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Seasonal dynamics of mineral N pools and N-mineralization in soils under homegarden trees in South Andaman, India

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Abstract Agroforestry trees are now well known to play a central role in the build up of nutrients pools and their transformations similar to that of forest ecosystem, however, information on the potential of homegarden trees accumulating and releasing nitrogen (mineralization) is lacking. The present study reports seasonal variations in pool sizes of mineral N (NH_4^+-N and NO_3^--N), and net N-mineralization rate in relation to rainfall and temperature under coconut (*Cocos nucifera* L.), clove (*Eugenia caryophyllata* Thunb) and nutmeg (*Myristica fragrans* Houtt. Nees) trees in a coconut-spice trees plantation for two annual cycles in the equatorial humid climate of South Andaman Island of India. Concentration of NH_4^+-N was the highest during wet season (May–October) and the lowest during post-wet season (November–January) under all the tree species. On the contrary, concentration of NO_3^--N was the lowest in the wet season and the highest during the post-wet season. However, concentrations of the mineral N were the highest under the nutmeg and the lowest under the coconut trees. Like the pool sizes, mean annual mineralization was the highest under the nutmeg (561 mg kg^{-1} yr^{-1}) and the lowest under the coconut trees (393 mg kg^{-1} yr^{-1}). Rate of mineralization was the highest during the post-wet season and the lowest during the dry season (February–April) under all the tree species. High rainfall during the wet season, however, reduced the rate of nitrification under all the tree species. The mean annual mineralization was logarithmically related with rainfall amount and mean monthly temperature.

Keywords Equatorial humid climate · Net nitrification rate · NH_4^+-N pool · NO_3^--N pool · Palm trees · Spice trees

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Introduction

Mineralization of organic soil N is fundamentally linked with productivity in most ecosystems (Schlesinger 1997). The largest proportion of nitrogen (>90%) in soils is found in organic forms that become available to plants upon mineralization to NH_4^+ (Wong and Nortcliff 1995; Kelley and Stevenson 1995). Under favorable conditions the NH_4^+ is oxidized further to NO_3^- (Wong and Nortcliff 1995). Both, ammonification and nitrification are aerobic biological processes (Breuer et al. 2002). However, they are influenced mainly by the quality and quantity of organic matter, rainfall amount and its distribution, temperature and allelochemicals (Powers 1990; Montagnini et al. 1989), as these factors influence soil microbial activity (Powers 1990).

The humid tropics, which covers about 10% of the world's land surface, is characterized of having impoverished or marginally poor soils (Sanchez and Logan 1992). High rainfall (>2,500 mm yr^{-1}) recently has been reported to reduce productivity in humid tropical forests (Nemani et al. 2003; Schuur 2003; Schuur and Matson 2001). In such forests, it is likely that moisture supply in excess of plant demand does not act as a resource of biotic processes (Schuur et al. 2001), rather it may suppress forest growth through variety of mechanisms (Schuur and Matson 2001). For example, high precipitation removes mobile nutrients in soil solution via leaching (Radulovich and Sollins 1991; Schuur and Matson 2001), that leads to low pH and low nutrient condition (Schuur and Matson 2001). It also restricts gas diffusion in soils and limits supply of oxygen from the atmosphere to the soil (Richards 1987) and thereby creates anaerobic condition even in upland soils (Hobbie et al. 2000), that causes reduction in soil N-mineralization rate (Schuur and Matson 2001). Many studies have reported soil N-mineralization in humid tropical forests (Chandler1985; Sierra and Marban 2000; Breuer et al. 2002), but the most of them are based on ex situ observations. There are limited studies that report seasonal variations in net soil N-mineralization and net nitrification in field conditions.

Agroforestry trees are now well known to play a central role in the build up of nutrients pools and their transformations similar to that of forest ecosystem (Browaldh 1995; Pandey et al. 2000). However, information on the innate characteristics of homegarden trees accumulating and releasing nitrogen (mineralization) is lacking. Homegarden is a prominent land use system in the humid tropics (Kumar and Nair 2004). It includes, typically, many species/life forms and involves several organic matter/nutrient input and output processes. Therefore, the present study was conducted in a coconut-spice trees plantation to quantify seasonal changes in net soil N-mineralization and net nitrification under coconut (*Cocos nucifera* L.), clove (*Eugenia caryophyllata* Thunb) and nutmeg (*Myristica fragrans* Houtt. Nees) trees in relation to rainfall and temperature. In addition, an experiment was conducted ex situ to understand how different amounts of soil–water influence net nitrification and net ammonification rates in the soils under the tree species in the equatorial humid climate of South Andaman Island, India.

Materials and methods

Study site

The study was conducted in a 20-year-old coconut-spice trees plantation at a research farm of Central Agricultural Research Institute located at Sipighat (11°30′–12°42′N lat. and 92°14′–93°14′E long.), South Andaman Island, India. Terrain of the island is mostly undulating. The study site lies at 315 m above mean sea level. Soils are young (Eocene deposits), entisols and their parent materials predominantly sandstone. The soils are gravelly–sandy–loamy in texture, slightly acidic in reaction and moderate in nutrients (Pandey et al. 2006). Potential natural vegetation in the study region is a tropical rainforest. Mostly evergreen tree species are found in the forest. A few deciduous trees are found interspersed in the evergreen forest on foothill, but decline on hill slope and disappear on hilltop. On interface of the sea and landmass mangrove vegetation is found which protects the island from the sea invasion (Pandey et al. 2006).

The climate is an equatorial humid tropical. About 10 years data (1995–2005) indicate that an average 3,000 mm rainfall occurs in the study region with mean monthly variation of 300–500 mm during wet season (May–October), 100–200 mm during post-wet season (November to January) and <100 mm during dry season (February–April). Mean monthly maximum and minimum temperatures vary from 29 to 32°C and 22 to 24°C, respectively. January is the coolest whereas April the warmest month. Relative humidity, varying from 71 to 85%, is the highest in September and the lowest in February.

In the plantation, coconut was planted at 7.5 × 7.5 m distance in two blocks, each 3 ha in size. Spice trees like clove and nutmeg were planted quincunxially, each separately in a block as an intercrop of the coconut. Leaf fallen on the ground floor of the plantation was put around the respective tree every month. Large leaves of the coconut were cut into pieces before they were placed. Weeding was performed once in a year in October in the plantation. Fertilizer and FYM were not applied in the plantation for the last 5 years before the study was started.

Soil sample collection

Six trees of the coconut, three from the each block, and six trees of each the clove and nutmeg from the respective block were selected randomly for sampling. Soil samples (0–10 cm depth) were collected from five random locations under all the tree species (1 m from the tree trunk), composited and pooled by a tree as one replicate. The sampling was done periodically at one-month interval for two annual cycles (2003 and 2004). Plant materials were hand-picked and fine roots were carefully removed. The each soil sample was divided into three parts. One part in field-moist condition was used for determination of pH, mineral N (NO_3^--N and NH_4^+-N), inorganic P and soil-moisture. The second part (field-moist) was used for assessing net N-mineralization rate. The remaining part was air dried and used for analyses of texture, organic C and total N.

Soil analyses

Texture analysis of the soils was done once in October 2003 by hydrometer. Soil pH was measured with glass electrode (1:2, soil:water ratio). Soil-moisture was determined periodically at one-month interval by oven-drying the soils at 105°C. Organic C was determined by Walkey and Black rapid titration method and total P was measured after $HClO_4$ digestion. Phosphate-P was determined by an ammonium molybdate-stannous chloride method (Sparling et al. 1985). Total N was measured by microkjeldhal digestion method using Kjel Plus auto N analyzer. These chemical analyses were performed two times, once in the each year in the month of October.

N-mineralization

In-situ

Nitrogen mineralization was measured by the buried bag technique (Eno 1960). A portion of the field-moist soil sample (150 g) was buried in situ at 0–10 cm depth under the each tree for a period of 1 month. The remaining portion of each the sample was transported to the laboratory and stored at 4°C. The stored (field-moist) samples were used for the analyses of NO_3^--N and NH_4^+-N within 24 h of collection. Nitrate–nitrogen (NO_3^--N) was measured by the phenol disulphonic acid method, and NH_4^+-N by the phenate method (Wetzel and Likens 1979). The NO_3^--N and NH_4^+-N were determined at time zero, and after 30 days of the field incubation when the buried bags were recovered. The increase in the concentration of NH_4^+-N plus NO_3^--N during the field incubation is defined as net N-mineralization and the increase in the amount of NO_3^--N and NH_4^+-N alone is referred to as net nitrification and net ammonification, respectively. All results are expressed on an oven-dry basis.

Ex-situ

Different soil–water regimes: To understand how different amounts of soil–water influence net nitrification and net ammonification rates in the soils under the tree species, three soil–water conditions i.e.100% field capacity (FC), 50% FC and 25% FC were created in the soils collected from beneath the coconut, clove and nutmeg trees. The soils were collected in October 2004 and normalized for 48 h at ambient temperature in the laboratory. After determination of gravimetric soil–water, the soils were brought to 25%, 50% and 100% FC and incubated in polythene bags in dark condition in the laboratory for 15 days. The soil–water was maintained by weighing at 2-day interval. The net nitrification and net ammonification rates were estimated as stated earlier. This experiment was replicated six times and was repeated thrice.

Statistical analysis

Data were subjected to multivariate analysis of variance using SPSS (PC+) statistical package. Treatment included: three tree species (coconut, clove and nutmeg), 12 months and 2 years. Significance of variations in the net nitrification and net ammonification rates under different soil–water regimes in the ex situ experiment was also tested using two way ANOVA. Means were compared using LSD ($P < 0.05$). Standard deviations were also computed to know variations in the physico-chemical parameters of the studied soils; and net-nitrification and net-ammonification rates in the soils under different soil–water regimes. Correlation and regression techniques were applied to establish relationship between the parameters.

Results

Physico-chemical properties of the soils

The soils under all the tree species were slightly acidic in reaction; and contained maximum about 73% fine sand particles (Table 1). Organic C and total N were the highest under the nutmeg and the lowest under coconut trees. Available P in general was extremely low in the soils, however, among the species it was the highest under the nutmeg and the lowest under coconut trees.

Rainfall, temperature and soil-moisture

Amount of rainfall and soil-moisture differed ($P < 0.001$) among the seasons during the study period (Table 2). Maximum 82–85% rainfall occurred during the wet season and minimum 5–6% during the dry season. The lowest soil-moisture was observed during the dry season and the highest during the wet season. Both the years, the soil-moisture did not differ due to the species. Mean monthly temperature was higher by 1.5°C during the dry season compared to that during the wet and post-wet seasons. Between the wet and post-wet seasons the mean monthly temperature did not differ significantly.

Mineral N pool

Mineral N pool (NH_4^+ and NO_3^-) in the soils varied among the tree species ($P < 0.001$), months ($P < 0.001$) and years ($P < 0.001$). Interactions among the species, months and years were also significant ($P < 0.001$). Nitrate-N pool was the lowest during the wet season and the highest during post-wet season under all the tree species both the years (Fig. 1). Nitrate-N pool under the nutmeg was nearly equal to that found under the coconut trees, but it was 8% higher compared to that under the clove trees. Contrary to that of the NO_3^--N pool, NH_4^+-N pool was the highest during the wet season and the lowest during the post-wet season (Fig. 2). Like NO_3^--N, NH_4^+-N was also the highest under the nutmeg and the lowest under the coconut trees. NO_3^--N/NH_4^+-N ratio was as high as 2.1–39.9 across the post-wet and dry seasons, but <1 during the wet season under all the tree species. Moreover, the ratio was the highest

Table 1 Physico-chemical properties of the soils under coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

Species	Gravels (>4 mm)	Fine sand (0.2–0.02 mm)	Silt (0.02–0.002 mm)	Clay (<0.002 mm)	pH	Organic C (g/kg)	Total N (g/kg)	C/N ratio	Total P (g/kg)	Available P (mg/kg)
Coconut	^{a}25.49 ± 1.00	^{a}71.28 ± 1.62	^{a}2.17 ± 0.06	^{a}1.05 ± 0.05	^{a}6.07 ± 0.008	^{a}9.78 ± 0.61	^{a}0.71 ± 0.04	^{a}13.90 ± 0.45	^{a}0.029 ± 0.003	^{a}0.27 ± 0.02
Clove	^{b}23.83 ± 0.93	^{a}72.92 ± 1.38	^{a}2.21 ± 0.30	^{a}1.04 ± 0.09	^{b}6.20 ± 0.065	^{b}10.60 ± 0.44	^{b}0.81 ± 0.09	^{a}13.37 ± 0.63	^{b}0.021 ± 0.002	^{b}0.35 ± 0.03
Nutmeg	^{a}26.10 ± 1.27	^{a}70.68 ± 1.91	^{a}2.16 ± 0.36	^{a}1.06 ± 0.11	^{c}5.97 ± 0.104	^{c}11.67 ± 0.60	^{c}0.93 ± 0.05	^{b}12.64 ± 0.26	^{b}0.020 ± 0.002	^{c}0.31 ± 0.02

Data are mean ± SD

Values of a parameter prefixed with different letters in a column are significantly different at $P < 0.05$

Table 2 Seasonal and annual net N-mineralization (mg kg^{-1} yr^{-1}) in the soils under coconut, clove and Nutmeg trees in a coconut-spice tree plantation in South Andaman Island of India

Season	Net N-mineralization						Rainfall (mm)		[e]Soil-moisture(%)
	Coconut		Clove		Nutmeg				
	I yr	II yr	I yr	II yr	I yr	II yr	I yr	II yr	
Dry	$^{a}76.65^{x}$ (25.55)	$^{b}65.31^{x}$ (21.77)	$^{b}66.0^{x}$ (22.0)	$^{c}85.83^{x}$ (28.61)	$^{b}65.52^{x}$ (21.84)	$^{d}126.72^{x}$ (42.24)	156	99	14.9^{a} (14–16)
Wet	$^{a}172.02^{y}$ (28.67)	$^{b}188.52^{y}$ (31.42)	$^{c}211.26^{y}$ (35.21)	$^{c}205.98^{y}$ (34.33)	$^{d}270.78^{y}$ (45.13)	$^{e}256.02^{y}$ (42.67)	2,229	1,793	31.2^{b} (29–34)
Post-wet	$^{a}147.27^{z}$ (49.09)	$^{a}138.90^{z}$ (46.30)	$^{b}164.58^{z}$ (54.86)	$^{c}151.68^{z}$ (50.56)	$^{c}145.65^{z}$ (48.55)	$^{d}178.26^{z}$ (59.42)	231	294	22.2^{c} (20–24)
Annual	$^{a}395.94$ (34.44)	$^{a}392.73$ (33.16)	$^{b}441.84$ (37.36)	$^{b}443.49$ (37.83)	$^{c}481.95$ (34.51)	$^{c}561.00$ (48.11)	2,616	2,186	NA

Data in parentheses are mineralization rates (μg g^{-1} $month^{-1}$)

Values of a parameter prefixed with different letters in a row are significantly different at $P < 0.05$

Values of a parameter suffixed with different letters in a column are significantly different at $P < 0.05$

The same prefixed and suffixed letters of the net N-mineralization refer to significance in the parentheses

[e] Soil-moisture range in parentheses

NA = not applicable

under the coconut and the lowest under the nutmeg trees.

In situ soil N-mineralization and nitrification

Net N-mineralization as well as net nitrification rate in the soils was influenced by the tree species ($P < 0.001$), months ($P < 0.001$) and years ($P < 0.001$). Species × months × years interactions also affected the nitrification and mineralization rates significantly ($P < 0.001$). The soil N-mineralization occurred every month both the years under all the tree species (Fig. 3). It increased quickly following the monsoon rains either in May or June, but declined quickly and remained low throughout the wet season. It increased further during the post-wet season when rainfall was moderately low and declined thereafter to the lowest during the dry season (Figs. 3 and 4). The rate of mineralization (y), across the seasons and species, was correlated with the amount of rainfall (x), both the years, but the relation was quadratic: $y = a + bx - cx^2$, ($r^2 = 0.19$–0.34, $P < 0.03$–0.001). The same quadratic relation was found between the mineralization rate and the mean monthly temperature, both the years, but it was not significant. High rate of mineralization was observed in two conditions, first just after dry month (March 2003; April 2004) and the second when high rainfall occurred in preceding month (November 2004). The mineralization rate, averaged across the months and the species, during the wet season was 7–71% lower compared to that during the post-wet season. The rate of mineralization was the highest under the nutmeg and the lowest under the coconut trees almost all the months. The nitrification rate contributed maximum 96–98% to the mineralization rate under all the tree species, therefore, its pattern of variations was closely similar to that of the latter (Fig. 5). Therefore, they are used synonymously sometimes in the discussion section. The nitrification rate showed the same quadratic relation with the rainfall amount ($r^2 = 0.20$–0.36, $P < 0.02$–0.001) and temperature ($r^2 = 0.13$–0.05, $P < 0.09$–0.40) as the mineralization rate did.

Mean annual mineralization was the highest under the nutmeg (561 mg kg^{-1} yr^{-1}) and the lowest under the coconut trees (393 mg kg^{-1} yr^{-1}) (Table 2). Under the nutmeg trees, it was 16% higher during the second year compared to that during the first year. The mean annual mineraliza-

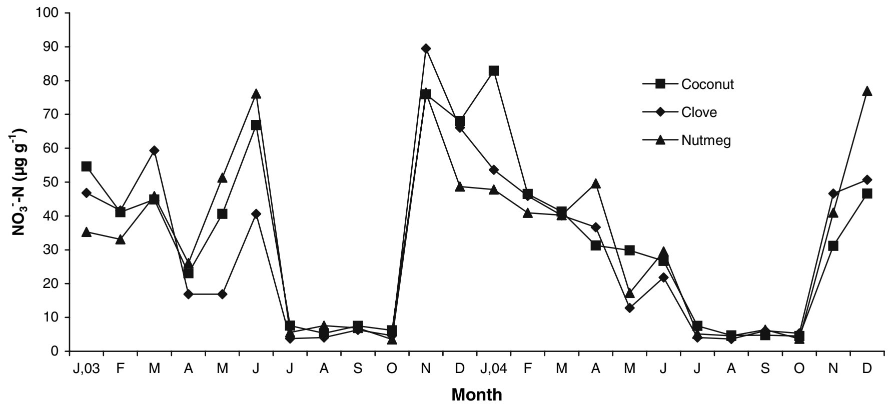

Fig. 1 Variations in nitrate-nitrogen (NO_3^--N) in the soils under coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

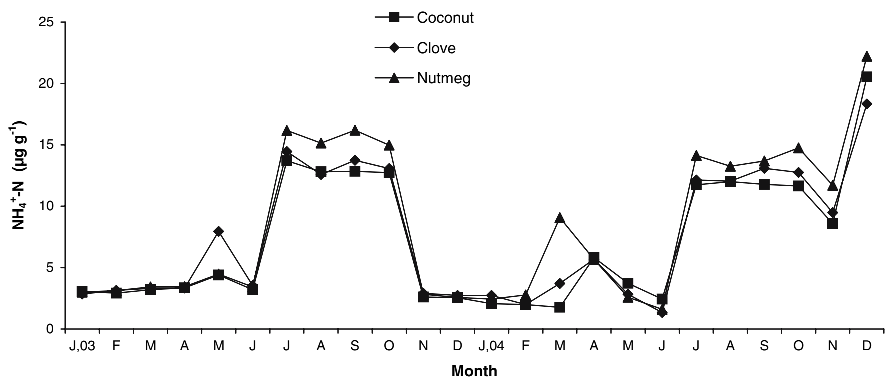

Fig. 2 Variations in ammoniacal-nitrogen (NH_4^+-N) in the soils under coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

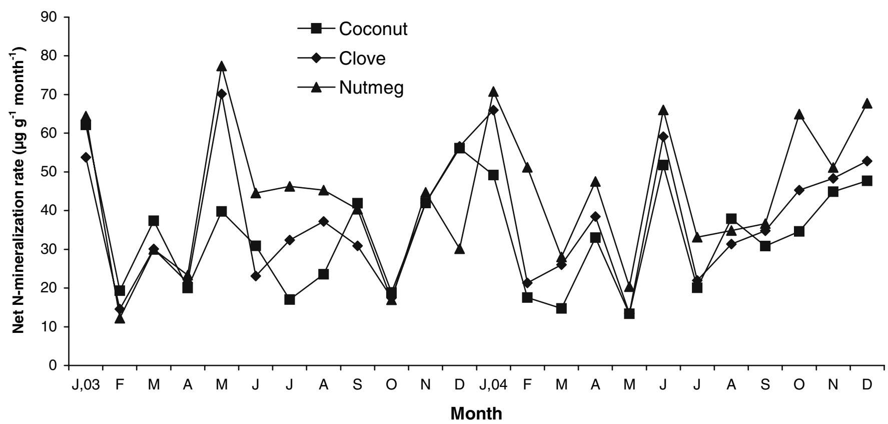

Fig. 3 Net N-mineralization rate under coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

tion (Y, mg kg^{-1} yr^{-1}) across the species and the years was logarithmically related with the amount of rainfall (R, mm): $Y = -111.94 + 43.4879 \ln(R)$, ($r^2 = 0.724$, $P < 0.0001$) and mean monthly temperature (T, °C): $Y = 19101.7 - 5716.0 \ln(T)$, ($r^2 = 0.55$, $P < 0.001$). Stepwise multiple regression, however, revealed that combined effect of the rainfall and temperature explained 62% of the variations in the N-mineralization. The same logarithmic relation was found between the mean annual mineralization and the amount of rainfall under the coconut ($r^2 = 0.783$, $P < 0.01$), clove ($r^2 = 0.794$, $P < 0.01$) and nutmeg trees ($r^2 = 0.6882$, $P < 0.001$), but the relation with temperature was weak ($r^2 = 0.59$–0.64, $P < 0.05$–0.07) under the species.

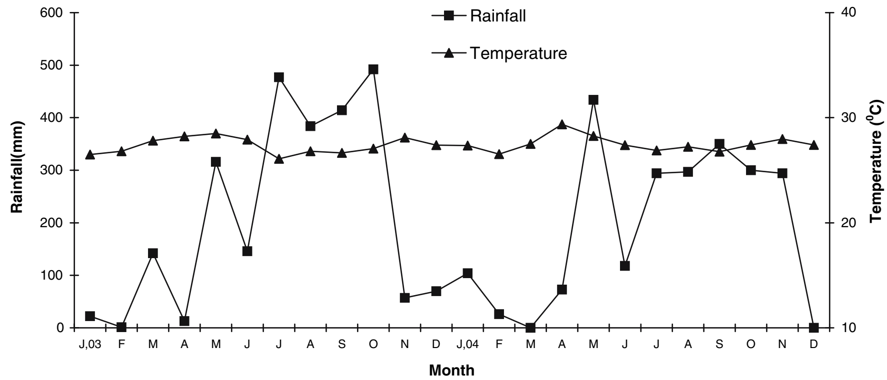

Fig. 4 Total monthly rainfall and mean monthly temperature at the study site in South Andaman Island of India

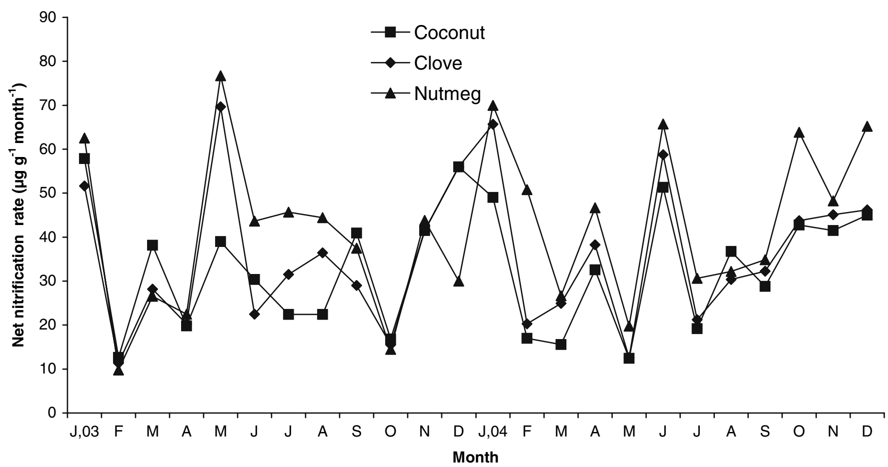

Fig. 5 Net nitrification rate under coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

Table 3 Ex situ ammonification and nitrification rates under different soil–water regimes in the soils sampled under the coconut, clove and nutmeg trees in a coconut-spice trees plantation in South Andaman Island of India

Species	Field capacity (%)	Net ammonification rate (µg g^{-1} day^{-1})	Net nitrification rate (µg g^{-1} day^{-1})
Clove	25	[a]–0.13 ± 0.008	[a]1.24 ± 0.105
	50	[b]0.12 ± 0.019	[b]0.61 ± 0.072
	100	[c]0.45 ± 0.021	[c]–1.21 ± 0.034
Nutmeg	25	[d]–0.04 ± 0.005	[d]1.56 ± 0.190
	50	[e]0.20 ± 0.019	[e]0.44 ± 0.014
	100	[f]0.52 ± 0.025	[f]–1.05 ± 0.089
Coconut	25	[g]–0.08 ± 0.029	[g]0.17 ± 0.034
	50	[e]0.18 ± 0.006	[h]0.09 ± 0.004
	100	[h]0.34 ± 0.008	[i]–0.39 ± 0.007

Data are mean ± SD

Values of a parameter prefixed with different letters in a column are significantly different at $P < 0.05$

Ex situ nitrification and ammonification

In the ex situ experiment, net nitrification rate was found the highest at 25% field capacity (FC) in all the soils (Table 3). However, it declined at 50% FC and became negative at 100% FC. Moreover, the rate of nitrification was the highest in the soils sampled under the nutmeg trees and the lowest in the soils sampled under the coconut trees. Contrary to that of the nitrification rate, ammonification rate was negative at the 25% FC and increased with increasing the soil–water amount and peaked at 100% FC in all the soils.

Discussion and conclusions

The aseasonal mineralization and nitrification under all the tree species in our study, unlike dry tropical climate (Roy and Singh 1995; Garcia-Mendez et al.

1991), were due to suitable temperature and sufficient soil-moisture (rainfall) almost all the year round. However, logarithmic relation between the rainfall amount and mean annual mineralization in the study suggests that high rainfall (>2,200 mm in our study) limits the formation of mineral N in humid tropics. This may, probably, be one of the reasons why stature and biomass of humid tropical forests worldwide tend to decrease with increased precipitation (Schuur and Matson 2001; Brown and Lugo 1982). Aseasonal net N-mineralization and net nitrification are reported to occur in some other tropical forests also (Neill et al. 1995). In the present study, rainfall amount explained greater variability in the N-mineralization compared to that of the temperature (72% vs. 55%). It indicates that rainfall amount acts as a major factor controlling the soil N-mineralization in the equatorial humid tropics. However, the highest N-mineralization under the nutmeg trees could have occurred mainly due to the highest concentrations of organic C and total N. Van der Krift and Berendse (2001), Roy and Singh (1995) found that plant species growing on high fertility microhabitats increased N-mineralization greater than species growing on low fertility microhabitats.

The lower rates of nitrification under the trees during the wet season could mainly be due to two reasons; first owing to inhibition of nitrification as evident from the NH_4^+-N accumulation, perhaps due to anaerobic condition caused by the high rainfall. In a simulated rainfall experiment, Breuer et al. (2002) found a clear trend of decreasing rates of nitrification with increasing amount of water added to soil cores up to 17 mm. At our study area, generally incessant rainfall occurs for a quite longer period of time, sometime a week or more, mostly (47%) with an average 8–84 mm rainfall per day during the wet season. According to Sexstone et al. (1985) non-aggregated sandy loamy soils become anaerobic immediately after addition of water, but it persists for a shorter period of time compared to that of clayey soils. Reduction in the rate of nitrification with simultaneous increase in NH_4^+-N at 100% FC in the ex situ experiment validates the results observed in the field condition. Chandler (1985) also found reduction in the nitrification rate at 100% FC in the rainforest soils of Malaysia.

Quick increase in the nitrification rate under all the tree species with the onset of post-wet season could be due to moderate amount of rainfall (soil-moisture) and high amount of NH_4^+-N accumulated during the preceding wet season. This observation supports the hypothesis that nitrification is an ammonia limited process (Robertson 1984). However, persistent high rates in the nitrification throughout the post-wet season could have occurred mainly due to wetting and drying effects caused by the low amount of rainfall, but high coefficient of variation (258–537%) in its distribution. Davidson et al. (1993) also found a very high nitrification rates after artificially rewetting soils from drought-stressed deciduous forests in Mexico at the end of dry season. The lowest rate of nitrification during the dry season in our study indicated that high temperature perhaps could have overridden the effect of soil-moisture (14–16%). Barraclough (1995) observed through ^{15}N isotope dilution technique that nitrogen mineralization occurred during dry season when soil-moisture contents were in the range of 8–10°C, but rate of mineralization was very low.

High NO_3^--N /NH_4^+-N ratio in the present study indicated that our soils, like the subtropical rainforest of Australia, predominated in NO_3^--N (Chandler and Goosem 1982). However, relatively greater accumulation of NO_3^--N during the post-wet and dry seasons under all the tree species could probably be due to lack of leaching and run off losses owing to low amount of rainfall, and low vegetative uptake. The lowest accumulation of NO_3^--N under the clove trees at the end of post-wet season was most likely due to comparatively greater vegetative uptake. Maximum leaf fall in the clove trees occurs during February to March, and leaf formation from March to April that triggers root growth at rapid rate. On the contrary, leaf formation and leaf fall in the coconut and nutmeg trees occur every month (L. Singh, unpublished). Neill et al. (1995) also found accumulation of NO_3^--N during dry season, the prolonged period of lower soil-moisture. Roy and Singh (1995) are of the view that temporal variations in the mineral N in soils are controlled by rainfall amount and its distribution, plant uptake dynamics and losses.

Our study concludes that organic C and total N accumulate under all the studied tree species, but the highest under nutmeg and the lowest under coconut trees. Seasonal variations in mineral N pools (NH_4^+-N and NO_3^--N) as well as net N-mineralization and net nitrification rates in humid tropics are regulated greater by rainfall amount than that of temperature. Moderate rainfall and low temperature interactively together facilitate higher rates in the nitrification and soil N-mineralization during the post-wet season, but the highest under the nutmeg trees the richest microhabitat and the lowest under the coconut trees the poorest microhabitat. High rainfall during the wet season probably creates anaerobic condition, which reduces the nitrification rate. The reduction in the nitrification rate with simultaneous increase in the NH_4^+-N during the wet season may be regarded one of the mechanisms of soil N conservation in the equatorial humid climate. Salati et al. (1982) found losses of NH_4^+-N in the stream waters of Amazon 5–10 times greater than NO_3^--N losses.

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