8.1. Physico-chemical characteristics of soils

*Soil temperature, soil moisture, bulk density, water holding capacity, pH, organic C, total N, NH$_4^+$-N, NO$_3^-$-N and total P*

Physico-chemical characteristics of the soils in the present study showed a declining trend of their values from highest in the undegraded forest site to the lowest in degraded forest site while moderately degraded site contained an intermediate range of their values at surface and subsurface soil layers. In general, the important soil parameters such as, soil profile (Ah) thickness (Plate 5), moisture content, water holding capacity, pH, organic C, total N, ammonium and nitrate-N and total P showed declining trend with the increase in forest soil disturbance i.e. the maximum values of these parameters were recorded from undegraded forest site followed by moderately degraded site whereas minimum values were recorded from the degraded forest site at both surface and subsurface soil layers. However, the parameters such as, soil temperature and bulk density were found highest in the degraded site followed by moderately degraded site. Lowest values these two soil parameters were noted from the undegraded forest site at surface and subsurface soil layers. This shows that soil disturbance through the intensive agriculture systems like shifting cultivation and selective logging practices caused significant impact on various physico-chemical characteristics of soils in different magnitudes in the humid tropical hill region of north-eastern India.
Higher soil temperature at surface and subsurface soil layer of the degraded site than the moderately degraded and undegraded sites could be due to the heating up of the soil surface by direct exposure of soil surface to solar insolation in absence of tree canopy. The intensity of the increased soil temperature was very prominent during the mid summer season (April to July) in case of degraded site as compared to other sites. The lower soil temperature at surface and subsurface soil layers of undegraded site might be due to presence of abundant vegetal cover and thick layer of litter on the forest floor which protects direct heating of the soil surface due to insolation leading to lowering of soil temperature at the site. Soil moisture content did not vary significantly among the three study sites at surface soil layer though it varied significantly ($P<0.05$) at subsurface soil layer (Table 3.1). However, variation of soil moisture was significant in each of the study sites. Highest moisture content was recorded from the undegraded site in the month of June 2000 at both soil layers (Fig.3.2). The reason could be due to the ability of soils to retain water and reduction in faster runoff due to the presence of higher organic matter on the surface layer of undegraded site following rainfall. In fact, the forest floor of the undegraded forest site was covered with a thick layer of litter (the fallen leaves, broken twigs and debris of dried seasonal weeds and grasses of the forest vegetation) must have absorbed water and protected excessive evaporation after rain resulting in higher soil moisture content in this site. These properties of soil to retain water and reduce faster runoff after rainfall must have been lost as a result of long term shifting cultivation practices in the degraded site. Similarly, frequent logging
of trees along with cleaning of forest floors for alternate years in the moderately degraded site might have caused lowering of soil moisture content. At the same time, the absence of permanent forest vegetation, litter and exposure of the forest floor to atmosphere must have increased soil surface runoff and excessive evaporation causing decline in soil moisture in these sites.

Bulk density of the degraded site was found significantly ($P<0.05$) higher than the moderately degraded and undegraded forest sites at both the surface and subsurface soil layers (Table 3.1). There was an increasing trend of bulk density with the increase in degree of forest soil degradation where lowest bulk density was recorded from the undegraded site followed by the moderately degraded site and the highest bulk density recorded from the degraded forest site at both surface and subsurface soil layers. The main reason for the increase in bulk density of the degraded site might be due to enhanced compaction and hardening of the soil while the site was left abandoned as fallow land after continuous utilization for agricultural production through shifting cultivation practice. Usually, soil aggregates become smaller and smaller when it is used for cultivation by tillage practice. Large portions these smaller soil particles become lost through runoff from the hill slopes and some particles enters deeper layers along with gravitational water movement following rainfall during the period of vegetation regeneration for nutrient restoration. These might have caused removal of upper topsoil layer (Ah) and exposure of lower soil horizons (Bo). These causes decreased porosity of the soil leading to increased soil bulk density in
the degraded site. Hajabbasi et al. (1997) also reported similar results of 20% increase in bulk density as a result of conversion of tropical forests into agricultural land in Iran. This is in correspondence with present findings of 15% increase of bulk density in the degraded site as compared to the undegraded forest site.

Water holding capacity also varied significantly ($P<0.05$) among the three study sites at both soil layers though there was no significant variation recorded with change in sampling month. The maximum water holding capacity recorded form the undegraded site could be ascribed to the presence of large tree vegetation having diffused root network and thick layer of litter accumulated (round the year) on the forest floor of this site as compared to degraded and moderately degraded sites (Plate 4). Generally, the surface soil layers had higher water holding capacity than subsurface soil layers of the degraded, moderately degraded and undegraded sites showing a decline in water holding capacity with the increase in soil depth.

Arunachalam et al. (1996) and Maithani et al. (1996; 1998) have also reported higher water holding capacities of old aged forest soils than younger forest re-growths in the north-eastern region. Further, they concluded that increase in forest disturbance through logging practice caused decline in water holding capacity of soils.

Soil reaction of the degraded site revealed strongly acidic condition in comparison to the undegraded forest site at both the surface and subsurface soil layers. There was an increase in acidity of soils in all the there sites with the increase in soil depth from surface towards subsurface soil layers. The
reason for acidic pH in the degraded site might be due to strong leaching of bases from the surface soil through water runoff and presence of the $\text{Al}^{3+}$ in the degraded site following shifting cultivation practices (Nayak and Srivastava, 1995 and Bhattacharya et al., 1998). However, Singh et al. (1995) reported more acidic soil pH of jhum fallows as compared to natural bamboo forests of north-eastern India which is in contrast to the present findings of highly acidic soil in the abandoned jhum fallow as compared to an undegraded natural hill forest. The moderately degraded and undegraded sites had slightly acidic pH at surface and subsurface soil layers revealing that the these soils have buffering activity to protect higher base leaching due to the presence of large vegetal cover and thick layer of litter on the forest floor.

Organic C content of the undegraded site was highest in comparison to degraded and moderately degraded forest sites at both surface and subsurface soil layers. The main reason for higher organic C content must be due to the presence of permanent vegetation with higher species diversity and accumulation of large amounts of organic residues from the thick layer of litter on the forest floor of undegraded site. Whereas, lower organic C content in the degraded site might be due to the absence of a permanent vegetation cover (Plate 1) to provide forest floor litter other than seasonal weeds, ferns and grasses. Another reason could be the depletion of the soil organic matter, which is the source of nutrients for crops in soil during the period of shifting cultivation. Ultimately, poor nutrient status of the soil led to the abandonment of this site as fallow land. Similarly, the forest floors of the
moderately degraded site was cleaned and burned by forest department of the state for allowing proper growth of newly planted trees could have also led to reduction in organic C content in this site as compared to the undegraded site. Decline in organic C content of soils as a result of conversion of natural forests into agriculture lands, pastures and due to logging practices have been reported from the tropical and sub-tropical forests (Brown et al., 1994; Henrot and Robertson, 1994; Saikh et al., 1998 and Arunachalam et al., 1996, 1997; 1998). The organic C content also declined with the increase in soil depth from surface to subsurface layer of degraded, moderately degraded and undegraded forest sites in the present study.

Total N and available N (ammonium and nitrate-N) contents of the soil in the study sites revealed a declining pattern with the increase in degree of soil degradation. Total and available N contents were comparatively higher in the undegraded site followed by moderately degraded site and lowest was recorded from the degraded forest site. The higher N content in the undegraded site might be due to higher nitrification rate of the organic residues at favourable rainfall, soil temperature, moisture and organic C contents. Significant ($P<0.05$) positive correlations were observed between these parameters and total N and available N contents at surface and subsurface soil layers of the undegraded site. However, the total N and available N contents were lower in degraded and moderately degraded sites as compared to the undegraded site because these sites had been disturbed for shifting cultivation and selective logging practices followed by burning of
dried slash causing loss of N content along with decline in soil organic matter. Another reason for reduced N content in the degraded and moderately degraded sites could be due to rapid loss of nutrients through surface runoff during rainfall since enough vegetal cover and organic matter content were not there to retain the nutrients.

The distribution of total P did not vary among the three study sites in the present study site though its distribution varied significantly \((P<0.05)\) between degraded and undegraded site at both the surface and subsurface soil layers. However, the undegraded site contained slightly higher P in comparison to the other two sites at both soil layers.

Tiessen et al. (1992) and Agbenin and Goladi (1997) reported significant reduction in organic C, total N, available N (ammonium and nitrate N) and total P contents of soils in the long term when cultivation was practiced without proper input of nutrients based on either inorganic or organic fertilizer when compared to an undisturbed natural forest site. Ramakrishnan and Toky (1981) also reported decline in nutrient concentrations of cultivated soils due to faster decomposition rate of organic matter as a result of higher temperature and rapid surface runoff. These reports are in agreement with the present findings of reduced nutrient concentrations in the degraded and moderately degraded forest sites where shifting cultivation and selective logging were practiced for long time as compared to an undegraded natural forest site.
8.2. Biological characteristics of soils

Soil respiration, bacterial and fungal populations

All the biological characteristics namely, soil respiration, bacterial and fungal populations, vesicular-arbuscular mycorrhizal fungi (VAMF) diversity and microbial biomass C and N was found significantly affected by the degree of soil degradation in the present study.

The respiratory efficiency of the soil showed a declining trend from highest soil respiration in undegraded forest site followed by moderately degraded site to the lowest soil respiration in degraded site at both the surface and subsurface soil layers. The reason for the higher soil respiration in the undegraded site might be due to the presence of favourable soil environments such as, higher soil moisture, organic matter content, soil temperature etc. for rapid multiplication of microorganisms leading to increased soil respiration in this site. However, the degraded and moderately degraded sites were recorded with lower soil respiration since these sites. These micro-environmental conditions required for rapid microbial replication were repeatedly disturbed by shifting cultivation and selective logging practices which led to a decline in efficiency of soil respiration in the long term. Chang and Trofymow (1996) also reported the detrimental effect of forest clear-cutting and subsequent preparation for land use on the respiratory efficiency of soils. This is in correspondence with the present findings of the reduced soil respiration in degraded site which had been used for a long period for shifting cultivation practice.
There was a significant change in rate of soil respiration with the change in sampling months which reveals a clear impact of seasonal climatic change on the respiratory efficiency of soils in all the three study sites at both the soil layers. The maximum rate of soil respiration was recorded from the surface layer of undegraded site in the month of August 1998 where highest rainfall occurred during the entire sampling period of two years. Similarly, degraded and moderately degraded sites also showed maximum rate of soil respiration in this month at surface soil layers. There was significant ($P<0.01$) positive correlation between the rate of respiration and various soil parameters such as air and soil temperatures, soil moisture, bacterial population and monthly rainfall in all sites and at both surface and subsurface soil layers of the three study sites. This shows that increase in soil moisture, soil temperature increased bacterial multiplication leading to enhanced soil respiration in the present study. On the other hand, the minimum rate of soil respiration was recorded in the month of December 1999 at surface layer and in the month of February 1999 at subsurface soil layer of the degraded site. This could be due to decrease in bacterial population as well as soil moisture, temperature and rainfall during the dry winter season. In general, the respiratory efficiency declined during the dry winter season in all sites and at both the soil layers. The soil respiration was lower in the subsurface layer as compared to the surface soil layers of the three study sites which also revealed decline in bacterial population and other soil physical parameters in the subsurface soil layer leading to decrease in soil respiration. Dkhar (1983), Upadhyaya et al. (1987), Tiwari (1988) Lomoander et al.
(1998) have also reported seasonal variation in respiratory efficiency of soils in maize fields, tropical grasslands, pineapple orchards and forest ecosystems respectively. Further, they also reported positive correlation between soil respiration and soil moisture, soil temperature and rainfall in their studies.

Shifting cultivation and selective logging practices reduced bacterial and fungal populations in degraded and moderately degraded forest sites in comparison to the undegraded forest site at both the surface and subsurface soil layers. Maximum populations of bacteria and fungi were recorded from the undegraded forest site which was followed by the moderately degraded site while the minimum was recorded from the degraded site. There was significant (P<0.05) decline in the bacterial population in the degraded forest site as comparison to the moderately degraded and undegraded forest sites (Table 2.1). This is because of the presence of the evergreen forest cover with thick layer of leaf, twig and wood litter etc. on the forest floor protecting excessive evaporation of soil water, thus creating a favourable environment of rapid microbial growth and multiplication in presence of higher organic matter in the undegraded site. On the other hand, the degraded site had no permanent cover of vegetation or grass (only seasonal) on the forest floor causing rapid loss of soil water and nutrients form the topsoil layer and subsequently poor growth and multiplication of bacterial and fungal populations. There was decline in bacterial and fungal populations of all the three study sites at subsurface soil layers as compared to the surface soil layers. The main reason for depletion in the population status of bacteria and
fungi in the subsurface layers of degraded, moderately degraded and undegraded forest sites might be due to the decrease in nutrient requirements of these microorganisms and other physico-chemical parameters required for rapid growth and multiplication of the bacteria and fungi in this soil layer. Tiwari (1988) reported significant decline in bacterial and fungal populations in younger aged (1 and 5 year old) pineapple orchard soils as compared to the 10 year old pineapple orchards of north-eastern India. Jha et al. (1992), Arunachalam et al. (1997) also reported decline in bacterial and fungal populations due to forest degradation, altitudinal variation and seasonal changes and due to forest logging practices in the north-eastern India. Their study reported decreased in bacterial and fungal populations with increase in soil depth. In fact, the degraded site had been continuously used for cultivation of various crops after burning the dried slash prior to cropping for a long period without proper nutrient input. This must have caused depletion of the nutrients required for the growth of microorganisms in the soil environment due to loss of soil organic matter as a result of burning and nutrient utilization by the seasonal crops leading to long term detrimental effect on the restoration of microbial communities in this site. Similarly, the burning of the forest cover for every year or every alternate year along with logging practice continues in the moderately degraded site might have caused loss of soil nutrients preserved in the soil organic matter causing unfavorable conditions for microbial multiplication and growth. Another reason for reduced microbial populations in the degraded site and moderately degraded sites could be due to loss or killing of the microbial
propagules while burning the dried slash (since the fire intensity of field burning reaches upto a height of about 2 to 3 meters above the soil surface and its heat reaches upto a depth of about 10 to 20 cm inside the soil subsurface layers) while preparing for crop cultivation in shifting cultivation systems. Acea and Caraballas (1999) have also reported almost complete microbial sterilization of the upper soil layer when heated upto 200°C for only 1h. This shows that shifting cultivation through forest clear-cutting and selective logging with repeated burning of forest floor caused not only decline in soil organic matter which is the reservoir of various nutrients but also decreased the growth and multiplication of bacterial and fungal communities in degraded and moderately degraded forest sites as compared to an undegraded forest site.

**Vesicular-arbuscular mycorrhizal fungi (VAMF) diversity in forest soils**

The distribution of vesicular-arbuscular mycorrhizal fungi (VAMF) diversity in forest soils of the present study revealed a significant impact of soil disturbance through shifting cultivation and selective logging in the humid tropics. There was a decrease in spore population, species diversity and species abundance of VAMF with the increase in intensity of soil disturbance. The undegraded forest site was recorded with maximum spore population, species diversity and species abundance of VAMF followed by moderately degraded site and minimum was recorded from the degraded site at both the soil layers. There was a reduction in spore population of VAMF in degraded site by 70% and in the moderately degraded site by 30% at surface and subsurface soil layers as compared to the undegraded forest site.
Ahmad (1996) also reported 30-50% reduction in VAMF propagules when forest soils were severely disturbed through heavy soil mechanical compaction, exposure and erosion. Altogether, 44 species belonging to five genera namely, Acaulospora (6), Gigaspora (3), Glomus (27), Sclerocystis (1) and Scutellospora (7) were recorded from the three forest sites (Tables 4.2.3 and 4.2.4). Out of the 44 VAMF species recorded in the study, 21 were found as abundant in all the sites whereas, 14 species were restricted in undegraded site, 7 in moderately degraded site and 2 species in the degraded site respectively.

The average index of dominance for undegraded site was lower (0.12) indicating shared species dominance of VAMF species while the higher value of 0.16 and 0.15 in degraded and moderately degraded sites indicated dominance by a few species of VAMF only. In case of index of general diversity, the result was converse, a value of 0.99 for undegraded site, 0.85 for moderately degraded site while the lowest of 0.81 from the degraded site suggesting a greater diversity of VAMF species in the undegraded site than in degraded and moderately degraded sites respectively. There was a net reduction of 30% and 60% species diversity of VAM fungi in moderately degraded and degraded forest sites in comparison to the undisturbed forest site. This is in conformity with the higher number of VAM fungal species and propagules in undegraded site than in degraded and moderately degraded sites. The main reason for reduction in spore population, species diversity and species dominance in the degraded and moderately degraded sites could be due to long term practice of shifting
cultivation and selective logging in the degraded and moderately degraded sites. In shifting cultivation system, it is very common that all the vegetation is clear cut and burned the dried slash of the cut vegetation prior to direct sowing of seeds or growing of crops. This causes loss of specific host plants required by VAMF to establish its symbiotic association with the plant roots and at the same time viable propagules and dormant spores of VAMF are also destroyed along with loss of soil organic matter as a result of burning. This burning of the dried slash not only destroyed VAMF propagules and host plant roots but also caused alterations in micro-environmental conditions such as increased soil temperature, lower moisture content, decrease in soil aggregate stability leading to decline in growth of other soil microorganisms. These situations are also found in case of the moderately degraded site since forest floor clearing and burning were practiced every year or every alternate year for removal of excessive grass, weeds and fern growth to improve new forest plantations. Therefore, long term decline in the status of VAMF spore population, species diversity and lower species dominance were occurred in the degraded and moderately degraded forest sites at both the soil layers as compared to the undegraded forest site.

**Microbial biomass C and N**

Microbial biomass C and N contents of the soil in degraded, moderately degraded and undegraded forest sites showed a significant \((P<0.05)\) variation at surface and subsurface soil layers (Table 4.3.1). Maximum microbial biomass C and N contents were recorded from the undegraded site followed by moderately degraded site in all the sampling
months at both soil layers. Degraded forest site contained the minimum microbial biomass C and N at both the soil layers in all the sampling months. There was a decline in microbial biomass C and N contents with increase in soil disturbance from highest microbial biomass C and N in undegraded forest site towards lowest in the degraded forest site. The main reason for decline in microbial biomass C and N in these sites might be due to loss or decline in microbial populations and soil organic matters. The degraded site had been used for shifting cultivation for a period of 13 years continuously without proper nutrient input based on either organic or inorganic fertilizers to compensate the nutrients depleted during cropping period. Therefore, a decline in soil organic matter and decrease in microbial population status occurs as a result of burning of dried slash every time prior to crop sowing in the fields which ultimately led to reduction in soil organic matter, microorganisms and microbial biomass C and N in this site as compared to the undegraded forest site. Similarly, the moderately degraded site had also been disturbed frequently for logging purposes and burned the forest floor to eliminate excessive growth of unwanted grass and other weeds to improve new forest plantations. This must have also caused reduction in litter accumulation, loss in soil organic matter and destroyed active and dormant microbial propagules present on the forest soils that ultimately led to decreased microbial biomass C and N. Another important factor which might have contributed to the loss of soil organic matter and microbial biomass in cultivated fields and selectively logged forest is the faster surface runoff of the soil particles along with larger soil aggregates from the hill slopes during
rainy seasons. This is perhaps the most important problem faced by the farmers since longer period of rainfall occurring in the north-eastern hill regions causing tremendous loss of fertile topsoil which contains the largest amount of organic matter, nutrients and microorganisms in every soil profile. Srivastava and Singh (1991), Henrot and Robertson (1994) and Tiwari et al. (2002) have reported decline in soil organic matter and microbial biomass C and N as a result of vegetation removal and subsequent conversion of tropical forests into agricultural lands and due to the practices of shifting cultivation and selective logging in the humid tropics. The reason for higher microbial biomass C and N in the undegraded forest might be due to the presence of significantly higher soil organic matter, favourable micro-environmental parameters such as soil temperature, moisture and nutrients which lead to rapid microbial multiplication and subsequent immobilization of nutrients in the microbial cells. Microbial biomass C and N contents were positively correlated ($P<0.05$) to the air and soil temperatures, moisture content, pH, ammonium and nitrate-N, fungal population, soil respiration and phosphatase activity in the undegraded site (Tables 3.3 and 3.4).

The microbial biomass C and N of the soil in each site also declined from highest at surface to the lowest at the subsurface layer indicating poor distribution of soil organic matter and microorganisms at deeper soil layers. Decline in the microbial biomass C and N with increasing soil depth in three sites namely, permanent grassland, arable site with neutral pH and arable site with acidic pH had also been reported by Lavahun et al. (1996). Similar results of decline in microbial biomass C and N with increase in soil depth
have been reported from the disturbed subtropical forests of north-eastern India (Maithani et al., 1996).

8.3. Molecular microbial diversity of soils

*Bacterial diversity of soils as determined by 16S rDNA fingerprints*

Culture-independent studies of the microbial community structures based on genotypic and phenotypic techniques in the soils of degraded, moderately degraded sites revealed significant variation in distribution of the microbial communities. The analysis of the density gradient gel electrophoresis (DGGE) of the polymerase chain reaction (PCR) amplified 16S rDNA fingerprints demonstrated a high diversity of bacterial communities in the soils from the three study sites at the surface and subsurface soil layers. The undegraded site possessed maximum number of 16S rDNA fingerprints than the degraded and undegraded sites at both soil depths. The surface soil of the degraded site displayed minimum 16S rDNA fingerprints thereby suggesting the reduced bacterial diversity in this site as a consequence of the long term utilization of the soil through shifting cultivation in the past. The gel compare analysis of the DGGE fingerprints of 16S rDNA resulted three clusters (Fig.5.13B) with distinct separation of the study sites. The group I consists of the surface soil layer of degraded site displayed a minimum similarity index of 85% to the other soils while the group II comprised of the surface and subsurface soil layers of undegraded site which showed a maximum of 96% similarity index of the fingerprints. The group IIIa and IIIb were formed by surface and subsurface layers of moderately degraded site and the subsurface soil layer of the degraded site respectively.
This suggests the declining trend of the similarity index from highest in undegraded site to the lowest in the degraded site which means less number of bacterial genera and thus diversity in the degraded site as compared to the undegraded site.

Microbial community structure of soil as measured by phospholipid fatty acid (PLFA) profile analysis

Analysis of the phospholipids fatty acids (PLFAs) profiles of soils from the three study sites showed no significant variation in the amount of total PLFA contents. However, there was significant variation in distribution of the individual fatty acids representing indicators of specific microbial groups. A total of 133 fatty acids belonging to various PLFA fractions namely SATFAs, MUFAs, PUFAs, PLOHs (all ester-linked) and UNSOHs (non ester-linked) were recorded from all the soil samples.

The straight chain SATFAs with methyl branching at 10\textsuperscript{th} C-atom were largest subgroup. These fatty acids as indicators of actinomycetes in the soil were detected in maximum numbers at the surface layer of the undegraded site while least was detected in the subsurface soil of the degraded site. The fatty acids with methyl branching at \textit{iso} and \textit{anteiso} positions as indicators of Gram-positive and Gram-negative bacteria were detected in all sites and at both the soil layers though their percent concentration was lower than other fractions. These fatty acids are found in the genera \textit{Acetobacter}, \textit{Cytophaga} and \textit{Flavobacterium} (Brennan, 1988 and Hack \textit{et al.}, 1994) and were not affected by the shifting cultivation and selective logging in the long term. The diversity of the genera \textit{Bifidobacterium}, \textit{Closteridium}, \textit{Legionella} and \textit{Rhodospirillum} Gattinger \textit{et al.} 2002; Ratledge and Wilkinson, 1988 and
Zelles, 1999) and as revealed by the cyclopropyl ring containing fatty acids showed maximum in degraded site followed by moderately degraded site and least in the degraded site.

No variation in the microbial communities represented by the monounsaturated fatty acids were detected from all the sites. However, the majority of the microbial group, Gram-positive and Gram-negative bacteria and other eukaryotes including fungi represented by the fatty acids with unsaturation at ω9 were dominant microorganisms in these soils. The polyunsaturated fatty acids (PUFAs) as the markers of microeukaryotes (fungi) and cyanobacteria (Bossio and Scow, 1998 and Gattinger et al., 2002) were found distributed in all the sites. The degraded site contained 7 fatty acids with different degrees of unsaturations and represented maximum number of PUFAs than other sites at surface soil layer. Arachidonic acid (20:4-5, 8,11,14) was another PUFA which occurred at the surface soils of the three study sites with high percentage concentrations to the total PUFAs. The absence of this fatty acid at the surface layers revealed that archaetale communities were mostly aerobic occurring in the surface soil layers only.

The α-PLOHs as indicators of the Gram-negative bacteria (Pseudomonas) and Actinomycetales (Galbraith and Wilkinson, 1991; Gattinger et al., 2002; Yano et al., 1978 and Zelles, 1999) were the largest subgroup in terms of number of fatty acids. The β-PLOHs as the marker of the bacterial groups, Pseudomonas, E.Coli, Rhodococcus, etc. (Zelles 1997) showed highest diversity and concentration at the surface soil layer of the undegraded site expressed in per cent of the total PLOHs. There was a
sharp decline in the diversity and population of these microbes at the subsurface soil layer of the undegraded site as compared to the moderately degrade and undegraded sites which suggests the negative effects of the shifting cultivation on survival and multiplication of these organisms.

Oh-nsubstituted fatty acids (UNSOHs) are regarded as the general indicators of anerobes and eukaryotes (fungi) including the representatives of the genus, Closteridium (Gattinger, 2002 and Zelles, 1999) which showed a unique distribution pattern among the soil samples studied in this study.

8.4. Biochemical characteristics of soils

**Dehydrogenase, acid phosphatase and urease soil enzyme activities**

Biochemical characteristics of soil particularly dehydrogenase and acid phosphatase activities in degraded, moderately degraded and undegraded forest sites revealed marked variation due to site, season and soil depths. The urease activity showed marked seasonal variation rather than site and depth-wise variations.

The activity of dehydrogenase enzyme the soil in degraded and moderately degraded forest sites showed minimum as compared to the undegraded forest sites at both the soil layers. Maximum dehydrogenase activity recorded in the present study from the undegraded site could be due to presence of higher soil organic matter and favourable soil reactions as revealed by significant ($P<0.05$) positive correlation between the dehydrogenase activity with soil pH and organic C contents at both soil layers. Generally, soil dehydrogenase being an oxido-reductase enzyme is known for its role in initial oxidation of soil organic matter decomposition.
Therefore presence of the higher amount of organic matter and favourable soil pH in the surface and subsurface soil layers of undegraded site might have influenced enhanced activity of this enzyme as compared to the degraded and moderately degraded sites. Another reason for higher dehydrogenase enzyme activity could be the presence of abundant and permanent vegetal cover in this site providing favourable microclimatic conditions for larger microbial growth and accumulation of more enzymes on this forest soil. Tiwari et al. (2002) have reported higher dehydrogenase activity in an undisturbed forest site in comparison to a degraded site and a slightly degraded site in humid tropical regions of north-eastern India. However, the decline in the dehydrogenase activity of the degraded site might be due to the absence of a permanent vegetation to provide litter on the forest soil which led to poor growth of microbial population and lower enzyme accumulation. The lower amount of organic C and inhibitory effect of acidic pH might be another reason for reduced dehydrogenase activity in degraded site despite its positive correlation with organic C at surface soil layer. However, there was a positive correlation between dehydrogenase activity with organic C and soil pH ($P<0.05$). This suggests a long term detrimental effect of shifting cultivation practice on dehydrogenase enzyme activity. The moderately degraded site also showed lower dehydrogenase activity in comparison to the undegraded site at both soil depths. This might be due to presence of lower organic matter in terms of litter accumulation on the forest floor since cleaning and burning of litter were continuously practiced along with selective logging in this site leading to destruction of...
micro-environmental conditions for microbial growth, thus lower population of soil microorganisms and lesser enzyme accumulation.

Acid phosphatase activity in soils of the three study sites showed an increasing trend with decrease in soil disturbance at both the surface and subsurface soil layers. The undegraded site supported maximum phosphatase activity followed by moderately degraded site and minimum was recorded from the degraded site for both soil layers. The reason for higher phosphatase activity in the undegraded forest site might be due to presence of a permanent vegetation producing higher soil organic matter and creating a favourable micro-environment of soil microorganisms to grow and multiply rapidly for greater enzyme accumulation. Dinesh et al. (1998) also reported similar results with higher acid phosphatase activity in soils with higher organic matter content. There was a significant ($P<0.05$) positive correlation between the available phosphatase activity and other soil characteristics like, soil pH, organic C, total N and microbial N contents which reveals that acid phosphatase activity depends on these soil characteristics. Trasar-Cepeda and Gill-Sotres (1987) also reported higher activity of phosphatase soil enzyme in soils having higher organic matter contents. Acid phosphatase activity also varied significantly ($P<0.05$) with the seasonal climatic regimes. Generally, higher acid phosphatase activity occurred during the intervening periods of winter and spring seasons (January-March) and between late rainy season and early winter season (August-September) revealing an increase in phosphatase activity with increase in soil moisture at the beginning of spring seasons when there was an increase in soil moisture and
before decline in moisture with the onset of winter dry season. However, no positive correlation was found between acid phosphatase activity and soil moisture content, rather there was a significant \((P<0.05)\) negative correlation with soil moisture in degraded and moderately degraded sites at surface soil layer. This showed that moisture content of the soils might have inhibitory impact on acid phosphatase activity since its activity declined when the soil moisture was higher during peak rainy season and further its activity declined when the soil moisture is lowest during winter period. Higher acid phosphatase activity was also reported during spring-summer season from pineapple orchard soil of north-eastern India (Tiwari, 1988 and Tiwari, S.C. \textit{et al.}, 1989ab). There was a decline in acid phosphatase activity with the increase in soil depth of the degraded, moderately degraded and undegraded sites. The main reason of this decline in acid phosphatase activity could be due to the decline in soil organic matter and other nutrients required by soil microorganisms and subsequent decline in soil enzyme concentration with the increase in soil depth from surface to subsurface soil layer.

Soil urease activity also declined from its highest activity recorded from the undegraded site to the lowest in the degraded site whereas the moderately degraded site was recorded with an intermediate urease activity. There was a significant variation \((P<0.05)\) in urease activity among the three sites and between the degraded and undegraded sites at surface soil layer only (Table 6.1). However, the variation was insignificant between the degraded and moderately degraded sites and between the moderately degraded and undegraded sites at surface and subsurface soil layers.
Generally, higher urease activity was recorded from the undegraded site and it was followed by moderately degraded, and undegraded sites at both soil layers. The decline in urease activity in degraded and moderately degraded sites could be due to strong acidic reaction of the soil as revealed by its significant negative correlation ($P<0.05$) with the soil pH at the surface layer. However, undegraded site showed significant ($P<0.05$) positive correlation with the soil pH at surface soil layers revealing that available urease activity in these sites was controlled by favourable soil reaction in presence of higher soil organic matter. These findings in the present study suggests that shifting cultivation practice and selective logging of forest trees did not have highly significant impact on urease activity of the soils. However, variation in site and vegetal cover distribution might have been responsible for variation in urease activities among the three study sites. Pancholi and Rice (1973) reported higher urease activity related to type of vegetation and the quality of incorporated organic materials in the soil. Similarly, Palma and Conti (1990) also reported significant variation in distribution of urease activity in grassland and forest soils revealing direct relationship between pattern of urease activity to the type of vegetation and impact of organic matter. These reports are in conformity with the present findings that undegraded forest site with a permanent vegetal cover distribution with different tree species and year round accumulation of litter on the forest floor supported higher urease activity than the selectively logged forest and shifting cultivated forest sites. There was significant ($P<0.05$) variation in distribution of urease activity with the change in seasonal climate (Fig. 5.3). However, no significant variation
was observed between the surface and subsurface soil layers of the degraded and undegraded forest sites though moderately degraded site had shown significant \((P<0.05)\) variation of urease activity between the two soil layers in the present study (Table 6.2).

8.5. **Evaluation of forest soil degradation types by using stepwise discriminant function analysis (DFA)**

The data of all variables under physico-chemical, biological and biochemical characteristics were used for determining forest soil degradation types by using discriminant function analysis (DFA) as a statistical tool. The analysis resulted two important canonical discriminant functions (CDFs) which together contributes 100% variation in the sites.

CDF1 with organic C as the only important discriminating variable could differentiate upto 85.88% the forest soil degradation types between degraded, moderately degraded and undegraded sites. The CDF2 comprised of six variables of various soil characteristics namely, bulk density, microbial biomass C, dehydrogenase activity, total N, soil pH and soil temperature. This CDF2 had a maximum contribution of 14.12% in group variation. The structure matrix of the two CDFs in the table 7.4 depicted the largest absolute correlation of the respective variable to its function revealing the best discriminating property of these variables for soil degradation types. Organic C was the only variable in CDF1 with largest absolute positive correlation \((r=0.5024)\). Similarly, bulk density of the CDF2 had the largest absolute positive correlation \((r=0.6592)\) over the other variavles.

The selection of CDF1 as the most important function in discriminating the soil degradation types was due to the largest Eigenvalue and other
characteristics (Table 7.3). The significance level of the two functions reveals that CDF1 with maximum Chi-square value (348.773, 14 df) was more significant ($P < 0.000$) than the CDF2 which had lower Chi-square value.

Organic C content of the soils in the degraded, moderately degraded and undegraded forest sites was found as the only variable from the CDF1 which had contributed to a maximum of 85.88 % variance of soil degradation types and highest within-groups positive canonical correlation (0.502) in the present study. This suggests that stepwise DFA provide a much better classification of the soil degradation type among the three study sites based on the two discriminant functions, CDF1 and CDF2 as compared to the other visual site characteristics. It is clear from this analysis that the soil in each of the study sites differ significantly ($P \leq 0.05$) in terms of a gradient in organic C content or organic matter in the soils. Maximum organic C content in undegraded forest site varied towards a minimum organic C content in the degraded site through an intermediate value of organic C in the moderately degraded site.

Bulk density with a maximum canonical correlation value of 0.659 was the most significant variable in CDF 2 which had contributed maximum percentage in discriminating the soil degradation types of the three study sites. The average bulk density varied significantly between the three study sites where highest value was recorded from the degraded site followed by moderately degraded site and lowest bulk density was recorded from the undegraded site. This pattern of variation in bulk density is in contrast to that of organic C contents where maximum organic C content was undegraded
site followed by moderately degraded site and minimum was recorded from the degraded site.

8.6. Impact of soil degradation on soil characteristics in degraded and moderately degraded forest sites as compared to the undegraded forest site

A comparative analysis of the impact of soil degradation on various soil characteristics, namely physico-chemical, biological and biochemical parameters of degraded and moderately degraded sites revealed marked decline in these soil characteristics in terms of percentage as compared to the undegraded site (Fig.8.1). Most of the soil characteristics showed decline in their values with the increase in soil degradation from undegraded site to degraded site. However, a few soil physical characteristics namely, soil temperature was found to be increased by 3% with the increase in soil degradation in degraded site whereas bulk density was found increased by 27% in degraded site and 10% in moderately degraded site as a consequence of soil degradation through shifting cultivation and selective logging practices in this sites as compared to the undegraded site.

The magnitude of decline in the values of soil characteristics in terms of percentage ranged from a minimum of –2% for soil temperature to a maximum of -37% for fungal population in the moderately degraded site as compared to the undegraded site. In case of the degraded site, the percentage decline was ranged from a minimum of –6.9% for pH to a maximum of -59% for bacterial population as compared to the undegraded site. Among the physico-chemical characteristics of soil, organic C, total N and ammonium-N were found to be declined by –40%, 44% and –44% in the
degraded site revealing most pronounced impact of soil disturbance on these soil chemical characteristics against the undegraded site. Similarly, among the biological and biochemical characteristics particularly bacterial population, microbial biomass C, microbial biomass N and dehydrogenase activity were found declined by -59%, -56%, -54% and 50% respectively in the degraded site as compared to the undegraded site. These results suggests that soil degradation has the most pronounced detrimental impact on biological and biochemical characteristics of soil followed by chemical characteristics while the physical characteristics showed least effect of soil degradation. Thus, it may be suggested that the biological and biochemical characteristics are more sensitive and responsive to the soil disturbance due to shifting cultivation and selective logging practices in the humid tropical forests soils of north-eastern India. Therefore, these biological and biochemical characteristics coupled with few important physicochemical characteristics may be used to identify the status of soil degradation in this region in particular and other soils in general.
Fig. 8.1. Percentage reduction of physico-chemical, biological and biochemical characteristics of degraded (DF) and moderately degraded (MDF) forest sites as compared to undegraded (UDF) forest site.

(Note: ST=soil temperature, SM=soil moisture, BD=bulk density, WHC=water holding capacity, C= organic carbon, N=total nitrogen, P=total phosphorus, AN=ammonium, N, NN=nitrate-N, SR=soil respiration, BP=bacterial population, FP=fungal population, Cmic=micr trapella biomass C, Nmic=micr trapella biomass N, DHA=dehydrogenase activity, PA= acid phosphatase activity, UA=urease activity)