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Soil carbon stocks in Sarawak, Malaysia

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HIGHLIGHTS

- Soil carbon stocks in different soils in Sarawak
- In depth discussion of soil carbon pools in Histosols
- Strategies for conservation and management
- Future directions for research on soil carbon in tropical soils

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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_2O 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.

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 kg m^{-2} m^{-1}), while Oxisols and Ultisols rate second (about 10–15 kg m^{-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 1 m depths. Wet soils such as peatlands tend to store significant amounts of carbon. The highest values estimated for such soils are about 114 kg m^{-2} m^{-1}. Such appreciable amounts can also be found in the Aquepts.

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. Therefore, appropriate soil management practices should be instituted to sequester large masses of soil carbon on an annual basis. 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.

1. Introduction

Soil classification in Malaysia has undergone very limited amendments over the years primarily due to the heavy reliance on USDA's Soil Taxonomy from the perspectives of structure, nomenclature and genetic implications. In addition to this, there were apparent discrepancies in soil classification nomenclature and taxonomic structure between the states in Peninsular Malaysia and East Malaysia. Soils have become a non-renewable resource whose functions extend beyond agricultural purposes to cover critical issues such as forest conservation, local or regional level hydrological regulation, baseline for the assessment of soil productivity in varying levels of agricultural input and in recent times, a platform to assess changes in soil and environmental quality.

Soils of the tropics are subject to extreme weathering conditions that have an impact on the mineralogy, phyllosilicate charges, sorption–desorption characteristics, and response to changing microenvironmental conditions. It has been emphasized that spatial variability in the macro as well as micro sense controls the classification and management of soils in the tropics to a large extent (Padmanabhan et al., 2004; Padmanabhan and Eswaran, 2008). Managing such soils would require a series of compromises in the endeavors to attain sustainable production.

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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. It has been estimated that during the last two centuries, cultivation has resulted in the loss of about half of the soil carbon in managed ecosystems to the atmosphere (McCarl et al., 2007). Carbon sequestration itself is emerging as an important topic as it is strongly believed that this helps to offset emissions from 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.

There is an active research program on carbon storage in soils (Jarvis et al., 1995; Batjes and Sombroek, 1997; Eswaran et al., 1993; Gaston et al., 1998; Paustian et al., 1998; Woomer et al., 2000). Sequestration has been further subdivided to include potential-, attainable- and actual sequestration (Ingram and Fernandes, 2001). Soils have a finite capacity to sequester carbon (Paustian et al., 2000). Ingram and Fernandes (2001) pointed out that adsorption of soil organic carbon (SOC) to clay and silt sized particles increases the stability of the SOC. The level of adsorption itself is limited by the amount of clay and silt (Ingram and Fernandes, 2001). Therefore, potential carbon sequestration capacity is linked to physiological processes that determine potential yields in crops (Ingram and Fernandes, 2001). Attainable carbon sequestration is limited by the amount of carbon being input into the soil. Actual carbon sequestration actually refers to the amount of carbon in a soil at any given point in time.

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_2O 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 2500 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 1 m depth is estimated by several authors to range from 1220 Pg (Sombroek et al., 1993), 1576 Pg (Eswaran et al., 1993), and 1462–1548 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. Climate

The climate in Sarawak is classified as Af type (Koppen, 1916). This means that Sarawak has a tropical rainy climate characterized by temperatures higher than 18 °C in the coldest month. The area has also no definite dry periods. The soil moisture regime and soil temperature regime are classified as perudic (in places peraquic) and isohyperthermic (Soil Survey Staff, 2010).

3. Land use

The land use assessment of Sarawak was carried out at a minimum scale of 1:500,000 as this is considered as sufficient for the purpose of this chapter. Land in Sarawak is either used for agricultural purposes or preserved as primary forest land. Agricultural lands are further subdivided into permanent agricultural systems or shifting agricultural areas. Recent estimates indicate that approximately 22% of the land area in Sarawak is under cultivation.

4. The major soil orders in Sarawak

Several soil Orders (Soil Survey Staff, 2010) have been mapped in Sarawak. The major soil Orders in this region are Oxisols, Ultisols, Entisols, Inceptisols and Histosols. The general characteristics of these soil Orders are given here.

4.1. Oxisols

This Order consists of highly weathered soil materials. The oxide content (iron and aluminum) in the solum tends to be around 25% or more and color chromas of 4 or more. Gleying is absent and peds are well developed with strong crumb structures and friable consistencies. There is a lack of evidence of clay illuviation in the solum in particular the B-horizon. The parent rock is usually basic to intermediate igneous rocks.

4.2. Ultisols

This soil Order covers most of the upland soils of Sarawak. These soils may have an albic horizon (Soil Survey Staff, 2010) over the argillic horizon. Iron pans may be encountered in some soils within a depth of 1.0 m. Typically, there are no gley horizons within 0.50 m of the surface. The soils are usually moderately well drained with occasional evidence of moved clay. The parent materials for this soil Order are usually sedimentary rocks (sandstones and shales) and acid igneous rocks. Soil structures vary from massive in clay soils to crumb in sandy soils. Soil texture varies as a function of parent material. However, these soils tend to show a clay increase in the B-horizon. The common diagnostic subsurface horizons that can be found in this soil Order are the spodic and argillic horizons.

4.3. Entisols

This soil order consists of soils where the parent rock, if present, may be found below 0.25 m from the soil surface. Gley horizons are usually below 0.50 m from the soil surface. Diagnostic subsurface horizons such as albic, spodic and argillic are absent.

4.4. Inceptisols

This group of soils may have gleyed horizons within 0.50 m from the soil surface. There are no spodic horizons and neither are there any plinthites. The soils may have a cambic horizon. Organic layers do not exceed 0.50 m in thickness, if present. Soil texture may vary from light to heavy. Salt or brackish groundwater may be present in some cases.

4.5. Histosols

The Histosols merit a deeper discussion compared to other soils as this is an extremely complicated system as well as fragile system.

There are about 18.96 million km^2 of global wetlands. Estimates of the kinds of wetlands are given in Eswaran et al. (1999). The organic soils (Histosols) or the peatlands comprise about 13.34% of the total area of wetlands and about 2% of the global landmass. This includes about 1.01 million km^2 of peats in the tundra area, which are a part of the permafrost-affected lands (Table 1). In the tropics, there are about 3.18 million km^2 of peatlands (12.6% of the global peats). The area of peatlands and specifically the area within countries are subject to change. About 11% (or 36,000 km^2) of the land area in Malaysia comprises Histosols.

Peat or Histosols (Padmanabhan, 2002; Soil Survey Staff, 1999; Eswaran, 1986) in the tropics are found in two geomorphic positions. The topogenous peats are formed at high elevations where the temperatures are low and extreme humid conditions prevail. Rates of

Table 1
Estimates of average carbon contents (1 m) 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

accumulation exceed decomposition of organic matter in these environments and peats form even on slopes as steep as 40%. Land use is forest though small patches are cleared for vegetable growing. Most of the extensive peat lands are present in the swamps of the tropics. These are termed ombrogenous peat because they form in basin-shaped topographic conditions favoring rainwater accumulation. In this environment, decomposition of organic matter is retarded by the oxygen-free conditions of a permanent water table. Most ombrogenic peats occur along the coast, with frequent inundation by seawater.

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). Biodiversity changes accompanying peat dome formation and subsequent degradation have not been fully documented.

4.5.1. Physical–chemical properties

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 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, depth (Fig. 2) and cation exchange capacities.

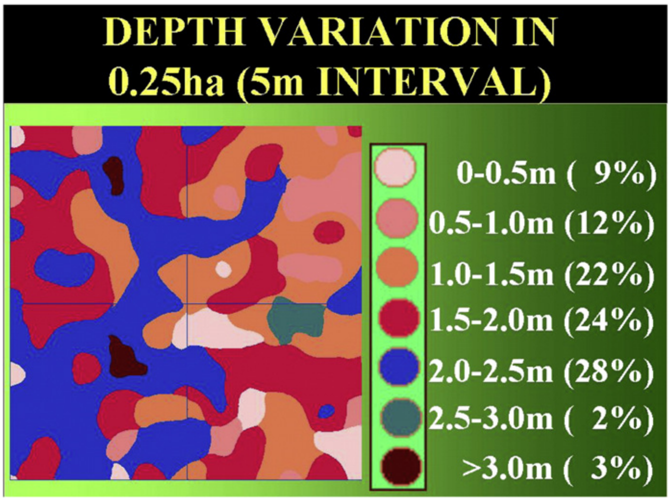

Fig. 2. Depth variation in peat.

In south Thailand, Pru Toe Daeng peat lands play an important hydrological role in regulating the quantity and quality of waters in lower basin. The peat lands buffer the high rainfalls of the months of November and December before eventually discharging the water into the sea. In Peninsular Malaysia, the North Selangor Peat Swamp Forest provides a significant supply of water (especially at the beginning of the dry season) to the adjacent Sekincan Rice fields—one of the key granary areas for the country.

A characteristic feature of many tropical peat is the acidic nature and consequently, low available nutrient content status. In contrast to temperate peats derived from moss or sedges, the woody nature

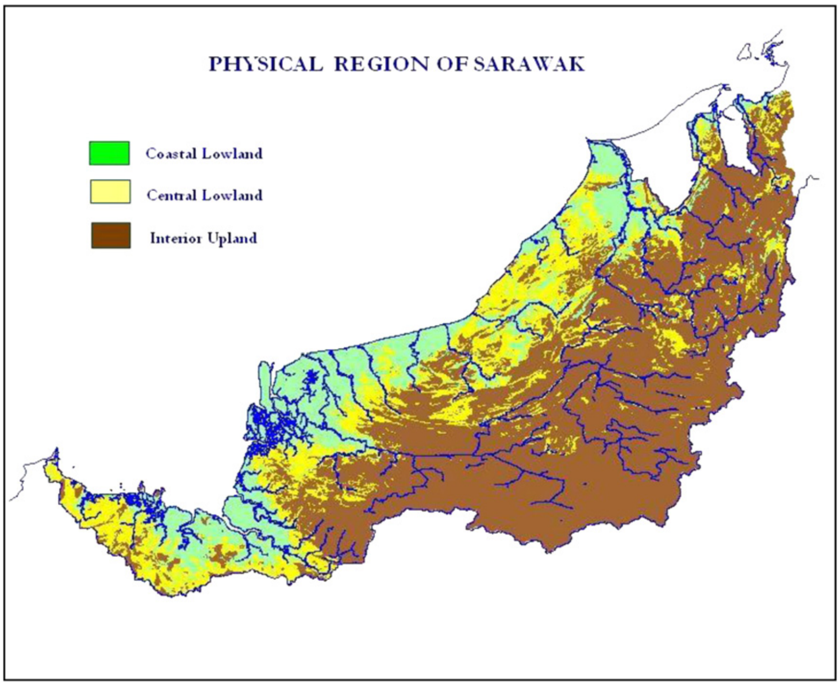

Fig. 1. The major physiological subdivisions in Sarawak.

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	Peak nos.	5	5	5	5	5	7	6	6	6	6, 7	6, 7, 8
		Frequency	1085.8	1083.9	1083.9	1083.9	1083.9	1083.9	1085.8	1087.8	1085.8	1083.9 1261.4	1080.1 1222.8 1265.2
		Intensity, % T	19.80	20.00	3.14	12.94	28.28	0.18	29.21	26.25	35.42	40.83 51.83	45.08 55.25 55.80
C═C (1500–1600)	Aromatic rings	Peak nos.	7, 8, 9	6, 7, 8, 9	6, 7, 8, 9	6, 7, 8, 9	9, 10	11, 12	10, 11	11, 12, 13	10, 11	11, 12	14, 15
		Frequency	1506.3 1539.1 1575.7	1506.3 1537.2 1542.9 1573.8	1508.2 1535.2 1544.9 1571.9	1508.2 1535.2 1544.9 1571.9	1506.3 1542.9	1512.1 1542.9	1510.2 1542.9	1512.1 1539.1 1579.6	1508.2 1541.0	1512.1 1544.9	1515.9 1550.7
		Intensity, % T	48.83 48.80 50.33	49.42 49.71 48.63 49.16	18.00 17.98 17.35 17.53	35.64 34.66 33.90 33.14	54.91 53.23	54.95 53.53	55.17 53.62	36.95 35.73 34.73	50.45 48.73	57.41 55.58	57.04 55.72
C – H (2850–3300)	Alkanes, alkenes, alkynes, aromatic rings	Peak nos.	15, 16	17, 18	15, 16	17, 18	14, 15	16, 17	16, 17	20, 21	17, 18	16, 17	21, 22
		Frequency	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2852.5 2922.0	2854.5 2923.9	2852.5 2922.0	2854.5 2923.9
		Intensity, % T	79.55 76.48	80.47 77.49	45.73 40.92	56.53 51.20	69.05 63.64	63.52 58.12	66.42 60.36	24.92 22.16	53.39 48.85	63.96 59.40	67.94 63.90
O – H (3200–3600)	Hydrogen-bonded alcohols, phenols	Peak nos.	17	19	17	19	16	18	18	22	19	18	23
		Frequency	3423.4	3427.3	3411.8	3398.3	3398.3	3396.4	3392.6	3448.5	3411.8	3406.1	3398.3
		Intensity, % T	64.48	67.23	32.44	45.46	60.59	55.03	59.71	12.13	42.53	53.01	56.64
C═O (1690–1760)	Aldehydes, ketones, carboxylic acids, esters	Peak nos.							13	16			
		Frequency							1706.9	1710.7			
		Intensity, % T							53.83	34.99			

of tropical peat makes mechanical cultivation extremely difficult. The partially decomposed wood fragments are interspersed with humified organic materials with variable degrees of water holding and cation exchange capacities. The zero point of net charge is very low and so anion exchange is insignificant. However, the large surface area and ability to hold cations imply that heavy metals are retained by the system. Recent findings suggest that kinetics and mechanism of adsorption of metals onto the organic complexes vary even among sapric materials (Hwai et al., 2001). This has been attributed to various factors, most importantly due to variations in the subsurface terric materials, the nature of the parent materials and differences in stretching bonds (Table 2). The significance becomes important in urban areas located close to peat lands. Urban and industrial wastes may be sources of heavy metals, which accumulate and remain in peats.

4.5.2. Functions

Unlike the Histosols of the temperate and colder climates, tropical Histosols are generally woody with large preserved timber in them. This is one of the reasons why it is more difficult to harvest tropical peats for horticultural purposes. The moss and sphagnum peats of cooler climates form a soft, homogenous mass that is easy for machine harvesting.

Coastal Histosols of the tropics are protected on the seaward side by raised sand ridges, which are stranded beach deposits. The inland swamps are fed with fresh water from the rivers, which are admixed with seawater. Brackish water prevails for significant periods during the formation of these tropical peat swamps. One of the minerals formed in such organic rich environments under brackish water conditions is pyrite. This mineral is largely responsible for the adverse acidity characteristics. The frequently associated soils with the Histosols are Aquents and Aquepts. These, unlike the Histosols are mineral soils but may contain high amounts of organic matter.

A recent review (Parkyn et al., 1998) on conserving peatlands emphasized the heritage value of peats such as being a natural archive of not only environmental history but also human history. Palynology yields information of past resource conditions and climate, and peats are amply supplied with preserved pollen.

In addition to providing for human needs, peatlands have other functions related to the quality of the environment. Their specific physiographic position and their properties play a distinct role in several aspects of the hydrology of the landscape (Padmanabhan, 2002). Being a wetland, they maintain the equilibrium of the water table. The system has not only free water but also has a high capacity to absorb water. Excess fresh water from rivers is discharged into the sea and the peat lands control the amount of seawater permeating into the land. It also buffers nutrient flows in and out of the system. The water table of the adjoining mineral soil is maintained and controlled by the peatlands; destruction of the peat lowers this water table and induces or aggravates drought conditions during dry seasons. The negative aspect of these properties arises when the adjoining lands are used for agriculture with heavy inputs of chemicals. Due to the high organic matter content, and the characteristic redox conditions, heavy metals and persistent organic pesticides entering the swamp are complexed and retained for a long time. Slow release of these into the water system is detrimental to aquatic life.

Peat lands sequester significant quantities of the world's carbon. The total amount of carbon in standing vegetation and peat soil has been estimated at between 20 and 35% of the total terrestrial carbon (IGBP, 1998).

It has been estimated that northern peat lands alone contain more than 500,000 million tons of carbon. Many peat lands produce only 20% of the methane produced by shallow water wetlands (IGBP, 1998). In addition, processes vary at different levels with a peat deposit. The lower levels of peat produce methane while the upper levels at least partially oxidize methane released from the lower levels. Although drainage of peat lands has been shown to reduce methane production, other studies have indicated that this may be more than compensated by the methane production in the associated drainage ditches. Carbon dioxide release will increase dramatically to levels as high as 15 t C/ha/yr in the temperate zone, and 50 t C/ha/yr in the tropics through decomposition of peat after drainage (Imirzi and Maltby, 1992).

Despite these values, functions, and fragility of the system, peat lands are rapidly being cleared and drained for other land-uses, especially agriculture. Much of the remaining forest has or is being logged over, seriously damaging the ecosystem in some cases e.g. the 1 million hectares of Mega Rice Project in Indonesia. Peat swamp forest is seriously under-represented in the protected area network in many parts of Asia as little is known about this ecosystem. Research is needed to investigate fundamental ecological questions, sustainable forestry techniques and natural hydrological processes.

5. Objective of the current work

In considering all the facts in the preceding discussion, it is apparent that an estimate for the carbon stocks in the soils of Sarawak under current conditions is needed. This will provide a platform for future work on sequestration or soil quality. There is also a need to review management strategies and identify measures for improvement in order to maintain the carbon stocks in these soils.

6. 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. Physical, chemical and mineralogical analyses were done according to Soil Survey Laboratory Staff (1992). 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. The Fourier Transform Infrared was done using a Shimadzu FTIR.

7. Results and discussion

7.1. Carbon sequestration in the various soil types

The amount of carbon that can be sequestered in a soil depends largely on the soil Order (Fig. 3) and as such tends to be spatially dependent. In comparison to the mineral soils found in Sarawak, 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.

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

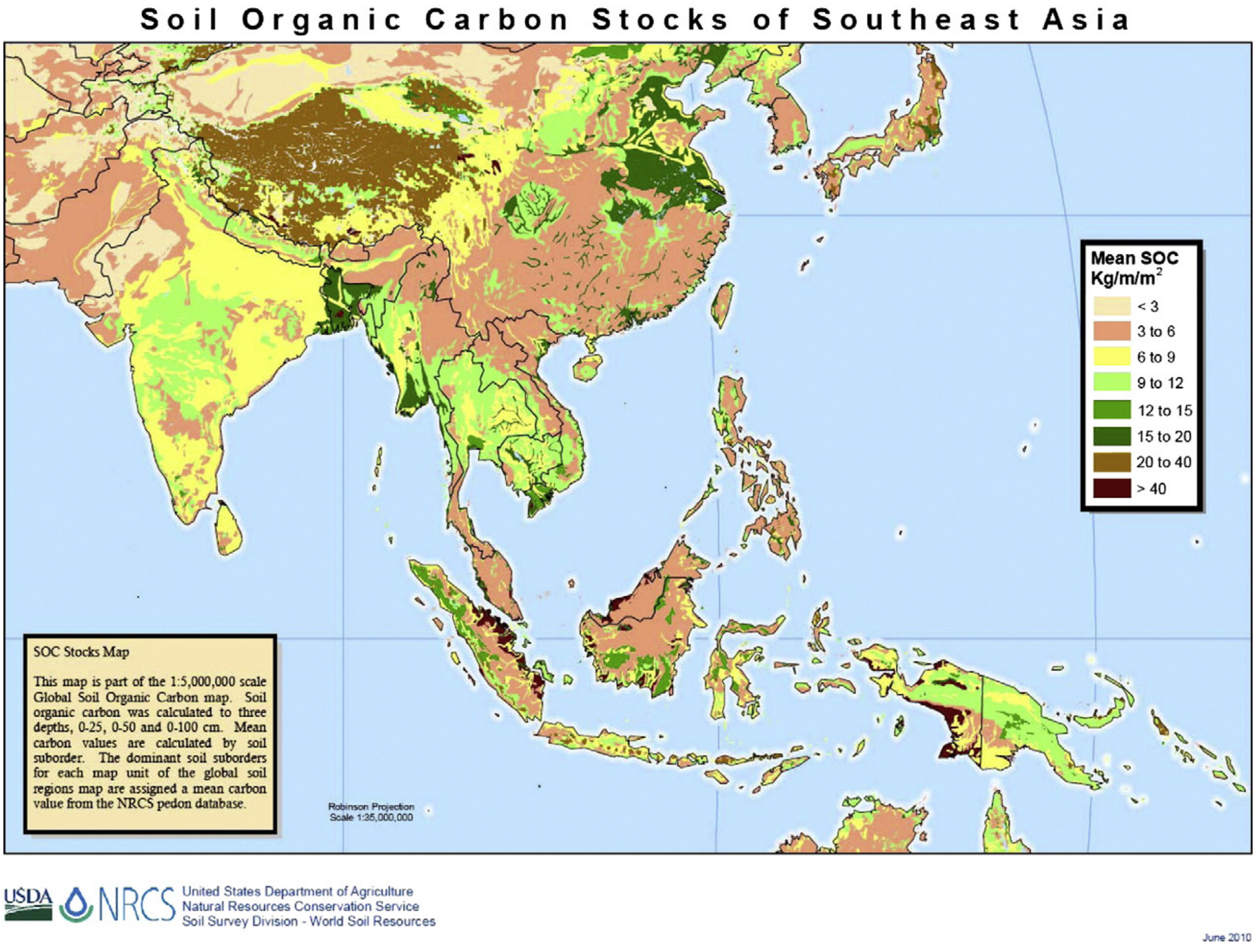

Fig. 3. Soil organic carbon stocks of Southeast Asia.

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 of Sarawak. 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.

As mentioned earlier, Histosols have the highest percentage of organic carbon distribution among the soil orders present in this state.

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 regard 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 for the carbon to be sequestered 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).

7.2. Impact of land use on emission of green house gases

It has been reported that methane has a relative global warming potential several times that of carbon dioxide (IPCC, 2001). Martikainen et al. (1992) and Flessa et al. (1998) have suggested that lowering the water table could lead to decrease in methane production and increase in the consumption of methane. Information on methane fluxes in tropical soils is limited and insufficient (Bartlett and Harriss, 1993; Inubushi et al., 2003).

7.3. 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 (Figs. 4, 5). 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 (Fig. 5). 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 (examples include continuous tillage, nutrient mining, poor water management, poor erosion control), which exist in most of the poorer countries of the world, will result in large losses. According to Eswaran et al. (1999), in 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 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.

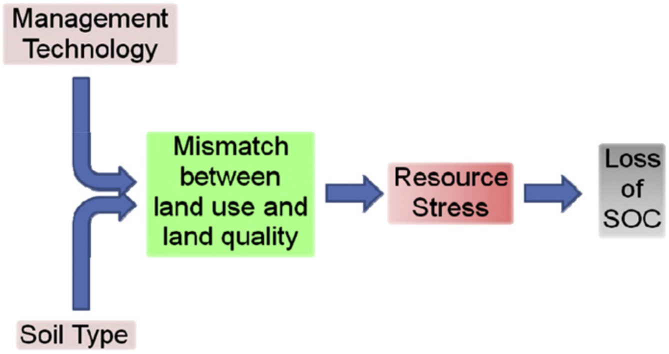

Fig. 4. Main cause of loss of SOC in soils.

8. Management strategies for soils of Sarawak in the future

Management can be enhanced to improve the sequestration capacity of soils. Despite the fact that cultivation is known to result in a loss of easily 25% of the soil organic matter, improved management strategies (stringent erosion controls, placement of fronds in interrow areas, adopting fertilizer application strategies such as foliar sprays, choosing appropriate stand per hectare based on terrain and use of biotechnology) especially in the plantation sector have reduced soil erosion, improved soil quality and as a consequence, appear to enhance the carbon sequestration capacity of soils.

The development of a database and a concerted effort 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 in Malaysia. 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.

Sustainable land management (SLM) is the system of technologies, with the associated objectives, activities, and outcomes, employed to maintain or enhance the quality and productivity of the resource base while promising an improved quality of life and intergenerational equity for the community (Eswaran, 1992). Therefore, when SLM is evaluated or monitored, the components that are considered are:

- Quality of life is maintained or enhanced;
- Ecosystem integrity is maintained or enhanced;
- Productivity, including quantity, quality, economics, and acceptance, is also maintained or enhanced.

The following are general considerations in designing SLM projects.

Indicators: The concept of sustainability incorporates a time frame of decades and SLM ensures the optimal functioning of the system over this time frame. The most important component of a SLM program are indicators that are used to monitor the progress of the system (Dumanski et al., 1992). A suite of indicators that monitor the stresses (pressure) experienced by the system, the state of the system, and the responses to the stresses, are needed. This suite is monitored regularly and analyzed to evaluate system behavior. The pressure-state-response matrix becomes a useful tool to evaluate progress. The matrix is applied to all sectors, biophysical, environmental, and the socioeconomic.

Design of land development project/s: Since the project deals with a large contiguous area, it must provide for niches for as many of the plant and animal communities that are known. Preserving the biodiversity is as important as the production part of the project. To develop a master plan, the characteristics of the biocommunities, including the needs of migratory birds, must be known or researched. Systems linkages with adjoining uplands and associated wetlands must be clearly demarcated and their role in ecosystem processes understood. These adjoining systems will be targets for special monitoring as they are also sensitive to changes. This design of the project must be made in consultation with a range of specialists and respected during the implementation phase.

Ownership of the concept: If sustainability remains a research concept, it has minimal impact and the system breaks down. There must be awareness in the community, particularly among the land-users. The land users must subscribe to the notion and this can be achieved through information dissemination and a participatory approach. The added value of biodiversity to the agro-ecosystem can be demonstrated and the land users can be charged to be the guardians of the biodiversity.

Fig. 5. A. Fires in peat swamp forests are common features when the water-table level is lowered below natural limits. B. Cultivation in peat areas requires careful management of water-tables. C. Opening up of lands in mixed terrain areas occupied by Ultisols, Entisols and Inceptisols for the purpose of cultivation requires soil conservation measures that are unique to the landscape and soil type. D. Exposure of road cuts increases the susceptibility to rock fall and soil erosion in Oxisols and Ultisols.

Economic viability: The economic viability of the farming community is the driver of the sustainability paradigm in the project area. In its absence, the farmers' preoccupation with survival prevents them from considering contributing to environmental concerns. Appropriate government support, marketing facilities, infrastructures such as road networks, and an efficient extension service assure the viability.

9. Research strategies

A good strategy anticipates constraints to sustainability and develops the activities to address them (Virmani et al., 1994). Though the theme of the paper is C-pool in soils of Sarawak, the socioeconomic component is critical to this and in many instances is more important than the technical solutions (Widjaja-Adhi and Karama, 1994). Needless to say, both these components are nullified if they do not operate in an appropriate policy environment, from national to local.

Some framing questions to develop the research strategy include the following:

1. Has the quality of life of the communities in the area been significantly enhanced by making available information on soils digitally?
2. What changes can be recommended to maximize profits and minimize risks?
3. What are the innovative methods that can be applied to enhance the estimation of carbon sequestration in the soil resources under various management practices in the tropical environment?
4. Is land degradation (or components of it) being changed and in what direction?
5. Is the productivity of the soil resource base being attained and maintained?
6. Is the current pattern and mix of land use the best for the goal of sustainability and overall C-sequestration?

Current concerns on soil conservation and management as outlined above have given rise to the following areas of prioritized research:

1. The recent estimates of organic carbon accumulation revolve around 1–2 mm per annum. What remains unclear is that is the peat/or peat swamp forest in the tropics a C sink or a source/emitter of C? Can this argument be extended to mineral soils in the interiors?
2. Is there an established link between cultivation and C-loss in tropical peat (Fig. 5)? Much of the work done on tropical peat points to irreversible subsidence or subsequent loss of carbon from the surface tiers after a fire incident.
3. The concept of multi-stake-holders approach needs to be introduced at a wider scale in order to conserve the various soils and eventually the sequestered carbon in these various kinds of materials.
4. There is a need to identify the least impact strategy for developing the soils of this region. The idea of requiring a least impact management is to minimize in particular soil erosion and curb the loss of SOC at the same time.
5. Other parameters that require further studies include evaluating CO_2 emission versus average drained depth and CO_2 emission versus average water table depth. Likewise, research has shown that 0.63 Gt CO_2/yr has been lost in some peat areas due to drainage and about 1.37 Gt CO_2/yr lost due to fire in peat.
6. More work is needed in refining the approach as visualized in REDD (acronym for reduced emissions from avoided deforestation and degradation). In the same token, it is worthy to take a closer look at the worthiness and appropriateness of policies for conservation and management of the soils in Sarawak.

The paradigm shift that SLM calls for is that research must be holistic and systems based. It should include not only agronomic and crop or livestock based observations but also the linkages of these to the ecosystem and to the socioeconomic conditions of the area. It should show change and specifically how the resource base is maintained or enhanced. The maintenance of the resource base depends heavily on the characterization phase itself. In the final analysis, it should clearly demonstrate that agriculture is environment friendly as well as based on policies and research methods that adapt to changing times.

10. Conclusions

The most widely used soils for agriculture also hold large reservoirs of carbon. These soils also have the potential to sequester larger amounts of C, 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. Aquic or wetter conditions favor C-sequestration over mineralization. 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.

Degradation of C pool is an irreversible process and therefore, great care has to be exercised in managing the carbon pool in soils. In this respect, tension zones have to be identified in Sarawak and appropriate management strategies have to be outlined.

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