

EFFECTS OF LAND-USE HISTORY ON SOIL QUALITY: IMPLICATIONS FOR SANDPLAIN GRASSLAND RESTORATION

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*Katherine Kleese
Department of Biology, Grinnell College, Grinnell, IA*

*Collaborator: Claire Treat
Department of Earth Science, Mount Holyoke College, South Hadley, MA*

*Advisor: Chris Neill,
The Ecosystems Center, Woods Hole Marine Biological Lab, Woods Hole, MA*

Abstract

Coastal sandplain grasslands contain many rare species not found in other habitats. Despite their recognized importance, there are very few sandplain grasslands remaining, and consequently many restoration efforts are focused on creating and maintaining these unique ecosystems. However, many of these restorations are started on land with soils altered from recent agricultural use. To evaluate the possible effects of restoring on these sites and the possible advantages of using other types of land, we surveyed a suite of soil characteristics at 29 forest and grassland sites on Martha's Vineyard with different land-use histories. We found that native sandplain grasslands had physical characteristics and N dynamics similar to plowed grasslands, and had base cation concentrations, pHs and microbial activity similar to all other land types.

Keywords and phrases: sandplain grassland, grassland restoration, land-use history, soil characteristics, soil quality

Introduction

Sandplain grasslands are important contributors to biodiversity because they support a wide variety of species and are habitats for many rare species not found in other ecosystems (Motzkin and Foster 2002). These globally endangered ecosystems sustain the highest concentration of rare species in the Northeast and are therefore a high priority for conservation and restoration (Dunwiddie 1998). Despite the recognized importance of these ecosystems, their abundance is rapidly declining in the US (Motzkin and Foster 2002). Some of the decline is because of urbanization or occupation of these habitats by invasive species, however much is due to succession to wooded habitats (Motzkin and Foster 2002).

Many grassland restoration efforts begin on formerly plowed agricultural fields, however plowing and the addition of lime and fertilizer can drastically change soil dynamics and composition of the soil. Instead of the nutrient poor, acidic soils characteristic of native grasslands, agriculture leaves soils nutrient rich and buffered (Tiffany 1997). These enriched soils are more productive for agriculture, but also provide

a competitive advantage for species adapted to higher nutrient levels (Tiffany 1997). These can be invasive non-native species or naturally successional woody species (Compton and Boone 2000). Soils can take centuries to form because of low organic matter turnover rates and the relatively slow acting effects of leaching. Because of this, it is widely believed that past land-use legacies can affect soil composition and vegetation for extended periods of time (Compton et al 1998; Eberhardt et al. 2003; Compton and Boone 2000; Goodale and Aber 2001). If these effects are long lasting, they have a potential to greatly influence efforts to restore native ecosystems.

Currently, several methods are used to restore grasslands. Burning and mowing are routinely used to deter recruitment of woody and invasive species. These treatments often have rapid, but temporary impacts, have to be repeated often, and can sometimes have adverse effects that are coupled with the benefits (Maron and Jefferies 2001). If our goal is to conserve coastal sandplain grasslands, we must reevaluate the current restoration techniques and assess the land we are using to restore these habitats. In reevaluating restoration and conservation techniques, we must ask several questions. Is soil quality limiting restoration success? What is the best land type to start from in order to most efficiently restore sandplain grassland? Consequently, is it more effective to clear forest for grassland construction or to start from already clear agricultural fields?

To answer these questions, we assessed a suite of soil characteristics that are indicators of soil quality and biogeochemical processes in sites with different current vegetation and land-use histories. We compared the different land types to sandplain grasslands in order to evaluate the similarities of their soils and the relative ease of restoring coastal grassland from each particular land type.

Methods

Site Selection. We investigated soil quality at 29 sites on the outwash of Martha's Vineyard, MA within six different categories of land-use histories (Appendix A). Dean (2002) established 25 sites on Martha's Vineyard within the six different categories and we have added four more. We chose sites based on their land-use history determined from Foster and Motzkin (1999). All pine plantations were planted in the late 1920s and early 1930s (Foster and Motzkin, 1999; Appendix A). Plowed pine sites were plowed in the 1920s and 1930s (Foster and Motzkin 1999). One plowed grassland site is still being plowed twice yearly and all others have been used for agriculture within the last 20 years.

Characterization of Soil Profiles. We dug soil pits deep enough to reach the bottom of either the plow layer or the B1 layer. We recorded depths of all visible horizons and recorded colors using the Munsell color chart.

Sample Collection. At each site, we collected two 15 cm deep mineral cores, one for bulk density and one for all other analyses. We homogenized those cores and removed all roots and rocks to use as a general mineral soil. We took one 10 cm x 10 cm brownie for organic layer bulk density and one larger brownie for all other analyses. We homogenized the separate brownies and removed roots and rocks before any analyses. At sites without an organic layer, we took the top 2 cm to of the soil to use as the 'organic' soil. We refrigerated all soils until we were ready to use them for analysis.

Bulk density, C and N Stocks, and C:N Ratios. We calculated bulk density using wet and dry weights of mineral cores and organic brownies. We ground all samples with

mortar and pestle and analyzed 5-15 mg of organic or 20-30 mg of mineral soil for C and N content using a Perkins-Elmer 2400 Series 2 CHNS/O analyzer. From this analysis, we calculated C and N stocks using bulk density measurements and molar ratios.

Soil pH. We mixed 5 g of organic soil or 10 g of mineral soil with 50 mL of DI water. We used this slurry to measure the pH of each sample using an Accumet pH/conductivity meter.

Base Cation Concentrations. We added 4-5 g from each sample to 100 mL of 1 M NH_4Cl . After the samples had shaken for one hour, we vacuum filtered them with Whatman GF/F filters. We added 12 drops of concentrated HCl to 50-60 mL of sample to prevent microbial growth. We diluted some samples 1:10 with DI water and added 1 mL of 1% LaCl_3 to 10 mL of each sample. We analyzed all samples on a Perkin-Elmer 2380 Atomic Absorption Spectrometer to obtain Ca^{2+} , Mg^{2+} , K^+ , and Na^+ concentrations (Mary Dean, 2002; Robarge and Fernandez, 1986).

Net N mineralization and Net Nitrification. For our initial reading, we added 10 g of organic or 15 g of mineral soil to 50 mL of 1 M KCl and shook at 150 rpm for one hour. We then pressure filtered all soils using Whatman GF/F filters. We froze all filtered samples until we analyzed them for NO_3^- and NH_4^+ using the procedure described above. For the final reading, we incubated approximately 50 g of soil at 30 °C for 15 days before using the procedure described above for extracting with KCL and measuring NO_3^- and NH_4^+ concentrations. We used a LACHAT QuickChem 8000 to measure NO_3^- concentrations. To measure NH_4^+ concentrations, we reacted the sample with phenol solution, then nitropusside solution, followed by hypochlorite oxidizing solution. We then measured the absorbance with a UV-1600 spectrophotometer at a wavelength of 640.0 nm. We calculated N mineralization and nitrification from the difference in final and initial NO_3^- and NH_4^+ concentrations.

Potential Nitrification. We measured potential nitrification on the tree oak and grassland sites in the lab using a method slightly modified from Belser and Mays (1980) and Schmidt and Belser (1982) and Weaver et al. (1994). We combined wet soil equivalent to 5 g of dry weight with 30mL of ammonium phosphate solution in 60 mL centrifuge tubes. We shook these tubes at 150 rpm at room temperature for 2, 6, 12, and 24 hours. At each time point, we centrifuged the tubes for 5 minutes and then gravity filtered the samples with Fisherbrand Q8 paper filters. We then pressure filtered each sample with Whatman GF/F filters. We froze all samples until we analyzed them for NO_3^- using the LACHAT as described above. In order to obtain rates of potential nitrification, we plotted all point for each sample and calculated the slope of the linear portion of the curve.

Soil Respiration. We put approximately 30 g of organic soil and 50 g of mineral soil to mason jars covered with plastic wrap with holes to allow air exchange. We let the soils settle at room temperature while keeping them at their initial moisture content. After five days, we measured the CO_2 flux with a Licor-6200 infrared gas analyzer for a period of 3 minutes. We calculated respiration based on the CO_2 flux.

Statistical Analysis. We calculated means and standard errors by land use. For each variable, we did a one-way ANOVA using land use as the independent variable. We conducted all ANOVAs with the Bonferroni mean at the 95% confidence level. Since we analyzed a representative set of land types for potential nitrification instead of all sites, we did the principle components analysis on two separate data sets, one with all of the

sites, but without potential nitrification included, and one including potential nitrification, but excluding scrub oak, plowed pine, and unplowed pine sites. We used SAS System for all ANOVAs and principle components analysis.

Results

Soil morphology and physical characteristics. The soils had similar color and horizon characteristics across most categories (Table 1). Many of the soils did not have an E layer or had an A layer combined with the early formation of the E layer. We were able to identify a deep Ap layer in all plowed sites, although some of the older plowed sites had the beginnings of the A and E layers as well (Table 1). The bulk density of the organic layer was lowest in oak and pine forests, which were all statistically similar. Both grasslands had significantly higher organic bulk densities with the recently plowed sites even higher than the non-plowed sites (Figure 1a). The density in the mineral soils was higher than the organic in every site, but did not show any difference between land types (Figure 1a). The thickness of the organic layer did not vary significantly where organic layers were present (Figure 1b). However there was little or no organic layer either the sandplain grasslands or recently plowed sites.

C and N Stocks. In organic soils, plowed pine forests had significantly higher stocks of C and N than tree oak forests, which were higher than plowed grasslands (Figures 1c,d). However, non-plowed pine and grasslands and scrub oaks showed no difference from any other land type. The stocks in the mineral soils showed exactly the same trend (Figures 1c,d). The C:N ratios in mineral and organic soils showed similar but slightly different trends. In the organic soil, the pine forests had the highest ratios followed by the scrub oak and native grasslands and the plowed grasslands had the lowest (Figure 1e). The tree oak forests were not significantly different from any other land use. In the mineral soil, the non-plowed pine and scrub oak had the highest ratios, followed by tree oak and native grassland and plowed grassland again the lowest (Figure 1e). The plowed pine was not statistically different from any other type.

Soil pH and base cations. Both organic and mineral soils in all treatments had pHs between 4 and 5 without much variation. The only statistically significant difference was the recently plowed grasslands, which had much less acidic organic and mineral soils than any of the other land types (Figure 2a).

All organic soils had higher concentrations of Ca^{++} and Mg^{++} than K^+ and Na^+ (Figure 2b). Most mineral soils had the highest concentration of Na^+ with the exception of the plowed grasslands, which showed significantly higher concentrations of Ca^{++} and Mg^{++} than any other soils (Figure 2c) For organic soils, tree oak forests had significantly more total cations than the non-plowed grasslands, however there were no other significant differences (Figure 2d). All mineral soils had low total base cation concentrations except the recently plowed grasslands, which had significantly higher concentrations than all other soils (Figure 2e).

Soil N concentrations, N dynamics, and respiration. There were no differences in NO_3^- and NH_4^+ stocks between any land types in either organic or mineral soils, however there was a trend for higher concentrations of NO_3^- in plowed grasslands (Figures 3a,b). When we combined the organic and mineral soils, which were statistically the same, into one sample and compared that to the organic and mineral soils of the other land types, the

plowed grasslands were significantly higher than both pine forests and the tree oak sites, but not the native grasslands or the scrub oak.

In the organic soil, non-plowed pine forests had a higher rate of net N mineralization than non-plowed pine forests, and oak sites and a significantly higher rate than both grasslands (Figure 3c). The mineral soil showed no difference in rates of net N mineralization for any land types (Figure 3d). In both the organic and mineral soils, the plowed grasslands appeared to have higher rates of net N mineralization than the non-plowed, however this was not statistically significant in either case. There appeared to be almost no net nitrification in pine or oak forests in both organic and mineral soils. The plowed grasslands had significantly larger rates of net nitrification than every site except the native grasslands where there was no statistical difference (Figure 3e). All of the sites measured had greater rates of potential nitrification rates than rates of net nitrification (Figures 3e, 4).

The oak sites and non-plowed grasslands showed low rates of potential nitrification, while the plowed grassland showed a rate of almost $20 \text{ ug N g}^{-1} \text{ soil day}^{-1}$. This trend was present and clear in both organic and mineral soils, however there was no statistical difference in either case because of too much variation in a small sample size (Figure 4). When we combined the organic and mineral soils for the grasslands, which were statistically the same, into one sample and compared to the separate organic and mineral soils of the tree oaks, plowed grasslands showed a significantly higher potential for nitrification than native grasslands or oak sites.

In the organic layer, tree oak and native grasslands did not have statistically different respiration rates than any other type, however plowed grasslands did have a significantly lower rate than both pine forests and scrub oak sites (Figure 5a). All mineral soils showed lower rates of respiration than the organic soils and again not much change between land types (Figure 5b). However, the mineral soil in the plowed grassland had a significantly higher respiration rate than all other types.

Principle components analysis. In a principle components analysis using all measured variables except potential nitrification, we found that principle component one (PC 1) explained approximately 40% of the variance. PC 1 was predominantly influenced by organic layer depth, C:N ratio, and total base cations in the organic layer and by pH and potential nitrification in the mineral layer (Table 2). Adding PC 2, influenced by N stock and NO_3^- in the organic layer and by density in the mineral layer (Table 2), increased that to around 55% of the variation. Adding PC 3, which was influenced by equally by most characteristics in both layers (Table 2), raised the portion of the variance explained to 65-70%. In all of the analyses, the majority of the separation was along the PC 1 axis. The principle components analysis showed all sites in one cluster except the plowed grasslands, which stretched off to one side of the group. However within the large cluster, the native grasslands are in a subgroup that is closer to the plowed grasslands (Figures 6a-d). When we did this analysis for a small subset of samples, but with potential nitrification included, the native grasslands were in a group between the tree oak cluster and the plowed grassland cluster (Figures 7a-d). These patterns occur in both the mineral and organic layers.

Discussion

This study shows that, while some differences are apparent between forest soils with different land-use histories, overall these soils are very similar despite the former plowing and the current difference in vegetation. The biggest differences in soil properties were between the forests and the formerly agricultural grasslands with the native sandplain grasslands falling between the forests and the recently plowed grasslands. Most of the differences between the two grassland types were due to base cation concentrations, pH, and microbial activity. However we found most of the differences between forests and native grasslands predominantly in physical characteristics and N dynamics.

Physical characteristics. The bulk density and depth of the organic layer showed similar trends. Since the plowed grasslands had no organic layer and the native grasslands had little or no organic layer, we called the first 2 cm of these sites the 'organic' layer when it was in actuality the top of the mineral soil. This lack of organic layer was correlated with the high bulk densities of the organic layer.

The patterns in C and N stocks probably reflect the present vegetation more than its past use, since pine and oak forests have much more litter than a grassland and therefore add more biomass and different quality of litter to the soil pools. This is consistent with the findings of other studies (Goodale and Aber 2001; Compton and Boone 2000) that C and N stocks are more affected by the regional variation or present vegetation than past land-use. The patterns in C:N ratios are also most likely a function of present vegetation. Pines pine needles have a high lignin content and therefore the soils underneath pine forests routinely have a higher C:N ratio than either oak forests or grasslands. The low C:N ratios in the plowed grasslands are may be due to N rich fertilizer applied to the soils that decrease the ratio of C:N. They could also be due to higher microbial activity and therefore more N enriched soil.

Soil pH and base cations. The higher pH of the plowed grasslands is due to the common agricultural practice of liming that results in a well-buffered soil. However this elevation in pH is not shown in the plowed pine plantations, which indicates that the effects of agriculture are not permanent and can disappear in 60-70 years. Compton and Boone (2000) studied sites that were plowed from the mid 1700s to the early 1900s and found that formerly agricultural soils had slightly higher pHs than non-plowed soils by an intermediate amount in relation to the plowed grasslands versus the plowed pine forests in our study. This suggests that the forests studied by Compton and Boone (2000) were probably more severely limed and plowed than the sites in this study. The site studied by Goodale and Aber (2001) support our finding of similar soil pH across the forests and non-plowed grasslands, suggesting that their sites could have had similar agricultural histories. Additionally, raising the pH in the plowed soils could result in increased microbial activity because of more optimal conditions.

The only large difference in the base cation concentrations is in the plowed grasslands, where the Ca^{++} and Mg^{++} concentrations are much higher than any other land type. This is just as we expected since liming ads Ca^{++} and Mg^{++} to the soil in large quantities. The difference in the total cations is a function of the Ca^{++} and Mg^{++} added. In all samples, close proximity to the ocean of all of the sites resulted in similar and relatively high Na^+ concentrations.

N dynamics. The similarity of NH_4^+ and NO_3^- concentrations in most soils is not surprising considering the rates of net N mineralization and net nitrification are also similar for most land types with the only differences being that grasslands have lower

rates of both in organic soil than non-plowed pines. Goodale and Aber (2001) also found similar rates in forests with different land-use histories. Furthermore, Compton and Boone (2000) and Compton et al. (1998) found higher rates of net nitrification in plowed hardwood forests that mirror the increases in net nitrification from native to plowed grasslands in this study. However, Compton et al. (1998) found that species composition affected N dynamics, specifically the difference between pine and oak forests. In this study, there was no difference in N dynamics except in the grasslands.

Potential nitrification. The high potential for nitrification in plowed grasslands may be due to more nitrifying bacteria present because of the ideal environment created for the microbes by fertilizing and mixing the soil to raise pH and availability of NH_4^+ . All sites measured had a greater potential nitrification than net nitrification, suggesting that all sites are limited by the NH_4^+ availability. This alludes to a shortage of NH_4^+ , in relation to the bacterial populations, across the outwash on Martha's Vineyard.

Respiration. The lower rates of respiration in the 'organic' layer of the plowed grasslands are most likely due to the fact that there is almost no organic layer. In all sites, the respiration rates were significantly lower in the mineral layer than in the organic layer, so a relatively lower rate in the 'organic' soil of the grasslands is to be expected. The higher rate in the plowed mineral soil compared to the other mineral soils can be attributed to the addition of nutrients and higher pH in the agricultural land that can support a greater bacterial population.

Principle components comparison. The patterns shown in this analysis suggest that the native grasslands fall somewhere in between plowed grasslands and all forest types with regards to their soil characteristics. Most of the separation of the three groups comes from differences in pH, organic layer depth, potential nitrification rates, and total base cation composition. With the exception of organic layer depth, these factors all emphasize differences between the plowed grasslands and all other land types, placing plowed grasslands in a group of their own as outliers from the rest of the soils. The principle components analysis highlights the large effects recent plowing can have on soils while also shedding light on fact that the residual effects of plowing in the land converted to pine plantations largely disappeared after 70 years. This suggests that, geologically speaking, plowing has an acute but fleeting effect on soils.

Since all of the soils we surveyed were on the outwash of Martha's Vineyard, they were somewhat uniform and the past land-use was not influenced by the soils, as it is in many parts of the country. In physical characteristics, nitrogen dynamics, and 'organic' layer respiration, the native grasslands were similar to only the plowed grasslands. However they showed considerably lower concentrations and rates for mineral layer cations, and respiration, pH in both layers, and potential nitrification. In these characteristics, they were similar to everything except the plowed grasslands. We do not know what differences would be most inhibiting to grassland restoration, however it is known that increased nutrients result in more woody and invasive species than the low nutrients of the native grasslands. Even if the grassland species grow on the agricultural land, they may be out competed by other non-sandplain grassland species. Assuming soil quality is an important factor in restoration, restoring to grasslands could be somewhat challenging if you started from the plowed areas.

Implications for restoration

With the goal of restoring sandplain grasslands in mind, there are several paths available to us. 1) We can start from agricultural land and try to lower pH, base cation concentrations, and microbial activity. 2) We can start from forests, which would involve clear-cutting, reducing C and N stocks, organic material, and nitrification. Each presents certain advantages and disadvantages. Cleared agricultural fields are not common on Martha's Vineyard and, considering the factors in which they differ from sandplain grasslands, it could be hard to alter them to favorable levels for sandplain grassland species. However these fields are already clear so restoring grasslands from them would not involve the hassles of clear-cutting. The forests would have to be clear-cut, but there are not large differences in soil characteristic that would have to be overcome. The biggest difference is in the organic layer depth, which could be cleared from the land along with the clear-cut trees. Additionally, forests are abundant and available for restoration use on Martha's Vineyard.

With these factors in mind, and also considering the social impacts, the pine plantations at the Correllus State Forest would be exceptional candidates for sandplain grassland restoration sites. They are similar to the grasslands in many characteristics, regardless of plowing or lack of plowing, and are abundant and already owned by the state. Furthermore, these plantations are not naturally occurring and seen as a fire hazard. Clearing some of these plantations for grassland restoration could reduce the fire hazard while reestablishing native and important habitats that support many rare or threatened species.

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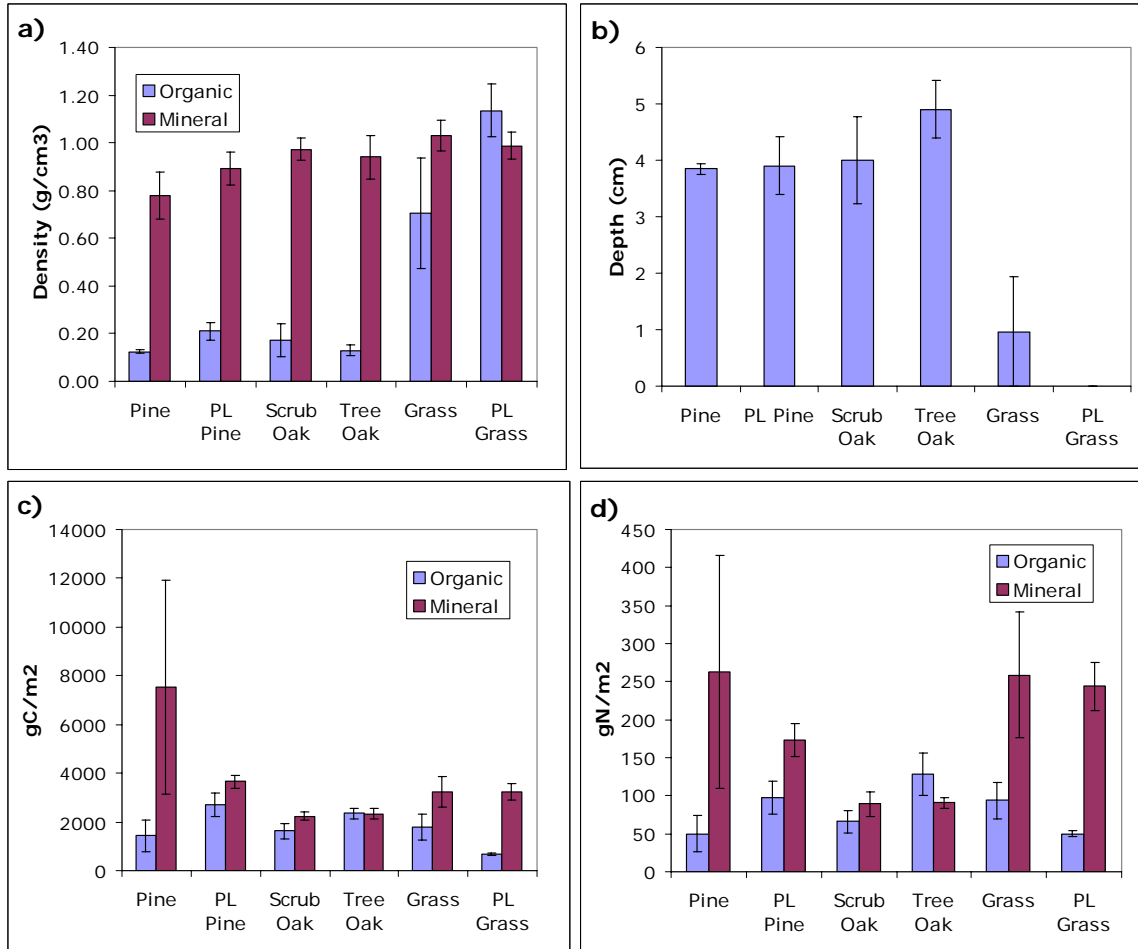


Figure 1. Physical properties of organic and mineral soils: a) bulk density, b) depth of organic layer, c) carbon stock, d) nitrogen stock. Former agricultural sites are marked by PL. Error bars represent standard error (n=4 for grasslands, n=5 for all other land types).

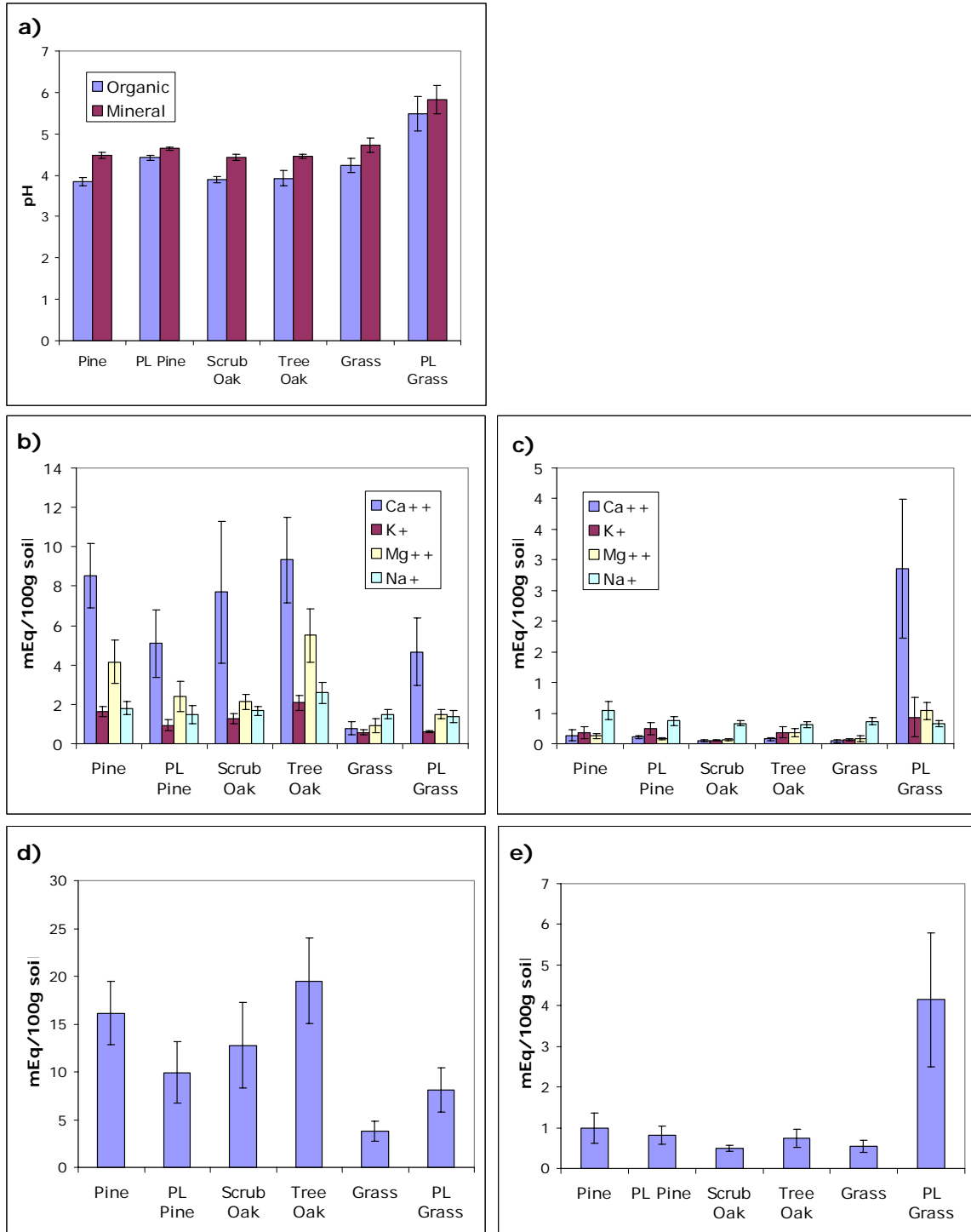


Figure 2. Soil pH and base cation concentrations in organic and mineral soils: a) pH, b) organic soil base cation concentrations, c) mineral soil base cation concentrations, d) total organic soil base cations, d) total mineral soil base cations. Former agricultural sites are marked by PL. Error bars represent standard error (n=4 for grasslands, n=5 for all other land types).

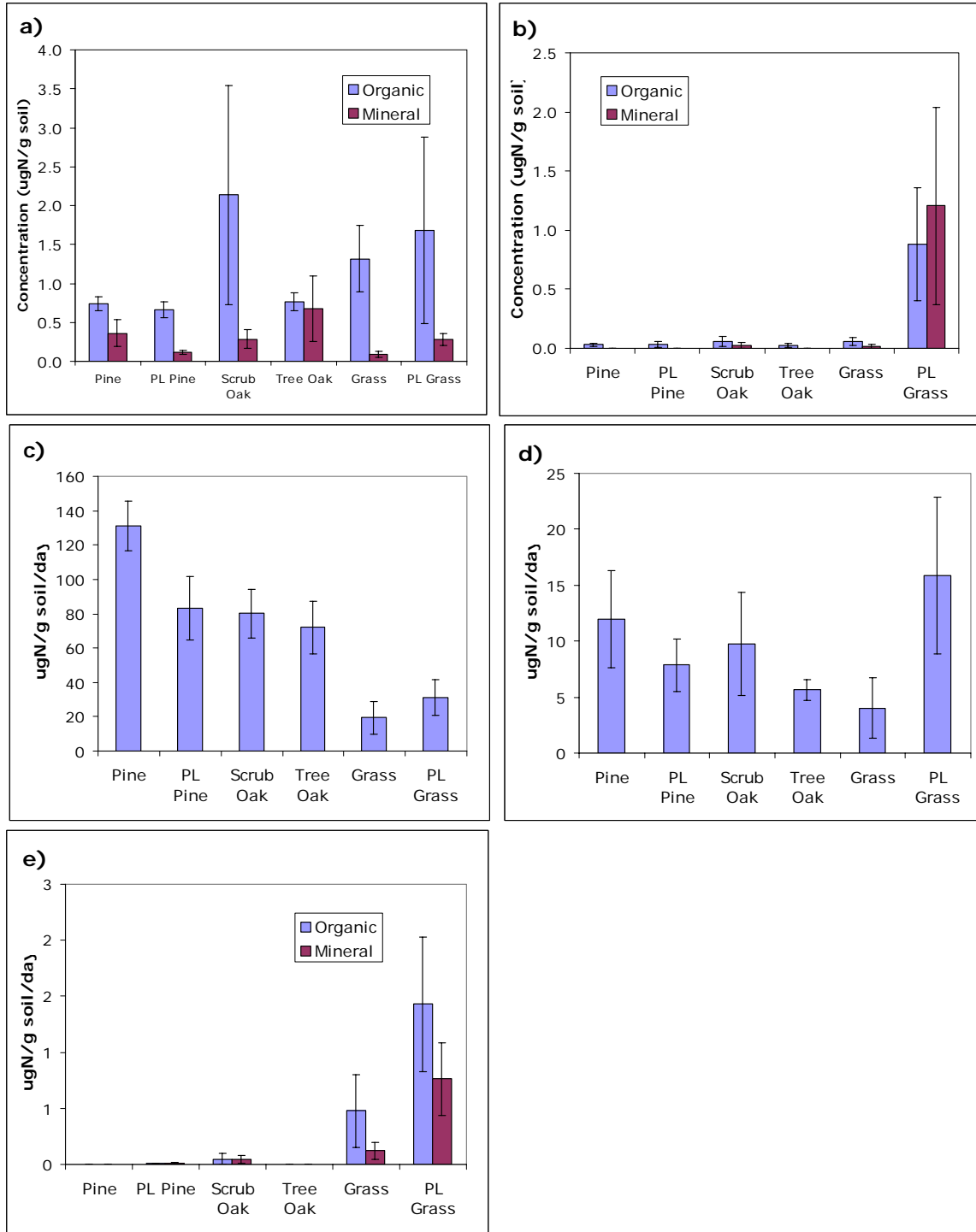


Figure 3. Nitrogen dynamics in organic and mineral soils: a) NH_4^+ concentrations, b) NO_3^- concentrations, c) net N mineralization in organic soils, d) net N mineralization in mineral soils, e) net nitrification. Former agricultural sites are marked by PL. Error bars represent standard error (n=4 for grasslands, n=5 for all other land types).

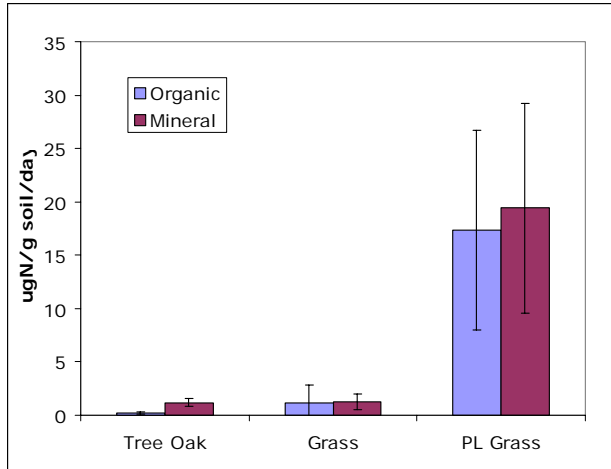


Figure 4. Potential nitrification rates in organic and mineral soils. Rates were measured in the lab to obtain an index. Former agricultural sites are marked by PL. Error bars represent standard error (n=4 for grasslands, n=5 for all other land types).

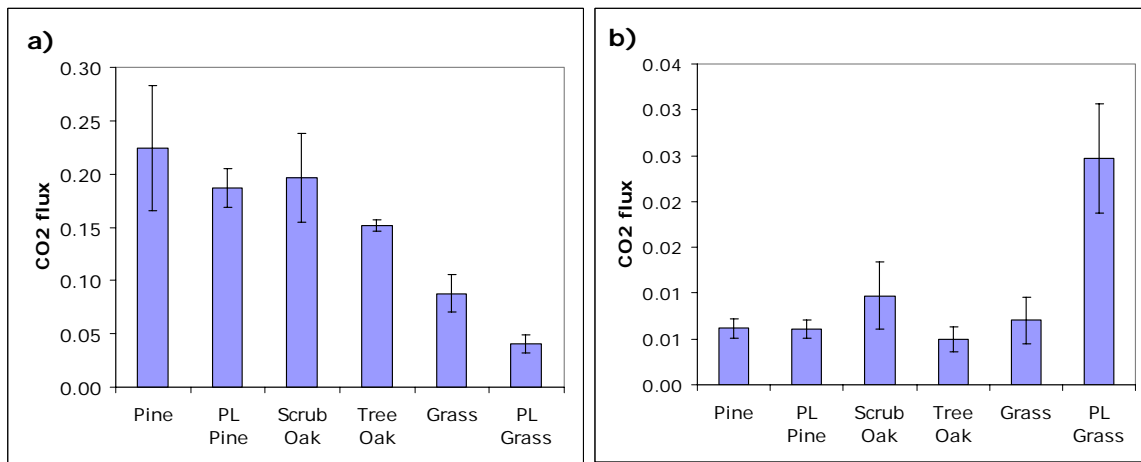


Figure 5. Respiration rates in organic and mineral soils: a) organic soil, b) mineral soil. Rates were measured in the lab to obtain an index. Former agricultural sites are marked by PL. Error bars represent standard error (n=4 for grasslands, n=5 for all other land types).

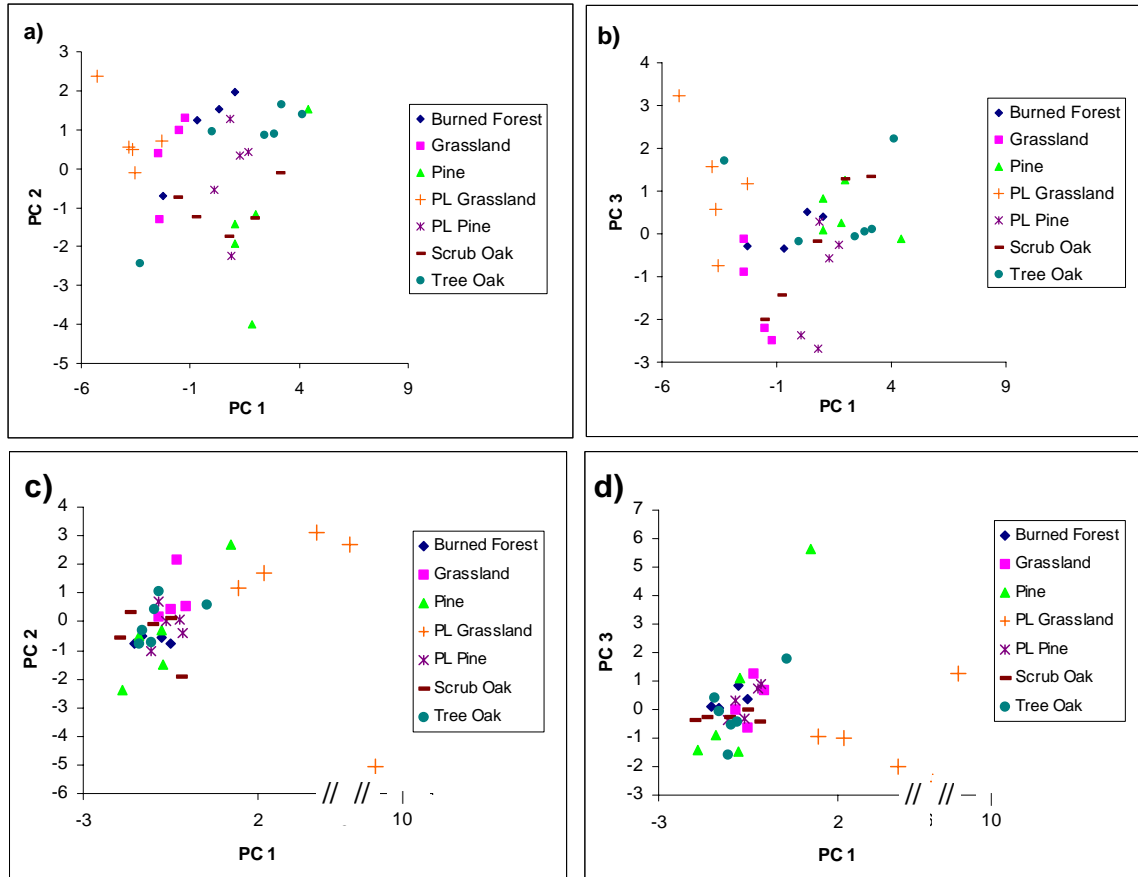


Figure 6. Principle components analysis of organic and mineral soils: a) PC1 and PC2 of the organic layer, b) PC1 and PC3 of the organic layer, c) PC1 and PC2 of the mineral layer, d) PC1 and PC3 of the mineral layer. Analysis was conducted on all sites. Axes include bulk density, depth of organic layer, C and N stock, pH, cation concentrations, NH_4^+ and NO_3^- stocks, net N mineralization, net nitrification, and respiration. Former agricultural sites are marked by PL.

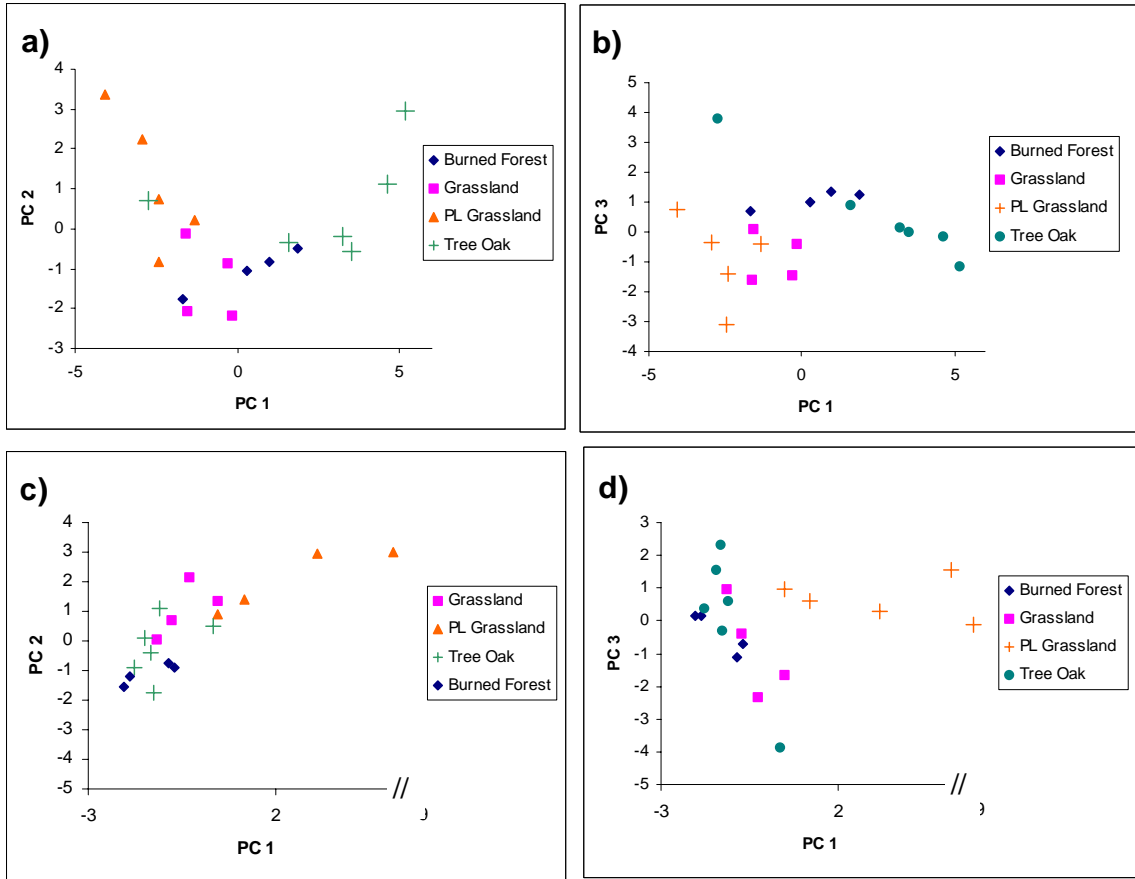


Figure 7. Principle components analysis of organic and mineral soils: a) PC1 and PC2 of the organic layer, b) PC1 and PC3 of the organic layer, c) PC1 and PC2 of the mineral layer, d) PC1 and PC3 of the mineral layer. Analysis was conducted on only sandplain grasslands, plowed grasslands, and tree oak forests. Axes include bulk density, depth of organic layer, C and N stock, pH, cation concentrations, NH_4^+ and NO_3^- stocks, net N mineralization, net nitrification, respiration, and potential nitrification. Former agricultural sites are marked by PL.

Red Pine	O		A		E or Ap		B1		B2
	Depth	Color	Depth	Color	Depth	Color	Depth	Color	Color
RP2	3.5	10YR 2/1	0-1	10YR 2/1	1-2	10YR 3/1	>2	10YR 4/6	-
RP4	3.5	7.5YR 3/2	-	-	0-2.5	10YR 3/1	>2.5	10YR 4/6	-
RP18	4.5	7.5YR	-	-	0-1	10YR 3/1	1-17	10YR 4/4	10YR 4/6
RP33	7	5 YR 2.5/2	0-1.5	5YR 2.5/1	1.5-5.5	10YR 5/1	5.5-12.5	7.5YR 3/4	7.5YR 4/6
RP41	5	2.5YR 2.5/2	0-1	7.5YR 2.5/1	1-5.5	10YR 4/1	5.5-9.5	10YR 3/4	10YR 4/6
Plowed Pine									
AP1	4.5	7.5YR 2/2	-	-	0-13.5	7.5YR 2.5/1	>13.5	10YR 3/6	-
AP2	4	7.5YR 2.5/2	-	-	0-12.5	7.5YR 2.5/1	>12.5	10YR 3/4	-
AP3	2	10YR 2.5/2	0-1.5	10YR 2/2	-	-	1.5-5	10YR 3/4	10YR 4/4
AP5	4	7.5YR 2.5/1	0-2	10YR 2/1	2-21	10YR 3/3	>21	10YR 4/6	-
AP6	4.5	5YR 3/4	0-2	5YR 3/1	2-16.5	7.5YR 3/4	>16.5	5YR 3/4	-
Scrub Oak									
SO1	4.5	5YR 2.5/1	0-1.5	7.5YR 2.5/1	1.5-4.5	10YR 4/1	4.5-10.5	10YR 3/4	10YR 5/6
SO2	6	10YR 2/2	0-4	7.5YR 3/1	-	-	>4	10YR 4/6	-
SO3	2	10YR 2/1	0-3	10YR 2/1	-	-	3-20	10YR 3/1	7.5YR 4/6
SO4	2	7.5YR 2.5/1	0-5	10YR 2/1	-	-	5-10.5	10YR 3/1	10YR 3/6
SO5	4.5	10YR 2.5/1	0-1	7.5YR 2.5/1	1-2	10YR 2/1	2-8	10YR 3/4	10YR 5/6
Tree Oak									
TO1	4.5	5YR 2.5/2	0-1.5	5YR 2.5/1	1.5-3.5	10YR 4/1	3.5-7	10YR 3/2	10YR 4/6
TO2	6	7.5YR 2.5/2	0-0.5	10YR 2/1	0.5-4.5	10YR 4/1	4.5-7.5	10YR 3/3	10YR 4/6
TO3	4	7.5YR 2.5/2	-	-	0-1.5	10YR 4/1	1.5-14.5	10YR 4/4	10YR 4/6
TO4	4	7.5YR 2.5/1	0-1.5	10YR 2/1	1.5-2.5	10YR 4/1	2.5-5	10YR 4/4	10YR 4/6
TO5	6	5YR 2.5/2	0-1.5	7.5YR 2.5/1	1.5-3.5	10YR 4/2	>3.5	10YR 4/6	-
Sandplain Grassland									
SG1	3	10YR 2/1	-	-	9	10YR 4/2	18	7.5YR 3/2	10YR 3/3
SG2	3.5	2.5YR 2.5/1	0-4.5	10YR 3/1	-	-	>4.5	10YR 3/4	-
SG3	1	7.5YR 2.5/1	0-4	10YR 2/2	-	-	4-15	2.5YR 3/3	10YR 4/6
SG4	-	-	0-3	10YR 2/1	-	-	3-14	10YR 3/2	10YR 4/4
Plowed Grassland									
PL1	-	-	-	-	0-23	10.5YR 3/1	>23	10.5YR 4/6	-
PL2	-	-	-	-	0-23	10YR 3/2	>23	7.5YR 4/6	-
PL3	-	-	-	-	0-22.5	10YR 3/2	>22.5	10YR 4/6	-
PL4	-	-	-	-	0-27	10YR 2/2	>27	10YR 3/3	-
PL5	-	-	0-20.5	10YR 2/2	20.5-27.5	10YR 3/2	>27.5	10YR 5/6	-

Table 1. Characteristics of soil profiles up to 30 cm in individual sites. Dashes denote absent horizons.

	PC1	PC2	PC3
O-without potential nitrification	O Depth	N stock	Ca++
	C:N ratio	-Respiration	Total Cations
	K+	-N min	NO3-
	Total Cations		-C stock
O-with potential nitrification	O Depth	-C:N ratio	Density
	Total Cations	NO3-	Potential nit
	C stock	Potential nit	-NH4+
	N stock	N min	Nitrification
M-without potential nitrification	pH	Density	C stock
	Respiration	N stock	N stock
	NO3-	-N min	-Na+
	Total Cations	Ca++	
M-with potential nitrification	pH	Density	C stock
	Potential Nit	Ca++	Mg++
	Respiration		NH4+
	NO3-		Na+

Table 2. Influential variables in principle components. Bold type denotes variables with the most weight for that particular principle component.

Appendix A. Description and maps of sites sampled.

SITE #	PREVIOUS USE	CURRENT USE/ VEGETATION	MAP LABEL	DESCRIPTION
1	Not plowed	Red pine	RP#2	Foster and Motzkin plantation number 2. Red pine, planted in 1934.
2	Not plowed	Red pine	RP#4	Foster and Motzkin plantation number 4. Red pine, planted in 1934.
3	Not plowed	Red pine	RP#18	Foster and Motzkin plantation number 18. Red pine, planted in 1929.
4	Not plowed	Red pine	RP#33	Foster and Motzkin plantation number 33. Red pine, planted in 1930.
5	Not plowed	Red pine	RP#41	Foster and Motzkin plantation number 41. Red pine, planted in 1929 or 1930.
6	Plowed	Red pine	Ap #1	Previously plowed area in Correllus State Forest identified by Foster and Motzkin. Red pine, planted in 1961
7	Plowed	Red pine	Ap #2	Previously plowed area in Correllus State Forest identified by Foster and Motzkin. Red pine, planted in 1935
8	Plowed	Red pine	Ap #3	Previously plowed area in Correllus State Forest identified by Foster and Motzkin. Red pine, planted in 1961
9	Plowed	Red pine	Ap #5	Previously plowed area just outside Correllus State Forest.
10	Plowed	Mixed white oak and red pine	Ap #6	Previously plowed area in Correllus State Forest identified by Foster and Motzkin.
11	Scrub oak	Scrub oak	SO #1	Hazy Acres frost bottom.
12	Scrub oak	Scrub oak	SO #2	Quampache frost bottom.
13	Scrub oak	Scrub oak	SO #3	Wintucket Cove Frost bottom.
14	Scrub oak	Scrub oak	SO #4	Deep Bottom frost bottom.
15	Scrub oak	Scrub oak	SO #5	Willow Tree frost bottom.
16	Tree oak	Tree oak	Oak #1	Smith Woods
17	Tree oak	Tree oak	Oak #2	Kohlberg property control north unit.
18	Tree oak	Tree oak	Oak #3	Oak woods to W. of road into Mazar property
19	Tree oak	Tree oak	Oak #4	Oak forest just N. of Red Gate Field. Sampled E. of Pohogonot Rd.
20	Tree oak	Tree oak	Oak #5	Trustees of Reservations Long Point Preserve
21	Native SP grass	Native SP grass	SG #1	Katama Airfield. Sampled just E. of grass runway at corner of Slough Cove Rd.
22	Native SP grass	Native SP grass	SG #2	In maritime grassland area just behind dunes at Kohlberg property
23	Native SP grass	Native SP grass	SG #3	Fire break running N. from parking lot at N. end of Pohogonot Rd.
24	Native SP grass	Native SP grass	SG #4	Savanna area near Meshacket Cove, just to S. of new house construction
25	Recently plowed	Pasture grassland	PI #1	Herring Creek Farm property, southern portion.
26	Recently plowed	Pasture grassland	PI #2	Recently-plowed field on Macafee property.
27	Recently plowed	Pasture grassland	PI #3	Recently-plowed field to W. of road into Mazar property
28	Recently plowed	Pasture grassland	PI #4	Herring Creek Farm. Sampled just S. of horse barns, across from parking area
29	Recently plowed	Plowed agricultural field	PI #5	Morning Glory Farm sampled just across from store in currently plowed field.

