



# CHAPTER III

## RESULTS



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All the results obtained from the study are presented in Tables and Figures. Tables (Tables 1-8) are given in appendix. The values presented in Tables and Figures are all mean values (n=3-12). ANOVA was performed for some of the experiments. The results are described under separate headings.

### 3.0 Physical parameters

#### 3.0.1 Soil pH

Mean soil pH values at different depths of three types of land cover were shown in Table 1. Soils at the study area are slightly acidic to neutral with pH ranged from  $6.58 \pm 0.02$  to  $6.91 \pm 0.01$ ;  $6.46 \pm 0.04$  to  $6.92 \pm 0.01$  and  $6.51 \pm 0.05$  to  $6.96 \pm 0.01$  at different depths under teak, bamboo and mixed land covers, respectively. Soil pH values did not differ statistically at different depths and between types of land cover. Soil pH value at top layer (0-2cm) was slightly lower in bamboo land cover ( $6.46 \pm 0.04$ ) followed by mixed ( $6.51 \pm 0.05$ ) and teak land cover ( $6.58 \pm 0.02$ ). Highest soil pH value ( $6.96 \pm 0.01$ ) was observed in mixed land cover at 100-125 cm depth followed by bamboo ( $6.92 \pm 0.01$ ) and teak land cover ( $6.91 \pm 0.01$ ). Soil pH values gradually increased from top layer (0-2 cm) to deeper layer (100-125 cm) of three types of land cover. The increase in soil pH value from surface layer to deeper layer was higher in mixed (0.46) followed by bamboo (0.43) and teak (0.33) land cover.

#### 3.0.2 Soil particle size distribution

Soil particle size distributions (sand, silt and clay proportion) differed at different depths and between types of land cover (Figure 1). Sand proportion gradually increased from top layer (0-2 cm) to deeper layer (100-125 cm) of the soil profiles of three types of land cover. Silt proportion showed a clear trend of increase (with few exclusions) from top to deeper layers of soils under three types of land cover (Figure 1). Clay proportion showed an increasing trend from top to deeper layer of the soil profile of teak land cover.

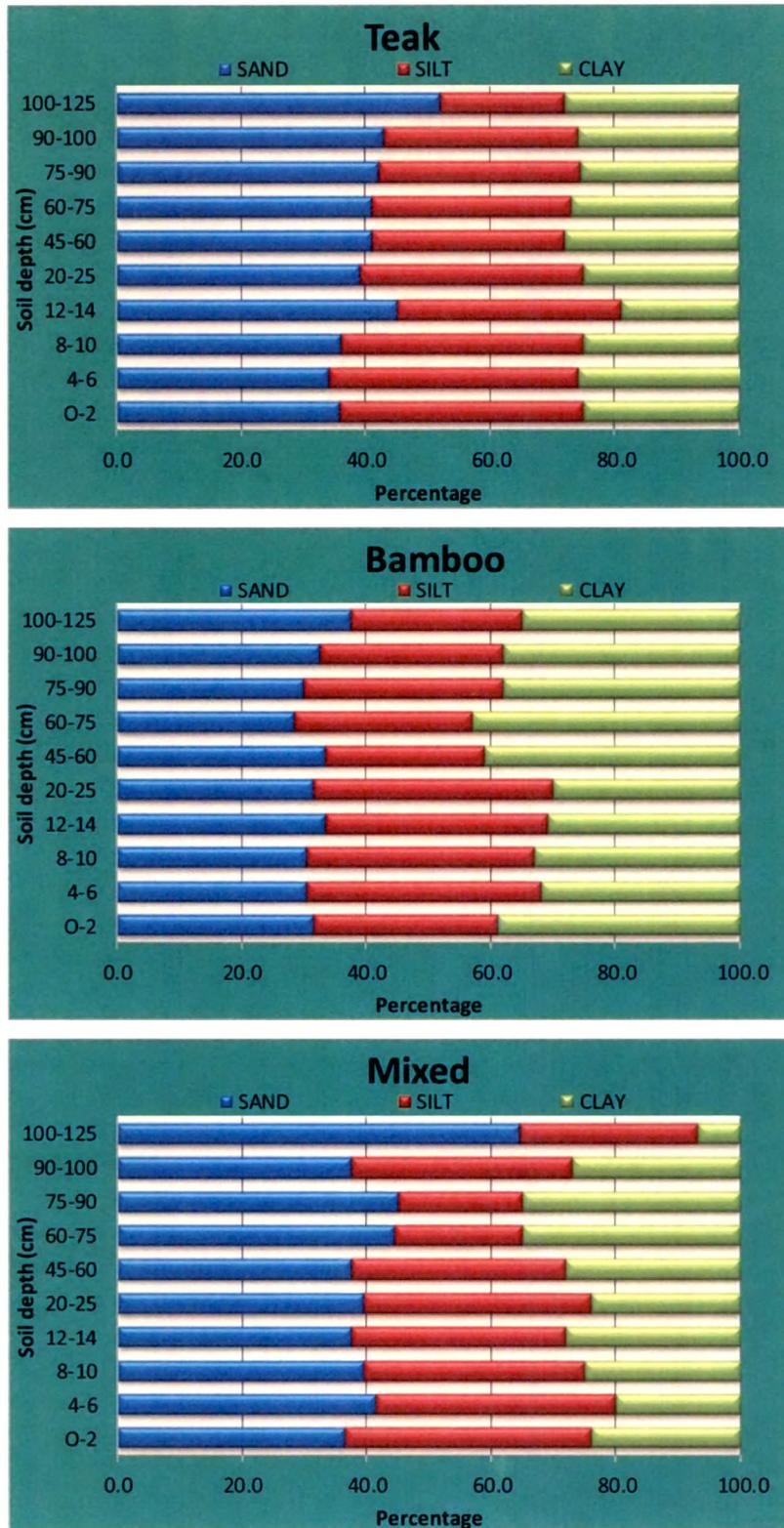
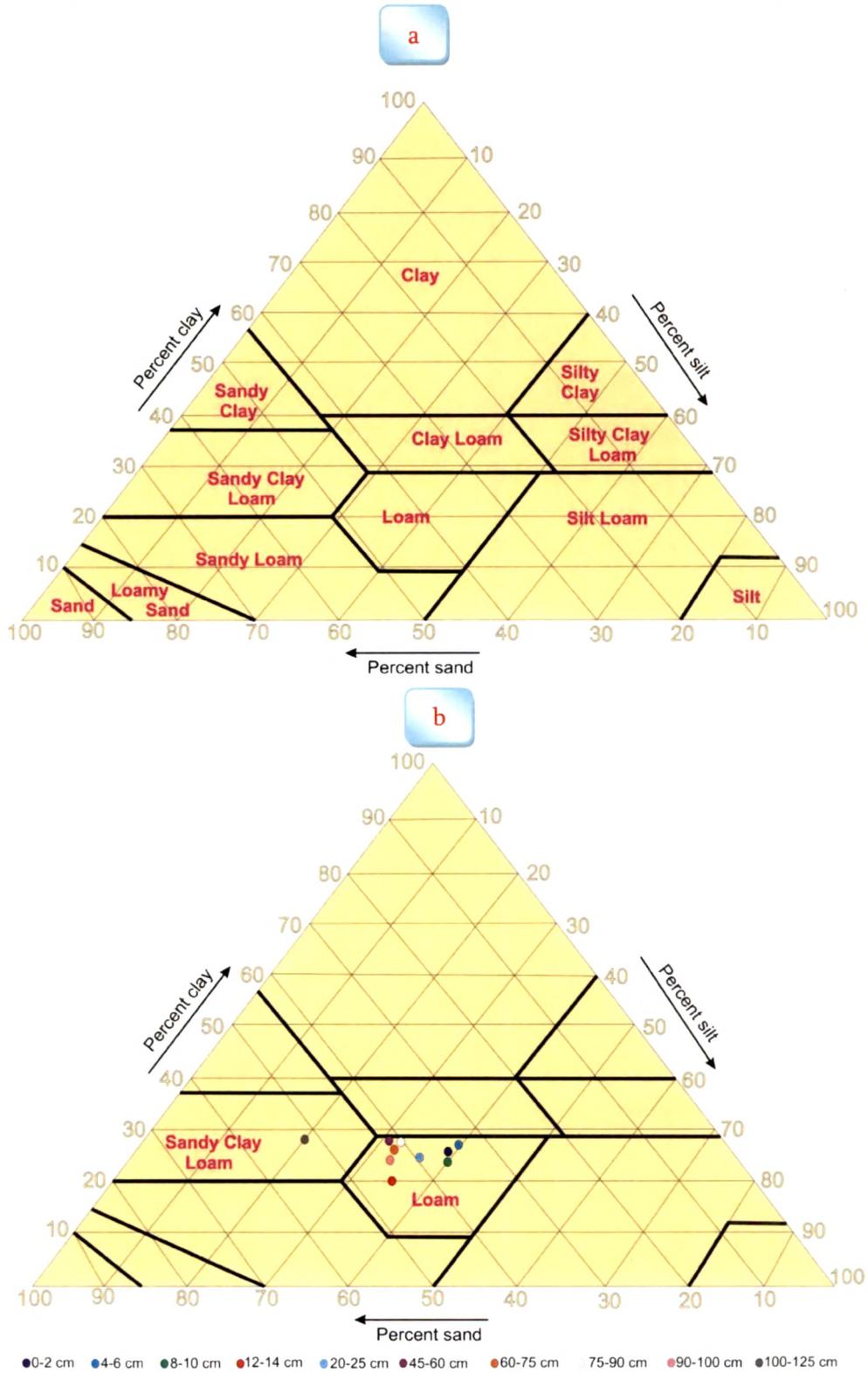


Figure 1: Particle size distribution (%) of soils under three types of land cover.

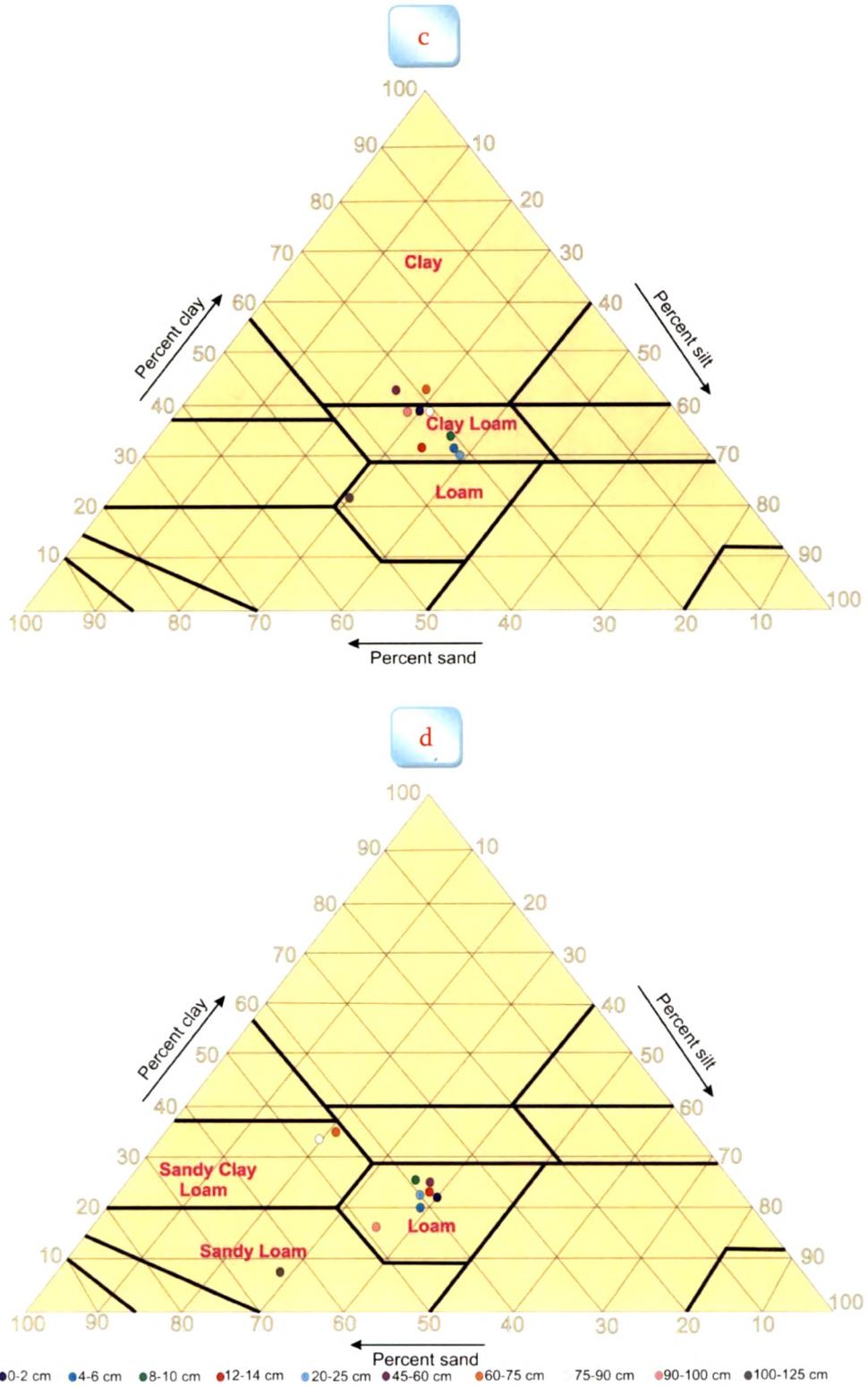
In bamboo and mixed land cover, the clay proportion increased from 0-2 cm to 60-75 cm depth, after wards it was decreasing up to 100-125 cm depth. Overall, sand proportion at different depths of soil under mixed cover was higher as compared to teak and bamboo land cover. Highest silt proportion was observed under teak land cover followed by bamboo and mixed land cover at different depths. But the clay proportion was higher in bamboo land cover than teak and mixed land cover. Teak land cover had sandy clay loam to loam type of soil texture at different depths (Figure 2). The soil of bamboo land cover at different depths had clay, clay loam and loam type while mixed land cover had sandy loam, sandy clay loam and loam type of soil texture (Figure 3) at different depths.

### 3.0.3 Soil bulk density

Soil bulk density of three types of land cover at different depths was shown in Figure 4. The differences across soil depths and between different land covers were found to be significant at  $P < 0.01$  level. Soil bulk density was lower in top layers while it was higher in deeper layers of the soils under three types of land cover. Bulk density of the soils at different depths ranged from 1.25 to 1.36 g cm<sup>-3</sup>, 1.14 to 1.29 g cm<sup>-3</sup> and 1.26 to 1.48 g cm<sup>-3</sup> at 0-2 cm to 125 cm for teak, bamboo and mixed land covers, respectively. Soil bulk density values are higher at different depths of mixed land cover followed by teak and bamboo land cover.



**Figure 2:** The USDA soil texture classification system (a) and the range of soil texture classes at different depths of teak land cover (b).



**Figure 3:** The range of soil texture classes at different depths of bamboo (c) and mixed land cover (d).

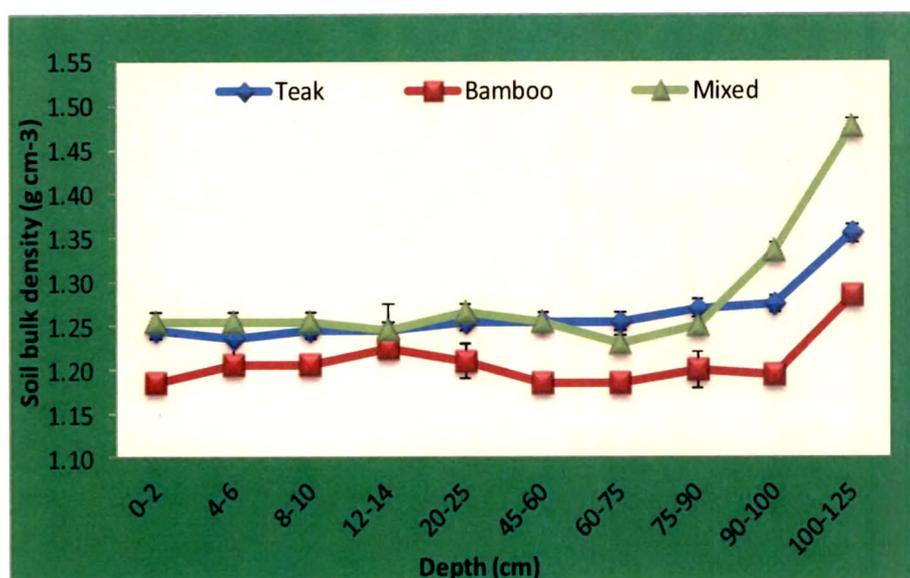


Figure 4: Soil bulk density of three types of land cover with standard error bars ( $n=3$ ).

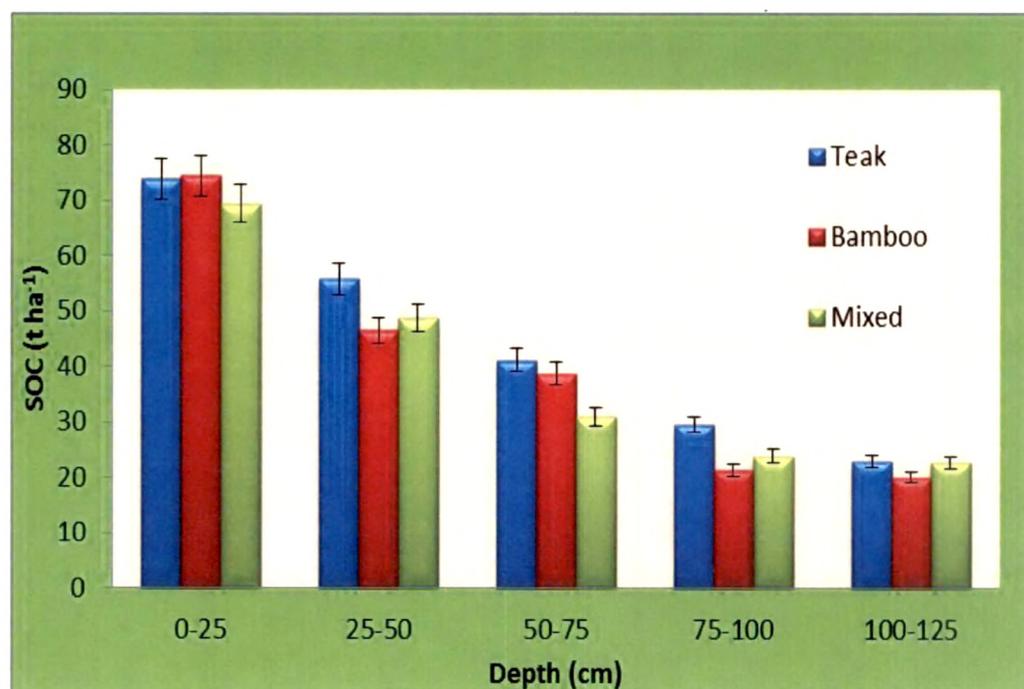
### 3.1 Chemical parameters

#### 3.1.1 Soil organic carbon (SOC)

SOC values coming from the three types of land cover showed significant differences (Table 2). Differences across soil depths and between types of land cover were found to be significant at  $P < 0.01$  level. SOC content decreased significantly with increase in depth in all types of land cover and ranged from 33.7 g kg<sup>-1</sup> to 8.1 g kg<sup>-1</sup>, 30.8 g kg<sup>-1</sup> to 6.6 g kg<sup>-1</sup> and 30.8 g kg<sup>-1</sup> to 6.5 g kg<sup>-1</sup> of teak, bamboo and mixed land cover, respectively (Table 2). SOC content was high in the top layers (0-2 cm) of three types of land cover and it was lower at 125 cm depth (Table 2). The decrease of SOC was gradual in all types of land cover. SOC in the top layer differed corresponding to the type of vegetal cover. SOC content (up to 125 cm depth) was higher in teak followed by bamboo and mixed land cover. At deeper layers (60-75 cm onwards) SOC content was more in teak land cover than that in bamboo and mixed land cover. Differences seen in the SOC contents of soil

samples picked up at two successive years were found to be statistically insignificant.

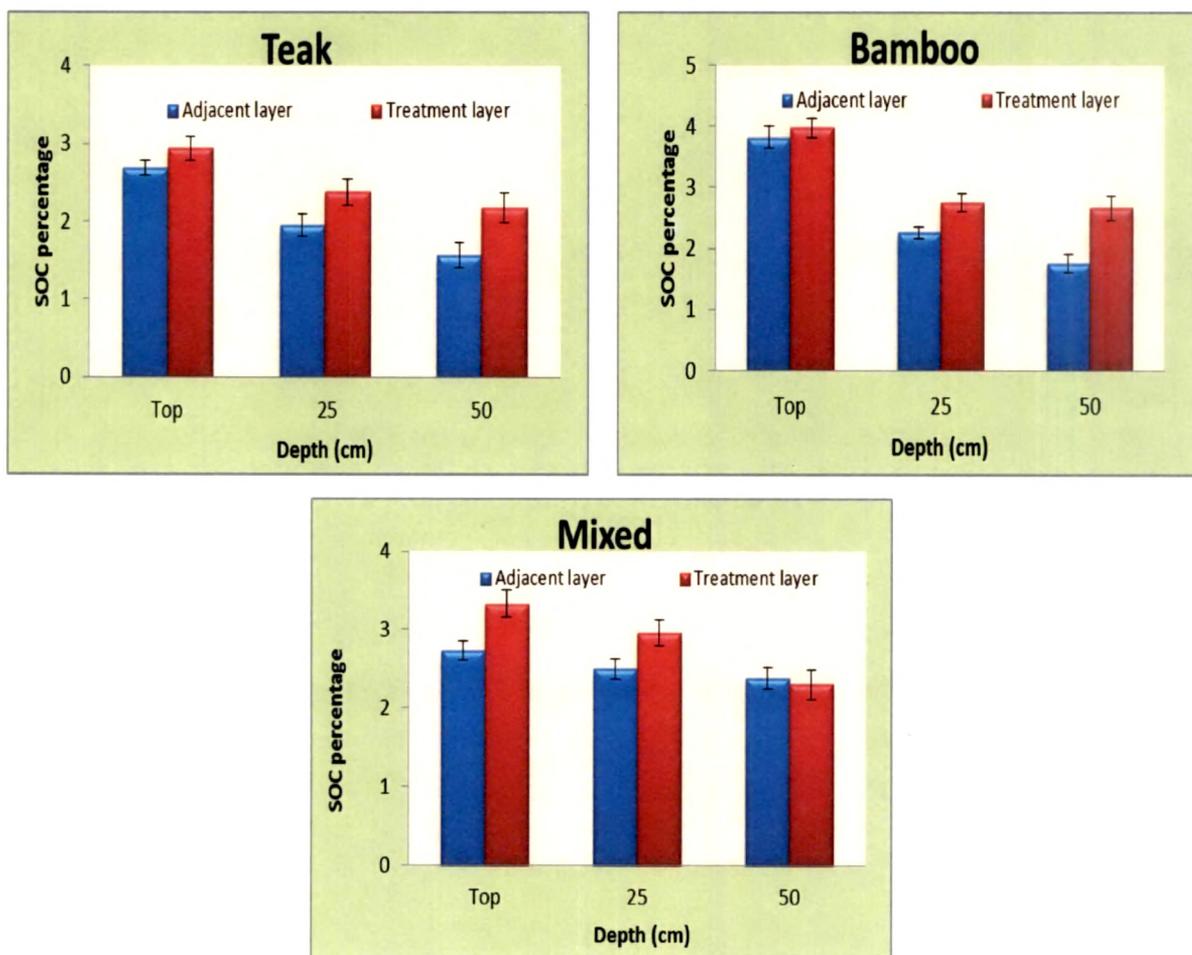
Pooled SOC with a depth interval of 25 cm showed how SOC movement across the soil system gets differed due to vegetal cover (Figure 5). The SOC content was calculated as 223.52 t ha<sup>-1</sup>, 201.36 t ha<sup>-1</sup> and 196.09 t ha<sup>-1</sup> up to 125 cm depth under teak, bamboo and mixed land cover respectively (Figure 5). The top layer (0-25cm) had 73.91 t ha<sup>-1</sup>, 74.44 t ha<sup>-1</sup> and 69.49 t ha<sup>-1</sup>, which was about 31.40%, 34.05% and 32.06% of total carbon of teak, bamboo and mixed land cover respectively. A steep fall in the SOC content was observed up to 50 cm and at subsequent depths the decrease was much lesser. Thus top layer had more amount of carbon as compared to deeper layers of soils under three types of land cover. Bamboo land cover had more amount of carbon in the top layer (0-25 cm) as compared to teak and mixed land cover (Figure 5). But at the deeper layers (beyond 50cm) teak land cover had more amount of carbon followed by bamboo and mixed land cover (Figure 5).



**Figure 5:** SOC content (t ha<sup>-1</sup>) under three types of land cover.

### 3.1.2 SOC in the soils collected from litter bag experiment study

SOC concentration was increased in treatment layers (where litter kept), at all the three different depths, of soils as compared to adjacent layers (where litter not kept) under three types of land cover (Figure 6). The increase was much higher in deeper layers of soils under three types of land cover. Increase of SOC in treatment layer was significant at  $P < 0.05$  level. The increase of SOC was more in deeper layers as compared to top layers of three types of land cover (except at 50 cm layer in mixed land cover, here the values are virtually same).



**Figure 6:** SOC (%) in the soil (treatment layer) of litter bag study and adjacent layer of three different stands and depths with standard error bars ( $n=3$ ).

### 3.1.3 SOC pools

Results of physical fractionation of SOC (into two different size fractions such as  $>250 \mu\text{m}$  and  $<250 \mu\text{m}$ ) at three different types of land cover gave a better understanding of SOC movement in the soil. The present study was combined the four different size fractions into two important SOC pools viz., fractionated soil sample fractions ( $>500-2000 \mu\text{m}$ ,  $>250-500 \mu\text{m}$ ) was called mobile pool (Pool 1) and while  $>53-250 \mu\text{m}$  and  $<53 \mu\text{m}$  sample fractions were designated as the recalcitrant pool (Pool 2). The SOC content within Pools 1 and Pool 2 decreased (few exclusions) with increasing soil depth of three types of land cover. The SOC content in Pool 2 was much higher as compared to Pool 1 at different depths of three types of land cover. However, the proportions of pool size (Pools 1 and Pool 2) in the composite samples of the three types of land cover remained almost the same (5-20% for Pool 1 and 95-80% for Pool 2) at different depths (Table 3). Variation in vegetal cover showed minimal impact in Pool values. Differences seen across in Pools 1 and Pool 2 were statistically significant at  $P < 0.01$  level.

Physical fractionation of soils collected from litter bag experiment showed an increase in SOC of Pools 1 and Pool 2 at three different depths of three types of land cover (Figure 7). The increase in SOC of Pools 1 and Pool 2 at three different depths and between land cover was significant at  $P < 0.01$  level. The increase was more in Pool 1 and it was low in Pool 2 at three different depths of three types of land cover. The relative increase in SOC was more in lower layers (25 and 50 cm) as compared to top layers (0-2 cm) of three types of land cover. The increase in SOC of Pools 1 and Pool 2 at three different depths was higher in bamboo followed by mixed and teak land cover.

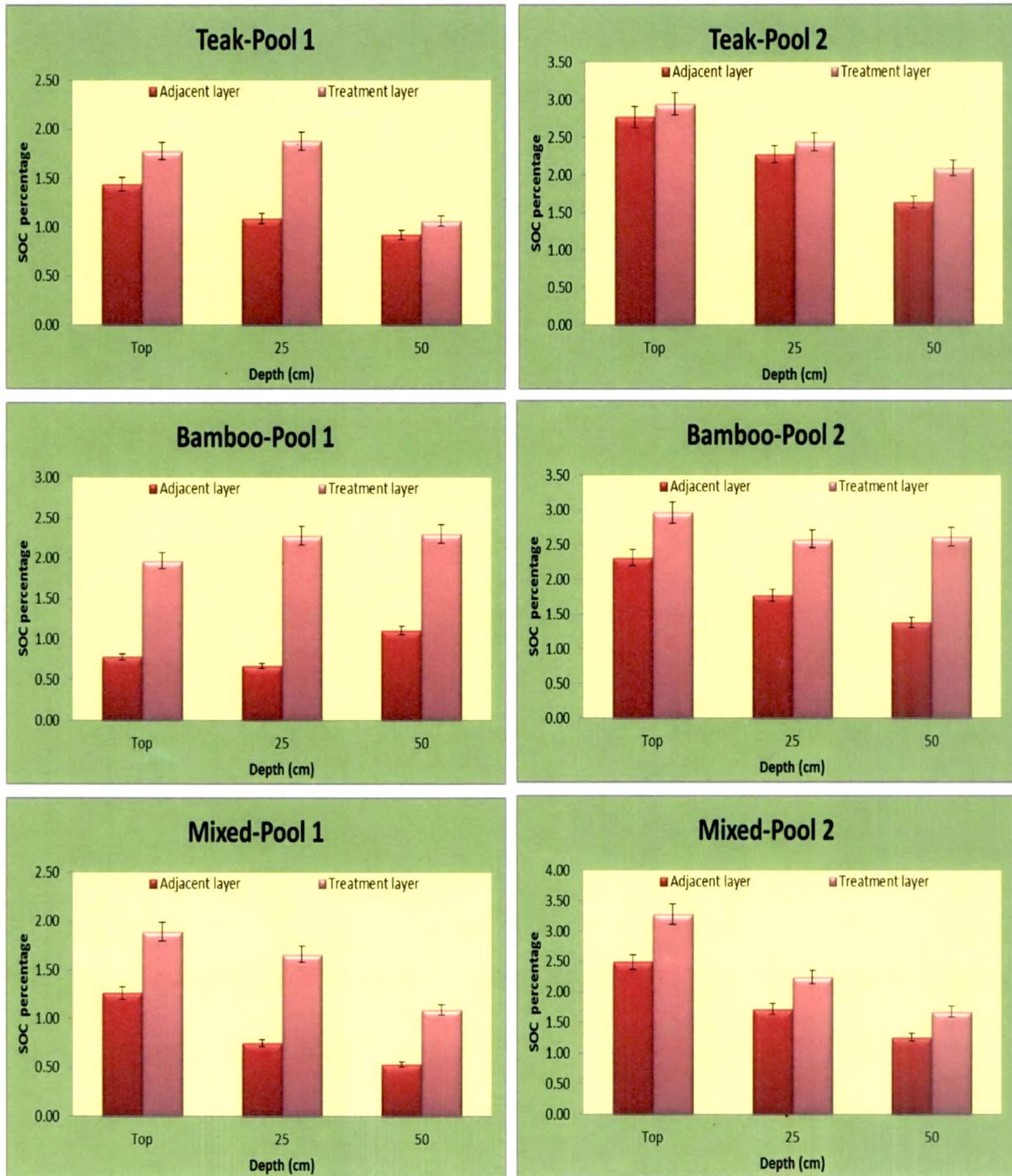
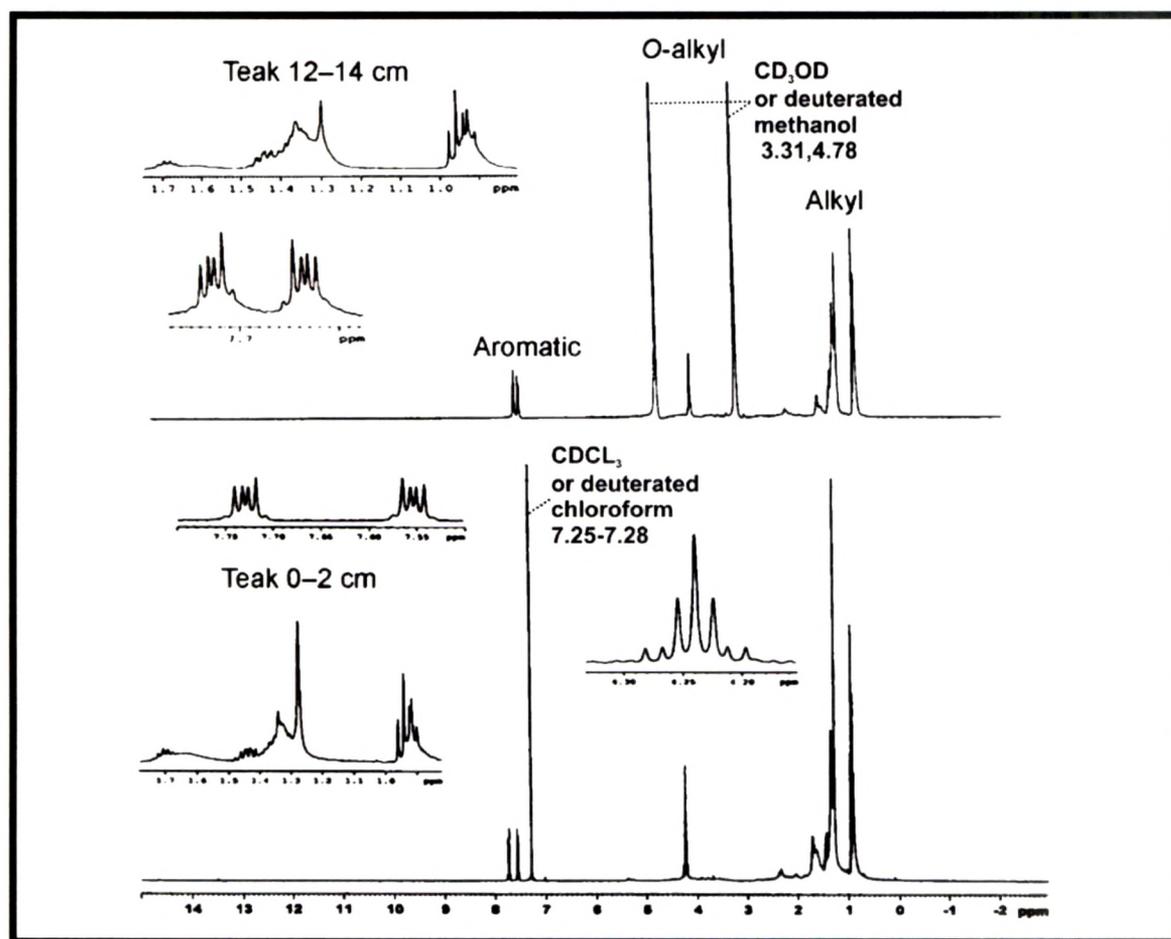


Figure 7: SOC content (%) in the Pools 1 and Pool 2 (treatment layer after 320 days) of litter bag study and adjacent layer of three types of land cover, three different depths with standard error bars ( $n=3$ ).

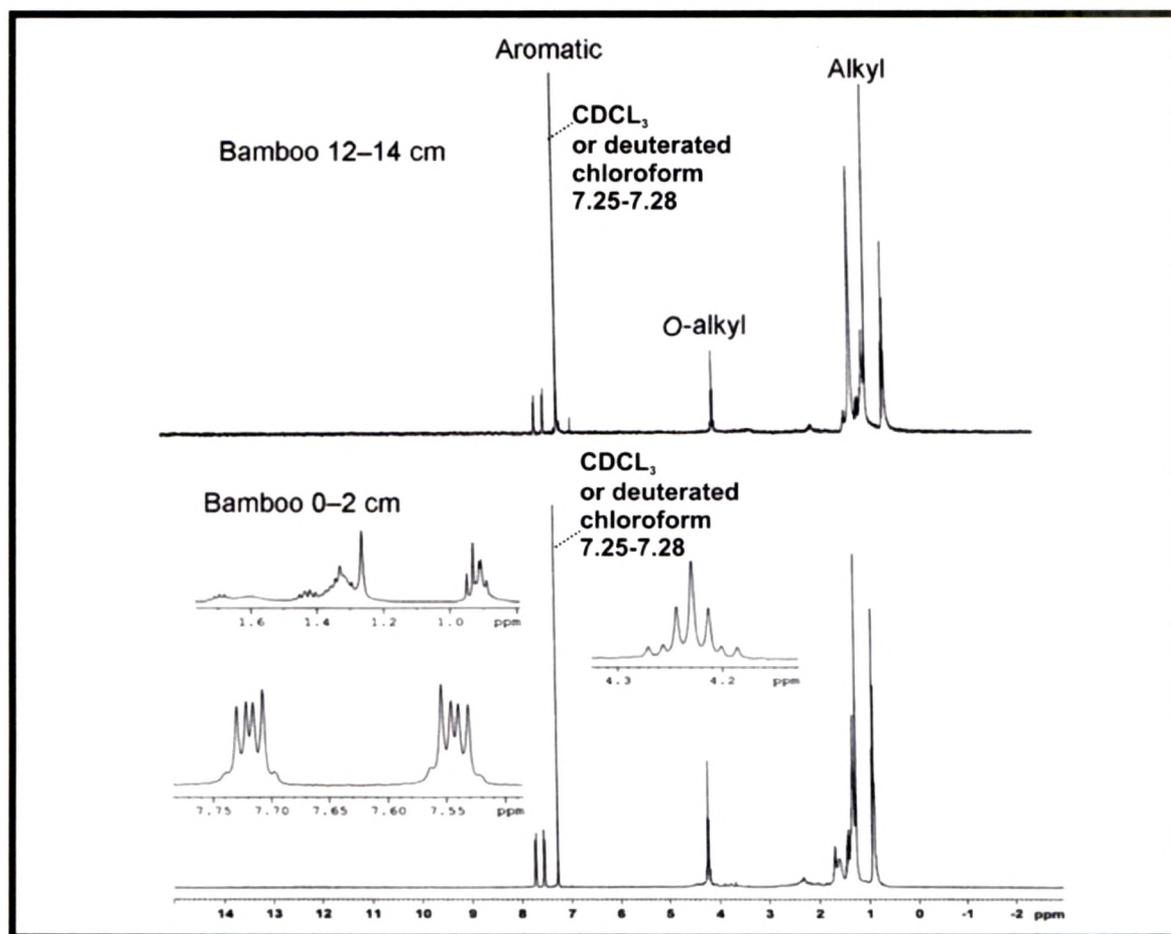
### 3.1.4 Proton NMR analysis of SOC

The data in Table 4 and spectra on Figures 8-10 showed the proton NMR spectra acquired for the soil samples at two different depths (0-2 cm and 12-14 cm) of teak and bamboo land cover. It was also obtained for Pools 1 and Pool 2 of teak land cover. Soil samples displayed similar distribution of functional groups, in the following order viz., alkyl-C, *O*-alkyl-C, and aromatic-C. There is no difference in the results coming from teak and bamboo land cover. The carboxyl group was missing completely in all the samples. Variations in the proportion of different groups were minimal across land cover and across different depths. The most noticeable functional group was at 0.5-2 ppm region (Figure 8-10) i.e. alkyl-C. In teak land cover, the alkyl-C proportion decreased with increasing depths while it was contrasting in bamboo land cover (Table 4). Another important group seen was, *O*-alkyl-C, (observed at 3-5ppm) *O*-alkyl-C region slightly increased from 0-2 cm to 12-14 cm layer while it was opposite in bamboo land cover (*O*-alkyl-C region was decreased from 0-2 cm to 12-14 cm layer). It was almost the same in Pools 1 and Pool 2 of teak land cover (Table 4). Aromatic-C region was noticed at 7-8 ppm. Aromatic-C group was increased from 0-2 cm to 12-14 cm layer of teak land cover. But it was reverse in bamboo land cover. Though, aromatic-C was not much differed in Pools 1 and Pool 2 of teak land cover. Proportions of these three groups in Pools 1 and Pool 2 also remained the same (Figure 10). Variations in the proportions of different groups were minimal across vegetal cover and across depths (Table 4). The proportions of *O*-alkyl and aromatic groups almost remained the same (Figures 8-10). Fluctuations are seen in the proportion of alkyl groups at two different depths of teak and bamboo land cover (Figures 8-10).

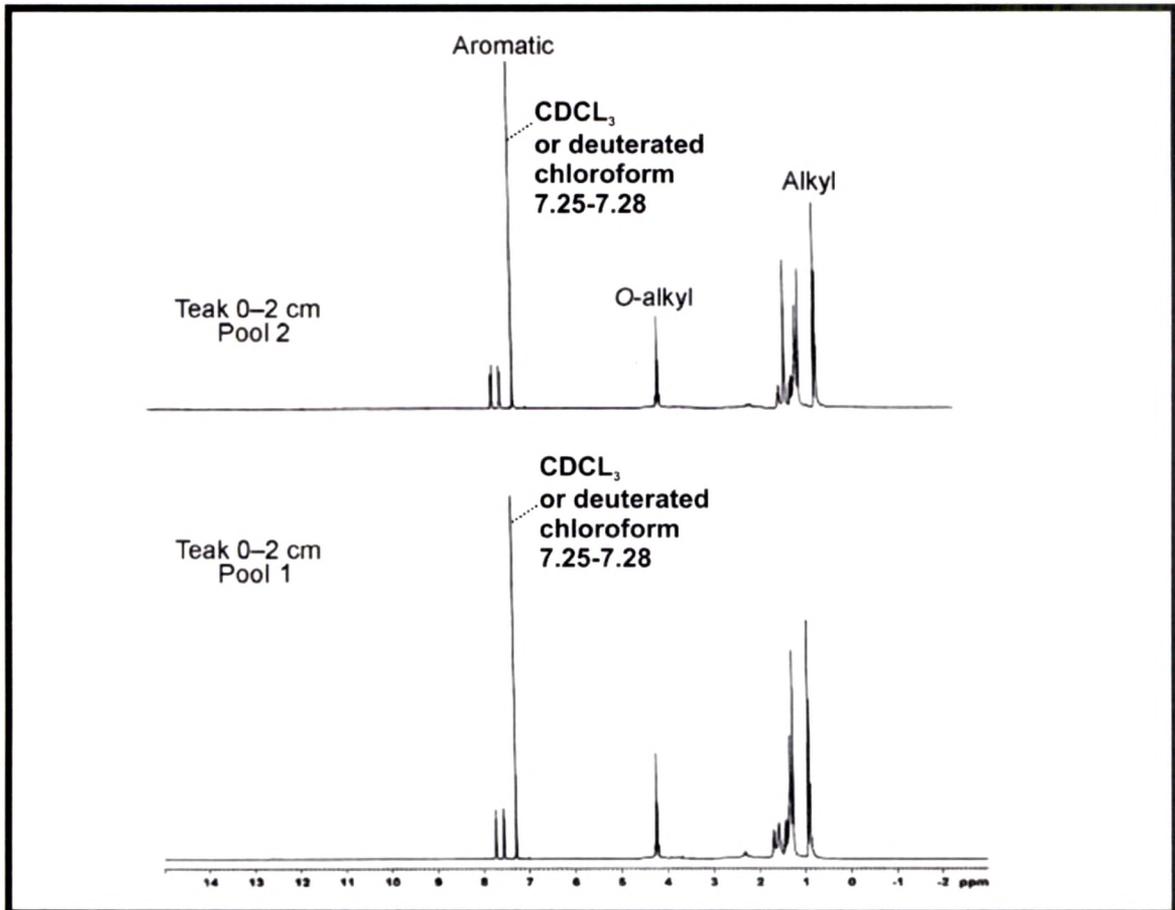


**Figure 8:** Proton (<sup>1</sup>H) NMR spectra of teak soil extracts at 0-2 and 12-14cm depths.

The spectra shows three groups (alkyl, O-alkyl and aromatic).



**Figure 9:** Proton (<sup>1</sup>H) NMR spectra of bamboo soil extracts at 0-2 and 12-14cm depths. The spectra shows three groups (alkyl, *O*-alkyl and aromatic).



**Figure 10:** Proton ( $^1\text{H}$ ) NMR spectra of pools 1 and pool 2 (physical fractions of teak) at 0-2cm depth. The spectra shows three groups (alkyl, O-alkyl and aromatic).

### 3.1.5 Carbon isotope analysis

#### 3.1.5.1 Stable carbon isotopes ( $\delta^{13}\text{C}$ )

The stable carbon isotope composition of plant litter to soils (at three different depths) of teak, bamboo and mixed land cover ranged from  $-27.90 \pm 0.01$  to  $-21.22 \pm 0.01$ ,  $-28.37 \pm 0.01$  to  $-21.47 \pm 0.02$  and  $-26.66 \pm 0.01$  to  $-24.03 \pm 0.02$ , respectively (Figure 11a). The increase in  $\delta^{13}\text{C}$  values with depth was observed in soils of three types of land cover (Figure 11a). Differences in  $\delta^{13}\text{C}$  values at different depths and between land cover types were statistically significant at  $P < 0.01$  level. Enrichment of  $\delta^{13}\text{C}$  values (with increasing depth) observed in three types of vegetal cover is attributed to isotopic discrimination associated with soil organic matter decomposition. This is cross checked with Rayleigh equation fitted between observed carbon contents and corresponding  $\delta^{13}\text{C}$  signatures at different depths in the profile (Accoe *et al.*, 2002; Diachon *et al.*, 2009). The equation is,

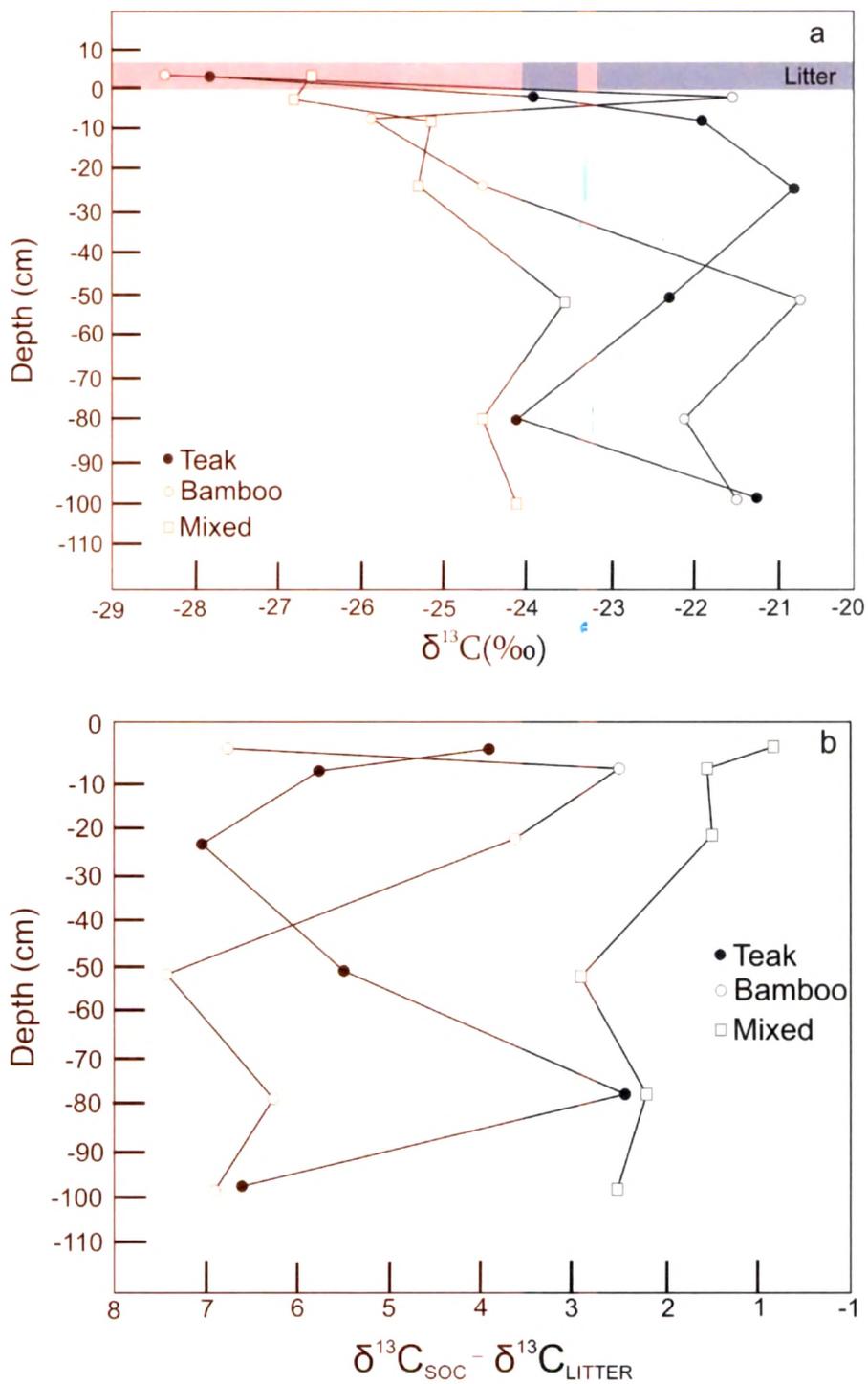
$$\delta = \delta_0 + \epsilon \ln[C/C_0]$$

where  $\delta_0$  and  $C_0$  represent initial signature and initial carbon content.  $R^2$  value of mixed cover is high (0.68) (Figure 12). The enrichment factor associated with the observed data in the soil profile of teak, bamboo and mixed land cover was  $-0.27 \pm 0.8$ ,  $-1.46 \pm 0.8$  and  $-1.36 \pm 0.5$ , respectively. The changing  $\delta^{13}\text{C}$  values were compared across the three types of land cover at three different depths by calculating a discrimination factor relative to the respective plant litter  $\delta^{13}\text{C}$  values. The discrimination factor ( $\delta^{13}\text{C}_{\text{soc}} - \delta^{13}\text{C}_{\text{litter}}$ ) at three different depths of teak, bamboo and mixed land cover ranged from 3.91 to 7.02, 6.84 to 7.63 and -0.1 to 2.97, respectively (Figure 11b). The negative discrimination factor value was observed at 0-2 cm layer of mixed land cover.

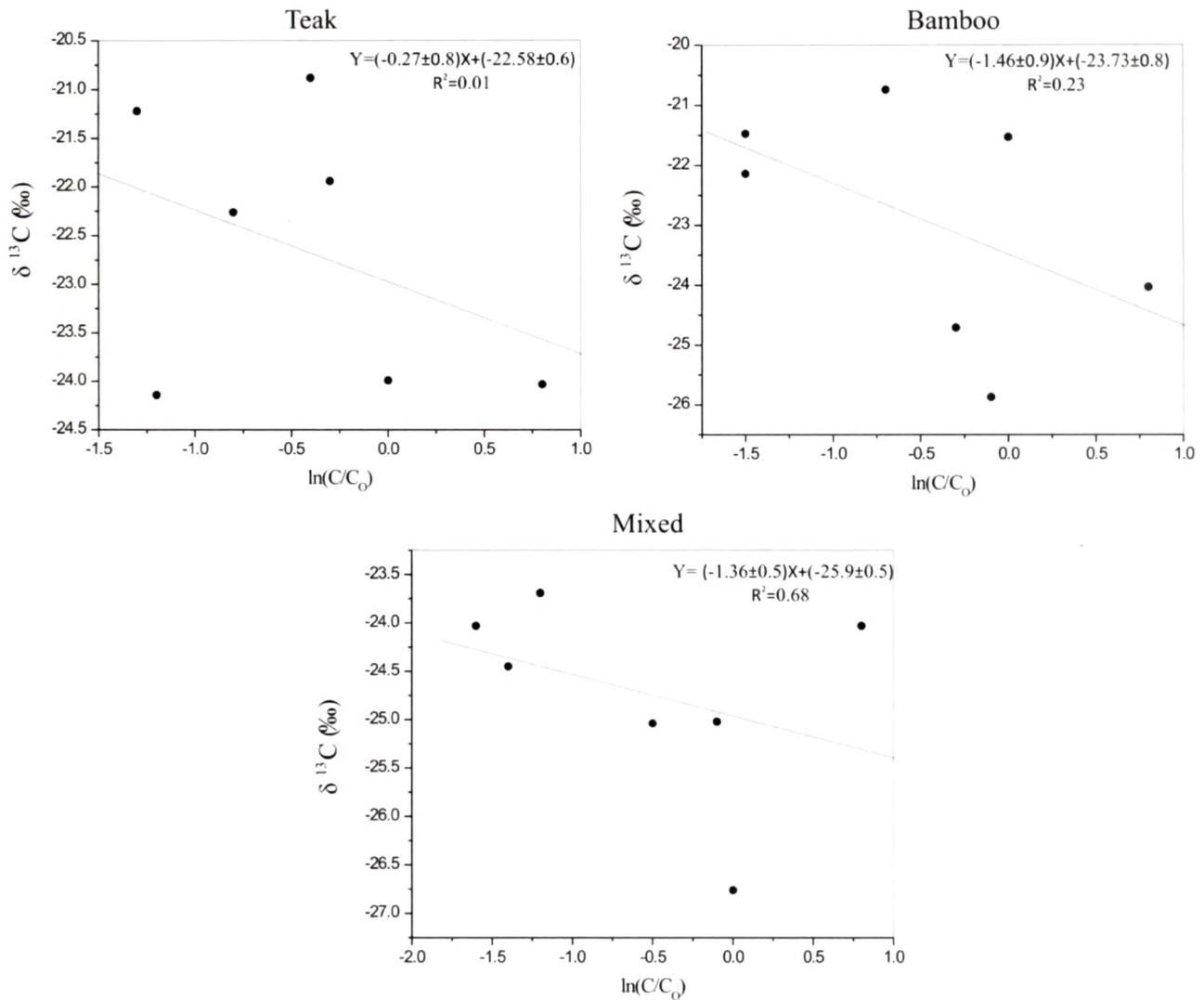
#### 3.1.5.2 Correlation analysis

The mean  $\delta^{13}\text{C}$  values of litter and SOC at three different depths of three types of vegetal cover were plotted against the logarithm of their respective mean carbon content (Figure 13). The slope of this regression line (beta value,  $\beta$ ) predicts the

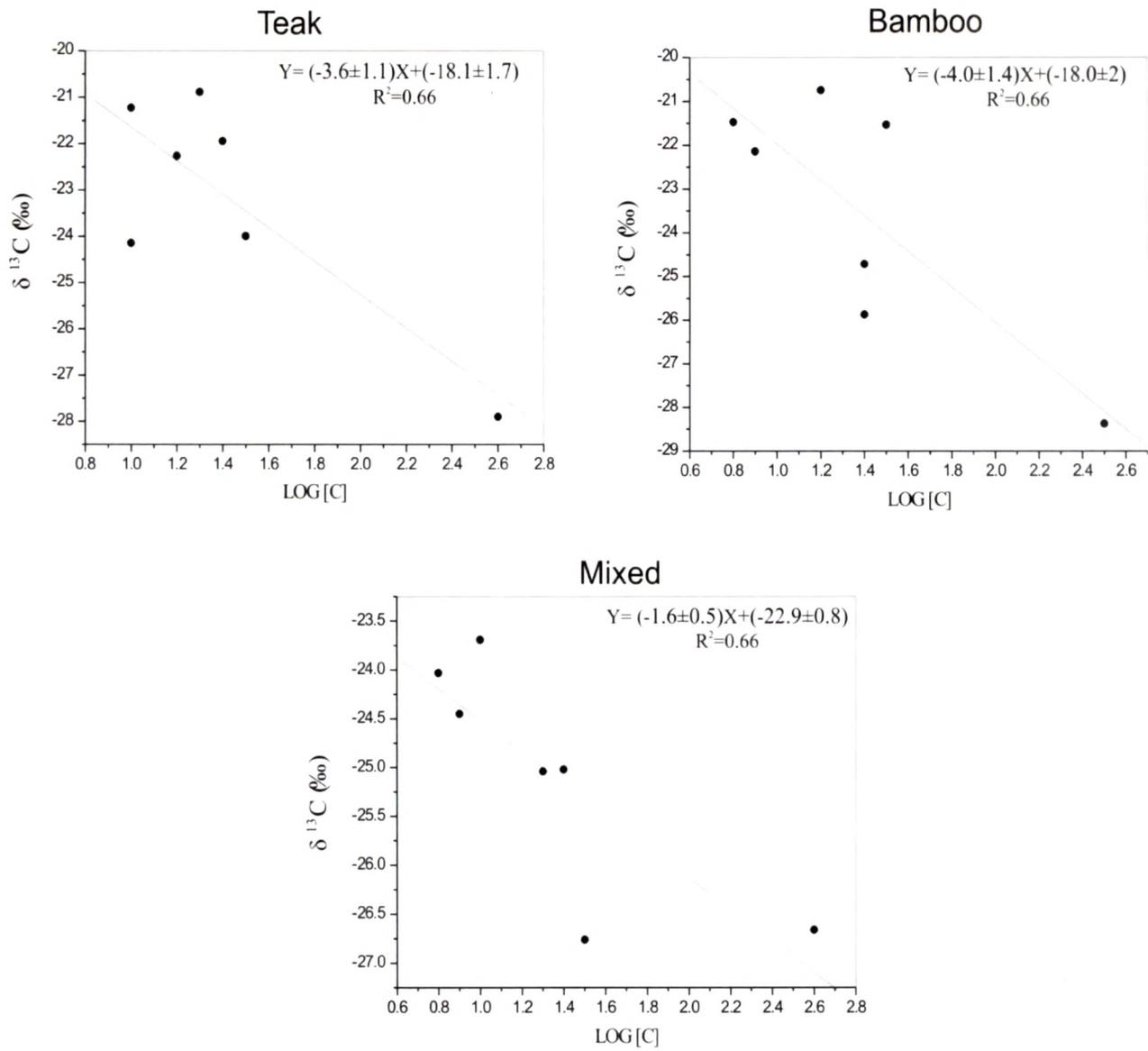
expected change in the  $\delta^{13}\text{C}$  value, or isotopic discrimination, for every tenfold increase in carbon concentration (Garten *et al.*, 2000). The beta value was more in mixed land cover followed by teak and bamboo land cover (Figure 13). The isotopic composition ( $\delta^{13}\text{C}$ ) in bamboo and mixed land cover soils at three different depths was positively correlated with abiotic variables such as soil pH and % sand (Figures 14-16). But it was not seen in teak land cover. Also a negative relationship between  $\delta^{13}\text{C}$  of SOC and % silt was found in bamboo and mixed types of land cover. There was no relationship between  $\delta^{13}\text{C}$  of SOC at different depths and % clay in teak land cover (Figure 14). But in bamboo and mixed land cover,  $\delta^{13}\text{C}$  of soil at three different depths was positively correlated with % clay (Figure 15). However the study did not find relationship between  $\delta^{13}\text{C}$  of SOC at different depths and % of silt + clay of three types of vegetal cover (Figure 14-16). The relationship between beta values and abiotic variables of three types of land cover at three different depths were shown in Figures 17-18. The beta values of three types of land cover were positively correlated with soil pH (Figure 17). Other variables such as sand, silt, clay, and HF-soluble carbon are weakly correlated with beta values of three types of land cover (Figure 17).



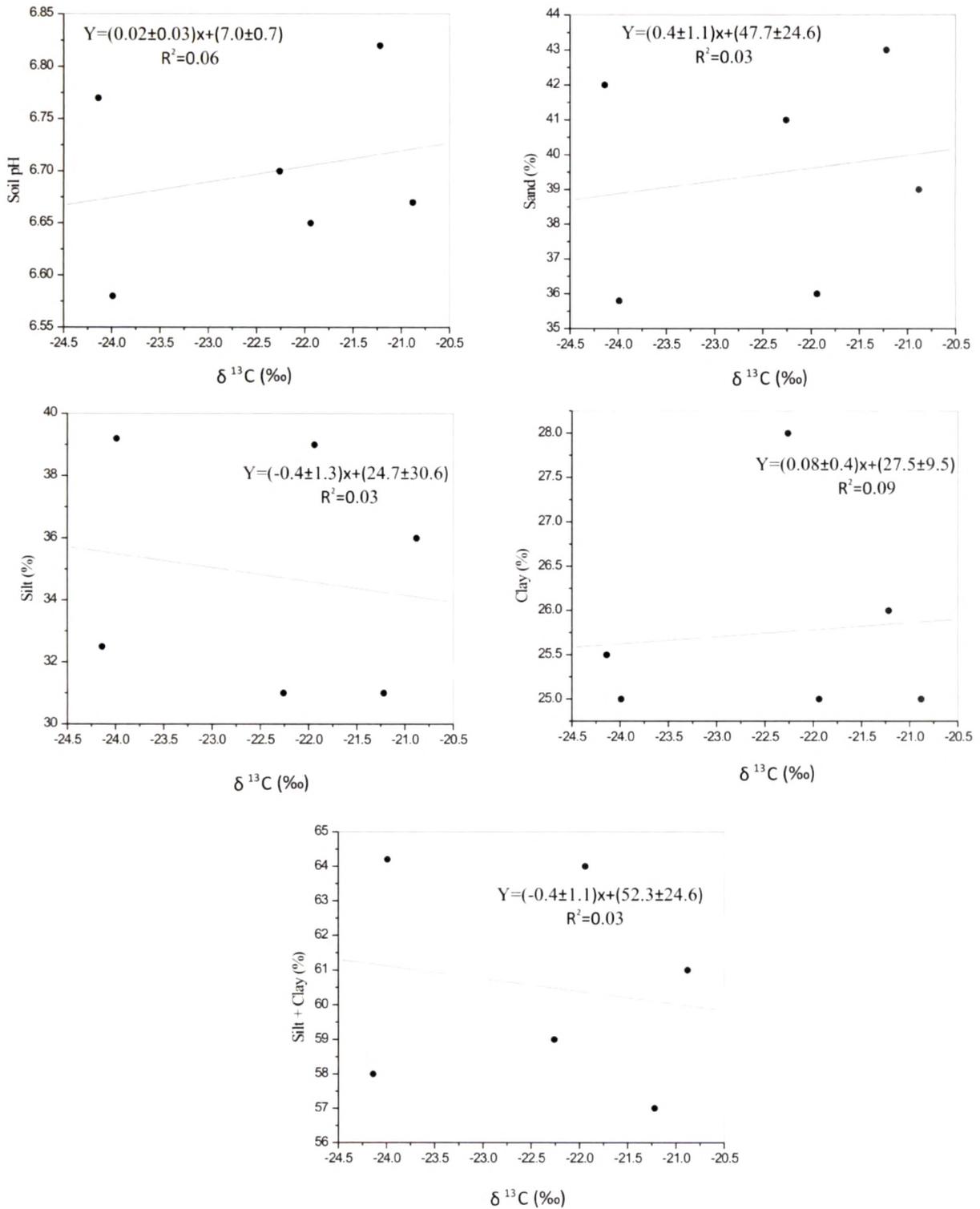
**Figure 11:** The  $\delta^{13}C_{SOC}$  values at three different depths (a) and the discrimination factor values (b) at three different depths of teak, bamboo and mixed land cover.



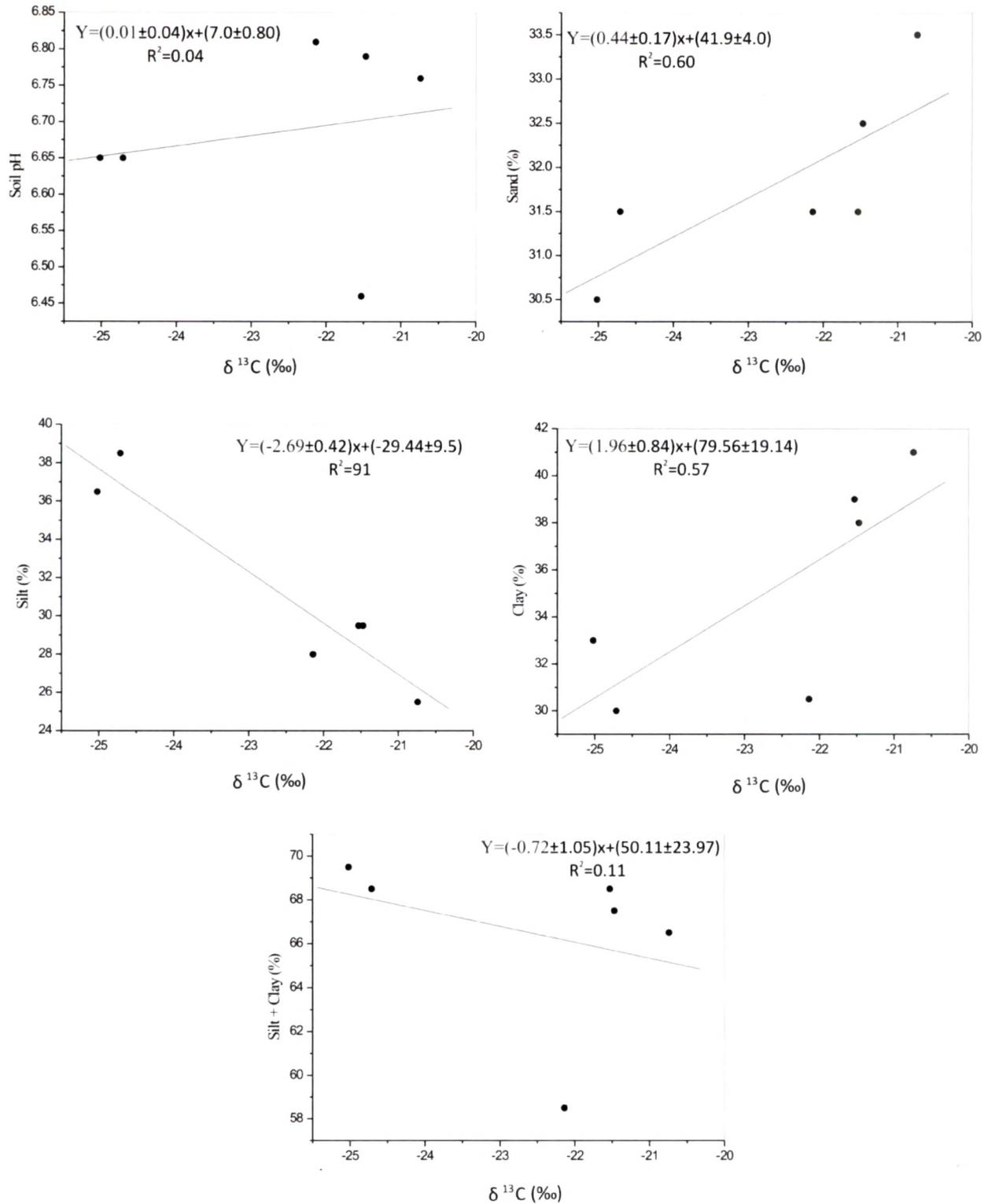
**Figure 12:** Regression line between  $\ln(C/C_0)$  and the  $\delta^{13}C$  values at three different depths (0-2, 45-60 and 90-100 cm) of teak, bamboo and mixed vegetal cover.



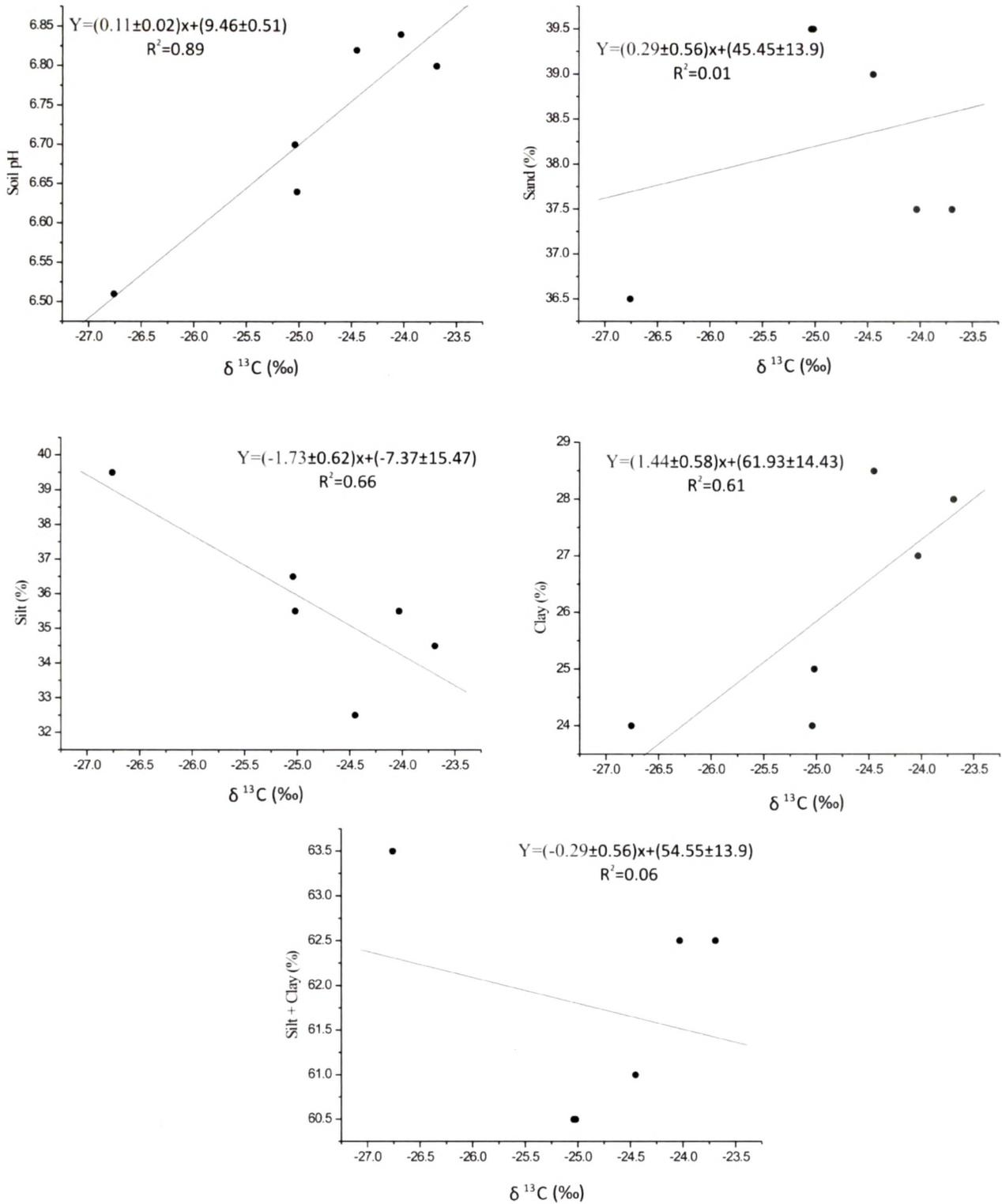
**Figure 13:** Regression line between  $\delta^{13}\text{C}$  and log-transformed carbon ( $\text{g kg}^{-1}$ ) of litter and soils at three different depths of three types of vegetal cover.



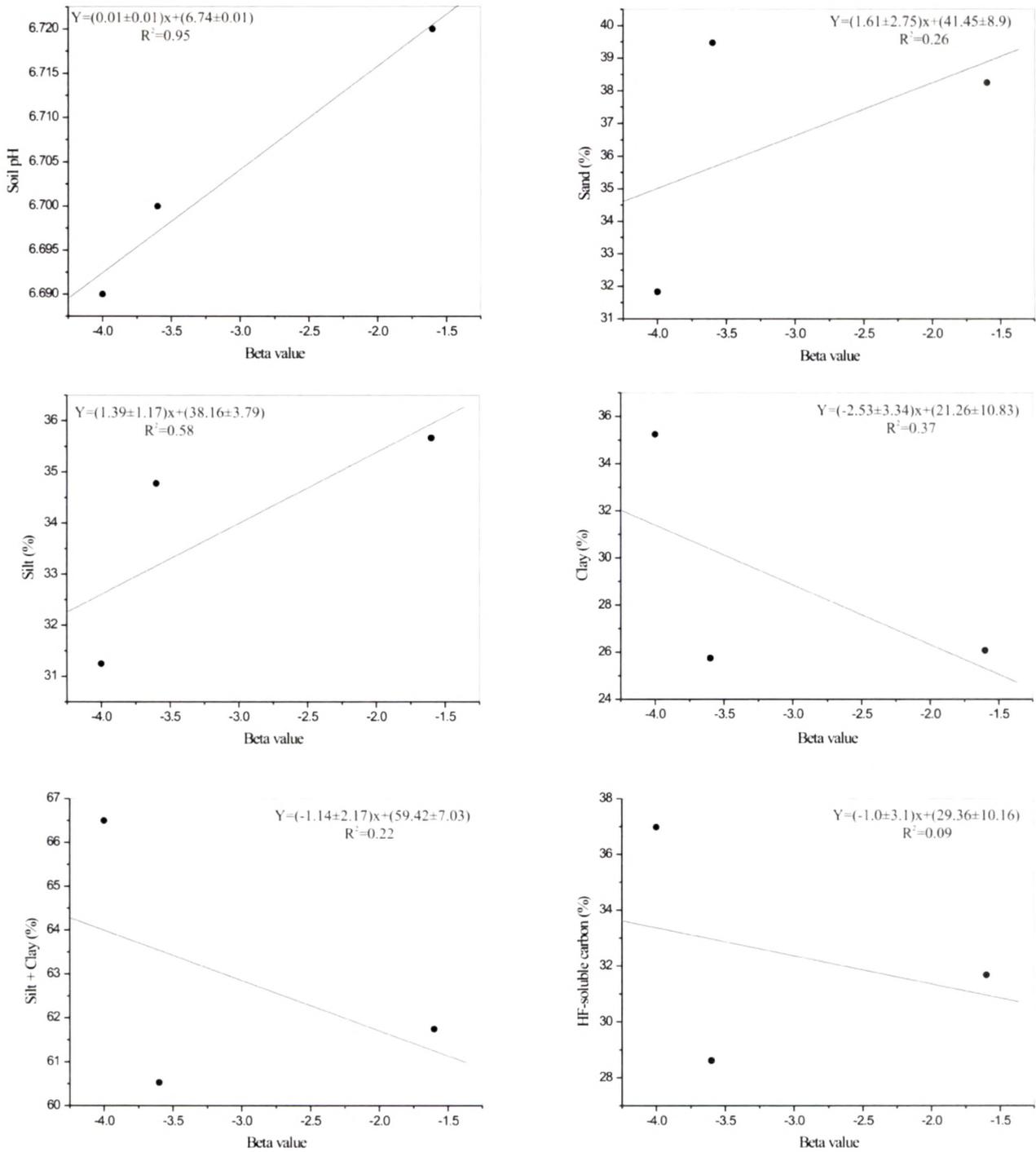
**Figure 14:** The relationship between  $\delta^{13}\text{C}$  and abiotic variables (soil pH, sand (%), silt (%), clay (%) and silt+clay (%)) at three different depths of teak land cover.



**Figure 15:** The relationship between  $\delta^{13}\text{C}$  and abiotic variables (soil pH, sand (%), silt (%), clay (%) and silt+clay (%)) at three different depths of bamboo land cover.



**Figure 16:** The relationship between  $\delta^{13}\text{C}$  and abiotic variables (soil pH, sand (%), silt (%), clay (%) and silt+clay (%)) at three different depths of mixed land cover.



**Figure 17:** The relationship between beta value ( $\beta$ ) and soil pH, sand (%), silt (%), clay (%), Silt +clay (%) and HF-soluble carbon (%) of three types of land cover.

### 3.1.5.4 Radiocarbon age of SOC

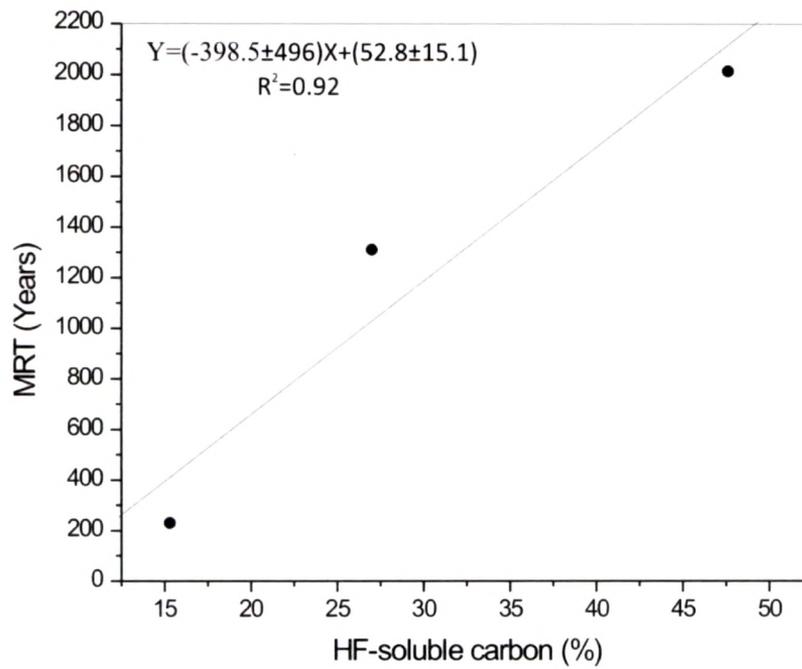
Calculated radiocarbon age and mean residence time (MRT) at three different depths of teak vegetal cover were presented in Table 5. Radiocarbon age increased with increasing soil depth. The top soil (0-2 cm) contains a significant portion of carbon fixed in recent decades indicated by the presence of bomb carbon ( $pMC=100.80\pm 0.95$ ). The lowest value of  $76.70\pm 0.77$  pMC was observed at 90-100 cm depth and this corresponds to a  $^{14}C$  age of  $2200\pm 80$  years BP. The pMC at 45-60 cm was  $83.72\pm 0.84$  with corresponding to  $^{14}C$  age of  $1470\pm 80$  years BP. The radiocarbon age increases almost linearly with depth reaching to a value of 2200 years at the depth of 100 cm. The positive linear relationship between HF-soluble carbon and MRT was found in teak vegetal cover (Figure 18). Positive linear relationship was also seen between discrimination factor ( $\delta^{13}C_{soc} - \delta^{13}C_{litter}$ ) values and MRT of teak vegetal cover (Figure 19).

### 3.1.6 HF-soluble carbon

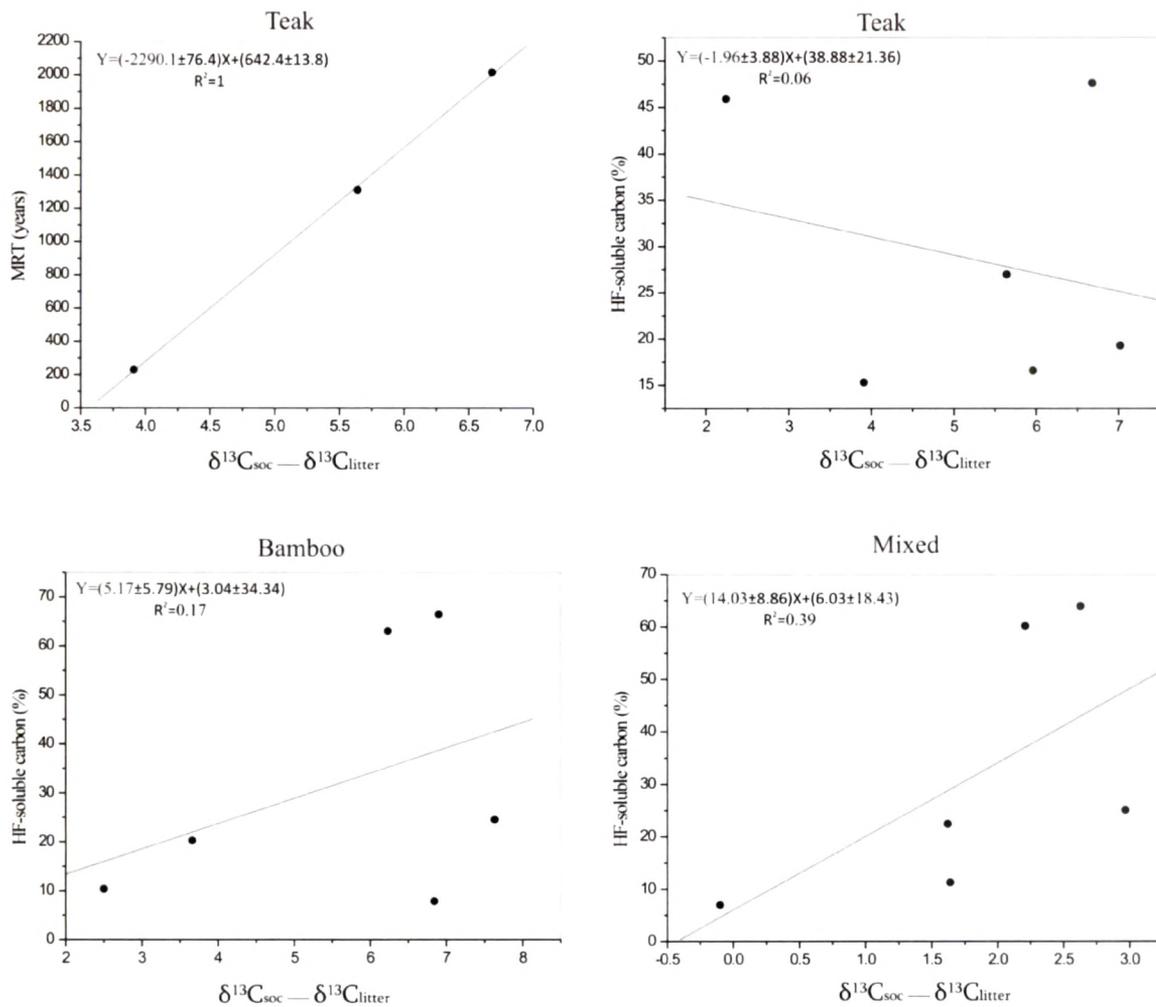
#### 3.1.6.1 HF-soluble carbon in the soils used for carbon isotope analysis

The percentage of HF-soluble carbon (of total SOC) at three different depths for three types of land cover is shown in Table 6. The percentage of HF-soluble carbon ranged between 15.3 to 47.6 %, 7.9 to 66.5 % and 7 to 64 % for teak, bamboo and mixed land cover respectively. The percentage of HF-soluble carbon was more at top layer (0-2 cm) of teak followed by mixed and bamboo vegetal cover. At deeper layer (90-100 cm), the percentage of HF-soluble carbon was higher in bamboo vegetal cover followed by mixed and teak land cover. Overall, the HF-soluble carbon was more in deeper layer of soils under three types of vegetal cover. A positive linear relationship (very weak) was found between  $\delta^{13}C$  values and HF-soluble carbon at three different depths of teak vegetal cover (Figure 20). A positive linear relationship (very weak) was seen between discrimination factor ( $\delta^{13}C_{soc} - \delta^{13}C_{litter}$ ) values and HF-soluble carbon of bamboo

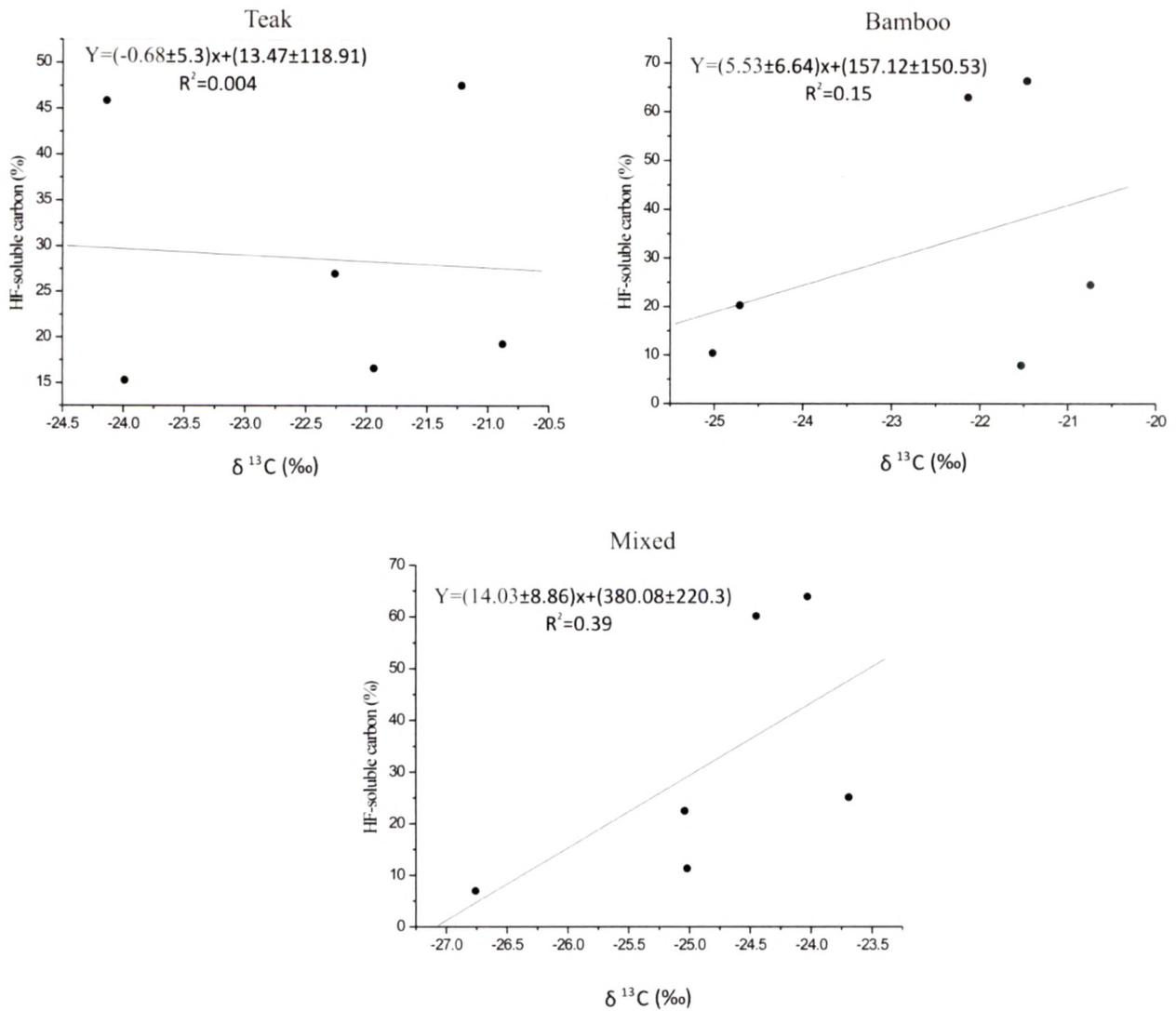
and mixed types of land cover (Figure 21), while it was not seen in teak land cover.



**Figure 18:** Relationship between HF-soluble carbon and MRT at three different depths of teak vegetal cover.



**Figure 19:** Regression line between the discrimination factor ( $\delta^{13}\text{C}_{\text{soc}} - \delta^{13}\text{C}_{\text{litter}}$ ) values and MRT of teak, HF-soluble carbon concentrations of teak, bamboo and mixed vegetal cover.



**Figure 20:** Regression line between δ<sup>13</sup>C and HF-soluble carbon of three types of land cover.

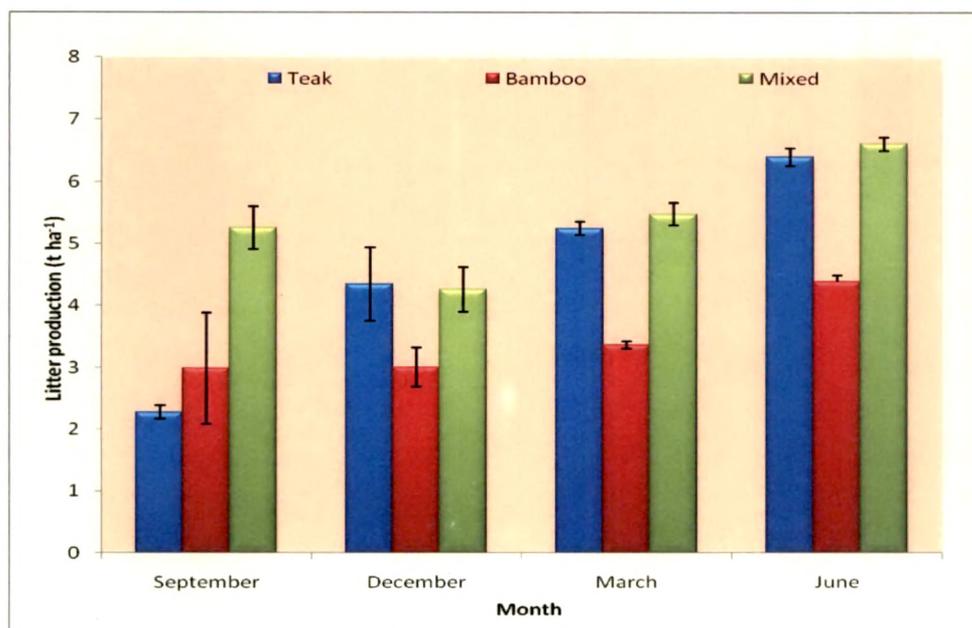
### 3.1.6.2 HF-soluble carbon in SOC Pools 1 and Pool 2

The amount and percentage of HF-soluble carbon in SOC pools 1 and Pool 2 was presented in Table 7. The amount of HF-soluble carbon was more in Pool 2 as compared to Pool 1 at three different depths of three types of land cover. The amount of HF-soluble carbon was higher in Pool 2 at top layer under teak land cover followed by bamboo and mixed land cover. The amount of HF-soluble carbon was decreased with increase in depth at three types of land cover. The percentage of HF-soluble carbon in SOC Pools 1 and Pool 2 was maximum in top layers of soils under three types of land cover. The minimal difference (percentage of HF-soluble carbon) was noticed in SOC pools 1 and Pool 2 at 0-2 cm layer under three types of land cover (Table 7).

## 3.2 Biological parameters

### 3.2.1 Litter fall

Litter fall (dry weight of leaves) gradually increased from September to June at three types of land cover sites (Figure 21). Litter fall was more in mixed land cover followed by teak and bamboo land cover. Litter fall values showed significant ( $P < 0.01$ ) differences between types of land cover and different periods of litter collection. There was a gradual increase in the litter fall values of teak and bamboo land cover. The increase was much higher in teak land cover. Spikes in the litter fall values of teak and bamboo land cover clearly revealed the deciduous nature of both the species. Mixed land cover showed a different pattern as it had several evergreen species as well. Annual leaf litter addition was maximum in mixed species land cover followed by that of teak and bamboo land cover.



**Figure 21:** Litter production ( $\text{t ha}^{-1}$ ) of three types of land cover at different seasonal months.

### 3.2.2 Litter decomposition

Litter bag experiments showed near completion in the decomposition of litter kept within a year (Figures 22-24). There was a difference in the decomposition of litter kept at different depths. Influence of plant trait variation could be seen in the rate of decomposition. Decomposition was faster in teak and mixed cover than in bamboo. Differences in the decomposition of litter for different types of leaf material at different depths in soil were found to be significant ( $P < 0.01$ ). The one kept at the top soil got decomposed to a maximum extent in the first 90 days and the proportion was less at the other two depths (Figures 22-24). At the end of 320 days decomposition was the maximum at all the depths. At the site where litter bags were exchanged between vegetal covers (teak litter bag in bamboo cover and *vice versa*), initially (at 90 days) the decrease was less but as time progressed proportion of decomposed material was almost similar (at 320 days) to the previous experiment (Figures 25-26).

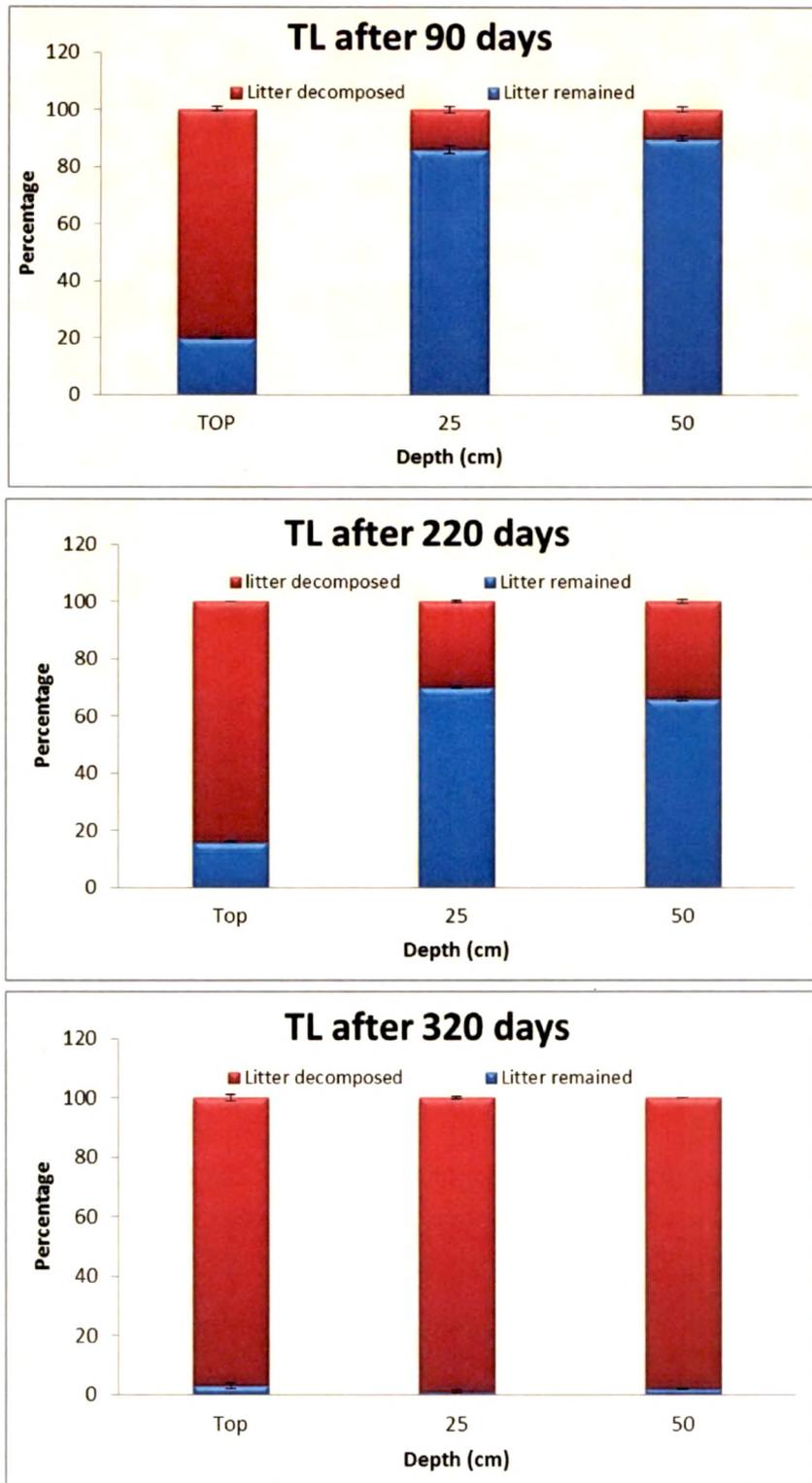
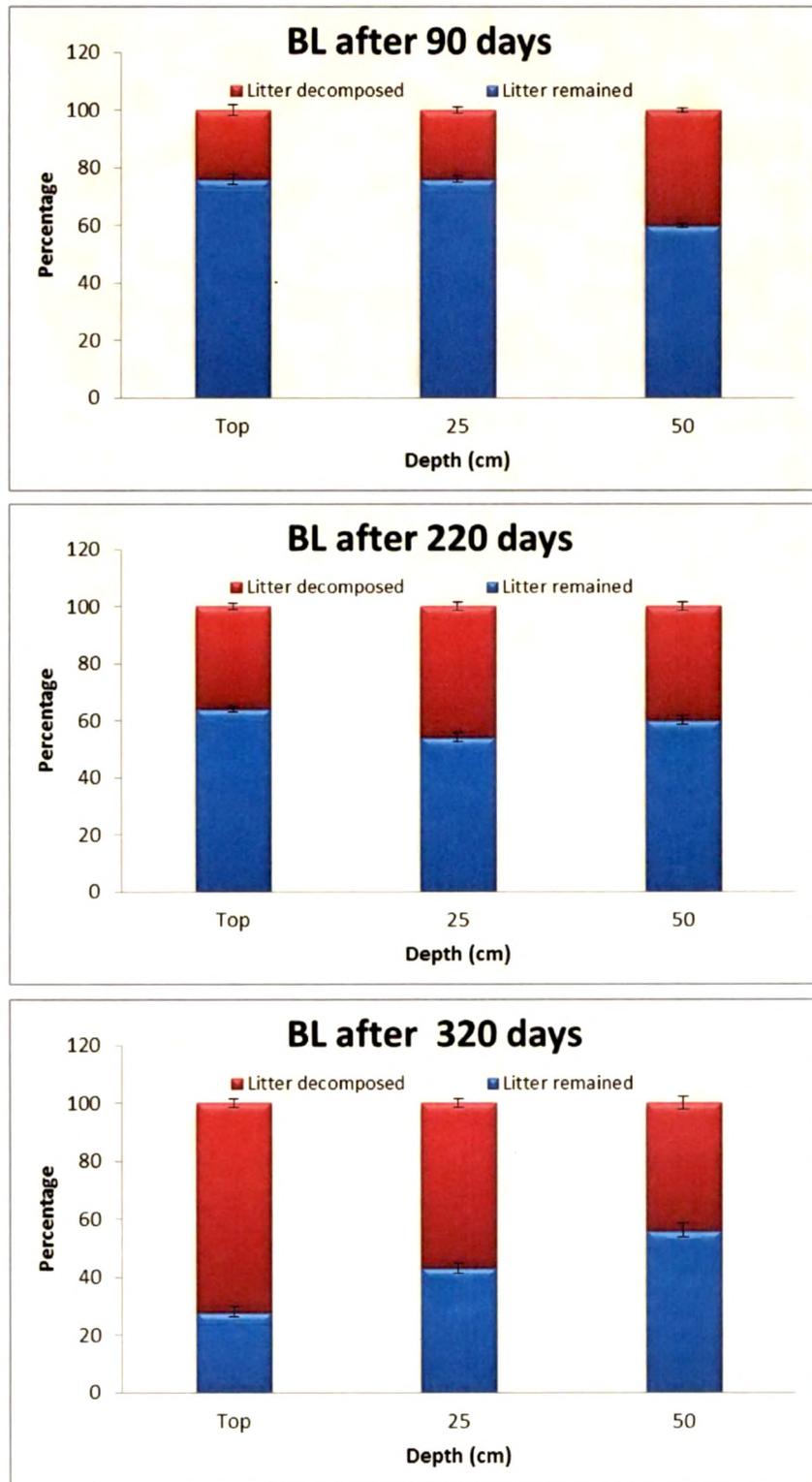
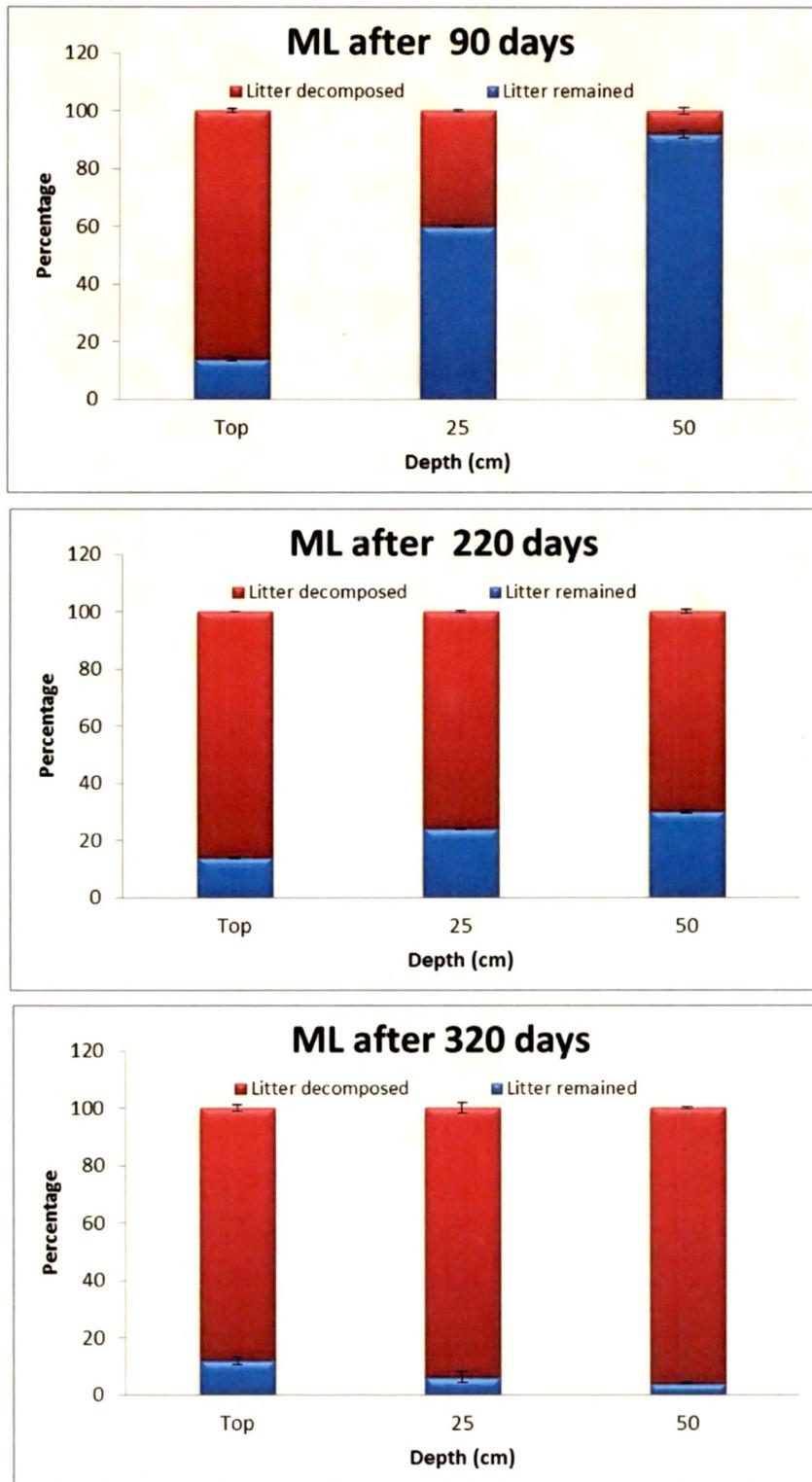


Figure 22: Litter decomposition of teak cover at three different depths, after 90, 220 and 320 days with standard error bar ( $n=3$ ). TL- teak litter.



**Figure 23:** Litter decomposition of Bamboo cover at three different depths, after 90, 220 and 320 days with standard error bar ( $n=3$ ). BL- bamboo litter.



**Figure 24:** Litter decomposition of mixed cover at three different depths, after 90, 220 and 320 days with standard error bar ( $n=3$ ). ML- mixed litter.

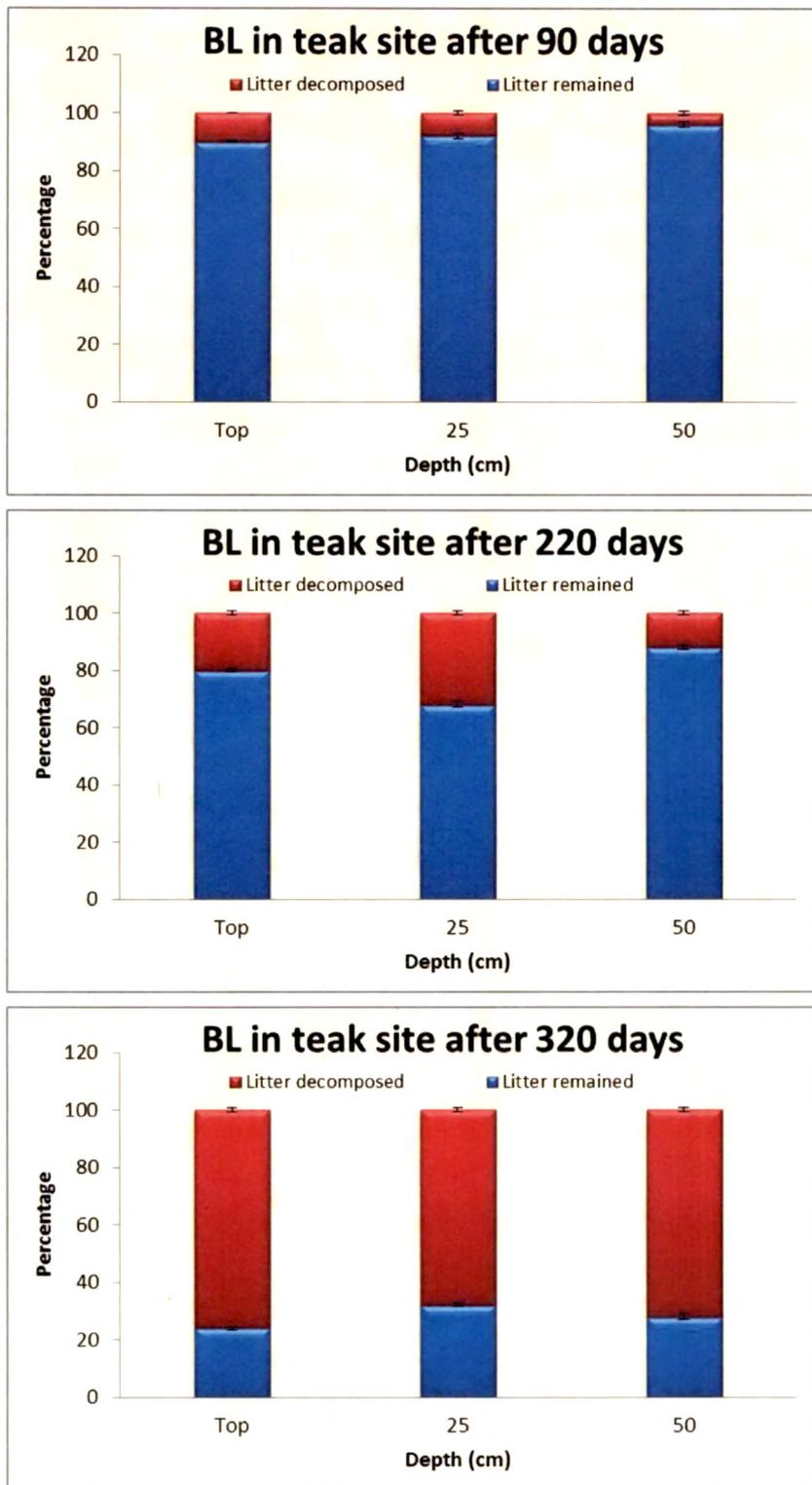


Figure 25: Litter decomposition of bamboo litter in teak site at three different depths, after 90, 220 and 320 days with standard error bar ( $n=3$ ). BL- bamboo litter.

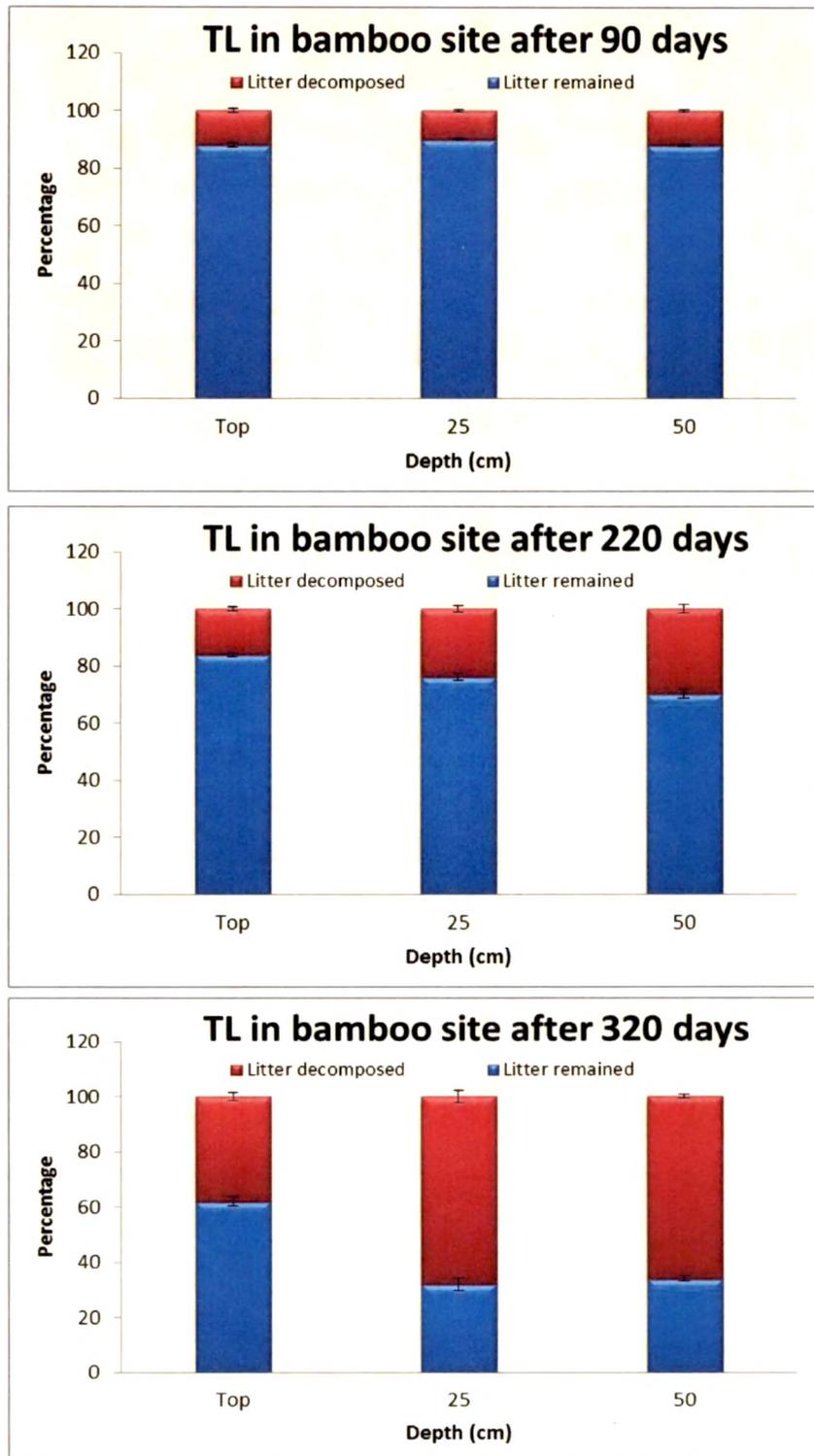
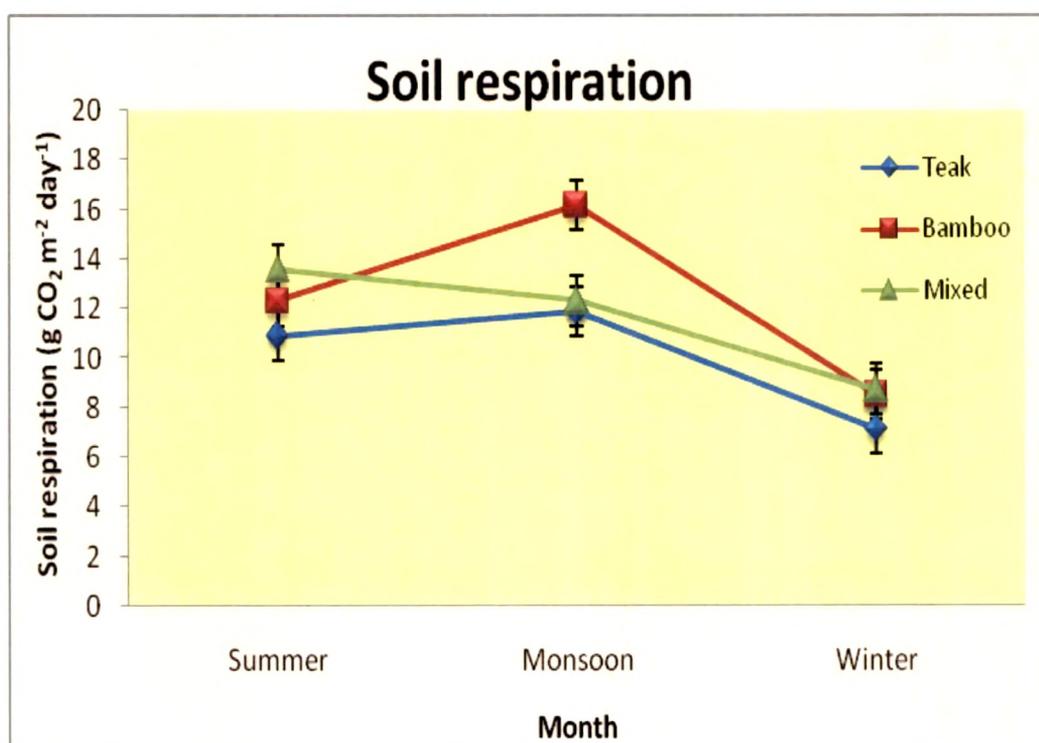


Figure 26: Litter decomposition of teak litter in bamboo site at three different depths, after 90, 220 and 320 days with standard error bar ( $n=3$ ). TL- teak litter.

### 3.2.3 Soil respiration

Soil respiration in teak land cover ranged from 7.11 to 11.88 g CO<sub>2</sub> m<sup>-2</sup> day<sup>-1</sup>, in bamboo land cover it ranged from 8.47 to 16.13 g CO<sub>2</sub> m<sup>-2</sup> day<sup>-1</sup> and in mixed land cover it ranged from 8.32 to 13.52 g CO<sub>2</sub> m<sup>-2</sup> day<sup>-1</sup> in three different seasons of the year (Figure 27). Soil respiration values are significant at  $P < 0.05$  level in three different seasons and between land covers. Both teak and bamboo land cover showed similar patterns in their values, high in monsoon and less in winter (Figure 27). Bamboo land cover showed higher soil respiration in monsoon than teak land cover. But it was contrast in mixed land cover; there soil respiration was maximum in summer.

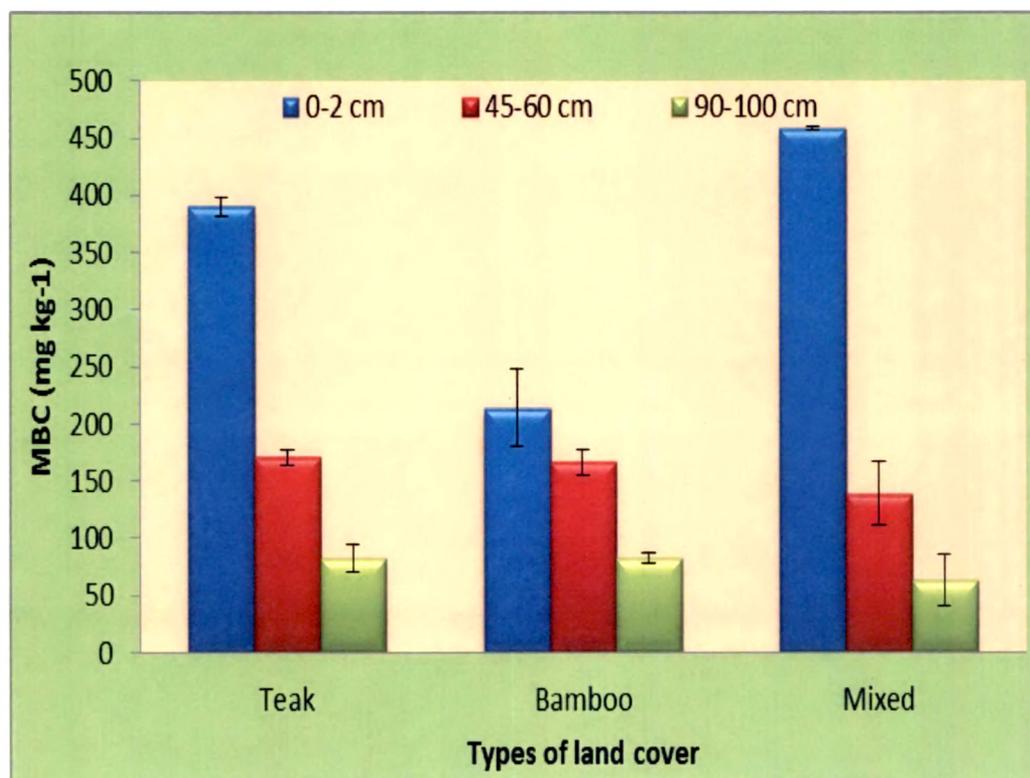


**Figure 27:** Soil respiration (g CO<sub>2</sub> m<sup>-2</sup> day<sup>-1</sup>) from three different vegetal cover soils with standard error bars ( $n = 5$ ).

### 3.2.4 Microbial biomass carbon (MBC)

#### 3.2.4.1 MBC in the soils used for carbon isotope analysis

MBC in teak land cover at three different depths ranged from  $82.35 \pm 11.52$  to  $390.30 \pm 8.06$ , in bamboo land cover it ranged from  $82.35 \pm 11.52$  to  $219.84 \pm 33.6$ , while in mixed land cover it ranged from  $63.36 \pm 22.40$  to  $458.1 \pm 1.83$  (Figure 28). Maximum value of MBC was observed at top layer (0-2 cm) and minimum at deeper layer (90-100 cm) in three types of land cover. The ANOVA indicated a significant difference ( $P < 0.01$ ) at three different depths and between land cover.



**Figure 28:** MBC ( $\text{mg kg}^{-1}$ ) at three different depths of soils under three types of land cover.

