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Impact of Savannization on Nitrogen Mineralization in an Indian Tropical Forest

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Abstract

The effects of conversion of an Indian dry tropical forest ecosystem into savanna, on mineral nitrogen (N), net N-mineralization rate and microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) in soil were studied for two years. There was a marked seasonal variation in all the above parameters at both (upper, 0-10 cm and lower, 10-20 cm) the soil depths of forest and savanna ecosystems. In forest ecosystems the mean annual values of mineral N, net nitrification rate, net N-mineralization rate, MBC, MBN and MBP at both depths were 17.41 and 13.2 µg g^{-1}, 18.76 and 10.96 µg $g^{-1}mo^{-1}$, 23.54 and 12.83 µg $g^{-1}mo^{-1}$, 623 and 195µg g^{-1}, 116 and 29µg g^{-1}, 16 and 9µg g^{-1}, respectively; while in savanna ecosystems the values were 20.15 and 15.73 µg g^{-1}, 10.74 and 6.29 µg $g^{-1}mo^{-1}$, 16.59 and 10.11 µg $g^{-1}mo^{-1}$, 453 and 150µg g^{-1}, 79 and 21.7µg g^{-1}, 13 and 6µg g^{-1}, respectively. The soil microbial biomass was positively related to root biomass and total plant biomass (i.e., above- and below-ground biomass). Interestingly, seasonal soil moisture and temperature are reciprocally related to microbial biomass and mineral N and directly related to nitrification and N-mineralization. The microbial biomass, nitrification and N-mineralization are negatively related to clay content. Savannization caused significant loss of soil mean organic carbon (OC), total N (TN) total mean annual nitrification, N-mineralization, MBC, MBN and MBP by 40, 42, 27, 27, 29 and 7%, respectively at upper soil depth and 18, 21, 42, 29 and 22%, respectively at lower soil depth. The reflectances of soil microbial biomass to OC were 1.22 and 1.06 folds at upper and lower soil depths, respectively.

Thus, conversion of dry tropical forests into savanna affects remarkably the soil N transformation; microbial biomass and loss of soil organic C which adds to the environmental pollution.

Keywords: Mineral-N; Nitrification; N-mineralization; Microbial biomass; Immobilization; Seasonal pattern; Savannization; Forest ecosystems

Introduction

Much of the earth's grasslands are over used and poorly managed [1], and significant amounts of native forest, shrub land, and woodland have been converted to grassland [2]. Dry tropical forest once occupied more land area than rainforest, at 42% of all intra-tropical vegetation. However, it is easily converted to cattle pasture by logging and burning, and now very little dry tropical forest remains. In Ecuador less than 2% of the original extent of this forest type remains, a statistic which is characteristic of most tropical dry forest regions in the world; however, in Central America sadly less than one-tenth of one percent remains. Because of these tremendous rates of loss, organisms that once were common in these forests now face extinction, merely for lack of habitat. Furthermore, because few functioning dry forest ecosystems remain (the forest is reduced to small, isolated patches in most parts of the world), their ecology is poorly studied (http://www.ceiba.org/loorecology.htm accessed on 24/11/2010).

According to Mishra [3] and Srivastava & Singh [4], most of the grasslands in India have been derived from dry forests. The conversion of forest into grassland or savanna due to forest harvesting, fertilization, atmospheric deposition, and climate change alters the soil nitrogen cycling to a significant extent [5]. This conversion leads to several changes in vegetation and soil properties [4]. Forest clearing and land-use changes have important consequences not only for nutrient availability but also for soil organic matter (SOM) stability [6]. Any alteration in ecosystems shows the loss of N and the variation aids in developing management strategies to manage nitrogen losses [7].

Soil organic matter (SOM) is a major resource that links the physical, chemical and biological properties of soils, and is considered a major binding agent that stabilizes soil aggregates [8,9]. The soil organic carbon (SOC) acts as an exchange surface for cations and direct source of N, P and S through microbial C and N-immobilization/mineralization reactions [10,11]. Soil N is the most important nutrient influencing the productivity and sustainability of ecosystems [12]. Since N is incorporated into soil microbial biomass to a higher extent, it is very important to determine N mineralization to evaluate N availability and soil fertility [13].

Nitrogen (N) mineralization is an important component of nitrogen supply for plant growth [14] and the nutrient dynamics is controlled by the rate of decomposition of organic matter [15]. N-mineralization is of prime importance in ecosystem productivity [12,16], hence for the ecosystem and nutrient cycling, soil nitrogen transformations are measured as indices of potential availability and ecosystem losses of nitrogen [17]. In forest and grassland ecosystems, N-mineralization is affected by the biological factors, such as soil animals, soil microorganisms and plants and the non-biological factors, such as environmental factors and anthropogenic disturbances [12,18,19].

Microbial activity is fundamental in the processes that make energy

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and nutrients available for recycling in the ecosystem [20,21]. Microbial biomass acts as a source of plant nutrient in dry tropical forest and savanna ecosystems [22]. Soil microbes play key roles in ecosystems and influence a large number of important ecosystem processes, including nutrient acquisition [23,24], nitrogen cycling [25], carbon cycling [26] and soil formation [27]. Microbial uptake of nutrients also has important implications for ecosystem nutrient storage and temporal partitioning of nutrients between plants and soil microbial pools. Immobilization of N by microbes, for example, has been shown to act as a short-term sink for N in several terrestrial ecosystems [28-30], thereby potentially limiting the export of N to adjacent ecosystems [31]. Seasonal patterns of N immobilization by microbes is also important for plant N-acquisition, especially in strongly N limited ecosystems where microbial communities immobilize N maximally in autumn, after plant senescence, and retain it throughout the winter until spring, when it is released for plant uptake [32]. Microbial uptake of N is also important for longer-term ecosystem N retention, via the transfer of the nutrients from within microbial tissues to more stable organic matter pools after cell death [28].

Land use changes, such as conversion of forest to grazed grassland or savanna can drastically change plant species composition, and dominant life forms, which, in turn, markedly affect soils and soil processes [33-35]. Thus, any change in forest ecosystem, and consequently the microbial N may have significant impacts on nitrogen availability and overall forest nitrogen cycling [36]. Microbial biomass can serve as an estimate of microbial N immobilization and due to its importance in the functioning of different ecosystems, dynamics of microbial biomass and its role in plant nutrition under different ecosystem conditions are of greater significance [37]. We hypothesized that conversion of forest into savanna leads to a loss of soil nitrogen and carbon which may affect the soil microbial biomass, N-transformation rate and availability of the mineral nitrogen.

The objectives of this study were to determine the effects of conversion of a tropical forest into savanna on plant available N-pool, nitrification and N-mineralization rates and soil MBC, MBN and MBP.

Methods

Study sites

The study sites were located in Similipal Biosphere Tiger Reserve in Mayurbhanj District of Orissa state (India). The Reserve lies between 85°4' to 87°10' longitude and 20°17' to 22°34' N latitude at an average elevation of 1000 m above mean sea level. Similipal is extended over an area of 4374 km^2 and includes the biogeographic zone of Deccan Peninsula, Chhotanagpur and Mahanadian regions. It was constituted by the Govt. of India as a Biosphere Tiger Reserve for conserving the biodiversity of plants and animals in their natural ecosystem. The forest and savanna cover an area of 845 sq km, 2129 sq km, respectively.

Similipal is a dry tropical deciduous forest, inhabiting more than one thousand plant species. The forest is one of the best sal (*Shorea robusta*) forests of India. Besides *S. robusta*, the other frequently occurring mixed species found in this biosphere reserve are *Terminalia tomentosa, Anogeissus latifolia, Bauhinia variegata, Sterculia urens, Terminalia arjuna, Murraya koenigii, Schleichera chinensis, Samanea saman, Xylia xylocarpa,* etc. The area of savanna comprises of two communities, one dominated by Imperata cylindrica and the co-dominant species are Themada gigantica and Saccharum spontaneum. The other species include Ergrostis atrovirens, Sporobolos indicus. Heteropogon contortus and the co-dominant species *Cymbopogon flexosus, Bothriochloa bladhii* are the other communities abundantly found in this forest, while *Bracharia racemosa, Digitaria stricta, Dicanthium caricosum* and *Panicum notatum* are some other species thriving in the biosphere reserve. The elephant population of Simlipal is the largest and best of the Central-Indian population. Bulk population within the Biosphere Reserve is of tribals having very low level of skill. Agriculture is mostly rain fed and not well developed. Tribals produce only one paddy crop in a year. The anthropogenic pressure on forests is too much and it is not only need based but it is activity, occupation and habit based. So, most of the people derive their income from collection of minor forest products (MFP), sale of firewood and timber. In addition to these MFP are also collected by them for their own use. 'Akhand Shikar' is another traditional custom, which results in large-scale killing of wild animals. Savanna has been derived from the forest ecosystem due to anthropogenic pressure like cutting of the forest for timber and fuel wood, forest fire, grazing by the animals [19].

Two forest sites (sal forest and mixed forest) and two savanna sites (Imperata and Heteropogon dominated communities); both derived from the forest were studied seasonally for two years in the years May 2004-December 2005. In savanna ecosystem, a few species of *Shorea robusta*, *Madhuca indica* and *Terminalia arjuna* are scattered. The savannization process was likely initiated by the local tribal residing for clearing lands for the cultivation of paddy crops.

Climatic conditions and soil characteristics

The climate of Similipal forest reserve is tropical and includes three seasons; summer (April to June), rainy (July to September) and winter (November to February). October and March constitute the transition months between the rainy and winter seasons and between winter and summer seasons, respectively. About 79% of the annual rainfall occurs in the rainy season. The ambient temperature remains about 20°C between December last week to January first week and maximum 48°C during May. Relative humidity during morning hour accounts upto 70-100% and 30% during midday [19].

Rocks are metamorphosed, sedimentary and igneous. The soil of Similipal is acidic in nature, red loam, derived from haematite rocks. Soils are also of clay and clayey loam type, formed due to weathering of shales. The outcrop of sub metamorphic sand stone and quartzite hematite's, on disintegration, produce reddish sandy soil. Soil erosion has recently emerged as a problem, particularly around the valley [38]. The organic carbon contents are rich in the soil, but the nitrogen and phosphorus are very poor.

Sample collection

Three uniform plots of one ha each were marked in two forest and two savanna sites for the sample collection and from each plot soil samples were randomly collected in 5×5 cm block from the both upper (0-10 cm) and lower (10-20 cm) soil depths. All the 25 samples of respective depths were composited to get one sample per plot from each depth of the soil in the months of May, for summer season, August, for rainy season and December, for winter season for two consecutive years (2004 and 2005). Large pieces of plant materials were picked out by hand for removing the large plant materials to check the nutrient immobilization [39,40] and the soils were sieved through 2 mm mesh screen. Root sampling (5 Nos. per plot of size 15cm×15cm) was confined to 0-10cm and 10-20 cm depths of soil. Each soil sample was divided into two halves. One half in the field moist condition was used for determination of mineral N, microbial nutrients, and the other part was air-dried (<0.2% moisture) for all the other analyses.

Soil analyses

Soil sampling for texture analysis was done once in winter (December) 2004, and for physico-chemical characterization, viz., organic C, N, and P, total N and P, Mineral N and Microbial C, N and P it was done seasonally (winter, summer and rainy season). All the data reported in this paper are means for three plots. Estimations of pH, nitrate-N and ammonia-N were done in the field-moist condition of forest and savanna soils. The other parameters, such as water holding capacity (WHC), bulk density (BD), particle size distribution, organic carbon (OC), total N (TN) and total P (TP) were analyzed in air-dried soil.

Soil pH (soil: water ratio = 1:2) was estimated by ORION ion analyzer. Bulk density and water holding capacity were determined following Piper [41]. Organic C of soil was determined following Walkley Black's method and total N by modified Kjeldahl method [42]. The percent soil organic matter (SOM) was calculated by multiplying the percent organic C by a factor of 1.72 following the standard practice that organic matter is composed of 58% carbon. For the determination of total P, the perchloric acid digestion method was followed [43].

Analyses for mineral nitrogen (nitrate and ammonium-N), nitrogen mineralization and microbial biomass C, N, P

Nitrogen mineralization in soil was quantified by in situ buried bag technique [44,45]. Freshly collected soil samples (ca. 150 g) enclosed in polyethylene bags were buried at both depths (0-10 and 10-20 cm) in field and incubated for 30 days. Nitrate-N and ammonia-N were determined at zero time, i.e., the day of fresh sample collection and after 30 days of field incubation. Nitrate-N was estimated by Phenol-di-sulfonic acid method [42] and ammonium-N by phenate method [46]. An increase in nitrate-N during the course of incubation indicates the net nitrification. Net N-mineralization was calculated by taking into account the increase in the concentration of ammonium-N plus nitrate-N in between the period zero day and 30 days of incubation [47,48].

Microbial C in soil sample was determined using the $CHCl_3$ fumigation-incubation method of Jenkinson and Powlson [49] except that liquid $CHCl_3$ was used instead of vapour and CO_2-C evolved from fumigated soil during 10-20 days was taken as control [38,50]. Microbial C was calculated as: Microbial C = Fc/0.45.

Microbial N in all soils was determined by the chloroform fumigation extraction method [51]. All the samples were stored in the field-moist condition at room temperature without adjusting the soil moisture, to settle down the respiration [52]. The flush of total N was obtained by subtracting the K_2SO_4-extractable N in unfumigated soil from that of the fumigated soil, and is divided by a fraction value (K_N) of 0.54 [51] of biomass N extracted after chloroform fumigation.

Microbial P was determined by the $CHCl_3$ fumigation-extraction method [38,53] and was calculated from $CHCl_3$ released Pi by dividing with a k_p value of 0.40 [53], i.e., by assuming that 40% of P in the biomass is released as Pi by $CHCl_3$. Biomass P was further corrected for P fixation during $NaHCO_3$ extraction by measuring the recovery of a spike of added Pi as KH_2PO_4 [53]. According to Srivastava and Singh [52], fractions of microbial C and nutrients mineralized (k_C, k_N and k_P) after fumigation could vary from soil to soil and from season to season.

Plant biomass

Above ground litter biomass in forests and canopy biomass in savanna were measured in randomly placed five 1x1 m quadrats per plot. For belowground biomass (live+dead root) five replicate monoliths of 15x15x10 cm followed by 10-20 cm size were sampled. The monoliths were washed with a fine jet of water using a 0.5 mm mesh screen. Both above- and below-ground samples were oven dried at 80°C till the constant weight.

In forest, quantification of above- and below-ground biomass of forest was in May 2004 and 2005 (at the time when the litter layer on the ground is at a maximum). The canopy biomass and belowground biomass of the savanna was measured in September 2004 and 2005 (at the time of peak biomass) [4].

The statistical analyses (analysis of variance, least significant difference) of the mean values of the forest and savanna data were analyzed (MANOVA) following Snedecor and Cochran [54] and SPSS [55].

Results

Physico-chemical characterization

A summary of the mean annual values of physico-chemical characteristics of soil is given in Table 1. The conversion of forest into savanna at both soil depths (0-10cm and 10-20cm), increased significantly the BD by 18.33 and 13.15%, and decreased the OC, TN and TP by 40 and 18%, 38 and 30%, and, 13 and 39%, respectively.

Above- and below-ground biomass

The mean annual values of above ground and below ground biomass for both ecosystems are given in Table 2. The conversion of forest into savanna resulted into a decline of above- and below-ground biomass in 0-10 cm by 4% and 42.68%, respectively. The below ground biomass in 10-20 cm soil depth was declined by 60%. There was a decline of 28.4% in total biomass after the conversion of forest into savanna.

Inorganic nutrient status

The seasonal concentrations of nitrate-N and ammonia-N in forest and savanna sites at both soil depths are given in Table 3. Available nutrients, such as nitrate-N and ammonia-N were highest during summer season and lowest during the rainy season in both the years. Mean values across the season and sites and depths indicated significant differences due to site and season ($p<0.05$). Savannization caused decline in nitrate N in both soil depths by 21% and 23%, and increased in ammonium N by 37% and 46%, respectively.

Net nitrification and Net N-mineralization

The seasonal values of net nitrification rate and net N-mineralization in forest and savanna sites at both depths are given in Table 4 and 5, respectively, with a maximum value in rainy season and minimum value in summer season at both the soil depths. Mean values across the season and sites at both soil depths indicated significant differences due to site and season ($p<0.05$). Savannization caused decline in net nitrification rate and N-mineralization rate at 0-10 cm soil depth by 43 and 29% and at 10-20cm depth by 43 and 21%, respectively.

Soil microbial C, N and P

The seasonal values of microbial C, N and P across the sites at both soil depths are given in Table 6, with a maximum value in summer season and minimum in rainy season at both the soil depths. Mean values across the season and sites at both depths indicated significant differences due to site, season and depths ($p<0.05$). Conversion of

S. No.	Parameters		Sal forest		Mixed forest		Savanna (*Imperata*)		Savanna (*Heteropogon*)	
			0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
1.	pH		5.76 ± 0.02	5.22 ± 0.02	6.01 ± 0.02	5.68 ± 0.02	4.78 ± 0.011	4.55 ± 0.02	4.58 ± 0.011	4.25 ± 0.02
2.	Temperature°C		20.2	18	22.5	20.5	24.40	22.2	24.6	22.5
3.	Moisture (%)		10.32 ± 0.02	8.62 ± 0.02	9.17 ± 0.017	8.10 ± 0.02	7.72 ± 0.12	6.35 ± 0.02	7.41 ± 0.12	6.10 ± 0.02
4.	Soil Particle Size	>0.2 mm (%)	66 ± 0.7	60 ± 0.7	68 ± 0.5	60.1 ± 0.7	72 ± 1.0	67 ± 0.7	75 ± 1.4	67 ± 0.7
		0.2-0.1mm (%)	18 ± 0.4	19 ± 0.4	20 ± 0.5	20.2 ± 0.015	19 ± 0.4	23 ± 0.067	14 ± 0.36	21 ± 0.42
		<0.1 mm (%)	16 ± 0.8	21 ± 0.7	13 ± 0.8	17 ± 0.7	8 ± 0.7	10 ± 0.7	10 ± 1.2	12 ± 0.93
5.	Bulk Density (g cm^{-3})		0.97 ± 0.17	1.12 ± 0.028	1.075 ± 0.013	1.16 ± 0.033	1.20 ± 0.012	1.28 ± 0.021	1.22 ± 0.013	1.30 ± 0.017
6.	WHC (%)		38.96 ± 0.052	35 ± 0.052	36.41 ± 0.32	34 ± 0.04	32.98 ± 0.05	29 ± 0.12	34.33 ± 0.034	31 ± 0.046
7.	Organic C (%)		1.98 ± 0.02	0.8 ± 0.16	1.84 ± 0.026	0.75 ± 0.017	1.11 ± 0.02	0.62 ± 0.018	1.17 ± 0.02	0.65 ± 0.022
8.	SOM		3.40	1.37	3.16	1.29	2.08	1.03	2.01	0.89
9.	Total N (%)		0.362 ± 0.02	0.095 ± 0.02	0.346 ± 0.019	0.085 ± 0.033	0.21 ± 0.02	0.062 ± 0.034	0.23 ± 0.017	0.065 ± 0.018
10.	Total P (%)		0.045 ± 0.003	0.014 ± 0.027	0.039 ± 0.004	0.014 ± 0.006	0.038 ± 0.003	0.0135 ± 0.022	0.035 ± 0.005	0.013 5 ± 0.003
11.	Organic C/N Ratio		5.47	8.42	5.31	8.82	5.29	8.25	5.1	8.46

Table 1: Physico-chemical characterization of soils of forest and savanna ecosystems (means ±1 S.E.) at different depths.

Ecosystems		Aboveground biomass (kg ha^{-1})	Belowground biomass at different depths (kg ha^{-1})		Total
			0-10cm	10-20cm	
Forests	Sal Forest	3630 ± 235	6280 ± 530	2806 ± 125	9910
	Mixed Forest	3520 ± 235	6560 ± 570	3018 ± 130	10080
Mean		3575	6420	2912	9995
Savanna	*Imperata* community	3530 ± 150	3780 ± 470	1264 ± 75	7310
	Heteropogon community	3333 ± 130	3670 ± 450	1038 ± 60	7003
Mean		3431	3725	2912	7156

Table 2: Mean aboveground plant biomass and root biomass in forest and savanna ecosystems (means ±1 S.E.).

Parameter	Ecosystem	Season							
		Rainy		Winter		Summer		Mean annual	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Nitrate-N	Sal forest	9.73 ± 1.0	7.08 ± 0.8	11.06 ± 0.9	8.14 ± 0.7	12.59 ± 1.2	9.33 ± 0.6	11.12 ± 0.9	8.18 ± 0.8
	Mixed forest	7.70 ± 0.8	5.47 ± 0.6	8.80 ± 0.7	7.2 ± 0.6	10.05 ± 0.8	8.72 ± 0.6	8.85 ± 0.7	7.13 ± q0.6
	Mean	8.72 ± 0.9	6.27 ± 0.7	9.93 ± 0.8	7.67 ± 0.6	11.32 ± 2.0	9.02 ± 1.2	9.99 ± 1.9	7.65 ± 1.4
	Savanna (*Imperata*)	6.79 ± 0.8	4.27 ± 0.4	7.49 ± 0.7	5.95 ± 0.6	9.06 ± 0.8	7.42 ± 0.6	7.78 ± 0.7	5.88 ± 0.4
	Savanna *Heteropogon*)	6.84 ± 0.6	4.28 ± 0.4	7.84 ± 0.8	6.08 ± 0.6	9.25 ± 0.8	7.18 ± 0.6	7.97 ± 0.7	5.84 ± 0.4
	Mean	**6.81 ± 0.7**	**4.27 ± 0.4**	**7.66 ± 0.75**	**6.01 ± 0.6**	**9.15 ± 0.8**	**7.3 ± 0.6**	**7.87 ± 0.7**	**5.86 ± 0.4**
Ammonium-N	Sal forest	7.71 ± 0.8	5.55 ± 0.5	8.37 ± 0.7	7.0 ± 0.5	9.31 ± 0.6	7.85 ± 0.6	8.46 ± 0.7	6.8 ± 0.5
	Mixed forest	5.17 ± 0.4	3.35 ± 0.2	6.26 ± 0.4	4.4 ± 0.3	7.71 ± 0.5	5.15 ± 0.4	6.38 ± 0.5	4.3 ± 0.3
	Mean	6.44 ± 0.6	4.45 ± 0.3	7.31 ± 0.5	5.7 ± 0.4	8.51 ± 0.5	6.5 ± 0.5	7.42 ± 0.6	5.55 ± 0.4
	Savanna (*Imperata*)	8.50 ± 0.5	6.15 ± 0.5	9.97 ± 0.7	7.75 ± 0.5	11.09 ± 0.8	8.45 ± 0.6	9.85 ± 0.6	7.45 ± 0.5
	Savanna (*Heteropogon*)	8.83 ± 0.5	7.35 ± 0.6	10.59 ± 0.8	8.7 ± 0.6	12.02 ± 0.9	10.1 ± 0.7	10.48 ± 0.8	8.72 ± 0.6
	Mean	**8.66 ± 0.5**	**6.75 ± 0.5**	**10.28 ± 0.7**	**8.22 ± 0.5**	**11.55 ± 0.8**	**9.27 ± 0.6**	**10.16 ± 0.7**	**8.08 ± 0.5**

Table 3: Mean seasonal variations of nitrate-N (μg g^{-1}) and ammonium-N (μg g^{-1}) in forest and savanna ecosystems (± 1S.E.) at different depths.

Ecosystem	Season							
	Rainy		Winter		Summer		Mean annual	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Sal forest	22.27 ± 1.8	11.16 ± 0.9	11.85 ± 0.8	8.39 ± 0.6	8.31 ± 0.6	5.98 ± 0.5	14.14 ± 0.7	8.51 ± 0.7
Mixed forest	44.08 ± 2.2	21.08 ± 1.4	15.67 ± 1.0	11.13 ± 0.7	10.44 ± 0.7	8.05 ± 0.5	23.39 ± 1.2	13.42 ± 0.9
Mean	*33.17 ± 2.1*	*16.12 ± 1.1*	*13.76 ± 0.9*	*9.76 ± 0.6*	*9.37 ± 0.6*	*7.01 ± 0.5*	*18.76 ± 0.8*	*10.96 ± 0.8*
Savanna (*Imperata*)	18.93 ± 1.2	9.9 ± 0.7	8.36 ± 0.5	6.7 ± 0.4	6.86 ± 0.5	4.95 ± 0.2	11.38 ± 0.3	7.18 ± 0.6
Savanna (*Hetero*)	17.06 ± 1.2	8.22 ± 0.6	7.11 ± 0.5	4.49 ± 0.3	6.15 ± 0.4	3.52 ± 0.1	10.10 ± 0.6	5.41 ± 0.4
Mean	17.99 ± 1.1	9.06 ± 0.6	7.73 ± 0.5	5.59 ± 0.3	6.50 ± 0.4	4.23 ± 0.2	10.74 ± 0.4	6.29 ± 0.5

Table 4: Mean seasonal variations of net nitrification (μg g^{-1} mo^{-1}) in forest and savanna ecosystems (± 1S.E.) at different depths.

forest into savanna caused decline in MBC, MBN and MBP at upper depth by 27%, 32% and 19% and at lower soil depth by 23%, 24% and 33%, respectively.

Statistical analysis

Analysis of variance (MANOVA) has shown a significant difference ($P<0.05$) in the concentration of mineral N (μg g^{-1}), rates of net nitrification, net N-mineralization (μg $g^{-1}mo^{-1}$) and microbial biomass C, N and P (μg g^{-1}) due to sites, seasons and depths.

Mean annual MBC, MBN, MBP were positively correlated with inorganic nutrient concentration ($r^2=0.99$, $P<0.05$), belowground biomass ($r^2=0.83$, $P<0.05$), net nitrification ($r^2=0.99$, $P<0.05$) and net N-mineralization rate ($r^2=0.90$, $P<0.05$). Soil moisture is negatively related to microbial biomass C, N and P ($r^2=0.84$, $P<0.1$), while positively related with net nitrification ($r^2=0.82$, $P<0.05$) and net N-mineralization ($r^2=0.86$, $P<0.007$). With clay content in soil, a negative correlation has been found for MBC, MBN and MBP ($r^2=0.54$, $P<0.5$), net nitrification ($r^2=0.58$, $P<0.5$) and net N-mineralization ($r^2=0.59$, $P<0.5$). A positive relation of total N with microbial N ($r^2=0.98$, $P<0.05$), net nitrification ($r^2=0.97$, $P<0.05$) and net N-mineralization ($r^2=0.98$, $P<0.05$) has been found. In the present study, a significant correlation of OC content with microbial C ($r^2=0.88$, $P<0.05$), net nitrification ($r^2=0.94$, $P<0.05$) and net N-mineralization ($r^2=0.88$, $P<0.05$) has been found.

Discussion

Physico-chemical characteristics

The conversion of forest into savanna at both soil depths significantly increased the BD. The increase may be attributed to differences in soil organic matter content due to soil run off and compactness of the soil. Savannisation caused loss of OC, TN and TP in upper and lower depths of soil by 40 and 18%, 38 and 29%, and 13% and 39%, respectively. The OC loss can be translated into 5736 and 643 kg/ha in upper and lower soil depths, respectively. This may be one of the reasons for the atmospheric addition of carbon. Soil organic matter (SOM) was higher in forest and conversion to savanna led to a drop in SOM content [56]. Land use practices that have detrimental effects on SOM content have far reaching implications because of the multiple roles SOM plays in governing soil quality**.** Cleveland et al. [57] also reported that land transformations caused reduction in organic C and other nutrients in soil. According to Lal [58] and Pullicino et al. [59], anthropogenic changes in natural land conditions may have a significant impact on soil carbon (C) stocks; possibly transforming large areas that were once net C sinks to C sources. These changes may decrease the soil organic C pool, reduce structural stability, increase soil's susceptibility to water runoff and erosion, disrupt cycles of water, C, nitrogen (N) and other elements and cause adverse impacts on biomass productivity, biodiversity and the environment. Basu and Behera [60] reported decline of organic C by 40-46% in India. Saikh et al. [61] and Tripathi and Singh [19] have also reported a decline of 38% in OC due to alternate land uses. According to Singh [62], the reason for a decrease in soil nutrient stock may be the lower inputs of organic matter in the converted systems due to decline in the plant biomass.

In forest the course soil fraction was lower and fine soil fraction was higher compared to savanna. After the conversion of forest into savanna the soil texture became sandy. The reason attributed to this change in soil texture is that under sparse vegetation the clay fraction is likely to be lost to processes of selective erosion and migration down the soil profile [56]. According to Singh [62] and Singh & Singh [63], primary soil particles, particularly clay, tend to cohere under natural conditions to form secondary units called aggregates, through the action of microbially derived polysaccharides. Conversion of forest into savanna (and cropland) reduces the organic matter input to the soil and the proportion of macroaggregates. They opined that reduction in the proportion of macroaggregates indicates soil deterioration. Several authors (Bird et al. [64]; Desjardins et al. [65]; Powers and Veldkamp [66]) have described the relationship between texture and soil organic content in tropical soils**.**

Inorganic nutrient status

The seasonal patterns show that the nitrate-N and ammonium-N were maximum in summer and minimum in the rainy season at both soil depths. The decrease in inorganic N during the rainy season is mostly due to the strong demand of these nutrients by the vigorously growing higher plants, during the period [22]. However, leaching and denitrification may also be responsible for this decline. Conversely, an increase in summer season is associated with a decreased nutrient uptake demand by the plants. According to Sanchez [67] and Singh et al. [68] in tropical soils the previously present or recently formed nitrate in the sub-soil may also move up and accumulate in the topsoil. Birch [69] and Singh et al. [70] opined that greater amount of ammonium N during the dry period may be partially due to the release of free ammonium and amino acids due to soil drying. Perhaps the most important route by which free-living microbes influence plant nutrient availability, is via processes of nutrient mineralization, whereby soil microbes break down soluble and insoluble organic matter and convert it into inorganic, plant available forms [30].

In the present study, mean annual nitrate-N decreased by 21% and 23% at both soil depths, respectively due to conversion of forest into savanna. According to Singh [62], the conversion of a tropical forest of India into savanna resulted into a decline of 13.2% in mineral N and 52.3% in organic N. Interestingly; the mean annual ammonium-N was increased by 37% and 46%, respectively at both soil depths, respectively due to conversion into savanna (Table 3). According to Neill et al. [71], NH_4^+ dominates the inorganic N pool in pastureland and NO_3^- in forest ecosystems of Amazon forest. The decrease in nitrate-N and increase in ammonium N in the dry tropical savanna soils may be due to higher percentage of net ammonification rates as compared to forest. This may also be one of the conserving mechanisms of nitrogen in dry tropical ecosystem to check easily mobile nitrate nitrogen loss from the open derived ecosystems.

Net nitrification and Net N-mineralization

Rates of soil N mineralization and nitrification are indicators of the ability of soils to supply N for plant growth and to retain N following disturbances [71]. The seasonal patterns of net nitrification and net N-mineralization were similar; both being highest in rainy season and lowest in the summer season. In dry tropical forest ecosystems, nitrification and N-mineralization are moisture limited. During dry periods plant uptake of nutrients is greatly reduced and N-mineralization and nitrification are either immobilized in microbial biomass or accumulate in the soil as inorganic N [22] According to Cassman & Munns [72], a strong and significant relationship is found between soil moisture and temperature, which affects N-mineralization. Birch [73] and Sorenson [74] have reported increased N-mineralization of dry soil after rewetting. In arid conditions, the high stock of nutrients is rapidly released when rainfall occurs. Consequently, the net N-mineralization significantly enhanced in all the sites of dry tropical soils during rainy season due to high soil moisture, which is limiting in the tropical deciduous forest [19]. Maly et al. [75] also supported that under more intense fluctuation in soil moisture content microbial activity stimulated the mineralization of organic N. Hence, a strong seasonal variation of nitrification and net N-mineralization can be seen in the dry tropical deciduous forest of the present study.

Mean annual nitrification rates in forest and savanna ecosystems at both soil depths are 19 and 11 kg $ha^{-1}mo^{-1}$, and 13 and 8 kg $ha^{-1}mo^{-1}$, respectively and net N-mineralization values at both soil depths in these ecosystems are 24 and 15 µg $g^{-1}mo^{-1}$ and 20 and 13 kg $ha^{-1}mo^{-1}$, respectively. Higher net nitrification and N-mineralization potential in forest is fully consistent with the general idea that higher nitrogen in litter provides greater mineralization of nitrogen (Arslan et al. [12]) in upper depth of soil and also may be due to higher soil aeration, fine root production and higher microbial biomass. The root growth is reduced at lower depth due to the greater bulk density and mechanical resistance (Pietola [76]) consequently, N-mineralization is lower.

The decline in mean annual net nitrification rates at both soil depths was 43% and 43%, respectively, while the decline in N-mineralization rates at both soil depths was 27% and 21%, respectively due to conversion of forest into grassland (Table 7). The loss of nitrogen mineralization rates at both soil depths can be translated into 13.47 kg $ha^{-1}yr^{-1}$ and 7.2 kg $ha^{-1}yr^{-1}$, respectively. The reason for this nitrogen loss may be the lower input of organic matter through plant biomass, consequently the total N and microbial biomass content was lower in the soils of savanna ecosystems. The high N mineralization rates found in dry-forest soils are in agreement with the study of Vitousek and Matson [77] that lowland tropical forests are characterized by high rates of N mineralization. Scowcroft et al. [78] have also reported higher rates of net N-mineralization in forest as compared to grassland. Further, higher soil microbial biomass in forest also contributes to the enhancement of net N-mineralization rates. The annual contribution of N-mineralization in total N was 7.3% and 15.8% in upper soil layer and 8% and 16%, in lower soil layer, respectively in forest and savanna ecosystems. This indicates that plants utilize comparatively higher nitrogen from lower soil layers in both the ecosystems to prevent the leaching losses of nitrogen in dry tropical ecosystems. According to Barber [79], readily mineralizable nitrogen comprises approximately 1/3 of total organic soil N.

Whenever the forests are cleared, the thin layer of humus with nutrients readily washes away. Consequently, soils from other land uses are much lower in organic matter and other nutrients than comparable virgin areas [52,68,80]. Reiners et al. [81] reported decreased acidity, decreased cation exchange capacity (CEC), increased bulk density, decreased soil porosity, greater concentrations of NH_4^+, lower concentrations of NO_3^- and lower rates of net N-mineralization following conversion of lowland tropical rainforest to pasture grasses. Recent studies reveal that the N losses from undisturbed forest are much lower and mainly in the form of dissolved organic compounds

Ecosystem	Season							
	Rainy		Winter		Summer		Mean annual	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Sal forest	35.79 ± 2.0	13.58 ± 1.0	15.21 ± 1.0	9.13 ± 0.6	11.12 ± 0.9	7.48 ± 0.6	20.71 ± 1.2	10.06 ± 1.0
Mixed forest	47.65 ± 2.5	23.89 ± 1.8	18.83 ± 1.0	13.91 ± 0.9	12.60 ± 0.8	9.02 ± 0.7	26.36 ± 2.2	15.60 ± 0.8
Mean	41.72 ± 2.2	18.73 ± 1.3	17.02 ± 1.1	11.52 ± 0.7	11.86 ± 0.7	8.25 ± 0.6	23.54 ± 1.75	12.83 ± 0.9
Savanna (*Imperata*)	28.93 ± 1.6	16.95 ± 1.2	13.26 ± 0.8	8.25 ± 0.5	10.05 ± 0.8	6.13 ± 0.4	17.2 ± 1.2	10.44 ± 1.1
Savanna (*Heteropogon*)	25.73 ± 1.4	12.92 ± 0.8	9.37 ± 0.7	7.1 ± 0.5	8.13 ± 0.7	5.73 ± 0.4	15.05 ± 0.9	8.58 ± 0.6
Mean	27.83 ± 1.5	14.93 ± 1.0	12.19 ± 0.7	7.67 ± 0.5	10.09 ± 0.7	5.93 ± 0.4	16.59 ± 0.5	9.5 ± 0.6

Table 5: Mean seasonal variations of Net N-mineralization (µg g^{-1} mo^{-1}) in forest and savanna ecosystems at different depths.

Season	Forest		Savanna	
	0-10	10-20	0-10	10-20
MBC				
Rainy	449 ± 8	173 ± 2	340 ± 8	147 ± 2
Winter	631.5 ± 9	196 ± 2.5	465.5 ± 8	172 ± 2.5
Summer	789 ± 9	213 ± 3	531 ± 9	191 ± 2.5
Mean	623 ± 9	195 ± 2.5	453 ± 8	170 ± 2.5
MBN				
Rainy	78 ± 1	18 ± 0.8	54 ± 1	12 ± 0.5
Winter	114 ± 1.2	29 ± 0.8	72 ± 1	21 ± 0.7
Summer	155 ± 1.2	41 ± 0.9	110 ± 1.2	32 ± 0.9
Mean	116 ± 1.2	29 ± 0.8	79 ± 1	22 ± 0.7
MBP				
Rainy	9 ± 0.9	4.5 ± 0.2	8 ± 0.9	3 ± 0.2
Winter	16 ± 1	8.5 ± 0.3	13.5 ± 1	5 ± 0.2
Summer	22 ± 1.4	14 ± 0.5	19 ± 1.5	11 ± 0.4
Mean	16 ± 1.0	9 ± 0.3	13 ± 1.2	6 ± 0.2

Table 6: Mean seasonal variations of MBC, MBN and MBP (µg g^{-1}) in forest and savanna ecosystems at different depths.

Parameters	Percent change	
	0-10 cm	10-20cm
Organic C	-40	-18
Total N	-38	-29
Total P	-13	-39
Microbial C	-28	-64
Microbial N	-32	-24
Microbial P	-19	-33
Nitrification	-43	-43
N-mineralization	-27	-21
Inorganic-N	16	19

All values are means (±1 S.E.) of 2004-2005

Table 7: Percent change in values at different depths for selected soil properties (μg g^{-1}) in savanna ecosystem as compared to those of native forest.

than the disturbed savanna ecosystem [68,82]

Soil microbial C, N and P

There are marked seasonal variations in MBC, MBN and MBP similar to those of inorganic N at both soil depths. Microbial biomass was highest in summer season and lowest in rainy season. Singh et al. [22] suggested a reciprocal relationship between the plant growth rate and microbial biomass in Indian tropical ecosystems. Microbial biomass of dry tropical soil is pre-adapted to moisture stress and accumulates intracellular solute under conditions of low water potential [83]. Sanchez [67] proposed that the microbial activity continues during the summer season, because the microbial activity is sensitive to soil water potential and the increase in soil water potential in the rainy season may induce plasmoptysis. In wet period, the microbivore population is greatly enhanced. Feeding by this microbivore population may cause reduced microbial biomass and increased microbial turnover in the wet period [84]. The dynamics of soil microbial biomass N is associated with environmental (such as soil moisture and temperature) and biological events (such as the activities of microbial-feeding fauna, litter inputs etc.) which affect microbial growth [19,29,34]. There exists a strong relationship between soil moisture and temperature with nitrification and nitrogen mineralization [72] and also with microbial biomass C, N and P.

The soil microbial biomass is higher in upper depth of soil because microorganisms are mostly confined to the surface soil layer and lead to better aeration and greater nutrient availability. Thus, the microbial biomass in the upper soil depth is increased in comparison to the lower depth of soil, where the organic carbon content and nutrient availability are low and aeration is poor [85]. Microbial processes are driven by the availability of decomposable organic carbon, which highlights the importance of sustaining and improving soil organic matter concentrations if large populations of microbes are to be active in the soil [86]. Microbial biomass and activity generally decline with soil depth. After forest harvesting the patterns of microbial nutrient content and turnover may differ with soil depth or horizon because harvesting can change forest floor cover, incident solar radiation, and rates of fine-root growth and turnover by soil horizon. According to Idol et al [36], plant rooting density and N uptake by soil horizon may change during forest regeneration; changes in microbial biomass by horizon could impact N bioavailability and plant-N uptake. They also suggested that the higher organic matter concentration, greater fine-root activity, and the closer proximity to the forest floor in upper horizon are the causal factors for higher activity and concentration of microbes in the A horizon.

The conversion of forest into savanna resulted into a decline of in mean annual MBC, MBN and MBP by 89, 23 and 1.62 kg ha^{-1}, in upper soil layer and by 3, 5 and 2.5 kg ha^{-1} in lower soil layer, respectively (Table 6). The greater loss was found in upper soil layer. The decline in soil organic matter and microbial nutrients may be due to lower inputs of organic matter into soil [87]. Consequently, the microbial biomass also decreased in the savanna ecosystems. Srivastava and Singh [52], and Singh [88] reported that there was a decline of 31-42% in microbial nutrients due to savannization and 46-62% due to cultivation in dry tropical forest ecosystem of Vindhyan range. Basu and Behera [60], Singh [62] have shown a decline of 50% and 42%, respectively in MBN in savanna ecosystem over the forest ecosystem. Recent work has shown that microbial diversity in soil ecosystems is reduced because of land-use intensification and increased nutrient availability (e.g. Helgason et al. [89]), nitrogen deposition (Lilleskov et al. [90]), and chemical contamination [30,91]. In the present study, mean microbial biomass C, N and P in upper soil layer reflected in OC, TN and TP were 3.26%, 3.19% and 3.33% in forest soil and 3.97%, 3.57% and 3.44% in savanna soil, while the values in lower soil layer reflected were 2.51%, 3.22% and 3.21% in forest soil and 2.68%, 3.36% and 3.53% in savanna soil, respectively. The influence of savannization caused increase in soil biomass contribution in both soil layers. According to Gans et al. [91] disturbance in savanna increases the contribution of microbial biomass in organic nutrients. This indicates that the conversion of forest into grassland led to increased immobilization by microbial nutrients in dry tropical ecosystems due to disturbance. Roy and Singh [45] and Singh and Singh [92] have reported the similar observations. Microbial uptake of N is also important for longer-term ecosystem N retention, via the transfer of the nutrients from within microbial tissues to more stable organic matter pools after cell death [28]. Thus, soil microbial activity and levels of soil microbial biomass play an important role in nutrient cycling in alternate land use ecosystems. Soil microbial biomass is a critical factor in the recovery of drastically disturbed sites as it aids in the re-establishment of nutrient cycling [92,93]. However, the reduction in total microbial biomass C, N and P in grassland is due to reduced leaf litter inputs, fine root production and plant biomass present in both the soil layers. According to Singh and Singh [92] there is a relationship between the soil N and the quantity of N deposited by litter fall indicating that soil is indeed a function of N returned by the vegetation to the soil. Evidently, the species, which allocate a greater proportion of biomass to foliage and produce N-rich litter, will be accelerative of soil fertility restoration. According to Anderson and Domsch [94], the ratio of microbial biomass C to soil organic C provides an insight into the C status of a soil and a decline in the ratio indicates loss of soil organic C. A decline in the ratio along with loss of soil organic C in the savanna and plough land as observed in the present study thus substantiates the view of Anderson and Domsch [94]. The comparatively higher ratio observed in the forest samples of the present study can be explained on the basis that the more diversified organic substrate production in the natural forest supported a greater interdependence among the various parts of the food web, providing a greater quantity of microbial C per unit of soil organic C [93,94].

In the present study, microbial N was positively related to the net N-mineralization ($P<0.05$) according to the regression equations:

Microbial N (μg g^{-1})=6.5537+0.554 Net N-mineralization (μg g^{-1} mo^{-1})

These regression equations explained about 95.16% variability in the microbial N due to variability in net N-mineralization.

Similarly, microbial N was positively related to the belowground biomass and total plant biomass (P<0.05) according to the regression equations:

Microbial N (μg g^{-1})=7.741+0.006 belowground biomass (g m^{-2})

and

Microbial N (μg g^{-1})=10.855+0.003 total biomass (g m^{-2})

These regression equations explained about 83.6% and 67.62% variability in the microbial N due to variability in belowground biomass and total biomass, respectively. Srivastava and Singh [4] also reported a positive relation between microbial biomass N and belowground biomass, and microbial biomass N and total plant biomass in Indian dry tropical soils.

Conclusion

We suggest that inorganic nitrogen concentration, nitrification, N-mineralization and microbial biomass are the critical indicators of the influence of conversion from a dry tropical forest as they aid in the re-establishment of nutrient cycling. The loss of carbon, nitrogen and phosphorus can be taken as functional indices of ecosystem stability and the level of soil biomass C, N and P as functional indices of soil redevelopment in both the soil depths.

There is direct impact of conversion of a pristine dry tropical forest ecosystem into savanna, as evident by the changes in plant available inorganic nitrogen concentration, nitrification, N-mineralization and microbial biomass. In dry tropical forests, soil moisture and microbial biomass regulate the nitrogen availability, nitrification and nitrogen mineralization rates. The conversion of forest into savanna also resulted loss of soil OC, TN and TP and soil microbial biomass and its transformation rates in both the soil layers of the nutrient impoverished dry tropical forest. Finally, savannization caused loss in soil OC and which adds carbon dioxide in the atmospheric environment.

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