Soil N-transformation Rates in Two Differently Managed Dry Deciduous Forests of West Bengal, India

Sangita Ganguli, Hema Gupta (Joshi), Kashinath Bhattacharya

Abstract— **N-mineralization is crucial to supply available N for plant growth and productivity in forest ecosystem. A study was conducted to estimate the soil N-transformation rates (N-mineralization and nitrification) in two differently managed dry deciduous forest ecosystems. The study areas included Ballavpur Wildlife Sanctuary (created and protected; 23°39'25"N to 87°41'39"E) in Birbhum district and Garhjungle (natural and sacred; 23°40'54.4"N to 87°40'20.2"E) in Burdwan district of West Bengal, India. Soil samples were collected for an annual cycle divided in three seasons (winter, summer and rainy) during January 2014 to September 2014. Both N-mineralization and nitrification rates were higher in Ballavpur than Garhjungle. The annual mean for N-mineralization rate was 14.9 and 20.5 µg g-1 month-1 and nitrification rate was 11.8 and 16.7 µg g-1 month-1 in Garhjungle and Ballavpur, respectively. N-mineralization and nitrification rates as well as soil moisture content were highest in rainy season and lowest in summer season. These rates were significantly positively correlated with soil moisture and negatively with soil mineral-N content. The result suggested that the variation in the rates soil N-transformations were related to the differences in soil moisture content, nutrient status, organic matter content and vegetation types.**

Index Terms— **Dry deciduous forest, N-mineralization, nitrification, protected forest, soil moisture.**

I. INTRODUCTION

Forests contribute significantly to economy of rural and marginalized strata of the society besides providing valuable ecosystem services. Although nutrient availability, topography and climatic factors are important in determining the distribution and productivity of forest ecosystems, associated nutrient cycling characteristics through soil microbial processes like N-mineralization and nitrification are important in the functioning of these ecosystems (Singh and Kashyap, 2007). Hence, the soil N transformation in an ecosystem may serve as index of potential availability and ecosystem losses of nitrogen (Singh et al., 2009). In forest ecosystems environmental and biological factors (anthropogenic disturbances) affect N-mineralization (Wang et al., 2004; Singh and Kashyap, 2006). The anthropogenic disturbances include grazing and browsing, besides collection of grasses, cutting and lopping of trees and shrubs for fodder and fuel wood, etc. (Sagar and Singh, 2003).

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The tropical deciduous forests support a nutrient deficient soil and heterogeneous mosaic of plant communities (Singh and Kashyap, 2007). The N-availability depends upon topography (Weintraub et al., 2015), micro relief and seasonality (Rasche et al., 2011). N-mineralization involves the microbial conversion of complex organic-N into simpler available mineral-N (NH_4^+ -N + NO_3^- -N). Nitrification involves the conversion of NH_4^+ -N into NO_3^- -N by two different groups of chemoautotrophic bacteria. Many studies have reported soil N-mineralization and nitrification to be limited by a suite of climatic and edaphic parameters like temperature, aeration, soil moisture, pH, C:N ratio, soil organic matter, quantity and quality of litter, and soil type (Corre et al. 2003; De Neve *et al.*, 2003; Kiese *et al.*, 2003; Owen *et al.*, 2003; Ross et al., 2004). The degradation of forest ecosystem by anthropogenic pressure also cause changes in nitrogen transformation rate in the soil leading to formation of more inorganic nitrogen and decline in fine root biomass, microbial biomass and ultimately loss of nitrogen from the soil (Singh et al., 2007).

Lateritic zone in West Bengal harbor floristically important Northern Tropical Dry Deciduous forests (Champion and Seth, 1968). Many plants of this region have medicinal and dye yielding properties besides providing minor forest products including lac, sal seeds and leaves, mohua flowers, fibres and flosses, grasses, barks, gums and resins. Lateritic soils are characterized by acidic pH, low fertility status, low NPK content and high iron (Chakraborty *et al.*, 2002). Nothing is known about soil N-transformation rates form these dry deciduous forests, their seasonal variations and the impact of disturbance on these rates, as it has never been explored. Therefore the present study aims to fulfill this lacuna.

The chosen study areas are two differently managed tropical dry deciduous forests on red lateritic soils of West Bengal. No previous study has quantified rates of N-mineralization and nitrification in these forest ecosystems. Our objectives were (i) to estimate the rate of soil N-mineralization and nitrification in the two forests, and (ii) to find the relation of these rates with soil moisture and mineral-N content.

II. MATERIALS AND METHODS

2.1 Study Area

The study area included two dry deciduous forest ecosystems of West Bengal under different management regimes, and situated nearly 50km apart (Fig 1). Ballavpur wild life sanctuary (WLS) is situated in the Birbhum district 23°39'25"N latitude and 87°41'39"E longitude, and falls under biogeographic zone 7B-Chota Nagpur plateau. The forest is manmade and created in a phased manner between 1953 and 1999. The altitude ranges from 50 to 64 meters above the sea level. The whole area is characterized by red-lateritic soil with undulating topography.

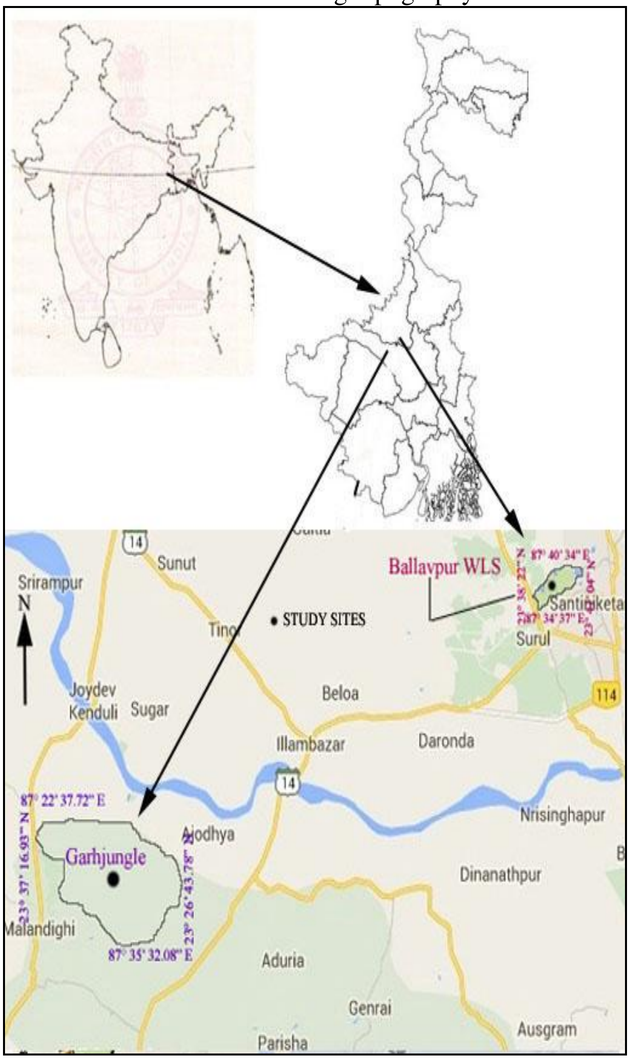

FIGURE 1: LOCATION OF THE TWO SELECTED STUDY SITES

Garhjungle forest is situated in the Burdwan district between 23°40'54.4"N latitude and 87°40'20.2"E longitude. The altitude ranges from 65 to 68 meters above the sea level. This natural forest considered sacred among locals and carry historical significance. The place is supposed to be one of oldest places of ancient India. As per the verses of Puranas and Bhagbats this is the place of Satya Yuga where Raja Surath performed Durga Puja at the instruction of Mahamuni Medhas. In current days Jogiraj Brahmananda Giri of the Dashami cult rediscovered the place and started Durga Puja at the same temple founded by Raja Surath (Wikitravel, 2015). Thousands of devotees visit the place from nearby areas during Durga Puja festival.

The climate of both the study areas is tropical. The temperature ranges from 34˚C to 45˚C in summer and 8˚C to 15˚C in winter. Annual rainfall ranges from 120 to 150 cm. Soils of both the sites are red lateritic which is known for high level of iron content and poor in nutrient status. Ballavpur WLS is dominated by *Acacia auriculiformis* (Linn. A. Cunn) belonging to Mimosaceae family and Garhjungle is dominated by *Shorea robusta* (Gaertn. F.) belonging to Dipterocarpaceae family.

2.2 Soil Sampling and Analysis

Soil samples were collected seasonally during January 2014 to September 2014 in winter (January to February), summer (April to June) and rainy (July to September) seasons. Three samples were collected from three distantly located places from both the forests in three seasons summing up to 18 samples in the annual cycle. The soil samples were collected from 10cm depth and stored in zip lock packet and transported to the laboratory within 24 hours. The soil samples were sieved through a 2 mm mesh screen. Large pieces of plant materials like roots etc. were removed by hand sorting. Each sample was then divided into two parts- one part was used for determination of different soil parameters including mineral-N (NH_4^+ -N and NO_3^- -N) and the second part was kept in incubation for 30 days at 25±2˚C for the determination of N-mineralization and nitrification.

Soil texture was analyzed by Hydrometer method (Bouyoucos, 1927). Soil pH and electrical conductivity (EC) were determined by using pH meter (1:2 soil: water ratio) and conductivity meter (1:5 soil: water ratio) respectively. Gravimetric soil moisture was determined by drying the soil samples at 105˚ C for 24 hours in a hot air oven (Buresh, 1991) and water holding capacity (WHC) by Piper (1944) method.

Mineral N (NH_4^+ -N and NO_3^- -N) was estimated using Kjeldahl distillation method (Jackson, 1958). Organic carbon was determined by Walkley and Black's method (Walkley 1947). Nitrogen mineralization and nitrification rates were determined seasonally from a 30 days period of laboratory incubation of the soil samples in constant temperature (25±2˚C). Rate of N-mineralization was calculated as the difference in the concentration of mineral-N (NH_4^+ -N + NO_3^- -N) in the incubated and initial sample. Nitrification rate was calculated as difference in the concentration of NO_3^- -N in the incubated and initial samples (Hart et al., 1994; Jha et al., 1996).

2.3 Statistical Analysis

Correlation analysis (Excel 2007) was done to determine the relation of N-mineralization and nitrification with soil moisture and mineral-N content. Significance of differences in N-mineralization and nitrification rates due to forests and seasons was determined by two-way ANOVA (SPSS 20).

III. RESULTS

3.1 Physico-chemical Properties of Soil

The mean physico-chemical properties of soils in the two selected forests are presented in Table 1. Water holding capacity was low in both the forest sites, Ballavpur WLS had 28.72% and Garhjungle had 29.18%. Soil pH was acidic in both the forests (5.1 to 5.7). Soil electrical conductivity, pH, moisture content and organic-C were higher in Ballavpur WLS than Garhjungle, but mineral-N content was higher in Garhjungle.

TABLE 1
PHYSICO-CHEMICAL PROPERTIES OF SOILS FROM THE TWO FORESTS

Sites ->	Ballavpur WLS	Garhjungle
Soil type	Sandy loam	Sandy loam
WHC (%)	28.72%	29.18%
pH	5.7	5.1
EC (µs/cm)	63.12	27.8
Moisture %	4.1	3.2
Organic C (µg g^{-1})	3800	2800
Mineral-N (µg g^{-1})	112.41	194.13

There was a marked seasonal difference in soil moisture content in both the forests with maximum in rainy season and minimum in summer. Contrary to this, mineral-N content was maximum in summer season and minimum in rainy season (Fig 2).

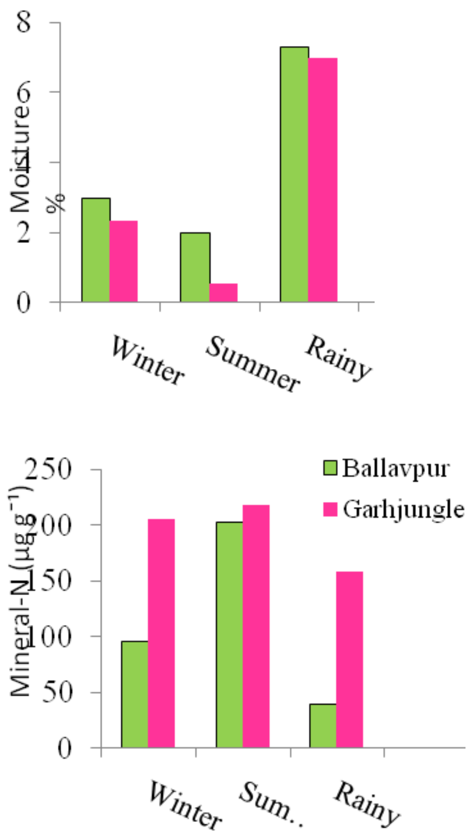

FIGURE 2: SEASONAL VARIATION IN MOISTURE % AND MINERAL-N CONTENT OF SOILS FROM THE TWO FORESTS

3.2 mineralization and Nitrification Rates

Soil N-mineralization and nitrification rates for both the forests were maximum in the rainy season and minimum in the summer season (Table 2). The rates of N-mineralization and nitrification were higher in the protected forests of Ballavpur WLS than Garhjungle.

Soil N-mineralization and nitrification rates were significantly positively related with moisture content. Pearson's correlation coefficient (r) was 0.98 and 0.96 ($p<0.001$) for N-mineralization, and 0.93 and 0.98 ($p<0.001$) for nitrification in Ballavpur WLS and Garhjungle, respectively. Contrary to this, these rates were significantly negatively correlated with mineral-N content with r values being -0.93 and -0.95 ($p<0.001$) for N-mineralization, and -0.98 and -0.97 ($p<0.001$) for nitrification in Ballavpur WLS and Garhjungle, respectively. There were significant differences in both mean N-mineralization and nitrification rates due to forests ($p<0.05$) and seasons ($p<0.0001$). However forest and season interaction did not cause significant difference in both the rates ($p>0.05$) indicating that the season did not influence the two forests in different manner.

IV. DISCUSSION

Our seasonal range of N-mineralization (9.3 – 29.8 µg g^{-1} mo^{-1}) and nitrification (5.6 – 26.1 µg g^{-1} mo^{-1}) rates is within the reported seasonal range in other dry deciduous forests of India:- mineralization 8.4 – 46.78 µg g^{-1} mo^{-1} and nitrification 7.07 – 43.33 µg g^{-1} mo^{-1} in Simplipal (Singh et al., 2007), and mineralization 0.6 – 37.3 µg g^{-1} mo^{-1} and nitrification 1.2 – 25.6 µg g^{-1} mo^{-1} in Vindhyan dry forests (Singh and Kashyap, 2007).

In the present study soil N-mineralization and nitrification rates differed significantly in the two forests with higher rates in the protected forests of Ballavpur WLS than unprotected Garhjungle. The protected forests of Ballavpur WLS had higher values of soil organic-C than those of Garhjungle. Soil moisture was also higher in Ballavpur WLS in all the seasons leading to high mineralization rate. Presence of adequate soil moisture enhances microbial activity, hence decomposition rate is faster leading to more input of organic matter. Most organic matter input in the tropical forest soil is in the form of litter fall (Weltzin et al., 2005). Though Garhjungle is dominated by *Shorea robusta* producing huge amount of leaf litter, but decomposition might be limited by inadequate soil moisture. This might be one of the reasons behind low input of organic matter in Garhjungle.

TABLE 2
MEAN N- MINERALIZATION AND NITRIFICATION RATES (µg g⁻¹ month⁻¹ ± SE) AT THE TWO FORESTS

Sites	Seasons			Annual
	Winter	Summer	Rainy	mean
		N- mineralization		
Ballavpur WLS	18.6 ± 1.8	13.1 ± 1.8	29.8 ± 3.6	20.5 ± 2.8
Garhjungle	14.9 ± 1.8	9.3 ± 1.8	20.5 ± 1.8	14.9 ± 1.8
		Nitrification		
Ballavpur WLS	16.8 ± 3.2	7.4 ± 1.8	26.1 ± 1.8	16.7 ± 3.1
Garhjungle	11.2 ± 3.2	5.6 ± 0	18.6 ± 1.8	11.8 ± 2.1

Soil N-mineralization and nitrification rates showed a distinct seasonal variation with maximum rates in rainy season and minimum rates in summer. Similar kinds of reports are there in seasonally dry forests, savannas and croplands (Jha et al., 1996a; Roy and Singh, 1995; Singh and Kashyap, 2007). The N-transformation rates also reflected a reciprocal relationship with the mineral-N content, but positively related with soil moisture content. Highest mineral-N was observed in the dry summer season and lowest in the wet period. Similar results were reported from different tropical ecosystems (Jha et al., 1996a; Neill et al., 1995; Roy and Singh, 1995, Singh and Kashyap, 2007). In dry soil, microbial activity is limited by water availability. Low vegetation demand for nutrients (Jaramillo and Sanford, 1985) and microbial cell death due to air drying of soil (Okano, 1990) increases mineral-N concentration during dry period. On the contrary heavy nutrient demand by vigorously growing plants (Singh et al., 1989) lowers it during the wet season. Decreased nitrification and N-mineralization in summer does not indicate its absence but reduction in plant intake immobilizes the N-mineralized in microbial biomass (Singh et al., 2007).

The protected forests of Ballavpur WLS had lower values of soil mineral-N than unprotected forests of Garhjungle. Singh et al. (2007) also reported lower mineral-N in protected forest than degraded forest and attributed it to higher organic N. Disturbance and degradation caused transformation of considerable amount of organic N to mobile mineral forms which suggested higher leaching losses in unprotected soil (Mo et al., 2003). N losses from undisturbed forests are much lower (Perakis and Hedin, 2002) and consequently pool of inorganic N is lower, but potential of N-mineralization is higher (Singh et al., 2007). Greater N-mineralization and nitrification is needed in nutrient poor site to fulfil the strong demand of inorganic N by the plants during wet period (Singh and Kashyap, 2007).

N-mineralization is also affected by vegetation cover through litter quality and quantity (Lovett et al. 2004). Ullah and Moore (2009) reported increase in N-mineralization and nitrification rates with increase in litter fall and litter N input. Litter with higher N decompose faster and increase N-mineralization rate (Owen at al., 2010). Litterfall and litter chemistry were not measured in present investigation but Garhjungle being dominated by *Shorea robusta* received more leaf litter, but being an unprotected forest the fallen leaves were collected by local people for making bowls and plates. Fuelwood and other NTFP were also collected. Although it is considered sacred, but it appears that it is not traditionally maintained like other sacred groves of India. On the contrary leaves of *Acacia auriculiformis* have no such utility, moreover all the fallen litter decompose inside the protected forests of Ballavpur WLS.

V. CONCLUSIONS

It is concluded that the two forests had different N-transformation rates related to the soil moisture, nutrient (mineral N) and organic matter status, and possibly with their distinct vegetation types. In-situ decomposition of litter might be responsible for increase in organic matter and soil moisture, and hence N-mineralization in Ballavpur WLS. Additional studies quantifying N-transformation rates for another annual cycle and analysing them with respect to additional soil parameters such as total C, total N, organic N, C/N ratio will further greatly improve our understanding of soil N transformations in these forests. Future work will also investigate the impact of N-transformation on overall vegetation structure and diversity of these two differently managed forests.

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