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Long-term effects of afforestation on soil characteristics and net nitrogen mineralization in sandy soils

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Summary

Afforestation can make a substantial contribution to soil characteristics and nutrient cycling. This study aims to determine the effects of two tree species (*Robinia pseudoacacia* L. and *Pinus nigra* Arnold.) on some soil characteristics and nitrogen mineralization four decades after the afforestation. Soil sampling was carried out in four seasons of a year at 0-10 and 10-20 cm soil depths. Soil samples were aerobically incubated under both field and laboratory conditions for 30 days to determine net nitrogen mineralization rate. Four decades after the afforestation, soil organic C and total N concentrations were considerably higher in planted areas in comparison to open field. Both species significantly increased net N mineralization under laboratory conditions whereas only black locust had a higher rate of mineralization in the field. Furthermore, nitrate was the dominant form of the mineral N, accounting for 60 to 100 percent of the mineral nitrogen for all types of cover. These results indicate that forest cover, especially the one with black locust, has a pronounced effect on soil C and N storage and cycling.

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1. Introduction

Mediterranean countries have put a lot of effort into afforestation projects in recent years to increase the quality and quantity of forest lands. In fact, Turkey has established forests on approximately 2 million ha of land since 1939 (Konukçu 2001). Black pine (*Pinus nigra* Arnold.) and black locust (*Robinia pseudoacacia* L.) have been among the most widely used species in these afforestation activities. Most of these activities have been carried out on somewhat marginal sites with poor soils, but their effects on nutrient storage and cycling has been poorly quantified.

Land use and plant species may have a profound effect on the ecosystem processes including nutrient cycling (Hobbie 1992; Kara and Bolat 2008). Afforestation with nutrient-demanding tree species with short rotations may lead to a decrease in soil nutrients (Ens et al. 2013); however, if the forest is established on a poor site, organic matter accumulates in the forest floor and soil in the medium to long term (Fernandez-Ondono 2010). The accumulated organic matter slowly decomposes and releases elements to serve as new sources of nutrients (Gurlevik et al. 2003). Among these nutrients, nitrogen (N) is considered as the most important nutrient limiting the growth of plants (Binkley et al. 1995). This limitation is mainly a result of the fact that soil N reserves are largely in organic form and this organic matter needs to be mineralized before uptake (Morris and Campbell 1991). Nitrogen mineralization is considered as one of the indicators of site productivity (Reich et al. 1997) and it depend mainly on quality of the organic matter (Powers, 1990; Stump and Binkley 1993, Scott and Binkley, 1997; Piatek and Allen 1999) and environmental conditions as they affect the microbial activities and control the movement of substrate and minerals within the soil (Stanford et al., 1973; Cassman and Munns 1980; Kladivko and Keeney 1987; Goncalves and Carlyle 1994; Sierra 1997; Zak et al. 1999).

Hobbie (1992) indicated that species might have more important effects than abiotic factors in controlling ecosystem fertility. Deciduous species provide less shelter for the ground in fall, winter and spring; therefore, soil is more exposed to direct sunlight and precipitation. On the other hand, coniferous species provide shelter to the ground in all seasons. Deciduous and evergreen species also produce litterfall in different quantities with varying quality. For example, it was reported that black pine plantations accumulated more organic matter on the forest floor and less organic matter in the mineral soil in comparison to black locust plantations (Karatepe 2005). It was also reported that black locust stands might be subject to more hot-water and KCl-extractable organic C and N, mineral N, microbial C and N, and enzyme activities in their soil in comparison to pine stands (Landgraf et al. 2005). These changes have a potential to influence nutrient cycling, especially nitrogen mineralization.

There is only a limited amount of information on N mineralization in Mediterranean ecosystems. This research was conducted to determine the effects of two commonly used tree species (black pine and black locust) on site characteristics; including (a) soil chemistry, (b) soil temperature and moisture regimes, and (c) net nitrogen mineralization under field (in-situ) and laboratory (ex-situ) conditions. We hypothesized that both species would improve soil C content in comparison to open field and, in turn, lead to increased net N mineralization.

2. Materials and methods

2.1. Study Area

The study was carried out in Gölcük Nature Park near the city of Isparta in Turkey. The park covers a total area of 5,925 ha, 83 ha of which is covered by a freshwater lake. Black locust, black pine and Taurus cedar (*Cedrus libani* Rich.) have been planted in the park since 1956 to prevent soil erosion and protect the water reserves. The site was declared as a Nature Park in 1991. Since then, all cultural activities were banned except for some mandatory protection and sanitation measures. This resulted in relatively undisturbed pure patches of forestland with different species within the park.

According to Thorthwaite method (Feddema, 2005), the site's climate is B2 B1‘ s2 b2‘, which refers to humid mesothermal climate with large water deficiency in summer (Kantarcı 1991; Karatepe 2005). The most dominant parent rock/material in the park is andesite, traki-andesite and Gölcük formation, which consists of loose mixtures of tuff, tuffite and pumice. In addition, there are some alluvial accumulations in the southern parts (Karaman 1986; Kuşçu and Gedikoğlu 1990). In this particular study area, the soil is sandy regosol at the foothills of surrounding mountains (Karatepe 2005), the slope of the land is less than 5 % and the elevation is approximately 1400 meters.

2. 2. Soil sampling

The study was conducted under three types of vegetation cover (black locust, black pine afforestation and empty field), at four seasons and two soil depths (0-10 and 10-20 cm) with three sampling plots as replicates for each cover type. Soil sampling and field incubations were carried out at three randomly selected sampling points within each plot.

Three adjacent sites which had different cover types and relatively similar site characteristics were chosen within the park. Both pine and locust sites were pure stands with full canopy closure, while the open site had less than 10 % canopy cover with scattered locust trees. The pine site had no understory vegetation while the black locust site had a thick layer of grass (Poaceae). The open field, on the other hand, was covered mostly with *Astragalus*, *Trifolium*, *Verbascum* and *Euphorbia* species (Fakir 1998; Karatepe 2005).

At the start of each sampling in the field, forest floor and any ground vegetation were removed aside carefully from the ground at three sampling points in each plot. Then, soil pits were dug up at approximately 20-30 cm depth. Nearly 500 mL of disturbed soil samples were taken from two consecutive depths (0-10 and 10-20 cm) and mixed quickly in a bucket to have a composited sample for each plot and soil depth. This composited soil was cleared of any extraneous material such as large stones, fresh roots during mixing. Some of the samples were used in the in-situ field incubation and the rest was taken to the laboratory in plastic bags in a cooler for ex-situ incubation and analysis. Moreover, soil temperatures were also measured at mid-day with a portable thermometer at the midpoint of each soil depth in the beginning and at the end of each sampling season.

2.3. Field and Laboratory Incubations

Mineralization was studied both under field and laboratory conditions. For the in-situ field mineralization, polypropylene cups (8 cm depth and 180 mL volume) were used as incubation containers. First, several small (2-3 mm) holes were punched at the bottom of the cups to allow vertical aeration inside the cup. Then, the cups were filled with composite soil samples and soil was compressed to approximately original bulk densities with a few taps at the bottom of the cup. Filled cups were placed upside down back to the soil pits at the corresponding depths in three sampling points within in each plot. Plastic lids were covered on top of the cups to prevent drainage from inside the cups during the incubation. Finally, the pits were filled back with soil and forest floor was laid back on the surface of the ground. After 30-day incubation period, each pit was carefully dug up; the incubation samples were lifted and transferred to laboratory in coolers for analysis.

Laboratory incubation was carried out on the same composite samples aerobically in an incubator at field capacity and 30 °C temperature for 30 days. Ten grams of soil samples were weighed into 50-mL polypropylene centrifuge tubes and capped loosely to prevent quick drying. Soil samples were taken out of the incubator every week for a short time for aeration and any lost water was supplemented to the tubes with some deionized water to bring the soil back to field capacity.

2.4. Extraction and Analysis

Soil samples were extracted before and after each incubation to determine initial (extractable) and final amounts of mineral nitrogen (NH_4^+–N and NO_3^--N). Ten grams of soil samples were shaken for one hour in 100 mL of 2M KCl solution for the extraction and then the amount of mineral N was determined with steam distillation method (Mulvaney 1996). Monthly net nitrogen mineralization was calculated by subtracting the initial amount of mineral N from the final values (Liu et al. 2014), assuming that there was no plant uptake or leaching of mineral nitrogen during the incubation period (Powers 1990). The increase in the amount of mineral N was assumed to account for the monthly net mineralization while the decrease was considered to represent immobilization. Another set of soil samples were dried in an oven at 105 °C for 24 hours to determine the gravimetric moisture content of the samples. Besides, the total N (semi-micro Kjeldahl), total organic C (Walkley-Black), pH (1:2.5 in H_2O), texture (hydrometer method) and field capacity (pressure plate method at 1/3 atmosphere suction) were determined in a mixture of composite soils extracted in two sampling seasons to have an overall representation of the soil characteristics. All laboratory analyses were performed in duplicates.

Analysis of variance was conducted to test the effects of cover types, season, soil depth and their interactions on the monthly estimates of extractable soil N as well as on in-field and laboratory mineralization. Furthermore, basic soil characteristics were also analyzed through analysis of variance. If the F test revealed any significant difference, Duncan's multiple range test were used to differentiate homogenous groups. Significance was agreed to be $p \leq 0.05$ for all analyses.

3. Results

3.1. Soil characteristics

The results show that the soils from the top 20 cm had sandy loam texture with less than 15 % of field capacity and were neutral to slightly acidic reaction (Tables 1 and 2). Forested sites were relatively similar to each other whereas open field tended to have more sand, less silt, lower field capacity and slightly higher pH. However, organic carbon and total N values were considerably different across the cover types and also depths. In comparison to open field, locust soils had 2.7 times more C and 2.3 times more N in the top 20 cm of the soil. Similarly, pine site had 2.1 times more C and 2.2 times more N. The higher C and N concentrations in the locust and pine sites essentially resulted from the top 10 cm of the soil. Especially in the locust site, top 10 cm of the soil had 4.7 and 3.9 times more C and N, respectively, than the lower layer.

Table 1: Basic soil characteristics of three different cover types and two depths in Gölcük Nature Park. Different letters indicate statistically significant difference at $p \leq 0.05$

Cover type	Depth (cm)	Sand (%)	Clay (%)	Silt (%)	FC (%)	pH (H_2O)	Organic C (mg g^{-1})	Total N (mg g^{-1})	C/N ratio
Locust	0-10	70.0	12.1	17.9	14.3	6.70	23.5	1.5	15.6
	10-20	70.7	14.3	15.0	11.0	6.94	5.0	0.4	15.1
Pine	0-10	64.9	13.4	21.6	15.2	6.86	14.2	1.1	13.5
	10-20	65.9	10.2	24.0	13.7	6.81	7.9	0.7	11.7
Field	0-10	80.8	9.8	9.4	11.1	7.05	7.0	0.4	16.2
	10-20	78.2	13.0	8.8	9.7	7.05	3.6	0.4	11.7
Locust	0-20	70.3ab	13.2	16.4a	12.6b	6.82b	14.3a	1.0a	15.3
Pine	0-20	65.4b	11.8	22.8a	14.4a	6.84b	11.0b	0.9a	12.6
Field	0-20	79.5a	11.4	9.1b	10.4c	7.05a	5.3c	0.4b	14.0

Table 2: Probability values from the analysis of variance for soil characteristics of three cover types and two depths. Significant differences at $p \leq 0.05$ were indicated in bold

Source	Sand (%)	Clay (%)	Silt (%)	FC (%)	pH (H_2O)	Organic C (mg g^{-1})	Total N (mg g^{-1})	C/N ratio
Cover	**0.008**	0.626	**<0.001**	**<0.001**	**0.001**	**<0.001**	**0.011**	0.586
Depth	0.920	0.676	0.850	**<0.001**	0.154	**<0.001**	**0.002**	0.298
Cover*Depth	0.868	0.231	0.571	0.093	0.067	**<0.001**	**0.022**	0.734

Seasonal changes in the soil moisture and temperature were considerably large and they showed opposite trends throughout the seasons (Fig. 1a and 1b). Gravimetric soil moisture content ranged mostly from 15 to 20 % in spring, late fall and winter with a maximum of 24 %, while it was as low as 1 % in the summer. On the contrary, soil temperature was between 17 and 30 °C in the summer, and it was as low as 0 °C in the winter.

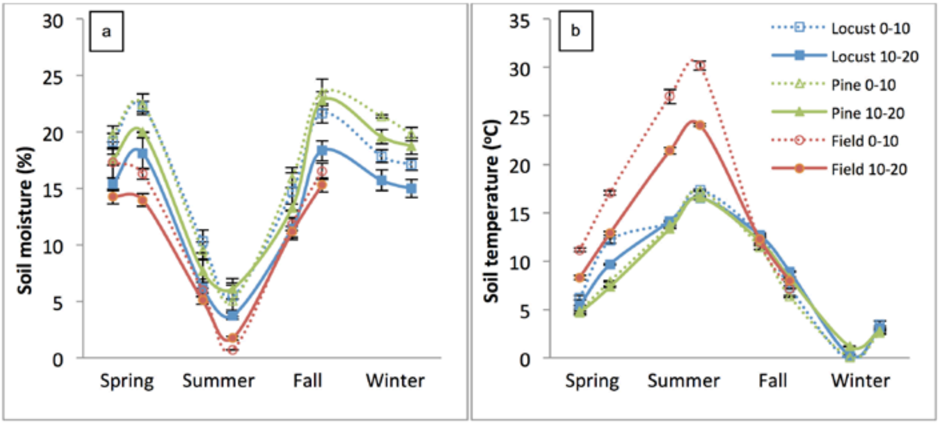

Fig. 1: Changes in (a) gravimetric soil moisture and (b) temperature in two soil depths (no measurements were taken in open field in winter due to frozen soil; error bars indicate 1 standard error of the mean)

Open field usually had less moisture and higher temperatures in comparison to the two other sites. The temperature difference was as large as 13 °C in the summer. Overall, the black pine had the highest amount of moisture and lowest temperature throughout the seasons. Soil temperatures showed great differences across the cover types and soil depths in spring and summer, while it was relatively similar for all cover types and soil depths in other seasons. The soil was frozen down to approximately 20 cm in open field in winter; therefore, no soil sample was taken from this particular site in winter. On the other hand, forested sites had freezing conditions only in top 1-5 cm of the soil profile.

3.2. Extractable N

Cover types, soil depth and season appeared to have an effect on the amount of extractable N (Table 3 and 4; Fig. 2a). In comparison to the open field site, the locus site had 3.9 times more extractable N, and the pine site had 1.5 times more N in the top 20 cm of the soil. In general, top soil had more N than the lower soil layer for all three cover types. Only in winter, the lower layer had more N than the top layer of the soil. Nitrate-N was the dominant form of N, accounting for an average 87 % of the total extractable N in the locust site, while 61 % in the pine and open sites for the top 20 cm of the soil. Ammonium-N did not vary significantly according to the cover type or season but the soil depth had a significant effect, with the topsoil having more ammonium.

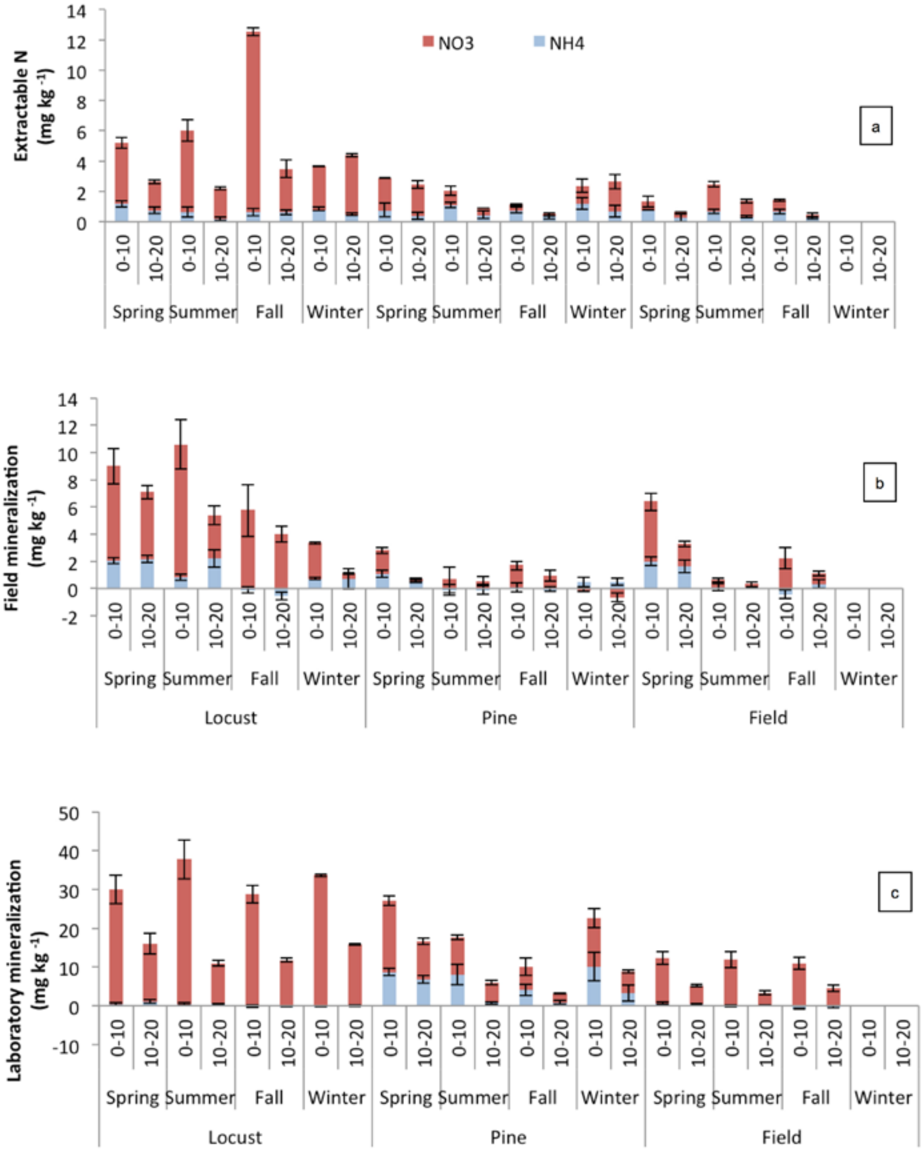

Fig. 2: Amount of (a) extractable N, monthly net N mineralization in the (b) field and (c) laboratory across three cover types, four seasons and two soil depths in Gölcük Nature Park. no measurements were taken in open field in winter season due to frozen soil (error bars indicate 1 standard error of the mean)

3.3. Net Mineralization

Net N mineralization under field and laboratory conditions was significantly affected by cover type, season and soil depth (Table 3 and 4; Fig. 2b and 2c). Overall, the locust site had the highest net mineralization under both field and laboratory conditions. However, in comparison to the open field, the pine site had greater mineralization under laboratory condition but had the least amount of mineralization under field conditions. Upper soil layer had about 2 times more N mineralization under both conditions. Laboratory mineralization was much greater than field mineralization for all cover types (4.0 fold for locust, 15.5 fold for pine and 3.5 fold for open site).

Table 3: Means of main effects from the analysis of variance for extractable soil N and monthly net N mineralization in the field and laboratory (mg kg-1). Different letters indicate statistically significant differences at $p \leq 0.05$

Source	Extractable N			Net field mineralization			Net lab mineralization		
	NH_4^+-N	NO_3^--N	Inorg. N	NH_4^+-N	NO_3^--N	Inorg. N	NH_4^+-N	NO_3^--N	Inorg. N
Locust	0.68a	4.35a	5.02a	1.01a	4.69a	5.70a	0.27b	22.78a	23.05a
Pine	0.73a	1.13b	1.85b	0.31b	0.59c	0.91c	5.35a	8.66b	14.01b
Field	0.50a	0.78c	1.28c	0.61b	1.63b	2.25b	0.00b	7.85b	7.85c
Spring	0.69a	1.83b	2.52b	1.58a	3.28a	4.85a	3.04ab	14.84ab	17.88a
Summer	0.57a	1.93b	2.50b	0.51b	2.48a	2.99b	1.64bc	12.95bc	14.59b
Fall	0.56a	2.68a	3.24a	-0.12c	2.55a	2.43b	0.60c	10.70c	11.30c
Winter*	0.81a	2.46a	3.27a	0.61b	0.57b	1.18c	3.32a	16.90a	20.22a
0-10 cm	0.85a	2.89a	3.73a	0.61a	3.28a	3.89a	2.87a	19.10a	21.97a
10-20 cm	0.44b	1.52b	1.96b	0.69a	1.46b	2.15b	1.22b	8.04b	9.26b

* No measurements were made in open field in winter due to frozen soil

Table 4: Probability values from the analysis of variance for extractable soil N and monthly net N mineralization in the field and laboratory

Source	Extractable N			Net field mineralization			Net lab mineralization		
	NH_4^+-N	NO_3^--N	Inorg. N	NH_4^+-N	NO_3^--N	Inorg. N	NH_4^+-N	NO_3^--N	Inorg. N
Season	0.514	**<0.001**	**<0.016**	**<0.001**	**<0.001**	**<0.001**	**0.006**	**0.002**	**<0.001**
Cover	0.317	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Depth	**<0.001**	**<0.001**	**<0.001**	0.606	**<0.001**	**<0.001**	**0.002**	**<0.001**	**<0.001**
Season*cover	0.252	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.049**	**0.006**	**<0.001**
Season*depth	0.905	**<0.001**	**<0.001**	0.354	0.505	0.626	0.362	0.260	0.059
Cover*depth	0.728	**<0.001**	**<0.001**	0.491	**0.008**	0.070	**<0.001**	**<0.001**	**<0.001**
Season*cover*depth	0.964	**<0.001**	**<0.001**	0.178	0.019	0.213	0.423	0.082	0.204

Nitrate was the main form of mineral N in both mineralization conditions. Overall, nitrate accounted for 82, 65 and 73 % of the monthly mineralization under field conditions and 99, 62 and 100 % of the mineralization under laboratory conditions for the locust, pine and open field site, respectively.

Laboratory and field mineralization data showed somewhat weak correlation when individual monthly data was used (Fig. 3). However, organic C and total N of the soil was also highly correlated (Fig. 4a). It also appeared that soil C consistently had positive effects on most forms of mineral N, explaining about 69 % of the variation in extractable N, 40 % of the variation in field mineralization and 89 % of the variation in laboratory mineralization (Fig. 4b, 4c, 4d).

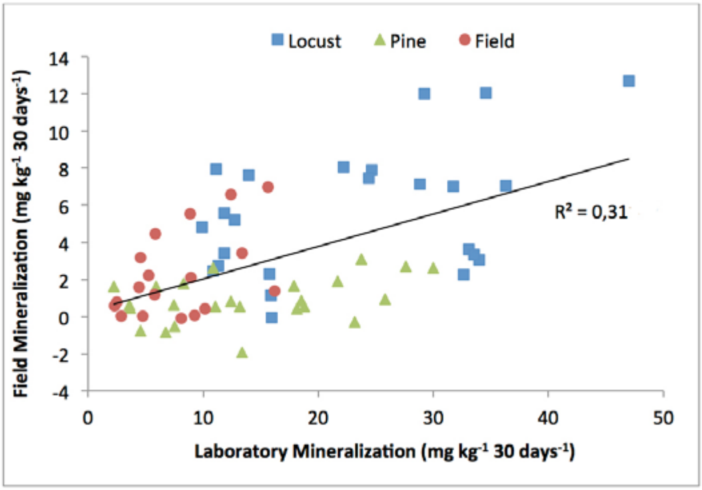

Fig. 3: Relationship between mean monthly net N mineralization (NH_4^+-N plus NO_3^--N) under laboratory and field conditions

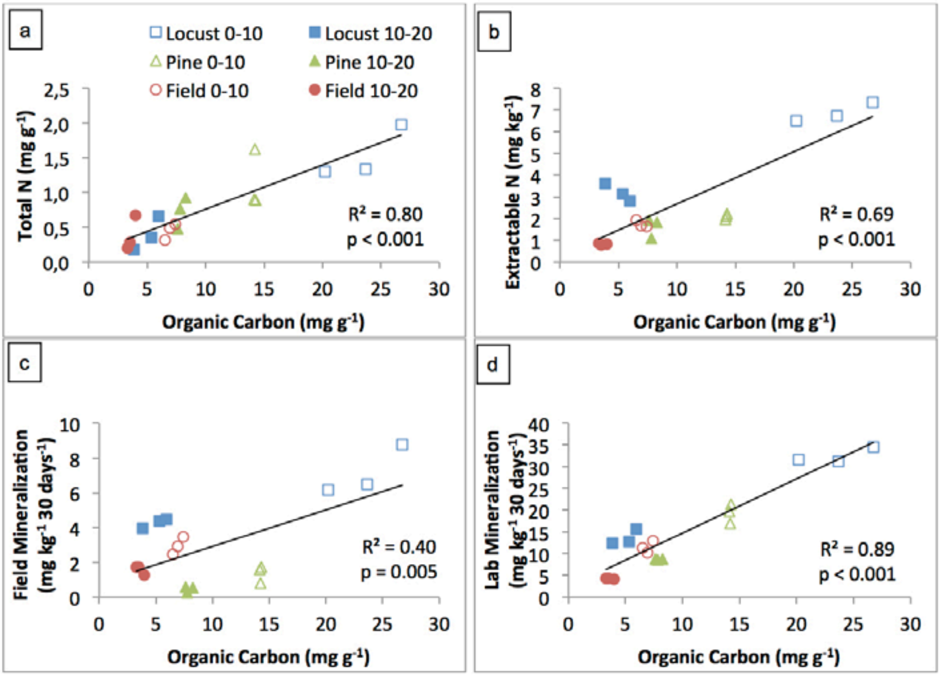

Fig. 4: Relationships between soil organic C and (a) total Kjeldahl N, (b) extractable N, (c) net field mineralization, (d) net laboratory mineralization in three cover types

4. Discussion

Afforestation has a large potential to change the dynamics of terrestrial ecosystems over time. After the establishment of a plantation, bare lands are covered with perennial woody trees and their canopy cover significantly changes microclimatic characteristics of the site and soil. In our study area, the open site had only a limited ground cover mostly with herbaceous vegetation and had direct exposure to sunlight and wind. This resulted in very high soil temperatures with very low moisture content in summer and freezing temperatures in winter. However, soils of the planted sites were cooler and more humid than the open site mainly due to the buffering effects of the canopy and litter covers above the soil, which blocked solar radiation and reduced surface temperature and evaporation (Boggs and McNulty 2009; Gray et al. 2002).

The most notable influence of afforestation was on C and N contents of the top soil. It was apparent that the open field had somewhat less soil organic C concentration (10 Mg ha^{-1}) than the locust (24 Mg ha^{-1}) and the pine soil (21 Mg ha^{-1}) in the top 20 cm of the soil. Inherently, low soil C and N content can be attributed to lack of vegetation cover and sandy texture of these soils (Chen et al. 2010). But after the introduction of afforestation, forest floor and top soil started to accumulate organic matter. Needlefall and fine roots were probably the main input of C to the forest floor and mineral soil in pine site, which had no understory vegetation. However, both litterfall and above- and belowground biomass of herbaceous understory vegetation contributed to soil C in the locust site.

Contrary to soil C, Karatepe (2005) found that the amount of organic matter in the forest floor was higher in the pine stands (34-46 Mg ha^{-1}) than in the locust stands (2-3 Mg ha^{-1}) in the same forest. The large difference between the amounts of forest floors may be explained by the differences in the stand structure (evergreen vs deciduous) and annual input and decomposition dynamics of the organic matter. De Marco et al. (2012) demonstrated that black locust litter decomposes five times faster than black pine litter at initial stages and then the rate of decomposition remains more or less the same for both species. In fact, in our study, there was very little visible locust litter left on the ground by the end of the vegetation season, but fresh or dead herbaceous biomass was always present on and in the ground all year long. This indicated that herbaceous biomass was the main form of organic matter in the soil of the locust site (Conant et al. 2001; Chen et al. 2010.) Positive effects of afforestation were also shown by other studies (Tremblay and Ouimet 2013) but it may take a long time to reach soil fertility status of native forests (Fernandez-Ondono 2010).

Our results revealed that the rate of nitrogen mineralization was significantly affected by afforestation and cover type. Both black locust and black pine increased the amount of extractable N and net N mineralization under laboratory conditions, but the increase was more evident in the locust site. Total soil organic C was the main driver in this increase, especially in laboratory mineralization (R^2=0.89) where environmental factors were fixed at optimum temperature and moisture levels. Similar to our results, Landgraf et al. (2005) showed that black locust stands had more available C and N, mineral N in comparison to Scots pine stands. They also showed that locust stands had more microbial biomass, which was positively related to the amount of readily available C. In addition to total organic C in the soil; faster fine root turnover, exudates and secretions from herbaceous ground vegetation under locust trees might have also contributed positively to the pool of available C in these soils (Hobbie 1992). Faster mineralization of N in locust sites was also reported in other studies (Rice et al. 2004).

Interestingly, pine afforestation significantly reduced net field mineralization of N. One possible reason may be the cooler soil temperatures under the dense cover of the pine canopy. In fact, pine stands were 6-13 °C cooler in spring and summer. The other possible reason for the reduced field mineralization in the pine stand is the recalcitrant nature of the pine litter. De Marco et al. (2012) indicated that pine litter provides relatively more aromatic C to the soil while locust provides relatively more aliphatic C during the decomposition and humification process, resulting in different qualities of soil organic matter.

It is generally assumed that undisturbed forest soils produce only a small amount of nitrate which is usually increased after a disturbance (Vitousek et al. 1979; Vitousek and Matson, 1985; Persson and Wiren 1995; Hart and Stark 1997). For example, net nitrification can be as low as 1-2 % of the total net mineralization in pine stands, but treatments such as vegetation control and fertilization can increase the proportion of nitrate up to 70-90 % (Gurlevik et al. 2004). However, this assumption is generally true for acidic soils. Neutral or alkaline soils may produce significant amounts of nitrate for both the forest and grassland soils (Paul and Clark 1989; Cheng et al. 2013). In our near-neutral soils, nitrate was the primary form of mineral N for all cover types. In fact, pine soils always had the least proportion of nitrate, but still accounted for 61-65 % of the total extractable or mineralized N in our study. Under the laboratory conditions, nitrate accounted for up to 100 % of the total mineralized N for the locust and open sites. Higher nitrification in locust and grasslands was also observed in other studies probably due to the continuous input of symbiotically fixed N and greater amount of mineralizable organic matter (Boring and Swank 1984; Unver et al. 2012). Depending on site and stand characteristics, black locust forests can fix 30-110 kg N per hectare, annually (Boring and Swank 1984, Danso et al. 1995). The fixation of N not only increases soil N concentration, but also reduces soil pH, especially through the process of nitrification. These differences in net nitrification between pine and locust sites also reflected in soil pH during the incubation. After 30 days of incubation in the laboratory, actual soil pH was reduced by 0.98 unit in locust soil and 0.50 unit in pine soil (data not shown).

Our results also indicated that net N mineralization was 3 to 15 times higher in the laboratory, and the results of field and laboratory mineralization were poorly correlated (R^2=0.31). Higher mineralization rates were somewhat expected since the rate of mineralization is closely related to environmental factors such as temperature and moisture. It is well documented that mineralization rate is increased when temperature is around 25-30 °C and moisture is near field capacity (Cassman and Munns 1980; Kladivko and Keeney 1987; Goncalves and Carlyle 1994; Sierra 1997). In our study, soil temperatures and moistures rarely reached these levels in the field, while they were kept at the optimum level in the laboratory.

5. Conclusion

Dry sandy soils inherently lack vegetation cover, stored C and nutrients, and they should be managed with great care since they are in tight nutritional budget. Afforestation has a great potential to alter the chemical and physical site conditions and improve fertility of a site through accumulation of organic matter and plant nutrients over time. However, our research showed that only black locust increased net N mineralization under field conditions, even though both species had higher mineralization under laboratory conditions. This indicated that pine stands tend to store nitrogen in soil organic matter while black locust has a faster turnover of soil N. In addition, significant proportion of mineral N was in the form of nitrate, which can be leached easily. Disturbances to such ecosystems can alter nutrient storage and cycling processes and can result in loss of nitrate. Therefore, minimal disturbance should be the key idea, since the extent of erosion or losses of the nutrients due to leaching might be large and detrimental to these poor soils.

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