Impacts of Historical Land Use on Soil Nitrogen Cycles in Falmouth, MA and the Threat of Chronic N Amendment Demonstrated at the Harvard Forest LTER, Petersham, MA

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Abstract: Nitrification is an important aspect of soil nitrogen cycling. Historic agriculture land use and modern atmospheric nitrogen deposition both impact soil nitrogen cycles. To evaluate agricultural land use I compared plowed fields with unplowed forests in Falmouth, MA. To determine the impact of nitrogen deposition I collected soil samples from a mixed hardwood forest plot fertilized with 150 kg N ha^{-1} yr^{-1}, at the Harvard Forest LTER, in Petersham, MA. At each site I measured: pH, C:N ratios, extractable inorganic nitrogen pools, net mineralization and nitrification rates as well as potential nitrification. In addition I evaluated plant species composition and soil profiles at each land use site. Nitrification increased from -0.012 μg N gds^{-1} day^{-1} in forest organic soil to 0.289 μg N gds^{-1} day^{-1} in field surface soil. Also, nitrification increased -0.013 μg N gds^{-1} day^{-1} in control organic soil to 1.04 μg N gds^{-1} day^{-1} in fertilized soils. Both agricultural and fertilized soils had elevated nitrification potential relative to forest and control soils, indicating a shift in the microbial community. These changes in nitrogen cycling have important implications for historical and future transport of nitrogen from terrestrial to aquatic systems.

Key words: *nitrification, agricultural land use, nitrogen deposition, soil nitrogen cycling*

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Introduction:

Farmer and poet Wendell Berry wrote, *"that the leaves are harvested/ when they have rotted into the mold"* (Berry 1984). This is a poetic insight into the importance of decomposition in biogeochemical nutrient cycling. Decomposition is the process by which nutrients are recycled in terrestrial ecosystems (Aber & Melillo 2001 p. 205). Nitrogen is an essential nutrient for biological processes. Mineralization is the conversion nitrogen in decaying organic matter to inorganic forms, such as ammonium (NH_4^+) and nitrate (NO_3^-), which are available for plant uptake (Schlesinger, 1997 p. 195).

When NH_4^+ is present in excess of plant and microbial demand, nitrification becomes and important process in soil nitrogen cycling. ammonia-oxidizing bacteria (AOB) use the conversion of NH_4^+ to NO_3^- to generate energy (Kowalchuk & Stephen, 2001). Recent evidence indicates that ammonia-oxidizing archaea belonging to the phylum Crenarchaeota may be an even more significant contributor to nitrification than AOB (Leininger et al. 2004). Nitrification decreases soil pH and mobilizes nitrogen; the leaching of NO_3^- contributes to degradation of downstream water quality. Nitrogen loading to estuaries is of particular concern because of widespread eutrophication (Vitousek et al 1997). Rates of mineralization and nitrification are influenced by soil pH, C:N ratio, quality of decomposing organic material, and availability of NH_4^+. Ecological disturbances have also been shown to have substantial impacts on these processes (Goodale & Aber 2001).

European settlement transformed the ecological landscape of North America. In the North East the clearing of forested land for agricultural use was a large part of this transformation. It has been estimated that as much of 50% of the land area in Massachusetts was cleared at one point for agricultural use (Hall et al. 2002). During the past 200 years agriculture has declined steadily and most of the landscape is now forested. Despite its decline the disturbance of agricultural use has been shown to have lasting impacts on plant species composition, soil structure and soil nitrogen cycling processes (Bellemare et al, 2002). A better understanding of these impacts could change our understanding of ecological landscape during the early years of European settlement.

In recent years atmospheric nitrogen deposition has raised the threat of nitrogen saturation in the North East. Humans have dramatically altered the global nitrogen cycling largely through the production of fertilizer and combustion of fossil fuels (Vitousek et al. 1997; Galloway 1997**)**. These factors have contributed to deposition of atmospheric nitrogen on the order of 12 kg ha^{-1} yr^{-1} in the Cape Cod region (Bowen & Valiela 2001). Forest ecosystems can absorb atmospheric inputs to a certain extent before they reach nitrogen saturation and soil nitrogen cycles are fundamentally altered (Aber et al 1989). Nitrogen deposition is a continuing threat that we face today.

Despite fundamental differences in their driving factors the impacts of land use change and chronic nitrogen deposition both have important implications for soil nitrogen cycling in the North East. I focused my research of land use in the vicinity of Falmouth, MA. To explore the threat of I sample soils from Chronic Nitrogen Amendment Plot in the Harvard Forest LTER, Petersham, MA. In this paper I will explore how 1) historic agricultural land use impacts plant species composition, basic soil attributes and nitrogen cycling particularly nitrification; 2) how chronic nitrogen addition impacts soil nitrogen cycling particularly nitrification. In order to better understand these impacts I have compared plant species composition, soil bulk density, moisture, pH, C:N ratio as well as mineralization, nitrification and potential nitrification rates.

Methods

Site selection: Historical agriculture land use has heavily impacted much of Cape Cod. I compared historically plowed fields and unplowed woodlands at Coonamessett Reservation (CR), Francis Crane Wildlife Management Area (FCWMA), and Peterson Farm (PF). These three sites are located in the vicinity of Falmouth, MA. By comparing fields and woodlands at each site I was able to reduce the potential that variability between treatments could be caused by substantial differences in site geography. Coonnamessett Reservation is a town owned conservation area located off route 151, part of the land is a historically plowed field. FCWMA is a large area managed for hunting also located off route 151. FCWMA includes fields, which have been historically plowed, and more recently cleared to create game bird habitat. Peterson Farm was established in 1679, a small part remains as open sheep pasture today; adjacent unplowed areas are dominated by forest cover. I used the presence or absence of a clear Ap horizon to verify if a particular area had been plowed (Fig 1).

The Chronic N Amendment Site was established in 1988 at the Harvard Forest LTER. The goal of the experiment was to examine the long term impacts of nitrogen fertilization. I collected samples from the hardwood forest control and high nitrogen addition plots. The high nitrogen site was sprayed with 113 kg N ha $^{-1}$ yr $^{-1}$ during the first year and has been 150 kg N ha $^{-1}$ yr $^{-1}$ for the past 16 years (Aber et al 1993).

Soil Sample Collection: I used a stainless steel soil corer with a 5 cm diameter to collect 15 cm deep soil samples at five intervals along an 80 meter transect representative of each field and woodland location. At each interval I collected two 10 x 10 cm organic layer samples. In the absence of an organic layer I collected 10 x 10 cm samples of the top two cm of soil. At each forest and woodland location I dug a 40 cm deep soil pit to characterize soil horizons and collect two fixed volume bulk density cores of mineral soil at 10, 20 and 30 cm depths. I collected one soil core and one organic layer sample from 5 subplots of the control and fertilized plots at Harvard Forest.

All organic and mineral soils were separated in the field and kept on ice, or refrigerated, until processing. I homogenized samples, removing rocks, and roots during preparation for all analysis except bulk density measurements.

Plant Species Cover Estimate and Soil Profile: I only conducted these measurements at land use sites. At each 20-meter interval I estimated plant species cover within a 2 x 2 meter quadrate. I assigned a cover value ranging from: 0-10, 11-30, 31-60, 61-90, 91-100% to each plant species. For comparison I used the median percent cover for each class. To get an idea of the under ground soil structure I characterized soil horizons, measuring their depth and assigning a color based on the Munsell Soil Color Chart.

pH, C:N molar ratio, Soil Moisture, Bulk Density:

I combined 10 g fresh mineral soil or 5 g fresh organic soil with 50 ml DI water and measured pH with a Fischer Science Accumet pH meter. To measure C:N ratios I combined equal weights of soil from field and woodland samples to create a well mixed composite sample. I prepared these composites, as well as three organic and three mineral samples from the Harvard Forest control and fertilized plots, for CHN analysis. I used an Elmer Perkins CHN analyzer to measure the percent Carbon, percent Nitrogen (results not presented) and the C:N molar ratio of each sample. To determine soil moisture content I measured the wet weight and oven dry weight of organic layer samples and bulk density cores. I determined bulk density by measuring the dry weight of samples with a known volume.

Inorganic Nitrogen Pools, and Nitrogen Cycling:

To get an initial value of extractable inorganic nitrogen I combined 15 g wet soil with 50 ml 1M KCl and shook for one hour. I allowed samples to settle and gravity filtered each through a pre-rinsed Whatman Q6 filter. I froze filtered extract until analyzing for NO_3 and NH_4. To get a final reading I incubated 50 grams of homogenized soils at 28 ºC for three weeks. I kept incubated samples in closed containers to minimize water loss. Following the incubation period I extracted another 15 grams of soil following the method described above. I analyzed the filtered extract for NO_3 following method for the Lachat Flow Injection Analyzer adapted from (Ward et al 1967). I measured NH_4 using phenol-hypochlorite method modified from Strickland and Parson (1969). I combined 3 ml sample with 0.12 ml of Phenol solution, 0.12 ml sodium-nitroprusside solution, and 0.3 ml of oxidizing solution and read absorbance at 640 nm on a a Shimadzu 1601 spectrophotometer. I used the difference between initial and final concentrations of NH_4 and NO_3 to calculate net mineralization and nitrification rates.

I measured potential nitrification by adapting a method provided by Christopher Neill (1994) based originally on (Belser and Mays 1980). I combined the equivalent of 15 grams dry weight with 100 ml of working phosphate buffer (K_2HPO_4, KH_2PO_4) and 0.2 ml of ammonium sulfate solution. I shook these samples for 24 hours. At 4 and 12 hour intervals I used a syringe to remove 10 ml of sample and gravity filtered the solution through pre rinsed Whatman Q6 filters. After 24 hours I transferred 45 ml of each sample into 50ml centrifuge tubes and centrifuged them for 3 minutes. I allowed the centrifuged samples settle in a refrigerator for one hour before gravity filtering the supernatant. I analyzed each sample for NO_3^- using the Lachat Flow Injection Analyzer method mentioned above.

Statistical Analysis:

I used a student t-test to determine if there were statistical differences between treatments. I conducted student t-tests using SAS software to determine the P value of each variable. I accepted all differences with a P value less than 0.05 as significant. Due to small sample size and the variability of soils I found a number of strong trends that didn't prove to be statistically significant yet I interpreted most as ecologically important. Additionally sampling is needed to further demonstrate these trends.

Results

Land Use:

Species composition: I found substantial differences between field and forest plant cover. Graminoide species including *Carex pensylvanica*, *Andropogon scoparius*, and a number of unidentified grass species accounted for 63% of total field cover. While forbs such as *Solidago canadensis,* and *Trifolium repens* accounted for 30% (fig 2**).** In contrast 89% of the forest under story cover was shrubs such as *Gaylussacia baccata, Vaccinium sp* and *Kalmia latifolia* (fig 3**).** The percentage of exotic plant species cover decreased from 44% of field cover to zero percent of forest cover **(**Table 1**)**. I found 41 different plant species in the fields and only 12 different species in the forest (Table 2**).**

Soil profile: Soil profiles of field sites revealed the absence of an organic layer, a persistent grey Ap horizon to an average depth of 30 cm, and a yellowish C horizon below that. The average forest soil profile had a 6 cm thick dark organic horizon, a thin dark A horizon, a thin grey E horizon, a 13 cm thick reddish B horizon, on top of similar yellowish C horizon **(**Fig 1**)**.

pH, C:N, Soil Moisture and Bulk density: I found a significant difference in pH between field and forest soils. Field surface soils had an average pH of 5.93; field mineral soil had a pH of 5.69. Forest organic and mineral soils were both significantly more**.** I measured a pH of 4.04 in the forest organic layer, and pH of 4.57 in forest mineral layer (Table 3).

Field surface soils had an average C:N ratio of 19.32; the mineral soil C:N ratio was 17.54. Both the forest organic layer C:N ratio of 33.43 and the mineral soil C:N of 30.25 were significantly higher than field soil values. I measured significantly lower gravimetric soil moisture in the field surface layer 0.49 g H_20 gds^{-1}, when compared to 1.68 g H_2O gds^{-1} in the forest organic horizon.

Mineral soil moisture content varied from 0.21 g H_20 gds^{-1} in field soils to 0.17 g H_20 gds^{-1} in forest soils. The bulk density of field surface soils was 0.83 g cm^{-3}. The forest organic layer was only 0.20 g cm^{-3}. There was no substantial difference between the bulk densities of field and forest mineral soils.

Inorganic Nitrogen Pools, and Nitrogen Cycling: Pools of extractable inorganic nitrogen revealed no significant differences. In the mineral soil I found 2.32 μg N-NH_4 gds^{-1}, only slightly higher than forest soil levels of 1.21 μg N NH_4 gds^{-1} (fig 4). I found a similar trend in levels of extractable NO_3^-. Surface soil levels ranged from 0.51 μg N-NO_3 gds^{-1} in the field to 0.69 μg N- NO_3 gds^{-1} in the forest. I measured 0.27 μg N- NO_3 gds^{-1} in field mineral soil and 0.12 μg N- NO_3 gds^{-1} forest mineral soil.

After a three-week laboratory incubation period I found obvious differences in the total amount of inorganic nitrogen mineralized by soil microbes. I measured a low mineralization rate of 0.29 μg N gds^{-1} day^{-1} in field surface soils compared to a significantly higher rate of 4.09 μg N gds^{-1} day^{-1} in forest surface soils (fig 5**).** Mineralization in field mineral soils was also low, around 0.39 μg N gds^{-1} day^{-1} and higher in forest soils, around 1.25 μg N gds^{-1} day^{-1}.

Nitrification rates varied considerably, so I found no significant differences, yet my results revealed clear trends in both organic and mineral soils. Nitrification in field surface soils proceeded at a rate of 0.29 μg N-NO_3 gds^{-1} day^{-1}, while NO_3^- was actually immobilized in forest organic soils, resulting in a slightly negative rate (fig 6**)**. Similarly field mineral soil produced 0.30 μg $N\text{-}NO_3$ gds^{-1} day^{-1} while there was zero nitrification in forest mineral soil.l

Potential nitrification rates revealed a similar trend. Even though there was a large degree of variability between individual samples, field surface soil had a rate of 0.23 μg $N\text{-}NO_3$ $gds^{=1}$ hr^{-1} in field surface soils, much higher than the forest organic soil rate of 0.062 μg $N\text{-}NO_3$ $gds^{=1}$ hr^{-1}(fig 7).

Nitrogen Saturation:

*pH, C:N ratio***:** The control organic soil had a pH of 4.10, significantly higher than fertilized organic soil, which had a pH of 3.74 (Table 4**)**. I also measured a significantly higher pH in the control mineral soil relative to the fertilized mineral soil. My measurement revealed no differences in the C:N ratios of either organic or mineral soils.

Inorganic Nitrogen Pools, and Nitrogen Cycling: Fertilization caused substantial changes in pools of inorganic nitrogen, no significant difference in mineralization rates, increased nitrification rates and potential nitrification rates. I measured higher pools NH_4^+ in both organic and mineral fertilized soils (fig 8**)**. NO_3^- was also higher in fertilized soils, I measured a significant increase from 0.602 μg $N\text{-}NO_3$ gds^{-1} to 7.29 μg $N\text{-}NO_3$ gds^{-1} in the organic layer and a change from 0.102 μg $N\text{-}NO_3$ gds^{-1} to 3.273 μg $N\text{-}NO_3$ gds^{-1} in the mineral layer**.**

Mineralization rates remained fairly constant in both organic and mineral soils, ranging from 3.543 μg N $gds^{=1}$ day^{-1} in the control to 4.21 μg N $gds^{=1}$ day^{-1} in the fertilized organic soil. Rates in mineral soils ranged from 0.708 μg N $gds^{=1}$ day^{-1} to 0.883 μg N $gds^{=1}$ day^{-1} (fig 9**).**

Nitrification rates increased in the fertilized plot. I measured slight immobilization of NO_3^- in the control organic layer and 1.04 μg $N\text{-}NO_3$ gds^{-1} day^{-1} in the fertilized organic layer. Nitrification in the mineral soil increased significantly from 0.126 μg $N\text{-}NO_3$ gds^{-1} day^{-1} in the control to 0.518 μg $N\text{-}NO_3$ gds^{-1} day^{-1} in the fertilized plot (fig 10). Potential nitrification rates in the organic layer also increased with fertilization ranging from 0.15 μg $N\text{-}NO_3$ gds^{-1} hr^{-1} in the control to 0.80 μg $N\text{-}NO_3$ gds^{-1} hr^{-1} in the fertilized plot (fig 11**).**

Discussion

As others have shown results reveal that historic agricultural land use has persistent impacts on plant species composition, soil horizons, basic soil attributes and key nitrogen cycling processes (Compton & Boone 2000; Goodale & Aber 2001)

Species composition: Clearing land for agriculture has obvious impacts on plant species composition. Historically land was cleared of native trees and shrubs and planted with crops or pasture grasses. Agricultural activities are also result in the introduction of exotic weeds such as *Galium sp.* or deliberate introduction pasture grasses such as *Dactylis glomerata*. Given time abandoned fields typically become dominated by forest species (Compton & Boone 2000). The persistence of graminoides at these sites indicates that there has been relatively recent mowing or grazing in order to keep the land clear. Changes in soil nutrient cycles caused by land use history are also believed to have an impact on plant species (Motzkin et al 2002**)**. The introduction of plant species associated with agriculture is an important element of global change (Vitousek et al 1997).

Soil Profile: The dramatic changes in above ground vegetation are matched by disruption of soil horizons caused by plowing. Plowing results in a deep homogenized Ap horizon. Fields typically have low inputs of relatively rapidly decomposed organic matter resulting in the absence of an O horizon in field soils. In contrast forest soil profiles reveal horizons formed over very long time periods. The thick forest O horizon is the result of large inputs of recalcitrant organic matter (Aber & Melillo 2001 p. 19). The A horizon is formed by the development of humic materials. The E horizon is formed by the leaching of iron and aluminum oxides we reprecipitate, causing the reddish color of the B horizon. The relative consistency of C horizon color across all sites indicates that all of the soils have developed from similar parent material. The presence of an Ap horizon is a useful tool for the identification of historically plowed sites (Motzkin et al 2002).

Basic soil attributes: Plowing and agricultural activity also change the basic attributes of soils by raising pH, decreasing C:N ratio and altering the soil moisture content and bulk density of the surface soil. pH is naturally balanced by biological activity and the weathering of underlying mineral soil (Aber & Melillo 2001 p. 16). Historically farmers increased pH by applying lime to their fields (Neill unpublished). As the forest O horizon develops it becomes separated from the mineral soil, so the effects of biological activity are no longer buffered by weathering of mineral material resulting in very acidic forest soils.

The C:N ratio of soils is partially determined by the type and quality of litter inputs (Aber & Melillo 2001). Field soil litter is dominated leafy material from graminoides and forbs which typically have low C:N ratio's. In contrast forest litter has a higher C:N ratio and includes woody material with a high lignin content. Lignin is structurally complex and resistant to decomposition. As a result forest soils remain high in carbon content. As mentioned above the input of this organic material results in the formation of a thick O horizon. C:N ratio of soils can also be lowered by former agricultural activity such as adding manure (Compton & Boone 2000).

Differences between field and forest soil moisture and bulk density can be attributed to the presence of this O horizon. Field surface soil is structurally very similar to mineral soil resulting in a much higher bulk density and lower capacity for retaining moisture. The formation of an O horizon results in a great deal of open pore space, which absorbs moisture and reduces density.

Soil Nitrogen Cycling: Factors such as pH, C:N ratios, soil moisture and available pools of inorganic nitrogen are important in regulating mineralization and nitrification (Schlesinger p. 197). Extractable pools of NH_4^+ and NO_3^- represent available nitrogen in soils (Aber & Melillo 2001 p. 169). However, these pools are highly dependent on the rate at which nitrogen become available through decomposition, as well as the influence of plant uptake and microbial activity. Concentrations of limiting nutrients such as nitrogen are generally very low in soils.

Mineralization occurs when the carbon quality of decaying organic matter limits microbial growth (Aber & Melillo 2001 p. 231). High rates of mineralization are generally associated with low C:N ratios, because more nitrogen is available relative to carbon. However, I found mineralization to be highest in the forest organic layer with an average C:N ratio of 33.4. This high rate of mineralization may be related to a decrease in labile carbon in recently deposited litter. Quality of carbon has been shown to play an important role in mineralization rates (Magill & Aber 2000). Additionally mineralization of nitrogen is believed to begin when lignin begins to be decomposed (Aber & Melillo 2001 p. 231). Bohlen et al. (2001) found seasonal variation in mineralization rates. The high rates of mineralization I found in forest soils may be the result of seasonal variation in organic material inputs.

I found the highest rates of nitrification in agricultural soils which have a high pH and low C:N ratio. A regression analysis of these variables indicates that there is a positive linear relationship between soil pH and nitrification (R^2= 0.936) and a negative linear relationship between C:N ratio and nitrification (R^2= 0.978) (fig 12**)**. In contrast the lack of nitrification in forest soils may be related to low pH, inhibitory compounds produced by plants, or low populations of nitrifying microorganisms (Vitousek et al. 1982). I found no relationship between NH_4^+ pools and nitrification rates. In a survey of forest soils Compton and Boone (2000) found that only formerly cultivated sites had measurable rates of nitrification. This is consistent with my findings that agricultural land use increases rates of nitrification.

Potential nitrification rates were also higher in agricultural soils. This experiment measures nitrate production under ideal conditions for nitrification. High potential nitrification rates in agricultural soils indicated that there was a large, active population of ammonia oxidizing microorganisms. Studies using molecular techniques have shown larger populations of ammonia oxidizing bacteria in fertilized soils. (Okano et al. 2004**).** Further understanding of the factors influencing populations of nitrifying organisms is essential to determine their importance in increased soil nitrification potential.

Agricultural land use alters vegetation patterns, eliminates soil horizons, and changes soil attributes such as pH and C:N ratio which are important in regulating soil nitrogen cycles. Agricultural soils exhibit higher rates of nitrification and higher potential nitrification than forest soils. These differences have important implications for our understanding of historical nitrogen cycling in New England, as well as for our modern understanding of how different terrestrial ecosystems retain nitrogen. High rates of nitrification could potentially contribute more inorganic nitrogen to aquatic systems adding to issues of eutrophication.

Nitrogen Saturation:

Chronic nitrogen is clearly a threat to the function of soil nitrogen cycles. Measurements from fertilized plots in Harvard Forest revealed evidence of nitrogen saturation. Decreased pH in the fertilized soil is evidence of increased soil acidity caused by nitrification (Aber et al 1989**).** Fertilization also increased inorganic nitrogen pools. High concentrations of NH_4^+ and NO_3^- in fertilized plots indicate that fertilizer is being applied in excess of plant demand. Consistently elevated levels of NH_4^+ are one of the primary factors contributing to nitrification (Aber & Melillo 2001 p. 257).

High rates of nitrification in fertilized soils indicate that heavy loads of nitrogen deposition can dramatically alter nitrogen cycling in forest soils, despite limiting factors of pH and C:N ratio. These observations indicate that the impacts of chronic nitrogen are on going. Earlier measurements of this plot also revealed increased nitrification (Magill et al 2004). High potential nitrification indicates that a community of nitrifying organisms has become established.

These results reveal the considerable threat of chronic nitrogen deposition. Revealing what can happen when nitrogen loading causes forest systems to become saturated.. With these extreme changes in mind we must continue to evaluate the ability of different ecosystems to retain nitrogen and mitigate the transport of NO_3^- to aquatic systems. systems. These changes may be combined with shifts in microbial populations.

Implications of Land Use Change and Chronic N amendment:

The disturbances of agricultural land use and nitrogen deposition both have the capacity to dramatically alter soil nitrogen cycling. Historically high levels of nitrification in agricultural soils could have changed nutrient fluxes across the North East. Continual atmospheric nitrogen deposition could have a similar impact on future nitrogen cycling across the region. Increased nitrification may be related to long-term shifts in soil attributes and microbial communities. It is clear that this changes have important implications for the transport of nitrogen to aquatic systems and the long term response of terrestrial ecosystems to wide spread disturbance.

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Figure 1: Peterson Farm field and woods soil profiles measured to a depth of 40 cm. A) Field soil, notice the thick Ap layer and the absence of an organic horizon. B) Forest soil demonstrates O, A, E, B and C horizons.

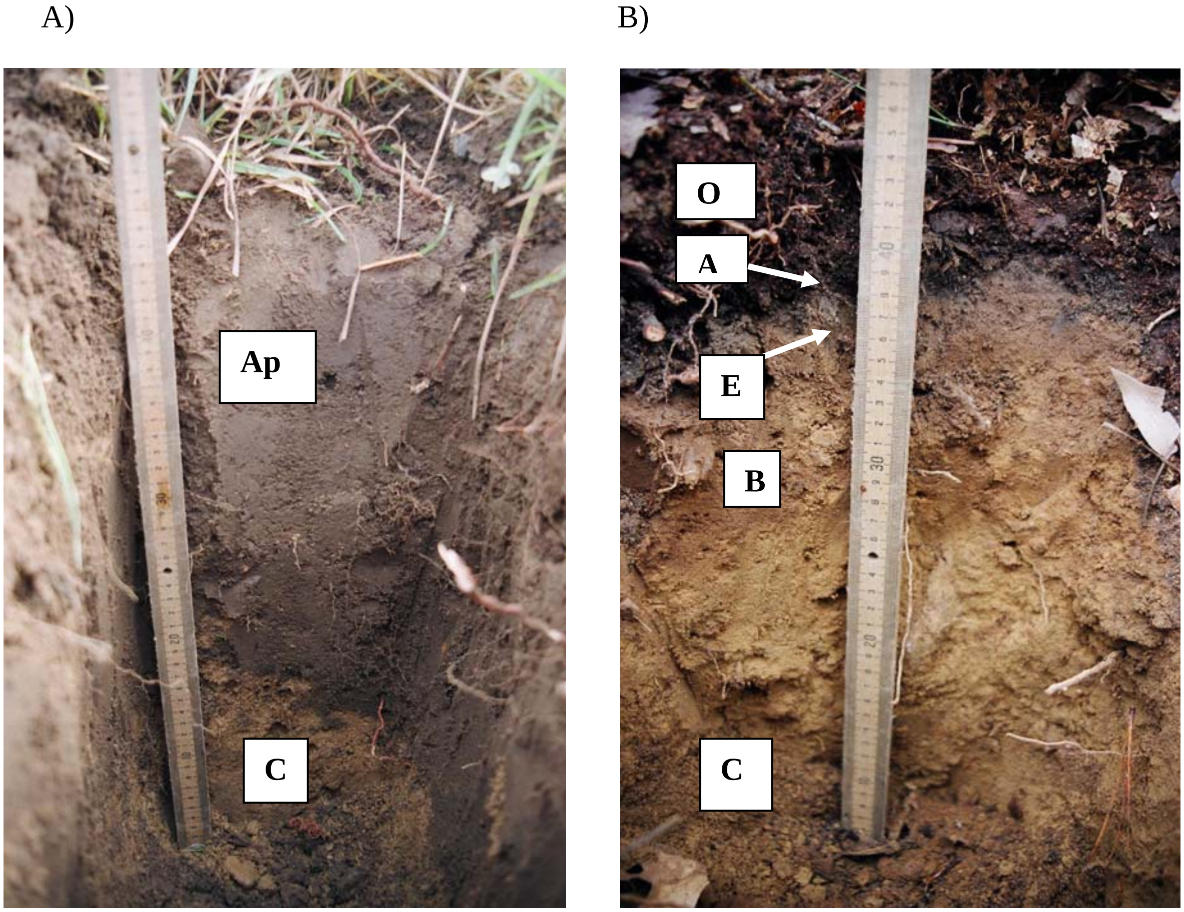


Figure 2: Field cover, percent of by group.

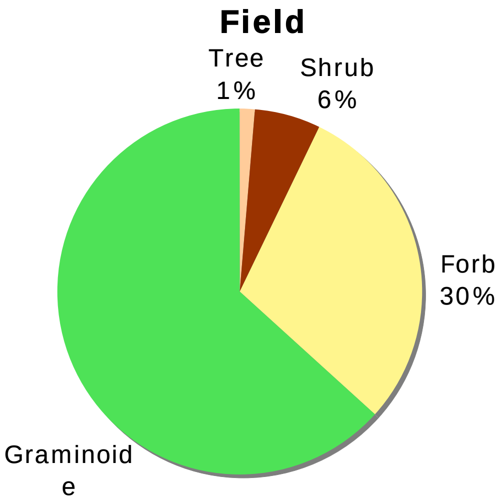


Figure 3: Forest under-story cover by group, data provided by Cora Johnston.

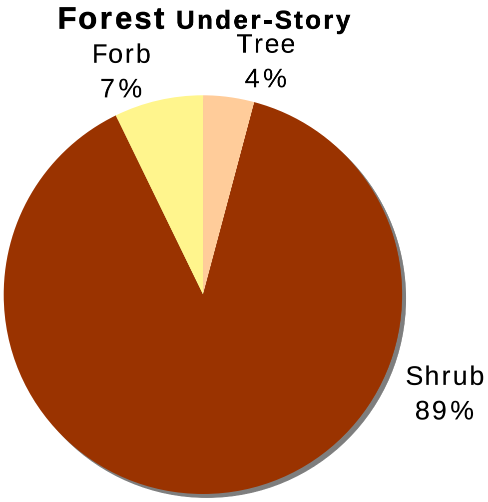


Table 1:

% total cover	Native Cover	Introduced Cover
Field	56.4%	43.6%
Woods	100%	0%

Table 2: Land use species list.

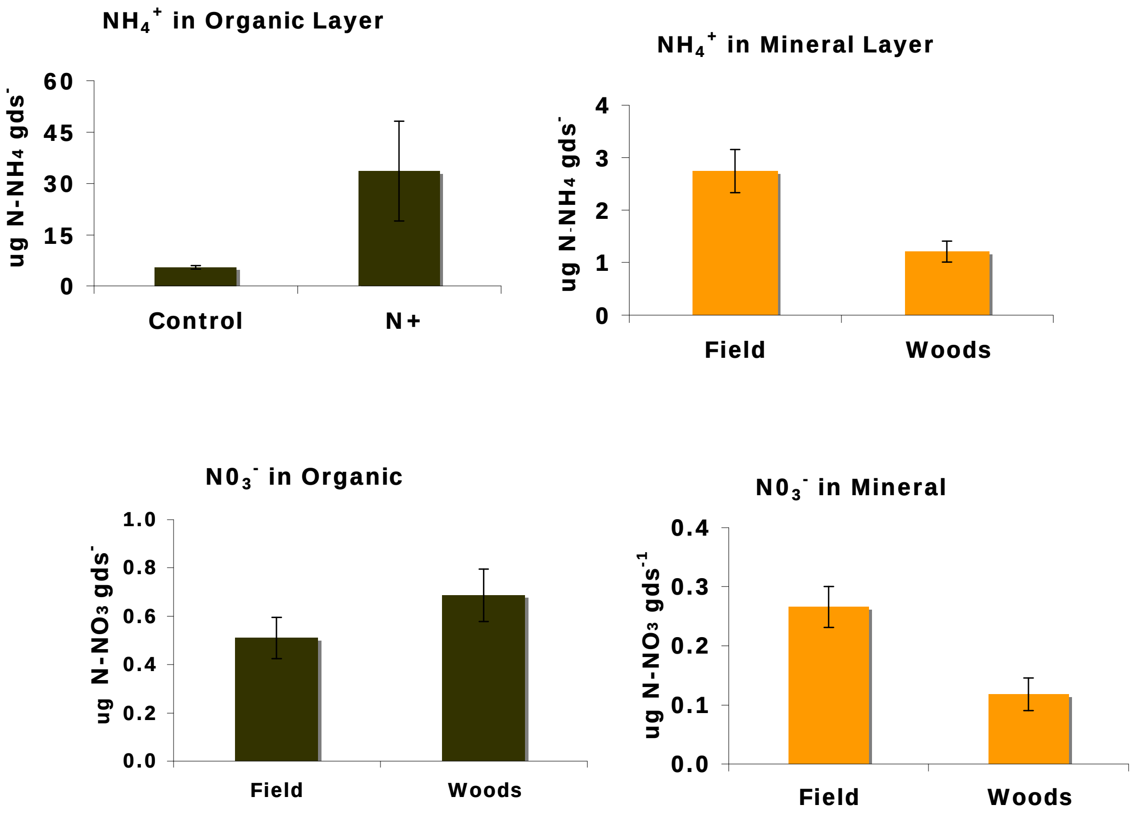
Treatment	**Common Name**	***Scientific Name***	**Group (Tree or Shrub, Forb, Graminoide)**	**Origin (Native or Introduced)**	**Average Median Cover**	**Frequency**
Field	Common Yarrow	*Achillea millefolium*	Forb	Native	3.5	2
Field	Bent Grass	*Agrostis sp.*	Graminoide	Native	3.4	1
Field	Little Bluestem	*Andropogon scoparius*	Graminoide	Native	16.3	1
Field	Aster	*Aster spp.*	Forb		1.3	2
Field	Pennsylvania Sedge	*Carex pensylvanica*	Graminoide	Native	18.6	2
Field	Chicory	*Cichorium intybus*	Forb	Introduced	1.4	1
Field	Orchard Grass	*Dactylis glomerata*	Graminoide	Introduced	14.5	1
Field	Queen Anne's lace	*Daucus carota*	Forb	Introduced	0.3	1
Field	Autumn Olive	*Elaeagnus umbellata*	Shrub	Introduced	5.7	2
Field	Wild Strawberry	*Fragaria virginiana*	Forb	Native	1.7	2
Field	Bedstraw	*Galium sp.*	Forb	Introduced	0.3	1
Field	Geranium	*Geranium sp.*	Forb	Native	0.3	1
Field	Velvet Grass	*Holcus lanatus*	Graminoide	Introduced	16.0	3
Field	Path rush	*Juncus tenuis*	Graminoide	Native	0.7	2
Field	Yellow Toadflax	*Linaria vulgaris*	Forb	Introduced	1.0	1
Field	Honey Suckle	*Lonicera Morrowii*	Shrub	Introduced	1.3	1
Field	Pitch Pine	*Pinus rigida*	Tree	Native	0.3	2
Field	Buckhorn plantain	*Plantago lanceolata*	Forb	Introduced	1.0	1
Field	Oldfield cinquefoil	*Potentilla sp*	Forb	Introduced	1.0	3
Field	Bracken Fern	*Pteridium aquilinum*	Forb	Native	3.1	2
Field	Black Oak	*Quercus velutina*	Tree	Native	1.7	2
Field	Multiflora Rose	*Rosa multiflora*	Shrub	Introduced	2.1	2
Field	Dew Berry	*Rubus sp.*	Forb	Native	3.5	2
Field	Black-eyed Susan	*Rudbeckia hirta*	Forb	Native	0.3	1
Field	Red Sorrel	*Rumex acetosella*	Forb	Introduced	0.7	1
Field	Goldenrod	*Solidago canadensis*	Forb	Native	16.3	2
Field	Dandelion	*Taraxacum officinale*	Forb	Introduced	3.1	2
Field	White Clover	*Trifolium repens*	Forb	Introduced	4.7	2
Field	Vetch	*Vicia sp.*	Forb	Introduced	0.7	1
Field	Unknown shrub (CR)		Shrub		0.3	1
Field	Unknown Grass 6 (PF)		Graminoide		0.3	1
Field	Unknown Forb 1(CR)		Forb		0.3	1
Field	Unknown Forb 3 (PF)		Forb		0.3	1
Field	Unknown Forb 2 (PF)		Forb		0.7	1
Field	Unknown Shrub 2 (FCWMA)		Forb		1.4	2
Field	Unknown Grass 5 (PF)		Graminoide		3.1	1
Field	Unknown Grass 1 (CR)		Graminoide		4.1	1
Field	Unknown Grass 2 (CR)		Graminoide		5.1	1
Field	Unknown Grass 4 (PF)		Graminoide		5.1	1
Field	Unknown Grass 3 (FCWMA)		Graminoide		12.9	2
Woods	Wintergreen	*Gaultheria procumbens*	Shrub	Native	19.6	2
Woods	Huckleberry	*Gaylussacia baccata*	Shrub	Native	62.0	3
Woods	Sheep Laurel	*Kalmia latifolia*	Shrub	Native	20.7	2
Woods	Maleberry	*Lyonia ligustrina*	Shrub	Native	1.4	1
Woods	Pitch Pine	*Pinus rigida*	Tree	Native	1.4	1
Woods	Bracken Fern	*Pteridium aquilinum*	Forb	Native	12.7	2
Woods	Black Oak	*Quercus velutina*	Tree	Native	6.1	1
Woods	Dewberry	*Rubus sp.*	Forb	Native	0.3	1
Woods	Catbriar	*Smilax rotundifolia*	Shrub	Native	16.6	1
Woods	higher blueberry	*Vaccinium sp.*	Shrub	Native	38.1	3
Woods	Arrow wood	*Viburnum dentatum*	Shrub	Native	0.3	1
Woods	Viburnum rotundifolia	*Viburnum rotundifolia*	Shrub	Native	1.4	1

Table 3: Land use soil characteristics, values annotated with different letters have a P value <0.05

Organic Layer	**Field**	**Woods**
pH	5.93^{a}	4.04^{b}
Soil Moisture (g H_2O gds^{-1})	0.49^{a}	1.68^{b}
Bulk Density (g cm^{-3})	0.83^{a}	0.20^{b}
C:N Molar Ratio	19.32^{a}	33.43^{b}

Mineral Layer	**Field**	**Woods**
pH	5.69^{a}	4.57^{b}
Soil Moisture (g H_2O gds^{-1})	0.21	.17
Bulk Density (g cm^{-3})	1.14	1.10
C:N Molar Ratio	17.54^{a}	30.25^{a}

Figure 4: Land use pools of inorganic nitrogen



NH_4^+ in Organic Layer

NH_4^+ in Mineral Layer

$N0_3^-$ in Organic

$N0_3^-$ in Mineral

Figure 5: Land use mineralization rates measured over a three week laboratory incubation period.

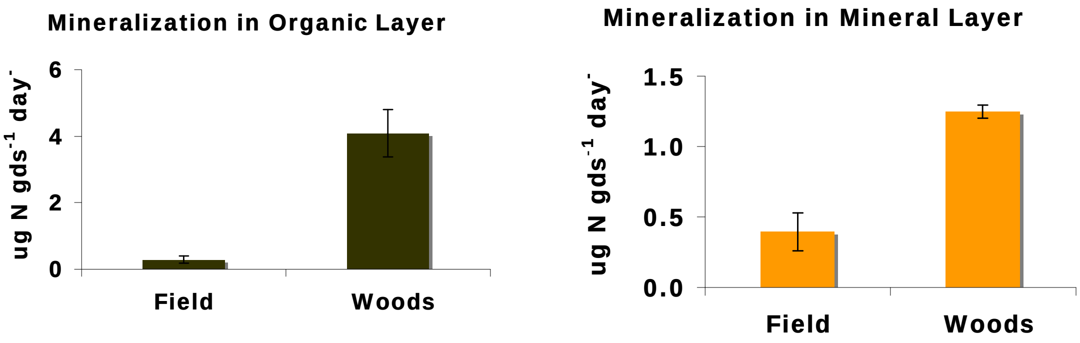


Figure 6: Land use nitrification measured over a three-week laboratory incubation period

Figure 7: Land use potential nitrification

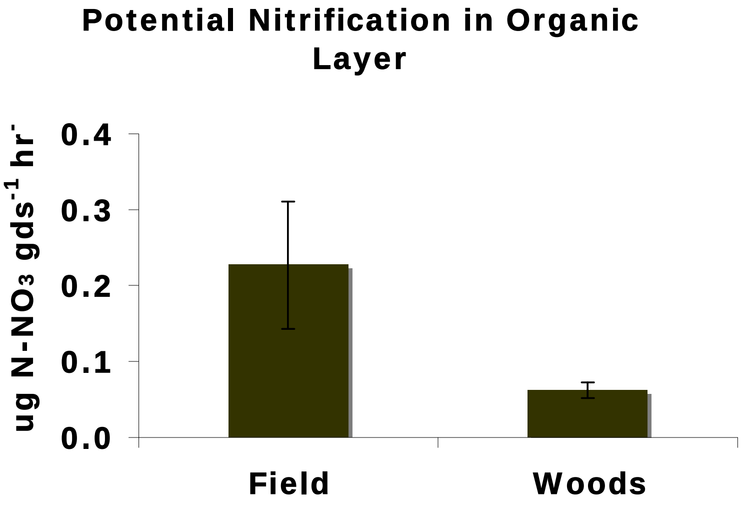


Table 4: Nitrogen saturation soil attributes, values annotated with different letters have a P value <0.05

Organic Layer	Control	N+
pH	4.10^{a}	3.74^{b}
C:N Molar Ratio	29.4^{a}	29.7^{a}

Mineral Layer	Control	N+
pH	4.36^{a}	4.06^{b}
C:N Molar Ratio	24.4^{a}	25.9^{a}

Figure 8: Nitrogen saturation pools of inorganic nitrogen.

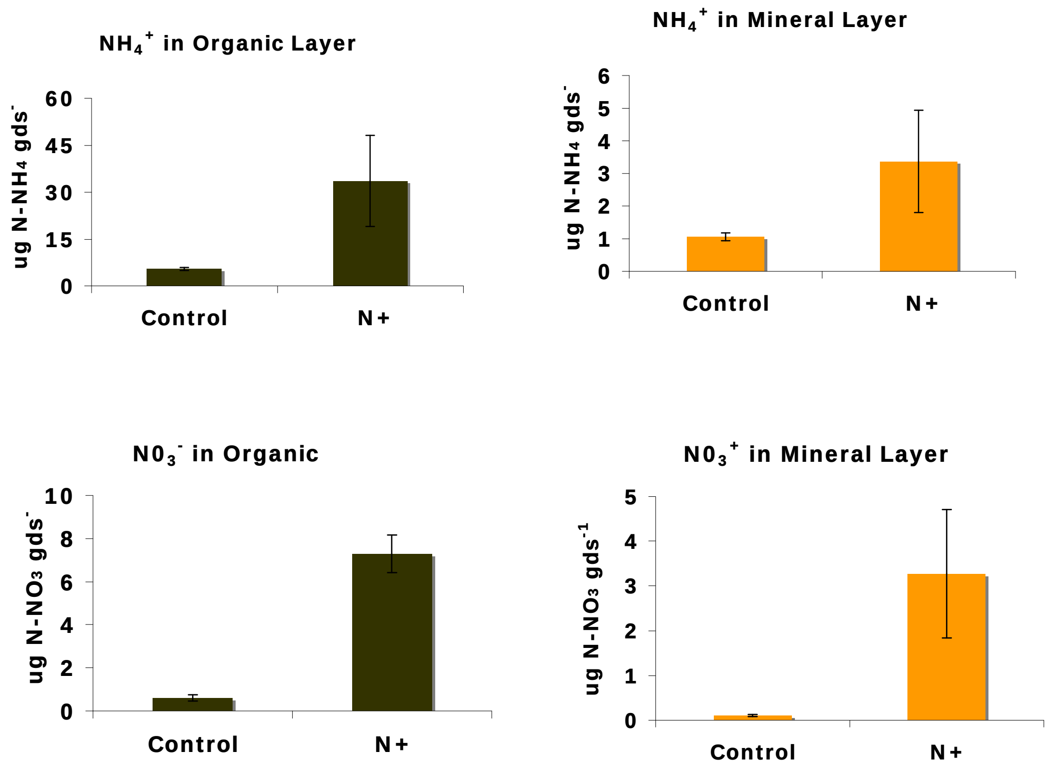


Figure 9: Land use mineralization rates.

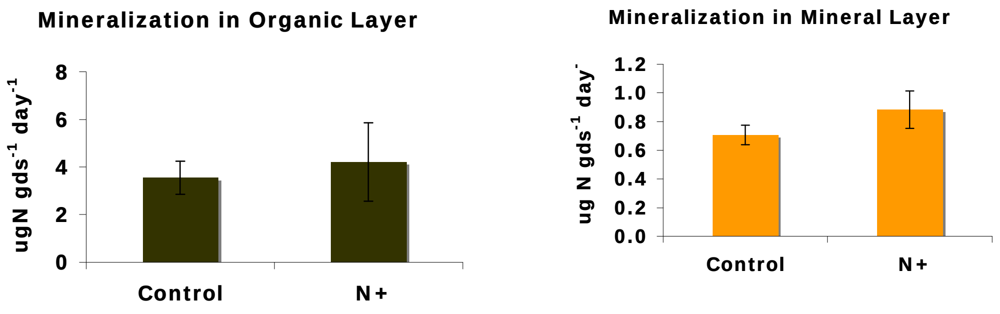


Figure 10: Land use nitrification rates:

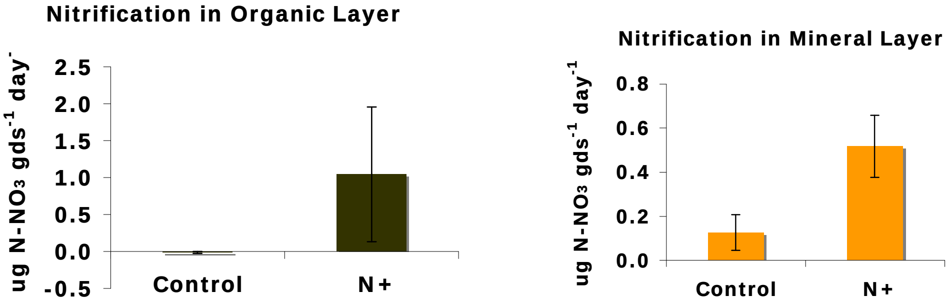


Figure 11: Nitrogen saturation potential nitrification

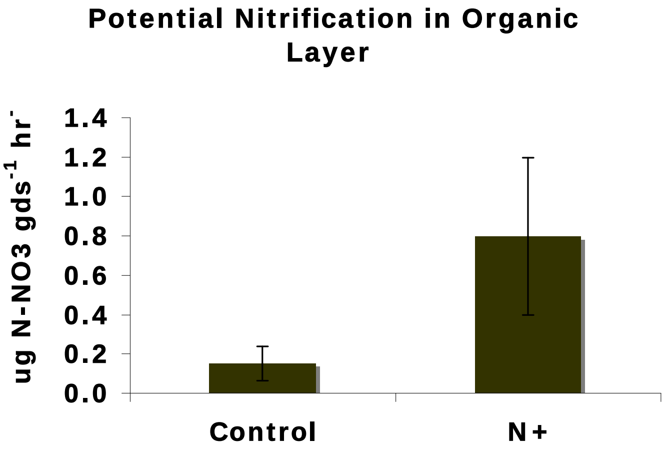


Figure 12: Regression analysis of pH and C:N vs. nitrification rates.