Himalayan Soil Ecology: Nitrogen Cycling Dynamics

Paled Maheshwari(Chemistry), Dept. of Chemistry, Research Scholar, SunRise University , Alwar(Rajasthan)
Dr. Shiv Brat Singh (Chemistry) , Professor (Dept. of Chemistry), SunRise University , Alwar(Rajasthan)

ABSTRACT

This study investigated the influence of temperature and elevation on nitrogen (N) transformation rates in Himalayan Soils. Results showed increased gross N mineralization, NH_4^+consumption, and NH_4^+immobilization with rising temperature, while gross nitrification was unaffected. NH_4^+ immobilization was the primary NH_4^+ consumption mechanism at higher temperatures. Microbial activity was found to be mainly influenced by edaphic factors rather than elevation. Upper soils displayed higher N pool and turnover rates compared to bottom soils, indicative of greater microbial activity. However, nitrate concentrations and residence duration remained unchanged. The findings highlight the complexity of N cycling and the role of temperature in Himalayan mountain soils.

Keywords : Himalayan Soils, NH_4^+immobilization, Microbial Activity

INTRODUCTION AND LITERATURE REVIEW

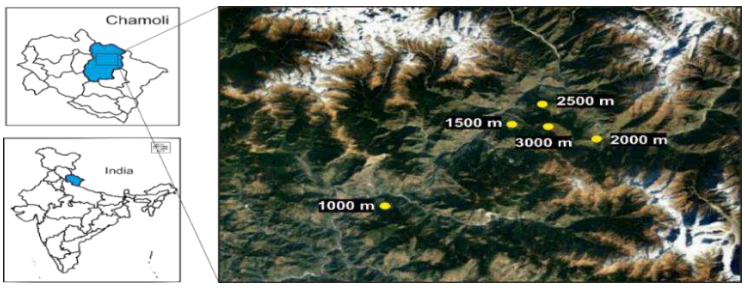
The top meter of soil around the world contains over 1500 teragrams (Tg) of total C and 92-140 Tg (Tg) of total N, making it the biggest terrestrial pool for C and N (Oertel et al., 2016). The soils of forests are a significant part of the worldwide soil C and N pool. Carbon (C) is stored in both soils and biomass in forested ecosystems, with the proportion being controlled by the local climate. Soil stores the majority of total C in boreal forests, but biomass stores a bigger percentage in tropical forests (Pan et al., 2011). Due to the low temperature and slow rate of organic matter decomposition, forest soils are the primary reservoir of C in tropical montane environments (Moser et al., 2011; Nottingham et al., 2016). Low temperature and slow decomposition rates reduce the production of mineral N (Tanner et al., 1998; Stewart, 2000), limiting the availability of nutrients like N in montane soils and potentially affecting the above- and below-ground productivity of these ecosystems.

Because microorganisms are highly sensitive to environmental changes, the soil nutrients pool is highly dynamic and can either increase or decrease ecosystem productivity. The dynamics of microbial nitrogen in montane ecosystems are controlled by changes in both temperature and altitude. The link between soil respiration and primary productivity in tropical montane ecosystems has been the focus of numerous studies (Nottingham et al., 2015, 2016, Selmants et al., 2016). High-latitude regions have been the focus of most research on the effects of temperature and elevation change on N transformation rates (Knoepp and Swank, 1998; Shaw and Harte, 2001; Knoepp and Vose, 2007; Zhang et al., 2012; Schütt et al., 2014), while the tropics have received less attention. An increase in temperature, even by a small amount (Nadelhoffer et al., 1997; Knorr et al., 2005; Davidson and Janssens, 2006), can have a profound effect on the rates of organic matter mineralization, soil respiration, and apparent nutrient availability in low temperature ecosystems found at high latitudes and altitudes. Several studies have noted a substantial shift in microbial activity associated with N transformations based on the temperature sensitivity of microbially driven processes, generally evaluated as Q10 coefficient (Dalias et al., 2002; Wang et al., 2006; Auyeung et al., 2012; Fraser et al., 2013). It has been hypothesized that the availability of organic carbon is crucial to the temperature sensitivity seen (Dessureault-Rompré et al., 2010; Gutiérrez-Girón et al., 2015). In order to address the reaction of various N transformation processes to a rise in temperature, numerous research have looked beyond the Q10 coefficient to examine the direct influence of temperature change on N dynamics. Most of these investigations showed that N transformation rates and related microbial activity increased with increasing temperature, which is in general agreement with studies of the Q10 coefficient. Due to the high temperature sensitivity of the subterranean biota, future global warming has the potential to alter the pattern and emission flow of greenhouse gases, respiration rates, and nutrient turnover in the soils of colder locations. The impact of rising temperatures on tropical montane ecosystems' gross N changes has only been studied in a handful of cases so far (Wang et al., 2016; Yuan et al., 2016).

Temperature in montane ecosystems is inversely proportional to altitude, meaning that the higher you go, the cooler it gets. Most studies on N transformation rates have been conducted in high-latitude regions (Powers, 1990; Knoepp and Swank, 1998; Hart and Perry, 2001; Zhang et al., 2012), with a focus on net rates (Kitayama et al., 1998; Marrs et al., 1988), but this phenomenon is largely unexplored in tropical montane regions. In tropical montane ecosystems, available nutrients in the litter, notably N, decrease with increasing elevation due to limited nutrient availability, and litter production increases due to the addition of N and P (Tanner et al., 1998). This demonstrates how elevation plays a crucial role in controlling productivity in montane ecosystems. The relationship between N transformations and elevation is complicated by the fact that both increasing and decreasing rates of N transformations have been reported with increasing elevation (Kitayama et al., 1998; Knoepp and Swank, 1998; Marrs et al., 1988; Zhang et al., 2012). No reports have come from the Himalayas, one of the youngest and most ecologically sensitive high-altitude regions of the world, despite the fact that temperature and elevation play crucial roles in shaping nutrient dynamics and primary productivity in montane ecosystems. Therefore, the current study attempted to measure the gross rates of N transformations using the ^{15}N isotope dilution technique in the Himalayas to discern the potential changes in N transformation rates under varied temperature and elevation settings. Soils from five different elevations were incubated under two different temperature settings to conduct tests measuring gross N mineralization and nitrification, as well as NH_4^+ consumption and immobilization rates. We postulated that when soil temperatures rose, N transformation rates would rise and N transformation rates would fall with increasing elevation.

EXPERIMENTATION AND SAMPLING METHODS

The state of Uttarakhand in India is home to the Garhwal Himalayas, where the samples were taken . Bagchi and Singh (2011) and Rawat and Chandra (2014) both note that the monsoon has a significant role in shaping the region's climatic conditions, which range from cold temperate to tropical. According to Bagchi and Singh (2011), the average annual rainfall in the area is around 1395 millimeters. Western regions are more likely to see snowfall in the winter. Snowstorms in the mountains are a source of disruptions (Bagchi and Singh, 2011). The average high in January is 19.6 degrees Celsius and the average low is 4.6 degrees Celsius, while the average low and high in June are 32.6 degrees Celsius and 36.5 degrees Celsius, respectively (Bagchi and Singh, 2011). Lesser Himalayan soils represent the most majority of the area and can be roughly classified as Dystric Eutrudepts, Lithic Udorthents, or Typic Udorthents (Bagchi and Singh, 2011). Topography, soil, climate, and geographical location all



have a role in shaping the Himalayas' rich flora and fauna (Chandra et al., 2010).

Figure 1: Sampling locations at different elevations above mean sea level at the Garhwal Himalayas

Figure 2: Field photographs showing different types of vegetation and topographyof the sampling region.

Soils were collected from three sites in the Garhwal Himalayas (Figure 2) at five different elevations (3000 m, 2500 m, 2000 m, 1500 m, and 1000 m above sea level) in November 2017 (n = 30). Temperatures ranged from 8°C to 17°C along the height gradient at the time of sample collection, with a mean of 12°C (Table 5.1). Each sampling site had a distinctive vegetation pattern, and there was evidence of a shift in vegetation cover as altitude increased (Table 1). Unless otherwise specified, elevations over 3000 m and below 2500 m asl are referred to as higher and lower, respectively, whereas elevations above 2000 m and below 1500 m and below 1000 m asl are referred to as lower.

Table 1: Soil Physical Properties, Vegetation, and Climate type at different Elevations.

	3000 m	2500 m	2000 m	1500 m	1000 m
Location	30° 31' N, 79° 33' E	30° 32' N, 79° 33' E	30° 29' N, 79° 36' E	30° 31' N, 79° 31' E	30° 24' N, 79° 22' E
Temperature	8 °C	9 °C	11 °C	17 °C	16 °C
pH	4.5 ± 0.3	5.0 ± 0.6	6.1 ± 0.7	6.5 ± 0.2	6.3 ± 0.0
Bulk density(g cm^{-3})	1.0 ± 0.2	1.0 ± 0.1	1.1 ± 0.2	1.3 ± 0.1	1.0 ± 0.2
GWC (%)	21.7 ± 10.8	33.3 ± 5.9	11.4 ± 5.2	8.8 ± 6.2	6.4 ± 2.6
Major vegetation	*Rhododendron arboreum, Quercus floribunda, Cedrus deodara, Betula utilis, Pinus wallichiana*	*Rosaceae, Fragaria sp, Rubus foliolosum, Rhododendron arboreum, Acer oblongum, Quercus incana*	*Thuja orientalis, Berberis sp, Cedrus deodara, Arenaria neilgherrensis, Pinus roxburghii*	*Rubus macilentus, Cersium sp, Lantana camara*	*Aegle marmelos, Pinus roxburghii, Shorea robusta*
Climatezone	Alpine-cold temperate	Cold temperate	Warm temperate	Warm temperate	Sub- tropical
Forest type	Himadri forest	Moist semi temperate	Moist semi temperate-tropical pine	Tropicalpine	Tropical deciduous

^{15}N isotope dilution experiments were performed, as on soils obtained at various altitudes in order to quantify gross N transformation rates. However, incubation of the treated soils took place under two temperature conditions to ascertain the impact of temperature on the microbial N conversions. Both the low temperature incubation (10±2 °C) and the high temperature incubation (room temperature) were performed. The average temperature of the room was 23 degrees Celsius, whereas the temperature ranged from 17 degrees to 30 degrees Celsius daily over the incubation period. The original (pre-incubation) nutrient contents and their isotopic (^{15}N atom%) enrichments were measured by extracting a subsample of the amended soils in 2 M KCl solution during the ^{15}N isotope dilution experiments. As was previously noted, the residual soils were separated into two piles and incubated in the dark for two days at two different temperatures. Consequently, the pre-incubation pool size and isotopic enrichment of nutrients were similar for the two incubation settings, whereas the post-incubation pool size and enrichment were temperature-dependent.

PHYSICO-CHEMICAL PROPERTIES OF SOILS

Soils at all elevations were permeable enough to allow for respiration and root growth since their bulk density was low (1.0 g cm^{-3}) and remained essentially consistent with low soil

moisture throughout (40%; Table 1). Soil porosity appears to be highest at higher elevations, making them more vulnerable to weathering due to the low temperatures and high wind speed seen in these monsoon-influenced wooded regions (Carroll, 1970). At higher altitudes, soil pH was lower than at lower altitudes ($F_{4,25} = 25.73$, $p < 0.001$), and vice versa (Table 1). Soils at higher elevations are more acidic than those at lower elevations because of increased weathering of the bedrock. The majority of the N in the minerals was found as NH_4^+, and this form of N was shown to be substantially more abundant in the upper layers than the lower ones ($p < 0.01$, Figure 3a). There was no discernible gradient in NO_3^- concentrations with decreasing depth (Figure 3b). Upper elevation top soils had higher average concentrations of nutrients (NH_4^+ and NO_3^-) than lower elevation top soils, with variation in the middle (Figure 3). The occurrence of various species diversity at different elevations can alter the amount and quality of organic matter, which in turn can affect nutrient dynamics. Species richness in the region's vegetation increases with decreasing altitude (Gairola et al., 2011).

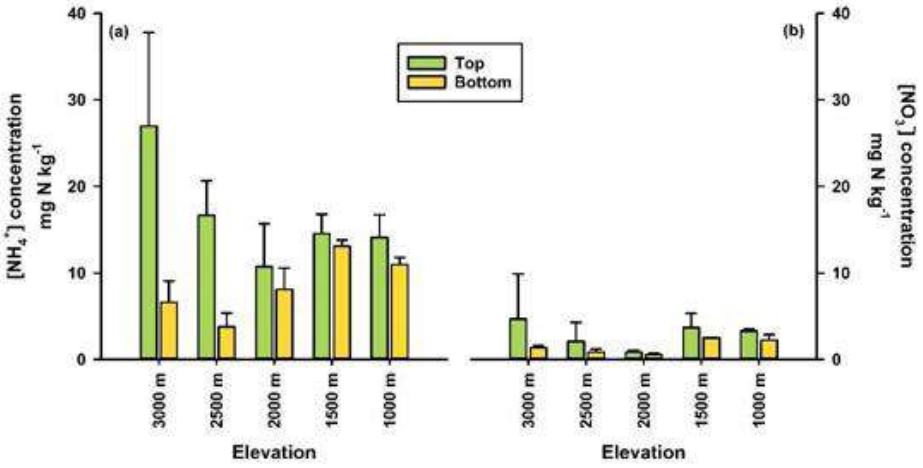


Figure 3: Layer wise variation in (a) NH_4^+ and (b) NO_3^- concentrations in the Himalayan soils at different elevations (mean ± 1σ).

The average TN and TOC concentrations of soils were comparatively greater at the upper compared to the lower elevations (Figure 4), notwithstanding substantial variability at higher elevations. Despite differences in soil physicochemical parameters and vegetation, neither total nitrogen (TN) nor total organic carbon (TOC) increased significantly with elevation ($F_{4,25} = 0.91$, $p > 0.05$).

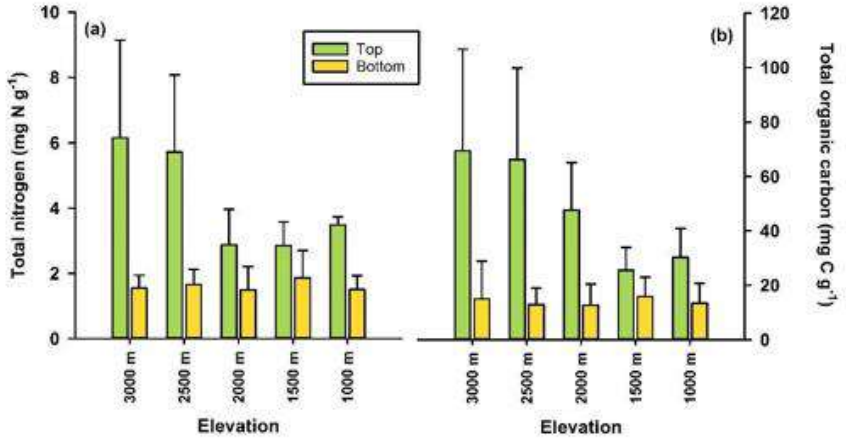


Figure 4: Layer wise variation in (a) TN and (b) TOC contents in the Himalayansoils at different elevations (mean ± 1σ).

As can be seen in Table 1, broadleaf plants at higher elevations contributed more litter than pines and shrubs at lower elevations did throughout the current study. Higher nutrient concentrations (Figure 3), total nitrogen (TN) and total organic carbon (TOC) contents (Figure 4), and TN and TOC contents (Figure 5) in the soils can be attributed to the greater litter

quantity provided by the trees present at 3000 m (primarily Rhododendron arboreum) compared to other elevations.

THE GROWTH AND TRANSFORMATION OF NITROGEN MASSES

N transformation rates mirrored the inconsistent trend seen in nutrient concentrations with increasing altitude shown in the top soils, while no such trend was seen in the bottom soils (Figure 5). Top soils at an altitude of 3000 m asl had considerably higher rates of gross N mineralization than those at lower altitudes ($F_{4,10} = 6.25$, $p < 0.01$; Figures 5a & 5b). The rates of gross nitrification were not correlated with altitude (Figures 5c & 5d), but they were noticeably greater in the bottom soils at 1500 m asl than at any other altitude. The rates at which NH_4^+ was consumed did not vary significantly with elevation (Figures 5e and 5f), in contrast to the rates of gross nitrification, which were higher in the top soils at the higher than the lower elevations. There was also no discernible change in NH_4^+ immobilization rates with increasing altitude. Top soil NH_4^+ immobilization rates, on the other hand, decreased with decreasing elevation (Figures 5g and 5h). The present investigation corroborated previous findings that N transformation rates both rise (Knoepp and Swank, 1998; Nottingham et al., 2015) and decrease (Kitayama et al., 1998; Zhang et al., 2012; Yuan et al., 2016) with increasing altitude. Variations in climate, water availability, and soil composition typically accompany changes in altitude, leading to distinctive plant communities. Many research demonstrate linear connections of soil C and N dynamics with elevation despite the change in vegetation type (Kitayama et al., 1998; Zhang et al., 2012; Yuan et al., 2016). Since neither the concentration of nutrients nor their rates of transformation into nitrogen decreased with increasing altitude, it became clear that variables other than altitude played a significant role in controlling nutritional dynamics in the area. As was said before, the presence of a variety of tree species over a range of elevations can contribute to a wide range of organic matter with varying nutritional, TN, and TOC levels, which may in turn influence nutrient dynamics. Edaphic variables have also been demonstrated to control nutrient dynamics in montane soils, leading to distinct vegetation and nutrient turnover (Yang et al., 2015). Higher influence of edaphic factors over climate in montane systems may also be at play in the present investigation, as evidenced by differences in slope facing, sunlight availability, and micro-climatic conditions at the sampling locations. Kitayama et al. (1998) found that the geological substrate (sedimentary vs. ultrabasic rocks) considerably affected the N mineralization rates with elevation. Consistent with a recent study that found no substantial increase in N transformation processes in soils of varying elevations incubated under laboratory conditions (Marrs et al., 1988), our data demonstrated that the rates of these processes did not alter significantly with elevation.

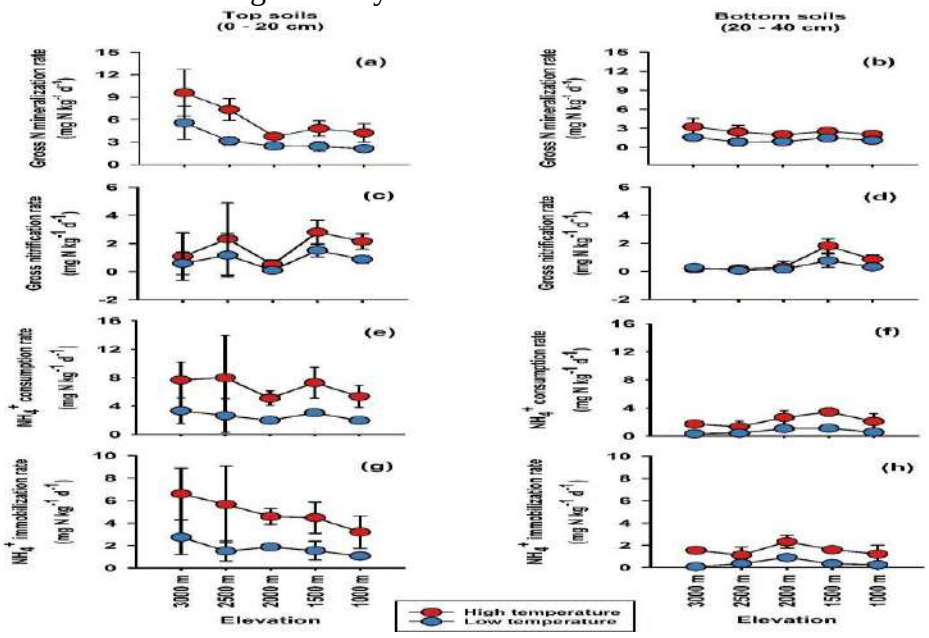


Figure 5: Gross N transformation rates (mean ± 1σ) at high and low incubation temperature conditions in the Himalayan soils: (a) gross N mineralization rates in top

soils, (b) gross N mineralization rates in bottom soils, (c) gross nitrification ratesin top soils, (d) gross nitrification rates in bottom soils, (e) NH_4^+ consumption ratesin top soils, (f) $NH4^+$ consumption rates in bottom soil layer, (g) NH_4^+ immobilization rates in top soils, and (h) NH_4^+ immobilization rates in bottom soils.

RATES OF TOTAL NITROGEN REDUCTION AND TEMPERATURE

One of the most influential abiotic factors controlling soil N availability and cycling is temperature. Temperature becomes a function of elevation in mountainous terrains, which can mold the microbial capacity for N conversions in ways distinct from those seen in the plains. This can have an effect on the ability of plants at different elevations to sequester carbon by altering their production and utilisation of available nutrients, particularly those produced by biotic pathways like N. Increasing the incubation temperature from low (10 ^oC) to high (23^oC) in this investigation resulted in a statistically significant increase in the gross N transformation rates. High temperature incubation resulted in significantly ($p < 0.05$) higher rates of all N transformation processes, including gross N mineralization, gross nitrification rates, NH_4^+ consumption, and NH_4^+ immobilization, particularly in the top soil layers (Figure 5). This indicated that temperature has a crucial role in determining the total rates of N transformation in the soils of the Himalayas. Similar increases in gross N transformation rates have been observed in other studies (Andersen and Jensen, 2001; Shaw and Harte, 2001; Niboyet et al., 2011; Jansen- Willems et al., 2016), which have generally been attributed to an increase in microbial activity at high temperatures. Figure 6 shows that when temperatures are high, the capacity for NH_4^+ consumption in Himalayan soils is greater than gross N mineralization rates. The opposite is true when temperatures are low. This demonstrated the temperature sensitivity of these two processes and the relative impact of temperature conditions on N retention in soils. Temperature increases the N immobilization potential of microorganisms, as shown by the higher ratio of NH_4^+ immobilisation to gross N mineralisation at high temperature compared to low temperature condition (Figure 6). Both $NH_4^+$and NO_3^- had longer residence durations under low temperatures compared to high temperatures (Figures 7; $p < 0.05$). Increases in temperature speed up the turnover of nutrients, which may be attributable to more efficient microbial activity, as the long residence period of nutrients under low temperatures was in stark contrast to that under high temperatures. Soil nutrient accumulation (Figures 7) may have occurred because the present study's low temperature condition was lower than the required optimal temperature for efficient microbial functioning.

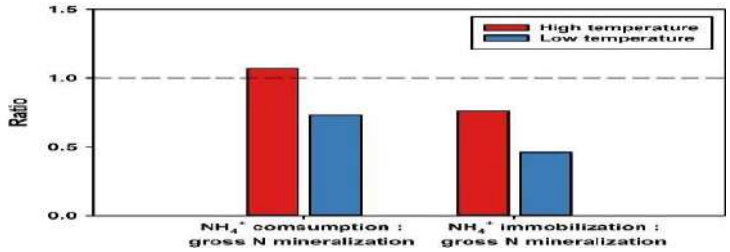


Figure 6: Ratios of NH_4^+ consumption rates: gross N mineralization rates and NH_4^+ immobilization rates: gross N mineralization rates at both high and low incubation temperature conditions in the Himalayan soils. The dashed line represents 1:1 ratio.

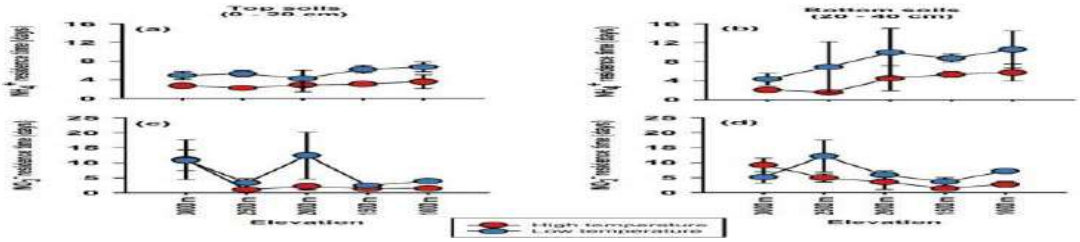


Figure 7: Residence time of nutrients (mean ± 1σ) at high and low incubation temperature conditions in the Himalayan soils: (a) NH_4^+ residence time in top soils, (b)

NH_4^+ residence time in bottom soils, (c) NO_3^- residence time in top soils, and (d) NO_3^- residence time in bottom soils.

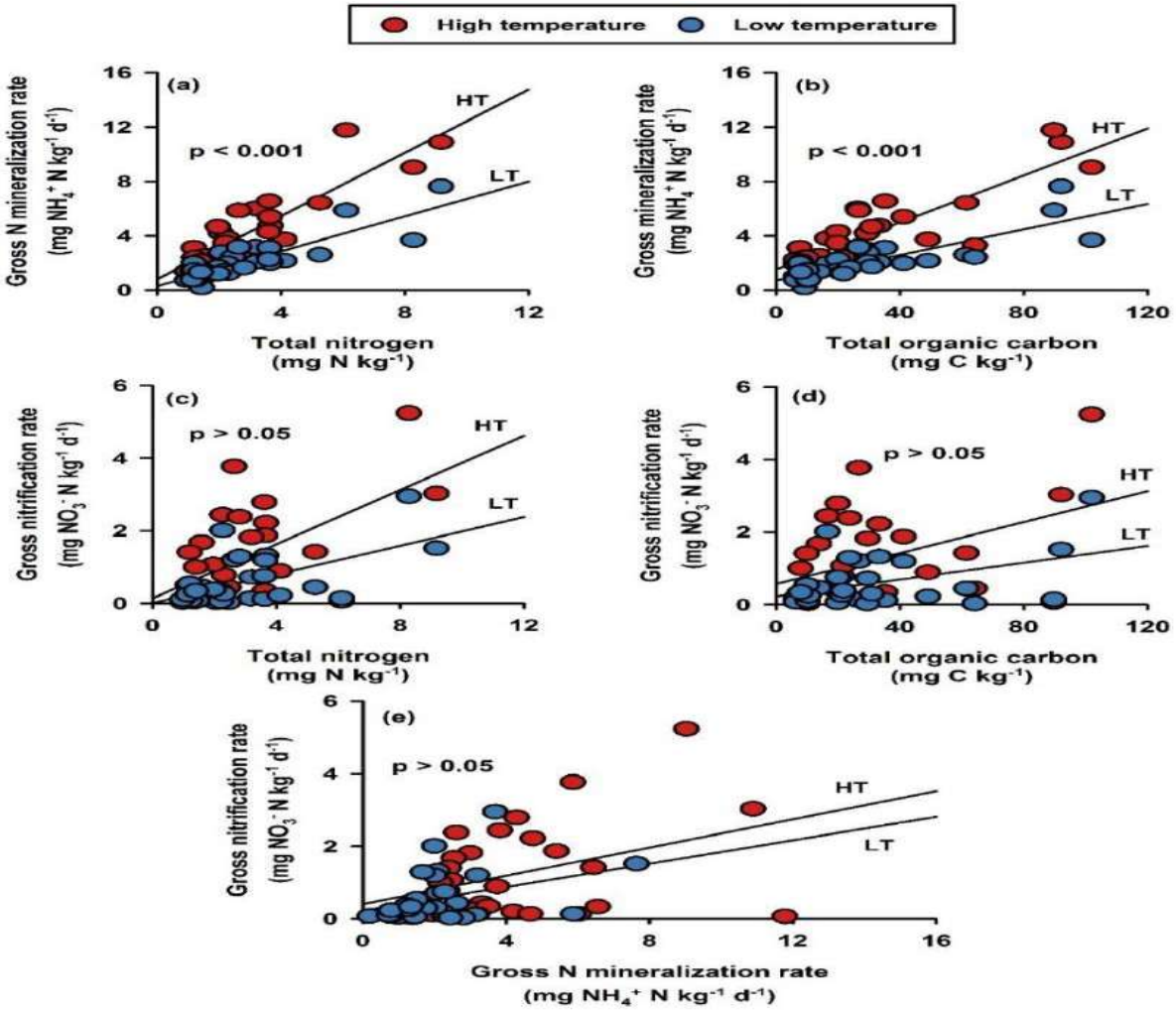
Table 2: Correlation matrix indicating squared Pearson correlation coefficient (r^2) for N transformations and related parameters. Sections above and below the inclined line represent correlations at high and low incubation temperature, respectively. The abbreviations are - MR: gross N mineralization rates, A-CR: NH_4^+ consumption rates NR: gross nitrification rates, A-imm: NH_4^+ immobilization rates, A-RT: NH_4^+ residence time, N-RT: NO_3^- residence time, TOC: total organic carbon, TN: total nitrogen. Significance of correlations are reported as follows: ***: p < 0.001; **: p < 0.01; *: p < 0.05; NS: Not significant.

	MR	A-CR	NR	A-imm	A-RT	N-RT	NH_4^+	NO_3^-	TOC	TN
MR		0.63 ***	0.16 *	0.75 ***	NS	NS	0.72 ***	0.25 **	0.75 ***	0.78 ***
A-CR	0.61 ***		0.60 ***	0.87 ***	NS	NS	0.50 ***	0.30 **	0.65 ***	0.69 ***
NR	NS	0.50 ***		0.25 **	NS	0.28 **	0.20 *	0.47 ***	0.19 *	0.34 ***
A-imm	0.67 ***	0.76 ***	NS		NS	NS	0.51 ***	NS	0.73 ***	0.66 ***
A-RT	0.19 *	NS	NS	NS		NS	NS	NS	NS	NS
N-RT	NS	NS	0.29 **	NS	NS		NS	NS	NS	NS
NH_4^+	0.78 ***	0.61 ***	0.17 *	0.61 ***	NS	NS		0.35 ***	0.56 ***	0.58 ***
NO_3^-	0.39 ***	0.36 ***	0.51 ***	NS	NS	NS	0.35 ***		0.20 *	0.40 ***
TOC	0.66 ***	0.65 ***	0.20 *	0.63 ***	NS	NS	0.56 ***	0.20 *		0.84 ***
TN	0.72 ***	0.69 ***	0.33 ***	0.53 ***	0.13 *	NS	0.58 ***	0.40 ***	0.84 ***	

Stronger correlations among different N transformation processes, such as NH_4^+ consumption, gross mineralization, gross nitrification, and NH_4^+ immobilization, were observed at high temperature compared to low temperature (Table 2), indicating efficient cycling of N due to efficient microbial functioning. Any ecosystem's soil carbon and nitrogen levels can be utilized as a valid metric of soil quality and microbial efficiency (Knoepp et al., 2000; Louis et al., 2016). Soil TN (R2 = 0.78, p < 0.001) and TOC (R2 = 0.75, p <0.001) contents positively linked with gross N mineralization rates under high temperature conditions; this relationship remained significant, albeit at a lower strength, under low temperature conditions (Figure 8a & 8b). Gross nitrification rates, like gross N mineralization rates, were positively correlated with both soil TN (R2 = 0.34, p< 0.001; Figure 8c) and TOC (R2 = 0.19, p< 0.05; Figure 8d) concentrations. Changes in N transformation rates with regard to TOC were not as dramatic as those for TN (Table 3), despite the fact that gross N mineralization and nitrification rates correlated well with TN and TOC contents of soils under both high and low temperature regimes. As a result, it was concluded that the availability of N is a significant regulator of N transformation processes in the soils of the Himalayas. Soil organic matter is effectively transformed into inorganic nutrients at high temperature, as evidenced by the stronger correlations of total organic carbon and total nitrogen with gross N mineralization and nitrification rates at the high temperature condition (Figures 8a-d). A greater slope was observed during the high temperature condition compared to the low temperature condition

(Table 3), suggesting that at a given TN and TOC level, an increase in temperature significantly increased N mineralization capacity in soils. For a given TN and TOC, the gross nitrification rates were higher under the high temperature condition (Figures 8c & 8d). Statistically identical slopes for two temperature settings show that this increase was not significant, in contrast to N mineralization (Table 3). This suggested that nitrifying microorganisms were less affected by temperature changes than N-mineralizable microorganisms. Figure 8e and Table 2 show a positive correlation between gross nitrification and gross N mineralization rates under high temperatures (R2 = 0.16, p< 0.05), but not under low temperatures. The weak correlations between gross nitrification and NH_4^+ concentrations (Table 2) at both high and low temperature conditions, as well as the similar slope of gross nitrification with gross N mineralization rates (Figure 8e), all lend credence to the idea that nitrifying microbes are relatively less sensitive to temperature.

Figure 8: Relationships between (a) gross N mineralization rates and TN, (b) gross N



mineralization rates and TOC, (c) gross nitrification rates and TN, (d) grossnitrification rates and TOC, and (e) gross nitrification rates and gross N mineralization rates at both high and low incubation temperature conditions in the Himalayan soils (n = 30). The p-value indicates difference in the slopes

Table 3: Regression equations for nitrogen transformation rates at different incubation temperatures (high: 23 °C and low: 10 °C). The dataincludes both top and bottom soils (n = 30). Significance of correlations are reported as follows: ***: p < 0.001; **: p < 0.01; *: p < 0.05; NS: Not significant

DependentVariable	Independent variable	Incubation temperature	Equation	R^2	p-value forslope

N Mineralization rates (Min)	TN	High	Min = (1.16 ± 0.12) × TN + 0.81	0.78***	< 0.001
	TN	Low	Min = (0.64 ± 0.07) × TN + 0.31	0.72***	
	TOC	High	Min = (0.09 ± 0.01) × TOC + 1.52	0.75***	< 0.001
	TOC	Low	Min = (0.05 ± 0.01) × TOC + 0.73	0.66***	
Nitrification rates (Nit)	TN	High	Nit = (0.37 ± 0.10) × TN + 0.14	0.34***	0.12
	TN	Low	Nit = (0.20 ± 0.05) × TN + 0.01	0.33***	
	TOC	High	Nit = (0.02 ± 0.01) × TOC + 0.56	0.19*	0.30
	TOC	Low	Nit = (0.01 ± 0.01) × TOC+ 0.22	0.20*	
Nitrification	N Mineralization	High	Nit = (0.19 ± 0.08) × Min + 0.41	0.16*	0.80
Nitrification	N Mineralization	Low	Nit = (0.16 ± 0.08) × Min + 0.23	0.13^{NS}	

Net nitrification rates were shown to decrease in the current investigation, in contrast to a prior study (Grundmann et al., 1995) that found an increase in these rates during high temperature incubations. Gross nitrification was not influenced by soil heating, although the present results were consistent with a recent study showing an increase in gross N transformations as a result of soil heating (Shaw and Harte, 2001). Overall, warming of soils present in colder montane climate can lead to significant production of NH_4^+, which may eventually get consumed through immobilization rather than nitrification. This is due to the increase in N mineralization and immobilization as well as the insignificant response of nitrification under high temperature condition.

DEPTH-DEPENDENT CHANGES IN THE NITROGEN TRANSFORMATION RATES

Compared to the bottom layers, the top layers had significantly higher NH_4^+ concentrations, TN and TOC contents, gross N mineralization, NH_4^+ consumption, NH_4^+ immobilization, and gross nitrification rates (Figures 3, 4, 5, & 7), indicating more microbial activity. Because of factors like organic matter concentration, increased fine root activity, and proximity to the forest floor, top soils are more conducive to microbial life than deeper layers (Bolton et al., 1993; Winkler et al., 1996; Kellman et al., 2014; Shang et al., 2015). Our data also show that variability in N transformation rates and nutrient pools is greater in the top soils than in the bottom, suggesting that changes in these parameters, as well as other biotic and abiotic variables, are more likely to affect the top soils. During the present study, nitrification appeared to be generally unaffected by environmental circumstances, as neither NO_3^- concentrations nor NO_3^- residence time varied considerably with depth (Figures 3 and 5).

CONCLUSION

The purpose of this research was to examine the effect of temperature and elevation shifts on the rates of gross N transformation in Himalayan soils. Gross N mineralization, NH_4^+ consumption, and NH_4^+ immobilization all increased considerably with increasing temperature, while gross nitrification did not. Our original hypothesis predicted that if temperature was raised, the rates of all N transformation activities would increase significantly. The potential

for accelerated production and consumption of N in the Himalayan soils was highlighted by the fact that the rates of both gross N mineralization and NH_4^+ immobilization increased at high temperature. Furthermore, under elevated temperatures, NH_4^+ immobilization was the primary mechanism for NH_4^+ consumption. We found that the microbial activity in the soils of this tropical montane ecosystem was mostly regulated by the edaphic variables at different elevations, refuting our alternative hypothesis that these processes and pools associated to N transformations would change consistently with elevation. Compared to the top soils, the bottom soils had significantly lower N pool and turnover rates, suggesting that the top soils were comparatively more microbially active. This was not the case for NO_3^- concentrations or its residence duration in soils.

REFERENCES

1. Singh, K. P., & Singh, B. (1992). Nitrogen mineralization and nitrification in a Himalayan mountain soil. Soil Biology and Biochemistry, 24(6), 637-641.
2. Pandey, A. N., & Singh, J. S. (1981). Energy flow in the Himalayan (Kumaun) grassland ecosystem: III. Nutrient cycling. Ecological Monographs, 51(2), 195-213.
3. Tiwari, S. C., & Singh, J. S. (1987). Decomposition of organic matter and nutrient cycling in a central Himalayan forest. Soil Biology and Biochemistry, 19(5), 489-496.
4. Kumar, K., & Singh, B. (2000). Nitrogen mineralization in soils of the Indian Himalayan region. Soil Biology and Biochemistry, 32(12), 1863-1873.
5. Adhikari, B. S., & Singh, J. S. (2003). Nitrogen mineralization and microbial biomass in a Central Himalayan soil. Soil Biology and Biochemistry, 35(4), 549-554.
6. Ram, K., & Singh, J. S. (1982). Standing crop and nutrient distribution in natural and man-made ecosystems in the Himalayan region. Vegetatio, 48(2), 87-95.
7. Tripathi, R. S., & Singh, J. S. (1992). Nitrogen dynamics in the soil-plant system of a Himalayan oak forest. Forest Ecology and Management, 53(3-4), 243-257.
8. Tiwari, S. C., & Singh, J. S. (1986). Nitrification in relation to nitrogen availability in a Central Himalayan forest. Soil Biology and Biochemistry, 18(5), 471-476.
9. Sharma, E., Ambasht, R. S., & Singh, J. S. (1985). Nitrogen mineralization in a Himalayan forest soil. Soil Biology and Biochemistry, 17(5), 667-672.
10. Chaturvedi, R. K., & Singh, J. S. (1987). The influence of nutrient manipulations on the growth of tree seedlings in a Central Himalayan forest. Forest Ecology and Management, 22(3-4), 173-182.
11. Rai, S. C., & Proctor, J. (1986). Ecological studies on four rainforest sites in the Garhwal Himalaya, India. Journal of Ecology, 74(1), 123-138.
12. Chaturvedi, R. K., & Singh, J. S. (1986). Soil nutrient dynamics in a Central Himalayan forest in relation to weathering and nutrient cycling. Soil Biology and Biochemistry, 18(5), 461-469.