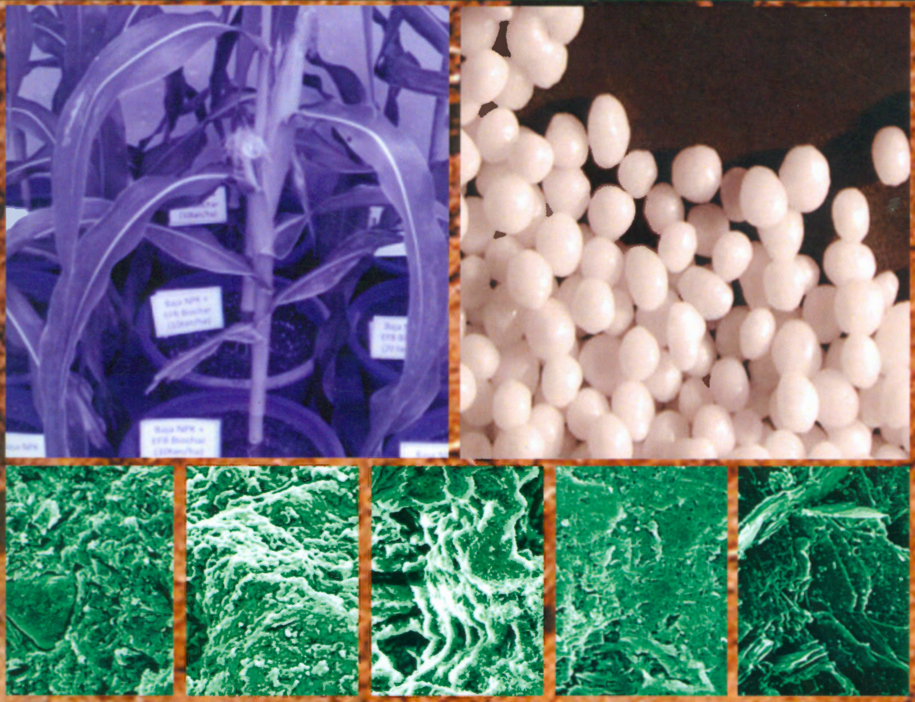
Volume 2

# Advances in Tropical Soil Science



Editors
Hamdan Jol & Shamshuddin Jusop

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Land is an indispensable resource for the survival and prosperity of mankind as well as for the maintenance of all terrestrial ecosystems. In agriculture, potential production of arable land and its susceptibility to degradation are dependent on the management strategies employed and on inherent soil and other characteristics. Over the years, increased demand and pressure on land resources results in competition for land use, declining crop production and degradation of land quality in agriculture areas.

In the tropics, it is known that agricultural intensification of an area for cropping causes decline in soil quality. Transforming the natural ecosystem to an agro-ecosystem can involve significant changes in organic matter input and turnover rates. These changes alter the infiltration, water retention, bulk density, soil strength, mineralization of nutrients and their availability to plants, cation exchange capacity, soil fertility and accumulation of heavy metals and toxic chemicals.

This book embodies the results of the on-going research on tropical soils as well as those completed in the last several years by the academic staff of the Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia and collaborative research works with other research agencies in Malaysia. Fifteen articles were submitted and published, covering wide range of topics in the area of soil genesis, soil physic, soil chemistry, soil microbiology and strategic soil fertility management in the tropics, particularly Malaysia.

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# Chapter 11

# Soil Organic C Sequestration due to Different Oil Palm Residue Mulches

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Ahmad Husni Mohd Hanif and Che Fauziah Ishak

## INTRODUCTION

Carbon dioxide ($CO_2$) is a major greenhouse gas in the atmosphere which is produced mainly from burning and decomposition of C-based materials such as oil and crop residues. The concentration of $CO_2$ in the atmosphere is increasing and would result in global warming. According to NOAA-ESRL (2012), $CO_2$ concentration in the atmosphere has increased from 315.97 ppm in 1959 to 391.57 ppm in 2011, at the rate of almost 2.2 ppm $y^{-1}$ (IPCC, 2007). As a greenhouse gas, $CO_2$ traps infrared radiation emitted from the earth surface which, in turn, warms up the atmosphere and ground surface. Therefore, appropriate methods are needed to reduce the emission of greenhouse gasses in particular $CO_2$ into the atmosphere.

One of the methods is by soil C sequestration which would not only result in the improvement of soil C stock, but would also offset the net $CO_2$ emission into the atmosphere; thereby, reducing the impact of atmospheric $CO_2$ on global warming. Moreover, soil C sequestration is essential to enhance the quality of soil and hence to increase soil productivity and eventually food security. Carbon sequestration is the transferring of atmospheric $CO_2$ into durable reservoirs and storing it securely so that it is not immediately reemitted (Lal, 2004). Therefore, soil C sequestration implies increasing soil C stocks via wise land use and recommended management practices (RMPs) such as application of crop residue mulches, conservation tillage, agroforestry and various cropping systems, use of manure, compost, and biosolids (Lal, 2004). Increase in soil C stocks through RMPs leads to decrease in $CO_2$ concentration in the atmosphere because part of the photosynthesized biomass is converted into stable humus with a long mean residence time in soil (Lal, 2011). The rate of soil organic C sequestration with the adoption of RMPs ranges from 50 to 1500 kg $ha^{-1}$ $y^{-1}$ and follows a sigmoid curve, reaching the maximum limit 5 to 20 years after adoption of the recommended management practices (Lal, 2004; 2011). One of the best management practices to increase soil organic C is recycling of oil palm residues as mulch.

Malaysia, with 5 million ha of oil palm plantations, produces a huge amount of oil palm residues every year. These residues are oil palm empty fruit bunches (EFB) and pruned oil palm fronds (OPF). Empty fruit bunch is one of the major solid wastes of the oil palm fresh fruit bunches after oil milling process and accounts for 20-25% of oil palm fresh fruit bunches (Chan *et al.*, 1980; Loong *et al.*, 1987; Husin et. al., 1987; Lim and Zaharah, 2000; Budianta *et al.*, 2010; Rosenani *et al.*, 2011). More than 17 million tons of EFB is produced in Malaysia every year. Eco-mat (ECO) is a carpet-like material made from EFB fiber to reduce the EFB bulkiness. Pruning is a normal practice in oil palm plantations where one or two fronds supporting the ripped bunch is pruned about twice a month from each palm to facilitate fresh fruit bunch harvesting. Based on 24 pruned fronds per palm per year and assuming the moisture content of the fronds as 65.57 %, Chan *et al.* (1980) reported that 34 t $ha^{-1}$ $y^{-1}$ pruned fronds are produced in the field. This means every year over 142 million tons of pruned OPF is produced in Malaysia. The pruned fronds are stacked on the soil surface as a mulch to decompose and release their nutrients into the soil and improve soil fertility and plant productivity. According to Germer and Sauerborn (2007) and Moradi *et al.* (2012), these oil palm residues contain about 50 % C which would release during decomposition mostly as $CO_2$. A fraction of C is also released as $CH_4$ as a result of anaerobic decomposition (Germer and Sauerborn, 2007; Reijnders and Huijbregts, 2008). In the past, EFB was incinerated to generate steam (Ma *et al.*, 1993) which caused air pollution by emitting $CO_2$ into the atmosphere. However, due to the regulated environmental pollution policy of zero burning imposed by the Malaysian government, EFB is mainly today used as mulch. Application of the EFB and other oil palm residues as mulch has potential to reduce GHG through improving soil C sequestration. However, there is not enough evidence to confirm that the released C from these residues would enter the soil and increase soil C sequestration or emitted into the atmosphere. Therefore, the objective of this chapter was to determine whether the application of the EFB, ECO and OPF as mulch would increase soil C sequestration.

## METHODOLOGY

A field experiment was conducted in the Balau Estate oil palm plantation (2.9325° N and 101.8822° E), Semenyih, Selangor, Malaysia, for four years from 2006 until 2009. The area was cultivated with 8-year-old oil palm (*Elaeis guineensis* Jacq.) trees in 8 × 8 m triangular spacing (Figure 11.1) on a hill slope of 6°. Average annual rainfall and daily mean air temperature in the area were 2105.2 mm and 26.9 °C, respectively.

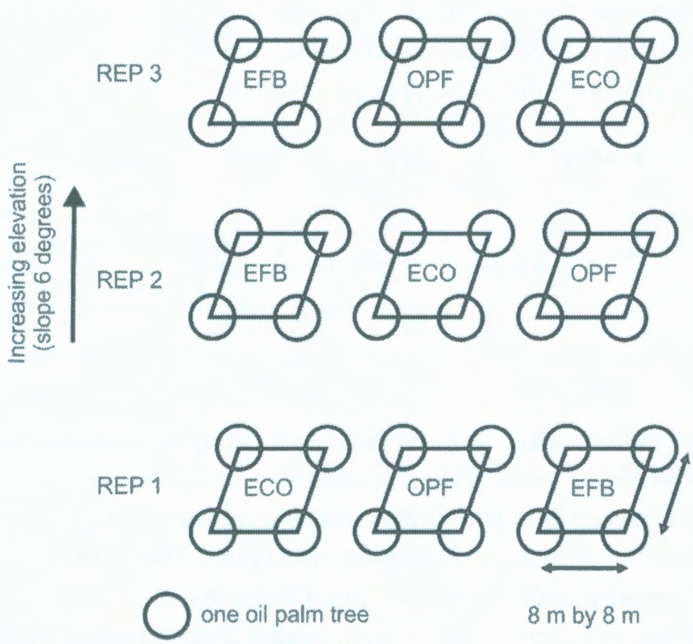


**Figure 11.1** Field layout of the experiment at Balau Estate. EFB, ECO, and OPF denote empty fruit bunch, Eco-mat and oil palm frond, respectively

The soil of the experimental area was classified as a Typic Paleudult (Rengam Series), which has a sandy clay loam texture in the topsoil (0-0.15 m depth) and sandy clay in the subsoil layer (0.15-0.30 m depth), respectively (Table 11.1). Three oil palm residues including pruned OPF, EFB and ECO were applied on the soil surface between the oil palm trees in March 2006. Empty fruit bunches were applied in the middle of each EFB treatment plot (in a 30 $m^2$ area) at a rate of 1000 kg per plot per year in a single layer, following the customary field practice in Malaysia (Chan *et al.*,1980; Loong *et al.*, 1987; Lim, 1989; Lim and Zaharah, 2000). The empty fruit bunches applied on the land surface so that the gaps between them were minimal. Likewise, four pieces of 1 × 2 m ECO having 0.02 m thickness were placed in a single layer on the soil surface between the trees in the center of each ECO treatment plot. The EFB and ECO were re-applied in January 2007, 2008 and 2009. Two OPFs were pruned each month at fruit bunch harvesting stage (following the conventional field practice) for four years and the pruned fronds were stacked on the soil surface between the trees in alternate rows. This means that there were 24 pruned fronds per palm added to the fronds heap every year. Each mulching treatment plot was replicated three times.

**Table 11.1** Initial soil properties of the experiment site

| Depth (m) | pH | EC (dS $m^{-1}$) | CEC (cmol (+) $kg^{-1}$) | OC (%) | BD (Mg $m^{-3}$) | Particle size distribution (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | <2 µm | 2-50 µm | >50 µm |
| 0.00-0.15 | 4.93 | 1.11 | 7.00 | 1.15 | 1.59 | 28.88 | 12.55 | 58.49 |
| 0.15-0.30 | 4.82 | 0.93 | 6.73 | 1.05 | 1.65 | 44.11 | 7.71 | 48.07 |

Five pruned OPF, EFB and ECO were sampled randomly, weighed and analyzed for their respective chemical composition. The samples were then placed in labelled plastic bags, transferred to the laboratory and cleaned by wiping with a moistened towel. The samples were then cut into small pieces and placed in an oven at 70 °C overnight. After oven drying, the samples were ground using a grinding machine (Retsch SM100) fitted with a 1-mm sieve and analyzed for C by Dumas method (Skjemstad and Baldock, 2008) by using of a LECO CR-412 Carbon analyzer (LECO, USA). A 0.5 g of mulch sample was placed in an oven at 105 °C for 1.5 hours. After that, its carbon content was measured by the LECO CR-412 Carbon analyzer (LECO, USA) at 1000 °C. Soil samples from each treatment plot were also taken at 0-0.15 and 0.15-0.30 cm depth before mulch applications and analyzed for C by the Dumas method. One g of soil which had been air-dried and passed through 0.3-mm sieve was placed in an oven at 105 °C for 1.5 hours. After that, its carbon content was measured by the LECO CR-412 Carbon analyzer (LECO, USA) at 1350 °C.

Soil bulk density was determined by the core ring method (Blake and Hartge, 1986) and used to calculate the soil mass which, in turn, used for calculation of the soil C content. Soil C (kg) per $m^2$ in each EFB, ECO and OPF treatment for 0-0.15 and 0.15-0.30 m depth was calculated by multiplying soil volume by soil bulk density by soil C concentration every year just before annual mulch applications and one year after last annual mulch application.

Regression analysis was used to evaluate the impact of the oil palm residue mulches on soil C content using the REG procedure in SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). Regression equations were derived to show how soil C at 0-0.15 and 0.15-0.30 were affected by cumulative organic C applied from different oil palm residue mulches.

## RESULTS AND DISCUSSION

### Characteristics of the Mulching Materials

The OPF had significantly higher C and N concentration but lower C/N ratio compared with EFB and ECO (Table 11.2). EFB had nearly the same C but higher N concentration than those in ECO. However, the C/N ratio of the EFB was lower than the ECO. Each OPF was 2.9 times heavier than each EFB and about 1.4 times heavier than each piece of 2 × 1 m ECO. Each EFB was 7.5 and 3.5 times thicker than each ECO and OPF, respectively. Both EFB and OPF had statistically similar water content, and both of them had significantly higher water content than ECO. The EFB had about 2.2 times lower bulk density and 12.25 % higher porosity than ECO.

**Table 11.2** Selected characteristics of the oil palm residue mulches

| Property | OPF | EFB | ECO |
|---|---|---|---|
| C (%) | 49.94 a | 48.64 b | 48.47 b |
| N (%) | 1.24 a | 0.87 b | 0.60 c |
| C/N | 41.38 c | 56.15 b | 82.09 a |
| Water content (w/w, %) | 65.57 a | 64.17 a | 12.58 b |
| Weight (kg) | 10.50 | 3.65 | 7.39 # |
| Thickness (m) | 0.04 | 0.15 | 0.02 |
| Bulk density (Mg $m^{-3}$) † | N/A | 0.11 | 0.24 |
| Porosity (%) † | N/A | 91.53 | 81.54 |

OPF, EFB, and ECO denote oil palm frond, empty fruit bunch, and Eco-mat, respectively. N/A – data not available.

For the first four properties, values in the same row and with the same letter are not significantly different from one another at 5% level of significance according to the LSD test.

# Mean weight of one Eco-mat pre-cut in factory to size 1×2×0.02 m.

† Data from Teh *et al.* (2010).

## Changes in Soil Organic C due to Oil Palm Residue Mulches

Changes in soil organic carbon due to different mulching practices over time for 0-0.15 and 0.15-0.30 m soil depths are shown in Figure 11.2 and 11.3, respectively. Soil organic C was significantly affected by the mulching practices at only 0-0.15 m depth (Figure 11.2). At this depth, only annual application of EFB mulch significantly increased soil organic C (Figure 11.2a).

Neither ECO nor OPF was effective in increasing soil organic C content. Their regression slopes were not statistically significant at 5% level (Figures 11.2b and 11.2c). The rate of increase in soil C due to the EFB mulch was 0.18 g C per kg of soil per month. Significant increase in soil organic C due to the EFB mulching was likewise reported by Hamdan *et al.* (1998), Zaharah and Lim (2000), Wan Rasidah and Wan Asma (2003), and Rosenani *et al.* (2011).

Changes in soil organic C at 0-0.15 and 0.15-0.30 m depths in response to cumulative organic C added following the four annual applications of EFB, ECO and OPF are shown in Figure 11.4 and 11.5, respectively. There

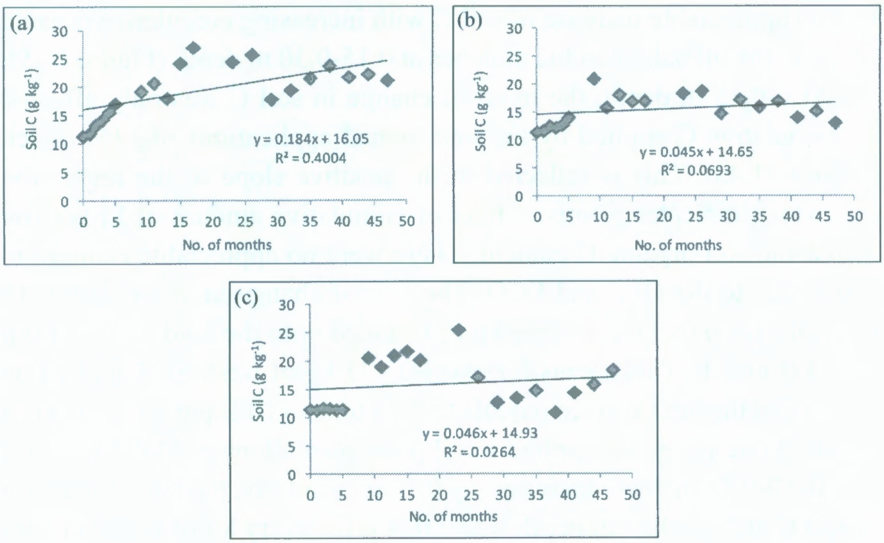


**Figure 11.2** Changes in soil organic C at 0-0.15 m depth for EFB (a), ECO (b) and OPF (c) over time. EFB, ECO, and OPF denote empty fruit bunch, Eco-mat and oil palm frond, respectively

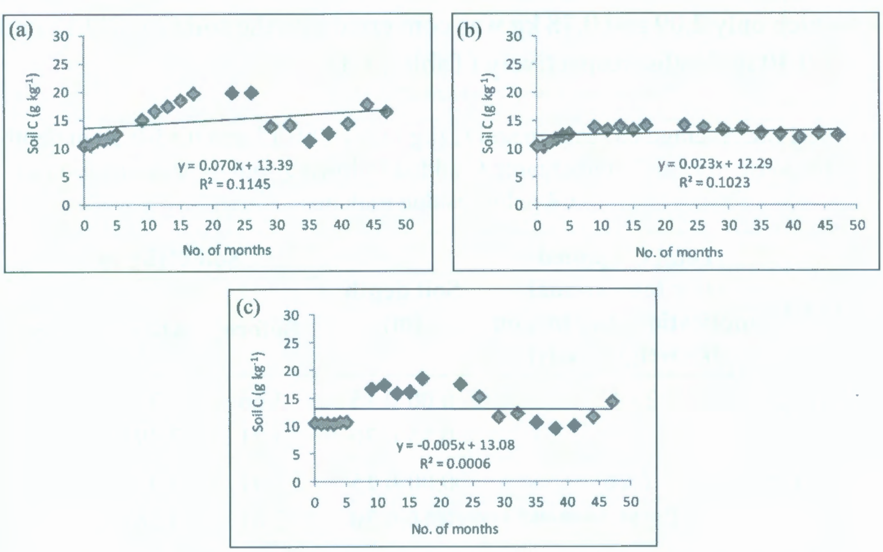


**Figure 11.3** Changes in soil organic C at 0.15-0.30 m depth for EFB (a), ECO (b) and OPF (c) over time. EFB, ECO, and OPF denote empty fruit bunch, Eco-mat, and oil palm frond, respectively

was no appreciable increase in soil C with increasing cumulative organic C due to the oil palm residue mulches at 0.15-0.30 m depth (Figure 11.5).

At 0-0.15 m depth, the trend of change in soil C was only affected by cumulative C applied by the four annual applications of EFB mulch (Figure 11.4a). This is reflected in the positive slope of the regression line which indicates positive effect of cumulative amount of EFB C on increasing soil organic C content. There were no appreciable changes in soil C due to the OPF and ECO. The rate of change in soil C at 0-0.15 m depth was 0.090 g for every kg of C added onto the land surface from the EFB mulch. This means for every 33.33 kg of fresh EFB applied on each $m^2$ of the land surface (equals to 37.5 tons of EFB per ha, which is a standard rate generally applied in oil palm plantations in Malaysia), soil C at the 0-0.15 m depth increases by 0.52 g. Similarly, the rate of increase in soil C at 0.15-0.30 m depth was 0.034 g for every kg of C added onto the soil from the EFB mulch corresponding to 0.198 g increase in soil C for every 33.33 kg of fresh EFB applied on each $m^2$ of the land surface. Therefore, after four consecutive annual applications of EFB mulch at a rate of 37.5 t $ha^{-1}$, 23.42 kg organic C added to each $m^2$ of the land surface, of which only 2.09 and 0.78 kg was converted into the soil C at 0-0.15 and 0.15-0.30 m depths, respectively (Table 11.3).

**Table 11.3** Average increase in soil C (kg $m^{-2}$) at 0-0.15 and 0.15-0.30 m depth in response to cumulative organic C added following four-year application of oil palm residue mulches

| Mulch | Total C applied after four annual applications (kg $m^{-2}$, on dry weight basis) | Soil depth (m) | Soil C (kg $m^{-2}$) | | |
|---|---|---|---|---|---|
| | | | Before | After | Increase |
| EFB | 23.42 | 0.00-0.15 | 3.66 | 5.75 | 2.09 |
| | | 0.15-0.30 | 3.21 | 3.99 | 0.78 |
| ECO | 6.26 | 0.00-0.15 | 3.91 | 4.07 | 0.16 |
| | | 0.15-0.30 | 3.01 | 3.28 | 0.27 |
| OPF | 8.55 | 0.00-0.15 | 4.30 | 4.74 | 0.44 |
| | | 0.15-0.30 | 3.36 | 3.51 | 0.15 |

EFB, ECO, and OPF denote empty fruit bunch, Eco-mat, and oil palm frond, respectively.

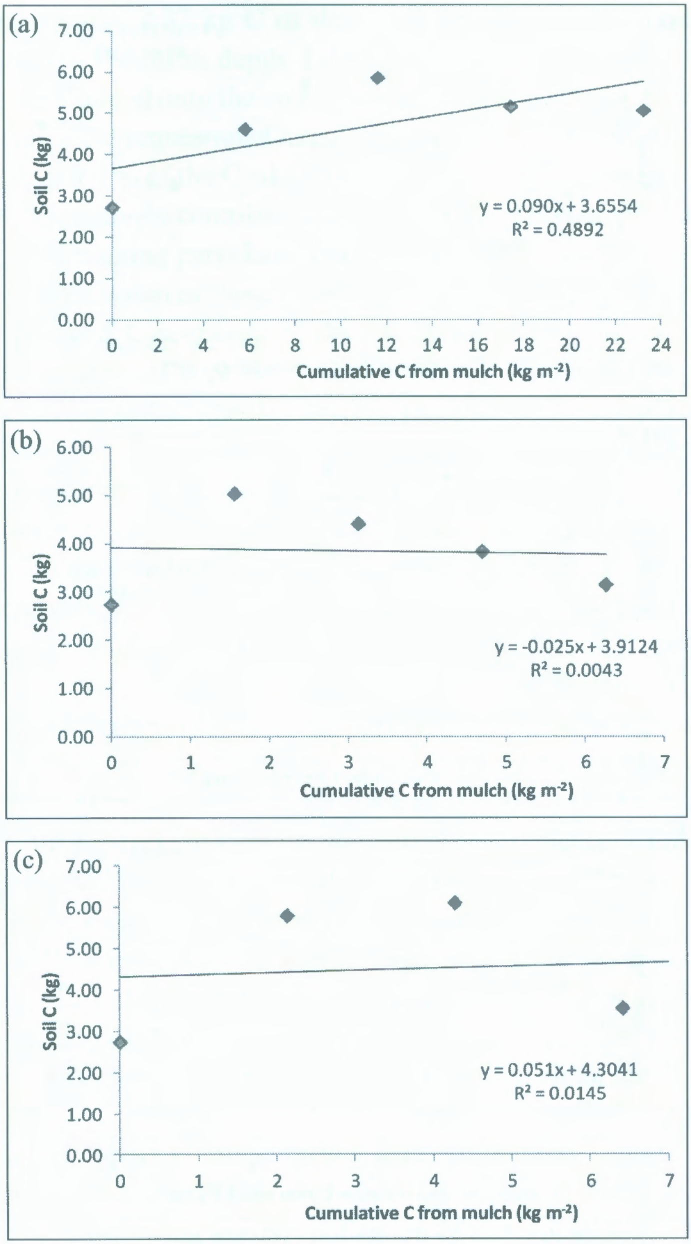


**Figure 11.4** Changes in soil organic C at 0-0.15 m depth for EFB (a), ECO (b) and OPF (c) in response to organic C added over four years. EFB, ECO, and OPF denote empty fruit bunch, Eco-mat, and oil palm frond, respectively

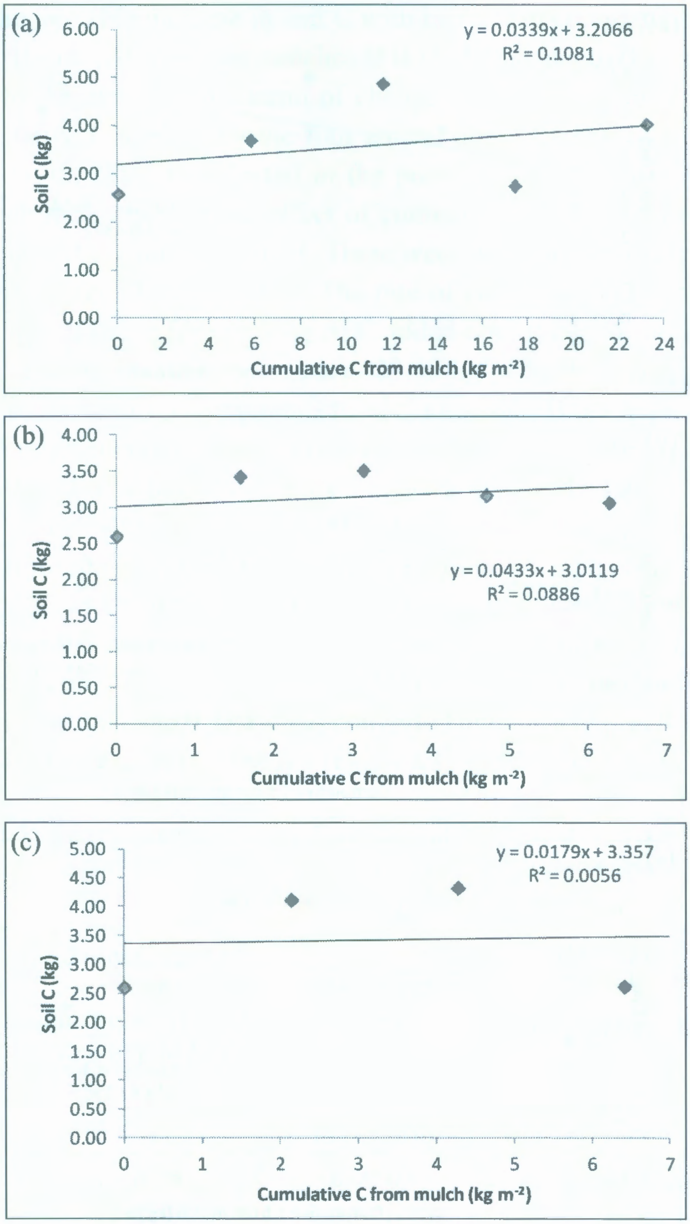


**Figure 11.5** Changes in soil organic C at 0.15-0.30 m depth for EFB (a), ECO (b) and OPF (c) in response to organic C added over four years. EFB, ECO, and OPF denote empty fruit bunch, Eco-mat, and oil palm frond, respectively

Consequently, 2.87 kg C of the 23.42 kg EFB C was sequestrated into the soil at 0-0.30 m depth. Likewise, 0.43 and 0.59 kg of the 6.26 and 8.55 kg C added onto the unit land area surface by the ECO and OPF, respectively were sequestrated into the soil at the same depth. This means only 12, 7, and 7 % of the C added onto the soil surface by the EFB, ECO and OPF, respectively contributed in increasing soil C content at 0-0.30 m depth. The remaining parts have potential to produce greenhouse gasses and enhance emission of these greenhouse gasses into the atmosphere.

The low soil C sequestrated due to the oil palm residues could be explained in terms of depletion and degradation severity of the tropical soils. According to Lal (2004), the C sink capacity of tropical soils may be high, but the rate of C sequestration can be low because of severe depletion and degradation of the soils of the tropics. Furthermore, the rapid turnover of soil organic C in the tropics reduces the accumulation of organic C in the soil and hence causes the soil organic C to be increased not appreciably. For example, Johnston (2011) reported that 75% of C in farmyard manure, 64% of C in biosolids and 60% of C in compost were lost during decomposition. Craswell and Lefroy (2001), Ross (1993) and Johnston (2011) also supported this idea and pointed out that the breakdown rate of organic matter is significantly faster in the tropics than in the temperate climate. Six *et al.* (2002) showed that mean residence time (MRT) of C in the soil surface of tropical soils (35 years) was 0.56 times of that for temperate soils (63 years) which confirms the faster C decomposition in the tropical than in the temperate soils. Besides the rapid decomposition, the loss of organic C by erosion and runoff (Craswell and Lefroy, 2001; Katyal *et al.*, 2001; Powlson *et al.*, 2011) and by leaching of dissolved organic C (Powlson *et al.* (2011) causes the soil C sequestration in the tropics to be low. Nonetheless, the increase in soil organic C content with EFB mulch application advocates that soil could play an important role in carbon sequestration on a short term basis. This is in accordance with Hao *et al.* (2003) who found a linear increase in soil organic C following annual application of cattle manure for 25 years.

## Global Soil C Sequestration due to EFB

The world area harvested for oil palm in 2010 was 15.4 million ha with an average fresh fruit bunch (FFB) yield of 14.1 t $ha^{-1}$ representing 217.9 million t $yr^{-1}$ FFB production (Table 11.4).

Considering 22% of the FFB is composed of EFB with a water content of 64.17% (Table 11.2), the amount of EFB dry matter produced in the world is 17.2 million t $yr^{-1}$. Multiplying this value by the C concentration in the EFB (48.64%, Table 11.2) results in 8.4 million t $yr^{-1}$ C available as EFB. As mentioned previously, only 12% of the EFB C was found to be converted in soil C at 0-0.30 m depth. Therefore, the amount of EFB C sequestrated into the soil globally is 1.0 million t $yr^{-1}$.

**Table 11.4** The area under mature oil palm trees, FFB and EFB production and EFB C produced annually in the world (FAO, 2010) and Malaysia (MPOB, 2010)

| Parameter | World | Malaysia |
|---|---|---|
| Harvested area (million ha) | 15.4 | 4.2 |
| FFB (t $ha^{-1}$) | 14.1 | 18.0 |
| FFB (million ton) | 217.9 | 75.5 |
| EFB (million ton) | 47.9 | 16.7 |
| EFB dry matter (million ton) | 17.2 | 6.0 |
| EFB C (million ton) | 83.6 | 2.9 |

FFB and EFB denote fresh and empty fruit bunch, respectively.

## Soil C sequestration due to the EFB in Malaysia

Malaysia covers 4.2 million ha of mature oil palm trees producing 75.5 million t $yr^{-1}$ of fresh fruit bunch (FFB) yield (Table 11.4). This translates into a total EFB dry matter of 6.0 million t $yr^{-1}$ which corresponds to 2.9 million t C produced in EFB every year. Because only 12% of the EFB C is converted into the soil C at 0-0.30 m depth (Table 3), the amount of EFB C which was sequestrated into the soil in Malaysia is 348,409 t $yr^{-1}$. Comparing this value with the global soil C sequestrated due to the EFB (Table 11.4) indicates that Malaysia contributes 34.7% of the global soil C sequestrated due to EFB.

## DISCUSSION

EFB mulch increased soil organic C the highest (and significantly) because of the higher loading rate of fresh EFB (following standard field practices in Malaysia) which, in turn, resulted in higher addition of organic C onto the unit area of the land surface as compared to the ECO and OPF mulches (Table 11.5). Annual amount of fresh mulch applied to each $m^2$ of the land surface for EFB, Eco and OPF were 33.33, 3.69 and 12.43 kg, respectively (Table 11.5).

**Table 11.5** Annual fresh mulch, dry matter and organic C applied (kg $m^{-2}$) to the land area surface as EFB, ECO and OPF

| | Mulch | | |
|---|---|---|---|
| | **EFB** | **ECO** | **OPF** |
| Annual fresh mulch applied (kg $m^{-2}$) | 33.33 | 3.69 | 12.43 |
| Dry matter concentration in mulch (%) | 35.83 | 87.42 | 34.43 |
| Annual dry matter applied from mulch (kg $m^{-2}$) | 11.94 | 3.23 | 4.28 |
| Annual C applied from mulch (kg $m^{-2}$) | 5.81 | 1.57 | 2.14 |

EFB, ECO and OPF denote empty fruit bunch, Eco-mat and oil palm frond, respectively.

As the EFB had an average water content of 64.17% (Table 11.2), the amount of dry matter added by the EFB was 11.94 kg $m^{-2}$ $y^{-1}$. The amount of ECO applied to each plot was 29.55 kg (four pieces of 1×2 m each one having 7.39 kg) and placed on 8 $m^2$ area in the middle of each ECO treatment plot. Because ECO has an average moisture content of 12.58% (Table 11.2), the amount of dry matter added by the ECO was 3.23 kg $m^{-2}$ $y^{-1}$. As mentioned previously, the normal practice for OPF is by stacking the pruned fronds on the soil surface in several layers between the trees and in alternate rows so that only the bottom most layer of frond touch the soil surface. At this research site, planting density was 148 palms per hectare with 3,552 pruned OPFs (an average weight of 10.5 kg per frond; Table 11.2) were produced every year. Since the moisture content of the OPF was 65.56 % (Table 11.2), 12,840 kg dry matter was added through pruned OPF per ha annually. Because this amount of pruned OPF was applied on about 60% of the land surface in every other row, the amount of dry matter added to the unit area of the land surface by the pruned OPF was 4.28 kg $m^{-2}$ $y^{-1}$.

Multiplying the amount of dry matter added to the unit area of the land surface by the EFB, ECO and pruned OPF (Table 11.5) by the corresponding C concentration in each of the mulches (Table 11.2) revealed that the amount of C added to the unit area of the land surface by EFB (5.81 kg) was 3.7 and 2.8 times higher than those for ECO (1.57 kg) and pruned OPF (2.14 kg), respectively (Table 11.5). Moreover, EFB decomposes at a faster rate than OPF and hence release a higher proportion of its C during decomposition. Decomposition rate constant calculated based on an exponential decay function (Olsen, 1963) and percentage of C released by EFB, ECO and OPF after eight months of decomposition are shown in Table 11.6.

**Table 11.6** Decomposition rate constant (k) and C released by EFB, ECO and OPF during eight months of their decomposition (adapted from Moradi *et al.*, 2012)

| Oil palm residue | k (% $month^{-1}$) | C released (%) |
|---|---|---|
| OPF | 0.15 b | 80.8 b |
| EFB | 0.20 a | 87.6 a |
| ECO | 0.18 ab | 86.4 ab |

OPF, EFB and ECO denote oil palm frond, empty fruit bunch and Eco-mat, respectively.

The decomposition rate (k) was the highest for EFB which was significantly different from that for OPF but not significantly different from that for ECO. During eight months of decomposition, EFB released 87.6% of its C content which was 6.9% higher than that released by the OPF (80.8%) during the same period. Therefore, the better performance of the EFB in increasing soil organic C as compared to the ECO was due to the addition of higher organic C to the land surface as a result of higher EFB loading rate. However, its better performance as compared to the OPF was due to the addition of higher organic C as a result of higher EFB loading rate and the faster decomposition rate of EFB. This is in accordance with Lal (2004) who stated that those management practices that add high amount of biomass to the soil can cause soil C sequestration.

The improvement of soil organic C due to the EFB mulching is important in maintaining tropical soil fertility especially on sloping lands via increasing the ability of a soil to resist water erosion and physical degradation, store water and supply nutrients for economic crop production (Hao *et al.*, 2003). Therefore, the increase in soil C as a result of the EFB mulching confirms that utilization of EFB as a mulch could play a significant role in reducing the emission of greenhouse gasses in particular $CO_2$ (major greenhouse gas producing during decomposition of the crop residue mulches) into the atmosphere through soil C sequestration. The soil C sequestration in turn increases soil and water quality and improve soil productivity for sustainable crop production.

## CONCLUSION

Among the three oil palm residues, only EFB mulching significantly increased soil organic C but mostly at the topsoil (0-0.15 m depth). Neither ECO nor OPF was effective in the improvement of soil organic C content. After four consecutive annual applications of EFB mulch, 23.42 kg C was added to the unit area of the land surface, of which only 12% was converted into soil organic C at 0-0.30 m depth. This corresponds to 1.0 million t $yr^{-1}$ EFB C sequestrated into the soil globally, of which Malaysia contributes 34.7%.

## REFERENCES

Blake, G. R., & Hartge, K. H. (1986). Bulk density. In A. Klute (Ed.), *Methods of soil analysis. Part 1. Physical and mineralogical methods*. (2nd ed.) (pp. 363–375). American Society of Agronomy, Inc. Madison, Wisconsin USA., .

Budianta, D., Wiralaga, A. Y. A., & Lestari, W. (2010). Changes in soil chemical properties of Ultisol applied by mulch from empty fruit bunches in an oil palm plantation. *Journal of Tropical Soils, 15*(2), 111–118.

Catyal, J. C., Rao, N. H., & Reddy, M. N. (2001). Critical aspects of organic matter management in the Tropics: The example of India. *Nutrient Cycling in Agroecosystems, 61*, 77–88.

Chan, K. W., Watson, I., & Lim, K. C. (1980). Use of oil palm waste material for increased production. In E. Pushparajah & S. L. Chin (Eds.), *Proceedings of the Conference on Soil Science & Agricultural Development in Malaysia* (pp. 213–242). Kuala Lumpur, April 10–12, 1980, Incorporated Society of Planters, .

Craswell, E. T., & Lefroy, R. D. B. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems, 61*, 7–18.

De Ridder, N., & Van Keulen, H. (1990). Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). *Fertil. Res., 26*, 299–310.

FAO. (2010). FAOSTAT online statistical service. Food and Agriculture Organization of the United Nations, Rome, Italy. Retrieved on Jan 1, 2013 from http://faostat.fao.org/.

Garmer, J., & Sauerborn, J. (2007). Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. Springer Science+Business Media BV.

Hamdan, A. B., Ahmad Tarmizi, M., & Mohd Tayeb, D. (1998). Empty Fruit Bunch Mulching and Nitrogen Fertilizer Fmendment: The Resultant Effect on Oil Palm Performance and Soil Properties. *PORIM Bulletin, 37*, 1–14.

Hao, X., Chang, C., Travis, G. R., & Zhang, F. (2003). Soil carbon and nitrogen responses to 25 annual cattle manure applications. Journal of Plant Nutr. *Soil Sci. 166*, 239–245.

Husin, M., Zakaria, Z. Z., & Hassan, A. H. (1987). Potentials of oil palm by-products as a raw materials for agro-based industries. In *Proceedings of the 1985 PORIM National Symposium on Oil Palm By-products for Agro-Based Industries*, Kuala Lumpur, 5-6 November, 1985, PORIM, 7–15.

IPCC. (2007). *Climate change 2007: The Physical Science basis*. Cambridge, UK: Working Group I. Cambridge Univ. Press.

Johnston, J. (2011). Soil organic matter changes towards an equilibrium level appropriate to the soil and cropping system. *Better Crops, 95*(4), 7–8.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*, 1623–1627.

Lal, R. (2011). Sequestering carbon in soils of agro-ecosystems. *Food Policy* (in press).

Lim, K. H. (1989). Soil erosion control under mature oil palms on slopes. In J. Sukaimi, H. Z. Z. Zakaria, K. Paranjothy, A. Darus, N. Rajanaidu, S. C. Cheah, M. B. Wahid, I. E. Hensom & H.M.T. Dolmat (Eds.), *Proceedings of PORIM International Development Conference,* Kuala Lumpur, Malaysia, Sept. 5-9, 1989, 191–198.

Lim, K. C., & Zaharah, A. R. (2000). Decomposition and N & K release by oil palm empty fruit bunches applied under mature palms. *Journal of Oil Palm Research, 12*(2), 55–62.

Loong, S. G., Nazeeb, M., & Letchumanan, A. (1987). Optimizing the use of EFB mulch on oil palm on two different soils. In H. Abdol Halim, C. P. Soon, B.J. Wood & E. Pushparajah (Eds.), *Proceedings of the 1987 International Oil Palm/Palm Oil Conference: Progress and Prospects– Agriculture*, Kuala Lumpur, Malaysia, Jun 23–26, 1987, 605–639.

Ma, A. N., Chean, S. A., & Chow, M. C. (1993). Current status of palm oil processing waste management. B. G. Yeoh *et al.* (Eds.), Paper presented at the *Conference on Waste Management in Malaysia: Current Status and Prospects for Bio Degradation*, Kuala Lumpur, 111–136.

Moradi, A., Teh, C. B. S., Goh, K. J., Husni, M. H. A., & Fauziah, C. I. (2012). Evaluation of four soil conservation practices in a non-terraced oil palm plantation. *Agronomy Journal, 104*(6), 1727–1740.

MPOB. (2010). Malaysian oil palm statistics: 2010. Retrieved on June 24, 2011 from http://www.econ.mpob.gov.my/economy/eid.

NOAA-ESRL. (2012). Trends in Atmospheric Carbon Dioxide. Retrieved on Dec 27, 2012 from www.esrl.noaa.gov/gmd/ccgg/trends.

Olson, J. S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. *Ecology, 44*, 321–331.

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., Hirsch, P. R., & Goulding, K. W. T. (2011). Soil management in relation to sustainable agriculture and ecosystem services. Food Policy (in press).

Reijnders L., & Huijbregts M. A. J. (2008). Palm oil and the emission of carbon-based greenhouse gases. *Journal of Cleaner Production, 16*, 477–482.

Rosenani, A. B., Siti, Z. D., Kulaseharan, S., & Jamaluddin, N. (2011). Effects of ten year application of empty fruit bunches in an oil palm plantation on soil chemical properties. *Nutrient Cycling in Agroecosystems, 89*, 341–349.

Ross, S. M. (1993). Organic matter in tropical soils: Current conditions, concerns and prospects for conservation. *Progress in Physical Geography, 17*(3), 265–305.

Six, J., Ferller, C., Denef, K., Ogle, S. M., Moraes Sa, J. C. D., & Albrecht, A. 2002. Soil organic matter, biota and aggregation in temperate and tropical soils – Effects of no-tillage. *Agronomie, 22*, 755–775.

Skjemstad, J. O., & Baldock, J. A. (2008). Total and Organic Carbon. In M. R. Carter & E. G. Gregorich (Eds.), *Soil Sampling and Methods of Analysis* (pp. 225–237). Canadian Society of Soil Science, CRC Press.

Teh, C. B. S., Goh, K. J., & Kamarudin, K. N. (2010). Physical changes to oil palm empty fruit bunches (EFB) and EFB mat (Ecomat) during their decomposition in the field. *Pertanika J Trop Agric Sci, 33*, 39–44.

Wan Rasidah, K., & Wan Asma, I. (2003). Effect of oil palm empty fruit bunch mulch on forest soil fertility. In Z. Eusof, C. I. Fauziah, Z. Z. Zakaria, K. J. Goh, Z. Malik & R. Abdullah (Eds.), *Proceedings of the Malaysian Society of Soil Science Conference*, Kota Bharu, Kelantan, April 15-16, 2003, pp. 198–201.

Zaharah, A. R., & Lim, K. C. (2000). Oil palm empty fruit bunch as a source of nutrients and soil ameliorant in oil palm plantations. *Malaysian Journal of Soil Science, 4*, 51–66.