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Research Article

Land Use Changes Affecting Soil Organic Matter Accumulation in Topsoil and Subsoil in Northeast Thailand

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The objectives of this study were to investigate effects of land use on accumulation of soil organic matter (SOM) in the soil profile (0–100 cm) and to determine pattern of SOM stock distribution in soil profiles. Soil samples were collected from five soil depths at 20 cm intervals from 0 to 100 cm under four adjacent land uses including forest, cassava, sugarcane, and paddy lands located in six districts of Maha Sarakham province in the Northeast of Thailand. When considering SOM stock among different land uses in all locations, forest soils had significantly higher total SOM stocks in 0–100 cm (193 $Mg{\cdot}C{\cdot}ha^{-1}$) than those in cassava, sugarcane, and paddy soils in all locations. Leaf litter and remaining rice stover on soil surfaces resulted in a higher amount of SOM stocks in topsoil (0–20 cm) than subsoil (20–100 cm) in some forest and paddy land uses. General pattern of SOM stock distribution in soil profiles was such that the SOM stock declined with soil depth. Although SOM stocks decreased with depth, the subsoil stock contributes to longer term storage of C than topsoils as they are more stabilized through adsorption onto clay fraction in finer textured subsoil than those of the topsoils. Agricultural practices, notably applications of organic materials, such as cattle manure, could increase subsoil SOM stock as found in some agricultural land uses (cassava and sugarcane) in some location in our study. Upland agricultural land uses, notably cassava, caused high rate of soil degradation. To restore soil fertility of these agricultural lands, appropriate agronomic practices including application of organic soil amendments, return of crop residues, and reduction of soil disturbance to increase and maintain SOM stock, should be practiced.

1. Introduction

Soil organic matter (SOM) is a key integral indicator of soil quality [1, 2]. Both soil organic carbon (SOC) and soil organic nitrogen (SON) are attributes of SOM used to describe SOM various functions [1]. The SOM dynamics are dependent on native vegetation, climatic conditions, soil types, management practices, land use history, and time of land conversion [3, 4]. Conversion of forest to agricultural land as a result of increasing population which creates a growing need of land for agricultural production has been occurring for decades [3]. Land use change affects soil ecosystems and their component microbial communities which, in turn, affects soil C and N availability [5, 6]. According to Assefa et al. [7], land use change could affect environmental conditions, such as soil temperature and moisture, which ultimately reduced the accumulation of SOC and SON, especially in sandy soil.

Numerous studies around the world have shown that land use change encompassing changes in vegetation cover, crop type, and agricultural practices has bearings on SOM accumulation. In Ethiopia, SOM stock in forest soil at 0–20 cm depth was higher than in agricultural land (i.e., eucalyptus plantation, grazing land, and cropland) [3, 7, 8]. In New Zealand, Ross et al. [9] also found that forest soil had a higher total N content (2.90 $g{\cdot}kg^{-1}$) than that under pine tree plantation (2.70 g·kg^{-1}). In the Northeast of Thailand, Tangtrakarnpong and Vityakon [10] as well as Kunlanit et al. [11] found that forest soils at 0–15 cm had significantly higher SOM content than agricultural soils. These findings were similar to those studied in China. Wang et al. [12] found that forest soil had higher SOM than upland crop soil. Most studies showed that leaf litter decomposition contributed to SOM accumulation in forest topsoil [13, 14]. However, some reports showed contrasting results. In Ethiopia, SOM accumulation in the lowland area under forest was lower than in cropland [7]. The reason put forward was that lowland forest soil had higher sand and lower clay contents than the cropland soil. Additional reason was burning of grass cover in lowland forest which lower SOM content. In China, N content in 0–10 cm soil depth increased after conversion from forest (*Pinus yunnanensis* Franch) (1.48 g·kg^{-1}) to wheat-maize rotation (1.85 g·kg^{-1}) [15]. The higher N in the wheat-maize rotation resulted from N fertilizer input and returning of crop residues to the soil. In Brazil, Ultisols with moderate clay contents had higher SOC stock in 0–100 cm under 35-year-old rubber tree plantation than that in secondary forest [16]. Accumulation of SOC in Ultisol soils was more pronounced in 0–40 cm soil depth than in the subsoils in which the accumulation of SOC decreased from 40 downward to 100 cm. Another study in Brazil on land use affecting SOM was that of coconut orchard treated with chemical-organic fertilizer application, leguminous cover crops, and mulching compared with forest soil. The coconut soil had higher SOM in 0–30 cm depth than the native forest soil [17]. In addition, surface soil layer (0–10 cm) from coconut field had higher SOM than in lower soil layer (10–30 cm).

Most of the earlier studies have focused on investigation of changes in SOM contents under land use changes in topsoil (0–20 cm) only. There were few studies focusing on SOM accumulation in soil profile (0–100 cm) under different land uses. Conversion from forest (close nutrient cycling system) to various crop cultivations (open system) with different agricultural practices alter soil processes involved in SOM formation and accumulation in topsoil and subsoil layers (>20–100 cm soil depth) of sandy soils.

Sandy soils cover a large area of Maha Sarakham province in the Northeast of Thailand, which was accounted for 35.6% (188,361 ha) of total area of this province. They are low fertility soils. The land of the province used to be predominantly covered by the dry dipterocarp forest dominated by various dipterocarp tree species. Conversion of forests to agricultural land has been carried out for close to, or in some areas more than, a century [18]. Paddy rice, cassava, and sugarcane are the most important major crops in this region. Dynamics of SOM under these rice paddy and upland crop systems are inherently different. Paddy soils are under periodically anaerobic conditions, while field crop soils (e.g., cassava and sugarcane) are totally under aerobic conditions [19]. Moreover, there were different agricultural practices among the land uses and different locations in this province. Conversion from forests to agricultural lands of various types is likely to affect the process of SOM formation and accumulation differently in top-subsoils. In this study, we hypothesized that land use change from forest to cropland reduces SOM stock in soil profile. We further hypothesized that patterns of SOM distributions among agricultural land uses are different since selected locations had different agricultural practices and soil textures. In order to test this hypothesis, we examined stocks of SOM in the soil profile (0–100 cm) as influenced by land use changes in the selected locations.

2. Materials and Methods

2.1. Study Locations. Six study locations were in six districts of Maha Sarakham province in the Northeast of Thailand. These districts including Muang, Kantharawichai, Kosum Phisai, Kut Rang, Borabue, and Wapi Pathum were selected for this study (Figure 1). Each location had four land uses, including secondary dry dipterocarp forest, and three agricultural land uses, cassava converted from the forest for five years, sugarcane converted from the forest for seven years, and rice paddy lands converted from the forests for more than 15 years. These land use plots in each location were located adjacent to each other.

The paddy fields are mostly situated at the lowest topographic positions in comparison to the other land uses (Table 1). Deciduous dipterocarp species were dominant trees in all locations for the forest land use in this study. Information obtained from interviews with the farm owners showed that agronomic practices for cassava, sugarcane, and paddy were different among locations (Table 1). Burning of rice stover and sugarcane leaves was practiced in the years that the rice stover and sugarcane leaves were excessive. However, cassava leaves were never burned. The fertilizer rates applied to the crops were provided in ranges based on estimates by farmers at each location (Table 1).

2.2. Sampling Procedures. All locations had four land uses including forest, cassava, sugarcane, and rice paddy. These land use plots were located adjacent to each other. The areas for sampling ranged from 6 ha for the forest, 3 ha for cassava, 3 ha for sugarcane, and 5 ha for paddy (Table 1). The study sites encompassed five soil series all of which were coarse textured including Nam Phong, Khorat, Ubon, Roi Et, and Satuk. Soil characteristics are shown in Table 2.

Soil sampling was done at nine positions for each land use at each location. This brought about 36 positions for four land uses in each location and 216 positions in total for six locations. Soil samples were collected in the dry season in March 2018 using an auger. The soil sample of each position was divided into five soil layers at 20 cm intervals from 0 to 100 cm. There were 1,080 samples altogether. Each soil layer from three of the nine sampling positions situated in the same contour line was mixed into a single pile. Therefore, there were three replications based on contour lines in each land use which brought the total number of samples down to 360. The soil samples were air-dried and passed through a 2 mm sieve. Laboratory analysis of SOM content for each soil sample was done in duplicate.

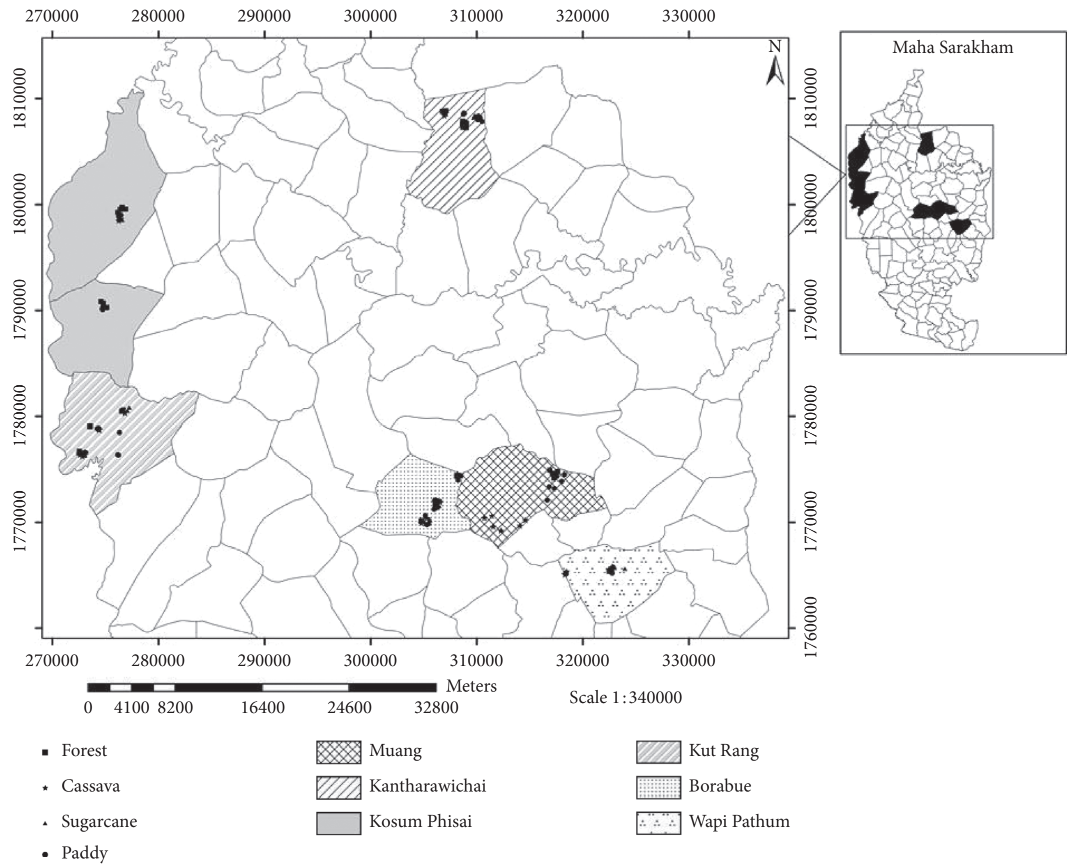

FIGURE 1: A map presenting study sites in Maha Sarakham province of Northeast Thailand.

2.3. Soil Analysis. Soil samples were analysed to determine SOM content using a wet oxidation method [24]. This method used potassium dichromate ($K_2Cr_2O_7$) as the oxidizing agent with external heat and back titration to measure the amount of unreacted dichromate.

Corrections were made for the calculated soil SOM stock by comparing the soil mass [25, 26] from the agricultural land use with the mass from the original forest land use, both at 100 cm, according to

$$\text{Layer thickness (cm)} = \left(\frac{\text{Mf}}{\text{Mm}}\right) \times 100\,\text{cm}, \quad (1)$$

where Mf ($g{\cdot}cm^{-3}$) is the mean soil bulk density of the forest soil at a given depth, Mm ($g{\cdot}cm^{-3}$) is the mean soil bulk density for each studied layer after forest conversion at the same depth. After the equivalent soil layers were corrected, the stock of SOM (Sm) was calculated by

$$\text{Sm}\left(\text{Mg}{\cdot}\text{ha}^{-1}\right) = \text{OM content (\%)} \times \text{bulk density}\left(\text{g}{\cdot}\text{cm}^{-3}\right) \times \text{layer thickness (cm)}. \quad (2)$$

2.4. Climate and Temperature during the Experiment Periods. Average monthly precipitation and temperature over the soil sampling periods (July 2017–June 2018) are presented in Figure 2. The climate data were provided by the north-–eastern meteorological center in Maha Sarakham province. The distribution of average monthly rainfall and temperature of the study sites were similar in which there was a precipitous drop in both climatic parameters during November–February period. The precipitation was the highest during July–October.

2.5. Statistical Analysis. The statistical design for analysis of variance was general ANOVA with three factors including location (six levels), land use (four levels), and soil layer (five levels) and three replications. Data were analysed statistically using Statistix 8.0 software (Analytical Software, Tallahassee, FL, USA). The data were adjusted for normal distribution. Individual analysis of variance was first performed for each location. The error variances were compared for variance homogeneity. Because error variances were homogenous, combined analysis of variance was performed for all locations across location, land use, and soil layer. Means were also compared by the least significant difference (LSD).

3. Results and Discussion

3.1. Bulk Density and Soil Moisture Content. Data for soil bulk density are presented in Table 3. Most locations had several soil series except for Kosum Phisai and Wapi Pathum

Table 1: Characteristics and agronomic management of studied plots of different land use systems at various locations.

Study location	Land use type	Sampling area (ha)	Altitude (masl)/1	Agricultural practices
Muang	Forest	6	192	/2Secondary dry dipterocarp forest.
	Cassava	3	193	/3Cassava (Kasetsart50 or KU50 variety) was cultivated yearly in the early rainy season (May to June). Nitrogen fertilizer, urea (46–0–0), was applied to the crop at the rate of 113 $kg{\cdot}ha^{-1}$ at planting and fertilizer formula 15–15–15 of $N–P_2O_5–K_2O$ at the rate of 313 $kg{\cdot}ha^{-1}$ was applied three months after planting (MAP). The crop was harvested from March to May of the following year.
	Sugarcane	3	198	/4Sugarcane KK3 variety was cultivated yearly in the late rainy season from October to February. Fertilizer formula 15–15–15 of $N–P_2O_5–K_2O$ was added to the crop in two split applications at planting and 4 to 6 MAP. Cattle manure was also added in some years.
	Paddy	5	174	/5Glutinous rice (RD6 variety) and nonglutinous rice (KDML 105 variety) were cultivated yearly by transplanting seedlings in June. Urea (46–0–0) was applied to the crop at the rate of 150–180 $kg{\cdot}ha^{-1}$ at planting and fertilizer formula 16–16–8 of $N–P_2O_5–K_2O$ was applied at the rate of 125–156 $kg{\cdot}ha^{-1}$ at the tillering stage. The crop was harvested during November to December.
Kantharawichai	Forest	6	157	/2
	Cassava	3	159	/3
	Sugarcane	3	154	/4Cattle manure was added in every single year before sugarcane plantation.
	Paddy	5	156	/5
Kosum Phisai	Forest	6	190	/2
	Cassava	3	190	/3
	Sugarcane	3	189	/4
	Paddy	5	182	/5
Kut Rang	Forest	6	203	/2
	Cassava	3	198	/3
	Sugarcane	3	195	/4
	Paddy	5	198	/5
Borabue	Forest	6	185	/2
	Cassava	3	181	/3
	Sugarcane	3	186	/4Cattle manure was added in some years.
	Paddy	5	174	/5
Wapi Pathum	Forest	6	185	/2
	Cassava	3	186	/3Green and cattle manures were applied before cassava planting in some years.
	Sugarcane	3	182	/4Cattle manure was added in some years.
	Paddy	5	182	/5

/1 = meters above sea level.

in which Khorat and Ubon soil series, respectively, were the only one found in all land uses of the respective locations.

Soil bulk densities in the range of 1.34 to 1.87 $g{\cdot}cm^{-3}$ were observed across locations, land uses, and soil depths (Table 3). Soil bulk densities of all soil layers for Muang, Kantharawichai, and Kosum Phisai were higher in the paddy land use than the forest and upland crops land uses, whereas soil bulk densities for Kut Rang, Borabue, and Wapi Pathum did not show consistent patterns. Soil bulk densities showed trends of increase with soil depth for all locations although there were some inconsistencies, for example, in cassava land use in Kut Rang and in sugarcane land use in Borabue.

In a previous study, soil bulk density was highly and negatively correlated with intensity of land use [27]. Croplands have intensive agricultural practices [27] which can cause high soil bulk density while forest land use incurs little soil disturbance. The results, especially for Muang, Kantharawichai, and Kosum Phisai in this study, supported the previous finding. However, the results for Kut Rang, Borabue, and Wapi Pathum did not follow similar pattern and other factors may be more influential than agricultural practices. Water runoff in the rainy season may remove soil surface and increase soil bulk density in forest soil [28]. High frequency of fire in the dry season also reduces SOM in forest soil [29] and, thus, increases soil bulk density.

Soil bulk density is an important parameter for determining overall soil quality or soil health as it is associated with SOM and acidity [30, 31]. Furthermore, it is dependent on soil texture [32] and degree of soil compaction [33]. That is, coarser textured soils have higher bulk density than finer textured ones.

Soil moisture contents ranged between 0.66 and 21.16% across locations, land uses, and soil depths (Table 4). The patterns of changes in soil moisture contents across land

Table 2: Some soil characteristics in this study.

Soil series	Soil classification[4]	Soil depth (cm)	Particles (%) Sand	Silt	Clay	Texture
Nam Phong[1]	Grossarenic Haplustalfs	0–20	90.9	6.5	2.6	Sand
		20–40	90.9	6.5	2.6	Sand
		40–60	91.2	2.1	6.7	Sand
		60–80	91.2	2.1	6.7	Sand
		80–100	91.2	2.1	6.7	Sand
Khorat[2]	Typic (oxyaquic) Kandiustults	0–20	79.3	13.5	7.2	Loamy sand
		20–40	77.5	11.4	11.1	Sandy loam
		40–60	74.9	16.7	8.4	Sandy loam
		60–80	67.1	20.1	12.8	Sandy loam
		80–100	57.7	19.9	22.4	Sandy clay loam
Ubon[2]	Grossarenic Haplustalfs	0–20	72.6	19.4	8.0	Sandy loam
		20–40	69.2	18.0	12.8	Sandy loam
		40–60	61.5	22.5	16.0	Sandy loam
		60–80	65.0	21.4	13.6	Sandy loam
		80–100	59.2	21.0	19.5	Sandy loam
Roi Et[2]	Aeric Kandiaquults	0–20	73.9	16.9	9.2	Sandy loam
		20–40	74.9	12.3	12.8	Sandy loam
		40–60	75.5	11.3	13.2	Sandy loam
		60–80	70.8	13.6	15.6	Sandy loam
		80–100	66.3	12.3	12.4	Sandy loam
Satuk[3]	Typic Paleustults	0–20	80.1	0.7	19.2	Sandy loam
		20–40	N/A	N/A	N/A	N/A
		40–60	N/A	N/A	N/A	N/A
		60–80	N/A	N/A	N/A	N/A
		80–100	N/A	N/A	N/A	N/A

[1]Toung et al. [20]; [2]Saenya et al. [21]; [3]Kaweewong et al. [22]; [4]Soil Survey Staff [23]. N/A: not available.

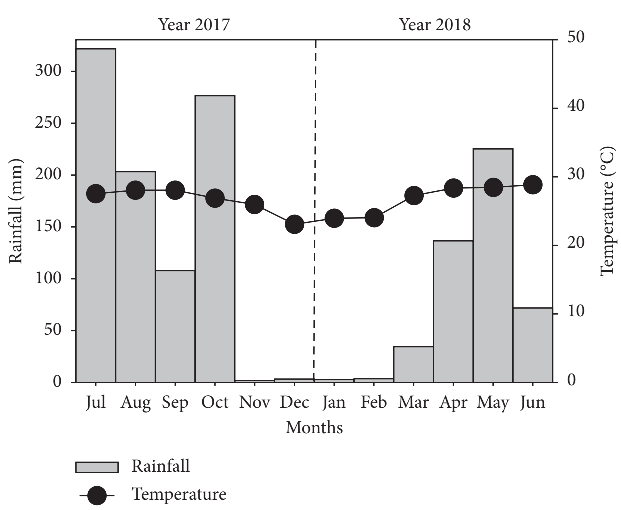

Figure 2: Climate condition and average temperature (°C) during July 2017–June 2018.

uses and soil depths were much clearer than those of soil bulk density. The pattern across land uses showed that soil moisture contents of forest soils were consistently substantially lower than those of the agricultural soils, especially paddy soils in all locations. Evapotranspiration in forest soil was higher than in agricultural soils because of the higher density of natural vegetation and deeper root systems [34]. Furthermore, agricultural lands, especially paddy land, were located at lower altitudes indicating their higher water table than the forest land. The other pattern of soil moisture content changes was that along soil depth; that is, they increased with soil depth, which was found in all land uses.

In an earlier study, soil moisture content was found to be positively and significantly correlated with SOC [35]. Decomposition rates of SOM increased in aerobic condition relative to submerged conditions [36]. Anaerobic (soil water logged) condition reduced SOM decomposition rates due mainly to low soil oxygen [37]. Therefore, SOM in paddy land is better conserved than in other land use systems because it has a more extended wet period. However, forest land can conserve rainwater in the rainy season and reduce runoff as it had high natural vegetation cover.

3.2. Changes in Soil Organic Matter Stock across Locations, Land Uses, and Soil Depths. Three analyses of variance were performed for SOM stocks (Table 5). Analysis 1 was carried out for one soil depth (0–100 cm). Analysis 2 was carried out for two soil depths (0–20 and 20–100 cm), and analysis 3 was carried out for five soil depths at 20 cm intervals. All analyses showed significant differences among locations for SOM stocks, and the differences among land uses were also substantial. The difference between topsoil and subsoil was substantial and the differences among soil layers were also significant for SOM stocks.

All primary level interactions (location × land use, location × soil depth, and land use × soil depth) were significant for SOM stocks, and the secondary level interaction

Table 3: Soil series and bulk density in soil profile under different land uses.

Location	Land use types	Soil series	Bulk density (g·cm^{-3}) Soil depth (cm)					
			0–20	20–40	40–60	60–80	80–100	0–100
Muang	Forest	Nam Phong	1.60	1.50	1.49	1.54	1.55	1.54
	Cassava	Nam Phong	1.58	1.56	1.51	1.62	1.49	1.55
	Sugarcane	Roi Et	1.50	1.63	1.57	1.56	1.62	1.58
	Paddy	Roi Et	1.69	1.68	1.76	1.78	1.87	1.76
Mean		1.59	1.59	1.58	1.63	1.63		
Kantharawichai	Forest	Khorat	1.55	1.61	1.59	1.58	1.59	1.58
	Cassava	Nam Phong	1.54	1.59	1.63	1.59	1.60	1.59
	Sugarcane	Roi Et	1.63	1.57	1.75	1.60	1.71	1.65
	Paddy	Roi Et	1.62	1.83	1.70	1.77	1.87	1.76
Mean		1.59	1.65	1.67	1.64	1.69		
Kosum Phisai	Forest	Khorat	1.44	1.34	1.40	1.45	1.47	1.42
	Cassava	Khorat	1.49	1.52	1.49	1.51	1.65	1.53
	Sugarcane	Khorat	1.44	1.49	1.56	1.58	1.75	1.56
	Paddy	Khorat	1.62	1.67	1.60	1.61	1.63	1.63
Mean		1.50	1.51	1.51	1.54	1.63		
Kut Rang	Forest	Nam Phong	1.59	1.51	1.51	1.51	1.51	1.53
	Cassava	Nam Phong	1.50	1.65	1.59	1.74	1.73	1.64
	Sugarcane	Ubon	1.51	1.54	1.61	1.49	1.63	1.56
	Paddy	Satuk	1.71	1.59	1.56	1.87	1.63	1.67
Mean		1.58	1.57	1.57	1.65	1.63		
Borabue	Forest	Khorat	1.61	1.50	1.43	1.54	1.58	1.53
	Cassava	Khorat	1.58	1.78	1.60	1.53	1.56	1.61
	Sugarcane	Roi Et	1.55	1.58	1.55	1.95	1.84	1.69
	Paddy	Roi Et	1.56	1.60	1.58	1.63	1.72	1.62
Mean		1.58	1.62	1.54	1.66	1.68		
Wapi Pathum	Forest	Ubon	1.64	1.64	1.65	1.58	1.51	1.60
	Cassava	Ubon	1.54	1.57	1.60	1.70	1.72	1.63
	Sugarcane	Ubon	1.43	1.47	1.50	1.56	1.61	1.51
	Paddy	Ubon	1.57	1.64	1.60	1.66	1.78	1.65
Mean		1.55	1.58	1.59	1.63	1.66		

The data were from one replication.

(location × land use × soil depth) was also significant. *F*–ratios indicated that soil depth was the greatest source of variation followed by location and land use, respectively, whereas the variations due to interactions were rather small. The significant interactions are important for the evaluation of SOM.

Across six locations, land uses for cassava, sugarcane, and rice paddy had significantly lower SOM stocks than undisturbed forests (Table 6). The finding of higher SOM stock in forest soil than the other agricultural soils is similar to many previous works [4, 8–11] which was likely due to the accumulation and decomposition of litter input from forest vegetation. Litterfall and remaining residues on soil surfaces are brought about high SOM stock in the forest soils [14]. In other studies, high input of surface litter led to high SOM accumulation in the topsoil horizon [14, 38].

Not only higher litter input but also less removal in forest (close system) compared to agricultural fields (open system). For the latter system, organic residues in the form of harvested products are removed from the fields, which contributes to lower SOM content agricultural than forest soils.

The land for sugarcane had significantly higher SOM stock than those for cassava and rice paddy, and the reduction in SOM stock accounted for 11% compared to the forest land (Table 6). The lands for rice and cassava were similar in SOM stock, and the reductions in SOM stock accounted for 25 and 26%, respectively, compared to the forest land. Cultivated lands had lower SOM stock as indicated by lower mineralizable C and N than a forest land [30]. We had assumed that the highest reduction in SOM stock was in paddy land followed by sugarcane and cassava. This is because the periods of conversion were longest for rice paddy, intermediate for sugarcane, and the shortest for cassava. The results did not positively prove this assumption. It is plausible that the differences in agronomic practices were influential in affecting the changes in SOM stock after the conversion of forest to agricultural lands.

Cassava and rice paddy are annual crops, while sugarcane is a perennial crop based on its widely practiced ratoon crop cultivation of two or more crops after harvesting of the original planted crop. Therefore, soil under sugarcane is less disturbed than rice and cassava. Rice paddy soils showed a trend of having lower degradation than their cassava counterpart (Table 6) though the former had longer establishment than the latter system. Low degradation in

Table 4: Land use altitude and moisture in soil profile under different land uses.

Location	Land use type	Soil moisture (%) Soil depth (cm)					
		0–20	20–40	40–60	60–80	80–100	0–100
Muang	Forest	1.57	1.41	1.80	2.41	3.01	2.04
	Cassava	1.20	1.27	1.92	9.62	10.18	4.84
	Sugarcane	1.45	1.12	1.27	2.21	5.55	2.32
	Paddy	4.15	5.05	10.79	11.22	11.32	8.51
Mean		2.09	2.21	3.95	6.37	7.52	
Kantharawichai	Forest	3.95	2.92	3.33	3.94	4.28	3.68
	Cassava	10.60	3.85	2.26	5.07	5.60	5.48
	Sugarcane	5.50	6.60	4.89	7.74	11.11	7.17
	Paddy	6.59	9.64	13.06	14.40	13.92	11.52
Mean		6.66	5.75	5.89	7.79	8.73	
Kosum Phisai	Forest	0.96	1.82	0.96	1.92	2.78	1.69
	Cassava	4.64	5.26	5.40	7.68	15.98	7.79
	Sugarcane	4.13	5.74	6.10	9.40	13.73	7.82
	Paddy	3.95	7.57	8.87	11.17	21.16	10.54
Mean		3.42	5.10	5.33	7.54	13.41	
Kut Rang	Forest	0.66	0.83	0.87	0.99	0.85	0.84
	Cassava	4.01	7.14	7.56	12.96	16.33	9.60
	Sugarcane	0.85	2.07	10.91	6.10	12.09	6.40
	Paddy	4.85	4.9	14.39	13.89	12.13	10.03
Mean		2.59	3.74	8.43	8.49	10.35	
Borabue	Forest	1.38	1.43	2.15	7.97	7.83	4.15
	Cassava	1.37	6.35	6.72	7.33	7.11	5.78
	Sugarcane	4.73	3.47	3.54	11.58	12.27	7.12
	Paddy	1.17	1.97	4.64	9.42	14.23	6.29
Mean		2.16	3.31	4.26	9.08	10.36	
Wapi Pathum	Forest	2.26	5.07	5.47	4.7	9.84	5.47
	Cassava	5.06	3.71	13.07	18.33	18.80	11.79
	Sugarcane	7.12	8.02	9.29	11.15	14.52	10.02
	Paddy	2.23	7.07	16.36	19.66	17.46	12.56
Mean		4.17	5.97	11.05	13.46	15.16	

The data were from one replication.

paddy soil is due to anaerobic conditions during the wet season that reduced SOM decomposition [39]. Organic materials from higher lying areas (i.e., cassava and sugarcane fields and forest) are washed down in surface runoffs to accumulate in lower areas particularly in the rainy season, resulting in higher SOM stock in the lower-lying paddy land. Although paddy soil in some locations had higher clay contents (Roi Et and Satuk soil series), SOM stocks under paddy soils were not significantly different from upland soils (e.g., cassava and sugarcane land uses). In addition, paddy land could maintain higher SOM stock than the upland crop fields because of rice straw remaining in the fields, while the residues of cassava and sugarcane were removed from the fields after harvest.

The results of SOM stocks were further analysed to consider details of each location, land use, and soil depth (Sections 3.2.1 and 3.2.2).

3.2.1. Soil Organic Matter Accumulation in Topsoil (0–20 cm) and Subsoil (20–100 cm). Stocks of SOM in topsoil and subsoil were significantly different not only among the different land uses, but also among the different study locations (significant interaction, $P < 0.01$ Table 5). Figure 3 compares SOM accumulation in topsoil (0–20 cm) and subsoil (20–100 cm) in each land use and among land uses. The results did not show a consistent pattern of SOM accumulation in all land uses across locations. For example, in the forest, SOM stock in topsoil was higher than subsoil at one location (Muang), similar to subsoil at two locations (Kosum Phisai and Wapi Pathum) and lower than subsoil at three locations (Kantharawichai, Kut Rang, and Borabue).

Soil OM is the fraction of the soil consisting of plant or animal tissue in various stages of decomposition [40]. Theoretically, SOM accumulates largely in topsoil because it directly receives input from organic litter [41]. According to Esmaeilzadeh and Ahangar [42], SOM dynamics are influenced by different ecosystem properties in each soil layer. Therefore, SOM in topsoil can be similar to or lower than in subsoil for many reasons including the higher stabilization of SOM in lower soil layers with higher clay content [43], water erosion [44], soil moisture content [45], and soil texture [46]. For instance, in the current study, movement of SOM from a topsoil with lower clay content to

Table 5: Mean squares for soil organic matter in different soil depths from four land use types and six locations.

Source of variation	Degree of freedom	Mean square	F-ratio
(a) One soil depth (0–100 cm)			
Location	5	30493.50**	195.14
Land use type	3	10480.40**	28.16
Location × land use type	15	6533.70**	17.56
Error	36	372.10	
(b) Two soil depths (0–20 and 20–100 cm)			
Location	5	15246.60**	195.17
Land use type	3	5240.10**	47.37
Soil depth/1	1	31368.50**	283.56
Land use type × soil depth/1	3	1232.30**	11.14
Location × soil depth/1	5	2737.90**	29.53
Location × land use type	15	3266.90**	24.75
Location × land use type × soil depth/1	15	1627.40**	14.71
Error	84	110.60	
(c) Five soil depths (0–20, 20–40, 40–60, 60–80, 80–100 cm)			
Location	5	6098.70**	194.99
Land use type	3	2096.30**	77.28
Soil depth/2	4	28746.70**	1059.78
Land use type × soil depth/2	12	653.30**	24.08
Location × soil depth/2	20	1224.90**	48.17
Location × land use type	15	1306.80**	45.15
Location × land use type × soil depth/2	60	292.00**	10.77
Error	228	27.10	

**Significant difference by LSD ($P < 0.01$).

Table 6: Means for soil organic matter content ($Mg \cdot ha^{-1}$) in soil profiles averaged from four land use types and six locations.

Land use types	Soil depths		
	1[a]	2[b]	5[c]
Forest	192.80A (–)	96.43A (–)	38.57A (–)
Cassava	142.30C (−26%)	71.15C (−26%)	28.46B (−26%)
Sugarcane	172.40B (−11%)	86.24B (−11%)	34.49C (−11%)
Paddy	144.64C (−25%)	72.32C (−25%)	28.93C (−25%)
CV (%)	33.11	12.90	15.27

Means in the same column followed by the different uppercase letters are significantly different by LSD ($P < 0.01$). [a]One soil depth (0–100 cm); [b]two soil depths, including topsoil (0–20 cm) and subsoil (20–100 cm); [c]five soil depths, including 0–20, 20–40, 40–60, 60–80, and 80–100 cm.

a subsoil with higher clay content leads to SOM accumulation in the subsoil as seen by high SOM stock at the subsoil in all study locations, with the exception of Kosum Phisai location (Figure 3).

When topsoil and subsoil were compared across land uses, higher topsoil SOM stock than subsoil was found only in the forest soil in Muang ($P < 0.05$, Figure 3(a)). Topsoil SOM stocks were lower than subsoil in the other 13 land uses, consisting of three forests (Kantharawichai, Kut Rang, and Borabue), five cassavas (Muang, Kantharawichai, Kut Rang, Borabue, and Wapi Pathum), three sugarcanes (Kut Rang, Borabue, and Wapi Phatum), and two paddy fields (Kantharawichai and Wapi Pathum) ($P < 0.05$). Topsoil SOM stocks were comparable to subsoil for 10 land uses, including two forests (Kosum Phisai and Wapi Pathum), one cassava (Kosum Phisai), two sugarcanes (Muang and Kosum Phisai), and five paddy fields (Muang, Kantharawichai, Kosum Phisai, Kut Rang, and Borabue) ($P > 0.05$).

It is interesting to note here that topsoil had rather high SOM accumulation in forest soil, and it was rather low in agricultural soils in Muang and Kosum Phisai (Figures 3(a) and 3(c)). The differences were most pronounced under cassava fields. High SOM in the topsoil of forest soil has been reported in different regions [46, 47]. Decomposition of litterfall and fine root on soil surfaces enhances SOM in forest topsoils [15].

It is also worth mentioning that the subsoils had significantly higher SOM than the topsoils across most land uses (13 land uses) with exception of only one case, that is, the forest land use of Muang. The high SOM in subsoil was likely due to the movement of SOM from coarser textured topsoil to finer textured subsoil with higher clay content. The clay can adsorb and conserve SOM. As soil is a sink for C and N [48], the movement of SOM or SOC from topsoil to subsoil could reduce C and N emission to the atmosphere as CO_2, CH_4, and N_2O [49]. Assefa et al. [7] reported that SOM

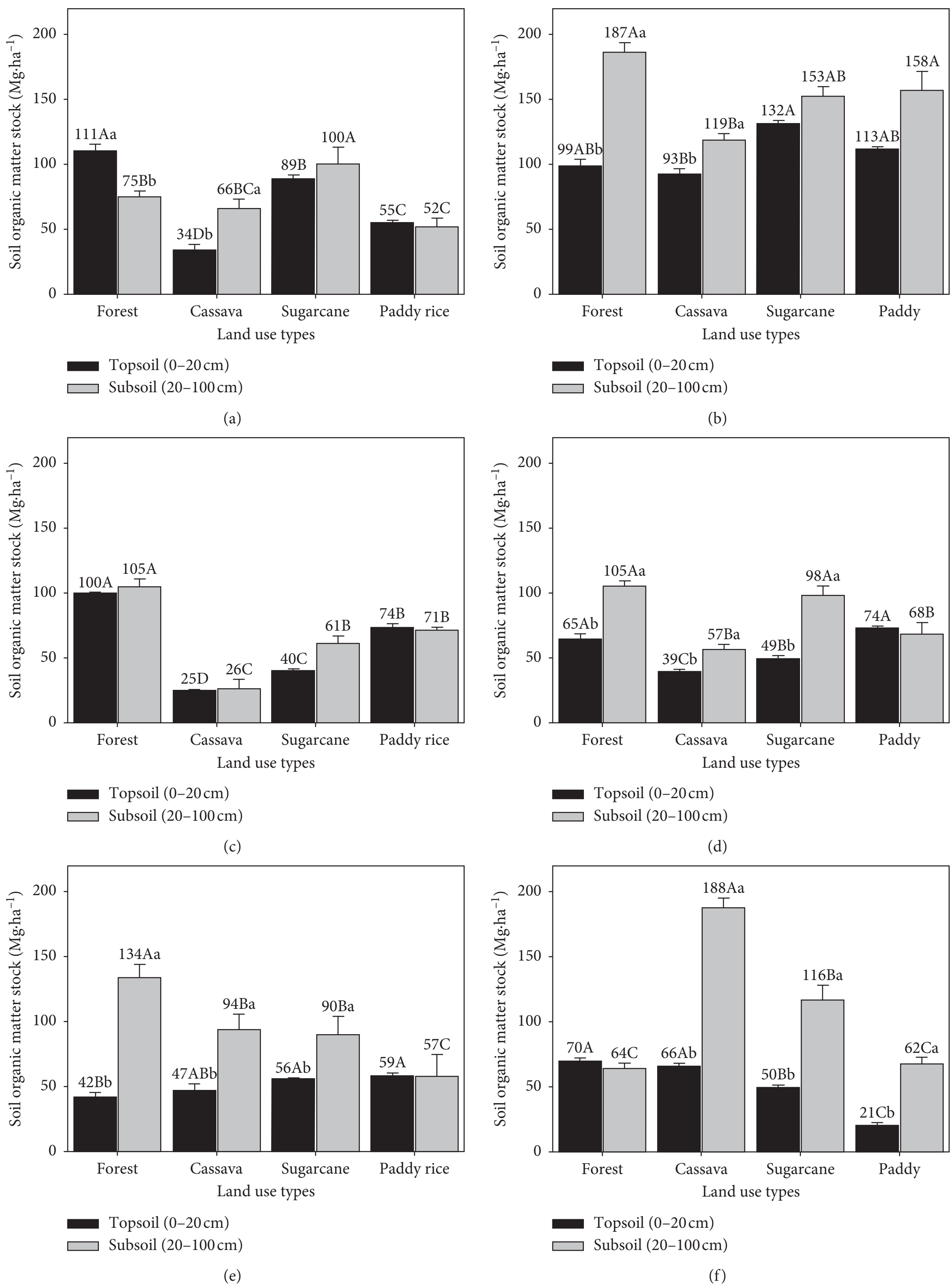

Figure 3: Land use changes affecting SOM stocks in topsoil (0–20 cm) and subsoil (20–100 cm) at six locations. Uppercase letters accompanying bar graphs denote comparisons of SOM stocks of a topsoil or subsoil among different land uses. Lowercase letters denote comparison of SOM stocks between a top and subsoil within a land use type. Similar letters indicate no significant differences ($P > 0.05$), as analysed by the LSD method. Error bars represent standard error of the mean. (a) Muang. (b) Kantharawichai. (c) Kosum Phisai. (d) Kut Rang. (e) Borabue. (f) Wapi Pathum.

sequestration in subsoil accounted for 40% of total SOM in 0–50 cm soil depth. According to Rumpel and Kögel-Knabner [50] and Deng [51], the interaction of OM with soil mineral surfaces led to stabilization of OM in subsoil horizons. Soil OM is preferentially associated with clay in the subsoil, which generally has high clay particles [52]. The interaction of SOM with clay mineral is a reason to store SOM in the subsoils which contain high clay content [53].

Rice paddy was more comparable to forests for SOM accumulation in topsoil. Soil OM under the forests and rice paddies were mainly derived from leaf litter and rice stubbles, respectively. The results in this study were similar to those in previous reports [7, 8, 10].

3.2.2. Soil Organic Matter Stock in the Whole Soil Profile down to 100 cm Depth. Stocks of SOM in soil profile (0–100 cm) were not only significantly different across the different land uses, but also across the different study locations (significant interaction, $P < 0.01$, Table 5). Three of six forest soils including Kosum Phisai, Kut Rang, and Borabue had higher SOM in the whole soil profile (0–100 cm) than agricultural soils ($P < 0.05$) (Figures 4(c)–4(e)). Forest and sugarcane soils were not significantly different for SOM stocks at Muang and Kantharawichai locations, but they were higher than paddy and cassava soils (Figures 4(a) and 4(b)). Soil OM stock in cassava soil was the highest at Wapi Pathum location followed by sugarcane, forest, and paddy soils, respectively, and SOM stocks in all land uses were significantly different ($P < 0.05$) (Figure 4(f)).

The authors compared SOM stock in the whole soil profile to gain an overview of effects of the changes in land use on SOM stock. Forest soil was still the prominent land use type that could maintain high SOM stock in most locations. The lower SOM stock in Wapi Pathum location could be due to several factors that reduced SOM stock in forest soil there. One outstanding feature was high soil bulk density at 0–60 cm depth (Table 3) indicating soil compaction which could result in low soil aeration and low activity of microorganisms for organic material decomposition.

Sugarcane soil showed a trend of having higher SOM stock than cassava and paddy soils in five out of six locations. Sugarcane has deep fibrous root system which permeates widely and deeply in soil. It is also a ratoon crop that can be harvested more than one time after planting which lessen soil disturbance due to annual planting. On the other hand, cassava and rice are annual crops which entail more frequent soil disturbance at planting than sugarcane. Soil disturbance through plowing lower SOM content as it breaks soil aggregate thereby lessens physical protection of SOM [54–56] and increases microbial activities through increasing aeration [54]. Cassava agronomic practices involve removal of plant-derived organic materials from the fields including harvestable products, that is, tubers, and planting materials for the next growing season, that is, aboveground stems to be used as cuttings. Sugarcane produced higher leaf litter fall than cassava as shown by an earlier similar study [10].

Although paddy soil had the longest period since land use change from forest to agriculture had taken place, the SOM in paddy soil was still high compared to soils under the upland crops, which had shorter durations since the land use conversion. Paddy soil in these areas had higher clay contents than upland soils. Soil OM is preferentially adsorbed to clay, resulting in high SOM in paddy soil as compared to other land uses. According to Christensen [57] and Six et al. [58], clay was quantitatively more effective in sequestering SOM than sand.

Additionally, soils rich in silt and clay contents had high SOM accumulation, and clay also had a positive correlation with SOM accumulation [7, 59]. Also, the remaining rice stubble is an input to SOM formation and accumulation in the paddy soil in the current study. Input of surface residues and dense root system contributed to a large amount of SOM in A horizon (topsoil) [57, 60]. Furthermore, topographic position of paddy fields at lower-lying areas than forest and upland fields is conducive to receiving deposits of sediments and organic materials from the upper areas as found earlier by Tangtrakarnpong and Vityakon [10].

Considering stocks of SOM in each of the five soil layers, they were significantly different among all land uses and all study locations. In addition, the location x land use x soil depth interaction was also significant ($P < 0.01$, see (c) in Table 5). When considering each soil layer (Figure 5), topsoil layer (0–20 cm) had higher SOM stocks than each deeper soil layer in all locations ($P < 0.05$). Forest soils in all locations except Borabue had high SOM accumulation in topsoils than subsoils due to high litter input which enhanced SOM stocks in forest topsoils in Muang, Kantharawichai, Kosum Phisai, and Wapi Pathum locations (Figure 5). Meanwhile, in sugarcane land use in Kantharawichai location, incorporation of cattle manure to soil every single year before sugarcane plantation (Table 1) brought about high SOM stocks in topsoil (Figure 5(b)). Similar to the forest, paddy had higher SOM accumulation in topsoils than subsoils in all locations except Wapi Pathum (Figure 5) which was due to input of rice stubbles remaining after harvesting. The results of this study supported previous findings that high accumulation of SOM was in the topsoil [58, 61]. However, it was found in forest and paddy land uses in Borabue and Wapi Pathum, respectively, that SOM stocks in topsoils were not different than subsoils (Figures 5(e) and 5(f)). Soil texture of the mineral horizon, that is, horizon below top organic horizon (topsoils), has been found to influence SOM distribution and SOM stock in the lower soil layer. Finer textured subsoil layers as indicated by higher content of fine fraction (<0.05 mm or silt + clay) led to higher accumulation of soil organic C in subsoil (mineral horizon) than the coarser textured counterpart [62].

Considering pattern of changes in SOM stocks of each soil layer, we found a uniformly SOM decline pattern with soil depth at all locations. The declines in SOM stocks with reference to the upper layer were larger in the second soil layer (20–40 cm), whereas those in the deeper soil layers were smaller. Nevertheless, at Wapi Pathum location cassava and sugarcane fields did not show the declines in SOM stocks in the soil layer below the second soil layer

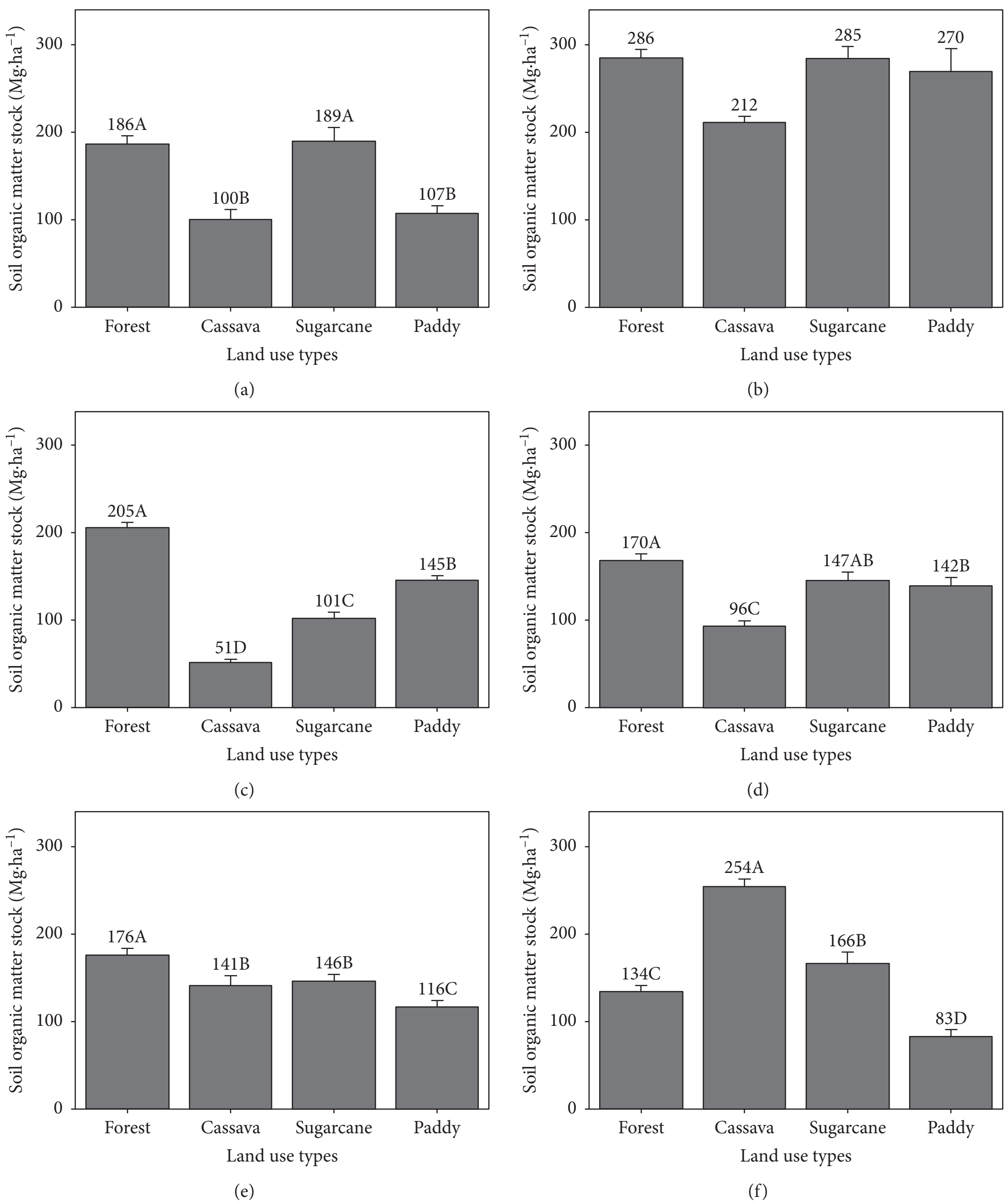

Figure 4: Land use changes affecting SOM stocks in whole soil profile (0–100 cm) in six locations. Uppercase letters accompanying bar graphs denote comparisons of SOM stocks among different land uses. Similar letters indicate no significant differences ($P > 0.05$), as analysed by the LSD method. Error bars represent standard error of the mean. (a) Muang. (b) Kantharawichai. (c) Kosum Phisai. (d) Kut Rang. (e) Borabue. (f) Wapi Pathum..

(20–40 cm). The Wapi Pathum location had applications of cattle manure in the upland crop fields (Table 1) which could have enhanced the subsoil SOM stocks. The application of manure at high rate could increase SOM stock in the subsoil to the levels similar to that in topsoil [63, 64].

Soil depth is an important factor influencing the variation in SOM [49], and lower soil layers have been found to contribute to longer term storage of C than topsoils as the loss of soil C in lower soil layers is less than their upper layer counterpart [65, 66].

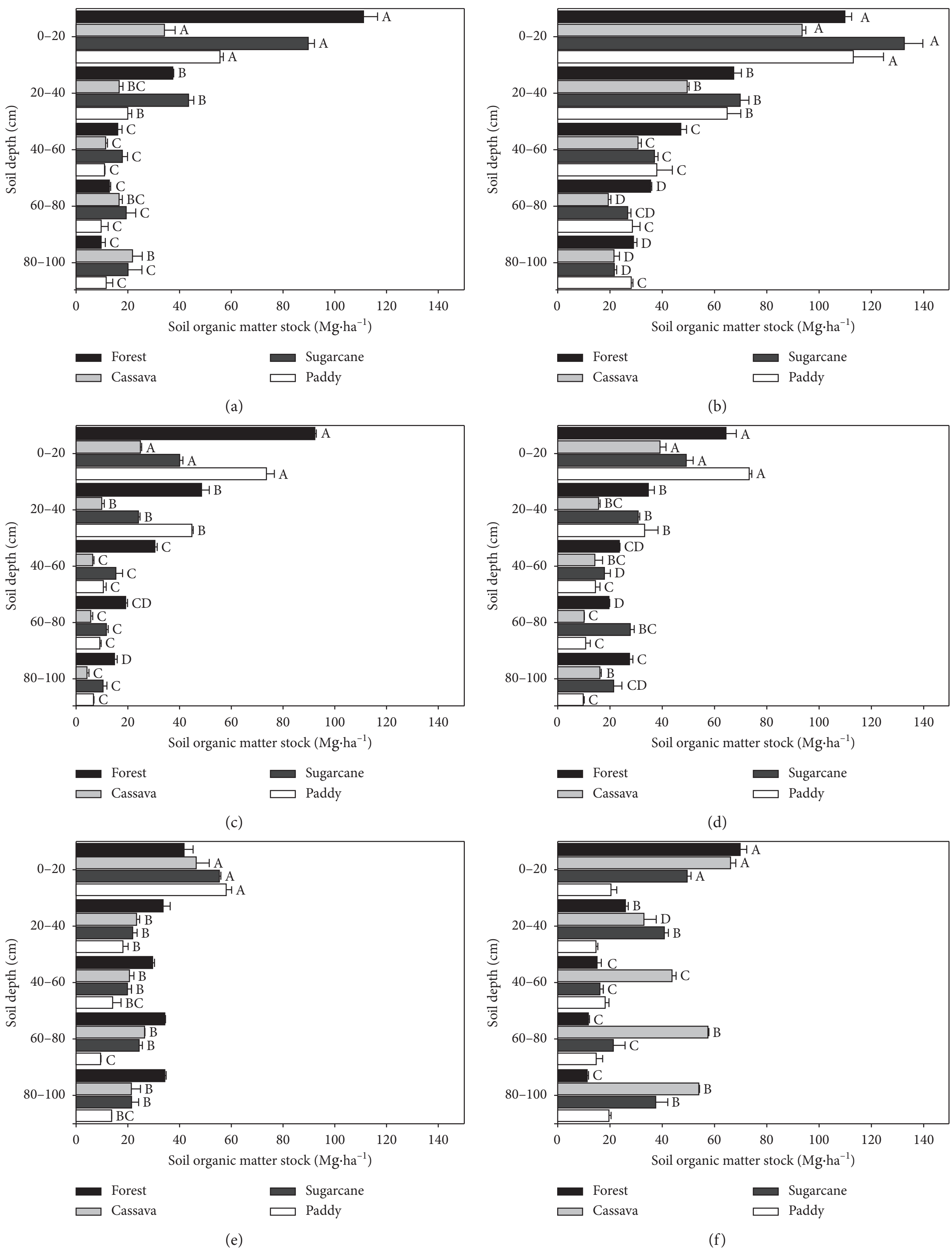

FIGURE 5: Land use changes affecting distribution of SOM stock in soil profile in six locations. Uppercase letters accompanying bar graphs denote comparisons of SOM stocks among different soil depths within a land use type. Similar letters indicate no significant differences ($P > 0.05$), as analysed by the LSD method. Error bars represent standard error of the mean. (a) Muang. (b) Kantharawichai. (c) Kosum Phisai. (d) Kut Rang. (e) Borabue. (f) Wapi Pathum.

4. Conclusions

Our results have shown conclusively that land use exerted significant influence on SOM stocks in soil profiles. Forest land use had significantly higher total SOM stocks in 0–100 cm (193 Mg·C·ha^{-1}) than agricultural land uses (142–172 Mg·C·ha^{-1}), including cassava, sugarcane, and paddy fields in all studied locations. General pattern of SOM stock distribution in soil profiles was such that the SOM stock declined with soil depth. This is due to deposition of organic materials and their decomposition in topsoils which was partly transported to be stabilized in the finer textured (higher clay and silt contents) subsoils. However, agricultural practices, notably applications of organic materials, such as cattle manure, could increase subsoil SOM stock as found in some agricultural land uses (cassava and sugarcane in Wapi Pathum) in our study. Although SOM stocks decreased with depth, the subsoil stock contributes to longer term storage of C than topsoils as they are more stabilized than those of the topsoils. We have shown that soil degradation as indicated by reduced SOM takes place when forest is converted to agricultural land use. Appropriate use of land and agronomic practices are important to maintain high soil fertility and high crop productivity. These involve application of organic soil amendments and reduction of soil disturbance to increase and maintain SOM stock. Upland agricultural land uses, notably cassava, cause high rate of soil degradation and need to be urgently restored by higher and more frequent applications of organic amendments, returns of crop residues, and reduction of soil disturbance.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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References

[1] M. R. Carter, E. G. Gregorich, D. W. Anderson et al., "Concepts of soil quality and their significance,," in *Soil Quality for Crop Production and Ecosystem Health*, E. G. Gregorich and M. R. Carter, Eds., pp. 1–20, Elsevier, Amsterdam, Netherlands, 1997.

[2] D. W. Reeves, "The role of soil organic matter in maintaining soil quality in continuous cropping systems," *Soil and Tillage Research*, vol. 43, no. 1-2, pp. 131–167, 1997.

[3] H. Kassa, S. Dondeyne, J. Poesen, A. Frankl, and J. Nyssen, "Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia," *Agriculture, Ecosystems & Environment*, vol. 247, no. 1, pp. 273–282, 2017.

[4] M. Prather, R. Derwent, and D. Ehhait, "Other trace gases and atmospheric chemistry," in *Climate Change 1994: Radioactive Forcing of Climate Change and the IPCC IS92 Emission Scenarios*, J. T. Houghton, Ed., pp. 73–126, Cambridge University Press, Cambridge, UK, 1995.

[5] J. Burton, C. Chen, Z. Xu, and H. Ghadiri, "Gross nitrogen transformations in adjacent native and plantation forests of subtropical Australia," *Soil Biology and Biochemistry*, vol. 39, no. 2, pp. 426–433, 2007.

[6] A. M. O'Connell, T. S. Grove, D. S. Mendham et al., "Impact of harvest residue management on soil nitrogen dynamics in *Eucalyptus globulus* plantations in south–western Australia," *Soil Biology & Biochemistry*, vol. 36, no. 1, pp. 39–48, 2004.

[7] D. Assefa, B. Rewald, H. Sandén et al., "Deforestation and land use strongly effect soil organic carbon and nitrogen stock in Northwest Ethiopia," *Catena*, vol. 153, pp. 89–99, 2017.

[8] N. Emiru and H. Gebrekidan, "Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat watershed, Western Ethiopia," *ARPN Journal of Agricultural and Biological Science*, vol. 8, no. 3, pp. 206–212, 2013.

[9] D. J. Ross, K. R. Tate, N. A. Scott, and C. W. Feltham, "Land-use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems," *Soil Biology and Biochemistry*, vol. 31, no. 6, pp. 803–813, 1999.

[10] S. Tangtrakarnpong and P. Vityakon, "Land use and soil organic matter in Northeast Thailand: microbial biomass, nitrogen transformation and humic acid," in *Proceedings of the Transactions of the 17th World Congress of Soil Science*, IUSS and Soil and Fertilizer Society of Thailand, Bangkok, Thailand, pp. 1–15, 2002.

[11] B. Kunlanit, S. Butnan, and P. Vityakon, "Land-use changes influencing C sequestration and quality in topsoil and subsoil," *Agronomy*, vol. 9, no. 9, pp. 520–616, 2019.

[12] T. Wang, F. Kang, X. Cheng, H. Han, and W. Ji, "Soil organic carbon and total nitrogen stocks under different land uses in a hilly ecological restoration area of North China," *Soil and Tillage Research*, vol. 163, pp. 176–184, 2016.

[13] M. C. Kundu, T. Das, P. K. Biswas et al., "Effect of different land uses on soil organic carbon in new alluvial belt of West Bengal," *International Journal of Bioresource, Environment and Agricultural Sciences*, vol. 3, no. 2, pp. 517–520, 2017.

[14] K. Lorenz, R. Lal, and M. J. Shipitalo, "Stabilized soil organic carbon pools in subsoils under forest are potential sinks for atmospheric CO_2," *Journal of Forest Science*, vol. 57, no. 1, pp. 19–24, 2011.

[15] Y. Xu and Z. Xu, "Effects of land use change on soil gross nitrogen transformation rates in subtropical acid soils of Southwest China," *Environmental Science and Pollution Research*, vol. 22, no. 14, pp. 10850–10860, 2015.

[16] L. C. Vicente, E. F. Gama-Rodrigues, and A. C. Gama-Rodrigues, "Soil carbon stocks of ultisols under different land use in the Atlantic rainforest zone of Brazil," *Geoderma Regional*, vol. 7, no. 3, pp. 330–337, 2016.

[17] D. V. Guimarães, M. I. S. Gonzaga, T. O. da Silva, T. L. da Silva, N. da Silva Dias, and M. I. S. Matias, "Soil organic matter pools and carbon fractions in soil under different land uses," *Soil and Tillage Research*, vol. 126, pp. 177–182, 2013.

[18] P. Vityakon, S. Subhadhira, V. Limpinunthana et al., "From forest to farmfields: changes in land use in undulating terrain of Northeast Thailand at different scales during the past century," *Southeast Asian Studies*, vol. 41, no. 4, pp. 444–472, 2004.

[19] P. Vityakon, S. Meepech, G. Cadisch, and B. Toomsan, "Soil organic matter and nitrogen transformation mediated by plant residues of different qualities in sandy acid upland and paddy soils," *NJAS-Wageningen Journal of Life Sciences*, vol. 48, no. 1, pp. 75–90, 2000.

[20] T. P. Toung, S. P. Kam, L. Wade et al., "Characterizing and understanding rainfed environment," in *Proceedings of the International Workshop on Characterizing and Understanding Rainfed Environments*, p. 488, Los Baños (Philippines): International Rice Research Institute, Bali, Indonesia, December 1999.

[21] J. Saenya, S. Anusontpornperm, S. Thanachit et al., "Potential of paddy soils for jasmine rice production in Si Sa Ket province, Northeast Thailand," *Asian Journal of Crop Science*, vol. 7, no. 1, pp. 34–47, 2015.

[22] J. Kaweewong, T. Kongkeaw, S. Tawornprek et al., "Nitrogen requirements of cassava in selected soils of Thailand," *Journal of Agriculture and Rural Development*, vol. 114, pp. 13–19, 2013.

[23] Soil Survey Staff, *Keys to Soil Taxonomy*, USDA–Natural Resources Conservation Service, Washington, DC, USA, 12th edition, 2014.

[24] G. E. Rayment and F. R. Higginson, *Australian Soil and Land Survey Handbook, Australian Laboratory Handbook of Soil and Water Chemical Methods*, Inkata Press, Melbourne, Australia, 1992.

[25] B. H. Ellert and J. R. Bettany, "Calculation of organic matter and nutrients stored in soils under contrasting management regimes," *Canadian Journal of Soil Science*, vol. 75, no. 4, pp. 529–538, 1995.

[26] T. F. Rittl, D. Oliveira, and C. E. P. Cerri, "Soil carbon stock changes under different land uses in the Amazon," *Geoderma Regional*, vol. 10, pp. 138–143, 2017.

[27] L. T. Nanganoa, J. N. Okolle, V. Missi et al., ""Impact of different land–use systems on soil physicochemical properties and macrofauna abundance in the humid tropics of Cameroon," *Applied and Environmental Soil Science*, vol. 2019, Article ID 5701278, 9 pages, 2019.

[28] M. Emadi, M. Emadi, M. Baghernejad, H. Fathi, and M. Saffari, "Effect of land use change on selected soil physical and chemical properties in North Highlands of Iran," *Journal of Applied Sciences*, vol. 8, no. 3, pp. 496–502, 2008.

[29] B. Frederick, C. Pierson, J. Williams et al., "Short–term effects of tree removal on infiltration, runoff, and erosion in woodland encroached sagebrush steppe," *Rangeland Ecology & Management*, vol. 67, pp. 522–538, 2014.

[30] D. F. Cari and J. P. Wright, "Effects of fire frequency on litter decomposition as mediated by changes to litter chemistry and soil environmental conditions," *PLoS One*, vol. 12, no. 10, Article ID e0186292, 2017.

[31] C. Yue, H. Yao, and S. Wenjuan, "Using organic matter and pH to estimate the bulk density of afforested/reforested soils in Northwest and Northeast China," *Pedosphere*, vol. 27, no. 5, pp. 890–900, 2017.

[32] M. Athira, R. Jagadeeswaran, and R. Kumaraperumal, "Influence of soil organic matter on bulk density in Coimbatore soils," *International Journal of Chemical Studies*, vol. 7, no. 3, pp. 3520–3523, 2019.

[33] M. Casanova, E. Tapia, O. Seguel, and O. Salazar, "Direct measurement and prediction of bulk density on alluvial soils of central Chile," *Chilean Journal of Agricultural Research*, vol. 76, no. 1, pp. 105–113, 2016.

[34] E. K. A. Twum and S. Nii-Annang, "Impact of soil compaction on bulk density and root biomass of Quercus petraea L. at reclaimed post-lignite mining site in Lusatia, Germany," *Applied and Environmental Soil Science*, vol. 2015, Article ID 504603, 5 pages, 2015.

[35] S. Wang, B. J. Fu, G. Y. Gao, X. L. Yao, and J. Zhou, "Soil moisture and evapotranspiration of different land cover types in the Loess Plateau, China," *Hydrology and Earth System Sciences*, vol. 16, no. 8, pp. 2883–2892, 2012.

[36] H. R. Manns, G. W. Parkin, and R. C. Martin, "Evidence of a union between organic carbon and water content in soil," *Canadian Journal of Soil Science*, vol. 96, no. 3, pp. 305–316, 2016.

[37] W. Dan, H. Nianpeng, W. Qing et al., "Effects of temperature and moisture on soil organic matter decomposition along elevation gradients on the Changbai mountains, Northeast China," *Pedosphere*, vol. 26, no. 3, pp. 399–407, 2016.

[38] T. A. Ontl and L. A. Schulte, "Soil carbon storage," *Nature Education Knowledge*, vol. 3, no. 10, pp. 1–11, 2012.

[39] A. J. Franzluebbers, "Soil organic matter stratification ratio as an indicator of soil quality," *Soil and Tillage Research*, vol. 66, no. 2, pp. 95–106, 2002.

[40] E. L. Balota, I. F. U. Yada, H. F. Amaral et al., "Soil quality in relation to forest conversion to perennial or annual cropping in southern Brazil," *Revista Brasileira de Ciência do Solo*, vol. 39, no. 4, pp. 1003–1014, 2015.

[41] K. L. Sahrawat, "Organic matter accumulation in submerged soils," *Advances in Agronomy*, vol. 81, pp. 169–201, 2004.

[42] J. Esmaeilzadeh and A. G. Ahangar, "Influence of soil organic matter content on soil physical, chemical and biological properties," *International Journal of Plant, Animal and Environmental Sciences*, vol. 4, no. 4, pp. 244–252, 2014.

[43] T. L. Sausen, G. F. d. P. Schaefer, M. Tomazi, L. S. d. Santos, C. Bayer, and L. M. G. Rosa, "Clay content drives carbon stocks in soils under a plantation of *Eucalyptus saligna* Labill. in southern Brazil," *Acta Botanica Brasilica*, vol. 28, no. 2, pp. 266–273, 2014.

[44] M. Matteodo, S. Grand, D. Sebag, M. C. Rowley, P. Vittoz, and E. P. Verrecchia, "Decoupling of topsoil and subsoil controls on organic matter dynamics in the Swiss Alps," *Geoderma*, vol. 330, pp. 41–51, 2018.

[45] E. J. Liu, X. P. Zhang, M. L. Xie et al., "Hydrologic responses to vegetation restoration and their driving forces in a catchment in the Loess hilly-gully area: a case study in the upper reaches of Beiluo River," *Acta Ecologica Sinica*, vol. 35, no. 3, pp. 622–629, 2015.

[46] A. F. Plante, R. T. Conant, C. E. Stewart, K. Paustian, and J. Six, "Impact of soil texture on the distribution of soil organic matter in physical and chemical fractions," *Soil Science Society of America Journal*, vol. 70, no. 1, pp. 287–296, 2006.

[47] C. Cerli, L. Celi, P. Bosio et al., "Effect of land use change on soil properties and carbon accumulation in the Ticino Park (North Italy)," *Studi trentini di scienze naturali*, vol. 85, pp. 83–92, 2009.

[48] K. Zajícová and T. Chuman, "Effect of land use on soil chemical properties after 190 years of forest to agricultural land conversion," *Soil and Water Research*, vol. 14, no. 3, pp. 121–131, 2019.

[49] A. Adugna and A. Abegaz, "Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega, Ethiopia: are these sign of degradation?" *Solid Earth Discussions*, vol. 7, no. 3, pp. 2011–2035, 2015.

[50] C. Rumpel and I. Kögel-Knabner, "Deep soil organic matter-a key but poorly understood component of terrestrial C cycle," *Plant and Soil*, vol. 338, no. 1-2, pp. 143–158, 2011.

[51] L. Deng, G.-y. Zhu, Z.-s. Tang, and Z.-p. Shangguan, "Global patterns of the effects of land-use changes on soil carbon stocks," *Global Ecology and Conservation*, vol. 5, pp. 127–138, 2016.

[52] C. Rumpel, A. Rodríguez–Rodríguez, J. A. González–Pérez et al., “Contrasting composition of free and mineral–bound organic matter in top–and subsoil horizons of Andosols,” *Biology and Fertility of Soils*, vol. 484 pages, 2012.
[53] N. H. Batjes, “Total carbon and nitrogen in the soils of the world,” *European Journal of Soil Science*, vol. 47, no. 2, pp. 151–163, 1996.
[54] J. Six, E. T. Elliott, K. Paustian, and J. W. Doran, “Aggregation and soil organic matter accumulation in cultivated and native grassland soils,” *Soil Science Society of America Journal*, vol. 62, no. 5, pp. 1367–1377, 1998.
[55] G. Curaqueo, E. Acevedo, P. Cornej et al., “Tillage effect on soil organic matter, mycorrhizal hyphae and aggregates in a Mediterranean agroecosystem,” *Journal of Soil Science and Plant Nutrition*, vol. 10, no. 1, pp. 12–21, 2010.
[56] S. Butnan and P. Vityakon, “The interactive effects of soil disturbance and residue quality on soil nitrogen mineralisation in a tropical sandy soil,” *Soil Research*, vol. 58, no. 3, p. 277, 2020.
[57] I. Schoning and I. Kogel–Knabner, “Chemical composition of young and old carbon pools throughout Cambisol and Luvisol profiles under forests,” *Soil Biology and Biochemistry*, vol. 38, no. 8, pp. 2411–2424, 2006.
[58] J. Six, R. T. Conant, E. A. Paul, and K. Paustian, “Stabilization mechanisms of soil organic matter: implications for C–saturation of soils,” *Plant and Soil*, vol. 241, no. 2, pp. 155–176, 2002.
[59] B. T. Christensen, “Carbon in primary and secondary organomineral complexes,” in *Structure and Organic Matter Storage in Agricultural Soils*, M. R. Carter and B. A. Stewart, Eds., pp. 97–165, CRC–Lewis Publishers, Boca Raton, FL, USA, 1996.
[60] H. J. Schenk and R. B. Jackson, “The global biogeography of roots,” *Ecological Monographs*, vol. 72, no. 3, pp. 311–328, 2002.
[61] E. Błońska and J. Lasota, “Soil organic matter accumulation and carbon fractions along a moisture gradient of forest soils,” *Forests*, vol. 8, no. 11, p. 448, 2017.
[62] P. Gruba, J. Socha, E. Błońska, and J. Lasota, “Effect of variable soil texture, metal saturation of soil organic matter (SOM) and tree species composition on spatial distribution of SOM in forest soils in Poland,” *Science of the Total Environment*, vol. 521-522, pp. 90–100, 2015.
[63] B. Kunlanit, “Dynamics of soil organic matter and humic acid contents as influenced by land use changes,” *Khon Kaen Agriculture Journal*, vol. 45, no. 1, pp. 1334–1341, 2017.
[64] C. W. Robbins, L. L. Mackey, and L. L. Freeborn, “Improving exposed subsoils with fertilizers and crop rotations,” *Soil Science Society of America Journal*, vol. 61, no. 4, pp. 1221–1225, 1997.
[65] G. Börjesson, M. A. Bolinder, H. Kirchmann, and T. Kätterer, “Organic carbon stocks in topsoil and subsoil in long-term ley and cereal monoculture rotations,” *Biology and Fertility of Soils*, vol. 54, no. 4, pp. 549–558, 2018.
[66] M. Henry, R. Valentini, and M. Bernoux, “Soil carbon stocks in ecoregions of Africa,” *Biogeosciences Discussions*, vol. 6, no. 1, pp. 797–823, 2009.