



CHAPTER IV

DISCUSSION



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The objective of the present study is **(1) to estimate the organic carbon in different types of land cover and (2) different pools of soil organic carbon.**

All the results obtained from the study are discussed under separate headings with relevant literature for supporting the observations. The conclusions of the study are derived from a holistic approach with pertinent supporting literature.

Carbon sequestration in soils is very important because aboveground litter production in forests is likely to increase as a consequence of elevated atmospheric CO₂ concentrations, rising temperatures, and shifting rainfall patterns. As litter fall represents a major flux of carbon from vegetation to soil, changes in litter inputs are likely to have wide-reaching consequences for soil carbon dynamics. Such disturbances to the carbon balance may be particularly important in the tropics because tropical forests store almost 30% of the global soil carbon, making them a critical component of the global carbon cycle (Sayer et al., 2007). Soil carbon quantities are a result of the balance between carbon input to the soil and the decomposition of organic carbon in the soil (Takahashi et al., 2007). Carbon input to the soil through litter fall (both above-ground and below-ground) could vary depending upon the types of vegetal cover and climatic factors. Several studies have estimated the contribution of afforestation to the global carbon cycle at both regional (Niu and Duiker, 2006; Potter et al., 2007; Kula, 2010) and global scales (Benitez et al., 2007; Olschewski and Benitez, 2010). The potential impact of different types of vegetal cover on carbon sequestration in soils is very sketchy. Also, the ~~area~~ affects of different types of land cover in tropical deciduous forests on carbon sequestration are poorly understood. In addition plant species of higher carbon sequestration in soils should be screened for each land use systems, so that those with greater capacity to store carbon in soils can be prioritized in planting activities.

Carbon sequestration in any forest ecosystems is controlled by physical, chemical and biological properties of soils. According to Shi et al. (2009), soil properties may vary greatly depending on soil types, topography, climate, vegetation and anthropogenic activities, all of which affect the spatial distribution patterns of soils. In the present study, soil properties (physical, chemical and biological) were varied (except soil pH) significantly at various depths and between types of land cover. It clearly indicates that different types of land cover have an impact on soil properties even though they exist in the same climatic regime.

4.0 Soil physical properties

Soil pH values at different depths of soils under three types of land cover are comparable with earlier studies in tropical forests (Moraes et al., 1996; Johnson and Wedin, 1997; Paudel and Sah, 2003). Results of soil pH at different depths under three types of land cover are not showing significant differences. An earlier study (Laik et al., 2009) also did not find any significant change in pH values at two different depths of different plantations supporting observation of this study. Soil pH values observed under three types of land cover at different depths are more or less similar to earlier studies (Balagobalan et al., 1991; Shukla, 2009; Keel, 1975; Cheng et al., 2004). Soil pH may also have an indirect effect on the C- to- N ratio of soil organic matter via changes in litter quality (Kemmitt et al., 2006). Also Kemmitt et al. (2006) hypothesized that increased soil acidity would lead to a greater accumulation of soil organic matter due to a reduced rate of microbial mineralization. However, soil pH values at different depths and SOC content under three types land cover are not supporting the above hypothesis.

Particle size distribution is a fundamental physical property of soils (Skaggs et al., 2001). Soil system consists of two different fractions; they are 1) coarse-earth fraction (>2 mm in size) such as gravels, cobbles, boulders and other fragments of a soil and 2) the fine-earth fraction such as sand (>0.05-2 mm), silt (>0.002-0.05 mm)

and clay (<0.002 mm) (Carlile et al., 2001; Lesikar, et al., 2005). The U.S department of agriculture (USDA) developed a soil textural classification system based upon the proportions of sand, silt and clay of the soil sample (Skaggs et al., 2001). It is a feasible method to identify the type of soil in our study area. Thus most of the soil layers (up to 125 cm) under teak and mixed land cover were falls in the loam type, while the soils of bamboo land cover were falls in clay loam type. This clearly indicates that the soils under teak and mixed land cover are well drained as compared to bamboo land cover.

Bulk density (BD) values for different mineral soils may have, at least, a two-fold range, it is important that BD values are used in conjunction with concentrations of soil nutrients in ecological studies (Parfitt et al., 2010). In assessing stocks of carbon in soils, BD is also required for quantifying carbon on an area basis (Schlesinger, 1990; Morisada et al., 2004; Ramachandran et al., 2007; Arai and Tokuchi, 2010). Bulk density at different depths of soils under three types of land cover was increasing as depth increases. Earlier studies (Scott, 1999; Islam and Weil, 2000; Chen et al., 2005; Keller and Hakansson, 2010) also found the similar trend in various soils of tropical forests. Lower bulk density at different depths of teak and bamboo land cover as compared to mixed land cover indicates the effects of these covers on bulk density. An earlier study (Boley et al., 2009) did not find the effects of plantation on bulk density, although their bulk density values had slightly decreased from the natural forest cover. Also they said that effects of plantations on bulk density would not immediately evident and may require over 10 years of growth. In this study, teak and bamboo land cover was dominant in the study area for the past 75-100 years. Thus the effects of plantations (teak and bamboo) on bulk density are evident in this study.

4.1 Chemical and biological properties

4.1.1 SOC

SOC content in three types of land cover are in accordance with the earlier reports (Wang et al., 2004; Shrestha et al., 2004; Chen et al., 2005; Rossi et al., 2009; Usuga et al., 2010) mentioning that soils under natural vegetation had a high SOC content compared to other land use systems. Teak land cover had higher amount of SOC up to a depth of 125 cm than bamboo and mixed land cover. An earlier study (Usuga et al., 2010) reported that soil under patula pine soils have higher carbon stocks than the soil under teak (mining areas). However, in this study, teak land cover sequestered more carbon than bamboo and mixed land cover. The soils contain high organic matter content associated with large carbon stocks in the soil profile, which is where the highest carbon volume is accumulated in the system (Usuga et al., 2010). SOC in the top layer (0-2 cm) differed corresponding to the type of vegetal cover. Russell et al. (2007) also found the effects of different types of tree species on SOC in the surface layer of tropical moist forest. An earlier study (Kirby and Potvin, 2007) also observed the variations in carbon storage among different tree species. Results of this study are in confirmity. SOC stock with a depth interval of 25 cm showed how SOC movement across the soil system gets differed due to vegetal cover. A steep fall in the SOC content was observed up to ~50cm and at subsequent depths the decrease was much lesser. This is an indication of higher biological activity associated with top layers reflecting greater degradability of SOC at these depths. Values were significantly different across vegetal covers. In a similar manner Giardina and Ryan, (2000) reported that significant differences in SOC decomposition across different vegetal covers due to substrate availability. In this study variations in vegetal cover brought in different SOC substrates influencing their decomposition (see details in litter decomposition). SOC content is maximum in the top 25 cm. This is in confirmation with the earlier reports (Jobbagy and Jackson, 2000; Wang et al., 2004; Chen et al., 2005; Jagadamma and Lal, 2010). Bamboo showed the highest

content which could be attributed to its shallow root systems with prolific growth. It is said that carbon sequestration potential in soils is strongly affected by root production (Matamala et al., 2003). The results and inferences of the study are in similar lines. Soils with larger inputs (mixed land cover) may have had higher microbial activity because of large chemical diversity which was responsible for a larger fall in the ratios of SOC between 100-125 cm and 0-25 cm. Proportion of SOC moving down in this soil is much lesser. It is reported that carbon losses by accelerated microbial respiration are offset by increases in carbon input to the soil (Thornley and Cannell, 2001). The findings of the study are in coherence with this view.

4.1.2 Litter fall

The integrity of an ecosystem is maintained by transfer of matter and energy through litter fall. Litter production is of great importance for the fertility of forest soils (Pandey et al., 1993). In forested ecosystems, litter fall is the largest source of organic material and nutrients for the humus layer (Berg and McClaugherty, 2008; Berg and Laskowski, 2006). Litter fall is the largest source of organic material that will form humus substances and organic layers. The mean annual litter fall in the present study is comparable with the values reported by others (Brown and Lugo, 1982; Singh et al., 1993; Cordero and Kanninen, 2003; Zhou et al., 2005). Significant seasonal variation in litter production with highest values in dry month (June) is in agreement with the results of others (Sundarapandian and Swamy, 1999; Barlow et al., 2007). The mean annual litter fall in the present study was higher in the mixed land cover than teak and bamboo land cover. This difference in litter production between land covers is attributed to species composition. This was supported by earlier studies (Sundarapandian and Swamy, 1999; Wang et al., 2008) where they reported that mixed stand has higher litter production than pure stands, and also said that species composition is important for litter production within the same climate range.

4.1.3 SOC and litter fall

The rise in SOC is negligible in comparison with the quantities of litter added annually indicating that most of the litter that falls gets decomposed. This also shows that SOC present in the top layers of soil does not come from fresh litter alone. It is from the cumulative accumulation of undecomposed / partially decomposed leftovers of litter of previous years (up to decadal). The study ^{revealed} that SOC gets 'soaked' into lower layers. Addition coming from the decomposition of fresh litter (especially of leaves) is less. At all the experimental points leaf litter gets decomposed within a year while pieces of stem / branch remain for longer time. An earlier study (Brown and Lugo, 1982) reported that the turnover time of litter in tropical forests is less than one year. The results are in confirmity. Correlation is not seen between the quantity of litter and amounts of SOC present in top layers, indicating that the pattern of decomposition of litter is different for the three types of vegetal cover. There is a significant difference in the downward movement of SOC in the three types of vegetal cover. This confirms that SOC in tropical soils depends on the type of vegetal cover. SOC value itself is seen to be much higher than the values mentioned in some earlier reports (Richter et al., 1999; Zhou et al., 2006; Schwendenmann and Pendall, 2008). Growth rates in the forests of this study area (4 mmy^{-1} in the mean DBH) are higher than those reported (Vieira et al., 2005) for the Amazon forest area, as per the records of the State forest Department (unpublished data). This higher growth rate is likely to be good for the soil organic carbon. Similar accumulation of SOC was reported for the growth of old forests (Zhou et al., 2006). They proposed a non-equilibrium conceptual frame work for soil carbon dynamics. This study concludes that soils similar to the study area (of tropical regions) are likely to function as 'sinks' for carbon; they are yet to reach a steady state. Differences in the quantities and movement of SOC seen across the soils of the study area indicate that their sink potential is high.

4.1.4 Litter decomposition

The study of plant litter decomposition in terrestrial ecosystems commonly employs litter bags to compare the loss of mass among species, among sites, and under various experimental manipulations, or to investigate the process itself (Wieder and Lang, 1982). In the present study litter decomposition was monitored by litter bag experiment and the results showed differences in the decomposition of litter kept at different depths. Decomposition was faster at the top layers than at deeper layers. Quantity of litter decomposed is much higher than reported (Gartner and Cardon, 1994; Aerts, 1997; Sundarapandian and Swamy, 1999; Keith et al., 2008). This could be specific to tropics as the soils largely show more biological activity, warmer and humid. Uniformity was seen in the decomposition of teak and mixed species in spite of greater diversity at the site of the mixed species. This uniformity shows that richness of the diversity of species has not altered the overall process of litter decomposition. This is contrary to the results reported earlier (Keith et al., 2008). The results of litter bag experiment show that decomposition is influenced more by the time of stay of litter in the soil and not specifically by species diversity. Uniformity was seen in the decomposition of the three types of litter by the end of 320 days at all the depths irrespective of initial differences. This shows that microbial activity at deeper layers is stimulated slowly by fresh litter/organic carbon supply. Quantity of litter decomposed in the litter bags of teak and bamboo kept at the exchanged sites (teak litter bags in the soils covered by Bamboo and *vice versa*) was almost similar to the decomposition values coming from matching sites. This confirms that the microbial population is more generic by being responsive to compounds present in foliage for decomposition and not specific to plant/tree species (Zimmer, 2002; Hoorens et al., 2002; Hattenschwiler et al., 2005).

4.1.5 Sink potential of soils

Increases seen in SOC of soils coming from the litter bag experiment show that tropical soils do have additional absorptive capacity for organic carbon. The limitation is only with the input and not with their sink potential. Changes in SOC content at deeper levels (25 and 50 cm) revealed another dimension in decomposition activity. The newer inputs are relatively less than the base levels of SOC contents of previous years present in these layers. The proportion of decomposition is maximum for fresh inputs in litter bag compared to the small variations seen in the already existing SOC. This shows that microbes process SOC as per the law of diminishing returns. Availability of fresh SOC (in the bags) activates microbes and processing/ decomposing of fresh litter becomes faster. Once SOC reaches or becomes 'chemically stable' with compounds equivalent to the type present in these soil layers, the microbial activity becomes very low as the microbes do not get any further energy by the breakdown. This is contrary to the views of others (Fontaine et al., 2003, 2004, 2007; Orwin et al., 2006) who report that supply of fresh plant-derived carbon to the sub soil stimulates microbial mineralization of old carbon. Increase was seen in SOC Pools 1 (>250-2000 μm) and Pool 2 (<250 μm) at three different depths of three types of land cover. However, the increase was more in SOC Pool 1 as compared to SOC Pool 2 at three different depths of three type of land cover. The rate of decomposition and subsequent change/s seen in SOC of these soils indicated that additional inputs (though the quantity in the bags was small) can be easily taken in. Hence soils at the study area are act as a sink for carbon rather than a source while adding fresh inputs into soils.

4.1.6 MBC

The soil microbial biomass is the active component of the soil organic pool playing an important role in global carbon cycle. Microbial biomass is the key biological component of soil that affects decomposition, nutrient cycling and aggregation

(Haney et al., 2001). Therefore, measuring microbial biomass is a valuable tool for understanding the soil carbon sequestration in different types of vegetal cover. In this study litter addition showed a significant influence on MBC. MBC increased after addition of fresh inputs at three different depths after 90 days and decreased at 220 days and virtually stabilized at the end of the litter decomposition experiment (320 days). Similarly, Liu et al. (2009) found that enhanced litter input increased the content of MBC. It is generally accepted that organic matter inputs can increase soil microbial biomass and activity due to an increase in energy availability (Fontaine et al. 2004; Xiao et al. 2007). Results of the study are in confirmity. An earlier study (Jin et al., 2010) indicate that the effects of plant-derived SOC inputs on soil carbon stores involve more complex processes than simply changes in soil microbial production and activity. Therefore, the availability of substrates has a profound impact on changes in soil microbial biomass carbon in the study area.

4.1.7 HF-soluble carbon

The stability of SOC mainly depends on the association of mineral particles to organic carbon. HF treatment to soils preferentially removes the mineral bound organic matter and this organic matter fraction seems to be dominated by old carbon compounds, supporting the concept of the stabilizing function of minerals. The increasing HF-soluble carbon concentrations from surface to deeper layers of soils under three types of land cover clearly indicates that deeper layer contains old/stabilized carbon. Earlier studies (Eusterhues et al., 2003; Rumpel et al., 2008; Jagadamma et al., 2010) also reported that HF-soluble carbon concentration is more in deeper layer of soil profiles. Also they found that HF-soluble carbon at deeper layer of soil profiles were decades to century old. The increase of HF-soluble carbon in the soil samples coming from litter decomposition experiment indicating that the stabilized and/or old carbon associated with minerals are not depleted by microbes even after adding the fresh inputs into the soils at three

different depths. HF-soluble carbon in SOC pools 1 and Pool 2 at top layers of three types of land cover showed that at most 90% of carbon in these pools is associated with minerals while deeper layers showed very less as compared to top layers. This is attributed to the continuous addition of litter and decomposition process happening in the top layers of soils, while the addition of litter input and decomposition process in deeper layers of soils is very low.

4.1.8 Soil respiration

Soil respiration, which represents the CO₂ efflux from the soil surface, is one of the most important processes in the carbon cycle of terrestrial ecosystems (Adachi et al., 2005). Soil respiration (Rs), after gross primary productivity, is the second largest carbon flux between terrestrial ecosystems and the atmosphere (Raich and Schlesinger, 1992). Soil respiration values of the three vegetal covers were higher than the published values for tropical soils (Raich and Schlesinger, 1992; Raich and Tufekcioglu, 2000). This supports the conclusion that rates of decomposition observed in these soils are higher. Soil respiration values of three types of vegetal cover are differed between vegetal covers and between seasons. An earlier study also said that soil respiration varies with vegetation and among major biome types significantly (Raich and Tufekcioglu, 2000). Recently Yohannes et al. (2011) also found the effects of tree species on soil CO₂ efflux in an Afromontane forest in Ethiopia. Higher respiration values in monsoon and less in winter may be related to variation in soil moisture content. Bamboo showed higher respiration in monsoon as the leaves of Bamboo were holding relatively less moisture and increase in moisture content during monsoon enhanced the rate of decomposition. Earlier studies (Devi and Yadava, 2006, 2009) also reported that high rate of CO₂ released during the rainy season and it may be attributed to a congenial environment for the microorganisms dwelling in the soil and decomposing organic matter. Besides, the rate of decomposition of the litter material is also high during this period. Low rate of CO₂ release from the soil in summer months in three types

of land cover may be due to low moisture content of the soil, temperature and relative humidity, thereby inhibiting the microbial activity and decomposition (Devi and Yadava, 2006; Kosugi et al., 2007).

4.1.9 SOC pools

The total SOC pool can be compartmentalized into different fractions or pools of varying stability (Jagadamma et al., 2010). Six et al. (2002) comprehensively used the physical fractionation technique for measuring and understanding the different pools and carbon storage of afforested soils. The present study followed the method described by Six et al. (2002). The results of physical fractionation of SOC (into 2 pools of different particle size) at three types of land cover sites with different depths gave a better understanding of SOC movement in the soil. The present study disagreed with the assumption of considering SOC as a homogenous pool (Giardina and Ryan, 2000) and agrees with another considering it as a heterogeneous pool (Davidson and Janssens, 2006). The present study hypothesizes that within a layer, SOC gets decomposed from one fraction to another in a unidirectional manner towards recalcitrant pool. This is contrary to the complex four pool carbon model (Thornelly and Cannell, 2001) (four pool), where they said (concluded) that carbon transfers between fast, intermediate and slow pool during decomposition process and the fourth pool is called stabilized with low turnover rate and assumed no decomposition and there are no transfer between this pool to other three pools. The present study results are indicative of this. The SOC concentration in two different physical fraction pools decreased with increase in depth (up to 14 cm) in all three land cover sites. Across layers of different depths the size of recalcitrant pool increased as it is more stable. This is in accordance with the earlier findings (Shrestha et al., 2007). In addition, proportion of organic carbon in the two physical pool sizes (Pools 1 and Pool 2) remained almost the same across different soils. Uniformity in the pool proportion across the profile shows that all differences expected amongst vegetal cover are to be seen mostly at

the beginning of the process of decomposition. Once these initial stages are crossed, subsequent alterations are the same in these soils. This observation reaffirms that variations in vegetal cover will have an impact on the initial stages of decomposition only. Chemically diverse litter mixture would contain a more even representation of labile and recalcitrant compounds (Meier and Bowman, 2008). In this study similar observation is not seen. Proportion of recalcitrant pool was higher. Plant diversity did not influence this SOC fractionation into Pools 1 and Pool 2. Proportion of Pool 2 is seen to be much higher in the study compared to the ones reported (Lorenz et al., 2007; Lutzow et al., 2007). Thus the present study concludes that from each physical fraction SOC moves across different depths getting decomposed and converted towards recalcitrant pool. Decomposition of SOC was dependent on type of fraction and microbial activity at that depth. Percentage of recalcitrant pool increased with increasing depth in three types of vegetal/land cover due to the decomposition of other mobile pool at each layer. Uniformity in the proportion of SOC in both Pool 1 and Pool 2 across different vegetal covers led to check for any variation in their chemical constituents through proton NMR analysis.

4.1.10 Chemical break-up of SOC

Diverse groups of chemical compounds are present in the SOM; they are mostly derived from plant, animal tissues and microbial derivatives. Major components of plant tissues are polysaccharides, lignin, tannins and proteins, while soil bacteria and fungi consist mainly of homo- and heteropolysaccharides (e.g., chitin, peptidoglycan, lipopolysaccharides), and animals mainly of carbohydrates, proteins and lipids (Lorenz et al., 2007). The technique of ^1H and ^{13}C NMR spectroscopy has been widely used to identify the types of carbon and / or changes in the types of carbon in soil carbon dynamics studies (Preston et al., 1994, 1997; Lorenz et al., 2000; Six et al., 2001). These studies divided the spectra of litter, soil and humus residues into the following chemical shift regions; 0-50 alkyl carbon

(C) (for ^1H NMR spectra it is 0.5-2 ppm), 60-93 ppm O-alkyl C (for ^1H NMR spectra it is 3-5 ppm), 112-140 ppm aromatic C (for ^1H NMR spectra it is 7-8 ppm) and 165-190 ppm carboxyl C (for ^1H NMR spectra it is 8-12 ppm). ^1H NMR provides information about the number of protons in the molecule while ^{13}C NMR provides information about the numbers of carbon in the molecule (Pavia et al., 2001; Balci, 2005).

The present study used the ^1H NMR spectroscopy to determine the chemical nature of SOC and their pools. Of the four groups (Alkyl, O-alkyl, Aromatic and Carboxyl ones) reported in literature (Preston et al., 1997; Webster et al., 2001; Lorenz et al., 2007; Fontaine et al., 2007; Lutzow et al., 2007), Carboxyl group was completely missing in the samples. This is due to the tropical origin of the samples while most of the published reports indicated the presence of Carboxyl group in samples from temperate regions. Variations in the proportions of different groups were minimal across vegetal cover and depths. The proportion of O-alkyl and Aromatic groups remained almost the same. Fluctuations were seen in the proportion of Alkyl groups. As decomposition proceeds, the relative intensity of the Alkyl-C signals, representing partly decomposed plant residues and microbial compounds, increases whilst that of the O-alkyl-C decreased (Baldock et al., 1997; Preston, 1996; Hopkins and Chudek, 1997; Webster et al., 2001). The result of signal intensity of Alkyl-C at top and 12-14 cm layer of bamboo land cover was in confirmity. Proportions of these three groups in Pools 1 and Pool 2 also remained the same. These results clearly show that at least in tropical soils, the process of decomposition for different types of plant material eventually leads to uniformity in chemical composition. Subsequent changes become negligible. The proton NMR results support an earlier view (Lutzow et al., 2006) that the soil biotic community is able to disintegrate any organic matter of natural origin till it reaches uniform molecular recalcitrance. Proton NMR results support an earlier view of Lutzow et al. (2006) saying that the soil biotic community is able to

disintegrate any organic matter of natural origin till it reaches uniform molecular recalcitrance. Chemically Pool 1 and Pool 2 are almost the same. Variation is with reference to their physical association with particle size.

4.1.11 Carbon isotopes

4.1.11.1 $\delta^{13}\text{C}$

To understand the impact of annual decomposition cycle on long-term carbon storage in tropical soils, three land covers occupied predominantly by teak, bamboo and mixed vegetation are evaluated for carbon isotope composition. Teak and bamboo have naturalized distribution in the study area (SWS) and their spread increased by human management in the past century. Carbon has two stable isotopes (^{13}C and ^{12}C) and a radioactive isotope (^{14}C) that are useful tracers in the study of the soil carbon cycle. Terrestrial plants can be divided into three groups according to their photosynthetic pathways: C_3 (using C_3 or Calvin photosynthetic pathway), C_4 (using C_4 or Hatch–Slack photosynthetic pathway), and CAM Plants (Crassulacean acid metabolism) (Wang and Hsieh, 2002). Terrestrial plants with the C_3 (calvin cycle) pathway have $\delta^{13}\text{C}$ values in the range -35 to -20‰ (Boutton, 1991). Plants with the C_4 (Hatch-Slack) pathway have higher $\delta^{13}\text{C}$ values ranging from -19 to -9‰ (Boutton, 1991). In all three types of vegetal cover, the stable carbon isotopes ($\delta^{13}\text{C}$) values of litter confirmed that carbon inputs are completely C_3 dominated at present. The range of $\delta^{13}\text{C}$ values in soils of teak, bamboo and mixed land cover are comparable with the $\delta^{13}\text{C}$ values of C_3 plant communities i.e. -35 to -20 ‰ (Boutton, 1991). An earlier study (Martin et al., 1990) said that the isotopic composition of SOM is comparable to that of the plant material from which it was derived. Radio carbon ages and $\delta^{13}\text{C}$ values at two other points in teak cover indicate that the study area has been predominantly populated by C_3 vegetation during the past 2200 years. Martinelli et al. (1996) hypothesized that former C_4 vegetation would be evidenced by a large enrichment of ^{13}C with depth (9-10‰). They also mentioned that a possible cause for the

absence of large ^{13}C enrichment with depth could be due to the dominance of C_3 rather than C_4 grasses. The enrichment factors associated with the observed data in the upper 100 cm soil profile of teak, bamboo and mixed land cover were slightly lower than the ones coming from the data reported for C_3 permanent grass land (Accoe et al., 2002). The enrichment factors are higher than the ones reported for C_3 red spruce forest (Diocion et al., 2009). The $\delta^{13}\text{C}$ of SOC generally gets enriched with depth in soil that has remained under the same plant community during a long period (Bostrom et al., 2007; Fontaine et al., 2007; Bowling et al., 2008; Dumig et al., 2008; Arai and Tokuchi, 2010). In the tropics, enrichment of $\delta^{13}\text{C}$ values within the upper meter have been reported by several authors (Wynn et al., 2006; Krull et al., 2006; Jagadamma and Lal., 2010). The present study supports the hypothesis of the preferential utilization of chemical compounds of the plant litter that could lead to increased $\delta^{13}\text{C}$ with increasing depths (Santruckova et al., 2000; Kramer et al., 2003; Bostrom et al., 2007). Balesdent et al. (1993) reported that ^{13}C enrichment with depth is related to the increasing age and degree of decay of organic carbon. They also suggested that organic matter tends to migrate downwards as it decays and the relative proportion of old carbon is larger in deeper horizons, while the total carbon concentration decreases with depth. Increase in the proportion of HF-soluble carbon and decrease in total carbon concentration (up to 1 m) in the three covers of this study is in confirmity.

Higher proportion of HF-soluble carbon in the top layer of teak cover is indicative of recalcitrance of its leaf litter. Differences seen in the HF fractions of all the three covers up to 1 m depth indicate variations in the vegetal cover distributions over the past centuries. Increase in HF fraction across soil profile indicated that deep carbon persists by its association with soil minerals. Keeping ^{14}C age values of teak cover, it can be concluded that the changes have occurred during a 2200 year period. A positive linear relationship between HF-soluble carbon and MRT of teak

vegetal cover augments this view. The HF-soluble fraction contains high amount of old, stabilized organic matter and the observed positive correlation supports the assumption that the association of organic matter with soil minerals leads to a sequestration of organic carbon in soils (Eusterhues et al., 2003). Additionally, the present study revealed that interaction with mineral phase is the most important process of carbon stabilization in these soils. Lesser differences in $\delta^{13}\text{C}$ values of mixed vegetal cover are attributed to higher MBC values seen in the soils of this cover and diverse litter chemistry. The close relationships between $\delta^{13}\text{C}$ and abiotic variables (soil pH, % sand, and % silt and % clay) may indicate the differences in controls on changes in $\delta^{13}\text{C}$ values among land cover types. The relationship between $\delta^{13}\text{C}$ and particle size distributions (sand, silt and clay) in soils varied with land cover types. The relationship between $\delta^{13}\text{C}$ and % silt of bamboo and mixed land cover confirmed the % silt control over the changes in $\delta^{13}\text{C}$ values in depth. However, the positive linear relationship between $\delta^{13}\text{C}$ and % clay of mixed land cover indicates the role of clay content in soils influence the changes in $\delta^{13}\text{C}$ values. An earlier study (Powers and Schlesinger, 2002) found the relationship between $\delta^{13}\text{C}$ and % silt of low elevation alluvial soils. Results of this study are in conformity. Beta (β) values observed in the present study are comparable with other studies (Garten et al., 2000; Powers and Schlesinger, 2002). The positive linear relationship between β values and soil pH values of three types of land cover confirmed that ^{13}C enrichment is directly influenced by soil acidity. The positive correlation, but weak, between β value and %silt indicates, other than silt concentrations in soils, may be some other biological factors, of three types of land cover influence the ^{13}C enrichment of soils.

Stable isotopes revealed enrichment across the vegetal covers. pMC values showed that the study area supported C_3 vegetation predominantly and switch over of vegetal cover (C_3 to C_4 or *vice versa*) must not have occurred in the past 2200 years. Measured data give a better understanding of changes happening in tropical

systems. Inputs coming from this study are highly relevant in projecting the future scenario of carbon storage in tropical soils.

4.1.12.2 ^{14}C

Natural radiocarbon (^{14}C) is produced in the atmosphere by interactions of cosmic-ray produced neutrons with stable isotopes of nitrogen, oxygen and carbon, and has a natural abundance in the atmosphere of ~ 1 atom ^{14}C per 10^{12} atoms ^{12}C (Wang and Hsieh, 2002). The presence of ^{14}C with a half-life of 5570 year in plants and the transformation of this ^{14}C into SOM with little isotopic discrimination allows the SOM to be dated, providing an estimate of the age of the SOM. The ^{14}C dating technique is applicable within a time frame of 200–40,000 year; samples with an age less than 200 year are designated as modern (Six and Jastrow, 2002). Radiocarbon age of the three soil samples collected at various depth intervals from teak land cover showed a consistent increase with depth. Earlier studies (Torn et al., 1997; Trumbore, 2000; Krull et al., 2006; Fontaine et al., 2007; Dumig et al., 2008) were also found the similar kind of results. The measured ^{14}C activity (pMC) of bulk SOC samples represents a mean soil ^{14}C age (i.e. a mixture of young and old carbon) (Wang and Amundson, 1996). The ^{14}C value (pMC) of surface layer constitutes the younger part of SOC (pMC value is $>100\%$) indicating contribution from bomb derived carbon since the 1950. However, deeper layers (45-60 cm and 90-100 cm) of soil have constitutes older part of SOC, it was mirrored by the pMC values (pMC value is $<100\%$) of these layers. The positive linear relationship between discrimination factor values ($\delta^{13}\text{C}_{\text{soc}} - \delta^{13}\text{C}_{\text{litter}}$) and MRT of teak land cover confirmed the more enrichment of ^{13}C in soils is associated with old/stabilized carbon.