



## SOIL CARBON DYNAMICS AND GLOBAL WARMING POTENTIAL OF SELECTED SOIL SERIES AND LANDUSE CATEGORIES

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**Abstract:** Land use conversion is usually accompanied by a decline in soil organic carbon. This work is aimed to determine the soil organic carbon affected by the multiple land use in a particular soil series. The study was conducted in Ustic Haplohumults soil series of Kottayam district of Kerala including land uses like Cropland, Wetland, Agricultural land, Homestead and Mixed vegetation land. Change in land use induced significant losses of soil and particulate organic carbon. The maximum SOC content (7.39%) was observed in abandoned paddy field which is nearly 89% more than the lowest values of 0.76% recorded from the Homestead soil. Soil carbon sequestration potential of different land uses varies on spatial and temporal basis along with the interplay of environmental externalities. Potential for CO<sub>2</sub> production and global warming of various soils was in accordance with C mineralization and this explains the role and capacity of various land use under consideration to store and release carbon. In the present study it was found that the soils of coconut plantation serve as a better system in terms of maximum SOC storage and minimum carbon emission. The present study reveals the significance and importance of specific land use category which is optimal for particular soil series towards soil carbon storage.

**Key words:** Carbon mineralization; Global warming potential; Land use; Soil organic carbon

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## INTRODUCTION

Soils are most important as dynamic natural body and fundamental resource in many ecosystems (Emadodin *et al.*, 2009). In most soils the majority of carbon is held as soil organic carbon (SOC) and carbon in the form of organic matter is a key element to healthy soil. Soil carbon or soil organic carbon is the part of soil organic matter which is composed of decaying plant and animal matter. Soil organic carbon is an indicator of soil quality and environmental stability (Reeves, 1997) and the SOC pool is extremely sensitive to perturbations such as land use conversion, soil drainage, etc. Soil plays an important role in the global cycle and it may act as a source or sink of CO<sub>2</sub> in exchange with the atmosphere. The soil carbon pool has been estimated at approximately 3.3 times the size of atmospheric pool and 45 times the size of biotic pool (Lal, 2004). Soil organic carbon has various fractions which vary in degree of decomposition, recalcitrance and turnover rate (Haung *et al.*, 2008). Conservation and retention of terrestrial carbon has been highlighted in the recent years by the necessity to mitigate an increase in atmospheric carbon as well as by enhancing soil functions which support ecosystem (Kyung *et al.*, 2010). Land use and management practices have a strong effect on aggregation like soil properties and especially on soil carbon dynamics (Shrestha *et al.*, 2007). Within a climatic or soil zone the land use and

management can also impact on soil structure formation and storage of organic matter (Carter, 2002). Under different land use practices differences in SOC fractions can yield important information about the mechanisms of carbon sequestration (Six *et al.*, 2002). The inappropriate land use will lead to loss of SOC which cause a decline in soil quality and will also lead to emissions of carbon into the atmosphere (Lal, 2002). The labile fractions of SOC and macro aggregates have considerable effects on soil quality and therefore they are more sensitive indicators of the effects of land use compared to SOC (von *et al.*, 2000). SOC can be increased by appropriate land use and soil management (Banger *et al.*, 2009) and it can also improve soil quality and will partially mitigate the rise of atmospheric CO<sub>2</sub> (Lal and Bruce, 1999). The regional terrestrial carbon research in an entity can be considered in a global context is required for the realistic quantification of the carbon sink dynamics and understanding of the regional global linkage towards climate change and global warming. Thus the study of soil carbon dynamics is important to understand the carbon balance and their response to future global change. The main objectives of the study are: (1) to determine soil carbon dynamics of selected land use categories and to assess their major carbon fractions, (2) to assess soil derived Green House Gas (CO<sub>2</sub>) and its subsequent Global Warming Potential (GWP) and (3) to determine the source/ sink capacity of the selected land uses and their vulnerability status.

## EXPERIMENTAL

**Study site:** This study was conducted in Ustic Haplohumults soil series of Kottayam district (9°23'- 9°52' N latitude and 76°21'-77° E longitude). The study transect comes under a humid tropical climatic regime with severe summer and plentiful rainfall during monsoons. Annual average rainfall is 2591.0mm and the mean annual temperature is 27.40 degree C. The study area comprises all the land use categories as described by IPCC for the carbon inventory under multiple land use systems. The study area has five different soil series according to Bench Mark Soils Of Kerala (2007) which are Thapto-Histic Tropic Fluvaquents series, Fluventic Dystrusteos series, Ustic Haplohumults series, Oxid Dystrusteps series, and mixture of Oxid Dystrusteps and Typic Tropofluvents series. In the present study, Ustic Haplohumults series is selected for the detailed analysis due to its geographical disposition and extent there by making it a major soil series where almost all representative land categories can be traced. The Ustic Haplohumults soil series type extends between 9° 22'- 9° 52' N and 76° 20' – 76° 50' E. They have dark reddish brown, very strongly acid, gravelly sandy clay to gravelly clay A horizon and dark reddish brown to yellowish red, very strongly acid, gravelly clay B horizons. These are occurred on moderately sloping to steep lands of Kottayam district, at an elevation of 20 to 100 m above MSL.

**Soil Sampling:** Measurement methods for assessing loss or accumulation of carbon on land are done as per the methods prescribed by IPCC (2006). The total study transect is compartmentalized into desirable 32 grids of about 5 sq.km so as to obtain an ideal representation of soil series Vs land use combination of which 12 grids were randomly selected for further analysis. Soil samples were collected from 43 different sites from three different depths (0 - 10 cm, 10 – 20 cm, 20 – 30 cm).

**Soil Analysis:** The Walkley and Black wet oxidation method was used to determine organic C content (Maiti, 2003). Particulate organic carbon was determined following the sodium hexa-meta phosphate dissolution method (Cambardella & Elliot, 1992) and aggregate stability was measured in terms of Water Stable Aggregate (WSA) after the sand correction by wet sieving technique (Yoder, 1936). Carbon mineralization (C<sub>min</sub>) was determined through potential carbon mineralization (PCM) method of incubation by Haney *et al.* (2004). Identification of Carbon functional group was done by FTIR (Shimadzu IR, resolution 4cm<sup>-1</sup>). Organic carbon fractions were determined by wet oxidation using the method proposed by Chan *et al.* (2001). Separation of TOC into fractions of decreasing oxidability was done for two fractions: Carbon labile (CL) and Carbon non labile (CNL) or recalcitrant. CO<sub>2</sub> emissions of soils were carried out

through incubation study (Chakrabarthy, 1997). The corresponding global warming potential (GWP) of the respective emissions were computed as per Cai (1999) and IPCC (2001) for CO<sub>2</sub>.

## RESULTS

**Soil Organic Carbon (SOC):** Land use categories have a significant effect on total carbon content and thus the carbon stock of bulk soil. The SOC content ranged between 7.39 to 0.76% with an average value of 2.68% for the bulk soil of depth 0-30 cm. It is found that the abandoned paddy field (AP3) of this particular soil series recorded the maximum soil organic carbon value (7.39%) which is nearly 9.7 times higher i.e 89% more than the lowest values (0.76%) recorded among the Homestead soil (H3). The average SOC value (%) for various land categories varied in the order: Abandoned paddy (4.03) > Coconut plantation (3.88) > cultivated Paddy (3.69) > Areca nut plantation (2.65) > fodder grass (2.51) > Rubber plantation (2.04) > Mixed (2.03) > Homestead (1.65) > Teak plantation (1.52). Considering the average SOC values, the abandoned paddy showed 2.65 fold increase, nearly 62 % higher than the lowest value recorded in the soils of Teak plantation.

**Soil carbon counter parts:** POC has been considered as an intermediate fraction of SOC between active and slow fractions that change rapidly over time due to changes in management practices. The data showed considerable differences in POC contents between soils of different land use categories. The values varied between 1.57 to 3.99% with an average of 2.6% for the bulk soil. The maximum value (9%) was recorded under abandoned paddy field (AP3) followed by P1, which is a cultivated paddy site (6.12%). Minimum POC values were detected under homestead sample H3 (0.24%). The POC content ranged in the order: Coconut plantation (3.75%) > abandoned paddy field (2.91%) > Cultivated Paddy (2.84%) > Arecanut plantation (2.50%) > fodder grass (2%) > Rubber plantation (1.30%) > Mixed land (1.30) > Homestead (0.87%) > Teak plantation (0.27%). Thus the data showed extensive difference in the POC content between soils in different land categories.

**Potential carbon mineralization:** A comparison between land use categories showed that the PCM values ranged between 0.22 to 6.16 mg CO<sub>2</sub>-C/g<sup>-1</sup>. Soils of Paddy (P5) and homestead (H7) had significant greater PCM concentration (6.16 mg CO<sub>2</sub>-C/g<sup>-1</sup>) where as Teak plantation (T1) recorded the minimum (0.22 mg CO<sub>2</sub>-C/g<sup>-1</sup>) which is about 28 times lower than that of the highest value. The average PCM values varied in the order: Homestead (3.14) > Fodder grass (3.08) > Rubber plantation (2.79) > arecanut plantation (2.42) > Cultivated Paddy (2.34) > Mixed land (2.12) > Abandoned paddy field (1.59) > Coconut plantation (0.44) > Teak plantation (0.22). In other words, the sink capacity of homestead and fodder grass land were comparatively lower, rather they act as potential sources of carbon dioxide.

**Proportions of soil carbon:** The results of various proportions of carbon in soil are represented by the ratios like POC/SOC and PCM/SOC. The POC/SOC ratio represents the contribution of POC to SOC and for the bulk soil and the maximum value recorded was under P8 (0.98 which contribute 98% of SOC) which is the paddy site and a minimum of 0.18 under T1, the teak plantation which contribute 18% of total SOC. The mineralizable fraction of C in SOC (i.e., the PCM/SOC ratio) represents the carbon turn over. A maximum value for Carbon turnover is recorded under paddy land specifically under P5 (3.20). The ratio considerably reduced by 29 times in the soils of coconut cultivating site (C1) and the value is 0.11.

### Source and sink capacity of various land use

The sink capacity can be represented by soil carbon counter parts like soil organic and particulate carbon storage where as the source capacity can be represented by potential carbon mineralization. SOC Vs C<sub>min</sub> largely determines the capacity of a particular soil to act as either sink or source. Here it was found that when the paddy land is left abandoned the sink capacity i.e. the carbon storage capacity increased considerably where as the source capacity in terms of CO<sub>2</sub> emission reduced and the homestead soil turns

to be a potential source and a weak sink. The soils of coconut plantation serve as a better system in terms of maximum SOC storage and minimum carbon emission.

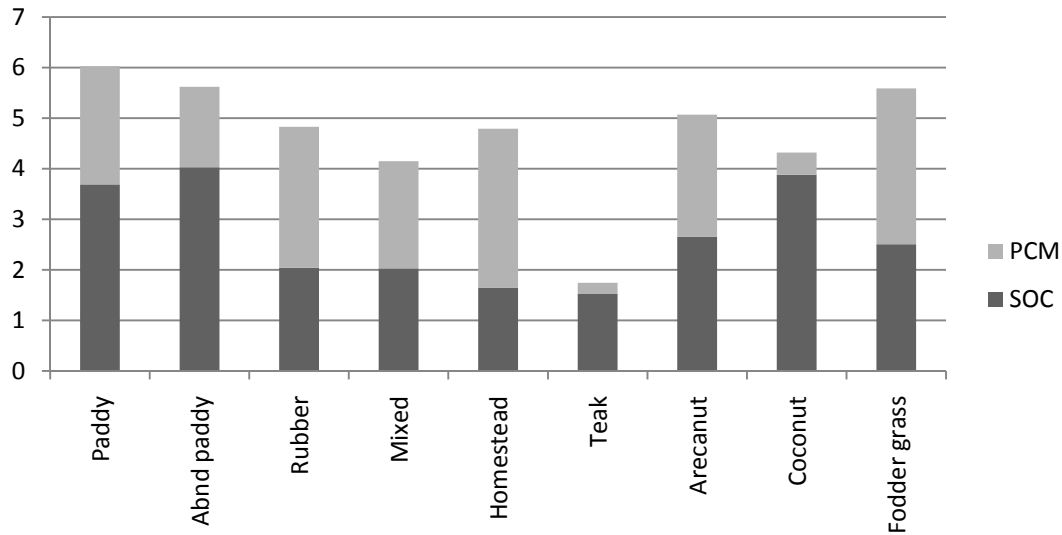


Figure 1. Source and sink capacity of various land uses

**Vertical distribution of SOC:** The SOC value ranged between 0.76 to 7.39 % with an average of 2.58 % in the 0-10 cm depth. AP3 Abandoned paddy site (AP3) recorded the highest value of 7.39%, nearly 10 times higher than that of Homestead (H3), which recoded the least value (0.76%). In the 10 – 20 cm section, the C concentration of Abandoned paddy (AP3) also recorded the maximum value (5.47%) which is about 11 times higher than that of homestead site, H3 (0.47%) and the average value recorded for this layer is 2.03 %. In the 20-30 cm section, paddy (P1) recorded the maximum (4.6 %) which is nearly 11.5 times higher than that of the lowest value recorded under rubber plantation, (R2) (2.84%). However greater variations were observed in the top 0-10 cm layers and it is observed that the carbon storage capacity of top layer among the entire land category under consideration was significantly higher. Irrespective of land use category a general trend in decreasing SOC with increase in depth has been observed.

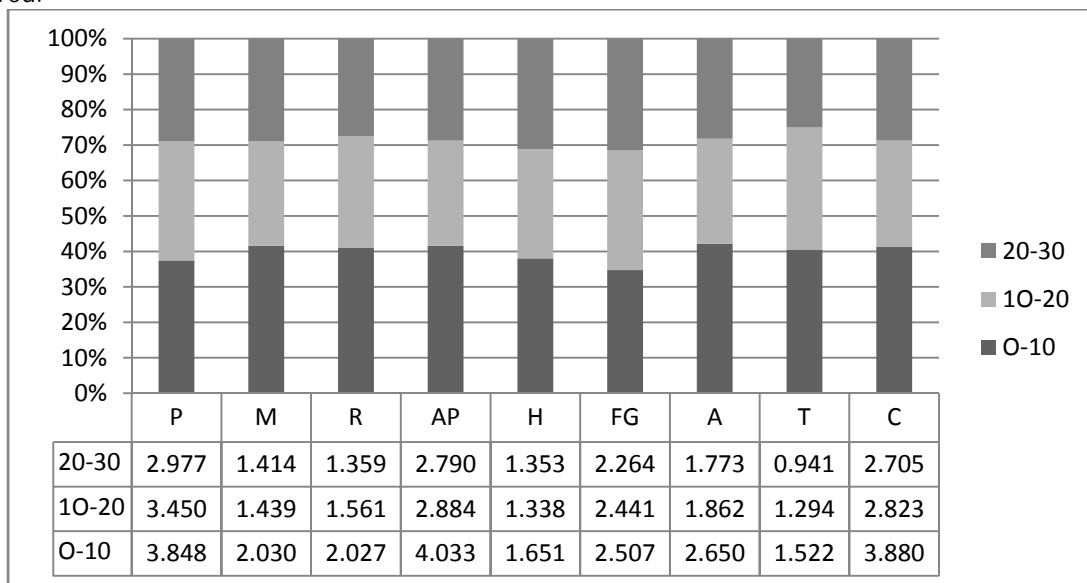


Figure 2. Storage profile of SOC

### Soil organic carbon fractions

The fractions of organic carbon extracted under grading oxidizing conditions were significantly different among the land use categories. In the present study it was found that irrespective of depth, the paddy soil has the greatest quantities of labile ( $C_L$ ) and recalcitrant ( $C_{NL}$ ) carbon counterparts where as soils from teak plantation represented lowest quantities of all carbon fractions. The sizes of soil labile and non-labile C pools and their contributions to the total soil C pool differed significantly among land use categories.

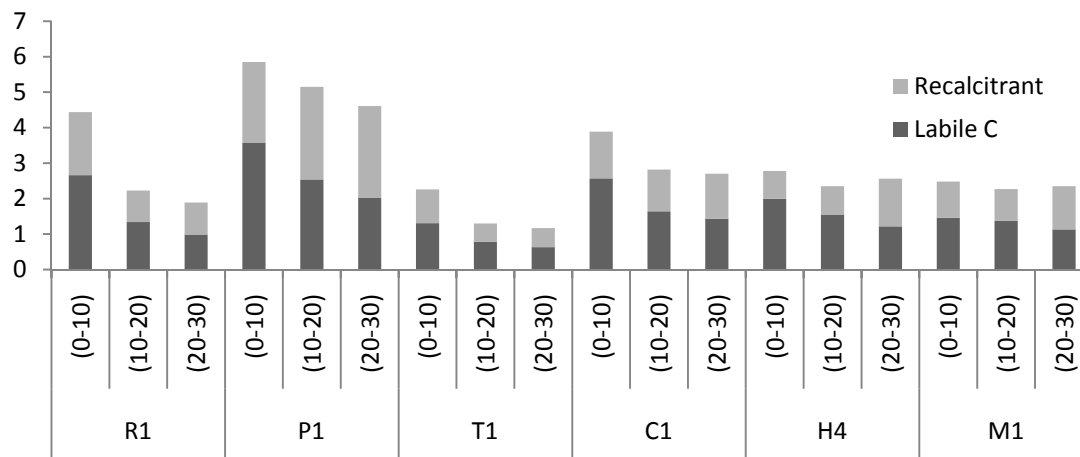


Figure 3. Depth wise distribution of Labile and non labile fractions

### C functional group

For the confirmation of labile and non labile carbon forms, FTIR analysis was carried out and the results showed the presence of labile C forms of O alkyl C containing carbohydrates and polysaccharides between  $1000-1050\text{ cm}^{-1}$ . The appearance of new peaks in the region 1000 indicates the presence of alkenes ( $=C-H$  bends), at  $950-1910$  carboxylic acids (O-H bands),  $900-675$  aromatics (C-H),  $1500-1400\text{ cm}^{-1}$  (C-C stretch in rings) aromatics and  $3500$  (OH stretch, H bonded) alcohols and phenols. This suggests that all the land use categories analyzed shows the presence of both labile C forms (alkenes, carbohydrate, polysaccharides) and recalcitrant (phenols, aromatics and carboxylic acids). Irrespective of depth variations the paddy soils showed maximum presence of functional categories under labile and recalcitrant groups which is followed by rubber and teak plantation.

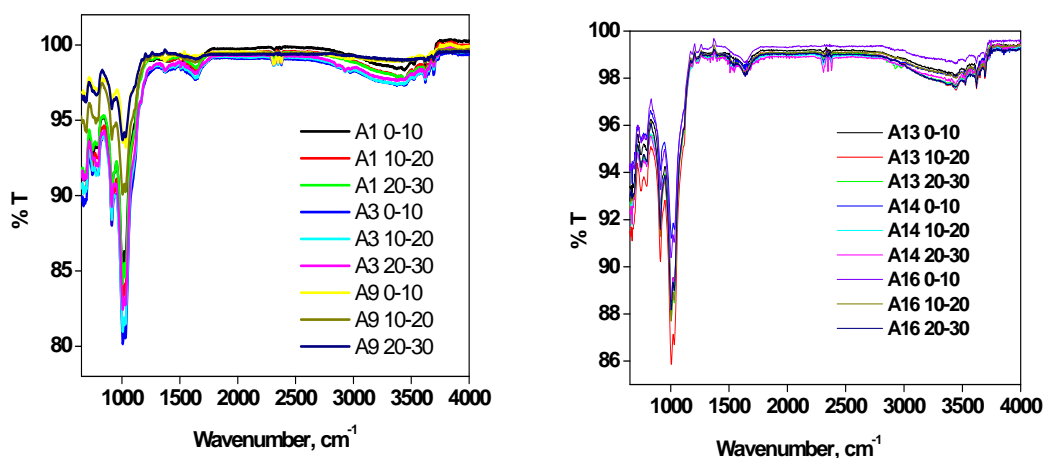


Figure 4. FTIR analysis spectra

### Water stable aggregate (WSA)

Soil aggregation is a factor which facilitates soil carbon storage. Representative samples of each category containing maximum and minimum SOC values have been selected for the assessment of water stable aggregate proportions. The macro-aggregation reached maximum in R1 (rubber with high SOC) (28.7%) whereas the minimum in H3 (Homestead with low SOC) (0.6%) with an average value of 7.67%. Micro-aggregate class recorded the maximum in H3 (Homestead with low SOC) (6.6%) while R1 recorded the minimum values (0.5%), where the average value recorded is 3.69%. Meso-aggregation was found to be prominent in mixed land use with low SOC followed by homestead with high SOC.

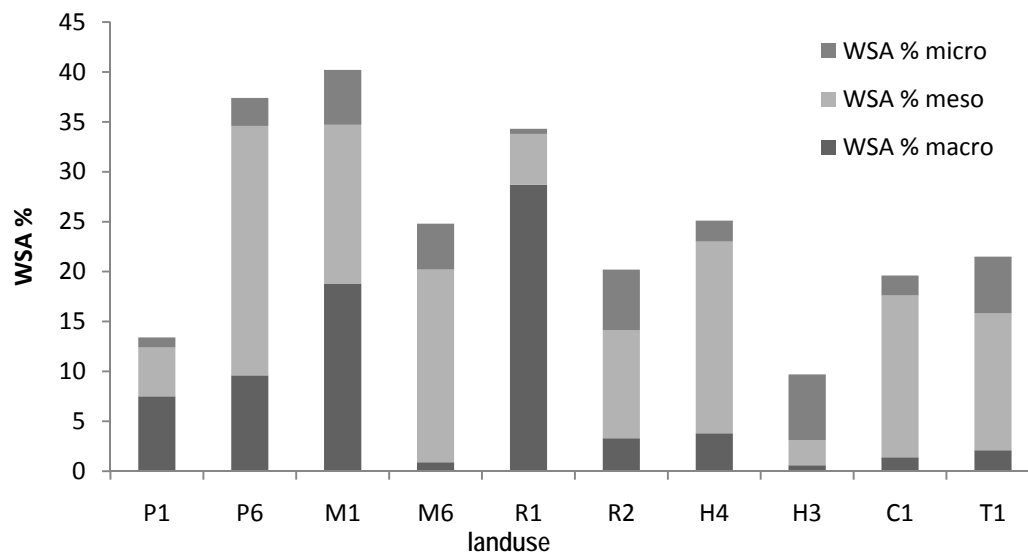


Figure 5. Proportion of water stable aggregates

### Global warming potential and Vulnerable carbon pool identification

The production potential of CO<sub>2</sub> released from different land use was assessed. GWP for CO<sub>2</sub> was calculated as per IPCC (2001), where 1 mmol-CO<sub>2</sub> is assumed as 1, for 20- year duration. The global warming potential of different land uses ranges from 5 to 140  $\mu\text{g g}^{-1}$  soil. The highest global warming potential is observed in paddy (P29) and homestead (H43) and lowest in teak plantation (T9). CO<sub>2</sub> production and global warming potential of various soils followed the same trend of C mineralization values and this explains the role and capacity of various land use under consideration to store and release carbon.

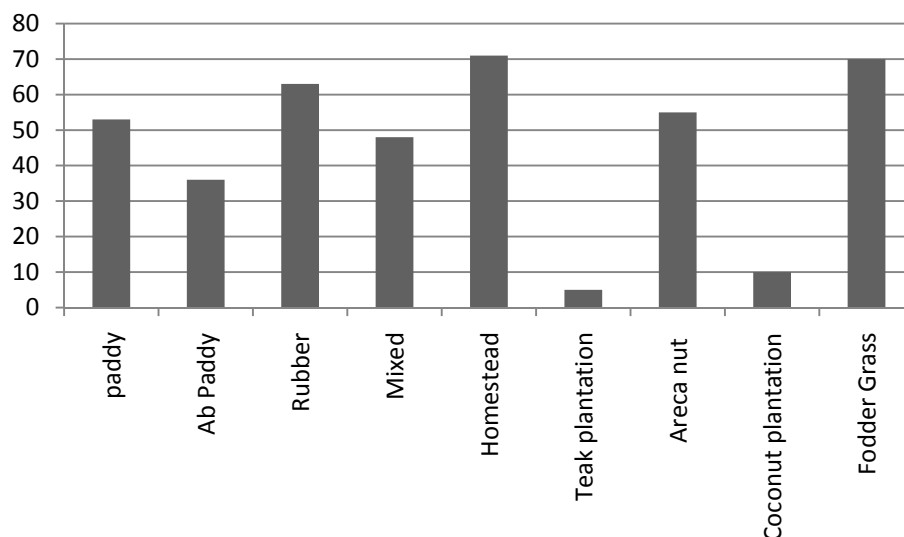


Figure 6. Average GWP of various Land use

Vulnerability of a particular soil carbon pool can be identified by the indicators like soil carbon storage, carbon mineralization in terms of CO<sub>2</sub> emission and carbon turnover computed by the ratio of C Min/C Storage. In the present study homestead soil is found to be a highly vulnerable carbon pool. The vulnerability pool status varied in the order: Homestead > Rubber plantation > mixed > fodder grass > Arecanut planatation > cultivated paddy > abandoned paddy > teak plantation > coconut plantation .

Table 1. Vulnerable pool: Mean average values of C pool indicators

SAMPLE	C Storage %	C Min. mgCO <sub>2</sub> -C/g <sup>-1</sup>	C turnover
Paddy	3.69	2.34	0.85
Ab paddy	4.03	1.59	0.47
Rubber	2.04	2.79	1.59
Mixed	2.03	2.12	1.28
Homestead	1.65	3.14	2.04
Teak	1.52	0.22	0.14
Arecanut	2.65	2.42	0.91
Coconut	3.88	0.44	0.11
Grass	2.51	3.08	1.23

### Relationship between carbon pools

The soil carbon pool of different land use categories are correlated each other and showed significant relationships from a carbon sequestration view point. POC, a major subset of SOC showed a significant positive correlation. In contrast, the C mineralisation bears a negative correlation with SOC. SOC and WSA showed a close association as SOC significantly increased with the macro aggregates where as decreased with meso and micro aggregate. From the results it can be seen that the presence of organic matter improves aggregate stability, considering all the soil samples irrespective of land use category. A significant positive effect was observed between POC and macro-aggregates where as a strong negative relation with micro-aggregates.

## DISCUSSION

The scrutiny of land disturbance intensity and soil carbon data suggested that, if a given land use change is responsible for soil carbon loss, then the reverse change could potentially increase soil carbon stocks. But it is important to recognize that it can take decades if not centuries to recover to the original level of soil carbon stocks after disturbance due to land use change (Guo and Gifford, 2002). During conversion, activities like landscaping and ground clearance might have exposed the soil surface and breaking of aggregates thereby increasing the magnitude of erosional activities and subsequent loss of SOC pool. Thus human-controlled factors during land conversion might have led to the depletion of soil carbon stocks (Conant and Paustian, 2002; Ojima, *et al.*, 1993).

In the present study abandoned paddy field has the highest SOC content. In paddy soil fertilizers influence SOC content (Shao-xian Wang *et al.*, 2012) and the organic amendments and rice residues (rice stubble and root) are the main C sources converted to soil C in paddy fields (Li *et al.*, 2010) and also the presence of decomposable organic matter under the conducive environmental condition might have resulted in the increase of SOC in paddy soil. However in teak plantation and homestead soils, a significant reduction in SOC content is observed. As a result of anthropogenic activities like ground clearance, a characteristic decline in vegetation was observed in the Homestead and Teak plantation sites those results in less accumulation of litter and thus low input of organic carbon in soils. In addition to this, erosion activity was significant in these sites which might have caused the displacement of SOC. The low SOC levels in rubber plantation, mixed land and other land categories can be attributed to human disturbances and interference for various purposes. The higher magnitude of POC in Coconut plantation site suggests that soils under this land build up active C pool as reported by Saha *et al.*, 2011. Conservative agriculture practices were observed in this site and studies by Chan (2001) showed that POC concentration tends to be greater under more conservative management practices which support our findings. Intensive land based activities including tillage, land clearance and tampering observed in all the sites might have led to the destruction of macro-aggregates which may result in the exposure of the inner core of POC facilitating rapid decomposition by microorganisms of this important organic carbon reserve in the soil (Six *et al.*, 1999; Six *et al.*, 2004). Being more labile, POC is a more sensitive indicator of change than organic carbon due to land use and management and the low POC levels in the disturbed sites of the study area illustrates this fact.

Potential carbon mineralization (PCM), a biologically active fraction of SOC (Saffigna, 1989; Bremner and Van Kessel, 1992) was in accordance with the textural and disturbance pattern of the soil. Greater PCM rates in homestead soils can be attributed to the human induced disturbances facilitating more C mineralization whereas the highest C turn over value (PCM/SOC) represented in this site shows the source capacity of this site. This observation indicates the vulnerability of this site as a potential C source due to disturbances. Here the high contribution of POC to SOC suggests the conservative agriculture practices prevailing in the paddy land and also the presence of conducive environment towards the building up of active POC in the site. Since the POC represents an intermediate fraction (which can be labile) of SOC, its fate can be determined by management activities and the level of human interference. Hence the presence of high value of POC/SOC ratio in paddy soil is an indication demanding proper management activity in future. The lower ratio represented in teak may be due to the intense land disturbance, where the loss of POC will be more.

In this study the high value of carbon turn over represented under paddy soil shows the result of disturbances, even though this site contains high levels of SOC. The possibility of shifting the status of this particular soil type from source to sink cannot be ruled out under the circumstances of increased



interference or land use conversion scenarios. Contrary to this, the ratio narrowed considerably in case of coconut plantation which shows the increased sink capacity of the soil thereby the chance of losing the stored carbon in the form of carbon dioxide is comparatively less. It is found that when the paddy land is left abandoned the sink capacity i.e. the carbon storage capacity increased considerably where as the source capacity in terms of CO<sub>2</sub> emission reduced, which can be considered as an appreciable observation from a climate change perspective. In contrary to this the homestead soil turns to be a potential source and a weak sink. In case of teak plantation the source capacity was seem to be minimum which is quiet preferable but the sink capacity is also found to be low and hence this soil cannot be preferred as a suitable system from a climate change view. In general, the soils of coconut plantation serves as a better system in terms of maximum SOC storage and minimum carbon emission. From the vertical distribution of SOC, the occurrence of top soil as a potential sink of SOC has been identified. The high amount of SOC in the top layers may be due to the presence of litter, humus and other organic matter. Apart from this the presence understory vegetation especially grass and herbs might have increased the SOC level. The presence of the root biomass of trees and plants might have contributed the SOC accumulation in the subsurface layers and the results were in accordance with Kaiser *et al.* (2002).

The sizes of soil labile and non-labile C pools and their contributions to the total soil C pool differed significantly among land use categories. The labile pool which turns over relatively rapidly, results from the addition of fresh residues such as plant roots and living organisms, whilst resistant residues which are physically or chemically protected are slower to turn over. The presence of C<sub>L</sub> fractions indicates the occurrence of easily mineralised organic compounds (Stecio *et al.*, 2007). The higher proportion of nonlabile carbon counterpart in paddy soil may be due to the faster conversion of organic inputs and labile C fractions to recalcitrant forms and its persistence under favourable conditions. C<sub>L</sub> fraction, the more easily oxidizable fraction, indicates greater predominance of labile organic C and the content could be considerably altered by even a minute disturbance on the paddy soil. FTIR analysis results suggests that all the land use category analysis show the presence of both labile C forms (alkenes, carbohydrate, polysaccharides) and recalcitrant (phenols, aromatics and carboxylic acids). Irrespective of depth variations the paddy soils showed maximum presence of functional categories under labile and recalcitrant groups which is followed by rubber and teak plantation. Reason for higher macro-aggregate class in the selected rubber plantation may be due to the efficient root system of rubber trees that helps in soil aggregation (Blanco-Canqui and Lal, 2004). The presence of litter and humus and also the understory associations in the site might have contributed towards this. The distribution of WSA of macro and micro categories shows the land disturbance intensity. The high proportion of micro-aggregate category in teak plantation site represents the disturbance induced turnover of macro aggregates (Debasish *et al.*, 2010). In the present study homestead soil is found to be highly vulnerable carbon pool owing to its low carbon storage capacity and high carbon mineralization which ultimately results in high carbon turnover rate. This shows the low mean residence time (MRT) of carbon in soil which facilitates low carbon sequestration rates and thereby contributing significantly towards high global warming and subsequent climate change issues on regional basis.

The negative correlation of SOC with C mineralization suggests the extent of carbon bioavailability (Ahn *et al.*, 2009) of various soils. The positive correlation between macro-aggregate category and SOC substantiate the fact that macro-aggregate formation could contribute the storage of organic carbon in soils (Carter and Gregorich, 1996). The correlation between POC and macro-aggregate category indicates that POC content improves the soil aggregation as it can form an organic core surrounded by clay, silt particles and micro-aggregates (Six *et al.*, 2000). The strong positive correlation between C mineralization and micro-aggregation shows the disturbance induced turnover of macro aggregates and the subsequent carbon mineralization.

## CONCLUSION

Soil carbon storage capacity indicates the C sequestration potential of the soils and from the study maximum SOC sequestration is found under abandoned paddy cultivation followed by coconut plantation. The higher magnitudes of POC, a subset of SOC was noted in the Coconut plantation site than that of abandoned and cultivated paddy sites showing the prevalence of conducive environment for the building up of this C store. Since the vulnerability status of homestead soils is high, the chance of the soil category to shift its status towards strong CO<sub>2</sub> source is high and hence calls for attention during further soil based interventions. The labile and recalcitrant C fractions of soil represents the measure of sustainability and the mode and type of soil management activities determine the fate of labile SC pool either to convert into recalcitrant pool or to lose as CO<sub>2</sub> into atmosphere. Any soil based disturbance can lead to CO<sub>2</sub> emission which will subsequently result in global warming from a regional basis and will be ultimately reflected on a global level. By incorporating optimal land use into our system, we can increase not only current soil C stocks but also potential soil C changes which help in future soil and land use management.

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CONFLICT OF INTEREST:           Nothing