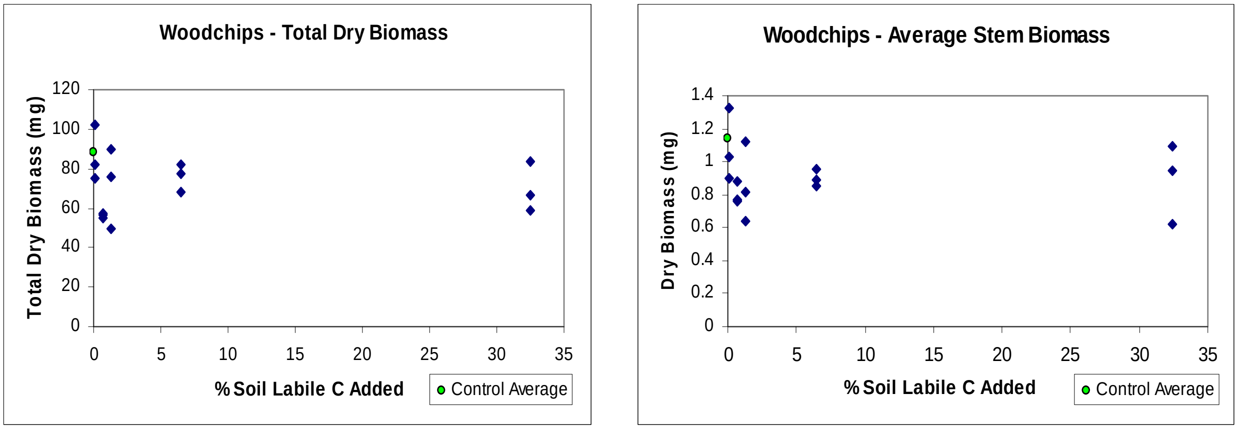
Figure 10. Total Net Nitrification for Sucrose Sawdust, and Woodchips and their respective 10 levels (including 0). Plotted as Flux (mg N m^{-2} d^{-1}) versus % soil labile C added.



Figures 11ab. Sucrose total dry biomass (mg) and average stem density (mg/individual). For this experiment, the first five levels of % soil labile C were used.



Figures 12ab. Sawdust total dry biomass (mg) and average stem density (mg/individual). For this experiment, the first five levels of % soil labile C were used.



Figures 13ab. Woodchips total dry biomass (mg) and average stem biomass (mg/individual). For this experiment, the first five levels of % soil labile C were used.

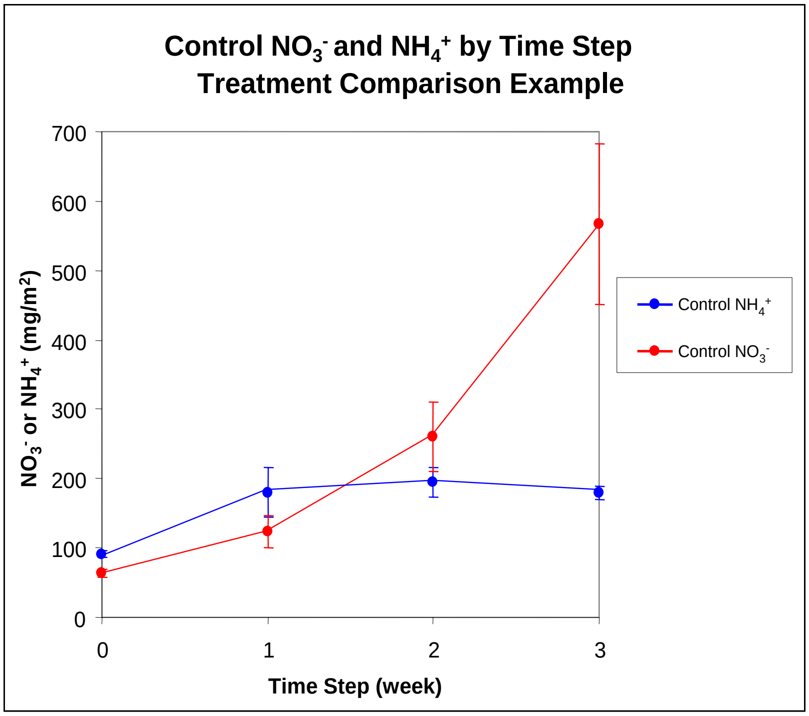


Figure 14. Control NH_4^+ and NO_3^- (mg/m^2) for the here times steps, plus initial.

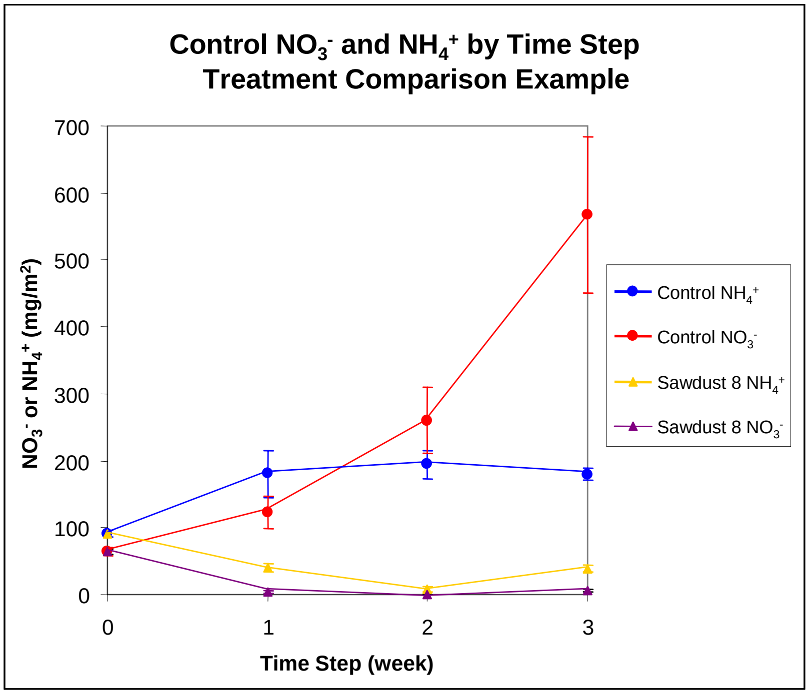


Figure 15. Control NH_4^+ and NO_3^- (mg/m^2) for the here times steps, plus initial, compared to sawdust 8's values over the time steps.