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Short Communication

# Soil N-mineralization dynamics under four major land use patterns in Eastern Himalaya

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**Abstract**

N-mineralization, nitrification and ammonification rates were studied in the major land use patterns viz., *Jhum*, agroforestry, vegetable and millet agro-ecosystems (AES) in East Siang district of Arunachal Pradesh, north-east India. Study was conducted for an annual cycle from June 2011 to May 2012 following standard methodology. N-mineralization showed significant variations between the sites and seasons. Greater amount of N-mineralization was recorded during the rainy season for agroforestry, and winter season for *Jhum*, vegetable and millet AES. Lowest mineralization rates were found during the spring for *Jhum* AES and during the rainy season for millet and vegetable AES. Ammonification rate was positively correlated with soil pH, soil organic carbon, $NH_4^+$-N and $NO_3^-$-N whereas, nitrification rate was negatively correlated with ammonium and nitrate concentrations which suggest that available nitrogen concentration was not saturated in these systems.

***Keywords:*** Autotrophic nitrifiers, Immobilization, Microbial activities, N-mineralization, Sustainable agriculture.

Soil nitrogen plays an important role in increasing the food value of crop and crop productivity and may also influence the quality of soil ecology. A large part of nitrogen present in the environment is not readily available for plant uptake. Initial product of heterotrophic mineralization is ammonium ($NH_4^+$), which may either consumed by the plants through several biochemical processes such as plant uptake, nitrification, immobilization and volatilization or further oxidized to form nitrate ($NO_3^-$) through nitrification by autotrophic microbes. The inorganic forms of nitrogen ($NH_4^+$-N and $NO_3^-$-N) and their concentrations are very important for the growth and survival of plants (Rice and Pancholy, 1972). N-mineralization process is influenced by biomass inputs, microbial activities, and different abiotic factors such as microclimatic variations and land use patterns. Agricultural practices may modify the plant composition and soil characteristics which regulate the water content, nutrient availability and energy in soil (Rhoades and Coleman, 1999). Potential mineralization rate indicates the amount of soil organic matter which is mineralized and subsequently is considered as the indicator of soil fertility status.

The study was carried out in the East Siang district, Arunachal Pradesh, a part of Eastern Himalaya. Altogether, four major land use systems prevail in the district viz., *Jhum*, agroforestry, vegetable and millet agro-ecosystems. These four systems were selected for the study. The study was conducted from the month of June 2010 to May 2011. Soil samples were collected on monthly basis from each of the respective study sites in five replicates at approximately 100 m intervals at each site. Samples

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were drawn from two depths (0-15cm and 15-30cm). Field moist soil was sieved (<2mm) and used for analysis of mineral-N ($NH_4^+$-N and $NO_3^-$-N) and N-mineralization and nitrification. A sub-sample of each soil was air dried, ground and sieved (<150 micron) prior to subjecting them for further physico-chemical analysis.

Soil texture was determined by Boyoucous hydrometric method detailed by Allen et al. (1974). Water holding capacity, porosity, total nitrogen, available phosphorus, available potassium, calcium and magnesium were determined as per the methods outlined by Allen et al. (1974). Bulk density, soil moisture content, soil pH, ammonium-N and nitrate-N were determined by the procedures detailed by Anderson and Ingram (1993). Soil organic carbon (SOC) was determined by rapid titration method (Walkley and Black, 1934). *In situ* N-mineralization was determined using buried-bag technique (Eno, 1960). Changes in ammonium and nitrate concentrations were obtained by subtracting 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 the data collected were statistically analyzed to compare seasonal and annual mean and related characters. The data on soil were analyzed using ANOVA to study the effects of various agro-ecosystems, sampling periods and soil depths on different properties of soils. Correlation analysis was done following Zar (1974) to study the relationship between soil characteristics and microbial biomass.

The physico-chemical properties of soils under present investigation are presented in Table 1. The soil textures of the sites were sandy loam and sandy clay loam (Table 1). Clay contents in *Jhum* and vegetable agro-ecosystem were higher in sub-surface layer while other systems revealed reverse trend. Silt content was very low in all the sites and ranged between 1.22% and 3.1%. Water holding capacity of the soil ranged from 58.66% to 82.97% in different sites and showed significant variation among the sites ($P$<0.05). It was found to be greater in surface layers (0-15 cm) than in the sub-surface layer (15-30 cm) in all the land use patterns. Bulk density ranged between 0.84 and 1.05 g $cm^{-3}$ and there was significant variation between the sites. Porosity ranged between 60.23% and 67.8%. Porosity decreased with increase in soil depth except in the vegetable and agroforestry sites. The soil was acidic in nature and pH ranged between 4.9 and 6.28 in the sites. It showed significant variations ($P$< 0.01) between the sites and seasons. Concentration of SOC was found to be greater in surface soil layer than the sub-surface soil layer. Total nitrogen significantly varied between the soil depths and among the sites. Extractable $NH_4^+$-N was higher than the extractable $NO_3^-$N in all the sites. Available phosphorus varied between 7.97 and 43.51 µg $g^{-1}$ in the study site and significant variations were found between depths and sites ($P$<0.01).

*Ammonium-N ($NH_4$) and Nitrate-N ($NO_3$)*

Among four selected land use systems, maximum concentration (20.20 µg $g^{-1}$) of ammonium ($NH_4^+$-N) was recorded from millet agro-ecosystem and the minimum (4.88 µg $g^{-1}$) in vegetable agro-ecosystem (Table 2). Maximum values in all the systems were found during the autumn and winter period and minimum values during the spring season (agroforestry), rainy (millet) and autumn season (vegetable AES). The maximum nitrate-N was found in the agroforestry and minimum in *Jhum* land. However, maximum $NO_3^-$-N was found during the rainy season (agroforestry), autumn season (*Jhum* AES) and winter period (millet and vegetable AES). On the other hand, minimum values were recorded during the rainy season (*Jhum,* agroforestry and vegetable AES). However, in millet AES the value was recorded during the spring season. Extractable $NH_4^+$-N was higher than the extractable $NO_3^-$-N in all the agro-ecosystems.

*Ammonification and Nitrification (µg $g^{-1}$ $month^{-1}$)*

Ammonification rate varies significantly ($P$<0.001)

*Table 1.* Physico-chemical properties of soils under selected land use pattern (values are the mean of 1 year).

| Properties | Depth (cm) | Agro-ecosystems | | | |
|---|---|---|---|---|---|
| | | *Jhum* | Vegetable AES | Agroforestry | Millet AES |
| Soil moisture (%) | 0-15 | 21.68±0.5 | 22.98±1.34 | 26.4±1.12 | 28.22±0.84 |
| | 15-30 | 19.88±0.9 | 22.51±2.06 | 25.34±1.08 | 26.12±0.55 |
| Sand (%) | 0-15 | 74.8±2.83 | 74.6±0.10 | 73.8±0.80 | 71.1±0.47 |
| | 15-30 | 74.6±1.10 | 74±0.5 | 74.2±0.32 | 72±0.42 |
| Clay (%) | 0-15 | 23.98±1.56 | 24±0.03 | 24.1±0.27 | 26±0.18 |
| | 15-30 | 24±0.32 | 24.2±0.04 | 23.4±0.13 | 24.9±0.21 |
| Silt (%) | 0-15 | 1.22±0.71 | 1.4±0.05 | 2.1±0.11 | 2.9±0.06 |
| | 15-30 | 1.4±0.02 | 1.8±0.06 | 2.4±0.12 | 3.1±0.01 |
| Textural Class | | Sandy loam | Sandy loam | Sandy loam | Sandy clay loam |
| Water holding capacity (%) | 0-15 | 72.06±11.6 | 64.44±7.69 | 66.06±2.73 | 82.97±7.69 |
| | 15-30 | 70.15±10.86 | 58.66±5.91 | 65.12±9.91 | 81.94±11.25 |
| Bulk density (g $cm^3$ ) | 0-15 | 0.94±0.02 | 0.94±0.07 | 1.05±0.03 | 0.84±0.10 |
| | 15-30 | 1.04±0.04 | 0.87±0.16 | 0.96±0.02 | 1±0.06 |
| Porosity (%) | 0-15 | 67.8±0.97 | 61±1.53 | 60.23±0.44 | 67.7±0.23 |
| | 15-30 | 61.54±0.13 | 63.5±1.49 | 63.54±0.36 | 61.54±0.26 |
| Soil Organic Carbon (%) | 0-15 | 1.80±0.06 | 0.85±0.03 | 1.40±0.03 | 1.80±0.02 |
| | 15-30 | 1.75±0.06 | 0.50±0.03 | 1.31±0.01 | 1.72±0.01 |
| Available P (µg $g^{-1}$) | 0-15 | 35.85±0.83 | 43.51±0.28 | 41.98±1.11 | 7.97±0.28 |
| | 15-30 | 32.48±0.84 | 36.16±0.16 | 38.61±0.56 | 10.42±0.45 |
| Available K (kg $ha^{-1}$) | 0-15 | 355.71±50.19 | 989.12±151.1 | 145.15±13.29 | 215.49±48.3 |
| | 15-30 | 232.51±76.39 | 873.38±87.83 | 180.99±38.37 | 285.38±42.2 |
| Total nitrogen (%) | 0-15 | 0.40±0.09 | 0.42±0.03 | 0.49±0.03 | 0.42±0.03 |
| | 15-30 | 0.46±0.03 | 0.43±0.06 | 0.49±0.06 | 0.44±0.06 |
| pH | 0-15 | 6.24±0.4 | 4.98±0.01 | 6.1±0.7 | 5.50±0.12 |
| | 15-30 | 6.28±0.6 | 4.90±0.32 | 6.18±0.6 | 5.66±0.06 |
| Ca (C mol $kg^{-1}$) | 0-15 | 1.95±0.14 | 1.17±0.06 | 2.32±0.35 | 2.11±0.14 |
| | 15-30 | 1.77±0.21 | 1.19±0.03 | 2.11±0.31 | 2.25±0.19 |
| Mg (C mol $kg^{-1}$) | 0-15 | 1.05±0.02 | 1.12±0.02 | 0.93±0.02 | 0.98±0.03 |
| | 15-30 | 1.11±0.03 | 1.07±0.03 | 0.90±0.01 | 0.99±0.02 |
| C/N | 0-15 | 4.55 | 2.02 | 2.75 | 4.28 |
| | 15-30 | 3.81 | 1.17 | 2.67 | 3.90 |

between the agro-ecosystems. In the soybean agro-ecosystem, maximum ammonification rate was recorded during the month of August (Table 3). Different agro-ecosystems had shown higher rate of nitrification in different months. Majority of the systems showed higher rate during the monsoon months. Higher nitrification rates were observed during September (*Jhum* AES), December (agroforestry and millet AES) and January (vegetable AES) (Table 3). Lowest nitrification rates were recorded during the month of November (*Jhum* AES), June (agroforestry and millet AES) and April (vegetable AES). However, significant variation was recorded between months and agro-ecosystems ($P<0.001$).

*N-mineralization (µg $g^{-1}$ $month^{-1}$)*

N-mineralization showed significant variations ($P<0.001$) between the seasons in the present study (Table 5). Higher amount of N-mineralization was recorded during the rainy season (agroforestry) and winter season (*Jhum*, vegetable, and millet AES). On the other hand, lowest mineralization rates were found during the spring season (*Jhu*m AES) and rainy season (millet and vegetable AES) (Fig 1). In the surface soil layer (0-15 cm), ammonification rate

*Table 2.* Monthly variations in the concentrations of ammonium and nitrate (µg $g^{-1}$) under selected land use pattern.

| Month | Depth(cm) | *Jhum* | | Vegetable AES | | Agroforestry | | Millet AES | |
|---|---|---|---|---|---|---|---|---|---|
| | | $NH_4$-N | $NO_3$-N | $NH_4$-N | $NO_3$-N | $NH_4$-N | $NO_3$-N | $NH_4$-N | $NO_3$-N |
| Jun | 0-15 | 9.45±1.08 | 1.45±0.06 | 5.44±1.95 | 2.43±0.49 | 8.99±1.41 | 2.80±0.00 | 13.63±3.50 | 2.61±0.02 |
| | 15-30 | 9.52±1.28 | 2.36±0.20 | 7.72±1.17 | 1.78±0.07 | 11.34±1.56 | 1.75±0.04 | 7.65±3.57 | 2.40±0.04 |
| July | 0-15 | 8.12±1.64 | 2.35±0.00 | 5.88±1.93 | 3.85±0.45 | 9.23±0.47 | 2.31±0.98 | 7.65±1.80 | 2.10±0.01 |
| | 15-30 | 9.30±0.93 | 1.88±0.11 | 5.94±0.15 | 1.98±1.10 | 9.65±0.26 | 2.65±0.00 | 5.89±1.97 | 2.07±0.01 |
| Aug | 0-15 | 11.33±1.52 | 4.12±0.44 | 6.38±2.59 | 2.43±0.16 | 11.34±0.49 | 7.84±0.12 | 10.33±3.03 | 3.85±0.12 |
| | 15-30 | 10.72±1.51 | 1.90±0.32 | 5.68±2.10 | 2.77±0.16 | 8.77±0.78 | 4.42±0.31 | 6.44±1.35 | 2.31±0.06 |
| Sep | 0-15 | 13.44±2.08 | 2.53±0.46 | 8.43±2.50 | 1.90±0.34 | 10.43±1.93 | 7.65±0.06 | 11.65±2.66 | 3.69±0.03 |
| | 15-30 | 10.02±1.67 | 6.27±0.47 | 4.88±1.99 | 2.61±0.49 | 8.77±2.10 | 2.83±0.32 | 5.44±5.16 | 4.02±0.05 |
| Oct | 0-15 | 12.77±2.25 | 3.12±0.12 | 7.24±0.74 | 2.87±0.17 | 11.28±1.00 | 2.16±0.09 | 9.21±1.71 | 1.98±0.06 |
| | 15-30 | 11.28±1.52 | 3.18±0.18 | 6.90±1.56 | 2.67±0.10 | 12.23±1.16 | 2.40±0.03 | 8.89±1.72 | 1.97±0.05 |
| Nov | 0-15 | 5.77±0.30 | 2.61±0.09 | 6.18±0.92 | 4.03±0.77 | 6.57±0.59 | 2.10±0.15 | 15.58±4.70 | 3.85±0.12 |
| | 15-30 | 5.59±0.34 | 2.57±0.23 | 5.70±1.55 | 4.15±0.69 | 6.46±2.16 | 2.07±0.01 | 14.78±5.05 | 3.61±0.29 |
| Dec | 0-15 | 5.59±0.36 | 2.80±0.04 | 5.52±0.70 | 3.73±0.75 | 5.91±0.10 | 2.31±0.22 | 20.20±7.82 | 7.81±0.71 |
| | 15-30 | 5.41±0.39 | 2.79±0.21 | 5.55±0.45 | 3.85±0.85 | 5.80±3.98 | 2.31±0.04 | 19.40±7.17 | 7.57±0.95 |
| Jan | 0-15 | 15.10±0.37 | 4.22±0.05 | 10.89±3.55 | 4.09±0.69 | 11.28±1.27 | 4.26±0.07 | 19.03±4.32 | 6.70±0.07 |
| | 15-30 | 14.92±0.32 | 4.01±0.28 | 11.52±3.95 | 4.21±0.96 | 11.17±2.36 | 4.02±0.03 | 18.23±4.79 | 6.46±0.55 |
| Feb | 0-15 | 9.52±0.27 | 1.78±0.20 | 8.91±3.04 | 3.88±0.26 | 9.30±0.22 | 1.98±0.26 | 10.72±1.53 | 2.77±0.21 |
| | 15-30 | 9.34±0.78 | 2.38±0.03 | 8.28±0.69 | 4.00±0.21 | 9.19±0.69 | 2.43±0.38 | 9.92±1.09 | 2.53±0.09 |
| Mar | 0-15 | 9.31±0.52 | 1.92±0.29 | 5.94±2.30 | 3.40±0.05 | 6.33±0.98 | 1.86±0.16 | 7.75±0.80 | 2.71±0.75 |
| | 15-30 | 9.13±0.37 | 2.11±0.11 | 6.33±0.65 | 3.52±0.30 | 6.22±0.84 | 2.16±0.10 | 6.95±1.31 | 2.47±0.47 |
| Apr | 0-15 | 8.53±0.33 | 2.17±0.62 | 5.10±1.42 | 3.43±0.34 | 5.49±0.99 | 2.19±0.04 | 6.10±0.52 | 2.05±0.00 |
| | 15-30 | 8.35±1.28 | 2.08±0.43 | 5.13±2.00 | 3.55±0.32 | 5.38±0.90 | 2.10±0.08 | 5.30±0.57 | 1.81±0.87 |
| May | 0-15 | 7.72±0.68 | 2.22±0.60 | 5.55±1.35 | 3.58±1.13 | 5.94±0.53 | 2.34±0.07 | 5.68±1.39 | 2.08±0.18 |
| | 15-30 | 7.54±0.98 | 2.14±0.14 | 5.94±2.05 | 3.70±0.72 | 5.83±0.67 | 2.16±0.14 | 4.98±1.80 | 1.84±0.20 |

± SE (n=3)

was positively correlated with soil pH, SOC, $NH_4^+$-N and $NO_3^-$-N. This indicates the overall importance of litter decomposition and nutrient release on the ground surface that facilitates a greater nutrient flux in the soil. On the other hand, nitrification rate is negatively correlated to ammonium and nitrate concentration which suggests that available nitrogen concentration was not saturated in these agricultural systems. However, N-mineralization rates are positively correlated with microbial biomass and nitrogen availability.

The greater carbon availability in the soil supports more active microbial biomass with greater nitrogen demand, thus promoting immobilization and recycling of nitrate. Mineralization is an index of available inorganic-N pools and general nutrients supplying ability of the soil (Antil et al., 2001). In most of the agro-ecosystem, higher mineralization was recorded during the rainy season, which might be due to elevated soil temperature and moisture content during this period (Garrett et al., 2012). On the other hand, lower mineralization during the summer could be associated with low microbial activities due to the moisture stress (Gilliam et al., 2001). In agroforestry, lowest mineralization rates were found during the winter period which could be associated with the low decomposition rates because of low microbial activities and greater immobilization of inorganic N resulting in reduced N-mineralization. Mineralization rate may increase during the spring season due to increase in temperature (Numan et al., 2000; Zhang et al., 2008). Microbial activities are limited at soil temperature near freezing and increase with rise in soil temperature and highest N-mineralization occurs when the soil temperature reaches 30-35$^0$C. In dry soils, N-mineralization is low because soil microbial activities are limited due to low water availability. In saturated soils, lack of oxygen limits the N mineralization because only soil microorganisms that can survive under anaerobic

*Table 3.* Monthly variations in soil N-mineralization (µg $g^{-1}$ $month^{-1}$) under selected land use type; 1-Ammonification, 2-Nitrification, 3- N-mineralization.

| Month | Depth | *Jhum* | | | Vegetable AES | | | Agroforestry | | | Millet AES | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (cm) | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Jun | 0-15 | 6.52±0.12 | 0.37±0.52 | 6.89±0.44 | -3.01±1.17 | 0.75±0.99 | -2.26±1.87 | 6.35±3.09 | 1.42±0.51 | 7.76±2.58 | 0.19±1.24 | -2.42±0.62 | -2.24±0.63 |
| | 15-30 | 4.03±2.13 | 1.08±0.27 | 5.11±1.78 | -5.94±1.98 | 0.59±0.87 | -5.35±1.36 | 7.05±3.07 | 1.61±0.07 | 8.66±3.14 | 0.93±0.64 | -1.47±0.68 | -0.53±1.32 |
| July | 0-15 | 3.46±2.07 | 0.71±0.37 | 4.17±1.83 | -2.03±1.03 | 2.69±0.52 | 0.66±0.66 | 6.38±3.19 | 1.45±0.32 | 7.83±2.87 | 0.02±2.50 | -2.08±0.48 | -2.05±2.03 |
| | 15-30 | 4.95±1.58 | 0.95±0.35 | 5.90±0.77 | 3.96±1.31 | -0.54±1.84 | 3.42±0.01 | 7.18±3.39 | 0.26±0.69 | 7.44±2.69 | -0.43±0.62 | -1.64±0.44 | -1.21±1.07 |
| Aug | 0-15 | 2.75±11.33 | 2.60±1.00 | 5.35±7.03 | 3.95±0.21 | 1.56±1.36 | 2.12±0.76 | 18.77±7.59 | 0.60±0.19 | 19.37±7.78 | -3.63±1.23 | -0.22±5.34 | -3.85±6.57 |
| | 15-30 | 5.64±1.74 | 0.39±0.35 | 6.04±1.58 | 2.91±4.44 | -0.43±0.27 | 2.48±4.25 | 8.10±3.45 | 1.08±0.00 | 9.18±3.45 | -1.22±0.06 | 1.09±1.23 | -0.13±1.16 |
| Sep | 0-15 | 5.31±0.05 | 0.45±0.77 | 5.76±0.74 | -6.53±0.59 | 0.05±1.41 | -6.48±1.59 | 5.24±1.46 | 1.99±0.31 | 7.23±1.78 | 2.33±1.17 | 1.36±0.35 | 3.69±1.52 |
| | 15-30 | 1.60±1.43 | 4.60±1.09 | 6.1±0.08 | -2.37±4.78 | 0.98±1.95 | -1.39±3.40 | 3.62±1.14 | 2.42±2.15 | 6.04±1.01 | 5.89±2.31 | -1.87±0.19 | 4.02±2.50 |
| Oct | 0-15 | 4.09±2.41 | 0.87±0.11 | 4.96±3.24 | 4.37±0.73 | 0.69±0.91 | 5.06±0.08 | 10.33±4.81 | 1.09±0.07 | 11.42±4.73 | 0.74±1.70 | 1.24±0.62 | 1.98±2.32 |
| | 15-30 | 3.55±4.80 | 1.66±0.24 | 5.21±3.16 | 4.23±0.93 | 1.49±0.38 | 5.72±0.67 | 10.33±4.60 | 1.18±0.19 | 11.52±4.79 | 1.16±1.38 | 0.81±1.54 | 1.97±2.92 |
| Nov | 0-15 | 2.21±1.72 | 2.31±0.79 | 4.52±2.56 | -2.15±0.68 | 3.68±1.63 | 1.53±0.48 | 8.89±4.21 | 0.74±1.31 | 9.62±2.90 | 0.49±1.78 | 3.36±1.13 | 3.85±0.64 |
| | 15-30 | 2.18±0.56 | 2.23±0.03 | 3.23±0.96 | -1.55±0.37 | 4.22±2.44 | 2.67±1.36 | 2.97±0.89 | 2.17±0.12 | 5.15±0.77 | 1.19±1.46 | 2.42±0.46 | 3.61±1.00 |
| Dec | 0-15 | 2.00±0.79 | 2.44±1.06 | 4.44±0.50 | 1.79±0.67 | 5.24±2.94 | 7.03±1.41 | 3.12±1.44 | 0.32±3.63 | 3.44±2.19 | 0.25±1.15 | 7.56±3.28 | 7.81±2.13 |
| | 15-30 | 1.94±0.35 | 2.40±0.81 | 4.34±0.56 | 1.70±0.20 | 5.00±2.58 | 6.70±1.63 | 1.44±0.13 | 4.02±1.18 | 5.46±1.06 | 1.19±0.63 | 6.38±2.59 | 7.57±1.96 |
| Jan | 0-15 | 3.58±3.43 | 3.85±1.26 | 7.43±1.17 | 6.80±0.25 | 5.07±1.91 | 11.87±1.10 | 8.43±4.02 | 1.34±2.48 | 9.77±1.54 | 0.42±1.20 | 6.28±1.63 | 6.70±0.43 |
| | 15-30 | 3.72±0.67 | 3.69±0.65 | 7.41±0.17 | 7.31±0.04 | 5.80±1.84 | 13.11±1.34 | 4.67±1.23 | 2.39±0.93 | 7.06±0.30 | 2.22±0.33 | 4.24±1.35 | 6.46±1.02 |
| Feb | 0-15 | 5.35±0.83 | 1.51±0.51 | 6.86±1.10 | 5.03±0.44 | 3.85±1.36 | 8.88±1.40 | 4.18±1.74 | 0.48±0.79 | 4.66±0.95 | 0.70±1.57 | 2.07±0.40 | 2.77±1.17 |
| | 15-30 | 3.92±3.26 | 1.60±0.26 | 5.53±2.05 | 4.28±0.71 | 3.17±1.19 | 7.45±0.13 | 8.53±4.19 | 1.08±0.65 | 9.61±3.55 | 0.16±2.14 | 2.37±0.72 | 2.53±1.42 |
| Mar | 0-15 | 4.85±0.52 | 1.40±0.13 | 6.25±0.23 | 2.54±1.15 | 2.32±0.27 | 4.86±0.96 | 5.58±2.24 | 1.13±0.24 | 6.71±2.01 | 1.10±0.83 | 1.61±0.49 | 2.71±1.32 |
| | 15-30 | 4.33±1.59 | 1.74±0.40 | 6.07±0.73 | 2.81±0.24 | -2.55±0.25 | 0.26±0.06 | 6.58±3.07 | 0.95±0.53 | 7.52±2.53 | 0.46±1.12 | 2.01±0.40 | 2.47±0.72 |
| Apr | 0-15 | 3.93±1.00 | 1.84±0.41 | 5.77±0.30 | 1.67±1.25 | -3.45±1.50 | -1.78±0.19 | 5.35±1.34 | 1.03±0.83 | 6.37±2.17 | 2.68±0.09 | -0.63±1.18 | 2.05±1.09 |
| | 15-30 | 4.01±0.63 | 0.80±0.09 | 4.82±0.36 | 1.58±1.46 | -2.15±0.88 | -0.57±0.84 | 3.12±0.68 | 0.98±0.47 | 4.10±1.15 | 1.77±0.79 | 0.04±2.23 | 1.81±3.02 |
| May | 0-15 | 3.48±4.49 | 1.54±0.47 | 5.02±2.71 | 1.97±1.60 | 2.25±1.97 | 4.22±0.20 | 9.82±3.58 | 0.60±0.60 | 10.43±4.19 | 2.68±0.04 | -0.60±1.31 | 2.08±1.35 |
| | 15-30 | 3.52±2.61 | 1.16±0.32 | 4.69±1.11 | 2.24±1.23 | 2.65±2.33 | 4.89±0.42 | 7.21±3.31 | 0.81±0.21 | 8.02±3.10 | 0.61±0.99 | 1.23±0.16 | 1.15±1.84 |

± SE (n=3)

*Table 4.* Correlation coefficients (r) for the relationships between soil properties and N-mineralization rates (µg $g^{-1}$ $month^{-1}$)

| Process | Depth (cm) | SMC (%) | Porosity | pH | Sand (%) | Clay (%) | MBC (µg $g^{-1}$) | MBN (µg $g^{-1}$) | TKN (%) | SOC (%) | Available P (µg $g^{-1}$) | BD ($gcm^{-3}$) | $NH_4$-N | $NO_3$-N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ammonification | 0-15 | -0.50 | 0.42 | 0.26 | 0.45 | -0.49 | -0.26 | -0.42 | 0.01 | 0.19 | -0.09 | 0.36 | 0.04 | 0.26 |
| | 15-30 | 0.48 | 0.10 | -0.38 | 0.53 | -0.73 | -0.37 | -0.43 | 0.14 | -0.05 | -0.10 | -0.19 | 0.06 | -0.17 |
| Nitrification | 0-15 | 0.39 | -0.76 | -0.07 | -0.31 | 0.33 | 0.50 | 0.21 | 0.14 | 0.38 | -0.26 | -0.39 | -0.15 | -0.10 |
| | 15-30 | -0.17 | -0.42 | 0.09 | -0.48 | 0.63 | 0.43 | 0.44 | 0.18 | -0.42 | 0.15 | -0.17 | 0.20 | 0.00 |
| N-mineralization | 0-15 | 0.39 | -0.76* | -0.07 | -0.31 | 0.33 | 0.50 | 0.21 | 0.14 | 0.38 | -0.26 | -0.39 | 0.15 | 0.10 |
| | 15-30 | -0.17 | -0.42 | 0.09 | -0.48 | 0.63 | 0.43 | 0.44 | 0.18 | -0.42 | 0.15 | -0.17 | 0.20 | 0.00 |

n=15; *P<0.05

BD- Bulk density, SMC-soil moisture content, WHC- water holding capacity, SOC-soil organic carbon, TKN-total kjeldahl nitrogen, $NH_4$-N-ammonium nitrogen, $NO_3$-N-nitrate nitrogen

conditions are active. Mineralization tends to be greater in coarse textured soil low in clay, and reduce as the clay content increases in the soil. Fine textured soils high in clay content are abundant in microspores in which organic matter can find physical protection from microbial decomposition.

High decomposition rate of these organic residues is important to release the nutrients through microbial mediation. Soils rich in organic matter tend to have high N-mineralization rates. The interaction of the N-mineralization and immobilization processes is closely connected to the carbon cycle, because decomposing microorganisms derive their energy from carbon compounds they find in soil organic matter. Carbon and nitrogen compounds in soil organic matter can be placed in two pools: a labile active and stabilized (passive) pool. Rate of ammonification was greater than nitrification in all the agro-ecosystems. Denitrification in anaerobic conditions might have negative effect on nitrification which is based on nitrate-N determination. It also might be due to heavy rainfall and increased soil moisture content which leads to development of anaerobic life forms and decrease the rate of oxygen diffusion inside the soil pores.

*Table 5*. Three way ANOVA showing the effects of depth, agro-ecosystem and month on Ammonification, Nitrification and N-mineralization

| Variable | Ammonification | | | Nitrification | | | N-mineralization | | |
|---|---|---|---|---|---|---|---|---|---|
| | df | F | P | df | F | P | df | F | P |
| Depth | 1 | 0.041 | NS | 1 | 2.439 | NS | 1 | 0.7340 | NS |
| Agroecosystem | 7 | 77.521 | 0.0001 | 7 | 18.695 | 0.0001 | 7 | 1.1490 | NS |
| Month | 11 | 25.185 | 0.0001 | 11 | 18.288 | 0.0001 | 11 | 6.4087 | 0.0001 |
| Depth X Agroecosystem | 7 | 5.514 | 0.001 | 7 | 4.411 | 0.001 | 7 | 0.6604 | NS |
| Depth X Month | 11 | 2.571 | 0.005 | 11 | 1.770 | NS | 11 | 0.4634 | NS |
| Agroecosystem X Month | 77 | 8.197 | 0.0001 | 77 | 10.107 | 0.0001 | 77 | 2.7756 | 0.0001 |
| Depth X Agroecosystem X Month | 77 | 2.597 | 0.0001 | 77 | 4.250 | 0.0001 | 77 | 0.6464 | NS |

df- degree of freedom, P- significant level, SOC-Soil organic carbon, TKN-total kjedhal nitrogen, NS-not significant.

Inorganic-N pools vary widely in different agro-ecosystems and seasons, which might be due to three factors, namely variation in mineralization rates, uptake by plants and microbes and losses through soil erosion, leaching, runoff and denitrification (Maithani et al., 1998; Singh and Kashyap, 2007). In agricultural fields where more organic matter was supplied, a gradual release of inorganic N to the soil is reported. During the winter season inorganic N pool was found to be higher, which might be due to lower uptake of nutrients by the crop plants. However, decreased ammonium-N and nitrate-N during rainy season could be due to the greater demand for these nutrients by the plants which grow vigorously during this period (Arunachalam et al., 1996). A huge amount of nitrate concentration may be lost due to plant uptake during the maturation of the crops. Lower concentration of $NO_3^-$ during rainy season may be attributed to leaching and percolation due to heavy rain and soil erosion. Besides leaching, nitrification is also greatly responsible for the decrease of $NH_4^+$ within the 0-20 cm soil layer (Kreibich et al., 2003). However, the significance of denitrification which is the paramount factor responsible for nitrogen loss during the rainy season cannot be ruled out. Variation in soil types and soil texture led to differences in soil moisture, inorganic N concentrations and net N-mineralization rates.

Lower concentration of $NO_3^-$ -N as compared to $NH_4^+$-N might be also due to more efficient uptake of $NO_3^-$ than $NH_4^+$ by the crop plants, or more consumption by the heterotrophic bacteria and denitrification due to high soil moisture percentage (Recous et al., 1988; Kreibich, 2002). Higher concentration of ammonium-N indicates greater rate of ammonification in these agro-ecosystems and potential higher loss of nitrate-N through leaching and runoff, which are generally observed in the hilly agricultural fields.

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