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Soil carbon and nitrogen in a pine-oak sand plain in central Massachusetts: Role of vegetation and land-use history

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Abstract Over the last 150 years much of the landscape of eastern North America has been transformed from predominantly agricultural lands to forest. Although cultivation strongly affects important ecosystem processes such as biomass accumulation, soil organic matter dynamics, and nitrogen cycling, recovery of these processes after abandonment is insufficiently understood. We examined soil carbon and nitrogen pools and nitrogen dynamics for 16 plots on a central Massachusetts sand plain, over 80% of which had been cultivated and subsequently abandoned at least 40 years ago. The two youngest old-field forests, located on sites abandoned 40–60 years prior to our sampling, had the lowest mineral soil carbon content (0–15 cm), 31% less than the average of unplowed soils. Soil carbon concentration and loss-on-ignition were significantly higher in unplowed soils than in all plowed soils, but these differences were offset by the higher bulk density in formerly plowed soils, leading to no significant differences in C content between plowed and unplowed soil. Soil C:N ratios were lower in formerly plowed soils (26.2) than in unplowed soils (28.0). While soil N content was not affected by land-use history or vegetation type, net N mineralization showed much greater variation. In situ August net nitrogen mineralization varied nearly 40-fold between stand types: lowest in pitch pine and white pine stands (−0.13 and 0.10 kg N ha^{-1} 28 day^{-1}), intermediate in scrub oak stands (0.48 kg N ha^{-1} 28 day^{-1}) and highest in aspen and mixed oak stands (1.34–3.11 kg N ha^{-1} 28 day^{-1}). Mineralization was more strongly related to present vegetation than to land-use history or soil N content. Appreciable net nitrification was observed only in the most recently abandoned aspen plot (0.82 kg N ha^{-1} 28 day^{-1}), suggesting that recent disturbance and residual agricultural lime stimulated nitrification. Carbon:nitrogen ratios increased and pH declined with stand age. Higher bulk density, lower loss-on-ignition and C:N ratios, and slightly lower C concentrations in the surface mineral soil are the persistent legacies of agriculture on soil properties. Short-term agricultural use and the low initial C and N concentrations in these sandy soils appear to have resulted in less persistent impacts of agriculture on soil C and N content and N cycling.

Key words Land-use history · Nitrogen mineralization · Nitrification · Species effects · Carbon storage

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Introduction

Throughout eastern North America, widespread agricultural abandonment during the late 19th and early 20th centuries led to extensive natural reforestation of former agricultural lands. While 50–70% of forested uplands in Massachusetts were cleared for agriculture by the mid-1800s, today 60–85% of these lands are forested (Foster 1995). Similar shifts in land-use and land-cover are predicted to occur in portions of New Zealand (Maclaren 1996) and northern Europe (Houghton 1996) over the next few decades, and occurred during the 19th and early 20th centuries in Puerto Rico (Garcia-Montél and Scatena 1994). These substantial changes in land use can have important implications for local and global biogeochemical cycling and local vegetation dynamics. For instance, re-growth of temperate forests represents a substantial sink of atmospheric CO_2 (Armentano and Ralston 1980; Delcourt and Harris 1980), resulting in a net increase in storage of 15×10^{15}g C in re-growing forests from 1850 to 1980 (Houghton 1996). In addition, historical land use is increasingly recognized as an important determinant of modern vegetation patterns throughout eastern North America, England, and Europe (Peterken and Game 1984; Whitney and Foster 1988; Hermy et al. 1993; Matlack 1994; Motzkin et al. 1996). Because the nature and intensity of land management plays a role in soil nutrient pools and vegetation trajectories, historical land use may have persistent effects on soil carbon and nitrogen content, organic matter quality, microbial activity, and mineralization of organic nitrogen.

Cultivation of temperate soils reduces soil carbon by an average of 30% (Johnson 1992; Davidson and Ackerman 1993) and soil nitrogen by 8% (Post and Mann 1990). However, changes in soil carbon and nitrogen levels and processes after agricultural abandonment are not well established and may be very site-specific. In previous studies of old-field succession, no consistent relationship has emerged between nitrogen mineralization and time since abandonment. For instance, potential nitrogen mineralization and nitrification generally increased in a chronosequence of old-fields in Minnesota (Pastor et al. 1987; Zak et al. 1990), and in succession from old-field to forest in New Jersey (Robertson and Vitousek 1981); nitrification alone increased with rainforest age on abandoned pastures in Australia (Lamb 1980). In contrast, other researchers found highest nitrification rates early in succession (Rice and Pancholy 1972; Haines 1977; Woodwell 1979; Christensen and MacAller 1985; Thorne and Hamburg 1985). The lack of consistent response of important soil processes to agricultural abandonment has led to the conclusion that the availability of nitrogen across a revegetation sequence depends on the type and intensity of agriculture (Vitousek et al. 1989). Some sites may have rapid nitrogen mineralization immediately post-abandonment because the fields were amended with fertilizer (as discussed by Robertson and Vitousek 1981). In addition, shifts in dominant vegetation over the course of succession may explain some of the patterns in nitrogen cycling rates (Covington 1981; Vitousek et al. 1989).

Old-field succession often takes place on soils depleted in organic matter and nitrogen. For instance, although plant biomass may increase quickly after land abandonment, over 200 years may be required for old-field forests to accumulate the forest floor mass observed on sites not previously plowed (Hamburg 1984). Recovery of mineral soil organic matter and re-development of stable soil aggregates may require an even longer period of time. Evaluation of the nature and duration of agricultural impacts on biogeochemical cycling should increase our understanding of present-day ecosystem processes and improve ecosystem management.

We evaluated the relative importance of land-use history and current vegetation on soil carbon and nitrogen pools and net nitrogen transformations on Montague Plain in central Massachusetts. Montague Plain is a large outwash deposit that supported extensive pine plains until at least 1830 (Massachusetts Archives 1830). After European settlement, the plain was logged for forest products during the 18th and early 19th centuries. In the mid-to-late 19th century, 82% of the plain was cultivated. These farms were abandoned in the early 20th century (Motzkin et al. 1996). The site is ideal for examining land-use impacts because soils of the sand plain are relatively homogeneous and the pattern of agricultural land use appears to be correlated with ownership boundaries rather than with inherent soil properties. The effects of land-use history, time since agricultural abandonment and present vegetation were examined to determine which factors are the most important influences on soil carbon and nitrogen storage and nitrogen cycling.

Materials and methods

Site description

Montague Plain, described in detail by Motzkin et al. (1996), is located in the Connecticut River valley of central Massachusetts, United States. The 775-ha plain is a flat outwash delta of sands and gravel deposited into glacial Lake Hitchcock, ranging in elevation from 96 to 112 m a.s.l. The soil is highly permeable and prone to drought despite an evenly distributed annual precipitation of 1100 mm. The regional water table is approximately 20 m below the surface. The soils of the plain belong to the Hinckley and Windsor series, developed in sorted siliceous sand and gravel, with a surface layer of aeolian loamy sand, and are classified as sandy-skeletal, mixed mesic, Typic Udorthents (Mott and Fuller 1967). Texture of the 0–15 cm depth is loamy sand to loamy fine sand, and soil textures are fairly homogeneous across the plain (Motzkin et al. 1996). The Ap horizon averages 22 cm thick, ranging from 16 to 33 cm thick (Motzkin et al. 1996).

Removal of forest products was likely the primary land use from the mid-1700s through the early 1800s (Motzkin et al. 1996). Large sections of the plain were then converted to tillage for maize and hay from the mid-1800s to early 1900s. There is no historical evidence of long-term residences in the study area and little evidence of widespread pasturing; thus we suspect that most plowed lands were not intensively amended with manure. Forest stands up to 120 years old apparently represent the first areas abandoned. Land-use history strongly controls the present plant communities: 97% of pitch pine stands occur on formerly plowed sites, while 89% of scrub oak stands are found on areas that were never plowed (Motzkin et al. 1996). Vegetation types and associated prior land use include grasses and aspen (*Populus* spp.) on formerly plowed sites abandoned 40–60 years ago, pitch pine and mixed white pine (*Pinus strobus* L.) - pitch pine (*P. rigida* Mill.) - scarlet oak (*Quercus coccinea* Muenchh.) stands on sites abandoned 55 to over 100 years ago, and scarlet oak, scrub oak (*Q. ilicifolia* Wang.) and dwarf chinquapin oak (*Q. prinoides* Willd.) stands on sites never plowed (Motzkin et al. 1996). Many of the aspen stands contain pitch pine, white pine and oak regeneration (G. Motzkin, unpublished work), which suggests that these stands will succeed to pine-oak communities in the future.

Methods

We selected a subset of 16 of the 121 plots sampled by Motzkin et al. (1996). An equal number of plowed and unplowed sites were chosen, spanning the dominant vegetation types described above (Table 1). The four largest trees within each plot were cored at the base to obtain an estimate of maximum stand age; tree rings were counted in the laboratory under 25 × magnification. Within each of the 16 20 × 20 m plots selected for investigation, soil was collected

Table 1 Stand type and age, land-use history, dominant trees (≥2.5 cm dbh), understory and tree basal area (BA) for study plots on Montague Plain. Stand age is the mean age in 1994 of the four largest diameter trees in each plot determined from the base (N no, Y yes). Depth is thickness of A or Ap horizon (cm)

Plot type and no.	Age	Plowed	Depth	Trees	Understory	BA/m^2 ha^{-1}
Mixed oak 15	76	N	9	*Quercus coccinea* *Acer rubrum* *Amelanchier* sp.	*Vaccinium angustifolium* *V. vacillans*	17
Mixed oak 37	65	N	8	*Pinus strobus* *Q. coccinea* *A. rubrum*	*V. vacillans* *V. angustifolium*	34
Mixed oak 80	54	N	6	*Q. coccinea* *Amelanchier* sp. *A. rubrum*	*Gaylussacia baccata* *V. angustifolium* *A. rubrum* *Gaultheria procumbens* *Q. ilicifolia*	21
Mixed oak 105	56	N	8	*Q. coccinea* *A. rubrum* *Betula papyrifera*	*G. baccata* *V. angustifolium*	17
Scrub Oak 24	7	N	8		*V. angustifolium* *Q. ilicifolia* *Comptonia peregrina*	na
Scrub Oak 26	49	N	7	*Pinus rigida*	*Q. ilicifolia* *V. angustifolium*	11
Scrub Oak 44	11	N	7		*V. angustifolium* *Q. ilicifolia Aronia* sp. *V. vacillans*	na
Scrub Oak 83	56	N	8	*A. rubrum* *Q. coccinea* *Amelanchier* spp.	*Q. ilicifolia* *G. baccata* *V. angustifolium*	11
Aspen 73	28	Y	21	*Populus tremuloides* *P. grandidentata* *Betula populifolia*	*Andropogon scoparius* *P. tremuloides* *Q. coccinea*	17
Aspen 79	31	Y	26	*P. tremuloides* *Pinus rigida*	*A. scoparius* *Polytrichum* spp.	13
Pitch pine 25	58	Y	21	*P. rigida*	*V. angustifolium* *Polytrichum* spp. *Q. coccinea* *Q. ilicifolia* *V. vacillans*	47
Pitch pine 42	36	Y	27	*P. rigida* *B. populifolia*	*Polytrichum* spp. *P. rigida* *V. angustifolium* *V. vacillans*	21
Mixed oak 16	63	Y	20	*B. populifolia* *P. rigida*	*Q. ilicifolia* *V. vacillans* *Q. coccinea* *A. rubrum*	23
Mixed oak 20	71	Y	21	*Q. coccinea* *B. populifolia* *Pinus strobus*	*Polytrichum* spp. *Q. ilicifolia* *Amelanchier* spp.	22
White pine 36	99	Y	24	*P. strobus* *A. rubrum* *Q. rubra*	*P. strobus* *A. rubrum* *G. baccata*	47
White pine 106	49	Y	18	*P. strobus* *Q. coccinea* *A. rubrum*	*V. angustifolium* *A. rubrum* *G. baccata* *P. strobus* *Q. ilicifolia* *V. vacillans*	27

on 4 August 1994 from four random locations. The buried bag technique was used to determine field net rates of nitrogen mineralization (Eno 1960, as modified by Boone 1992). The forest floor was removed and two soil cores were collected from the upper 15 cm depth of the mineral soil using a 5.2-cm-diameter cylindrical steel corer. We sampled the 0–15 cm depth in order to focus on the disturbance associated with the plow layer, but in many cases did not capture the entire plow layer (average depth 21.5 cm, Motzkin et al. 1996). Intact cores were kept in plastic tubes with caps, then placed in gas-permeable polyethylene bags. One core (time-zero) was stored on ice and returned to the laboratory within 12 h for processing. The second core was placed in a perforated plastic tube, which was then capped and placed in a polyethylene bag within a nylon mesh bag to prevent disturbance of the core by animals. The core was placed back in the original hole, covered with forest floor and incubated in the field for 6 weeks.

Soil cores were sieved to <2mm and extracted for inorganic nitrogen within 24 h of collection. Mass of the cores was used to determine bulk density. Ten grams of sieved fresh soil was extracted with 100 ml 2 M KCl for 24 h and suction-filtered through Whatman GF A/E filters. Moisture content (105°C for 24 h) and loss-on-ignition (550°C for 24 h) were determined on subsamples of sieved soil. High temperature combustion (> 450°C) should be a good index of organic matter content in these soils with low clay content (< 5%) and there is little loss of structural water from clay minerals (Nelson and Sommers 1997). Extracts were frozen until analysis a few weeks later for ammonium and nitrite plus nitrate by LACHAT AE continuous flow ion analyzer (LACHAT Instruments, Milwaukee, Wi.: methods 12-107-06-1-A and 12-407-04-1-B). It was assumed that all oxidized nitrogen would be present as nitrate in these well-drained soils. Coefficients of variation (CV) for replicate analyses of soil extracts were 2.5% for ammonium and 3.4% for nitrate. Net nitrification was calculated as the net change in nitrate between the time zero and time 6 week cores. Net nitrogen mineralization was the change in ammonium plus the change in nitrate.

Total carbon and nitrogen of the time-zero soils were determined by Fisons CHN analyzer using 30 mg finely ground soil (Fisons Instruments, Beverly, Ma.). Acidification of a subset of samples with 4 M HCl indicated that no carbonates were present. Three runs of the same soil sample had a CV of 6.3% for carbon and 5.5% for nitrogen; the average recovery of a known soil standard was 96% for carbon and 101% for nitrogen.

One-way analysis-of-variance (ANOVA) was used to independently examine the effect of present vegetation types and land use on soil properties. Plots were nested within land use or vegetation. Certain vegetation types such as aspen and scrub oak were only found on one type of prior land use, and therefore a factorial design combining land-use history and vegetation type was not possible. If significant effects were observed by ANOVA, Tukey's honestly significant difference test was used to determine differences among vegetation types. Effects having P values lower than 0.05 were considered significant. The Kruskal-Wallis non-parametric ANOVA was used to examine N mineralization, nitrification and soil C and N data because of unequal variances and non-normal distributions. All soil properties were compared with stand age by linear regression. All statistical tests were conducted using SYSTAT version 5.2.1 for Macintosh (SYSTAT 1992).

Results

Soil carbon concentration and loss-on-ignition were lower while bulk density was higher in the formerly plowed soils (Table 2). The strong difference in soil bulk density ($P < 0.001$) appears to offset the slight difference in soil carbon concentration ($P = 0.095$), resulting in no significant difference in soil C content by land use (Fig. 1). The aspen sites were abandoned most recently, 40 and 60 years prior to sampling, and contained 31% less carbon and 17% less nitrogen by mass over the 0–15 cm sampling depth than the average of all unplowed stands. White pine and unplowed scrub oak and mixed oak soils had the highest carbon content, significantly more than the aspen soil. Depth of the Ap horizon was negatively correlated with 0–15 cm soil C content ($P = 0.047$) in the plowed soils, although this rela-

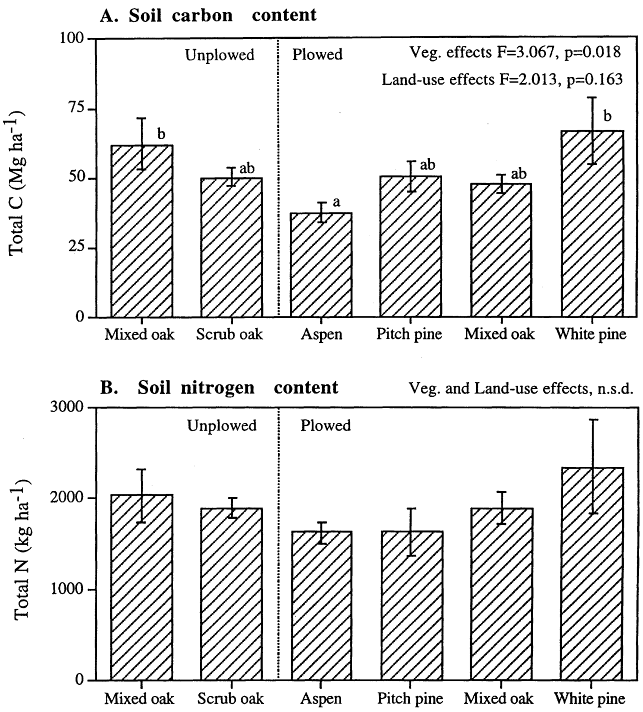

Fig. 1 Mean total **A** carbon and **B** nitrogen content of Montague Plain soils (0–15 cm depth) by land-use history and present vegetation. *Lowercase letters* indicate significant differences among vegetation types using Tukey's HSD ($P \leq 0.05$). Effects are the result of one-way ANOVA with plots nested within the main effect (land use or vegetation type). *Bars* are standard errors between plots within each vegetation type (n = 2 or 4)

Table 2 Properties of Montague Plain soils by land use and stand type (n number of stands, *BD* bulk density, *LOI* loss-on-ignititon). Effects of land-use history and present vegetation are presented as P values of one-way ANOVAs, except for pH data, which is analyzed by t-test. Letters signify Tukey's honestly significant differences between vegetation types ($P < 0.05$; mixed oak stands were grouped separately by land use)

Stand Type	n	BD g cm^{-3}	pH 2:1 H_2O	LOI %	Carbon g kg^{-1}	Nitrogen mg kg^{-1}	C:N g g^{-1}
Unplowed							
Mixed oak	4	1.10 a	4.46a	5.5 b	39.3 b	1360	29.6 b
Scrub oak	4	1.11 a	4.56a	5.4 b	34.6 b	1310	26.5ab
Average	8	1.11	4.51	5.5	37.0	1340	28.0
Plowed							
Aspen	2	1.28 c	5.17b	3.4 a	21.6 a	936	23.3 a
Pitch pine	2	1.23 bc	4.46a	5.2 b	29.9ab	1100	26.7ab
Mixed oak	2	1.19 abc	4.57a	4.9 ab	30.2ab	1200	25.6ab
White pine	2	1.16 ab	4.33a	5.1 b	43.0 b	1520	29.4 b
Average	8	1.21	4.63	4.6	31.2	1190	26.2
Use effect	P =	0.000	0.253	0.000	0.095	0.347	0.000
Veg. effect	P =	0.000	0.000	0.000	0.038	0.322	0.003

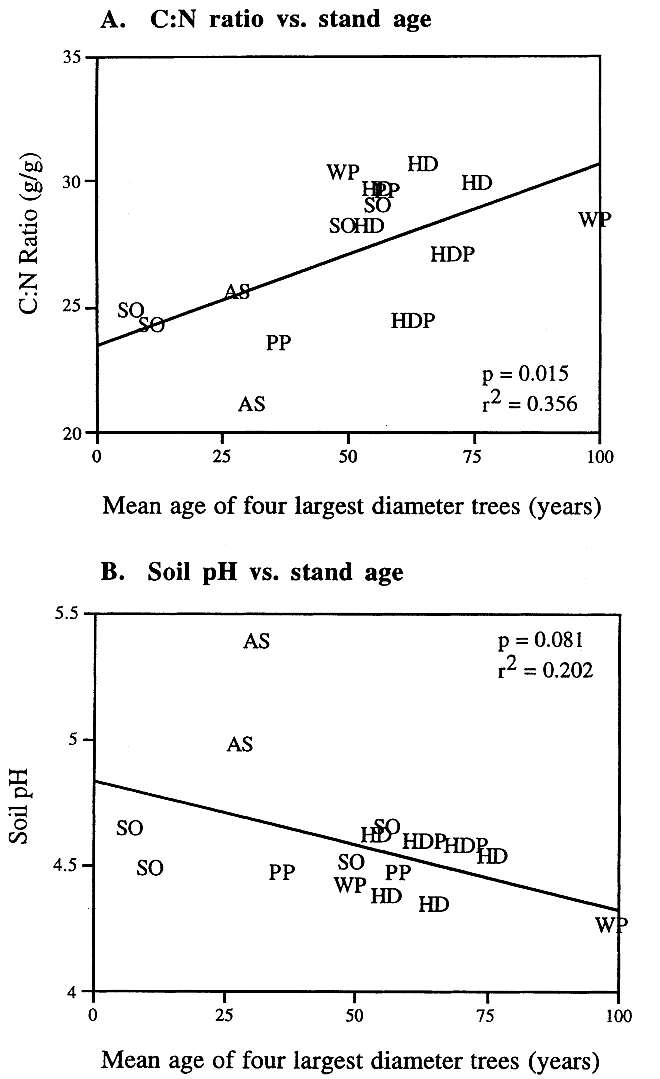

Fig. 2 **A** Soil carbon:nitrogen ratio and **B** soil pH in all plots as a function of stand age. Squared regression coefficients and *P* values of linear regression are shown for the relationships (symbols for stand types are: unplowed: *HD* mixed oak, *SO* scrub oak; plowed: *AS* aspen, *PP* pitch pine, *HDP* mixed oak, *WP* white pine)

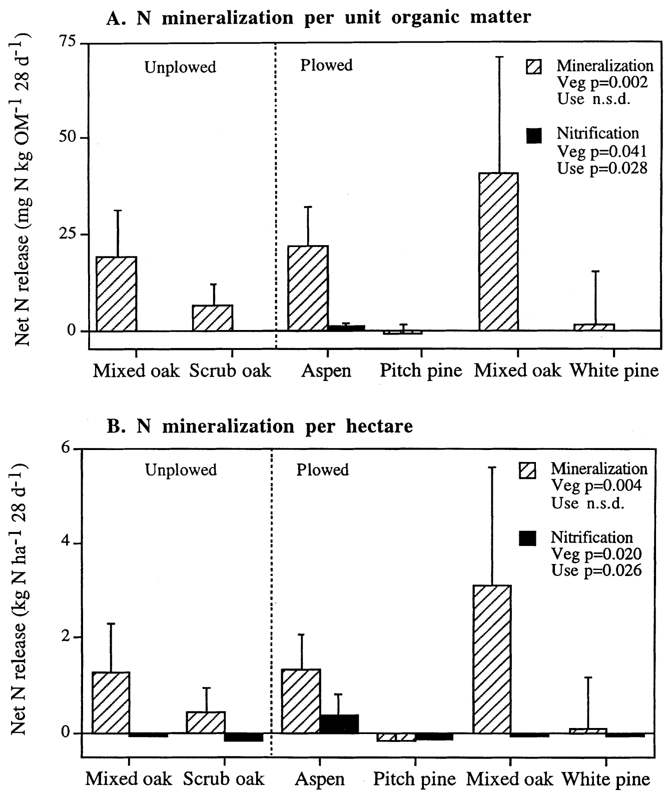

Fig. 3 August–September 1994 net nitrogen mineralization and nitrification **A** per unit organic matter and **B** per hectare in situ by stand type and land-use history. Results of one-way non-parametric ANOVAs on vegetation type or land use are shown, with plots nested within the main factor. *Bars* are standard errors between plots within each vegetation type ($n = 2$ or 4)

tionship was strongly controlled by one plot ($P = 0.228$ excluding this point).

No significant differences by land use or vegetation type were observed in soil nitrogen concentration or content (Table 2; Fig. 1). Carbon:nitrogen ratios were higher in the unplowed soils, and varied by stand type (Table 2). The lowest carbon:nitrogen ratios were in the aspen stands; ratios in the white pine and unplowed mixed oak soils were significantly higher. Soil pH was significantly higher in the aspen stands, while no overall land-use effect was detected (Table 2). Carbon:nitrogen ratio increased and pH decreased with stand age although the r^2 is low (Fig. 2). No other soil properties varied significantly with stand age.

Net nitrogen mineralization, whether expressed per area or per unit organic matter, varied among stand types but was not affected by land-use history (Fig. 3). Mixed oak and aspen stands had the highest mineralization rates per unit area and per unit organic matter, while scrub oak was intermediate and the pine stands had the lowest rates. The plowed mixed oak soils had higher mineralization than the pitch pine, white pine and scrub oak soils. Net nitrification was higher on plowed sites ($P = 0.028$ per unit organic matter; $P = 0.026$ per unit area basis), largely because of the higher rates in the aspen stands. All other sites exhibited low rates of net nitrate immobilization.

Discussion

Agricultural practices in the 19th and early 20th centuries apparently reduced surface mineral soil carbon and nitrogen contents, but this effect persists for only the most recently abandoned sites, 40–60 years after reforestation. The most recently abandoned aspen stand had 36% less carbon and 31% less nitrogen than unplowed sites and plowed sites abandoned earlier. These aspen stands were abandoned approximately 40 and 60 years ago (based on maximum tree age and aerial photography evidence), suggesting that more than 50 years of reforestation is required to accumulate levels found in surface soils of unplowed sites. Our findings are similar to those of Kalisz (1986) for abandoned sites in the Appalachians, where he found 32% less carbon in the 0–15 cm depth of soils abandoned 55 years previously. The other sites we examined were reforested for longer, and do not have significantly lower carbon contents in the surface mineral soil. Agricultural practices may affect soil carbon content less dramatically in soils with low inherent organic matter (Post and Mann 1990) such as these, although this conclusion was not supported by a more recent analysis (Davidson and Ackerman 1993). The increase in soil bulk density persists for a long period of time after abandonment in these soils, and to some extent offsets the differences observed in soil C concentration.

Measurement to a depth greater than 15 cm would provide a better estimate of the soil carbon recovery rate. Motzkin et al. (1996) also found less soil carbon in the 0–15 cm depth of plowed soils, but more carbon in the 15–30 cm depth, resulting in no overall effect. Their findings suggest that downward redistribution of carbon as a result of plowing rather than loss from the system contributes to the reduction of C in the upper soil. These sandy outwash-derived soils have a rather deep plow layer (21.5 cm average, ranging from 16 to 33 cm; Motzkin et al. 1996) compared with typical values of 15–20 cm for till-derived soils (Hamburg 1984; J.E. Compton, unpublished work). The 0–15 cm soil C content was negatively related to Ap horizon or plow layer depth, indicating that the depth of mixing is important in redistribution of C through the profile. Future assessments of management impacts on soil C distribution should include deeper sampling, perhaps to a fixed genetic horizon.

Soil carbon was more variable among sites and more strongly influenced by plowing and present vegetation than soil nitrogen (Fig. 1). Post and Mann (1990) found that soils generally lost a higher proportion of carbon (23%) than nitrogen (8%) upon cultivation. Low net nitrification, leaching and denitrification in these coarse-textured soils should result in low overall nitrogen losses. Nitrogen cycling rates at Montague Plain were much lower than the rates on a glacial till soil in central Massachusetts (8–10 kg N ha^{-1} $month^{-1}$ for N mineralization and 0–3 kg N ha^{-1} $month^{-1}$ for nitrification during August 1988 and 1990; Aber et al. 1993). This sandy outwash-derived soil has relatively low carbon and nitrogen concentrations, ranging from 2 to 5% carbon and 0.09 to 0.15% nitrogen in the 0–15 cm depth, much lower than soils derived from glacial till in central Massachusetts (0.26–0.36% N; Aber et al. 1993), and are more similar to values of 0.05–0.1% N for outwash sands in Minnesota (Pastor et al. 1987). Carbon:nitrogen ratios increased and pH decreased with stand age, implying that organic matter quality, microbial activity and the balance between litter inputs and decomposition vary with succession on Montague Plain.

While total carbon and nitrogen showed residual effects of land use in the most recently abandoned soils, net nitrogen mineralization was only affected by present vegetation types (Fig. 3). Net N mineralization and nitrification were measured during late summer when rates are typically high (Boone 1992); capturing seasonal patterns between stand types would require repeated sampling. Our findings suggest the importance of species differences in organic matter quality in affecting nitrogen cycling, specifically the difference between conifers and hardwoods. The white pine and unplowed mixed oak stands had very similar soil carbon and nitrogen content, but nitrogen mineralization in the white pine stand was only 10% that of the plowed mixed oak stand. Both stand types were among the oldest on the sand plain, hence there was no clear relationship between net nitrogen mineralization and stand age ($P = 0.247$). Net nitrogen release may be strongly affected by species effects on litter quality. Others have reported that lignin-to-nitrogen ratios ranged from 51 in white pine and 42 in lodgepole-jack pine to 29 in red oak and 21 in quaking aspen stands (McClaugherty et al. 1985; Taylor and Parkinson 1988).

Net nitrification was observed only in the aspen stands, where nitrification averaged 3 and 37% of net nitrogen mineralization per unit area in the two stands. Lime additions during the agricultural period may explain higher nitrification in these soils, since liming strongly increases nitrification rates in acid forest soils (Montes and Christensen 1979; Robertson 1982). There is little evidence for manure use during the 1800s (Motzkin et al. 1996), but the aspen sites were plowed into the mid-1900s when lime and inorganic fertilizers were widely available. The aspen soils had higher pH and extractable Ca and Mg, an indication of residual dolomitic lime, perhaps maintained for decades by high aspen litter Ca and Mg (discussed by Motzkin et al. 1996). Lower gross nitrate immobilization in plowed soils, reported for paired grassland and cropland comparisons (Schimel 1986), could also explain the higher net nitrification in the most recently abandoned sites.

We conclude that although there are striking long-term impacts of land-use history on vegetation patterns at Montague Plain (Motzkin et al. 1996), agricultural impacts persisted in only a subset of the soil properties examined. The increase in soil bulk density associated with plowing is a long-term legacy in these soils, and could influence soil water availability and root distributions. The unplowed soils had higher C:N ratios and slightly more soil carbon per gram soil. Only sites abandoned 40–60 years ago show residual impacts of cultivation on soil C content and nitrification. After reforestation proceeded for >50 years, carbon and nitrogen levels were quite similar to those in unplowed areas, and net nitrogen mineralization was controlled largely by tree species, presumably through litter quality differences, instead of by land-use history *per se*. Although plowing had important short-term effects on soil carbon storage, long-term impacts were not observed, indicating that the marginal agriculture at Montague did not dramatically influence soil properties other than bulk density. The impact of soil disturbance on the vegetation, notably the establishment of white pine and pitch pine stands in old fields, indirectly resulted in lower net nitrogen mineralization.

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