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Full Length Research Paper

Soil organic matter and related soil properties in forest, grassland and cultivated land use types

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The pattern of soil organic carbon storage is influenced by land use and landscape topo-sequence. The variations in soil carbon and land use also impact soil properties, such as bulk density, pH and soil water. The aim of this study was to determine the effects of selected land uses (forest, grassland and cropland) located in Universiti Malaysia Sabah Campus and soil depth on the soil organic matter, soil carbon and related soil properties. Soil samples from 0 to 15, 15 to 30 and 30 to 45 cm soil depths were collected for organic matter, carbon and pH analysis, and from 0 to 5 and 5 to 10 cm soil depths for soil water and bulk density determination for the cropland, forest and grassland land use types. There were significant differences in organic matter and carbon in forest, grassland and cropland for the three soil depths studied. Organic matter content at the 0 to 15 cm depth of forest, cropland and grassland were estimated at 2.27, 2.07 and 0.83%, respectively. The organic matter content in all land use types decreased land used decreased significantly with soil depth. The top 5 cm of the grassland at sampling time contained 33.2 and 48.53% more soil water than the forest and cropland, respectively. Soil bulk density in cropland soils was higher than for forest and the latter was higher than in grassland. The different land uses and soil depth accounted for the variations of soil carbon stocks. Soil pH was significantly lower in the forest soil.

Key words: Land use, soil organic matter, soil carbon, soil water, bulk density, forest, grassland, cropland.

INTRODUCTION

Soil organic matter (SOM) is a complex and varied mixture of organic substances that has great influence on the behaviour, functions and properties of the soil ecosystem. There is an enormous amount of carbon stored in SOM (Brady and Weil, 1996) and the SOM can influence the physical, chemical and biological properties of soils. First, SOM modify soil physical properties by increasing total porosity and thereby decreases bulk density, especially in clayey soils. Macro aggregate stability is closely associated with SOM and an increase in organic matter can facilitate aggregation with mineral particles, particularly clays. High stability of soil can improve permeability of water into soil profile and can physically protect particulate organic matter from decomposition. SOM also contains large quantities of plant nutrients which act as a major reservoir of nutrients for plants (Magdoff and Weil, 2004). SOM also influences pH buffering of surface soils, because it contributes a significant fraction of soil cation exchange capacity (CEC) and causes the dissociation of weak acid functional groups on SOM molecules (Brady and Weil, 1996). Furthermore, SOM is both a source of energy for the soil biota and a product of biologically mediated processes of soil. SOM is positively related to the size of the microbial

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community, which affect food web changes and nutrient cycling (Mulongoy and Merckx, 1993). Due to all these impacts of SOM, the maintenance and enhancing of SOM stocks and research on these is critical in improvingand sustaining soil quality.

Soils act as a carbon dioxide (CO_2) sink in exchange with the atmosphere in terrestrial ecosystems (Wang et al., 2008). At present, global climate change has focused great attention and research efforts on the study of the soil carbon cycle (Wang et al., 2003), as the patterns of soil organic carbon (SOC) storage and amounts in various soil types or locations are hugely important for determining the role of soil in the global carbon cycle (Yu et al., 2007).

Human-induced disturbances (Fossil fuel burning and degrading land use practices) to carbon stocks are associated with increase in atmospheric CO_2 concentration, air temperature and extreme climatic events at the global scale (Brady and Weil, 1996). Land use affect both SOC stock and CO_2 exchange between soils and the atmosphere (Wang et al., 2008). Changes in land use can induce changes in SOC storage and related soil physical and soil chemical properties (Breuer et al., 2006). Land use change can lead to an alteration of the amounts and qualities of SOM (Coleman et al., 1989) and can potentially either release or sequester soil carbon (Mendham et al., 2003).

Forest soil carbon stocks have been estimated at up to 40% of global soil carbon, so it represents a significant carbon pool to global carbon budget (Chhabra et al., 2003). Approximately 30% of world soil carbon resides in grassland soil carbon stocks indicating that grassland soil has significant implications on global carbon pool (Wang et al., 2002). Conversion from natural vegetation to cropland leads to a reduction in SOC (Wang et al., 2008; Bonino, 2006; Breuer et al., 2006; Tang et al., 2006; Evrendilek et al., 2004; Walker and Desanker, 2004; Carter and Steward, 1996; Coleman et al., 1989).

The objectives of this study were to: (1) quantify organic matter, carbon, bulk density, pH and water in selected forest, grassland and cultivated land use types in Universiti Malaysia Sabah (UMS), Campus and (2) evaluate the variation of organic matter, carbon, soil water and bulk density with soil depth.

MATERIALS AND METHODS

Soil samples were taken from a forest (at different slope positions), grassland and crop land which are all located in UMS Campus, Kota Kinabalu, Sabah at lacation 06°01'N, 116°07'E. The forest land toposequence consist of shoulder, back slope and foot slope. The forest is a secondary tropical rainforest, formerly a rubber estate and was reserved since 1994. The grassland and cropland are adjacent to the forest. Twelve composite soil samples at three depths (0 to 15, 15 to 30 and 30 to 45 cm) were taken at random with an auger for each location for chemical analyses. Three replicates from the composite soil samples per depth were used for each chemical analysis. Three soil samples at 2 depths (0 to 5 cm and 5 to 10 cm) were taken at random with cylindrical core rings for each location for determination of soil bulk density (BD) and soil water content.

The soil samples for chemical analyses were air dried and ground before passing through a 2 mm meshed sieve. For the modified Walkley and Black's Rapid Titration method (Walkley and Black, 1933), the soil samples were further passed through 250 micron meshed sieve.

The soil chemical parameters were SOM, SOC and soil pH. The soil physical parameters were bulk density and soil water content. SOC was determined by the modified Walkley and Black's Rapid Titration method (Norhayati and Singh, 1980; Walkley and Black, 1933). The percentage of SOM was calculated by multiplying the SOC with 1.724, the Van Bemmelen factor (Tan, 2005).

The soil pH was measured with a pH meter in a suspension of soil in distilled water pH_{water} (soil: distilled water; 10 g: 25 ml) (Brady and Weil, 1996) and pH_{KCL} using 1 N potassium chloride (KCl) solution (soil: KCl; 10 g: 25 ml) (Soil and Plant Analysis Council, 2000). For the soil water content, the weight of soil samples before drying was recorded. The samples were then oven-dried at 105°C to constant weight and weighed and the change in weight used to calculate the water content (Anderson and Ingram, 1993). Bulk density was determined by the core method (Carter, 1993).

Analysis of variance was used to compare land use types, forest slope positions and soil depths for the various parameters, and means were compared using Tukey's test by aid of SAS software.

RESULTS AND DISCUSSION

Figure 1 shows the soil carbon (C) content for the three land use types. There were significant differences ($P \leq 0.05$) in forest, grassland and cropland for the three soil depths. Soil C in forest soils was significantly higher than cropland but the latter was significantly higher than grassland. The forest top 15 cm soil showed 8.4 and 63.4% more C than the cropland and grassland, respectively. The C in the top 15 cm was higher for all land use types as compared to the lower soil depths. The trend in C along the toposequence of the forest is as shown in Figure 2. Soil C content increased significantly from the foot slope to back slope and shoulder for the three soil depths, with the exception of the 15 to 30 cm soil depth in back slope and foot slope. The differences in soil C for the three land use types was more pronounced in the 0 to 30 cm depth as compared to 30 to 45 cm depth. The trends in SOM were a complete reflection of the soil C results, because the values of SOM were calculated using the soil C data.

Studies have shown that forest soils have more SOM than cropland soils (Wang et al., 2008; Bonino, 2006; Breuer et al., 2006; Morisada et al., 2004). In a study by Evrendilek et al. (2004), they found that the SOM content in the 0 to10 and 10 to 20 cm layers of the cropland soil were 47.5 and 50.3% lower than those of the grassland soil, respectively. However, this study showed that SOM content at the 0 to 15 and 15 to 30 cm layers of the cropland soil were 59.9 and 57% higher than those of the grassland soil, respectively. The lower soil C content in the crop land could be attributed to soil tillage and cropping intensity (Stinson and Freedman, 2001; Zinn et al., 2005). The higher SOM in the cropland as compared to the grassland in this study might be due to recent C

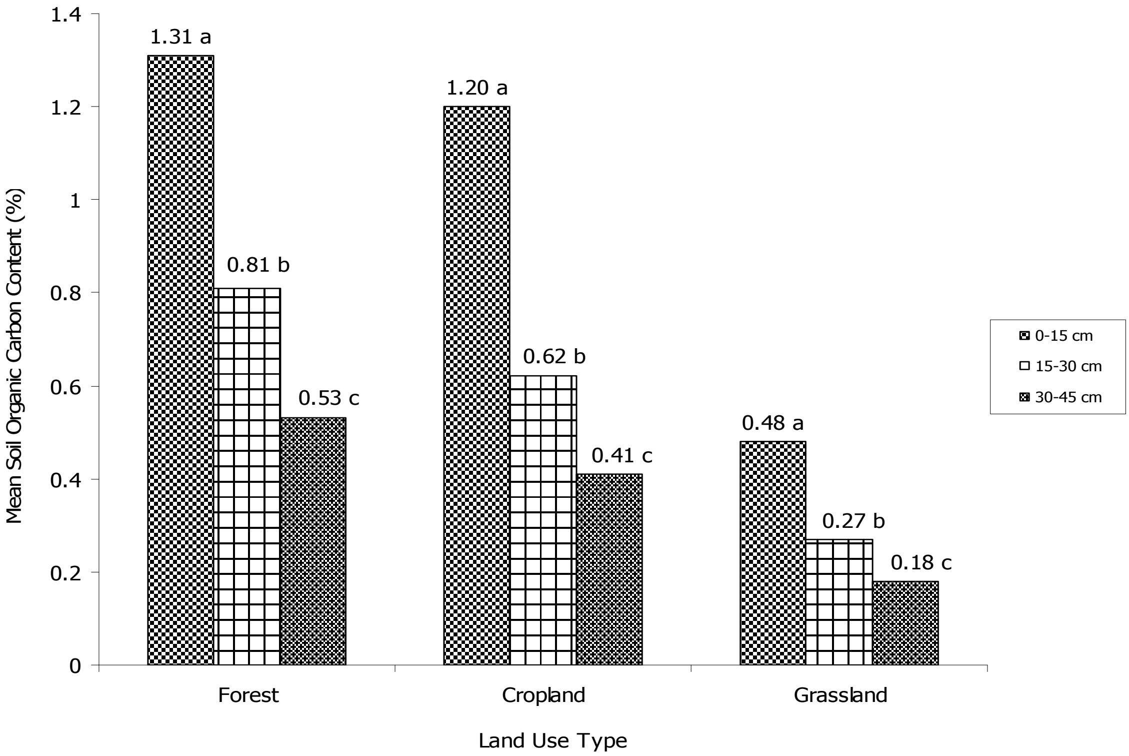

Figure 1. Soil carbon content for the land use types at various soil depths (mean with the same letter within a group of bars are not significantly different at P ≤ 0.05).

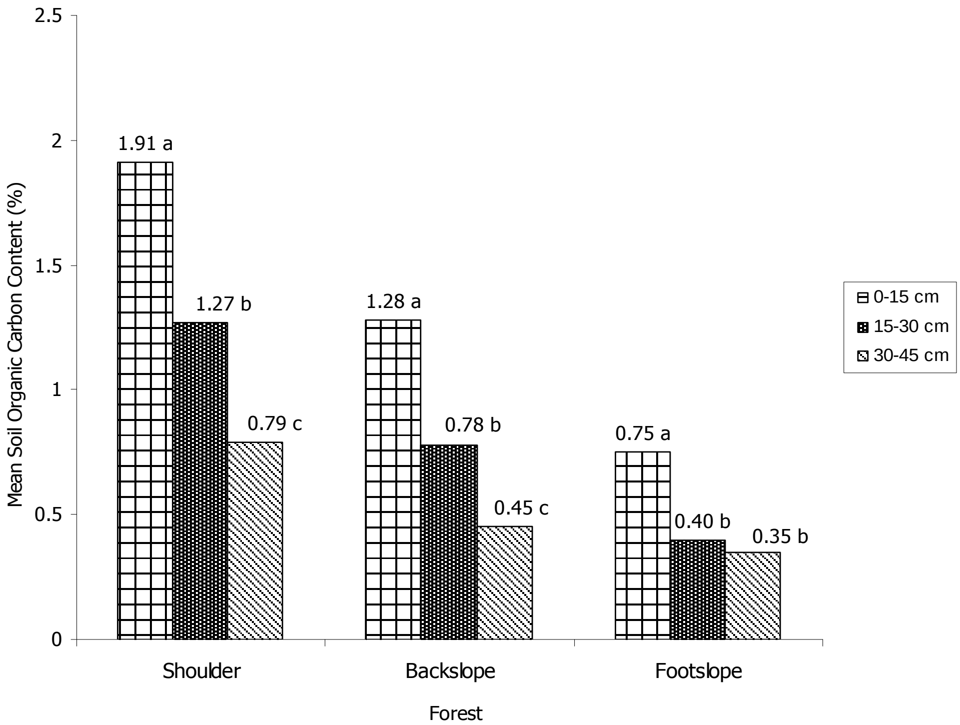

Figure 2. Soil carbon in the various topographic positions of forest for 3 soil depths (mean values with the same letter within a group of bars are not significantly different at P ≤ 0.05).

Table 1. Soil bulk density (g/cm^3) at two soil depths for the various land uses.

Land use	Soil depth (cm)		
	0 – 5	5 – 10	Mean
Forest	1.18^a	1.46^b	1.32^a
Grassland	1.28^a	1.46^a	1.37^a
Cropland	1.38^a	1.47^a	1.43^a

Mean values with the same letter within a row are not significantly different at P ≤ 0.05).

Table 2. Soil bulk density (g/cm^3) at two soil depths for the forest topographic positions.

Land use	Soil depth (cm)		
	0 – 5	5 – 10	Mean
Shoulder	1.21^a	1.42^a	1.32^a
Backslope	1.14^a	1.42^a	1.28^a
Footslope	1.19^a	1.54^b	1.37^a

*ns = no significant difference at P ≤ 0.05 between the forest toposequence (Mean values with the same letter within a row are not significantly different at P ≤ 0.05).

application of chicken and other organic manures (Foth, 1990) to the soil. Kamp et al. (2009) found a higher carbon stock under *Imperata* grassland (about 37.3 ton ha^{-1} in the first 40 cm) than under primary forest (33.19 ton C ha^{-1}). However, their findings contrasted with this study where results showed that grassland had lower carbon stock than forest. This is because the grassland of this study is not grazed by animals that contribute organic carbon from their droppings. Rezaei and Gilkes (2005) indicated that percentage soil C contents were significantly related to the slope gradient. Kamara et al. (2007) reported that for forest re-growth and cropped area, the shoulder and backslope had lower soil C content than foot slope. The results of this study correspond to the findings of Tsui et al. (2004), who indicated that the soil C decreased from the summit to the foot slope in a lowland rainforest, probably due to the quality of litterfall and lower rate of decomposition in the summit forest. At the shoulder of the study area, the plant density is higher than at the backslope with more plant residues on the soil surface of the shoulder area. The high organic matter produced by the leaf litter is returned back to the soil resulting in the high SOM content at the shoulder area. The backslope is relatively steeper causing greater surface runoff (Miyazaki, 1993) and loss of SOM. Wang et al. (2008) showed that the SOC contents in grassland and cropland generally decreased with increasing soil depth, with significant differences between the upper layers and the underlying layers. Mendham et al. (2003) reported that the proportion of total soil carbon in the 0 to 10 cm depth was higher than in the 10 to 30 cm depth for native vegetation, pasture and plantation. Those results are consistent with that of this study.

Soil bulk density (BD) for the three land use types at sampling are shown in Table 1. Soil BD in cropland soils was higher than for forest and the latter was lower than for grassland although not statistically different (P ≤ 0.05). The BD of cropland top 5 cm was 16.95 and 7.25% higher than for the forest and grassland, respectively (Table 1). The BD for the top 5 cm was lower for all land use types as compared to 5 to 10 cm depth, and the soil BD at 5 to 10 cm was significantly higher than 0 to 5 cm in the forest. Table 2 shows that there was no significant difference in soil BD along the toposequence of the forest but the soil BD at 5 to 10 cm was significantly higher than 0 to 5 cm in the foot slope.

Evrendilek et al. (2004) reported that cropland had a higher bulk density than forest and grassland in 0 to 10 cm and 10 to 20 cm depth. In this study, the bulk density in cropland was higher than forest and grassland, although not significantly different. Soils with higher SOM usually show lower bulk density as lower organic matter content decreases the stability of soil aggregation and decreases pore size and therefore increases bulk density (Yan et al., 2009; Arvidsson, 1998). Lee et al. (2009) reported an increase in soil BD with soil depth in a Malaysian tropical secondary forest which is consistent with the results of this study.

Soil water content for forest, grassland and cropland soils at the time of sampling are shown in Table 3. Soil water content in the grassland and forest was significantly higher than the cropland for the top 5 cm with the grassland containing 33.2 and 48.53% more soil water than the forest and cropland, respectively. The soil water content for the top 5 cm was always higher for the forest and the grassland as compared to 5 to 10 cm depth, with the exception of the cropland which had higher soil water

Table 3. Percentage (%) of soil water content at two soil depths for the various land uses.

Land use	Soil depth (cm)		
	0 – 5	5 – 10	Mean
Forest	24.97[a]	19.52[a]	22.25[b]
Grassland	37.38[a]	26.58[a]	31.98[a]
Cropland	19.24[b]	22.93[a]	21.09[b]

Mean values followed by the same letter in the same column are not significantly different at $P \leq 0.05$.

Table 4. Percentage (%) soil water content at two soil depths for the forest topographic positions.

Land use	Soil depth (cm)		
	0 – 5	5 – 10	Mean
Shoulder	19.51[b]	18.38[a]	18.95[b]
Backslope	17.00[b]	17.25[a]	17.13[b]
Footslope	38.39[a]	22.92[a]	30.66[a]

Mean values followed by the same letter in the same column are not significantly different at $P \leq 0.05$.

Table 5. Soil pH_{H20} and pH_{KCl} for land use types.

Soil pH analysis method	pH Water	pH KCl
Forest	4.7[c]	3.8[ba]
Grassland	5.5[a]	3.6[b]
Cropland	5.1[b]	4.0[a]

*Mean values followed by the same alphabet in the same row are not significantly different at $P \leq 0.05$.

content in 5 to 10 cm depth. The results for soil water content along the toposequence of forest are shown in Table 4. There was decrease in soil water content from shoulder to backslope followed by an increase from backslope to footslope, with the footslope having the highest soil water content. The footslope top 5 cm contained 55.72 and 49.18% more soil water than the backslope and footslope, respectively.

The soil texture in grassland is mostly clay soils, so it can withhold much more water (Foth, 1990). The crop-land was bare which increases soil water evaporation as compared to the grassland and forest. Gomez-Plaza et al. (2001) reported a negative correlation between slope angle and soil water content. They reported that steeper sites had the lowest soil water content. Their findings corroborate why the backslope in this study had the lowest soil water content along the toposequence of the forest. In addition, organic matter enhances the formation and stabilization of aggregates, resulting in abundance of pores which hold water under moderate tensions. Thus, organic matter increases the water holding capacity of soil. High stability of soil can improve permeability of rainfall and water into the soil profile and thereby increase the amount of water entering the soil to be stored for plant use (Foth, 1990).

Table 5 shows the results of soil pH for forest, grassland and cropland for two methods of soil pH analysis. There were significant differences ($P \leq 0.05$) in forest, grassland and cropland for the two methods. Soil pH_{H20} for forest soils was significantly lower than for cropland but the latter was significantly lower than for grassland. However, soil pH_{KCl} for grassland soils was significantly lower than for forest but the latter was significantly lower than for cropland. The soil pH_{H20} was consistently higher than for soil pH_{KCl} and the soils were acidic ranging from 3.6 to 4.0 for pH_{kcl} and 4.5 to 5.5 for pH_{H2o}. For soil pH_{KCl}, both exchangeable and active pools of acidity are measured resulting in pH values that are 0.2 to 0.4 units lower than pH_{H2O}. Organic and inorganic acids are formed from the decomposed SOM.

These can reduce the soil pH if the SOM is low in base-forming cations (Brady and Weil, 1996). Therefore high SOM in soils lowers soil pH.

Conclusion

The various land use types influenced soil organic matter content and this in turn influenced the physical and chemical properties of the soils. The positive influence of SOM indicates that it promotes healthy soils which would translate into sustainable soils.

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