Soil Carbon Stocks in Sarawak, Malaysia

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Abstract. The relationship between greenhouse gas emission and climate change has led to research to identify and manage the natural sources and sinks of the gases. CO_2, CH_4, and N_20 have an anthropic source and of these CO_2 is the least effective in trapping long wave radiation. Soil carbon sequestration can best be described as a process of removing carbon dioxide from the atmosphere and relocating into soils in a form that is not readily released back into the atmosphere. Noted benefits of soil carbon sequestration include conservation of soil and water resources, improvement of the soil structure and off-setting emissions from fossil fuel combustion and other carbon emitting processes. The total global pool was estimated over a decade ago at about 41,000 Pg, of which the ocean reservoir contains about 38,000 Pg, the atmosphere about 750 Pg, and the terrestrial the remaining 2,100 Pg carbon. In the terrestrial system, soils contain about 1,500 Pg and vegetation, about 750 Pg carbon. The quantity and quality of soil organic matter depends on the soil and the environmental conditions. There is also a time element in the sequestration process. Soils on stable geomorphic surfaces subject to minimal erosion have the time to stock higher quantities of carbon. Soils on actively eroding surfaces are poor in carbon. Cold and wet conditions promote accumulation while in warm, well-drained soils, oxidation of carbon releases it to the atmosphere. It is reasonable to expect that under low input systems, there will be a continuous net loss of C from soils. Previous studies have shown that land clearing for agriculture results in 20 to 60% loss of the original soil C content. The purpose of this study is to estimate carbon stocks available under current conditions in Sarawak, Malaysia. SOC estimates are made for a standard depth of 100 cm unless the soil by definition is less than this depth, as in the case of lithic subgroups. Among the mineral soils, Inceptisols tend to generally have the highest carbon contents (about 25 $kgm^{-2}m^{-1}$), while Oxisols and Ultisols rate second (about 10-15 $kgm^{-2}m^{-1}$). The Oxisols store a good amount of carbon because of an appreciable time-frame to sequester carbon and possibly lower decomposition rates for the organic carbon that is found at 1m depths. Wet soils such as peatlands tend to store significant amounts of carbon. The highest values estimated for such soils are about 114 $kgm^{-2}m^{-1}$. Such appreciable amounts can also be found in the Aquepts. Human activities on the land are increasingly contributing to enhanced degradation of the carbon stocks. Oxisols and Ultisols are generally used for zero to low input agricultural systems by small holders. The same soils and also peat soils are now being used by the plantation sector to cultivate oil palm. In a properly managed agricultural scheme, degradation of the organic pool will be minimal. However, in considering soil resilience, specifically the resilience of organic carbon under varying management systems, it becomes apparent that the long-term sustainability of the organic pool could be questionable. Degradation will inevitable reduce the productivity of soils and thereby increasing more concerns on food stability. In conclusion, it is pertinent to recognize that degradation of the carbon pool, just like desertification, is a real process and that this irreversible process must be addressed immediately. Tension zones have to be identified perhaps even at the resource management domain levels. This would require more accurate soil maps to be produced at National, State, Provincial levels. Since it is known that the most widely used soils for agriculture also hold large reservoirs of carbon, it is stressed again that these soils also have the potential to sequester larger amounts. Therefore, appropriate soil management practices should be instituted to sequester large masses of soil carbon on an annual basis. Past estimates also show that wetlands hold about 30% of the total SOC. Therefore maintaining wetlands in their natural state is a good policy to enhance carbon sequestration. In retrospect, draining these wetlands tends to release CO_2 into the atmosphere and it will be difficult to restore the original levels of SOC in a human time-span. Estimates have also shown that at the global level, forest soils stock about 580 Pg of SOC and about 360 Pg of above ground biomass carbon. This knowledge can be used effectively to formulate strategies to prevent forest fires and clearing: two processes that can quickly release sequestered carbon to the atmosphere in an almost irreversible manner.

Keywords: Soil organic carbon (SOC), Carbon sequestration

1.Introduction

Soil carbon sequestration specifically deals with the transfer of carbon dioxide from the atmosphere into the soil via crop residues and other organic solids in a form that is not easily released back into the atmosphere. Carbon sequestration itself is emerging as an important topic as it is strongly believed that this helps to offset emissions form the combustion of fossil fuels and other anthropogenic activities that contribute to the emission of carbon. An additional benefit of carbon sequestration would be to enhance soil quality and to improve the crop and soil productivity.

The relationship between greenhouse gas emission and climate change has led to research to identify and manage the natural sources and sinks of the gases. CO_2, CH_4, and N_20 have an anthropic source and of these CO_2 is the least effective in trapping long wave radiation (Mitchell, 1989). Some wetland soils are also a source of methane and some soils oxidize atmospheric CH_4.

It has been established that in order to enhance the application of current and future models on carbon fluxes, the size of the carbon pool must be ascertained and the dynamics of this pool evaluated (IPCC, 1996, Legros et al., 1994). There are three major pools of carbon; ocean, terrestrial and atmosphere. The oceans contribute approximately 39,000 Pg (10^{15} g) of C, the terrestrial system, about 2,500 Pg and, the atmosphere about 750 Pg (IPCC, 1990). The soil is the largest terrestrial pool and the amount of global soil organic carbon (SOC) to 1m depth is estimated by several authors to range from, 1,220 Pg (Sombroek et al., 1993), 1,576 Pg (Eswaran et al., 1993), and 1,462-1,548 Pg (Batjes, 1996). Divergent rates of accumulation of soil carbon have been reported (2.4 $g/m^2/yr$ by Schlesinger, 1990; 25 to 50 $g/m^2/yr$ by Jenkinson, 1991; 29 to 113 $g/m^2/yr$ by Alexander et al., 1989; 120 $g/m^2/yr$ by Lugo, 1991; and 20-60 $g/m^2/yr$ by Zdruli et al. (1995).

2. Materials and methods

Sarawak has a diversified landscape (Fig. 1). The lowlands are dominated by Histosols whereas other landscape positions comprise mineral soils in general. Samples for this study were collected from several locations in the state during a 15 year period. Some of the organic carbon data were obtained from legacy unpublished data. Soil organic Carbon (SOC) estimates were made for a standard depth of 100 cm unless the soil by definition is less than this depth, as in the case of lithic subgroups.

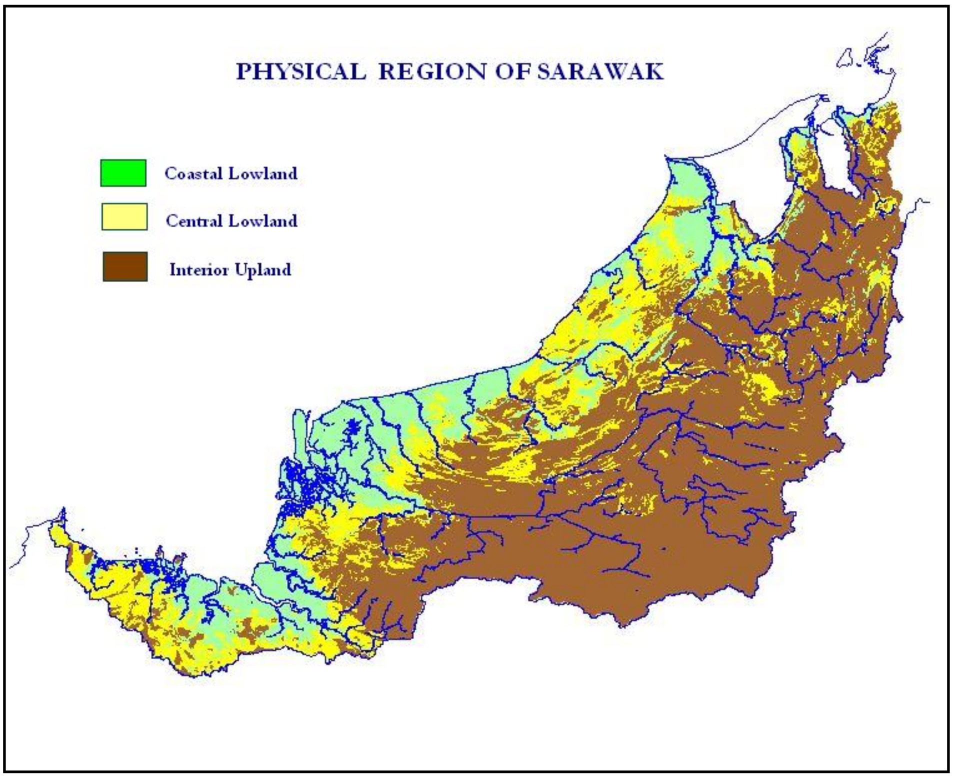

Fig. 1. The major physiological subdivisions in Sarawak

3. Results and Discussion

3.1. Carbon Sequestration in the Various Soil Types

In considering the mineral soils (Table 1), the Histosols have highest percentage of organic carbon (averaging about 110 kg m^{-2} m^{-1}). Next to this, the Oxisols (average about 20 kg m^{-2} m^{-1}) and Ultisols (average about 16 kg m^{-2} m^{-1}) have the second highest amounts of soil carbon. The Entisols have about 9 kg m^{-2} m^{-1} whereas the Inceptisols have the lowest soil carbon average of about 6 kg m^{-2} m^{-1}).

Among the mineral soils, the Oxisols, which occur almost exclusively in the tropics, have relatively high SOC content. This is related to the period available for the sequestration. Most of the Oxisols are on mid- to late-Tertiary geomorphic surfaces. Other reasons include deeper admixture in the Oxisols by biologic (termites) activity and lower decomposition rates for the deep-seated SOC.

Table 1. Estimates of average carbon contents (1m) for the various soil types found in Sarawak.

Order	**C Average Kg m^{-2} m^{-1}**	**Sub Group**	**C Average Kg m^{-2} m^{-1}**
Inceptisols	6.51	Aeric Endoaquept	6.51
Ultisols (NB. Some sub-groups are not shown here)	16.95	Aquic Hapludult	24.40
		Typic Hapludult	13.57
		Typic Epiaquult	34.65
		Typic Paleudult	9.76
Oxisols	20.60	Typic Haploperox	20.60
Entisols	9.51	Lithic Udipsamment	9.51
Histosols	109.31	Hydric Haplofibrist	109.31

An interesting observation on Oxisols is that the soil carbon sequestered appears to be occluded in the stable microaggregates. Studies indicate that the stability of the microaggregates is tantamount to guaranteeing long-term C sequestration despite possible climate changes. Oechel et al., (1993) postulated that in the event of global warming with largest temperature increases expected in the tundra and boreal regions, there will be significant SOC decomposition and CO_2 efflux; under these conditions, these ecosystems could transform into sources rather than sinks of CO_2.

The Entisols appear to average more that the Inceptisols in terms of carbon content as mentioned earlier. This can be explained in terms of the local ecological trends in the state. Mineral soils here are largely derived from Tertiary clastic sediments that are dominated by arenaceous facies. Erosion is common and perhaps on the higher side as the weathered rock is generally devoid of any effective cement to hold the grains together. Organic carbon that is deposited in the alluvial sediments in flood plains is derived mainly from the transportation of terrestrial organic matter. Despite high possibilities of the material being subject to subsequent phases of erosion and redeposition, the organic carbon distribution with depth in Entisols in this region remains high at surficial layers but varies inconsistently with depth as per norm.

Among the Ultisols, the Typic Epiaquult and Aquic Hapludult are quite high in carbon contents. This is best explained by the lower rates of mineralization due to higher degrees of water saturation compared to the other sub-groups.

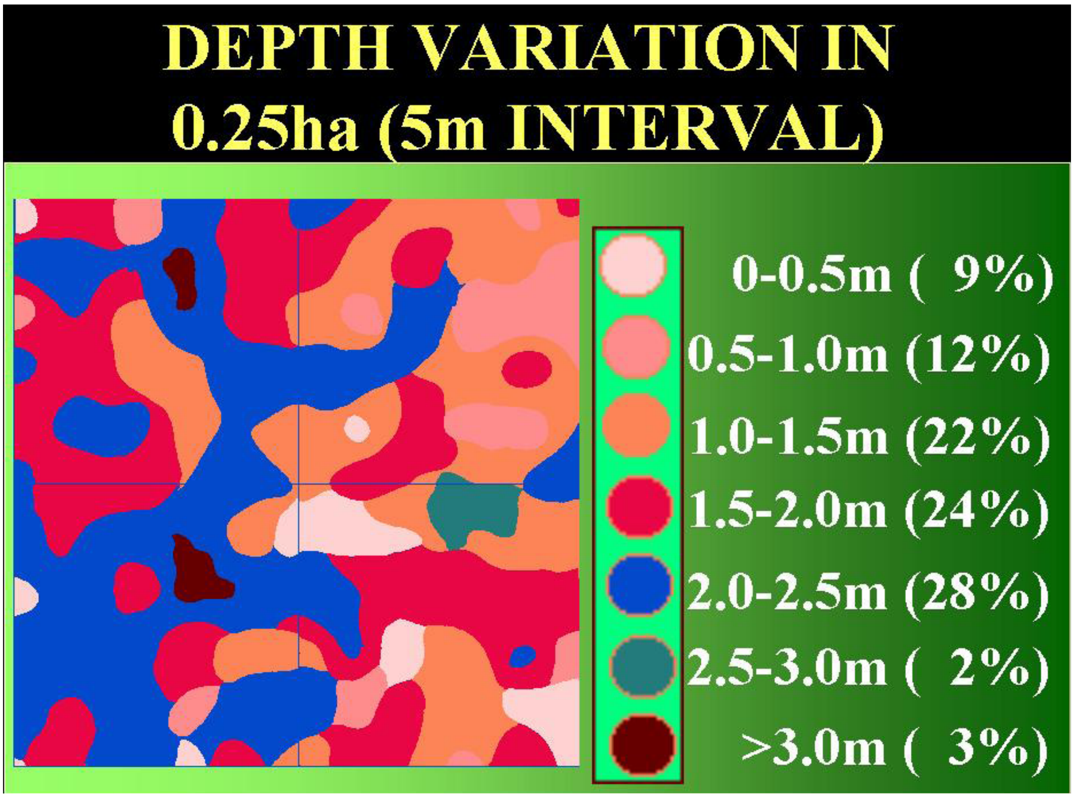

Fig. 2. Depth Variation in Peat

As mentioned earlier, Histosols have the highest percentage of organic carbon distribution among the soil orders present in this state. Peat or Histosols (Soil Survey Staff, 1999; Eswaran, 1986) in the tropics are found in two geomorphic positions; topogenous peats are formed at high elevations where the temperatures are low and extreme humid conditions prevail, whereas, ombrogenous peat form in basin-shaped topographic conditions favoring rainwater accumulation. The geo-genesis of peat domes has been quite well studied (Driessen et al., 1975). The growth of the peat dome is rapid initially and after a certain stage it slows down (Anderson, 1964). The growth dynamics are well enunciated by the study of Driessen and Subagio (1975). The parent material for peat is either wood or soft tissues such as the roots of reeds, leaves and twigs (Hwai et al., 2001). Consequently, there are differences in the bulk densities of the sapric material developed from wood (~ 0.4-0.8 g cm-3) and that derived from the softer tissues (< 0.3 g cm-3). Despite the fact that lateral flow of groundwater in peat is faster than vertical flow in through the system, the erratic stratification with depth results in spatial variability in the rate of lateral flow. Unpublished data of the senior author shows that tremendous spatial variability exists in the ratio of horizontal to vertical flow rates under saturated conditions in the Saprists and Hemists of Sarawak, Malaysia. There is also tremendous variability in the saturated hydraulic conductivity, rates of decomposition, humic to fulvic acid ratios and cation exchange capacities.

This micro-variability in soil carbon distribution spatially and temporally (Fig. 2) has serious implications for use and management of peatlands. The material itself has low bearing capacity as reflected by the low bulk densities, problems related to subsidence and irreversible shrinkage upon drying or de-watering, low nutrient status and complexities involved in determining the mechanisms of adsorption and desorption of cations and anions. Other problems relate to maintaining optimal hydrological conditions and the impact of developing such soils on the conditions and performance of adjoining soils. It is evident that many of these problems are still poorly understood and as such impose restrictions on proper utilization of these resources.

Another critical aspect that has not received much attention in discussions of carbon sequestration is the type of carbon compounds that we are dealing with. Table 2 shows some very interesting results with regards to variations in the functional groups from a spatial and temporal stand point. In particular, it can be seen that the soils show different intensities in the FTIR analysis (Fourier Transform Infrared Analysis) for the various functional groups. Also, it is evident that stretching bonds such as C=O are found only in certain types of Histosols. This then indicates that the response of Histosols to drainage or global climate change in terms of its resilience and capacity to sequester carbon is extremely complicated and unfortunately still poorly understood.

Biodiversity changes accompanying peat dome formation and subsequent degradation have not been fully documented. It has been known for a long time that decomposition of plant residues is extremely slow under anaerobic conditions, as in most of the Histosols, which form under waterlogged conditions, and there is a slow accumulation of SOC. If drained, however, the organic carbon is mineralized within a decade or less (Eswaran et al, 1999). Fires as in SE Asia frequently accompany drainage of the Histosols and so there is a very rapid loss of organic carbon from these soils. Many Histosols of Indonesia, Malaysia, and tropical America (which together comprise more than 80% of the warm Histosols) are being drained for plantation agriculture (Eswaran et al, 1999). The original forest on these soils is also being cleared and both these processes are important contributors to increase of atmospheric CO_2. It has been mentioned that another negative aspect of these practices in SE Asia and tropical America is the permanent loss of biodiversity (Eswaran et al, 1999).

3.2. Impact of SOC Changes on Land Degradation

Global climate change is predicted to accelerate land degradation. The urgency to address issues pertaining to land degradation as a concomitant result of changes in SOC stems from the fact that accelerated land degradation is taking place due to mismanagement of land in large parts of the world, particularly in the poorer tropical countries. Due to a mismatch between land use and land quality, degradation results and manifests itself in a marked decline in the quality of the land. A major reason for this decline is the loss of SOC.

It has been established that rates of SOC loss are a function of the management technology and the kind of soil. Some soils are very prone to erosion, which is the major cause of SOC decline due to land degradation. Level of management is the major cause of accelerated erosion. Low-input systems, which exist in most of the poorer countries of the world, will result in large losses. According to Eswaran et al. (1999), assessment of land quality classes (LQC) the poorer third world countries comprise the most susceptible LQC IV, V, VI and VII that also have a number of land resource stresses to be highly productive soils. Much of these lands are currently under agriculture but the practice of low-input agriculture by developing countries results in excessive soil loss and consequently rapid loss of SOC. What is being overlooked on a gross scale is that the the net loss of carbon from these soils is accelerating with time. In addition to this, it is worthwhile to note that two factors would prevent or reduce efforts to minimize these losses. First, most of the areas that are vulnerable to degradation are in countries that are poor and do not have the ability to invest in high-level management technology. Secondly, most of the soils in these areas have low resilience and occur in environments where rates of sequestration are not rapid. Hence, with degradation (with a distinct possibility to lead to desertification), there will be a progressive net reduction in land quality.

3.3. Management strategies for the future

The development of a database at the national level to monitor current and potential rates of carbon sequestration in forest soils as well as cultivated soils and that too under various types of management practices will be essential to the effective management of Carbon. This will also involve establishing baselines for the carbon sequestration potential for the major soil types in pristine versus cultivated areas.

Adoption of best management practices would be beneficial in maintaining the soil carbon status in a particular soil type.

Table 2. Distribution of functional groups in various types of peat studied.

Bond (Frequency Range, 1/cm)	Possible Type of compound	Data	T1-S1	T1-S2	T1-S3	T1-S4	T1-S5	T1-S6	T1-S7	T1-S8	T1-S9	T1-S10	T1-S11
C-O (1050-1300)	Alcohols, ethers, carboxylic acids, esters	Peaks No. Frequency Intensity, % T	5 1085.8 19.80	5 1083.9 20.00	5 1083.9 3.14	5 1083.9 12.94	5 1083.9 28.28	7 1083.9 30.18	6 1085.8 29.21	6 1087.8 26.25	6 1085.8 35.42	6, 7 1083.9 1261.4 40.83 51.83	6, 7, 8 1080.1 1222.8 1265.2 45.08 55.25 55.80
C=C (1500-1600)	Aromatic rings	Peaks No. Frequency Intensity, % T	7, 8, 9 1506.3 1539.1 1575.7 48.83 48.80 50.33	6, 7, 8, 9 1506.3 1537.2 1542.9 1573.8 49.42 49.71 48.63 49.16	6, 7, 8, 9 1508.2 1535.2 1544.9 1571.9 18.00 17.98 17.35 17.53	6, 7, 8, 9 1508.2 1535.2 1544.9 1571.9 35.64 34.66 33.90 33.14	9, 10 1506.3 1542.9 54.91 53.23	11, 12 1512.1 1542.9 54.95 53.53	10, 11 1510.2 1542.9 55.17 53.62	11, 12, 13 1512.1 1539.1 1579.6 36.95 35.73 34.73	10, 11 1508.2 1541.0 50.45 48.73	11, 12 1512.1 1544.9 57.41 55.58	14, 15 1515.9 1550.7 57.04 55.72
C-H (2850-3300)	Alkanes, alkenes, alkynes, aromatic rings	Peaks No. Frequency Intensity, % T	15, 16 2852.5 2922.0 79.55 76.48	17, 18 2852.5 2922.0 80.47 77.49	15, 16 2852.5 2922.0 45.73 40.92	17, 18 2852.5 2922.0 56.53 51.20	14, 15 2852.5 2922.0 69.05 63.64	16, 17 2852.5 2922.0 63.52 58.12	16, 17 2852.5 2922.0 66.42 60.36	20, 21 2852.5 2922.0 24.92 22.16	17, 18 2854.5 2923.9 53.39 48.85	16, 17 2852.5 2922.0 63.96 59.40	21, 22 2854.5 2923.9 67.94 63.90
O-H (3200-3600)	Hydrogen-bonded alcohols, phenols	Peaks No. Frequency Intensity, % T	17 3423.4 64.48	19 3427.3 67.23	17 3411.8 32.44	19 3398.3 45.46	16 3398.3 60.59	18 3396.4 55.03	18 3392.6 59.71	22 3448.5 12.13	19 3411.8 42.53	18 3406.1 53.01	23 3398.3 56.64
C=O (1690-1760)	Aldehydes, ketones, carboxylic acids, esters	Peaks No. Frequency Intensity, % T							13 1706.9 53.83	16 1710.7 34.99			

4. Conclusions

It is evident from the above that the most widely used soils for agriculture also hold large reservoirs of carbon. These soils also have the potential to sequester larger amounts, with appropriate soil management practices. Among the mineral soils in the state of Sarawak, the Ultisols and Oxisols make up a sizeable proportion of arable land.

Histosols (also to be treated as wetlands) hold about the highest percentage of the total SOC distribution in the state. Therefore maintaining the Histosols in their natural state is a good policy to enhance carbon sequestration. Draining them has been reported to release CO_2 to the atmosphere and it will be difficult to restore the original levels of SOC in a human time-span.

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