Tropical Ecology **47**(1): 99 -107, 2006 ISSN 0564 -3295

www.tropecol.com

Nitrogen availability and N-mineralization under different land use types in the humid tropics of Arunachal Pradesh

KUSUM ARUNACHALAM & A. ARUNACHALAM*

Department of Forestry, North Eastern Regional Institute of Science and Technology,
Nirjuli 791109, Arunachal Pradesh, India

Abstract: Nitrogen (N) availability and N-mineralization rates were characterized in three tropical ecosystems under different land use, viz., paddy field, shifting agricultural (jhum) fallow and forest. The soil was sandy loam and acidic in all three sites.Variation in soil organic carbon between the sites was small. However, total N was highest in the jhum fallow. Soil C/N ratio, organic carbon and pH were greater at lower depths than the top 0-10 cm soil layer. Total N concentration was higher in the top soil layer. Ammonium concentration was greater than nitrate in both soil depths (0-10 and 10-20 cm) across sites and seasons. Available-N (ammonium+nitrate) was comparatively greater in agricultural systems than the forest. Ammonification, nitrification and net N-mineralization rates were significantly different between sites and soil depths and seasons. Net N-mineralization rates were significantly higher during rainy season and lower during winter. Average net N-mineralization rate was highest in jhum fallow (1.47 g m^{-2} yr^{-1}), followed by paddy field and forest.

Resumen: La disponibilidad de nitrógeno (N) y las tasas de mineralización de N fueron caracterizadas en tres ecosistemas tropicales bajo diferentes uso del suelo: arrozal, barbecho de agricultura trashumante (*jhum*) y bosque. El suelo fue franco arenoso y ácido en los tres sitios. La variación en el carbono del suelo entre sitios fue pequeña; sin embargo, el N total tuvo su valor máximo en el barbecho de *jhum.* El cociente C/N, el carbono orgánico y el pH del suelo tuvieron valores más altos a mayores profundidades que en la capa superior de 0-10 cm de suelo. La concentración total de N fue más alta en la capa superior del suelo. La concentración de amonio fue mayor que la de nitrato en ambas profundidades del suelo (0-10 y 10-20 cm) en todos los sitios y estaciones. El N disponible (amonio + nitrato) fue comparativamente mayor en los sistemas agrícolas que en el bosque. Las tasas de amonificación y nitrificación, y la tasa neta de mineralización de N fueron significativamente diferentes entre sitios, profundidades del suelo y estaciones. Las tasas netas de mineralización de N fueron significativamente mayores durante la época de lluvias y menores durante el invierno. La tasa neta promedio de mineralización de N tuvo su valor más alto en el barbecho de *jhum* (1.47 g m^{-2} $año^{-1}$), seguida por el arrozal y el bosque.

Resumo: A disponibilidade de azoto (N) e taxas de mineralização de N foram caracterizadas em três ecossistemas tropicais sob diferentes usos da terra, *viz.* campos de arroz, agricultura itinerante pousio (jhum) e floresta. O solo era uma argila arenosa e acídica nos três sítios. A variação no carbono orgânico do solo entre os três locais era muito pequena. Contudo, a concentração do N total era mais elevada na camada superior do solo. A concentração em amónio era maior do que a de nitrato em ambas as

---

[*] *Corresponding Author;* e-mail: arunachalam_in@yahoo.com

profundidades consideradas (0-10 e 10-20 cm) através dos sítios e estações. O azoto disponível (amónio + nitrato) era comparativamente maior nos sistemas agrícolas do que na floresta. A amonificação, nitrificação e taxa de mineralização líquida de N foram significativamente diferentes entre sítios, profundidades de solo e estações. As taxas de mineralização líquida de N foram significativamente mais elevadas durante a estação de chuvas e menor durante o Inverno. A taxa média de mineralização liquida de N foi mais elevada no pousio 'jhum' (1,47 g m^{-2} ano^{-1}) seguida pelos campos de arroz e floresta.

Key words: Ammonium, ammonification, mineralization, nitrate, nitrogen, nitrification, shifting agriculture, tropical forest, wet-paddy cultivation.

Introduction

Nutrient cycling in agroecosystems is crucial in order to sustain future crop production (Tiessan *et al.* 1982, 1994). Several studies worldwide have concluded that nitrogen (N) is crucial to terrestrial production, particularly in tropical ecosystems such as forest and agroecosystems (Chao *et al.* 1993; Firestone 1982; Gorham *et al.* 1979; Vogt *et al.* 1986). Some studies have revealed the dynamics of total and available forms of nitrogen (N) in terrestrial ecosystems (e.g. Birk & Vitousek 1986; Olsson & Fakengren-Grerup 2000), and have shown that plant detritus and microbial biomass are major sources of N to the ecosystems (Johnson *et al.* 2000; Zogg *et al.* 2000). It is also established that soil microbes decompose organic materials and releases nutrients, thus mediating nutrient cycling and regulating plant and soil nutrient budget (Maithani *et al.* 1998a; Swift *et al.* 1979). Soil nutrient mineralization in an agricultural system depends on many external (organic stock, weed management, chemical application) and internal (texture, moisture) factors (Kumar & Goh 2000; Wang & Alva 2000). However, these factors tend to vary with ecosystems at various agro-climatic conditions.

In the humid tropics of Arunachal Pradesh in northeastern India, agriculture is primarily rainfed and is of two types: (i) wet-paddy cultivation system in the foothills and valleys, and (ii) slash-and-burn agriculture (locally called 'jhum') on the hill slopes (Arunachalam & Pandey 2000). Both these systems are usually managed under low to no-input conditions (e.g. fertilizers), and are poorly weeded (Arunachalam & Pandey 2003). Such management practices would result in differential behaviour of soil nutrients when compared to well-managed agroecosystems (Ramakrishnan 1992). It is hypothesized that land use and land cover types affect soil nutrients, particularly N. We studied the N availability and its mineralization in three ecosystems such as, paddy field, jhum fallow, and forest in a humid tropical belt in Arunachal Pradesh, India. The results have been discussed to discern changes due to land use types.

Materials and methods

Study area

The study was carried out during January, April, July and October (year 2001) representing winter, spring, rainy and autumn seasons in a humid tropical forest zone in the foothills (Nirjuli) of the Indian eastern Himalayas, Arunachal Pradesh (26°28'-29°30'N latitude; 91°30'-97°30'E longitude). Here jhum is practiced by the 'Nyishis', one of the major tribes of the State. The area receives moderate to high rainfall (average annual rainfall is 2500 mm). The rainy season extends from May to October, followed by a brief autumn (October-November) and winter between December to February; March-April represents spring with a dry-warm climate. Average monthly maximum and minimum temperatures were 34°C and 22°C respectively, and relative humidity was 60-80%.

Study site

We selected a paddy field (representing a settled form of valley cultivation system; 0.72 ha), a jhum land (3 year old fallow; 0.45 ha) and a forest stand (25 year old; 2 ha) in the humid tropical belt at lower elevations of Arunachal Pradesh (Kheel in Sagalee circle in Papum Pare district; < 310 masl). In the paddy field, monocropping was done during previous monsoon (year 2000) with no chemical input. The grains were harvested during October-November, and the crop was cut 5-10 cm above the ground for cattle feed. A few herbaceous plants were interspersed in the site. The jhum land was cultivated (mixed-cropped) with *Oryza sativa* (paddy), *Eleucine corocana* (ragi), *Zea mays* (maize), *Manihot esculenta* (tapioca), *Brassica juncea* (cabbage), *Cucurbita maxima* (pumpkin) and *Musa sapientum* (banana), 3 years previously under an 8 year jhum cycle, and had fallow vegetation. The forest stand was a social forestry plantation raised 25 years ago, and located within 1 km radius of the other two study sites. This site was dominated by tree species such as *Mesua ferrea, Duabanga grandiflora, Tectona grandis* and *Shorea robusta*.

Sampling and analytical procedures

Fifteen randomly located soil cores (6.5 cm inner diameter) at two soil depths (0-10 cm and 10-20 cm) in all three sites were collected during winter, spring, rainy and autumn months. During each sampling, the soil samples were pooled site-wise to form a composite sample, sieved through a 2 mm mesh screen, and brought to the laboratory to determine soil physico-chemical characteristics. Soil moisture content (SMC), pH, ammonium-N and nitrate-N were determined immediately within 24 hours of collection following methods outlined in Anderson & Ingram (1993). A part of the composite soil sample was air-dried, and analyzed for total Kjeldahl nitrogen (TKN), water holding capacity (WHC), texture and soil organic carbon (SOC) following semi-micro Kjeldahl, Keen's box, Boyoucous Hydrometric and rapid-titration methods, respectively (Allen *et al.* 1974; Anderson & Ingram 1993).

In-situ N-mineralization in soil was also measured seasonally at two depths (0-10 cm and 10-20 cm) using buried-bag technique (Eno 1960). Five paired soil cores were collected in each site. One of the cores from each pair was sealed in sterile polyethylene bag after removing coarse roots and larger organic debris, and reinserted to its respective depth. The other soil cores were brought to the laboratory, composited by depth in each stand, sieved (2 mm) and initial soil moisture content (SMC) and ammonium and nitrate concentrations were determined. After one month, the buried bags were retrieved and the soil samples were pooled according to depth and analyzed for final ammonium and nitrate concentrations. Changes in ammonium and nitrate concentrations were obtained by subtract-ing initial concentration from corresponding final concentration, and the resultant values were referred to as ammonification and nitrification rates, respectively. Net N-mineralization was calculated as the sum of changes in extractable ammonium-N and nitrate-N over one month. All analyses used five replicates and the results have been expressed on an oven-dry mass basis (24 h at 105°C). N-mineralization rate was expressed as g m^{-2} yr^{-1}

In all three sites, density and frequency of constituent plant species were also determined using five 10 m x 10 m quadrats for the woody vegetation and five 1 m x 1 m quadrats for the ground vegetation (Misra 1968).

Statistical analysis

Tukey's test was carried out to compare the mean values across the sites, soil depths and sampling months. Correlation analysis was done following Zar (1974) to study the relationship among soil characteristics.

Results

Community characteristics

There were 9, 14 and 16 plant species in paddy field, jhum fallow and forest stand, respectively (Table 1). Tree species dominated the forest site as expected. A few *Terminalia* individuals along with bamboos and tree ferns were interspersed in the jhum fallow. In the wet-paddy field, since harvesting was completed well before our sampling started, we could not count the paddy plants there. But, we identified

Table 1. Species composition, density (plants m^{-2}) and frequency (%) in study sites.

Species	Paddy field		Jhum		Forest	
	Density	Frequency	Density	Frequency	Density	Frequency
Herbaceous						
Ageratum conyzoides	7.6	100	2.33	66	-	-
Polygonam sp	5	100	0.66	33	-	-
Arundinella bengalensis	7	100	4.66	100	5.66	100
Commelina benghalensis	0.66	33	-	-	-	-
Vinca sp.	0.33	33	-	-	-	-
Malastonia merlabathricum	-	-	-	-	0.66	66
Achyranthus aspera	-	-	1.0	33	-	-
Alternathera sessilis	-	-	-	-	1.0	66
Gnaphelium indicum	1.33	66	-	-	0.66	66
Parthenium hysterosporus	0.66	66	1.33	66	-	-
Spylanthus sp.	1.66	66	1.0	33	2.33	66
Piper betlesides	-	-	0.33	33	0.33	33
Gleichenia longissima	-	-	3.33	100	3.0	66
Colocasia sp.	-	-	1.00	66	-	-
Musa sapientum	-	-	0.33	33	-	-
Imperata cylindrica	1.00	33	-	-	0.33	33
Saccharum spontaneum	-	-	0.66	33	-	-
Tree species						
Cythea gigantean	-	-	0.33	33	-	-
Dendrocalamus hamiltonii	-	-	0.33	33	-	-
Terminalia myriocarpa	-	-	0.66	33	-	-
Shorea robusta	-	-	-	-	1.0	66
Chukrasia tabularis	-	-	-	-	1.66	33
Mangifera indica	-	-	-	-	0.33	33
Tectona grandis	-	-	-	-	1.00	33
Duabanga grandiflora	-	-	-	-	0.66	33
Mesua ferrea	-	-	-	-	2.33	66
Tectona grandis	-	-	-	-	0.66	33
Anthocephalus cadamba	-	-	-	-	0.66	33

the herbaceous species including weed species (e.g. *Ageratum, Imperata* etc.) in the site. Nonetheless, the herbaceous plant density was highest in the paddy field and lowest in the forest stand (Table 1). A reverse trend was observed for species richness (Table 1).

Soil properties

Soil was sandy loam in all three sites at both depths and acidic (pH = 5.0-5.6). Soil moisture content was greater in the forest and wet-paddy field compared to jhum fallow (Table 2). However, soil temperature was higher in the paddy field and lower under the forest canopy. Water holding capacity (WHC) was greater in paddy field, followed by forest and jhum fallow. Bulk density varied between 1.37 and 1.57 g cm^{-3} in the study sites.

Variation in soil organic carbon (SOC) between sites was small. However, total Kjeldhal nitrogen (TKN) was highest in the jhum field (Table 2). Soil C/N ratio was always higher at lower depths compared to the top 0-10 cm soil layer. SOC and pH values remained greater in 10-20 cm soil layer than in the top soil, while total N concentration was higher in the upper soil layer.

Concentrations of ammonium and nitrate-N

Generally, ammonium concentration was greater than nitrate-N in all study sites and at both soil depths (Table 3). Seasonal variations

Table 2. Physico-chemical properties of soil at study sites.

Properties	Paddy field		Jhum Fallow		Forest	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Soil moisture (%)	26.53^a	28.20^a	21.26^b	21.66^b	28.70^c	29.90^b
Soil temperature (°C)	23^a	22^a	21^b	20^b	18^c	19^b
Water holding capacity (%)	78.86^a	62.62^a	52.46^b	43.32^b	61.12^c	65.51^a
Bulk density (g cm^3)	1.45^a	1.38^a	1.57^b	1.38^a	1.49^a	1.37^a
Clay (%)	11.72^a	11.79^a	12.82^a	14.10^b	11.19^a	11.22^a
Silt (%)	25.96^a	22.93^a	21.44^b	22.77^a	18.76^c	17.66^b
Sand (%)	62.31^a	65.28^a	65.76^b	63.13^b	70.05^c	71.12^c
Soil textural class	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH (1:2.5 w/v H_2O)	5.20^a	5.60^a	5.20^a	5.30^b	5.00^a	5.10^a
Soil organic carbon (%)	4.95^a	5.25^a	4.20^b	4.80^b	4.50^c	5.25^a
Total nitrogen (%)	0.40^a	0.30^a	0.60^b	0.45^b	0.55^c	0.35^c
C/N	12.38^a	17.50^a	7.00^b	8.25^b	7.75^b	9.05^b

Note: Values are the means of three monthly samplings, as there were little monthly variations. Values having different alphabetic superscripts across sites in 0-10 and 10-20 cm soil depths in each column are significantly different at $P<0.05$

Table 3. Seasonal variations in the concentrations of ammonium and nitrate (µg g^{-1}) in soil at three study sites**.**

Months/Seasons	Soil depth (cm)	Paddy field		Jhum Fallow		Forest	
		Ammonium	Nitrate	Ammonium	Nitrate	Ammonium	Nitrate
January (Winter)	0 - 10	1.32^a	0.31^a	0.85^a	0.37^a	0.93^a	0.29^a
	10 - 20	1.75^b	0.32^a	1.45^b	0.56^b	0.57^b	0.42^b
April (Spring)	0 - 10	2.02^a	0.52^a	0.84^a	0.39^a	1.04^a	0.35^a
	10 - 20	1.82^b	0.25^a	0.65^b	0.46^b	0.69^b	0.23^b
July (Rainy)	0 - 10	0.99^a	0.24^a	0.69^a	0.49^a	0.99^a	0.41^a
	10 - 20	0.98^b	0.15^b	0.41^b	0.24^b	0.54^b	0.29^a
October (Autumn)	0 - 10	1.09	0.24	0.91	0.34	0.91	0.31
	10 - 20	1.05	0.13	0.44	0.24	0.41	0.32

Values having similar alphabets across soil depths under each column within different samplings are not significantly different ($P<0.05$)

in ammonium and nitrate concentrations were significant ($P<0.05$), registering greater values during spring and lower values during monsoon. Over all, available-N (ammonium + nitrate) was comparatively greater in the agricultural systems than in the forest (Table 3). Spatial variation in N availability was also significant ($P<0.05$).

As a percentage of total N, the available N (ammonium + nitrate) remained equal or mostly greater in lower depth (10-20 cm) of the agricultural systems (0.004 - 0.081%). In the forest, the contribution of available N to total N did not vary much between seasons (0.020 - 0.023 %).

Net N-mineralization (ammonification + nitrification)

The ammonification, nitrification, and net N-mineralization rates (Table 4) were significantly ($P<0.05$) different between sites, and soil depths and seasons. Nitrification occurred during all four sampling months (Table 4). Over all, very low rates of ammonification was observed across the seasons, particularly in the paddy field (Table 4). Mean N-mineralization rates were greater in the jhum fallow (1.47 g m^{-2} yr^{-1}), followed by paddy field (1.32 g m^{-2} yr^{-1}) and forest (1.01 g m^{-2} yr^{-1}). During winter, the top soil registered

Table 4. Temporal variations in N-mineralization rates (μg g^{-1} month^{-1}) in the three study sites; 1 – Ammonification, 2 – Nitrification, 3 – net N-mineralization;

Sampling months	Soil depth (cm)	Paddy field			Jhum Fallow			Forest		
		1	2	3	1	2	3	1	2	3
January	0 – 10	-0.02^{a}	0.27^{a}	0.25^{a}	0.09^{a}	0.29^{a}	0.38^{a}	0.01^{a}	0.22^{a}	0.23^{a}
	10 – 20	0.07^{a}	0.31^{a}	0.38^{a}	0.09^{a}	0.24^{a}	0.33^{a}	0.12^{a}	0.27^{a}	0.39^{a}
April	0 – 10	0.03^{b}	0.38^{b}	0.30^{b}	0.15^{b}	0.22^{b}	0.38^{a}	0.07^{b}	0.23^{a}	0.29^{b}
	10 – 20	0.02^{b}	0.38^{b}	0.35^{a}	0.07^{b}	0.29^{b}	0.37^{a}	0.01^{b}	0.29^{a}	0.31^{b}
July	0 – 10	0.09^{c}	0.87^{c}	0.51^{c}	0.24^{c}	0.48^{c}	0.72^{b}	0.24^{c}	0.40^{b}	0.64^{c}
	10 – 20	0.13^{c}	0.64^{c}	0.18^{b}	0.24^{c}	0.40^{c}	0.64^{b}	0.25^{c}	0.31^{b}	0.57^{c}
October	0 – 10	0.09^{c}	0.59^{d}	0.68^{d}	0.31^{d}	0.32^{d}	0.63^{c}	0.20^{c}	0.40^{b}	0.60^{d}
	10 – 20	0.04^{d}	0.36^{bd}	0.40^{c}	0.10^{ad}	0.28^{bd}	0.38^{c}	0.17^{d}	0.28^{b}	0.45^{d}

Values having different alphabets, as superscripts across samplings in 0-10 and 10-20 cm soil layers in each column are significantly different at $P < 0.05$.

Table 5. Correlation coefficients (r) for the relationships between soil properties and N-mineralization rates (μg g^{-1} month^{-1}).

Process	Soil depth (cm)	Soil moisture content (%)	Soil pH	Soil organic matter (%)	Total Kjeldhal nitrogen (%)	Ammonium-N (μg g^{-1})	Nitrate-N (μg g^{-1})
Ammonification	0-10	-0.14	0.75^{**}	0.27	-0.03	0.67^{**}	0.50^{*}
	10-20	-0.16	-0.31	-0.45	0.57^{*}	0.24	0.85^{**}
Nitrification	0-10	0.27	-0.35	0.72^{**}	-0.42	0.08	0.08
	10-20	0.34	0.57^{*}	0.58^{*}	-0.67^{**}	0.33	0.07
N-mineralization	0-10	-0.01	0.69^{**}	0.40	-0.09	0.69^{**}	0.81^{**}
	10-20	-0.10	-0.27	0.46	0.52^{*}	0.27	0.72^{**}

N=15; $^{*}P<0.05$, $^{**}P<0.01$

lower N mineralization rates in paddy field and forest, whereas it was greater in jhum fallow (Table 4). Seasonally, the N mineralization rates were greater during rainy seasons and lower during winter and spring months. Among the subsoil samples, N mineralization rates were greater in the forest soil than in the paddy field and jhum fallow (Table 4).

Relationships between soil properties and N-mineralization rates

In the top 0-10 cm soil layer, ammonification rate was positively correlated with pH, ammonium and nitrate concentrations, while in~~ the lower depth (10-~~20 cm), it was correlated to total N as well as nitrate concentration (Table 5). This indicates the overall importance of detrital decomposition and nutrient release on the ground surface that facilitates a greater nutrient flux in the top soil layer. On the other hand, nitrification rate was negatively correlated to total N (Table 5). One of the interesting results in this study was that both ammonium and nitrate concentrations were correlated positively with ammonification and net N-mineralization rates, but not with nitrification rate. This indicates that the available N concentration was not saturated in these systems. Hence, there was no 'negative feedback reaction' between nutrient availability and its transformation rates. Eventually, N-mineralization was positively correlated to N availability (Table 5).

Discussion

~~Measurement of~~ soil~~ physical and chemic~~al properties in different ecosystems allowed us to discern changes resulting from different land use practices. For example, lower soil temperatures due to a better canopy cover in the forest and the wet-paddy cultivation system have resulted in a greater retention of soil moisture than in jhum fallow, where the canopy is open. However, the role of clay particles in moisture retention cannot be completely ruled out. On the other hand, sloping topography of the jhum fallow would facilitate loss of smaller soil particles (and organic matter) particularly in the top soil layer, thus lowering WHC and SOC, compared to wet-paddy cultivation system and forest stand (Table 2). Although not significant, soil temperature was slightly greater at lower soil depths. Given this situation, mineralization rates (mainly mediated by soil microbes) would also be expected to be greater in the subsurface soil layer. We did find considerable N-mineralization rates in the lower depths across different seasonal samplings, but on many occasions the top soil registered greater values. This may be due to greater total N stock in the top soil layer (Table 2).

It was observed that the top soils of paddy field and forest were close to a nutrient balance that a fertile soil could maintain (i.e., C/N ratio close to 10) (Myers *et al.* 1994). In all three sites, C/N ratio was greater in the lower soil depths, due mainly to the low concentrations of N as compared to the top soil layer (Table 2). All these different trends in SOC and total N indicates that apart from surface runoff losses, infiltration may also contribute significantly to the differences in nutrient stock and its availability in the soil profile. This, however, had profound effects on the relationship between soil properties and net N-mineralization rates too. But, the differences in the composition of litter and its relative decay and nutrient release rates would also affect the soil C/N ratio (Maithani *et al.* 1998b).

It is considered that greater the soil C/N ratio, lower would be the N availability (Maithani *et al.* 1998a). However, we obtained greater concentration of available-N (ammonium + nitrate) on several occasions in the lower soil depths that registered greater C/N (Table 2). This suggests that sampling frequency was not sufficient to capture the finer dynamics of N in these fragile ecosystems within a single season. Apart from these, other ecosystem processes such as plant growth, productivity, litterfall and root dynamics together with microbial biomass would also regulate the N availability and/or cycling (Arunachalam & Arunachalam 1998).

Greater concentration of ammonium compared to nitrate indicates not only greater rate of ammonification in these sites, but also the potential loss of nitrate-N to leaching, especially in the sloping agricultural fields (jhum fallow) where runoff losses could be higher. In the wet-paddy cultivation systems, infiltration rates remain higher (Johnson *et al.* 2000). Also, the acidic nature of soil may also have inhibited the growth and activity of autotrophic nitrifiers in the soil to some extent resulting in lower nitrification rates (Chao *et al.* 1993). This was true to the subsurface soil layer that showed a significant positive correlation between pH and nitrification rate. Paddy field, however, registered similar rates of nitrification and ammonification. In the other two sites, the ammonification rates were almost three-times greater than the nitrification rates. Lower nitrification may be attributed to anoxic conditions in soil microsites that could lessen nitrate production (Firestone 1982), and also due to lower winter temperatures that may be unfavourable to nitrifier populations (Maithani *et al.* 1998a).

Nadelhoffer *et al.* (1984) suggested that the variations in ammonium concentrations in soil during different seasons depend on net ammonification rate. A comparison of our mean values of ammonium across the sites fully corroborates this point. Evidently, there was a positive correlation between ammonification rate and ammonium-N (Table 5). This is opposite to the results of Maithani *et al.* (1998a), who established a strong negative correlation between ammonium-N and ammonification rate in regenerating forest stands. The inorganic-N represented a very small proportion of total soil N and its contribution to the latter varied with soil depth and land use type. The percentage contribution of inorganic N to total N in this study (0.004 - 0.023 %) was comparable to those (0.13 - 0.24%) of a humid subtropical forest ecosystem (Maithani *et al.* 1998a). Thus, most of the N is organically bound. This is in agreement with Singh *et al.* (1991) who reported that organic N is the major constituent of total soil-N. The high concentration of mineral-N in the agricultural system is due to increased mineralization of nutrients from soil organic matter (Table 5).

Average net N-mineralization rates in this study ranged from 0.75 g m^{-2} yr^{-1} to 2.01 g m^{-2} yr^{-1}. This is less than the range (4-20 g m^{-2} yr^{-1}) reported by Vitousek *et al.* (1982) for terrestrial ecosystems, and 8-17 g m^{-2} yr^{-1} reported by Maithani *et al.* (1998a) for secondary successional communities. During the cold and dry winter, a slow rate of decomposition, attributable to low microbial activity, might have resulted in greater immobilization of inorganic N by microorganisms resulting in reduced N-mineralization (Maithani *et al.* 1996). The rates and depth-wise trends remain similar in the forest and valley cultivation systems. Whereas, the jhum fallow stood distinct having comparatively better net N-mineralization rates at both soil depths. Although the system is seemingly more favourable to N-mineralization compared to paddy field and forest, such a process also signals potential threat to the loss of N through runoff and leaching during monsoon in this fallow land on the slope with a poor canopy development.

We found some interesting results while averaging the net N-mineralization rate irrespective of soil depths. The rates were close in paddy field (1.32 g m^{-2} yr^{-1}) and jhum fallow (1.47 g m^{-2} yr^{-1}) and were ca. 25% lower in the forest (1.01 g m^{-2} yr^{-1}). N-mineralization rate depends on the type and quality of detrital resources such as litter and fine roots available in the ecosystem (Maithani *et al.* 1998a). These organic residues need to be of good quality (C/N <25) to be able to decompose faster and to release the nutrients through microbial mediation. Some studies have revealed that agricultural crop residues decompose much faster than forest litter (Kumar & Goh 2000; Woomer & Swift 1994). This, perhaps, may partially explain why N-minerali-zation rates were lower in the forest stand.

Although not conclusive, the present study raises the following points for further long-term investigation: (i) impact of land use types on N mineralization in soil, and (ii) spatial and temporal variations of soil N availability, which is governed by other soil properties, N stock and microbial populations that link plant and soil through organic matter decomposition and nutrient mineralization.

Acknowledgements

The authors are thankful to the CSIR and DST, New Delhi, for financial assistance. Both the authors especially thank the DST, New Delhi, for the award of BOYSCAST fellowship. Special thanks to Professor H.N. Pandey, Professor A. Rennerberg and Professor K.S. Bawa for academic support. Mr. J. Saikia and Mr. M. Ingti helped in soil collection and processing. Mr. Lalsanglura and Mr. Deka helped in laboratory analyses of soil. Also, thanks to Mr. Mohan Seetharam for going through the first draft of the manuscript. The comments of the anonymous reviewer helped in improving the quality of the paper.

References

Allen, S. E., H.M. Grimshaw, J.A. Parkinson & C. Quarnby. 1974. *Chemical Analysis of Ecological Materials*. Blackwell Scientific Publications, Oxford.

Anderson, J. M. & J.S.I. Ingram. 1993. *Tropical Soil Biology and Fertility - A Handbook of Methods.* 2nd edn., CAB International, Wallingford, U K.

Arunachalam, K. & A. Arunachalam. 1998. Biological processes in soil nutrient dynamics. pp. 185-194 *In*: R. C. Sundriyal, U. Shankar & T. C. Upreti (eds.*) Perspectives for Planning and Development in North East India.* Himavikas Occasional Publication No. 11, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, India.

Arunachalam, A. & H.N. Pandey. 2000. *Evaluation of Microbial Biomass in Soil Fertility Management for Sustainable Productivity of Hill Agroecosystems in Arunachal Pradesh.* Final Technical Report, Council of Scientific and Industrial Research, New Delhi (#38(0924) EMR II).

Arunachalam, A. & H.N. Pandey. 2003. Microbial C, N and P along a weeding regime in a valley cultivation system of northeast India. *Tropical Ecology* **44**: 147-154.

Birk, E. M. & P.M. Vitousek. 1986. Nitrogen availability and nitrogen use efficiency in loblolly pine stands. *Ecology* **67**: 69-79.

Chao, W. L., K.D. Gan & C.C. Chao. 1993. Nitrification and nitrifying potential of tropical and subtropical soils. *Biology and Fertility of Soils* **15**: 87-90.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. *Soil Science Society of America Journal* **24**:277-279.

Firestone, M. K. 1982. Denitrification.pp. 289-326 *In*: R. J. Stevenson (ed.) *Nitrogen in Agricultural Soils*, Agronomy 22, American Society of Agronomy Inc., Madison, WI.

Gorham, E., P.M. Vitousek & W.A. Reiners. 1979. The regulation of chemical budgets over the course of terrestrial ecosystem succession. *Annual Review of Ecology and Systematics* **10**: 53-84.

Johnson, D. W., W. Cheng & I.C. Burke. 2000. Biotic and abiotic nitrogen retention in a variety of forest soils. *Soil Science Society of America Journal* **64**: 1503-1514.

Kumar, K. & K.M. Goh. 2000. Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield, and nitrogen recovery. *Advances in Agronomy* **68**:197-319.

Maithani, K., R.S. Tripathi, A. Arunachalam & H.N. Pandey.1996. Seasonal dynamics of microbial biomass C, N and P during regrowth of a disturbed subtropical humid forest in north-east India. *Applied Soil Ecology* **4**: 31-37.

Maithani, K., A. Arunachalam, R.S. Tripathi & H.N. Pandey. 1998a. Nitrogen mineralization as influenced by climate, soil and vegetation in a subtropical humid forest of north-east India. *Forest Ecology and Management* **109**: 91-101.

Maithani, K., A. Arunachalam, R.S. Tripathi & H.N. Pandey. 1998b. Influence of litter quality on N mineralization in soils of a subtropical forest regrowths. *Biology and Fertility of Soils* **27**: 44-50.

Misra, R. 1968. *Ecology Work Book.* Oxford & IBH, Calcutta.

Myers, R. J. K., C.A. Palm, E. Cuevas, I.U.K. Gunatilleke & M. Brossard. 1994. The synchronization of nutrient mineralization and plant demand. pp. 81-116 *In*: P. L. Woomer & M. J. Swift (eds.) *The Biological Management of Tropical Soil Fertility.* TSBF, John Wiley and Sons, New York.

Nadelhoffer, K. J., J.D. Aber & J.M. Melillo. 1984. Seasonal patterns of ammonium and nutrient uptake in nine temperate forest ecosystems. *Plant and Soil* **80**: 321-325.

Olsson, M. O. & U. Falkengren-Grerup. 2000. Potential nitrification as an indicator of preferential uptake of ammonium or nitrate by plants in an oak woodland understorey. *Annals of Botany* **85**: 299-305.

Ramakrishnan, P. S. 1992. *Shifting Agriculture and Sustainable Development.* MAB Series, UNESCO, Parthenon Publishing, Paris.

Singh, R. S., A.S. Raghubanshi & J.S. Singh. 1991. Nitrogen mineralization in dry tropical savanna: effects of burning and grazing. *Soil Biology and Biochemistry* **23**: 269-273.

Swift, M. J., O.W. Heal & J.M. Anderson. 1979. *Decomposition in Terrestrial Ecosystems.* Vol. 5, University of California Press, Berkeley.

Tiessen, H., J.W.B. Stewart & J. R. Bettany. 1982. Cultivation effects on the amounts and concentration of carbon, nitrogen and phosphorus in grassland soils. *Agronomy Journal* **74**: 831-835.

Tiessen, H., E. Cuevas & P. Chacon. 1994. The role of organic matter in sustaining soil fertility. *Nature* **371**: 333-350.

Vitousek, P. M., J.R. Gosz, G.C. Grier, J.M. Melillo & W.A. Reiners. 1982. A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. *Ecological Monographs* **52**: 155-177.

Vogt, K. A., G.C. Grier & D.J. Vogt. 1986. Production, turnover and nutrient dynamics of above- and below-ground detritus of world forests. *Advances in Ecological Research* **15**: 303-377.

Wang, F. L. & A.K. Alva. 2000. Ammonium adsorption and desorption in sandy soils. *Soil Science Society of America Journal* **64**: 1669-1674.

Woomer, P. L. & M.J. Swift. 1994. *The Biological Management of Tropical Soil Fertility.* John-Wiley and Sons, New York..

Zar, J. H. 1974. *Biostatistical Analysis.* 2nd edn. Prentice-Hall, Englewood Cliffs, NJ.

Zogg, G. P., D.R. Zak, K.S. Pregitzer & A.J. Burton. 2000. Microbial immobilization and the retention of anthropogenic nitrate in a northern hardwood forest. *Ecology* **81**: 1858-1866.