

THE EFFECTS OF INVASIVE SPECIES ON SOIL BIOGEOCHEMISTRY

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Abstract:

Invasive species are the second greatest cause of species extinctions, competing with native species for resources and space. Once exotic plants invade an area, they can affect entire ecosystems by out-competing native plants that provide food and habitat for native animals. Recent studies have shown that exotic species may actually change the biogeochemistry of the soil. These changes may create conditions that are preferable to exotic species and that are different from conditions to which the native species are adapted, thus causing natives to lose their competitive edge and facilitating further invasion by exotic species.

In this study I compare the biogeochemistry of sites on Cape Cod with similar land use histories (determined by the presence or absence of a plough layer) that are either un-invaded, or that are invaded by Oriental Bittersweet (*Celastrus orbiculatus*) or bush honeysuckle (*Lonicera morrowii*). I measured pH, soil respiration, C:N ratio, inorganic nitrogen, net mineralization and potential nitrification rates. I had 9 sites total, all of which compared bittersweet to un-invaded treatments, and 5 of which included a honeysuckle treatment.

I found that soils with exotic species had significantly higher pH in the O horizon, significantly higher inorganic nitrogen content, and measurably higher mineralization rates. Bittersweet soils had significantly higher potential nitrification rates and honeysuckle had measurably higher potential nitrification rates than un-invaded soils. Soil C:N ratios and respiration did not differ between treatments.

Introduction:

The purpose of this project was to study the effects of invasive plant species on soil biogeochemistry. Can invasive species invade undisturbed native forests on Cape Cod, and if so, how does the change in plant composition change the soil environment? Studies indicate that species composition does influence soil characteristics. This leads to the question of whether these soil changes facilitate further invasion, thereby exacerbating negative impacts on the ecosystem.

Invasive species are the second greatest cause of species extinction, just after habitat loss (Harold A. Mooney, Stamford University). And in fact, habitat disturbance or destruction can open up opportunities for invasive species to enter an ecosystem. Once invasives occupy an ecosystem, they threaten native species directly through competition for sunlight, nutrients and space. However, there has also been evidence that once an invasive establishes itself it can actually change the soil biogeochemistry to be either less hospitable for the native species or more hospitable for its own species, thereby creating conditions that facilitate further invasion.

Gary M Lovet *et al* (2002) conducted a study that compares the effects of a suite of variables on nitrate leaching to watersheds. The results show that soil C:N ratio is the only significant predictor of annual nitrate leaching to watersheds, and that soil C:N

ratios were most highly influenced by basal areas of red maple and red oak, indicating that nitrate leaching is different in oak dominated forests than in maple dominated forests. Because nitrogen can be limiting for plant growth, soil nitrogen retention is an important factor in an ecosystem. Also, this study showed the stream nitrate concentrations more than quintupled based on C:N ratios. Because species composition was correlated with soil C:N, this indicates that plant species composition could influence aquatic ecosystems by influencing soil chemistry.

Adrien C. Finzi *et al.* (1998) conducted a study solely on the correlation between tree species and soil carbon and nitrogen concentrations. They measured carbon and nitrogen directly beneath the tree crown of six tree species, and found that there were two groupings of trees with significant differences in C:N ratios and mineralization rates beneath their crowns. This further indicates the correlation between forest composition and soil chemistry.

However, indicating a correlation between species composition and soil chemistry does not necessarily imply species are responsible for differences in soil chemistry. Perhaps differences in species composition are caused by inherent differences in soil biogeochemistry, rather than soil differences caused by species composition. Joan G. Ehrenfeld *et al.* (2001) conducted a study in which the team potted invasive and native species in separate pots which all contained soil from the same, un-invaded forest, and allowed them to grow for over a year. The results show that invasive species created different soil conditions with different mineralization and nitrification rates than the natives.

In this study I focused on two invasive species, Oriental Bittersweet (*Celastrus orbiculatus*) and Bush Honeysuckle (*Lonicera morrowii*), in primarily pine-oak forests on Martha's Vineyard and in Falmouth, MA. I compared un-invaded stands to invaded stands. My hypothesis was that soils that are invaded with either bittersweet or honeysuckle will have higher C:N ratios, more inorganic nitrogen, and faster nitrogen mineralization rates than the un-invaded stands.

Methods

Field Analysis:

In order to compare the soil properties of un-invaded to invaded forests, I paired sites of un-invaded forests to invaded forests for sampling. These sites were similar other than the presence or absence of invasive species. I chose my sites based on the following criteria: similar land-use history between treatments, (indicated by the presence or absence of a plough layer), similar plant cover between treatments (I tried to ensure oak was a dominant species in all my sites), and treatments within a site had to be within 50m of each other. In the end I found 9 sites with both bittersweet and native treatments, and 5 of these sites also had a honeysuckle treatment (table 1).

Once I chose a site I dug a soil profile and recorded the depth and color of each horizon (colors identified using a Munsell color chart). I also took density samples with a corer at 5 and 15 cm, and analyzed samples from the O, A and B horizon for pH analysis in the lab.

I then used a corer to collect soil samples from the top 10cm of each site. I collected 4 of these samples from each treatment in each site, and homogenized them. I performed lab analyses on the homogenized samples.

Finally, I also documented species cover using a 6-point number system, 5 being the highest point and 1 the lowest. Definitions of each cover class are listed in table 2. I also collected leaves for C:N analysis. Because all the leaves had fallen from the trees at the time I was collecting samples, I had to collect dead leaf litter. I collected only honeysuckle leaves from the honey-suckle treatments, bittersweet leaves from the bittersweet treatments, and oak leaves from the un-invaded treatments, as oak was always present in my sites.

Lab Analysis:

To analyze pH, I mixed 10mL DI water with 5g fresh soil, and allowed the soil to settle before analyzing.

Density and Soil Moisture:

I dried the density cores in an oven set at 60C for at least 24 hrs, and recorded mass before and after drying to determine soil moisture content. I measured the volume of the corer to determine the density.

The surface cores I collected for ammonification and nitrification analysis I stored in a refrigerator at 40 C until I was able to perform the analysis. I homogenized the samples by hand, and removed approximately 12g for soil moisture analysis, 15 g for ammonia and nitrate analysis, 15g for potential nitrification, between 200g and 300g for incubation to determine mineralization and nitrification rates, approximately 50g for soil respiration, and a small amount for C:N analysis.

I used 50mL of 1M KCl to extract ammonia and shook the KCl soil slurry on a shaker table for 1 hour. I allowed the solids to settle before filtering through 25mm GF/C filters. The samples had to be frozen for several days until analysis. I analyzed ammonia colorometrically and nitrate on the lachat, and calculated concentrations on a per gram dry soil basis.

Because of the cold weather I assumed mineralization and nitrification rates would be slowed in the field, so I did not use the buried bag technique to measure mineralization and nitrification in the field in case the rate was too slow to detect well in the limited time constraints of this project. Because I am more interested in the relative rates of these processes between treatments than in the exact field rates, I instead incubated samples in plastic bags at 28 C for 2 weeks, and then followed the processes described above for ammonia and nitrate analysis. All of the incubated KCl-soil solutions had to be diluted in KCl for ammonia analysis, but only a few required dilution for nitrate analysis.

I analyzed potential nitrification based on methods described by Hart *et al.* (Methods of Soil Analysis: Part 2 – Microbiological and Biochemical Properties, pg 985-1018). The soil shook in an ammonia sulfate solution at 28 C for 24hrs. I took samples at 2hrs, 4hrs, 12hrs, and 24hrs. Then I centrifuged, filtered, and froze the samples until running analysis on the lachat.

I also measured respiration in the lab for the same reasons I analyzed mineralization and nitrification in the lab. I measured approximately 50g of soil into glass mason jars, and allowed them to reach room temperature. To analyze respiration I had mason jar lids with two holes in them, sealed with rubber septas, into which I inserted the Li-COR 6200 tubes. I recorded respiration for 5 min for each sample.

Soil and leaves for C:N analysis dried for at least 24hrs in the oven. I ground soil with a mortar and pestle, and leaves in the Wiley Mill.

Results:

Field Analysis:

All my sites had an O-horizon between .5 and 3 cm, and all were disturbed soils (an Ap rather than an A horizon). Profiles were usually very similar between treatments within a site, but there are a few sites which show differences in the depth of the Ap horizon (figures 1a-i). I chose these sites for sampling because, in my initial check, they both had plough layers. It was not until after I had identified my sites, while digging the deeper profiles, that I could identify these differences, and because of the time constraints I kept them as sampling sites even though they were not completely ideal. Most of my sites, however, had very similar profiles between treatments (figure 1j shows average horizon depths in each treatment), and my results did not differ much in these sites from sites that had almost exactly the same profiles between treatments.

Soil density did not differ between treatments (figure 2), nor did color of the different horizons (table 3).

I was usually unable to find sites with exactly the same species composition between treatments. Also, I designated percent cover values based on what existed in a 2 meter radius, so the forests surrounding my sampling areas were actually more similar than my data implies. However, the effects of different plant species on soil can be very localized (Finzi et al, 1998). So while I was not able to control perfectly for species composition, this data aided me in analyzing my soil data so that I might see how much my results were dependent upon differences in species composition. In most sites the dominant species were similar throughout treatments.

Lab Analysis:

pH is the only profile characteristic that differed significantly between treatments, particularly in the O-horizon (figure 3). The native soils are the most acidic and the bittersweet invaded soils the most basic. Even the most basic soils have a pH below 7.

The C:N ratios were highest in the oak leaves, and lowest in the honeysuckle. The difference between oak and bittersweet, and bittersweet and honeysuckle C:N ratios, is not significant, but the difference between oak and honeysuckle is significant. Soil C:N ratios were not different between treatments. (figure 4)

Based on the CHN and soil density data I calculated the carbon and nitrogen stocks per meter squared, down to 10cm depth. These, also, did not differ significantly between treatments (figures 5a and 5b), though honeysuckle seems to have a higher carbon stock and bittersweet a lower nitrogen stock than the other treatments. The high carbon stock in honeysuckle can be attributed to one site that had a particularly high C:N ratio. The other 4 honeysuckle treatments were actually very similar to the native and bittersweet treatments (figures 6a and 6b). The average low N stock in the bittersweet soils was actually attributed to a general trend existing between treatments.

Respiration rates did not differ between treatments (figure 7).

The inorganic nitrogen concentrations were significantly different between treatment types, and are highest in soils invaded by bittersweet and lowest in un-invaded soils (figure 8). Bittersweet had three times more ammonium than native soils, and

approximately 7 times more nitrate (figure 9a). Honeysuckle soils had more than twice the ammonia and 5 times the nitrate of the native soils (figure 9b).

Net mineralization rates were also higher in bittersweet soils than in un-invaded soils (figure 10), though the differences between treatments were not significant. All differences in mineralization rates between treatments were due to nitrification rates, as ammonification rates were similar between sites (figures 11a and 11b).

Potential nitrification was also highest in invaded soils and lowest in native soils, and it was significantly higher in the bittersweet invaded soils compared to the native soils, though not significantly different in the honeysuckle soils (figure 12).

Discussion:

Profiles:

The differences in the Ap horizon between treatments in some sites may indicate different land-uses for these sites, but for many of these sites the differences in the histories are not likely recent, as the O-horizons between treatments were the same. For example, in site 3 (figure 1c), the profile depths are very different, but in the native site the Ap horizon was a patchwork of the same bright colors of all the horizons in the bittersweet site, indicating some type of excavation or bulldozing that mixed the layers. The native and bittersweet treatments were both within the same horse coral, and only 15m apart. The coral has not been in use for some time, and has been there for at least 30 years, so the excavation most likely occurred before that.

There are a couple sites where the O-horizon is a little bit deeper in one of the treatments, even when the other horizons are similar. This can always be attributed to a particularly high percent cover of a species with particularly high C:N ratio. This would cause the litter to decompose more slowly, and result in a deeper O-horizon.

The general similarity of soil profiles between sites indicates that the sites have generally similar histories, and that consistent differences in soil characteristics between sites can generally be attributed to species cover over land-use history.

pH:

pH was the only soil profile characteristic that varied significantly between treatments. Because the horizon depths and densities were so similar, the difference in pH is most likely due to species cover rather than land-use history, especially since the difference is most pronounced in the organic layer. Mineralization lowers pH, but I found higher mineralization rates in invaded sites, which also had higher pH, so this cannot account for the pH trend between treatments. Plant uptake of nitrogen can increase pH, so it is possible that invaded sites have plants that take up nitrogen more rapidly. I did not measure primary production, so can not be certain whether or not this is the explanation for the pH patterns.

C:N Ratios:

The values presented here for the leaf C:N ratios may not be completely accurate because the leaves I collected were not all in equal stages of decomposition. The bittersweet leaves were far more decomposed than either the oak or the honeysuckle leaves, because honeysuckle drops its leaves so late in the season, and because oak leaves decompose slowly. I know the bittersweet leaves decompose more rapidly than the oak

leaves because when I first began identifying the sites, bittersweet still had some leaves on the vines, whereas there were no or almost no leaves on the oak trees. The fact that bittersweet leaves decompose so rapidly indicates their C:N ratio is much lower than the oak, but much of this nitrogen may have already been decomposed and leached from the leaves by the time I sampled them, and thus I was not able to make an accurate comparison.

Though the difference was not significant, the low N stock in bittersweet soils, despite a higher inorganic content, indicates a fast nitrogen cycling rate. Most of the organic nitrogen dropped from the leaves must be rapidly converted to inorganic nitrogen.

Respiration:

I suspect there to be some errors in my respiration data, because my jars all started out with very different initial concentrations (ranging from 500-1000ppm). Before sealing the jars of soil and logging respiration I had to thaw the soils, as they had to be stored in the fridge. I put them in the mason jars, and covered them to prevent water from escaping. I waited until after the jars had reached room temperature to analyze respiration. Because the jars were so small (240cc), there is a large probability of error, if I did not air out the jars evenly before sealing them with the lid attached to the Li-COR, or if I breathed into one accidentally. However, there was water in one of the dessicator tubes. I tried to dry this, but it did not dry before I had to run the experiment. I set up the dessicator so that the wet tube was leading into the dessicant, but this, perhaps, could have affected the readings of the concentrations, but would not have affected the readings of the rates.

I also noticed that the top of the soil sometimes dried during the course of the Li-COR reading. I don't know how much that may have affected the rates of respiration.

Inorganic Nitrogen:

The high ammonium and nitrate concentrations show an important difference between the chemistry of the invaded versus un-invaded soils. It is the inorganic nitrogen which plants use for growth, so though the total nitrogen stocks were not significantly different between treatments, increasing the availability of an important limiting nutrient, could have significant impacts on the plant species able to grow in the soils.

Nitrogen Mineralization:

The higher net mineralization rates in the invaded sites indicates a different microbial population existing under invasive plants than under native plants that are able to cycle nitrogen more quickly. I was not able to measure significantly higher mineralization rates in invaded site. But the fact that these sites had the same nitrogen stock, yet a larger portion of this nitrogen exists as inorganic nitrogen, indicates that my results represent an actual difference, even if measurements were not significant. I believe the differences would have been more pronounced if I could have measured mineralization rates immediately upon returning the soil to the lab. However, many of my soil samples were stored in a refrigerator until I had time to measure initial concentrations. Storing the samples in this way may have either killed the microbes, or they may have continued to metabolize, though slowly, thus depleting the inorganic

nitrogen stock before analysis. The samples that broke the general trend were all samples that I collected first and had stored the longest.

Potential Nitrification:

My potential nitrification measurements show more clearly the differences in the microbial populations between invaded and un-invaded treatments, particularly between bittersweet invaded and un-invaded soils.

Summary:

Overall, my results show that there is a biogeochemical difference between un-invaded forests and forests invaded by bittersweet or honeysuckle. These differences are most likely due to the invasive species rather than to different land-use histories.

In order to be even more certain of the land-use histories between treatments, it would be good to have documented histories of land-use rather than relying on soil profiles. Similar experiments would also benefit from more collaborators so that all the soil processes could be analyzed immediately upon return to the laboratory. Such studies are better suited to summer when respiration and mineralization can be measured in the field, and when it is possible to obtain fresh leaf C:N ratios.

Conclusions:

Though less pronounced, my results are similar to those obtained by Rice et al. (2002), who studied the effects of black locust invasion on native pine-oak forests in upstate New York. Black locust is a nitrogen fixer, so it is not surprising that nitrogen stocks were higher in black locust stands than in oak-pine stands. However, it is important to understand that even non-nitrogen fixing species can induce similar results. Now that there is evidence that even non-nitrogen fixing invasive species change soil biogeochemistry, it is necessary to determine what the effects on the ecosystem will be. Tillman et al. (1993) performed an experiment in Minnesota Grasslands in which they added nitrogen at various rates to several plots for four years. The results showed that higher rates of nitrogen addition resulted in a decrease in biodiversity. Grasslands may respond differently than native forests, so increased inorganic nitrogen availability may not decrease diversity, but there are still likely to be effects on species composition, if not to change diversity, then perhaps to change the species present.

Von Holle *et al.* (unpublished) performed a study comparing invasion rates of exotic species in native and black locust stands with similar land use histories in Cape Cod. She found higher rates of invasion in the black locust stands, describing them as “islands of invasion” within native forests that are resilient to invasion. Though black locust has a more pronounced effect on soil nitrogen than what I found for bittersweet and honeysuckle, Von Holle’s results indicate that increased nitrogen availability caused by invasive species can affect the susceptibility of native forests to invasion.

In terms of whether invasion facilitates further invasion, my results are inconclusive. I tried to control for species composition, and purposely did not chose sites with invasive species other than bittersweet or honeysuckle, but I only recorded species composition within a 2m radius circle. Based on qualitative analysis I can definitely say that outside of these small circles the invaded forests had multiple invasive species, while un-invaded forests had none or close to none.

Because I only performed analysis on disturbed soils, I cannot say much about the threat invasives pose to undisturbed native forests. Initially, however, I was looking to compare undisturbed invaded and un-invaded forests, but I was not able to find undisturbed forests invaded by bittersweet, indicating that bittersweet only effectively invades disturbed soils. However, honeysuckle did grow in undisturbed soils, which was my initial reason for including it in this study. But because I was focusing on bittersweet, I ended up looking only at disturbed soils.

Studies on other species would have to be done before making a general statement that undisturbed Cape-Cod forests are completely resistant to exotics. Though my results indicate that honeysuckle does not have as pronounced an effect on soil biogeochemistry as bittersweet, I cannot conclude from this experiment whether or not the effects are pronounced enough to facilitate invasion of other exotics in the future. It is possible that its ability to invade native forests makes it a kind of pioneer, and will allow further invasion by other species in the future. More studies would have to be conducted on honeysuckle, as well as on the specific seeding requirements of various exotics.

It could be important in forest management practices to identify the invasive species that are pioneers, capable of invading native soils and making the soil changes that facilitate invasion, because these species may actually be more of a threat to undisturbed forests of the Cape than the more prolific species, like bittersweet, that are limited to disturbed areas. Species such as bittersweet that cause significant changes in the soil chemistry pose an obstacle to rehabilitation of disturbed forests. Identifying species with the most pronounced effects on soil biogeochemistry is important, because it would allow for more educated prioritizing and effective strategizing in rehabilitation efforts.

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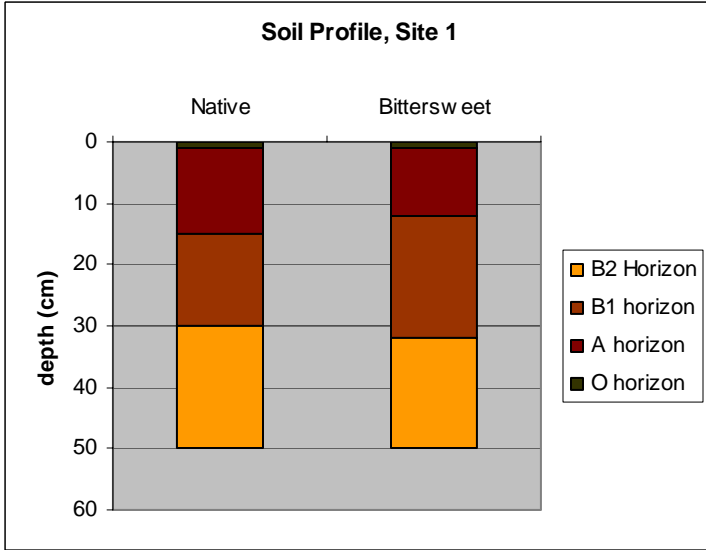


Figure 1a

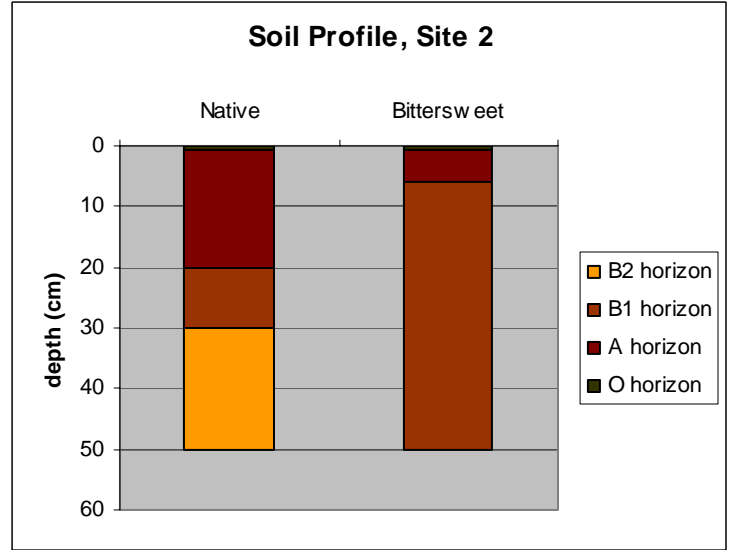


Figure 1b

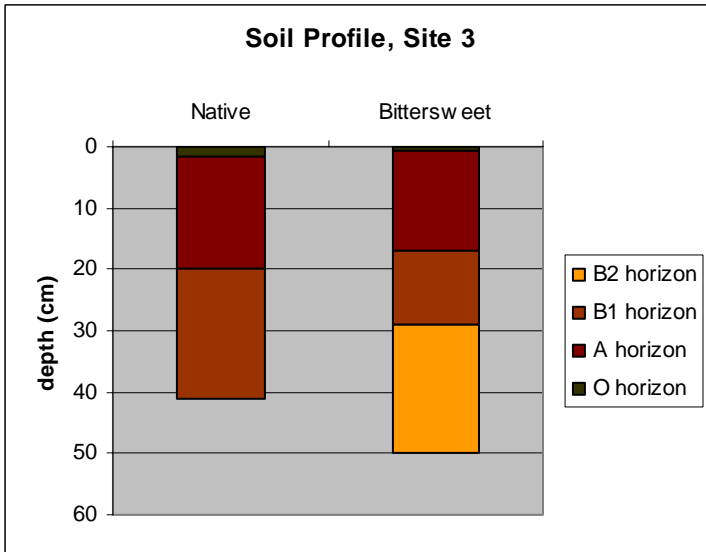


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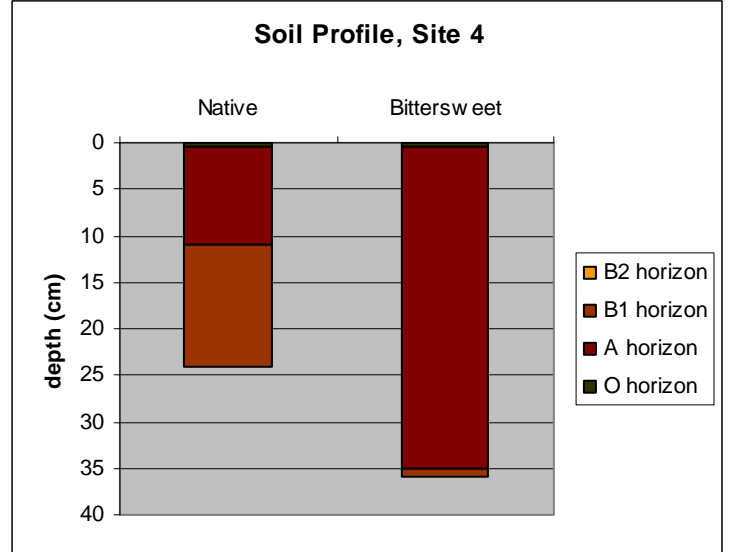


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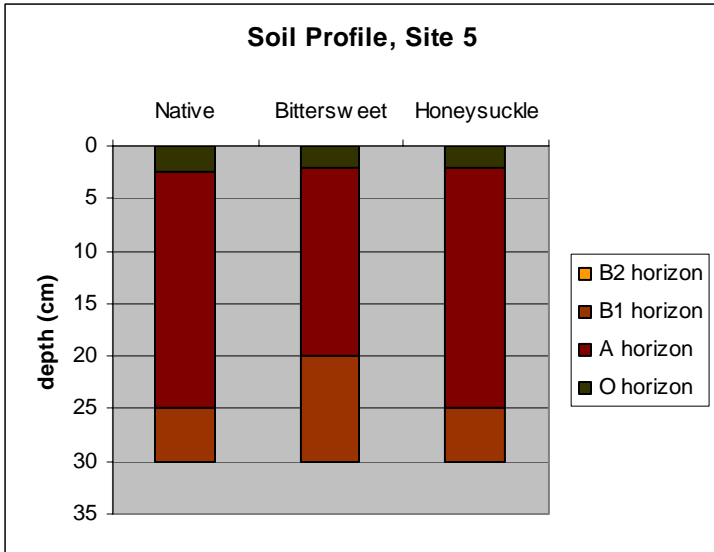


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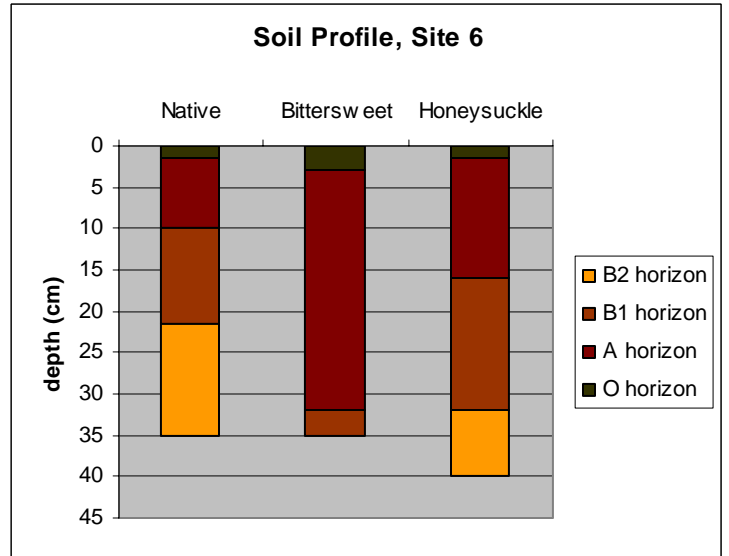


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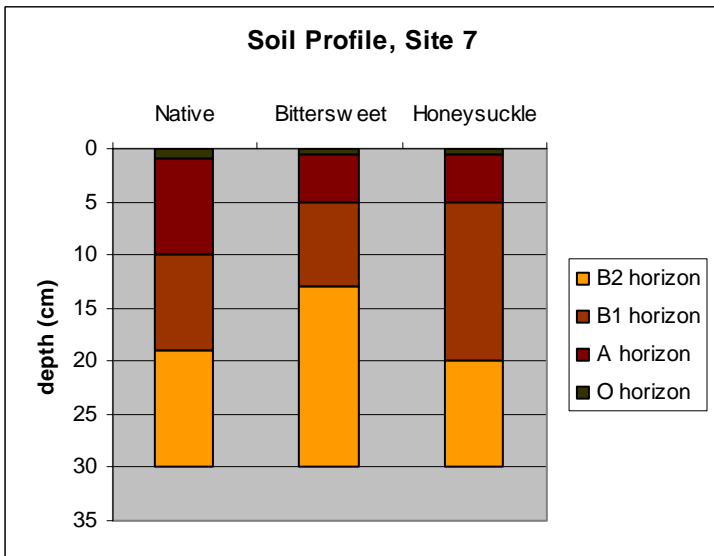


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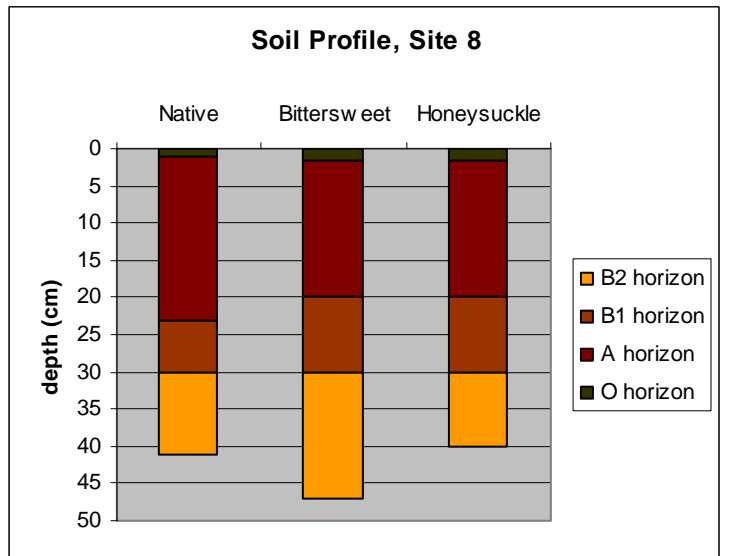


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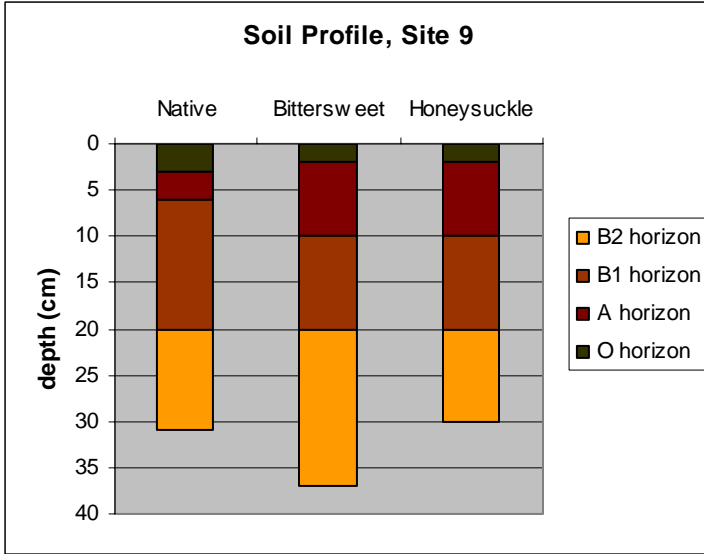


Figure 1i

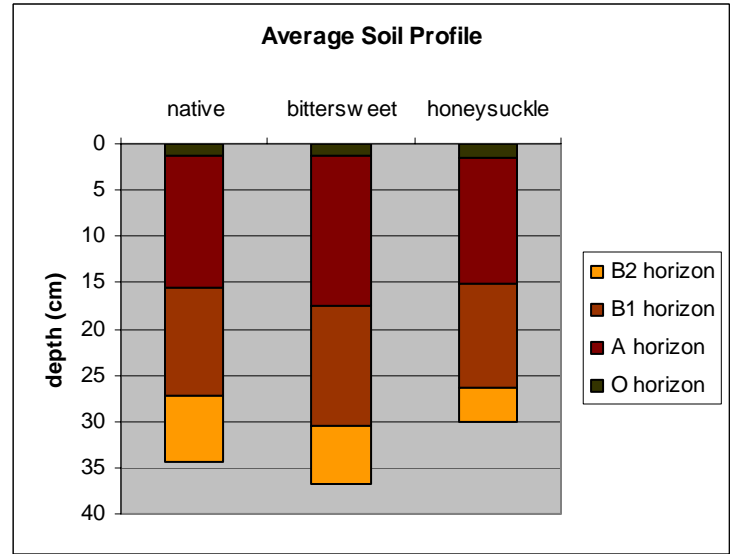


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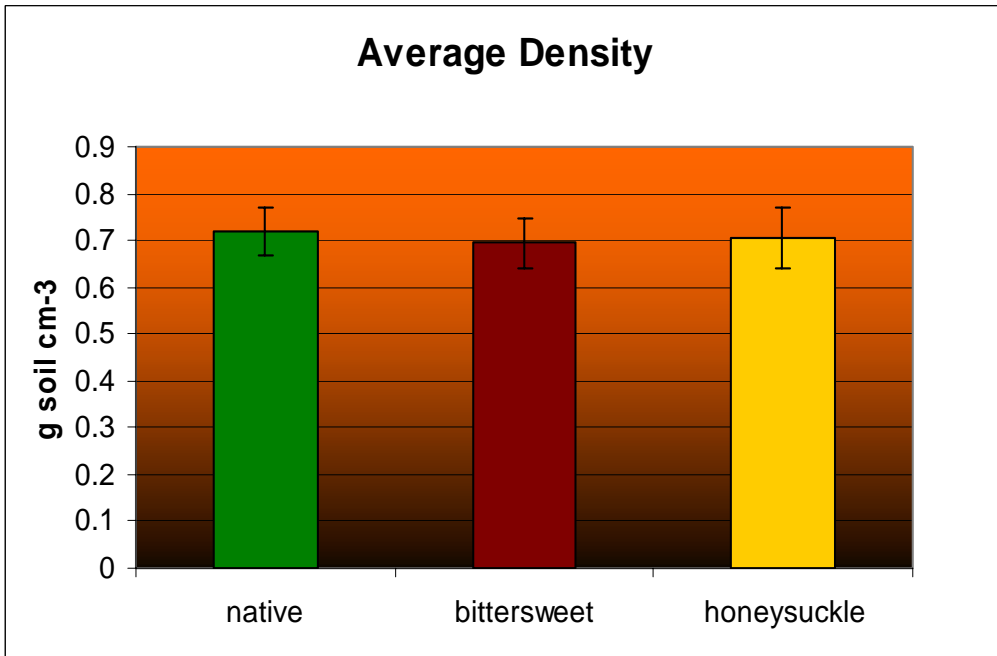


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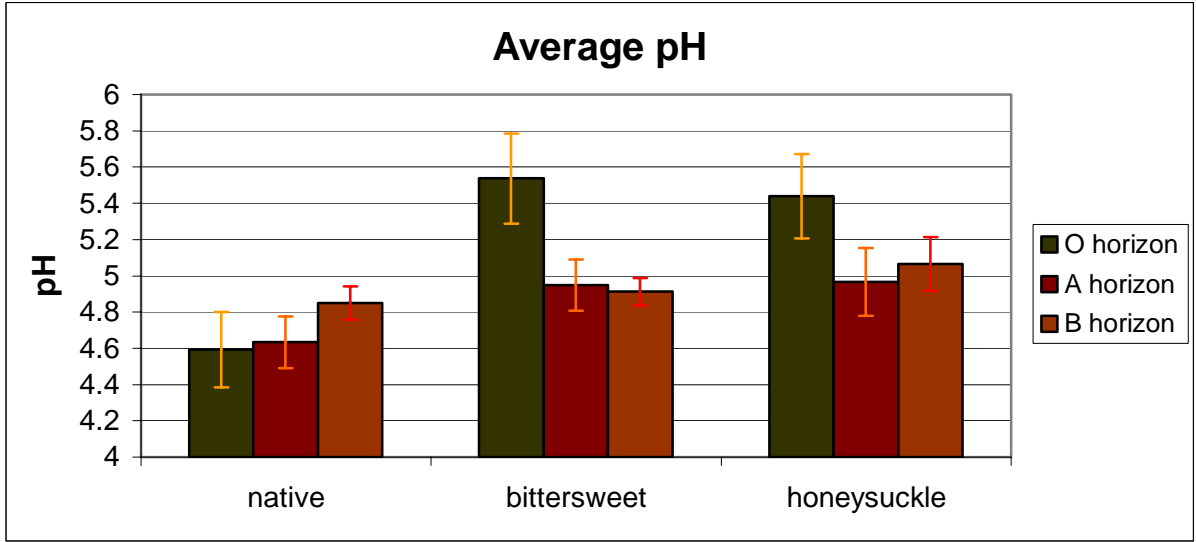


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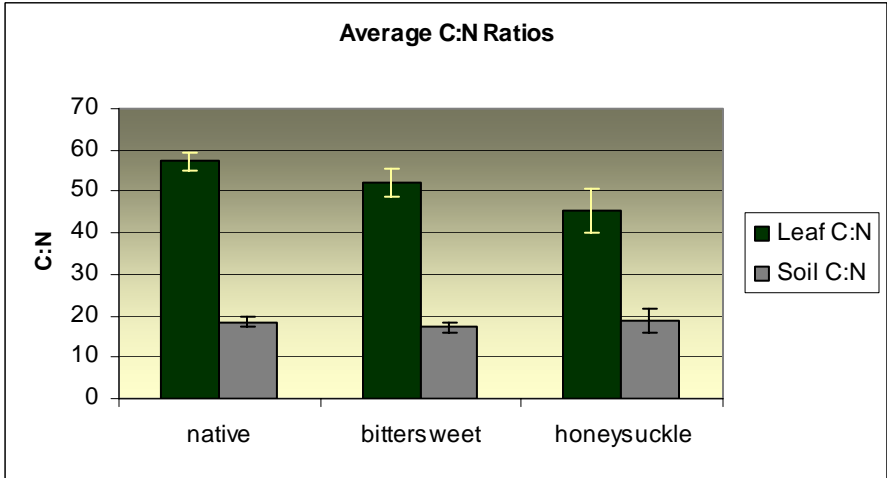


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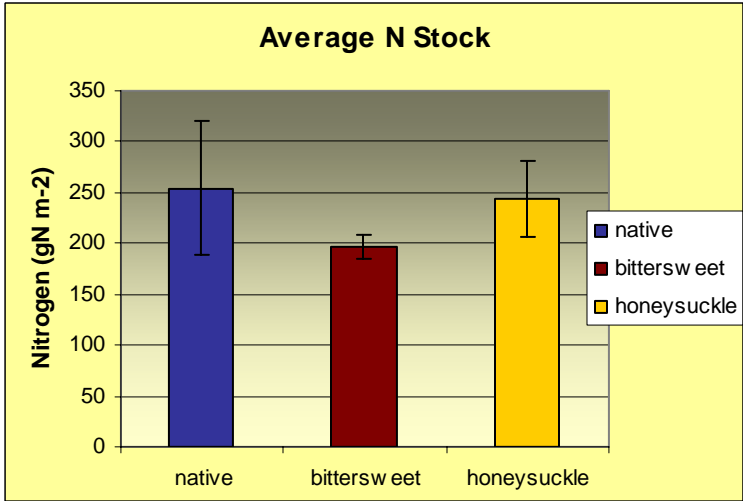


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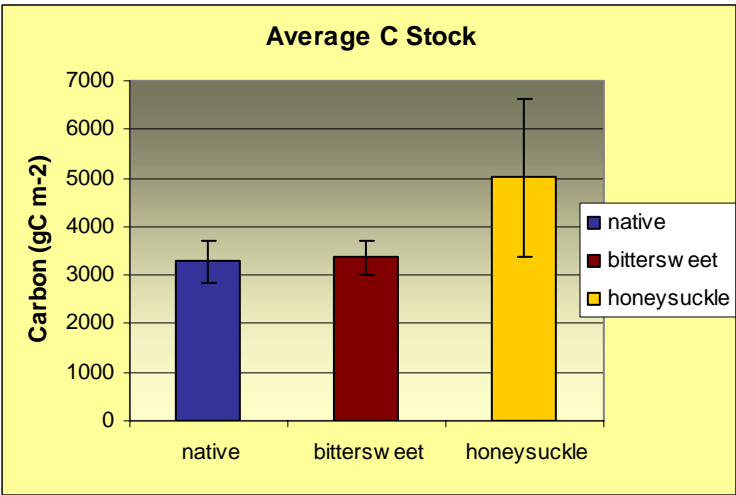


Figure 5b

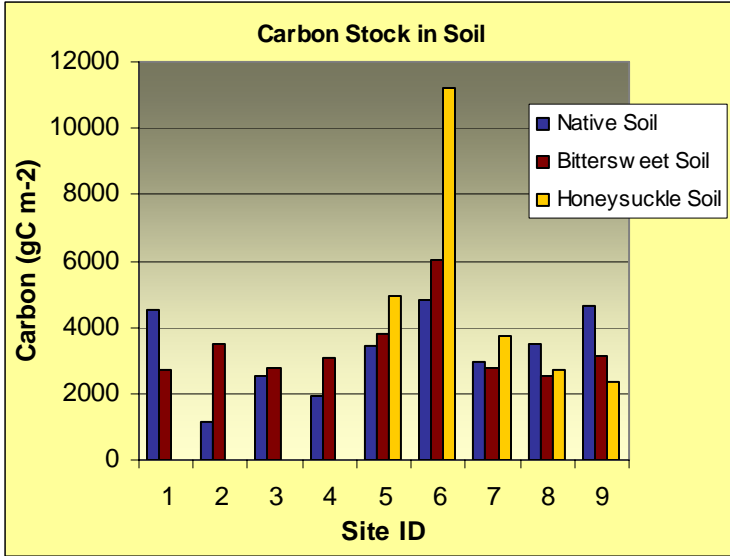


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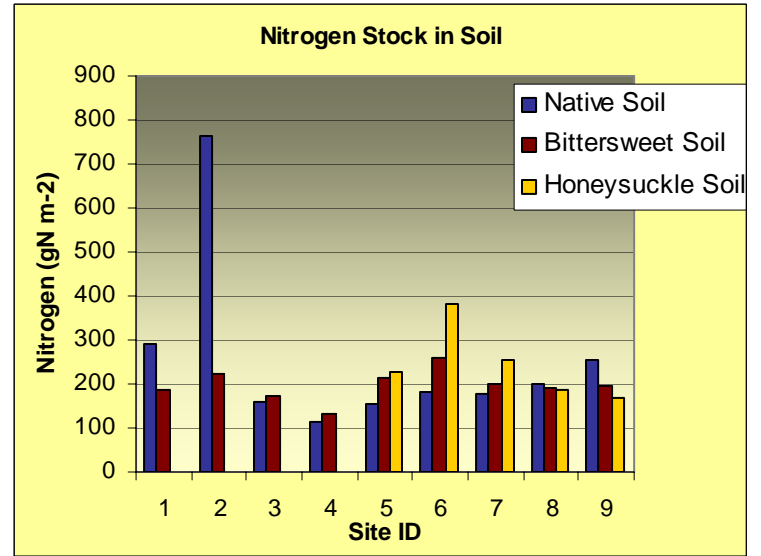


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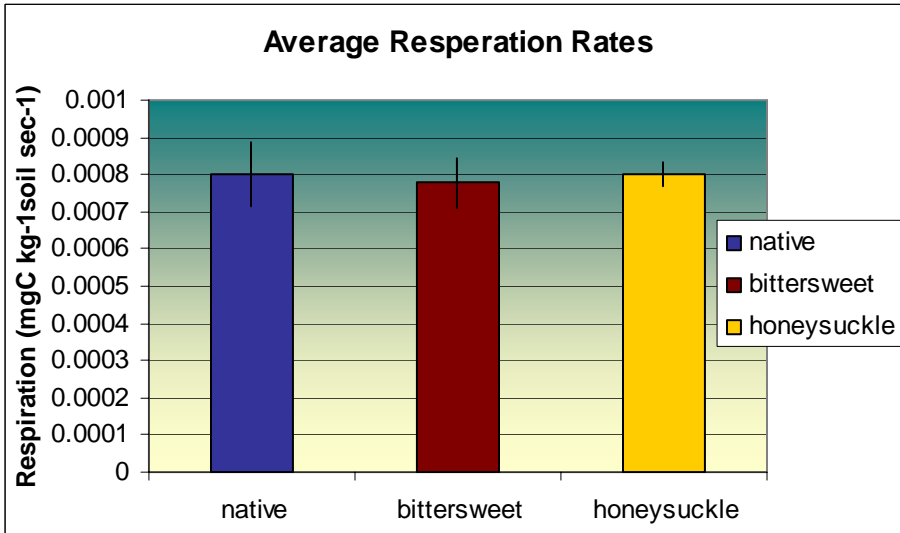


Figure 7

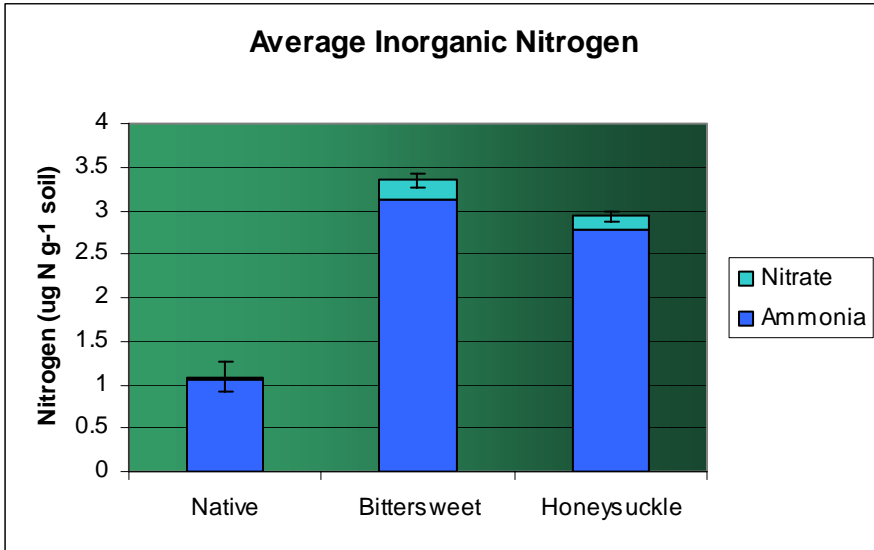


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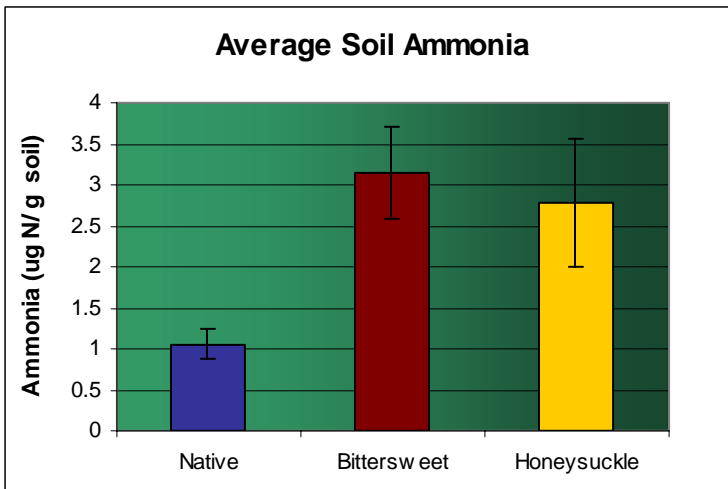


Figure 9a

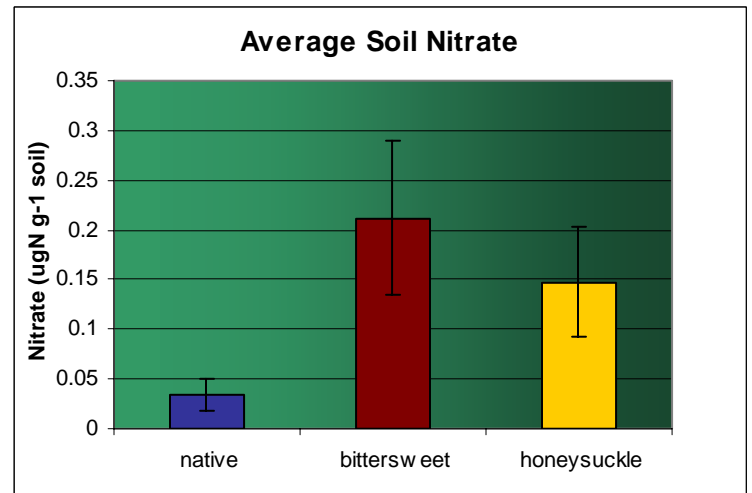


Figure 9b

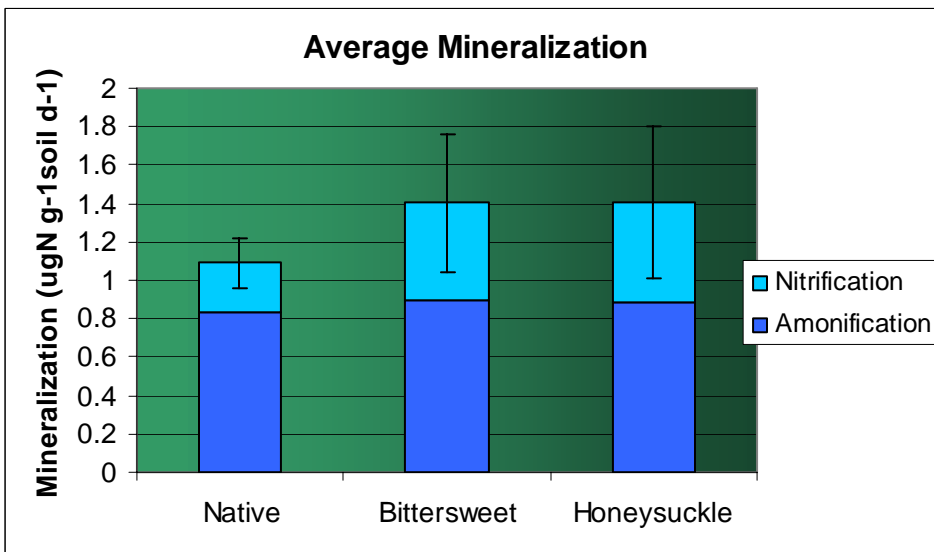


Figure 10

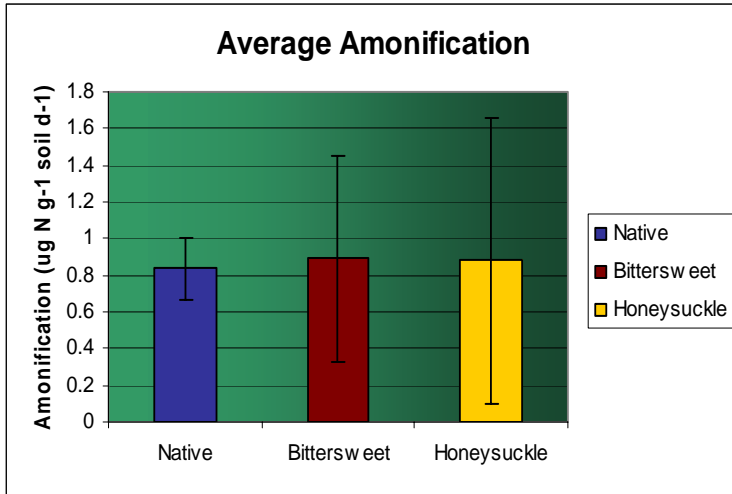


Figure 11a

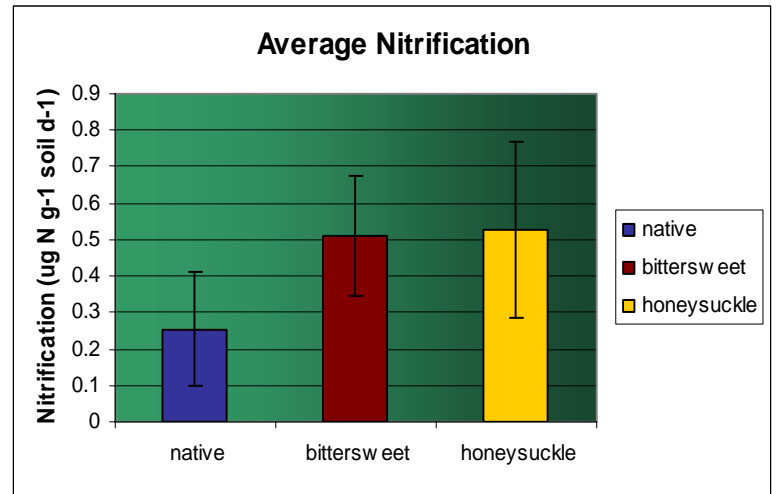


Figure 11b

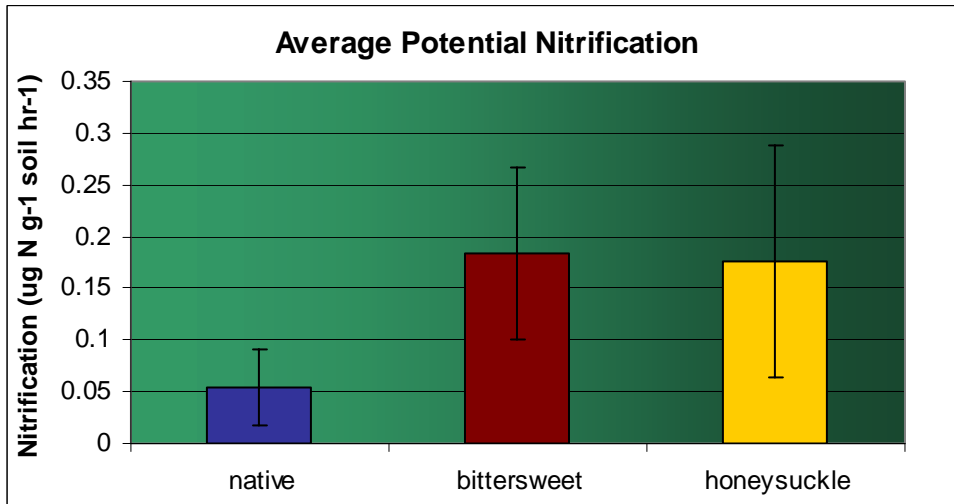


Figure 12

TABLE 2	species	%cover	species	%Cover	species	%Cover
5=75-100%	1N		1B			
4=50-75%	black oak	3	Bittersweet	5		
3=25-50%	Black cherry	2	Black oak	3		
2=6-25%	Solidago	2	rosa multiflora	1		
1=1-5%	rosa multiflora	2	black cherry	r		
r=<1%	white oak	1	vine honeysuckle	r		
	unknown	1	unknown	r		
	carex	r				
	vine					
	honeysuckle	r				
	2N		2B			
	black oak	5	bittersweet	4		
	carex	5	virginia creeper	3		
	beech	2	Solidago	3		
	Euthamia	1	Euthamia	2		
	moss	1	black oak	2		
	solidago	r	sweet fern	1		
			carex	1		
			unknown	1		
	3N		3B			
	Black oak	5	Black cherry	4		
	viburnum	3	viburnum	4		
	yew	3	bittersweet	4		
	smilax	1	yew	1		
	black cherry	1	black oak	1		
	4N		4B			
	black oak	5	Bittersweet	5		
	viburnum	4	vine honeysuckle	3		
	smilax	3	winged sumack	2		
	solidago	1	Solidago	2		
	Carex	1	unknown	2		
	orchard grass	1	rosa multiflora	1		
	rosa multiflora	r	smilax	1		
	Vine		orchard grass (dactylis)	1		
	honeysuckle	r	bush honeysuckle	r		
	Yarrow	r	bushy aster (simplex)	r		
	Trembling aspen	r				
	5N		5B		5H	
	pitch pine	5	cedar	3	cedar	5
	Viburnum	4	bush honeysuckle	3	carex	4
	white oak	3	black oak	3	bush	2

Cedar	2	carex	3	honeysuckle	
Unknown thorn	1	moss	3	White oak	2
		viburnum	2		
		bittersweet	2		
		unknown	2		
		pitch pine	1		
		unknown thorn	r		
6N		6B		6H	
Black oak	5	bittersweet	5	bush	
red cedar	3	bush honeysuckle	5	honeysuckle	3
Smilax	2	red cedar	5	red cedar	2
Carex	2	black cherry	3	viburnum	2
White oak	2	rosa multiflora	1	Black oak	2
Solidago	r			Carex	2
Unknown	r			Black cherry	1
				solidago	1
				Moss	1
				unknown	R
				vine	
				honeysuckle	R
				rosa multiflora	R
				unknown	R
7N		7B		7H	
White oak	5	bittersweet	3	bush	
red cedar	3	bush honeysuckle	2	honeysuckle	5
Unknown	3	solidago	2	Black cherry	5
Carex	3	black cherry	2	bittersweet	4
red oak	2	red cedar	2	red cedar	1
Vine					
honeysuckle	r	viburnum	r		
Bush					
honeysuckle	r	rosa multiflora	r		
Smilax	r	unknown	r		
Cherry	r				
8N		8B		8H	
Viburnum	5	bush honeysuckle	5	Black cherry	5
				bush	
Black oak	3	black oak	4	honeysuckle	3
White oak	2	bittersweet	3	viburnum	2
Black cherry	2	solidago	1	Black oak	2
Bush					
honeysuckle	r	viburnum	1	solidago	1
		black cherry	1	Moss	1
		unknown	r		
9N		9B		9H	
Black oak	5	Bittersweet	3	bittersweet	4

Unknown		4	bush honeysuckle	2	bush		
viburnum		3	black oak	2	honeysuckle		3
rosa multiflora	r		viburnum	2	unknown tree		2
vine					Black oak		2
honeysuckle	r		unknown shrub	1	pitch pine		1
solidago	r		unknown tree	1	Black cherry	r	
black cherry	r		wintergreen		unknown	r	
			rosa multiflora	r			
			black cherry	r			

Site	Ocolor	Acolor	Bcolor
1N	10YR, 2/2	10YR, 4/3	10YR, 5/6
1B	10YR, 2/2	10YR, 4/3	10YR, 5/8
2N	2.5Y, 3/3 10YR, 2/2	10YR, 4/6 10YR, 3/1.5	10YR, 3/2 10YR, 3/4*
2B	10YR, 3/3 10YR, 2/2	10YR, 3/3 10YR, 3/2	10YR, 5/8 10YR, 3/4
3N	10YR, 3/3 10YR, 2/2	10YR, 3/3 10YR, 3/2	10YR, 5/8 10YR, 3/4
3B	10YR, 3/3 10YR, 2/1	10YR, 4/4 10YR, 3/2	10YR, 5/8 10YR, 3/4
4N	10YR, 2/2 10YR, 2/2	10YR, 3.5/3 10YR, 3/4	10YR, 4/6 10YR, 4/6
4B	10YR, 2/2 10YR, 2/2	10YR, 3/4 10YR, 3/4	10YR, 5/6 10YR, 5/6
4H	7.5YR, 2/2 10YR, 2/1	10YR, 2/2 10YR, 2/3 10YR, 2/2	10YR, 3/4 10YR, 4/6 10YR, 3/3
5N	10YR, 3.5/2 10YR, 3/1 10YR, 2/2	10YR, 3/3 10YR, 3.5/2 10YR, 3/2	10YR, 3/4 10YR, 3.5/4 10YR, 3/3
5B	10YR, 2/1 10YR, 2/2	10YR, 3/2 10YR, 3/2	10YR, 4/6 10YR, 4/6
5H	10YR, 2/2 10YR, 2/2	10YR, 3/2 10YR, 3/2	10YR, 4/6 10YR, 4/6
6N	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
6B	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
6H	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
7N	10YR, 3.5/2 10YR, 3/1 10YR, 2/2	10YR, 3/3 10YR, 3.5/2 10YR, 3/2	10YR, 3/4 10YR, 3.5/4 10YR, 3/3
7B	10YR, 2/1 10YR, 2/2	10YR, 3/2 10YR, 3/2	10YR, 4/6 10YR, 4/6
7H	10YR, 2/2 10YR, 2/2	10YR, 3/2 10YR, 3/2	10YR, 4/6 10YR, 4/6
8N	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
8B	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
8H	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
9N	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
9B	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4
9H	10YR, 2/1 10YR, 2/1	10YR, 2/2 10YR, 2.5/2 10YR, 4/2	10YR, 3/4 10YR, 4/3 10YR, 3/4

Table 3

Site	Place (V=Vineyard, F=Falmouth)	Treatments (N=Native, B=Bittersweet, H=Honeysuckle)
1	V, Hoft Farm	N,B
2	V, Margery Rogers' Farm, abandoned horse coral	N,B
3	V, Margery Rogers' Farm, forest on edge of property	N,B
4	F, Peterson Farm	N,B
5	F, Crane Wildlife Refuge	N,B,H
6	F, Bourne Farm, rail road tracks	N,B,H
7	F, Bourne Farm, walking trail	N,B,H
8	F, Bike path	N,B,H
9	V, Side of Indian Head road, near Cedar Neck Sanctuary.	N,B,H

Table 1



The Effects of Invasive Species on Soil
Biogeochemistry

~Sarah Hicks

