Chapter – 5

DISCUSSIONS

Emphasis on sustainable agriculture especially for the tribal communities residing in the fragile Himalayan region has generated interest. Repeated perturbation affects the soil fertility and it becomes significant for knowing the impacts of biological factors on organic matter buildup. Earthworms and microorganisms play a vital role in this regard. Soil microbial biomass is a source and sink of nutrients, and affect of biological factors and changes in the microbial biomass can be used to predict the effects of ecosystem perturbations (Jenkinson and Powlson 1976; Jenkinson 1988; Diaz-Ravina et al., 1988; Hernot and Robertson 1994). The present chapter attempts to discuss the results recorded during the course of the study at Dimoria, Assam.

The results recorded through seventeen experiments during the course of the entire research study are elaborately discussed in this chapter under the following four major heads:

5.1 Vegetation and Biological Factors in Jhum fields
5.2 Soil Nutrient Dynamics in Jhum fields
5.3 Biological Factors during Jhum Redevelopment
5.4 GIS and Soil fertility Management
5.1 VEGETATION AND BIOLOGICAL FACTORS IN JHUM FIELDS

5.1.1 Vegetation in Jhum Fields

The study revealed that *Schima wallichii, Dillenia indica, Bambusa tulda* and *Litsea chinensis* are the predominant trees in 8-yr cycle jhum fields while *Bambusa tulda* is predominant in 4-yr cycle jhum fields. The most abundant shrub in 4-yr as well as 8-yr cycle jhum fields is *Lantana camara* while in addition *Musa spp.* and *Trema amboinensis* exist in 8-yr cycle jhum fields. The common abundant herbs in 4-yr and 8-yr cycle jhum fields is *Eupatorium odoratum*. Interestingly *Mikania micrantha* a climber is abundant in both the jhum fields. The abundant grass species in 4-yr cycle fields include *Napier spp.*, *Pteris spp.*, *Thysanolaena maxima* and *Erianthus longisetosus* whereas *Bambusa tulda, Pteris spp, Napier spp., Thysanolaena maxima* and *Erianthus longisetosus* are the common grass in the 8-yr cycle jhum fields.

While on the sacred forest *Terminalia bohera, Canarium strictum* and *Bombyx ceiba* are the dominant trees and the co-dominant trees include *Schima wallichii, Michelia champaka, Ficus benghalensis, Toona ciliata* and *Gmelina arborea*. Predominant trees include *Artocarpus sama, Artocarpus heterophyllus, Terminalia chebula, Lagerstroemia spp., Ficus glomerata, Ficus religiosa, Dillenia indica* and *Litsea chinensis*.

The clear differences in vegetation community perhaps might be due to rapid washout of nutrients from the jhum fields due to heavy rains and disturbed seed
banks due to repeated perturbations in the jhum fields. The present results are in line with Ramakrishnan (1988) who reported that after clear-cutting of the forest, natural recovery processes on steep slopes are retarded because of rapid wash-out of the top soil and nutrients, so that these grasslands are often maintained in an arrested state. Dell Castillo (2008), Vieira (2007), Kammesheidt (1999) and Finegan (1996) reported that vegetation recovery trajectory in clearings formed following suspension of cultivation were existing seed bank disturbance, presence of resprouters, and poor seed dispersal rates from surrounding forests. Studies on shifting cultivation by Uhl (1987), Raman et al. (1988) and Toky & Ramakrishnan (1983(a)) also reported that succession of pioneer vegetation following suspension of cultivation occurred rapidly in the early stages of regeneration, followed by delayed recovery of woody biomass.

The present status of community structure with decline in species diversity might be due to increase in number of cultivation cycles. Perhaps the number of years of cultivation as well as number of cultivation cycles has an important role to play in the recovery process. The study is in line with Lawrence (2004) and Uhl (1987). Vegetation parameters such as canopy cover, tree species richness, percentage of forest species in regeneration, and biomass were considerably higher in plots cultivated for three years in comparison with sites cultivated continuously for six years (Uhl, 1987). Lawrence (2004) reported that species density and evenness declined considerably with the increase in number of cultivation cycles in shifting cultivation successional sites in Indonesia. Factors such as harsh microclimatic
conditions in clearings, competition with existing vegetation, lack of soil nutrients
due to several years of cultivation, and high rates of seed predation and seedling
herbivory further impeded plant regeneration (Uhl, 1987; Ingle, 2003; Aid and
Cavelier, 1994; Hammond, 1995). The vegetation recovery period was also affected
by the crop cultivated: fields abandoned after cultivation of rice recovered tree
species diversity faster than fields cultivated with poppy Fukusima et al. (2008).

Lack of continuous natural forest adjacent to jhum fields at Dimoria might be
one reason for less diverse vegetation in the jhum fields. Karthik et al. (2009) in their
review concluded that community recovery can be expected to be accelerated when
relatively large forest tracts adjoin a shifting cultivation landscape, in comparison
with recovery in sites with shorter fallow cycles in the absence of contiguous forests,
reported from Bolivia that fallows adjoining tropical dry forests accumulated 75
percent of mature forest species within five years of active cultivation, although basal
area was comparable with that in mature forests only in 50-year old fallows.

In our present study arrested succession where weed species were not
succeeded by pioneer woody species was prominent in the 4-yr cycle jhum fields and
to some extent in 8-yr cycle jhum fields perhaps due to short fallow period. It might
indicate to the fact that over time seed banks of these weed species have gradually
replaced the original soil seed bank. The findings are in line with Raman et al.
(1998), Rao & Ramakrishnan (1989) and Saxena and Ramakrishnan (1984). They reported arrested succession in fallow cycles as short as 4 - 5 years in northeast India.

Another important finding is predominance of *Bambusa tulda* in 4-yr as well as 8-yr jhum fallows. Bamboo perhaps might have facilitated soil-nutrient recovery. The study is in line with Raman *et al.* (1998), Rao & Ramakrishnan (1989), however they reported bamboo as early colonizer in 10 yr jhum fallows. Other predominant species like *Schima wallichii, Dillenia indica* and *Litsea chinensis* in 8-yr cycle jhum fields might be due to gradual rebuilding of microhabitats especially by bamboo, *Mikania micrantha* and subsequent seed dispersal over time from the forest area. However, early colonizers such as bamboo, with relatively faster growth rates in comparison with woody tree species, may have facilitated soil-nutrient recovery and provided microhabitats for regeneration of shade-loving species.

Plants’ ability to create, maintain and exploit spatial heterogeneity may be a factor affecting species succession (Stark, 1994) and the establishment and survival of seedlings (Huante *et al.*, 1995; Lawrence, 2003).

5.1.2 *Earthworms in Jhum Fields*

Earthworms present in the jhum fields is one of the important biological factors that influences recycling of nutrients. It speeds up breaking down of organic resides in the jhum fields and brings back nutrients back into the pool as indicated by the results taken during jhum development phase. Lavelle (1988) and Six *et al.*
(1998) made similar reports stating that earthworms may speed up the initial breakdown of organic residues. In addition several studies have also indicated that earthworms may also stabilize soil organic matter through its incorporation and protection in their casts (Martin 1991, Gugenberger et al., 1996, Bossuyt & Hendrix, 2005, Pulleman et al., 2005).

Earthworm casts are enriched in organic C and N, exceeding the C and N contents of the non ingested soil by a factor of 1.5, and 1.3, respectively. Lal (1999) and Sechu (2003) reported that supply of nutrients is done mainly by earthworms largely through their burrowing activities by producing aggregates and pores on the soil surface, thus affects soil physical properties, nutrient cycling, and plant growth. Coq et al. (2007) reported that earthworms affect important soil ecological processes where they concentrate nutrients and resources that are further exploited by soil microorganism communities (Scheu, 1987). The activity of endogeic earthworms in the humid tropical environment accelerates initial soil organic matter turnover through indirect effects on soil C as determinants of microbial activity. Kale (2008) reported that due to selective foraging of organic particles, gut contents of earthworms are often enriched in organic matter, nutrients, and water compared with bulk soil and can foster high levels of microbial activity. The study also reported to enhance mineralization by first fragmenting SOM and then mixing it together with mineral particles and microorganisms, and thereby creating new surfaces of contact between SOM and microorganisms (Parmele et al., 1998). In the short term, a more
significant effect is the concentration of large quantities of nutrients (N, P, K, and Ca) that are easily assimilable by plants in fresh cast depositions (Bhadauria and Ramakrishnan, 1989). Most of these nutrients are derived from earthworm urine and mucus (Barrios and Lavelle, 1986). In highly leached soils of humid tropics, earthworm activity is beneficial because of rapid incorporation of the detritus into the soils (Bhadauria and Ramakrishnan, 1999). In addition to this mixing effect, mucus production associated with water excretion in the earthworm gut is known to enhance the activity of microorganisms.

Although earthworms may speed up the initial breakdown of organic residues (Lavelle, 1988 and Six et al. 1998), several studies have indicated that they may also stabilize soil organic matter through its incorporation and protection in their casts (Martin, 1991; Gugenberger et al., 1996; Bossuyt and Hendirx, 2005; Pulleman et al., 2005).

The study revealed presence of 5 to 6 species of earthworm in the jhum fields namely *Eutypheous assamensis*, *E. gigas*, *E. comillahnus* *E. gammiei*, *Kanchuria sumerianus* and *Pontoscolex corethrurus* in contrast to nine species of earthworms namely *Dichogaster bolau*, *D. affinis*, *Eisenia foetida*, *Eutypheous assamensis*, *E. comillahnus*, *E. gammiei*, *E. gigas*, *Kanchuria sumerianus* and *Metaphire houlleti* in the reference site. The species of these earthworms composing both indigenous and exotic has been previously reported for Assam, Meghalaya, Arunachal Pradesh, Mizoram and Tripura (Gates, 1972; Julka, 1988; Chaudhury et al., 2008).
Species diversity of earthworm ranged from 1 to 15 species, and most earthworm communities including those of tropical rain forest had around 3 to 6 species (Fragoso & Lavelle, 1992). The earthworm species diversity recorded during the present study in the jhum fields and the reference site (sacred forest) is well within this reported range. However differences of earthworm diversity in the jhum fields and the reference site points to the fact that heterogeneity in the environment affects earthworm diversity as has been shown by Fragoso & Lavelle (1987) in their study in the forests of Mexico. In spite of frequent disturbances in 4-yr cycle jhum than 8-yr cycle jhum, occurrences of similar earthworm species diversity indicates to the fact that original earthworm communities are retained in jhum cultivation and growth of common species during jhum abandonment period perhaps provide conducive physical habitat and trophic resource for good earthworm activity. Goswami and Sarma (2006) reported strong relationships between earthworms and *Mikania micrantha* in the abandoned jhum fields of Dimoria.

Of the earthworm species *Pontoscolex corethrurus* was recorded only in 4-yr jhum, 8-yr cycle jhum fields. This is the most common Brazilian species of earthworm that occurs throughout the world (Gates, 1972). This species has also been reported in areas from other northeastern states of India where anthropogenic interferences like forest clearing have been done. Dispersal of *Pontoscolex corethrurus* through *Hevea brasiliensis* plants from Brazil to different parts of the world is quite possible (Chaudhury *et al.*, 2008) and existence of *Hevea* plantation in
places of Dimoria close to jhum fields perhaps favoured dispersal of this species in the jhum fields which are exposed to perturbation repeatedly. Fragoso et al. (1999) reported that outstanding abilities to colonize by efficient assimilation of low-quality soil organic matter could explain wider distribution of exotic earthworm species and absence of native species in other regions. Sinha et al. (2003) during their study in Garhwal Himalayas found that functional guild diversity of earthworm is lower in agroecosystems with homogeneous ecological niches, compared to forest ecosystems. Texture, nutrient status and moisture condition of soil probably determine functional categories of earthworms (Chaudhury et al., 2008).

The soils of the 4-yr and 8-yr cycle jhum fields at Dimoria are acidic and that might be the reason for low density of earthworms in these perturbed agroecosystems since earthworms are neutrophilic (Lee, 1985). Similar results have been reported by Chaudhury et al. (2008) from rubber plantation of Tripura. Shakir & Dindal (1997) reported that population density of earthworms is positively correlated with pH and negatively correlated with species diversity. Native earthworm mainly Eutyphoeus assamensis showed narrow edaphic and ecological tolerances in contrast to exotic peregrine worms like Pontoscolex corethrurus which are adapted to a wide range of environmental conditions.

Increased biomass of Pontoscolex corethrurus might be linked to Mikania micrantha, which quickly covers the jhum fields at Dimoria during abandonment (Goswami & Sarma, 2007) and this vegetation perhaps favours Pontoscolex
corethrurus over other earthworm species. It is also interesting that very less occurrence of Mikania spp. in the sacred forest might be the reason why Pontoscolex corethrurus has not been recorded from soils of the sacred forest. Sarlo (2006) has also reported individual tree effect on P. corethrurus over other species. On the other hand increased biomass of Eisenia foetida in the sacred forest indicates favourable leaf litter of tree species for this species that occurs in the forest. Earthworm biomass in the sacred forest is significant from that of the jhum fields. Gilot et al. (1995) also reported that earthworms become abundant, with a biomass comparable to that in the original forest and high microbial activity when anthropogenic disturbances are minimized with increase in the age of rubber plantation. Low density and biomass of other earthworm species indicates that they are less aggregated and more uniformly distributed in the plantation floor. Presence of rare occurrence species like Kanchuria sumerianus, Eutychoeus gigas and E. comillahnus indicates rich biodiversity of earthworms in the jhum fields of Dimoria.

5.1.3 Microbes in Jhum Fields

The present study revealed presence of 8 and 11 species of fungus in the 4-yr and 8-yr cycle jhum fields and 17 species in the sacred forest. Alternaria, Aspergillus, Botrytis, Mucor, Penicillium and Rhizopus were the six common genera present in all the three different soils. In addition, members from genus Trichoderma was found in 8-yr cycle jhum fields and the reference site. Four additional genera namely Absida, Curvularia, Deightoneilla and Syncephalus were recorded only in
the soils of the reference site. Interestingly one genus i.e. *Geotrichum* was recorded only in the 4-yr cycle jhum fields.

The study also revealed 8 species of bacteria in 4-yr old jhum site, 9 species in 8-year old jhum, and 13 species in the reference site. Species of *Actinobacteria*, *Azotobacter*, *Bacillus*, *Beijerinckia*, *Calothrix*, *Klebsiella* and *Myxococcus* were recorded in 4-yr jhum, 8-yr jhum as well as the reference site. Species of *Pseudomonas* was recorded in 8-yr jhum as well the reference site. In addition four additional genera namely *Chroococcus*, *Cytophagales*, *Glococapsa* and *Staphylococeus* were recorded only in the soils from the reference site.

Similar species diversity has been reported by Tangjang *et al.* (2009). The reference site (sacred forest) has higher organic matter, which in the presence of adequate moisture supply is acted upon by the microorganisms to decompose the complex organic residues into simpler forms; hence, microbial counts are higher on the soils of the reference site. Shamir and Steinberger (2007) during their study also reported that due to higher organic matter content on the top soils microbes are generally higher.

Significantly lesser fungal diversity in the jhum fields perhaps might be due to highly acidic soils in the jhum fields. Ayanaba and Oyamuli, (1975) have reported that acidity significantly influences microorganisms abundance and diversity in soils. Kennedy *et al.* (2005) also reported that distribution of soil microbial population is
determined by a number of environmental factors like pH, moisture content and soil organic matter.

Throughout the decay process as quality of the substrate changes there are changes in the community structure of the microorganisms and their activity in holorganic layers.

Fungal colonies in the present study gradually increased after March and it reached its peak during September during the autumn season. Fungal colonies decreased after September and continued to decrease and minimum colonies are recorded during December i.e. the cold and dry months of the year. This trend has been observed in 4-yr, 8-yr cycle jhum fields and the reference site. The present study is supported by the works of Arunachalam et al. (1997). They also reported higher fungal population during autumn. The increased fungal population during this season might be due to the prevailing favorable moisture and temperature setting and also that leaf litter and other plant residues are decomposed faster during rainy season and sufficient soil organic matter and humus accumulates that may have enhanced the colonization of the soil microbes in subsequent period.

During the present study there was a gradual increase in bacterial population in 4-yr cycle jhum, 8-yr cycle jhum and reference site from winters to rainy season and peak bacterial population was maintained from June to September in the reference site whereas the maximum bacterial population in 4-yr and 8-yr cycle jhum
fields was recorded from June to August. Least number of bacterial colonies in all the sites was recorded in December i.e. dry and cold winter. Tangjiang (2009) also reported peak in bacterial population during rainy season. Bacterial population peak might be due to favorable soil moisture and temperature conditions and decomposition. On the other hand, minimum bacterial population during winters in the present study may be due to low ambient temperature and higher physiological water stress which enhances growth and activity of microbes.

During sowing i.e. just after burning as species microbial activity is supposed to be depressed by moisture stress and as rains starts its population increases. Similarly during winters its population supposed to be depressed with low temperature. The finding is in the line with that reported by Kubartova et al (2007). Berg and McClaugherty (2003) also reported seasonal changes in soil microorganism reflecting temperature and moisture conditions.

During the present study occurrence of Alternaria, Aspergillus, Botrytis, Mucor, Penicillium and Rhizopus perhaps is due to higher spore production and dispersal and might be partly due to their resistance over perturbations (Schimel, 1995). The fungal species richness recorded in the present study was lower than those reported from subtropical humid forest soils in north-east India (Arunachalam et al., 1997) and 26, 21 and 27 species, respectively from soils of valley land, terrace and slopes in this region (Shukla and Mishra, 1992), 41 fungal species isolated from South Dakota grassland soil (Dennis and Christensen, 1981). Another important
result is that few dominant species are present. Jha et al. (1992) pointed out that for a given community, only a few species are numerically predominant and may strongly affect the environmental conditions for the other.

Entry and Emmingham (1996) reported that type of vegetation affects change in fungal population. Bossio et al. (2005) reported that variation in microbes is due to physico-chemical characteristics of the soil and environmental complex of the locality. Low bacterial and fungal population during the present study is perhaps due to lesser availability of nutrients in the soils and higher microbial counts in the reference site might be due to abundant organic matter in the soil. Chung et al. (2007) have also recorded a correlation between fungal species composition and the species composition of the aboveground vegetation.

5.1.4 Economic Yield of Crops in Jhum Fields

During the present study the primary productivity from the jhum fields has been presented in terms of economic value. The main grain and seed crops in the jhum fields are *Oryza sativa*, *Sesamum indicum*, *Setaria italica* and *Zea mays*. Leafy and fruit vegetables cultivated in the jhum fields included *Benincasa hispida*, *Cucumis melo*, *Cucumis sativus*, *Lagenaria vulgaris*, *Luffa cylindrica* and *Momordica charantia*. Tuber and rhizomes cultivated in the jhum fields included *Amorphophalus complanatus*, *Colocasia antiquorum*, *Curcuma amada*, *Dioscorea globosa*, *Manihot esculenta*, *Typhonium trilobatum*, *Zingiber officinalis* and *Zingiber*
Only one medicinal plant species i.e. *Andrographis paniculata* were cultivated in the jhum fields.

Productivity in 4-yr and 8-yr cycle jhum fields were statistically on a par perhaps due to addition of almost similar quantities of nutrients through slashing and burning. In addition, Tawnenga (1990) reported addition of more nutrients in old than young field in the first year, due to better standing crop in former than latter. Since added nutrients remain on soil surface, they are vulnerable to loss in runoff and leaching under the influence of high rainfall (Ramakrishnan *et al* 1981; Pandey *et al* 1993).

Tawnega *et al* (1996) reported that added nutrients though enhanced productivity during first year, an appreciable proportion of them might have been lost through outflowing water. This could impoverish the soil and hamper the yield, particularly in old field. Ecosystem productivity though increased consequent to fertilizer application both in young and old fields, the per cent increase in young field was almost twice that of old field. This result indicates that the young field exhibits greater fertilizer use efficiency. In other words, productivity in young field is primarily limited by nutrient deficiency.

The economic yield (food production) during the present study was only marginally higher in 8-yr cycle jhum fields than 4-yr cycle jhum fields indicating that greater nutrient addition to soil through slash-and-burn in old field is not essentially channeled to greater seed set. The results are in line with Tawnega *et al* (1996).
Grain and seed crops covered 70% of the total jhum fields followed by tuber and rhizome which covered 25% of the total jhum fields. Leaf and fruit vegetables covered 4.5% of the jhum fields and medicinal plants are cultivated on the remaining 0.5% of the jhum fields. Yields of cultivated crops are not significantly variable within the jhum fields however the values were significant between 8-yr and 4-yr old jhum field. The composition recorded during the present study reveals the fact that farmers’ utilize their jhum land in such a way so as to minimize their risks and also maintains the agri biodiversity.

Rice yield under jhum cultivation from north-eastern India is highly variable, from as low as 190 kg ha\(^{-1}\) (Borthakur et al., 1978) to as high as 1200 kg ha\(^{-1}\) (Misra 1976). In another study on rice yield at low elevation in Meghalaya under different land use, Sahu (1978) obtained yearly outputs of 853 kg ha\(^{-1}\) under jhum, 738 kg ha\(^{-1}\) under terrace, and 3428 kg ha\(^{-1}\) under valley cultivation. The rice grain productivity recorded during the present study was much lower than what reported from other jhum cultivated area. It might be due to the fact that much of the nutrients gets leached with heavy rains. Because of low grain yield the farmers practice mixed cropping, and maximise economic yield by diversifying cropping and also increasing leafy and tuberous crops with shortening in jhum cycle. Similar findings have been reported from jhum fields of Meghalaya by Toky and Ramakrishnan (1981).
5.2 SOIL NUTRIENT DYNAMICS IN JHUM FIELDS

The results obtained through ten different experiments on soil physical, chemical, nutrients and biological factors in 4-yr cycle jhum, 8-yr cycle jhum fields and a reference site are furnished and elaborately described under the following subheadings.

5.2.1: Soil Nutrient Dynamics

The impact of secondary vegetation on soil fertility is the basis of shifting cultivation in the tropics (Nye and Greenland 1960; Brown and Lugo 1990; Dockersmith et al., 1999). During slash and burn micro-environmental changes in the fields due to increased isolation takes place and there are changes in soil physico chemical properties. Even the atmospheric and surface soil temperature conditions are also altered significantly due to clear cutting of the forest. These changes along with other changes in soil chemistry get accentuated after a low or high intensity burn before cultivation of the site (Toky and Ramakrishnan, 1981).

During the present study at Dimoria the bulk density of soils from jhum fields varied between 1.49 g cm\(^{-3}\) and 1.53 g cm\(^{-3}\). The soils of the jhum fields were bulkier than the soils from the reference site indicating that movements during jhum cultivation compact the soils and makes it bulkier.

Soil hydraulic properties exhibiting water stress situations like lesser soil moisture, lesser water holding capacity, less available water, higher soil temperature,
in the 4-yr cycle and 8-yr cycle jhum fields than the reference site during the present study indicates changes in the soil hydrology due to repeated perturbations. Perhaps regular perturbation as seen in the jhum fields facilitates loss of water from the soil. However, further studies are required in this field to prove this hypothesis.

Juo et al. (1995) reported that when forest land was cleared there was no change in soil pH, at least until 13 years of bush regrowth. Increase in the pH during the present study after burning and subsequent monsoon rains indicated a relatively greater production of organic acids during microbial decomposition. The findings are ascertained from the greater populations of bacteria and fungi, and higher microbial activity, in the reference site.

Toky and Ramakrishnan (1981) reported that in short jhum cycle of 5 years, burn is of low intensity since quantity of slash is much less, and therefore the surface soil humus is less affected. It may be noted here that the site under longer jhum cycles start with higher carbon and high intensity fire depletes it rapidly in the top soil. The depletion of organic matter depends upon the intensity of cropping, type of fallow vegetation and the ratio of cropping to fallow period. With optimum cropping and fallow period, the humus in the soil could be maintained at a relatively high level even after many years of shifting cultivation.

In the present study after burning the soil became less acidic. Roder et al. (1993) also reported similar findings from Bhutan. Average soil organic C and soil N
losses were 10 and 0.36 MT ha\(^{-1}\), respectively. Proportionally higher C losses resulted in a lower C:N ratio. The values for total P increased in all soils. This increase can only partly be attributed to the loss of soil mass (organic matter) and to P additions from plant and blue pine biomass. The bulk of the increase observed in total P is due to decomposition of the leaves of other species.

In the present study nitrification after the burn was accelerated probably as a result of microbial activity, due to rise in pH and temperature of the surface soil. The present finding is in line with Mellilo (1977). Increase in nitrification after clear cutting of forests due to the removal of chemical inhibitors has also been attributed by some workers. The level of NH\(^{+4}\)-N in the soils declined rapidly perhaps due to its removal by runoff and also due to absorption by fast growing crops species. Similarly the level of NO\(^{-3}\)-N in the soils declined because of leaching due to surface runoff and due to absorption by crops species. The decline in nitrogen level upto 3 year during revegetation of the fallow could perhaps be due to low litter production and also due to rapid utilization of nitrogen by the fast growing plant species. Organic carbon in the soil in general remained low due to its faster rate of mineralization. Only a fraction of the organic matter gets incorporated into the soil and this accounts for the low C/N ratio during all phases of jhum cycle.

During clearing the carbon pool of the above ground biomass is most vulnerable to loss as reported by Toky & Ramakrishnan (1983a,b) in their studies on secondary succession following slash and burning in Meghalaya, Kauffman \textit{et al.}
(1994) in Brazil when Amazonian forest was cleared to pasture lands, Prasad et al. (2001) during their studies from Rampa Forest, Eastern Ghats.

The decrease in the soil organic carbon level in jhum fields probably resulted from a combination of increased decomposition of soil organic matter because of soil disturbances during forest clearance and an increased soil temperature due to reduced shading. The findings are in line with (Raich 1983; Eden et al., 1991; Arunachalam et al., 1999). Decrease in soil organic carbon due to low input of organic material when the regrowth was still low (Aweto, 1981), and erosion of topsoil (Nye and Greenland, 1964). Vegetation regrowth up to the 16-year-old stage only led to a doubling of soil organic carbon (Arunachalam et al., 1999). The low soil organic carbon level during the present study coincided with a lower level of litter production. The present findings are in line with Arunachalam et al. (1998). Further reduction of soil organic matter from slashing to sowing in the jhum fields indicates its utilization by growing crops and its gradual increase after crop harvesting indicates accumulation of leaf litter on the jhum floor. The finding is further supported by the works of Tangjang et al. (2009).

Saxena and Ramakrishnan (1986) reported that the relationship between soil organic carbon and total Kjeldhal N of sandy laterite soils may not be always a linear one, as the rates of N transformations may be quite rapid. In the present study positive correlation of soil organic carbon and total nitrogen indicated that the relationship between total nitrogen and soil organic carbon was stabilizing during
succession, and that the conversion of total nitrogen into ammonium and nitrate was slowly progressing compared to dynamic agricultural systems (Juo et al., 1995). This was further supported by a positive correlation between total nitrogen and inorganic-\textit{N} (ammonium and nitrate).

There was increase in available phosphorus after burning. The rapid build up of available phosphorus level after the burn could perhaps be due to its release from the ash after rainfall and decrease in soil acidity and the subsequent increase in microbial activity which might have resulted in rapid mineralization of the residual humus. The sharp decline in available phosphorus after the cropping is perhaps due to rapid absorption of this available phosphorus by crops and also some removal by surface runoff when the plant cover is still developing. On the other hand accumulation of phosphorus, in the surface layers of the reference site might be due to transfer of phosphorus from the deeper layers of the soil to the upper stratum through litter fall. Ramakrishnan \textit{et al.} (1981); Ramakrishnan and Toky (1981) also reported similar findings while working in the shifting cultivated hills of Meghalaya.

The present study also reported quick release of cations after the burn on the surface layer of the soil in the 4-yr and 8-yr jhum fields with a high level being maintained even in a fallow that is three year old, after cropping. Similar findings upto one year old have been reported by Toky and Ramakrishnan (1981).
The amount of calcium and potassium released in the jhum fields might be due to high accumulation of these nutrients in bamboo. Toky and Ramakrishnan (1981) reported that bamboo is a heavy accumulator of potassium. Predominance of bamboo in jhum fields left abandoned perhaps releases this nutrient after the slashes are burnt. Although the difference between 4-yr cycle and 8-yr cycle jhum fields might be due to accumulation of more slashing materials in the 8-yr cycle jhum fields than the 4-yr cycle jhum fields. Decline in level of cation was perhaps due the ashes being blown out from the fields by winds. Blair (2005) in a study found reduction in P, N, K and Ca due to burning in a tropical wet forest patch. Toky and Ramakrishnan (1981) reported that the level of cations in the soil after a year of cropping, under a 30 year jhum cycle, was much higher than the level at any time under 5 year cycles. The exchangeable cations get depleted from the top soil as the forest fallow develops due to the rapid absorption by the developing vegetation and also due to losses due to surface runoff and percolation.

Valentine (1976) reported that the level of exchangeable potassium, calcium and magnesium declined rapidly in the first 7 years after the regeneration burn, which may be due to transfer from the soil pool to the living biomass. As the age of the jhum fallow increased, beyond 10 years, soil cationic level and particularly that of potassium increased due to faster return of nutrients into the soil through litter fall from a mature stand of vegetation containing species like *Dendrocalamus hamiltonii* (Toky & Ramakrishnan, 1981).
During the present study, short cycle jhum fields exhibited very low fertility levels in the soil. Apart from this, the low yield of crops under the jhum fields may also be due to poor physical conditions of the soil and perhaps weed problem, nutrient losses through leaching. Poor build up of soil fertility during abandonment for 3 years is understandable as due to short fallow period and depletion of already low level of fertility by the fast developing vegetation. The present findings are in line with Toky & Ramakrishnan (1981). They also reported that recovery of soil fertility is observable only in fallows of 10 years or older.

5.2.2: Soil Microbes and Nutrient Dynamics

During the present study MBC in the soils of the jhum fields was in the range of 347.1 µg g\(^{-1}\) to 874.7 µg g\(^{-1}\) while MBN in the soils of the jhum fields ranged from 31.2 µg g\(^{-1}\) to 19.02 µg g\(^{-1}\). On the other hand in the present study MBC and MBN from the reference site was 1701.1 µg g\(^{-1}\) and 25.3 µg g\(^{-1}\) respectively, which much higher than the jhum fields. The values of MBC estimated were slightly lower than those recorded for most of the other soils studied in the humid subtropics, but were well within the reported range (102 – 2073 µg g\(^{-1}\)) for various temperate and tropical forest soils (Hemot and Robertson 1994). Very dense growth of *Mikani micrantha* and greater accumulation of litter in the 4-yr and 8-yr cycle jhum fields of Dimoria perhaps is the main contributory factors for MBC and MBN. Very higher levels of MBC and MBN has been reported due to accumulation of litter and roots in the soil by (Arunachalam *et al.*, 1996; Maithani *et al.*, 1997), sacred grove and adjoining
ferndominated treeless site, compared to all the other sites, seem to have favoured the growth of the microbial population and accumulation of MBC in these sites (Maithani et al., 1996). Arunachalam et al. (1996) while comparing an undisturbed 22-year-old subtropical pine forest understorey with gaps and tree-cut plots also recorded similar observation.

It was also observed during the present study that MBC and MBN rapidly decreased after burning and it gradually increased by the time crops are harvested. It indicates that during the period of diversified crop cultivation in the jhum fields harvesting is a regular process and therefore there is addition of leaf litter and its decomposition is enhanced during the rainy season. Tripathi et al. (2009) also reported faster litter decomposition during rainy season. Arunachalam (2004) also reported that microbial biomass C increased gradually as cultivation progressed, while microbial biomass N and P showed a post-burn decreasing trend. The results of the present study indicates that cropping may result in temporary pattern homogenization of soil nutrient cycling, but can have drastic effects with continued slashing and burning for long-term agriculture. This argument is in line with Arunachalam (2004). Ralte et al. (2005) also reported significantly greater MBC and MBN in the soils of the undisturbed forest ecosystem than the soils under various land use practices.

The present study also indicated that during the rainy season increased population of earthworms facilitates building of soil aggregates which during the
autumn season is rapidly broken down releasing nutrients to the soil as revealed by higher population of microbes in the soil during autumn season. Holmes and Zak (1994) reported that N availability is primarily controlled by changes in the turnover rate of microbial biomass such that a relatively constant pool is maintained through time. However, Onwonga (2010) in a study on soil fertility management reported that correlations between mineral N and MBN were positive but non-significant at seedling and maturity stages of crop maize growth.

5.3 BIOLOGICAL FACTORS DURING JHUM REDEVELOPMENT

Biological factors play an important role during jhum redevelopment. These factors mainly composed of earthworms and microbes quickly releases the nutrient especially after the rains to the soil from the leaf litter of the fast colonizers. Increase in organic matter in the jhum fields at Dimoria from 5.0% after one year of abandonment to 5.2% after 3 yrs of abandonment indicates quick accumulation of leaf litter in the soil from fast colonizers especially Mikania micrantha in the jhum fields at Dimoria. Further result from the present study indicates increase in earthworm population during abandonment consequently leading to gradual increase in formation of soil aggregates. Decrease in C/N ratio in the soils with increase in microbe population further indicates its utilization by the microbes for decomposition of the aggregates and release of nutrient to the soil. In addition results of the present study indicated a faster rate of microbial biomass recovery during the initial stages of revegetation in a given disturbed or degraded site. Identical findings were reported by
Pandey et al. (1996) for regenerating broadleaved forest communities dominated by *Quercus dealbata* at higher altitudes of Meghalaya. Diaz-Ravina et al. (1988) have shown that soil with low organic C usually has less biomass, and vice versa. This could well explain the low MBC in the 4-year and 8-y cycle jhum fields in the present study. Hence, the variations in the MBC levels in this study may be explained in terms of their positive correlations with soil moisture, soil organic carbon and total nitrogen. Interestingly percentage contribution of MBC to soil organic carbon was in the range of (0.4–1.5%) which was within the lower limits of the ranges reported for a temperate ecosystem (0.27–5.0%) by Anderson and Domsch (1986) and lower than those reported for Amazonian pastures and forests (3.5–5.3%) by Luizao et al. (1992). Arunachalam et al. (1996) reported that contribution of MBC to SOC varied between 0.01% and 1.8% in disturbed pine (*Pinus kesiya*) forests. Ralte et al. (2005) reported recovery of microbial biomass during regrowth of vegetation on jhum fallows in Garo hills of Meghalaya.

The present study also points to the fact that perhaps C/N ratio is very much dependent on microbes. This argument is verified by the reports of Sridevi et al. (2003). They indicated dependence of decomposition and C mineralization of plant residues on N concentration and C/N ratio. From the results of the present study it can be pointed out that rapid colonizing of the jhum fallows is favourable for biological factors like growth of earthworms and microbes which consequently enhances nutrient cycling and rebuilds soil fertility. Mousa et al. (2007) also reported
that plants supply organic materials as energy sources for microbial growth, so the low soil microbial biomass could be a reflection of the low vegetation abundance.

During the present study negative relationship was revealed between MBC and surface runoff and also between MBN and surface runoff. It indicates that surface runoff washes off substrate for the microbes especially from the jhum fields when there is lack of vegetation cover. Soil of the jhum fields being bulkier and plastic facilitates faster runoff. In addition strong positive significant relationships have been developed during the present study between organic matter, phosphorus, ammonium and nitrate with microbes indicating that biological factors plays an important role in organic matter buildup in the soil.

4.4 GIS APPLICATION TO UNDERSTAND JHUM REDEVELOPMENT

During the present study annual organic matter buildup during abandonment of the jhum fields was mapped and georeferenced. Currently very few soil nutrients are identifiable (mapable) from satellite sensors. Daniel et al. (2009) reported relationship between surface reflectance values and SOM constituents of samples representative of Lop Buri district, Thailand and analyzed at cross-platforms. The present study at Dimoria is at a nascent stage and is limited for specific conditions at the time the measurements were obtained. Lack of studies in this respect handicaps comparing the obtained results.