NITROGEN DYNAMIC BENEATH FIVE TREE SPECIES IN IRRIGATED PLANTATIONS IN PAKISTAN

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ABSTRACT

In irrigated plantations of Punjab extensive management results in nutrient deficiency and tree growth becomes N limited on sites where non dinitrogen - fixing species are raised. The fast growing hybrid poplar and mulberry deplete the soil of its essential nutrients. The soils under *Pinus roxburghii* Sarg., Leucaena and *Eucalyptus camaldulensis* Dehn. show increased net nitrogen mineralization rates, whereas continuously grazed and leaf-litter harvested sites of mulberry and hybrid poplar (I-214) have comparatively low total soil nitrogen, net nitrogen mineralization rates and, consequently, low N assimilation.

INTRODUCTION

In the warm-temperate thorn-woodland zone of eastern Punjab, Pakistan (Holdrige 1967), where there is less than 500 mm of monsoonal rainfall, native and exotic tree species are grown in intensively managed, irrigated plantations. These species, which are growing outside of their normal ecological niche, are managed to produce timber, fiber, and fuelwood for domestic needs. They are also used for grazing, sericulture (silk production), and recreation. Harvest of wood and forage form these areas is very thorough, and this, coupled with irrigation and the relatively high temperatures of the area, produces unique soil and nutrient cycling conditions. The purpose of this study was to document the nitrogen dynamics in irrigated plantations of sevral introduced tree species.

Enrichment of soil N by dinitrogen-fixing rhizobia associated with leguminous tree species has been extensively studied. Such species increase soil N content and N mineralization rates (Spier *et al.* 1982, Lajtha and Schlesinger 1986, Montagnini *et al.* 1986, Hirschfeld *et al.* 1987, Javid and Fisher 1989). We wished to know how other species, most not dinitrogen fixers, affect N dynamics in intensively managed, irrigated plantations.

STUDY AREA

This study was carried out on the Changa Manga plantations, located between latitude 31°1' to 31°7' N and longitude 73°56' to 74°4' E, 75 km SE of Lahore, Pakistan. The soils of the area are the deep, alluvial silt loams of the Indus plain (Bokhari 1973). They are alkaline but not saline and heavy with very narrow C:N ratios (Table 1). The tree species studied were hybrid "Euramerican" a poplar (***Populus deltoides*** x ***P. nigra*** 'I-214), leucaena (***Leucaena leucocephala*** [Lam.] de Wit), chir pine (***Pinus roxburghii*** Sarg)., river red gum (***Eucalyptus camaldulensis*** Dehn.), and mulberry (***Morus alba*** L.).

Hybrid poplar was introduced in Pakistan during 1959; clones were imported from the U.S.A., U.K., Italy and other countries. The study plot had a pure stand of hybrid Euramerican a poplar. 'I-214' located in a compartment that in the past had been planted with Shisham (*Dalbergia sissoo* Roxb. ex DC). The poplars were planted in 1981-82 at a spacing of 5.48 x 5.48 m. For the first three years, the plantation was intercropped with turmeriĉ by local farmers as a weed-control measures. Leaves from the stand have been collected as a fuel source by local villagers, and the study area has been grazed since cropping ceased.

The leucaena plot was planted at a spacing of 1.5 x 3.0 m in ,June, 1968. Grazing and removal of leaf litter have not been practiced in this area. By the time of the study, the stand had complete canopy closure and a very dense seedling understory. The soil had distinct L, F, and H organic horizons, a type of profile development that is observed only in the absence of leaf-litter removal and grazing.

The chir pine plot was planted in August, 1955 at a spacing of 3.0 x 3.0 m. Restocking of the area was carried out in March 1963. This plot had been protected from grazing and litter gathering. The soil had a well-developed L horizon, but F and H layers were not present.

The red-gum plot was planted in December, 1962 with initial spacing of 1.5 x 3.0 m but had been thinned to a spacing of 3.0 x 3.0 m. This area had not been grazed, nor had litter been collected. The soil had well-developed L, F, and H organic horizons, and pronounced earthworm activity was observed at the time of soil sampling.

The mulberry study site was located in a forest compartment that had been previously vegetated by *D. sissoo*. The area was planted in 1983-1984 at a 1.5 x 1.5 m spacing to meet the local demand for mulberry leaves in sericulture. The area had also been grazed by livestock.

METHODS

The buried-polythene-bag technique was used to evaluate nitrogen mineralization rates *in situ*. This procedure has been used extensively by Gordon (1986), Nadelhoffer *et al.* (1984), Melillo (1977), and others. Net change in NH_4 -N and NO_3 -N over time was measured by comparing the before and after incubation values. The assumption was made that the polythene bags prevent any leaching loss or plant uptake of nitrate and ammonium. The polythene bags (0.02 mm) do allow O_2 and CO_2 diffusion, thus aerobic conditions were maintained in the enclosed soil, and it also experienced normal diurnal temperature changes (Gordon 1986, 1979).

In each stand, five sampling locations wre randomly chosen. Litter was removed and initial soil samples were taken from the 0-15 depth. A subsample was saved for analysis; 200 grams of soil were brought to a water content approximately 80% of field capacity and placed in a bag made of 0.02 mm thick polythylene. The bags wre sealed and buried in the soil at a 15 cm depth. The site was leveled and litter was replaced.

Incubations were carried out on each site for exactly 30 days. At that time the bags were collected, and a final soil sample was taken at each site to assay for N uptake by vegetation (Nadelhoffer *et al.*, 1984). All soil samples were stored at -10ºC in the soil testing laboratory at Lahore.

For analysis, 5 g samples were air dried, ground, and sieved and mixed with 1N K_2SO_4 extracting reagent. After a 15 min shaking, the samples were filtered; and 7.0 ml of clear alequot, 4 ml of sodium phenate and 3.0 ml of sodium hypochlorite (1.5%) were added to each sample. After mixing on a vortex mixer, the samples were placed in a water bath at 70ºC for 20 min and then allowed to cool for 30 min at room temperature, 21ºC (O'Brien and Fiore 1962). Absorbance was measured at 660 nm. Values were compared to a standard curve to detrmine ammonium-N content.

For nitrite and nitrate determination, prepared soil samples (2.5 g), along with 0.25 g of washed carbon black, were treated with 50 ml 0.5 M $NaHCO_3$ extracting solution. Samples were shaken for 30 minutes and filtered through Wahtman No.42 filter paper. One ml of extract was then treated with 3.0 ml of copper-sulfate solution, 2.0 ml of hydrazine-sulfate solution, and 3.0 ml of sodium-hydroxide (0.3 N) solution. The samples were mixed and placed in a water bath at 38°C for 20 min. After mixing and heating, 3.0 ml of colour reagent (5 g sulfanilamide and 0.25 g N-(1-napthyl)-ethylenediamine dihydrochloride in 30 ml concentration H_3PO_4 300 ml of water and 30 ml concentration $H_3 PO_4$) was added and allowed to stand for 20 min at 21°C (Hamm *et al.* 1970, Kamphake *et al.* 1967). Absorbance was determined at 540 nm, and NO_3-N concentrations were calculated from a standard curve. General soil physical and chemical properties were determined by using soil characterization procedures at the Soil, Plant and Water Analysis Laboratory of Utah State University.

RESULTS AND DISCUSSION

Ammonification, nitrification, and net N-mineralization rates were markedly different in soils vegetated by the different tree species (Table 5.2). Analysis of variance of the completely randomized design showed significant differences in mean values for all parameters (α - 0.05). Duncan's multiple range test was performed to determine differences between means, and significant differences (α - 0.05) were shown (Table 2). Soils of red-gum sites had high rates of ammonification, nitrification and net N mineralization. Soils of mulberry sites exhibited high rates of ammonification (12.11 kg ha^{-1}), but nitrification (14.11 kg ha^{-1}) and net N mineralization were low as compared to pine-chir and leucaena sites. The rates of N transformations in soils of hybrid poplar were consistently low. Surprisingly, soils at chir pine and red gum sites had higher rates of net N mineralization than the soils beneath dinitrogen-fixing leucaena (Table 2).

It is evident from Table 2 that nitrification is a dominant process in soils at all study sites. Net N mineralization is more closely correlated to nitrification (R - 0.88) than to ammonification (R - 0.26) and is related by the equation Y - 0.89 x - 0.89 x + 10.52, where x - mean nitrification, and y - net N mineralization.

It is notable that soils at the dinitrogen-fixing leucaena site have the second highest total N (Table 1) and initial ammonium-plus-nitrate N values, whereas soils beneath river red gum have remarkably high total N and initial NH_4-N and NO_3-N. All of the study sites previously supported dinitrogen-fixing *D. sissoo* stands. This likely accounts for their narrow C:N ratios. We cannot explain the high N content and nitrification rates of the red gum site. Hopmans *et al.* (1980) reported very low nitrification rates beneath native *Eucalyptus* stands in Australia. Higher temperatures, high pH, a previous crop of dinitrogen-fixing trees, and cultivation may have combined to make our red gum site anomolous.

The mulberry and hybrid-poplar sites were subject to grazing and leaf litter removal. This may account for both the low total N (Table 1) and rather slow N-turnover rates on these sites. Soils of the mulberry sites, however, exhibited one of the highest ammonification rates. Competition for ammonium N may have been very high at this site, thus reducing the substrate available for nitrification.

Nitrate nitrogen was the dominant form of nitrogen taken up by all tree species (Table 3). All values for ammonium nitrogen, except that for the red gum site, were negative. Nadelhoffer *el al.* (1984) concluded that negative values do not have any biological significance and are simply a result of sampling error. We presumed that nitrification rates may be stimulated in the enclosed environment of the polythylene bag by lack of competition for ammonium N. Nonetheless, net N mineralization should have remained unchanged. There were no significant differences in ammonium uptake by plants among sites. Thus there was no significant correlation between ammonium N uptake and ammonification, although ammonification varied significantly among sites (Table 2).

Nitrate-N uptake and total N uptake by plants varied significantly (α - 0.05) among sites. Red gum and leucaena took up significantly more N than hybrid poplar and mulberry (Table 3). Uptake by chir pine was intermediate between the high and low-uptake groups. In the study area, leucaena had the highest mean-annual-growth increment (29 m^3 ha^{-1} ye^{-1}), followed by hybrid poplar (15 m^3 ha^{-1} yr^{-1}), red gum, mulberry, and chir pine (Bokhari 1973). There was no correlation between the annual growth rate of these trees and N uptake (Table 3), but there was a good correlation between total N uptake for each species and the total (NH_4 + NO_3) N after a 30-day incubation at each site (R - 0.91, Y - 35X + (-5.16), where Y - total nitrogen uptake in kg ha^{-1} per 30 days). There was also a positive relationship between total N uptake for each species and the net N-mineralization rate of each site (R - 0.75, Y - 1.087X -10.31, where Y - total N uptake, and X - net N mineralization).

The soil at the mulberry site had a low total N (Table 1), a low net N mineralization rate (Table 5.2), and low N uptake (Table 3). Thus, the low nitrification rate cannot be explained by competition for ammonium N. It appears that the rapid growth and continuous harvest of leaves from hybrid poplar and mulberry plots stress the N cycle. In the chir-pine stand there was no grazing or litter harvest, and, although total soil N was low, net N mineralization was high, and this relationship sustained moderate rates of N uptake by plants.

Our study areas were located in sites that had been enriched in N by several rotations of dinitrogen-fixing *D. sissoo*. The management system used in these rotations apparently narrowed the soil C:N ratios (Javid and Fisher 1989). Non-dinitrogen-fixing species, subject to continuous grazing and leaf-litter harvest, appears to deplete available N, and tree growth apparently becomes N limited. Sites with non-dinitrogen-fixing species that were not subject to grazing and leaf litter removal had maintained or improved N content in the soil. The leucaena site had the highest negative value for NH_4-N uptake. The high nitrification rate in this stand determines the fate of available nitrogen and may lead to nitrate leaching (Montagnini *et al.* 1986). It appears that silvicultural practices, which alternate dinitrogen-fixing and non-dinitrogen-fixing tree species or grow them in a mixture would be a prudent practice in these intensively managed irrigated plantations.

Table 1 Some physical and chemical properties of soils under different introduced forest-tree species on an irrigated plantation

Tree species	pH	Ece mmhos/cm	Extractable P ppm	Extractable K ppm	%O.C	%T.N.
E. camaldulensis	7.8	0.8	6.0	>400	2.08	.45
L. leucocephala	7.7	0.5	3.0	166	1.30	.14
M. alba	8.0	0.4	7.8	290	1.34	.10
P. roxburghii	7.9	1.9	4.0	257	0.83	.11
Hybrid poplar I-214	7.8	0.6	4.4	264	1.45	.15

Table 2 Ammonification, nitrification, and net nitrogen mineralization in field soil (0-15 cm) of an irrigated plantation under different canopy covers

Species	NH_4-N		NO_3-N + NO_2-N				
	Incubated soil	Initial	Net Ammonifi-cation	Incubated soil	Initial	Net Nitrifi-cation	Net N Minera-lization
			kg ha^{-1}				
[1]*Morus alba*	31.32* (13.15)	19.21 (5.76)	12.11[bc,1]	27.37 (5.40)	12.60 (3.86)	14.77[a]	26.88[ab]
Pinus roxburghii	18.52 (3.54)	13.00 (3.52)	5.52[ab]	59.45 (8.11)	18.51 (3.07)	40.94[b]	46.46[c]
Leucaena leucocephala	27.17 (6.11)	24.21 (6.59)	2.96[a]	92.04 (10.55)	58.57 (9.28)	33.47[b]	36.43[cb]
Hybrid poplar	22.55 (6.48)	20.22 (6.63)	2.33[a]	31.05 (6.97)	14.43	16.62[a]	18.95[a]
Eucalyptus camaldulensis	45.39 (2.96)	30.91 (2.98)	14.48[c]	107.29 (18.22)	79.78 (4.59)	27.51[ab]	41.99[cb]

* Mean and (S.D.)

[1] Means having the same letter within a column were not significantly different by Duncan's multiple-range test (α - 0.05)

Table 3 Nitrogen uptake of different forest-tree species in irrigated plantation soil (0-15 cm) for a period of 30 days

Scpecies	NH_4-N Incubated soil	NH_4-N Final non-incubated soil after time t	NH_4-N uptake	NO_2+NO_3-N Incubated soil	NO_2+NO_3-N Final non-incubated soil after time t	NO_2+NO_3-N uptake	Total N-uptake
Morus alba	31.32[1] (31.52)	36.72 (9.12)	-3.3[a2]	27.37 (5.40)	17.35 (6.66)	10.01[a]	6.62[a]
Pinus roxburghii	18.52 (3.54)	19.37 (6.43)	-0.86[a]	59.45 (8.11)	28.51 (15.65)	30.99[bc]	30.09[bc]
Leucaena Leucocephala	27.17 (6.11)	37.70 (11.43)	-10.51[a]	92.04 (10.55)	40.66 (8.25)	51.38[d]	40.85[c]
Hybrid poplar	22.55 (6.48)	25.20 (4.73)	-2.65[a]	31.05 (6.97)	14.79 (9.59)	16.26[ab]	13.61[ab]
Eucalyptus camaldulensis	45.39 (2.96)	43.76 (4.44)	1.64[a]	107.29 (18.22)	66.02 (8.61)	41.28[cd]	42.90[c]

1 Mean and standard error

2 Means followed by the same letter in a column are not significantly different (α - 0.05) by Duncan's multipele range test.

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