Seasonal variations in available N and N-mineralization in relation to fine roots in landslide damaged sites in the sal forest ecosystem of Nepal Himalaya

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Abstract

Seasonal dynamics of available nitrogen and N-mineralization in relation to fine root biomass was studied in five landslide damaged (1 to 58 years old) sites in the moist tropical sal (*Shorea robusta*) forest ecosystem of Nepal Himalaya. Comparisons were made with an undisturbed mature sal forest site located in the same region. Concentrations of soil available-N (NH_4^+ and NO_3^-) increased with the age of site till 40-year old sites and then declined. However, the proportion of NH_4^+ in total available N increased distinctly with increase in the age of sites. The NH_4^+: NO_3^- ratio increased considerably from 1.15 in 1-year site to 2.4 in mature sal forest. On the other hand, the net N-mineralization rate increased consistently until 58 years of age but the proportion of nitrification rate relative to ammonification rate distinctly decreased beyond 40 years indicating the dominance of ammonification over nitrification in the older sites. Fine root biomass and N- mineralization rate both increased but available-N decreased during rainy season. On the other hand fine root biomass and N-mineralization rate both decreased and available N increased during summer season. During the summer season, fine root biomass decreased by 57 - 68% indicating a rapid turnover. High turnover of fine root at the younger sites (1 to 15 yrs old) add more organic matter for the developing vegetation. Fine root biomass was positively correlated with the concentration of available-N and N-mineralization rate. It is concluded that fine root development was facilitated by higher amounts of available-N.

***Key wards*:** Landslide disturbance, tropical moist sal forest, mineral-N, fine roots, ecosystem restoration

Introduction

Landslides, which constitute an important component of disturbance regime in tropical and temperate forests, occur due to creation of greater shear strain than shear resistance on forested slopes (Varnes, 1978). Because, landslide involves movement of soil and vegetation mass, the self-sustaining soil-plant system is fragmented and the retrogressed system is forced to begin the secondary succession. Number of studies has shown that recently formed landslide sites exhibit low soil nutrient status, scarcity or complete absence of advance regeneration due to forest vegetation removal, impoverished soil seed bank (Guariguata, 1990) and possibly a lack of mycorrhizal inoculum (Dalling & Tanner, 1995). To fill-up these gaps quick successional changes occur on unstable soil which leads to the recovery of structure and functioning of the disturbed ecosystem (Mou *et al*., 1993).

The functioning of most ecosystems, particularly the processes of primary production is generally influenced by the availability of nutrients which in turn depends on the amount of organic matter present in the soil, and its rate of decomposition and mineralization. Shed fine roots together with litter from aerial parts of plants provide the materials for the decomposition (Tripathi & Singh, 1996). After disturbance, mineralized nitrogen is lost as nitrate because nitrogen uptake by the plant is reduced due to vegetation removal (Likens *et al*., 1978). An array of species evolved to exploit these nutrient rich (especially NO_3-N) situation after disturbance which results into a substantial increase in primary productivity at the early succession stages (Bormann *et al*., 1974). However, appreciable quantities of solubilized nutrients may be lost in the process of regeneration which might be considered an expense paid for rapid recovery (Pierce *et al*., 1972). Inorganic soil N (NO_3^- and NH_4^+), which rarely exceeds 1 to 2% of the total soil N, reflects the fertility of soil and is the most limiting nutrient in many plant communities (Vitousek *et al*., 1989). However, little attention has been paid to the dynamics of available nitrogen during the recovery of landslide damaged forest sites. The pattern of fine root dynamics in relation to nutrient availability in forest ecosystem is poorly understood. Fine root turnover rate increases or decreases in nitrate-dominated or ammonium-dominated form of available N is still not clear.

In Nepal, geomorphological conditions accounted for more than 75% of all observed landslides which are more frequent in the Central Transitional Mountains, the Central Mahabharat Range and the eastern Siwaliks (Laban, 1979). The present study was carried out in sal forest ecosystem in the eastern Siwaliks of Nepal, where both geomorphic and climatic factors interact in making landslides. The study was conducted within a chronosequence of 1 to 58 years old landslide damaged sites and a mature sal forest to address the following questions:

1. How do the levels of available N change during the course of recovery?
2. How does the rate of N-mineralization change with passage of time?
3. What are the effects of seasonality on available nitrogen, N-mineralization in relation to fine roots during the recovery?

Study sites

The study sites were located in Eastern Siwaliks (Sub-Himalayan region) the catchment area of Koshi River (one of the largest rivers in Nepal), adjacent to Dharan, Nepal (26°47' to 26°52' N and 87°14' to 87°22' E), within the altitude range of 450 to 750 m msl. An age series of 1, 4, 15, 40, 58-year-old landslide damaged sites in a sal forest ecosystem and a mature (>100 years old) undisturbed sal forest, treated as a reference forest, were selected for this study. The reference sal forest inhabited on a deep soil plateau at the outer foot hills is locally called as Panch Kanya sal forest. As per the classification of Varnes (1978), all landslide sites were of translational and debris slide type. The ages of landslide sites were determined on the basis of field survey, forest departmental history records, and interviews with old and experienced people. The area, topographical features and dominant plant species of different landslide-damaged sites are given in Table 1.

Table 1. Characteristics of landslide damaged sites and the mature sal forest located between 450 and 750 m altitude in hill sal forest ecosystem in Eastern Nepal.

Age of site (years)	Area (m^2)	Aspect	Slope	Soil texture	Dominant vegetation Herb (H), Shrub (S), Tree (T)
1	150	W	35°	Sand	(H) *Eupatorium adenophorum*
4	1300	E	40°	Loamy sand	(H) *Eupatorium adenophorum* (S) *Maesa macrophylla*
15	1500	NE	42°	Sandy loam	(H) *Sida veronicaefolia* (S) *Colebrookea oppositifolia* (T) *Shorea robusta*
40	1950	NE	45°	Sandy loam	(H) *Thelypteris multilineata* (S) *Maesa chisia* (T) *Shorea robusta*
58	1800	W	38°	Loam	(H) *Pteris biaurita* (S) *Clerodendron infortunatum* (T) *Shorea robusta*
Mature sal forest	Large tract	Plateau		Loam	(H) *Dicliptera bupleuroides* (S) *Clerodendron infortunatum* (T) *Shorea robusta*

The climate of the area is tropical monsoon type. The year is divisible into three distinct seasons**:** (i) dry and warm summer season (March to mid-May); (ii) wet and warm rainy season (mid-May to October); and (iii) dry and cool winter season (mid-November to February). Based on data for 1992-1995, mean monthly minimum temperatures ranged; winter 11.5-16.7°C, summer 17.5-22.6°C and rainy 20-24°C. Mean monthly maximum temperatures ranged; winter 18.8-25°C, summer 26.7-31°C and rainy 27.7-30.7°C. The annual rainfall averaged 2221 mm, of which 76% occurred from June to September (Figure 1). Data for rainfall and temperature were recorded at Dharan Base Camp Observatory (altitude 610 m) of Soil Conservation Section, Eastern Region Road Maintenance, located within 2 km of the present study sties.

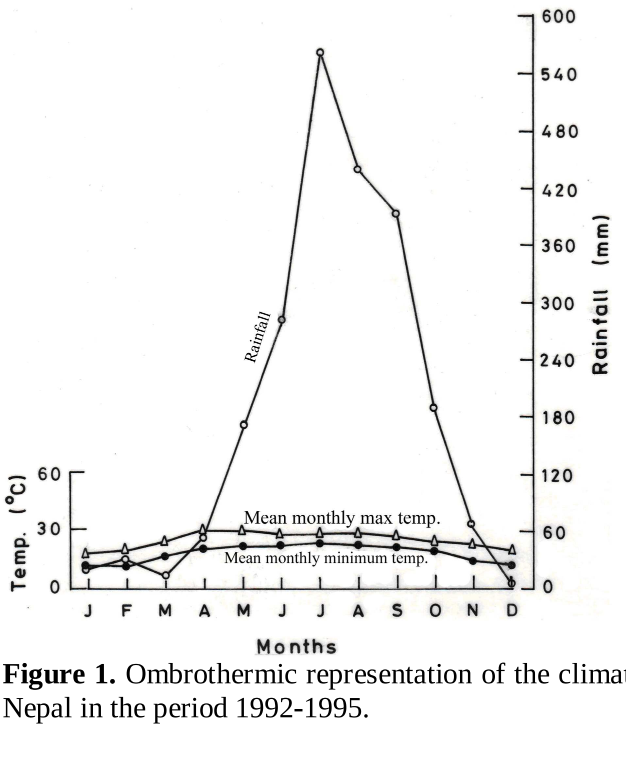

Figure 1. Ombrothermic representation of the climate in the study area in sal forest region of Nepal in the period 1992-1995.

Landslide damaged sites and reference sal forest were situated in the eastern siwalik hills. Siwaliks, the most recent mountains, have been formed from soft, very erodible sediments produced by the rising Himalaya during the middle Miocene to Pleistocene periods. The rocks of these hills are soft and susceptible to erosion as they are younger deposits of pebbles, boulder beds, conglomerates with sandstones, siltstones, claystones and so have weak lithological topography (Hagen, 1963). The soils of the landslide sites are residual and shallow; varying from entisols to inceptisols, with coarse textured sandy soil in 1-year and 4-year-old sites and distinctly loamy older sites (15, 40 and 58-year-old). Soil of the reference sal forest site is deep alfisols and loamy (Jackson, 1994).

The undisturbed reference forest (tropical moist forest according to the life zone classification of Holdridge *et al*. (1971) is dominated by *Shorea robusta* Gaertn. f. with *Schima wallichii* D.C. Korth and *Lagerstroemia parviflora* Roxb. as the main associates. The reference forest represents a moist sal forest, which comprises moisture loving tree species (e.g., *Syzygium cumini*, *Listea monopetala*, *Cassia fistula*) shrubs (e.g., *Clerodendron infortunatum*, *Murraya koenigii*), ferns (e.g., *Pteris biaurita*, *Dryopteris cochleata*) and shade loving grass (*Oplismenus compositus*). Forest landslides in the present study are at different regeneration states. On the landslide sites the species composition changed with the age of the sites. Annual forbs were dominant in the 1-year-old site in which *Eupatorium adenophorum* an early colonizer, was the predominant species. Perennials (*Pityrogramma calomelanos* and *Onychium siliculosum*) shared dominance with annuals at the 4-year-old site and replaced annuals from the 15-year-old site. Shrub appeared (*Maesa macrophylla*) in the 4-year-old site and number of species increased at later stages. In 15, 40 and 58-year-old sites, the vegetation were dominated by the canopy tree *Shorea robusta* with the variations in its associates at different successional stages.

Materials and Methods

Soil Sampling

Soil samples were collected from three random locations at each site. At each location the soil was collected from three pits, composited and pooled as one replicate. Soil sampling was done in May (1993), July and January (1994), representing the summer, rainy and winter season, respectively. After carefully removing the organic materials and fine roots, each composited moist field soil samples was divided into two parts. One part was transported to the laboratory for the determination of available nitrogen. The other part was incubated *in situ* for the estimation of N-mineralization rate.

Determinations of available nitrogen and N-mineralization rate

Moist field soil samples sieved through a 2 mm mesh screen were used for the analysis of inorganic N (NO_3-N and NH_4-N). NO_3-N was meausred by phenol disulphonic acid method, using $CaSO_4$ as the soil extractant (Jackson, 1958). NH_4-N was estimated by phenate method (Wetzel & Likens, 1979), using 2M KCl as the soil extractant. N-mineralization rate was measured *in situ* by buried bag technique (Eno, 1960). In order to avoid any marked immobilization during the incubation plant parts were removed carefully from the soil samples. Three soil samples (each about 150 g) enclosed in polythene bags were buried at 0-10 cm soil depth at each site and incubated for a period of one month. NO_3-Nand NH_4-N were determined initially (at time zero) and after the recovery of buried bags. The increase in NH_4^{-}N was considered as ammonification and the increase in NO_3-N as the nitrification. The increase in the concentrations of ammonium-N + nitrate-N during the field incubation was estimated as the net N-mineralization.

Fine root biomass estimation

Fine roots (<10 mm diameter) biomass was determined from five soil monoliths (10 cm × 10 cm × 30 cm depth) on each site in summer (May, 1994) and rainy season (September, 1994). Soil monoliths were washed over a sieve with fine jet of water to retrieve the fine roots which were oven dried at 80°C. Summer and rainy season values were averaged to obtain a mean annual fine root biomass. The fine root turnover was calculated as the ratio of mean fine root biomass to net fine root production.

Results

Available nitrogen concentrations

ANOVA of NH_4-N and NO_3-N data indicated that variations due to sites and seasons were highly significant ($P \leq 0.001$). Marked seasonal changes were observed in the levels of inorganic N (NO_3-N and NH_4-N) in soil in all landslide affected sites and mature sal forest. In all sites maximum values were recorded during the summer and minimum values in the rainy season (Figure 2). In summer NO_3-N concentrations ranged between 2.2 µg g^{-1} (1-year-old site) and 8.8 µg g^{-1} (40-year-old site). In rainy season NO_3-N ranged 0.5-3.6 µg g^{-1} in same sites. With increase in age of sites beyond 40 years, the NO_3-N concentrations tended to decline in all seasons. The difference was significant at $P \leq 0.005$ between 40 and 58-year-old site and at $P \leq 0.001$ between 40-year-old site and mature forest. The level of NH_4-N in summer ranged from 2.5 µg g^{-1} in 1-year-old site to 14.4 µg g^{-1} in 40-year-old site. The same sites showed the range 0.7-6.2 µg g^{-1} NH_4-N in the rainy season. As in case of NO_3-N, a tendency for decline of NH_4-N concentration at ages more than 40 year was apparent.

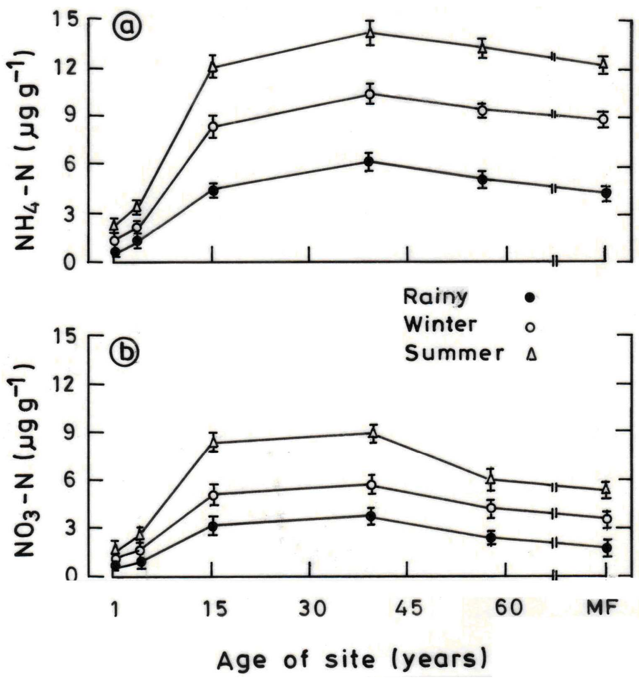

Figure 2. Seasonal variations in concentrations of available nitrogen in soils of landslide sites and mature sal forest (MF): (a) NH_4-N (b) NO_3-N.

Annual mean values of available nutrients are summarised in Table 2. NO_3-N ranged from 1.3-6.0 µg g^{-1} and NH_4-N ranged from 1.5-10.4 µg g^{-1}, the minimum concentration in 1-year-old and the maximum in 40-year-old site. In 58-year-old site and in mature sal forest the mean NO_3-N concentrations declined to 4.2 and 3.6 µg g^{-1} and NH_4-N concentrations to 9.3 and 8.8 µg g^{-1}, respectively. Beyond 40 years age, NO_3-N concentrations decreased by 30-40% between 40-year-old and mature sal forest, while NH_4-N decreased by 15% in the same sites, which showed that decrease in NO_3-N concentrations was faster than decrease of NH_4-N concentrations. In all the sites NH_4-N concentrations exceeded the NO_3-N concentrations in all seasons. The proportion of NH_4-N in total available N, however, increased distinctly with increase in age of sites. The NH_4-N **:** NO_3-N ratio increased considerably from 1.15 in 1-year-old site to 2.4 in mature sal forest.

Table 2. Available N (µg g^{-1}) in soils of landslide sites and mature sal forest. All values are mean of three seasons; summer, rainy and winter.

Available nutrients	Age of site (years)					Mature sal forest
	1	4	15	40	58	
NH_4-N	1.5 ± 0.2	2.3 ± 0.3	8.5 ± 1.1	10.4 ± 1.2	9.3 ± 1.1	8.8 ± 1.1
NO_3-N	1.3 ± 0.3	1.7 ± 0.3	5.7 ± 0.7	6.0 ± 0.8	4.2 ± 0.5	3.6 ± 0.5
Inorganic-N	2.8 ± 0.5	4.0 ± 0.6	14.2 ± 2.0	16.4 ± 2.0	13.5 ± 1.6	12.4 ± 1.7
NH_4-N : NO_3-N	1.15	1.35	1.50	1.73	2.20	2.40

N-mineralization rate

ANOVA indicated that variations in the rates of N-mineralization (ammonification and nitrification) due to sites and seasons were significant ($P \leq 0.001$). Marked seasonality was observed in N-mineralization (ammonication and nitrification) rates in all the sites. Maximum rates were recorded in the rainy season and minimum rates in the summer season (Figure 3). In the rainy season nitrification rates increased from 4.7 µg g^{-1} mo^{-1} in 1-year-old site to the maximum 15 µg g^{-1} mo^{-1} in 40-year-old site, but with further increase in age the nitrification rates declined. Although same trend for inter-site nitrification rates was noticed in other seasons, the differences among sites were smaller. Ammonification rates, however, increased consistently from 2.4 µg g^{-1} mo^{-1} in 1-year-old site to 21 µg g^{-1} mo^{-1} in the mature sal forest during the rainy season. In other seasons also ammonification rates increased with the age of sites but the range of variations was smaller. N-mineralization rates increased rapidly in the rainy season until 15-year age and thereafter slowly but consistenly; the range was; from 7.1 µg g^{-1} mo^{-1} in 1-year-old site to 31 µg g^{-1} mo^{-1} in the mature sal forest. N-mineralization ranges across sites in the winter and summer seasons were 3.1-14 µg g^{-1} mo^{-1} and 1.3-7.0 µg g^{-1} mo^{-1}, respectively. N-mineralization rates in the rainy season were conspicuously higher than the rates in other seasons.

Annual mean N-mineralization rates are shown in Table 3, which increased with age of sites. Ammonication rates which increased consistently, ranged from 1.33-11.76 µg g^{-1} mo^{-1} in 1-year-old to mature sal forest sites. Mature sal forest showed 19% greater ammonification rate than the 58-year-old site. In contrast to ammonification, nitrification rates increased until 40-year age, thereafter it declined. Nitrification rate increased from 2.5 µg g^{-1} mo^{-1} in 1-year-old to 8 µg g^{-1} mo^{-1} in 40-year-old site, and then decreased by 30% at mature sal forest site. Ammonification **:** nitrification ratio ranged between 0.53 and 0.70 in 1-year-old and 40-year-old sites, respectively, showing that nitrification was dominant over ammonification upto 40-year of age.

Beyond 40-year age, a reverse trend was observed when Ammonification : nitrification ratio increased to 1.58 and 2.1 at the 58-year-old and mature sal forest, respectively, indicating the dominance of ammonification over nitrification in the older sites.

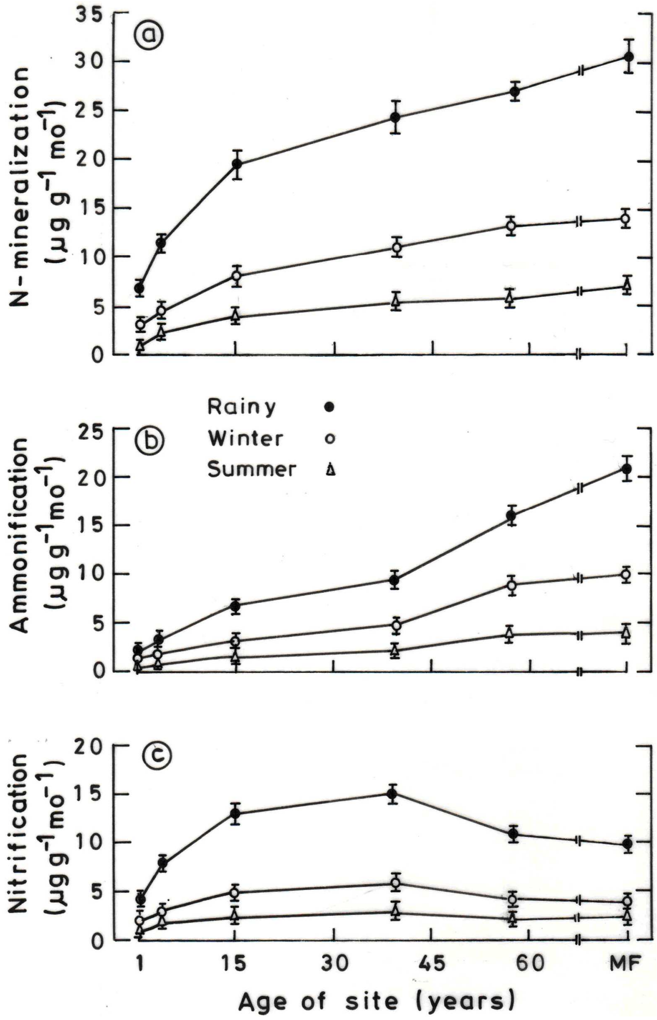

Figure 3. Seasonal variations in (a) N-mineralization rate (b) Ammonification rate and (c) Nitrification rate in soils of landslide sites and mature sal forest (MF).

Table 3. N-mineralization rates in soils of landslide sites and mature sal forest. All values are mean of three seasons; summer, rainy and winter. [a] Expressed as µg g^{-1} mo^{-1}.

Mineralization	**Age of sites (years)**					**Mature sal forest**
	1	**4**	**15**	**40**	**58**	
Ammonification[a]	1.33±0.3	2.00±0.4	3.90±0.7	5.66±1.0	9.53±1.7	11.76±2.0
Nitrification[a]	2.50±0.6	4.16±1.0	6.83±1.6	8.00±1.8	6.00±1.3	5.56±1.1
N-mineralization[a]	3.83±0.8	6.16±1.4	10.73±2.3	13.66±2.8	15.53±3.0	17.32±3.5
Ammonification:nitrification	0.53	0.48	0.57	0.70	1.58	2.11

Fine root biomass

The annual fine root biomass increased consistently with age of sites ranging between 0.3 t ha^{-1} in 1-year-old site and 7.0 t ha^{-1} in 58-year-old site (Table 4). In the 1-year-old site all fine roots belonged to herbs. With increase in age the bulk of fine roots belonged to woody species. Remarkable seasonal variation was observed in the amount of fine roots. Highest amount of fine roots of all root size classes were recorded during the rainy season which were decreased by 57-68% in the summer season indicating a rapid turnover of fine roots.

Table 4. Seasonal variation in fine root biomass (t $ha^{-1} \pm$ 1SE) for different size classes, stand fine root biomass and turnover in landslide damaged sites and mature sal forest.

Fine root size class (mm)		Age of site (years) 1	4	15	40	58	Mature sal forest
Summer	< 2	0.16 ± 0.016	0.35 ± 0.04	1.16 ± 0.12	1.67 ± 0.31	2.01 ± 0.28	2.33 ± 0.50
	2 - 4	-	0.20 ± 0.04	0.92 ± 0.07	1.17 ± 0.12	1.54 ± 0.31	2.00 ± 0.12
	4 - 10	-	-	0.20 ±0.02	0.32 ± 0.04	0.50 ± 0.07	0.63 ± 0.08
	Total	0.16 ± 0.016	0.55 ± 0.07	2.28 ± 0.14	3.16 ± 0.21	4.05 ± 0.48	4.96 ± 0.55
Rainy	< 2	0.48 ± 0.05	1.39 ± 0.05	4.30 ± 0.30	5.15 ± 0.29	5.75 ± 0.34	6.32 ± 0.33
	2 - 4	-	0.35 ± 0.07	1.64 ± 0.21	2.24 ± 0.12	2.78 ± 0.41	3.50 ± 0.32
	4 - 10	-	-	0.66 ± 0.07	1.09 ± 0.27	1.42 ± 0.31	1.58 ± 0.16
	Total	0.48 ± 0.05	1.74 ± 0.11	6.60 ± 0.56	8.48 ± 0.56	9.95 ± 0.85	11.40 ± 0.73
Stand fine root		0.3 ± 0.02	1.2 ± 0.06	4.44 ± 0.27	5.8 ± 0.31	7.0 ± 0.34	8.2 ± 0.49
Turnover		1.0	1.0	0.97	0.91	0.84	0.78

In 1-year-old site all roots were of < 2 mm diameter. In older sites fine roots < 2 mm diameter comprised 55-80% of total fine root biomass, their percentage decreased with increase in age. Sites, 15-year or older in age showed the presence of fine roots 4-10 mm diameter. Estimated turnover rate of fine roots was higher at early successional stages (1-15-year old sites) which decreased from about 1.0 in 1-year-old site to 0.78 in the mature sal forest.

Discussion

Changes in available nutrients

The disruption of soil-plant system caused by landslides resulted in loss of soil organic matter and decline in concentrations of available nitrogen. In the 1-year-old landslide site the soil surface was exposed and eroded and available nitrogen may be lost through enhanced leaching and runoff. Generally, NO_3- is lost through leaching and runoff and NH_4^+ retained in the soil cation exchange site reducing N losses by leaching and denitrification (Rice & Pancholy, 1972). Increase in NH_4-N dominance over NO_3-N with increase in age of landslide affected sites, reflects shift in N cycling characterized by loss of NO_3-N in early successional stages followed by gradual conservation of N in NH_4-N form in late successional stages as indicated by wider NH_4-N **:** NO_3-N ratio.

Disturbance often results into narrowing of NH_4-N **:** NO_3-N ratio and this ratio increases as the ecosystem approaches maturity (Walley *et al*., 1996). Rice and Pancholy (1972) suggested that the nitrifiers are inhibited in the climax, hence the NH_4-N is not readily oxidised to nitrate, as happens in the early successional stages. High availability of mineral N early in succession (as in 15 and 40-year-old sites) may result from accelerated N-mineralization as also reported in several disturbed forests (Vitousek *et al*., 1989). On the other hand, low levels of available N in soils of 58-year-old site and mature sal forest reflect high uptake of nitrogen by plants in late successional stage and climax sal forest. Vitousek and Matson (1985) stated that biological uptake of available N is relatively rapid in most intact forests and consequently the pool sizes of NH_4-N and NO_3-N are small.

Changes in N-mineralization

Nitrogen mineralization (nitrification + ammonification) conducted by soil micro-organisms is generally affected by disturbance due to change in structure and properties of soil and composition of soil microorganisms. In the 1-year-old site, low level of soil organic matter and microbial biomass resulted into lower N-mineralization rate, which, however increased with the passage of time (Mandal, 1999). Ammonification and nitrification ratio ranging from 0.53-0.70 in 1-year to 40-year-old sites, indicated dominance of nitrification over ammonification in early successional stages, while in late successional stage (58-year-old site) and mature forest much higher ratio (1.58-2.11) suggested predominance of ammonification, and possibly inhibition of nitrification. Nitrification rate generally increases after disturbance and decreases as recovery progressed (Walley *et al*., 1996).

Increased nitrification after disturbance may be due to the availability of NH_4-N substrate utilized by the nitrifiers (Robertson & Vitousek, 1981). Decreasing nitrification in late succession and in mature forest soil have been suggested due to several reasons which include allelochemic inhibition of nitrification, competition among organisms for limited nutrients, low initial population of autotrophic nitrifying organisms, and edaphic conditions including pH unfavourable to autotrophic nitrifiers (Montagnini *et al*., 1989). The quantities of allelopathic inhibitory compounds increase with succession. Robertson and Vitousek (1981) reported that number of ammonia oxidizing bacteria was significantly less (25000 cells g^{-1}) in the forest soils than the number found in earlier stages (about 130000 cells g^{-1}) along a secondary sere located on the New Jersey Piedmont. Low level of NO_3-N, and decreased nitrification in 58-year-old site and in mature sal forest may be due to reduced number and activities of nitrifiers at these sites. Rice and Pancholy (1972) reported high number of nitrifiers and low amount of NH_4-N in early successional stage and the reverse of these in the climax stage, in three different seres of Southern Oklahoma.

Available-N and N-mineralization in relation to fine root biomass

Annual mean fine root biomass at different sites were positively correlated with their annual mean level of available N ($r = 0.83$; $p \leq 0.01$) and net N-mineralization rate ($r = 0.99$; $p \leq 0.01$). Fine root biomass and N- mineralization rate both increased during rainy season. During this season high N- mineralization rate provides higher amounts of available N. But available N showed decreased value due to massive nitrogen uptake by the plants resulting in rapid plant growth during this period. On the other hand fine root biomass and N-mineralization rate both decreased during summer season while available N increased. This is associated with decreased demand or reduced nitrogen uptake by the plants during the dry period.

Mineralized N is either immobilized in microbial biomass or accumulated in the soil as inorganic N resulting in greater inorganic N pool during the summer in comparison to the rainy season (Singh *et al*., 1989). During the summer fine root biomass decreased by 57-68%, indicating a rapid turnover. Low turnover of fine roots in older sites happens in a situation when there is decreasing trend of available N and nitrification. Aber *et al*. (1985) reported an exponential increase in turnover of fine roots with increase in available N in the nitrate dominated stands. Furthermore, high turnover of fine root at the younger sites (1 yr-15 yr old sites) add more organic matter for the developing vegetation as also reflected in high rate of stand net production (Mandal, 1999).

Roy and Singh (1995) have also found a positive relation of fine root biomass with net N-mineralization rates and N-availability in a dry tropical forest. However, fine root biomass production showed increasing trend even in 58-year-old and mature sal forest sites when nitrification rates and NO_3-N decreased. Aber *et al.* (1985) reported in 13 forest stands of Wisconsin and Massachusetts, where fine root biomass was negatively correlated with nitrification. Decreasing nitrification in late succession and in mature forest soil has been suggested due to allelochemic inhibition on number and activities of nitrifiers (Montagnini *et al.*, 1989). Decreasing trend in NO_3-N and substantial plant uptake of nutrients in 58-year-old site and mature sal forest may be the reason of reduced amount of available nutrient pool as also suggested by Vitousek and Matson (1985). Fine root biomass increased in 58-year-old and mature sal forest sites in a situation where competition for nutrient existed. In conclusion fine root development was facilitated by higher amounts of mineral-N, as the rate of N-mineralization increased with the age of landside sites

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