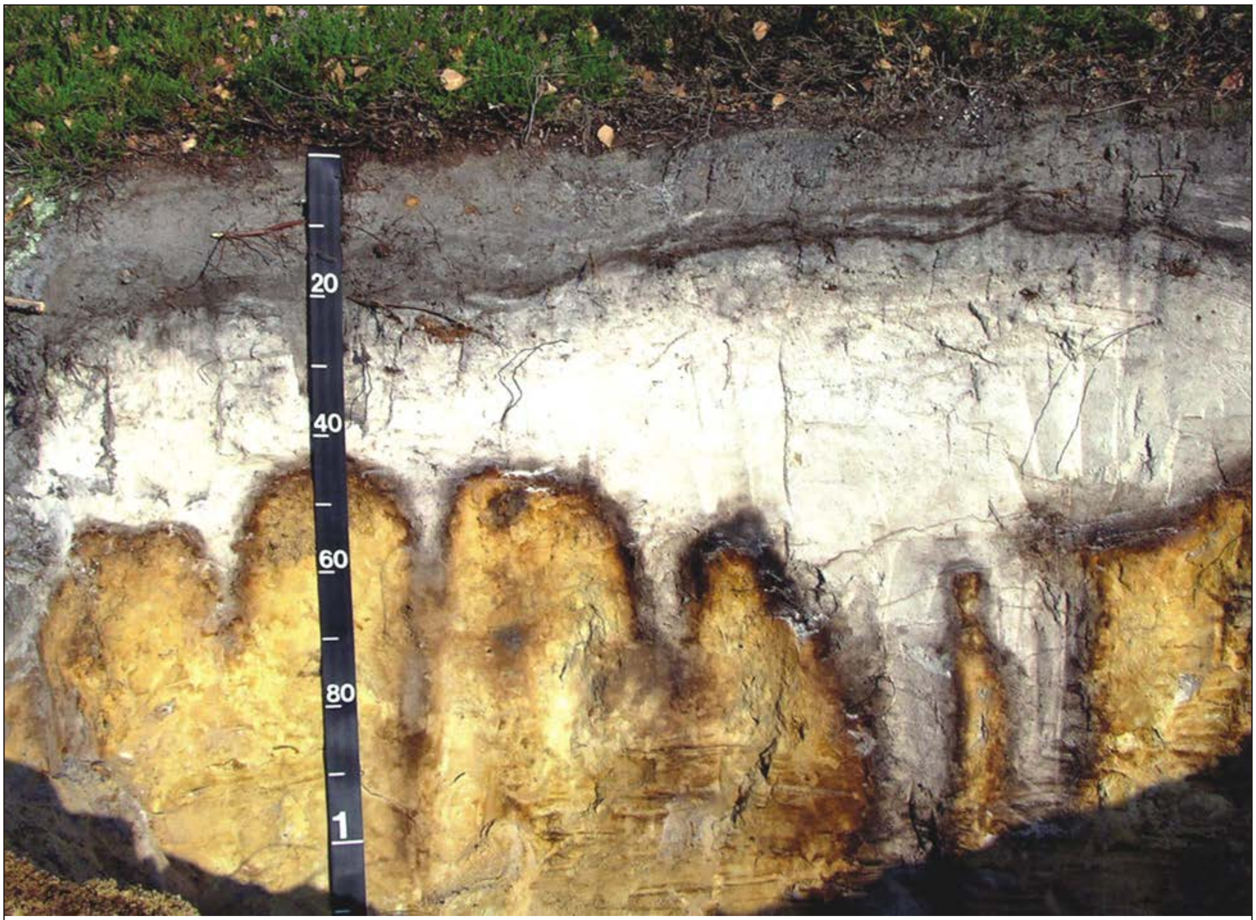

International Journal of

Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 10 (1): 17-27, 2015
ISSN 1816-4978 / DOI: 10.3923/ijss.2015.17.27

A Review on Carbon Sequestration in Malaysian Forest Soils: Opportunities and Barriers

Abdullahi Ahmed Chinade, Chamhuri Siwar, Shaharuddin Mohamed Ismail and Anizan Isahak
Institute for Environment and Development, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia

Corresponding Author: Abdullahi Ahmed Chinade, Institute for Environment and Development, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia

ABSTRACT

Carbon sequestration in forest soils is considered important for mitigation of carbon dioxide from the atmosphere and for improving forest health and land productivity. The measurement of soil carbon stock is also necessary for carbon inventory and calibration of carbon simulation models. Mitigation of carbon dioxide (CO_2) (the main Green-House Gas (GHG)) in the atmosphere can be accomplished by either reducing its emission or by sequestering it in biomass and in soil. Malaysia's large forested area, estimated at 17.7 M ha, offers an opportunity for carbon sequestration in soil. The forest ecosystem of Peninsular Malaysia alone, is reported to contain 23.48 Million tonnes of Carbon (or 86.17M to CO_2 equivalent) and a carbon sequestration potential of 4 tonnes of carbon ha^{-1} year^{-1}. However, this estimate excludes soil carbon stock despite the fact that the soil carbon component accounts for 36-46% of the total carbon in the forest ecosystem. This study reviews the opportunities and challenges facing carbon sequestration in Malaysian forest soils.

Key words: Soil carbon, forest soils, forest ecosystem, climate change mitigation, sustainable forest management

INTRODUCTION

Soil carbon sequestration is the process of transferring atmospheric CO_2 into stable pools of the soil, in the form of organic carbon, that would otherwise have been released into the atmosphere (Lal, 2008). According to IPCC (2001), World soils have the potential of sequestering 0.4-0.8 Pg year^{-1}. Carbon sequestration in soils of forest ecosystems is considered important for mitigation of climate change by reducing carbon dioxide (a major green house gases) concentration in the atmosphere (Lal, 2004, 2008; Batjes, 1999; Swift, 2001) and sustainable forestland management (Batjes, 2013; Ravindranath and Ostwald, 2008). This is because soil carbon constitute 50% of soil organic matter which is responsible for forest health and productivity. Determination of soil carbon sequestration has also become a very important exercise for comprehensive carbon invetory for different purposes (Ravindranath and Ostwald, 2008) and also for calibration of carbon models (Ngo *et al.*, 2013).

There is significant amount of carbon in the soil of forest ecosystems globally ranging from 36% (FAO., 2001), 40% (Dixon *et al.*, 1994) to 45.6% (FAO., 2006). In Malaysia, valuation and carbon inventory reports for the forestry sector largely excludes contribution of soil carbon

(Kato *et al*., 1978; Abdul Rashid *et al*., 2009). Considering the significant amount of carbon held in forest soil (36-46%), the carbon held in the forest ecosystems may have been under-estimated and under-valued.

This study reviews the importance of soil carbon sequestration in climate change mitigation, sustainable forest management. The study also emphasized the need for proper measurement of the soil carbon stock for a comprehensive Green House Gas (GHG) inventory. The opportunities and challenges associated with estimating and reporting soil carbon stock and sequestration capacity in Malaysian forests are also highlighted. The objective is to foster increased recognition of the soil as an important component of the forest ecosystem and also to encourage development of strategies and management practices that would specifically enhance carbon sequestration in forest soils.

CARBON STOCK IN FOREST SOILS

Carbon is stored in forest ecosystems mainly in biomass and soil and to a lesser extent in coarse woody debris (Ngo *et al*., 2013). The carbon stock in forest soils play a large role in global carbon cycle due to the large expanse of forest ecosystems estimated at 4.1 billion hectares globally (Dixon and Wisniewski, 1995). It has been estimated that, gloabally, the forest ecosystem contain about 1,240 Pg C (Dixon *et al*., 1994). Out of this amount, the plants (vegetation) contain about 536 Pg C while the soil is believed to contain up to 704 Pg of C. This is a very significant amount.

Globally, the soil contains two thirds of the total terrestrial carbon pool estimated at 1500 Gt C (Batjes, 2013; Lal, 2004). The forest ecosystems contains more than 70% of global Soil Organic Carbon (SOC) and forest soils are believed to hold about 43% of the carbon in the forest ecosystem to 1 m depth (Jobbagy and Jackson, 2000). In Malaysia, Saner *et al*. (2012) reported that the soil contains 23.5% of the carbon in Malua Forest Reserve, Sabah Malaysian Borneo. Neto *et al*. (2012) also reported that the soil contains 17% (30 cm depth) to 52% (3 m depth) of total carbon in Ayer Hitam Forest, Selangor, Peninsula Malaysia. Ngo *et al*. (2013) also reported that the soil contains 32.9% (3 m depth) of the total carbon stock of Bukit Timah Nature Reserve in neighbouring Singapore.

Table 1 shows the percentage organic carbon in soils of forest ecosystems as reported by different authors.

However, unfortunately this high carbon content inherent in natural forest soils is easily depleted by decrease in the amount of biomass (above and below ground) returned to the soil, changes in soil moisture and temperature regimes and degree of decomposability of soil organic

Table 1: Percentage organic carbon in soil in forest ecosystems as reported by different authors

Source	Organic carbon (%)	Forest ecosytems
FAO (2001)	36.0	Tropics
Dixon *et al*. (1994)	40.0	Global
Jobbagy and Jackson (2000)	43.0	Global
FAO (2006)	45.6	Tropics
Saner *et al*. (2012)	23.5	Sabah, Malaysia
Neto *et al*. (2012)	52.0	Selangor, Malaysia
Ngo *et al*. (2013)	32.9	Singapore
Lasco *et al*. (2006)	52.0	Philiphines
Average	40.625	

matter (due to difference in C:N ratio and lignin content) (Post and Kwon, 2000). Anthropogenic activities such as conversion of forests to agricultural land also deplete the Soil Organic Carbon (SOC) stock by 20-25% (Lal, 2005). Deforestation is reported to emit about 1.6-1.7 Pg C year^{-1} (about 20% of anthropogenic emission) (Watson *et al.*, 2000).

ROLE OF SOIL CARBON IN FOREST ECOSYSTEM

The carbon in soil plays significant roles in the forest ecosystems. Some of these include.

Mitigation of climate change: The continuous increase in the concentration of carbon dioxide (CO_2) and other GHGs in the atmosphere largely due to anthropogenic sources is believed to be responsible for climatic changes and related consequences being experienced across the globe (IPCC., 2001, 2007).

This situation has generated interest in developing strategies for reducing GHGs build up in the atmosphere. In the forest ecosystem, mitigation is accomplished either by reducing the amount GHGs, especially, CO_2 in the atmosphere or by increasing their removal (Ravindranath and Ostwald, 2008).

Out of the approximately 8.7 Gt C year^{-1} being emitted into the atmosphere, from anthropogenic sources, only 3.8 Gt C year^{-1} remains (Denman *et al.*, 2007; Lal, 2008). The unaccounted difference of 4.9 Gt C year^{-1} is believed to be sequestered in terrestrial (oceans, forests, soils etc) bodies which is referred to as the 'missing sink' (Battle *et al.*, 2000; Fung, 2000; Pacala and Socolow, 2004). This realization has generated interest on the potential of terrestrial sector (including soil) to sequester carbon in long-lived pools thereby reducing the amount that is present in the atmosphere (Stockmann *et al.*, 2013; Lal, 2004; Post and Kwon, 2000; Guo and Gifford, 2002).

Sustainable forest land management: Apart from reducing the concentration of Greenhouse Gases (GHGs) in the atmosphere, soil carbon sequestration also complements efforts geared at improving land productivity. This is because all strategies that sequester carbon in soil also improve soil quality and land productivity by increasing the organic matter content of the soil. Organic matter improves soil's structural stability, water-holding capacity, nutrients availability and favourable environment to soil organisms (Lal, 2004).

Carbon sequestration activities offers an opportunity for regaining lost productvity especially under agricultural systems. It has been reported that managed ecosystems such as agriculture have lost 30-55% of their original soil organic carbon stock since conversion (Batjes, 2013). The lost productivity of agricultural and degraded lands together offers an opportunity for recovering 50-60% of the original carbon content through adoption of carbon sequestration strategies (Lal, 2004).

Ancillary benefits: Apart from climate change mitigation and improving forest land productivity, carbon sequestration in forest soils also have several ancillary benefits. Some of these include: Improvement in water holding capacity and infiltration, provision of substrate for soil organisms, serving as a source and reservoir of important plant nutrients, improvement of soil structural stability among others (Lal, 2004). To further buttress the importance of ancillary benefits of soil carbon sequestration, a research conducted by Sparling *et al.* (2006) indicated that the environmental benefits associated with soil carbon sequestration is 40-70% higher than the productivity benefits (Stockmann *et al.*, 2013). Based on these reasons, therefore, any policy, strategy or practice that increase soil carbon sequestration also generates these benefits.

Carbon inventories: The obligation on countries that are parties to the UNFCC to periodically report their national greenhouse inventory requires a comprehensive estimation and valuation of all carbon sink and sources in the terrestrial and other sectors. These estimation and valuation of carbon in the forest ecosystem will be incomplete if the contribution of soil carbon is excluded due to its large percentage (36-46%). Carbon inventory is a process of estimating changes in the stocks (emission and removals) of carbon in soil and biomass periodically for various reasons. Some of the projects that require carbon inventory include: Aforestation and reforestation projects under the clean development mechanism, national greenhouse inventory to fulfill reporting obligation by parties to the UNFCC, sustainable forest management, land conservation and development projects etc. (Ravindranath and Ostwald, 2008).

National greenhouse inventory: Countries that are signatories to the UNFCC are required to prepare national greenhouse inventories periodically and report them to the UNFCC. Article 3.3 of the Kyoto Protocol provides that 'GHG emissions by sources and removal by sinks associated with those actvities shall be reported in a transparent and verifiable manner and reviewed in accordance with Article 7 and 8'. The GHG inventory for the purpose of national inventory reporting involves estimation of removals and emissions of GHG gases (such as CO_2, CH_4, N_2O). The inventories are rendered periodically (3-5 years interval) in the form of national communications to the UNFCC. Malaysia have rendered two national communications so far in 2000 and in 2009 (MNRE., 2011). These carbon inventories estimated carbon from biomass using allometric equations and conversion factors. Both reports had overlooked the contribution of soil carbon despite its large percentage in forest ecosystems:

- **Climate change mitigation projects:** Carbon inventories are needed to determine the baseline carbon stock and the project scenario under climate change mitigation projects. Some of the project actvitites carried out to enhance carbon sequestration or reduce carbon emission include: afforestation, reforestation, agroforestry, urban forestry, shelterbelts, biofuel projects etc (Ravindranath and Ostwald, 2008). The purpose of the carbon inventory carried out for these projects is to estimate and monitor incremental carbon emission avoided or carbon sequestered as a result of the given project, programme or policy initiative
- **Clean development mechanism projects:** These projects are also required to estimate and project the carbon stock likely to be sequestered as a result of the project over the project duration
- **Global Environment Facility (GEF) projects:** Carbon inventories are also required for GEF interventions such as the integrated ecosystem management and sustainable land management projects (Ravindranath and Ostwald, 2008). The inventory is conducted to assess the impact of the GEF project activities on carbon stocks and changes in soil and biomass of the project area
- **Forest development projects:** Carbon inventories are needed for forest development and conservation projects in order to estimate the biomass or timber production as wells as increase in soil organic matter as a result of the project (Ravindranath and Ostwald, 2008)

In all the above cases, assessment of the soil carbon stock and changes is necessary alongside the above ground component. This underscores the importance of soil carbon assessesment in terrestrial ecosystems such as forestry.

BARRIERS TO CARBON SEQUESTRATION IN FOREST SOILS

Although, there are a lot of opportunites in leveraging carbon stock and sequestration potential in the soil of forest ecosystem, numerous challenges also exist in ensuring this is achieved. Some of these challenges include.

Difficulties in measurement and verification: The stock of carbon in forest soils is difficult and very expensive to measure. Changes within the range of ten percent are very difficult to detect due to sampling errors, small-scale variability and uncertainties with measures and analysis (Trumbore and Torn, 2003). According to Ravindranath and Ostwald (2008), the annual incremental stock of carbon in soil is very small usually within 0.25-1.0 t ha^{-1}. It is even more difficult to account for little gains or losses in soil carbon at various scales due to methodological difficulties such as monitoring, verification, sampling and depth (Swift, 2001). Even if these small changes (gains or losses) are detected, it is not easy to link such changes to forest management or land use practice in a given context. Soil is very variable horizontally and vertically a lot of technical expertise is required in measuring its carbon stock or sequestration capacity (Swift, 2001). Small changes in carbon stock takes a very long period to occur due to a very slow process. The capacity of the soil to sequester and retain carbon is also finite as it reaches a steady state after sometime. The carbon sequestered is in various pools with different turnover periods ranging from few years to thousands of years (Walcott *et al.*, 2009; Swift, 2001; Lal, 2008; Ravindranath and Ostwald, 2008).

Despite these challenges however, newer methods are being developed to make measurement, monitoring and verification of soil carbon easier, faster and more accurate (Stockmann *et al.*, 2013; Capon *et al.*, 2010; Walcott *et al.*, 2009). In particular, the prospects of in-situ measurement techniques of soil carbon by using Near-Infra Red spectroscopy (NIR) and Mid-Infrared spectroscopy (MIR) technologies may address some of the challenges faced in measurement, monitoring and verification (Stockmann *et al.*, 2013).

Carbon pools: Sequestered carbon exists in the soil in different pools with varying degree of residence time in the ecosystem. These pools include:

- **Passive, recalcitrant or refractory pool:** Organic carbon held in this pool has a very long residence time ranging from decades to thousands of years
- **Active, labile or fast pool:** Carbon held in this pool stays in the soil for much shorter period due to fast decomposition. The residence time normally ranges from one day to a year
- **Slow, stable or humus pool:** Carbon held in this pool has long turnover time due to slow rate of decomposition. The residence time typically ranges from one year to a decade

Soil carbon sequestration for GHG mitigation can be successful only if the carbon is withdrawn from the atmosphere in large quantity and held in long-lived pool (Walcott *et al.*, 2009). However, this will require investment and adoption of land use and forest management practices that may have economic disadvantage to the forest owner. In addition, reliable and consistent methods are needed to isolate and allocate soil organic carbon into the different pools efficiently (Walcott *et al.*, 2009).

Permanence: Another challenge of carbon sequestration in forest soil is non-permanence of the sequestered carbon as it can be released back to the atmosphere as easily as it is gained as a result of decomposition or mineralization. It is for this reason that sequestered carbon is considered a short-term option for removing carbon from the atmosphere. The rate of carbon loss depends on several climatic, land use and management factors.

Separation: It is very difficult to isolate and differentiate the portion of carbon sequestered in the soil as result of project activities and that which occured naturally. The principle of separation in forest carbon projects require that carbon sequestered or GHGs emission prevented as a result of the project be distinguished from that which would have occured due to natural causes. This is because it has been suggested that changes in climate may have a positive feedback on carbon sequestration as increased temperature is expected to lead to increased Net Primary Productivity (NPP). The higher the NPP the more carbon is transferred to stable pools in the soils (Kirschbaum, 2000). However, a counter argument suggests that changing climate will reduce the carbon content of the soil as increased temperature is likely to accelerate mineralization of organic matter which in turn may lead to release of carbon from the soil into the atmosphere (Sitch *et al.*, 2008). Methods are therefore needed that can differentiate naturally sequestered carbon from that captured due to human management (Walcott *et al.*, 2009).

Additionality: A key obstacle to soil carbon sequestration in particular and carbon sequestration in the land use sector in general is the additionality requirement. The additionality principle pre-suppose that the carbon sequestered should be additional to the business as usual scenario. This means that, the amount of carbon sequestered by the project would not have occured without the project. On the basis of this requirement, pre-existing revenue-generating projects are automatically excluded (Ringius, 2002). This is a big barrier in the forestry sector, as the opportunity cost of alternative land use far outweighs potential revenue from carbon offsets.

Leakages: Another key barrier is the tendency of activities aimed at sequestering carbon or preventing emission in one area leading to more emission in another area. It is therefore essential to ensure carbon sequestration or emission preventioin activities do not create more forest conversion elsewhere. Leakage can be minimized in the contract design by paying for carbon stock sequestered over time, reducing payments *ab initio* based on estimated risk of potential leakage and leasing carbon credits or debits for finite periods (Murray *et al.*, 2007).

Trading barriers: A number of risks and uncertainties limiting the inclusion of soil carbon in trading scheme were identfied by Capon *et al.* (2010). These include difficulties in packaging soil carbon in units that could be traded and high transaction costs due to monitoring and verification. In addition there is a need for specialist knowledge on determining the potential and attainable carbon that could be sequestered by a given soil types in a particular location and time. A degraded soil for instance is expected to sequester more carbon than an undegraded soil.

STRATEGIES OF INCREASING CARBON STOCK IN FOREST SOILS

Although more attention seems to be given to strategies of enhancing carbon stock and sequestration capacity in agricultural soils, however, several studies have also reported about proven strategies to enhance C stock and sequestration in forest soils (Batjes, 1999). The difficulty associated with building C stock and enhancing C sequestration in forest soils is associated with the fact that there is more carbon in the biomass than soil in most forest ecosystems unlike agricultural systems where soil carbon is more than biomass carbon. Despite these challenges however, it is worth noting that all strategies that build biomass and increase organic matter content in the soil also build up the soil carbon stock and sequestration capacity (Batjes, 1999).

Some strategies that enhance carbon sequestration in forest soils include: Aforestation, reforestation, natural regeneration, enrichment planting, increasing the carbon stock of existing forests using several silvilcultural techniques among others (Batjes, 1999; Boer, 2001; Jandl *et al.*, 2007). Most of these strategies increases the carbon stock in biomass through photosynthesis and indirectly builds up below ground and soil carbon through increased deposition of organic matter. According to Post and Kwon (2000), organic carbon level of soil can be improved by increasing the amount of organic matter input, changing the decomposability of organic matter, placing organic matter in deep layer and enhancing better physical protection of the soil aggregates or formation of organo-mineral complexes.

MALAYSIAN FOREST ECOSYSTEM AND SOIL CARBON SEQUESTRATION

Malaysia covers an area of 329,758 km^2 and it comprises the Penisular Malaysia located on the southern part of Asia and the States of Sabah and Sarawak located on the north-western parts of Borneo Island.

The country has vast forested land that have the potential of sequestering carbon both in biomass and in the soil. Statistics from Malaysian Forestry Department indicate that, Malaysia has a total land area of 32.85 M ha. Out of this total land area, forested area acccount for 17.77 M ha and non-forested area constitutes the remaining 15.08 M ha (Ministry of Natural Resources and Environment, 2011). As at 2007, natural forests occupy about 18.56 million ha in Malaysia which is about 57% of the total land area (Thang, 2007).

Although Malaysian forests are typically dominated by dipterocarps species, however, topography seems to have a profound influence on the vegetation distribution. From sea level up to 300 m above sea level (asl) the forest types include mangroves, peat swamps and lowland dipterocarp. At 750 asl hill and upper dipterocarp species dominate while lower montane and upper montane species are found around 1300-1500 asl (Fig. 1).

Fig. 1: Map of Malaysia

The soils of Malaysia comprises sedentary and coastal alluvial soils (Nieuwolt *et al*., 1982). The sedentary soils consist of strongly weathered kaolinite based clay minerals developed from igneous, sedimentary or metamorphic parent materials. These soils are moslty found in the interior regions of the country and are classified as Ultisols and Oxisols. The alluvial soils are found mostly around the coastal peripheries and are classified as Entisols, Inceptisols and Spodosols (Chee and Peng, 2002). The alluvial soils comprises clay loam soils and are found in the west coast of the peninsula and some parts of Sarawak. About 2.7 M ha of peat and organic soils, acid sulphate soils are found along the west coast plains of the peninsula and Sarawak river while 'bris' (sand) soils are found along the east coast of the peninsula and coastal areas of Sabah. About 72% of the Malaysian land surface is covered by Ultisols and Oxisols (Jusop and Ishak, 2010).

Scope for carbon sequesteration in malaysian forest soils: The vast forest area (17.7 M ha) in Malaysia presents an opportunity for carbon sequestration in soils for the different reasons discussed above. These soils could sequester and retain carbon in stable pools, just like the above ground and below ground components, if the right strategies, practices and policies are adopted.

Apart from the forested area, a large swathe of non-forested areas could also be converted or rehabilatated to forested area for carbon sequestration. Example of such areas include abandoned tin mining fields, coastal dunes, landfills, urban forests among others. Research has shown that an estimated 11% of the total land area of Peninsular Malaysia is eligible for establishment of new forest for carbon sequestration purpose (Theseira *et al*., 2009).

Adoption of strategies to enhance carbon sequesteration or reduce emission in forest soils may make Payment Carbon Sequestration Services (PCSS) mechanism more viable by raising the value of carbon stock in the forest ecosystem. It has been reported that the forestry sector in Peninsular Malaysia has a carbon sequestration potential of 4 t of Carbon ha^{-1} $year^{-1}$ and contains an estimated 23.48 M t of Carbon (or 86.17 M t CO_2 equivalent) (Shamsudin *et al*., 2009). However, this figure does not include C uptake in soils clearly indicating that the carbon sequestered in the forestry sector in Malaysia is under reported due to non-inclusion of the soil component. The soil, holds 36-46% of the total carbon found in the forest ecosystem and therefore neglecting that component may have misrepresented the true value of carbon held in the forest ecosystem (FAO., 2001, 2006; Dixon *et al*., 1994; Jobbagy and Jackson, 2000).

Proper accounting and incorporation of the soil carbon in forest carbon stock estimates may make Payment for Carbon Sequestration Service (PCSS) through A/R CDM (afforestation and reforestation programme of the clean development mechanism) and REDD (reducing emissions from deforestation and forest degradation) mechanisms more profitable.

Malaysia has continued to retain 55% of its 33 M ha total land area under forest cover as required by the National Forestry Act (MNRE., 2011). This commitment has been reiterated in various international environmental fora such as the Earth Summit in Rio de Janeiro, Brazil of 1992 and at the 2009 COP 15 in Copenhagen, Denmark (Ministry of Natural Resources and Environment, 2011. At COP 15, Malaysia declared its policy commitment of reducing GHG emission by 40% of 2005 levels before 2020 (MNRE., 2011). This policy climate offers an opportunity for carbon sequestration in the biomass and soil of the forest ecosystem.

There is still the problem posed by the additionality requirement of the CDM, however which limits carbon credit only to forests established after 1990. The international carbon trading rules also excludes old growth forests from carbon offsets which put Malaysia at a disadvantage because the country has been conserving its forest decades before these rules were set. Despite this restriction, the vast forested areas of the country still renders environmental services to the

World by continuing to hold carbon and therefore reducing the amount in the atmosphere (Shamsudin *et al.*, 2009).

CONCLUSION

The knowledge of carbon stock and sequestration potential of forest soil is vital for accurate reporting of the national carbon inventory, for designing of possible carbon payment schemes and sustainable forest management. The soil and vegetation hold much promise in reducing the amount of carbon dioxide in the atmosphere through sequestration at least for some time pending when more reliable alternatives are found. Sequestration of carbon in forest soil also improves forest health and productivity even if proceeds from carbon revenue remain unattractive. However, the contribution of forest soils to total carbon stock and sequestration potentials of the forest ecosystem is not well recognized, especially in Malaysia which have led to under-reporting and under-valuing of mitigation potential in the forestry sector. More fundamentally, we have also shown that there are challenges associated with the concept and practical implementation of soil carbon sequestration in countries such as Malaysia and have discussed how these may be overcome.

To make soil carbon sequestration a viable policy alternative in climate change mitigation and sustainable land management, more research is needed and flexibility is required in the rules governing carbon offsets in the conventional and voluntary markets. It is also necessary to increase the carbon price by factoring other ecosystem services rendered by soil carbon in the valuation. There is also a need to develop forest management practices that enhance carbon stock and sequestration potential in forest soil. This may make carbon trading through A/R CDM or REDD economically feasible and at the same time improve forest health and productivity.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support received from National University of Malaysia (UKM) through grant number UKM-AP-2011-24 and also ERGS/1/2013/SS07/UKM/01/1.

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