The Effects of Land Use Changes in Malaysia on the Structural Characteristics of Soil Organic Matter.

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الملخص:

تم دراسة تأثير استخدام الأراضي على تغير محتويات الكربون والخصائص التركيبية للمادة العضوية في التربة، حيث تم استخدام التحليل الطيفي للأشعة تحت الحمراء وتم فحص عينات التربة من مزارع مختلفة مثل مزارع المطاط ، ومزارع زيت النخيل بأعمار مختلفة 5 و 15 عام ، بالإضافة إلى مراعي الثمام الكبير وذلك في النطاق الرئيسي لشبه جزيرة ماليزيا، وذلك لغرض تحديد آثار تغير استخدام الأراضي على محتويات التربة من الكربون العضوي والخصائص التركيبية للمادة العضوية، ومن ثم تمت دراسة التحليلات الكيميائية والخصائص التركيبية لعينات التربة حتى عمق 30 سم.

وقد أظهرت أطياف الأشعة تحت الحمراء للآفاق العضوية السطحية زيادة في النطاق الأليفاتي (2920 سم -¹) مع زيادة في النيتروجين الناتج عن الحفظ الانتقائي للتركيبات الأليفاتية المشتقة من النباتات الأصلية ذات المحتوى العالي من الشمع (المطاط) بالاضافة لإستخدام الأسمدة.

توضح هذه الدراسة أن الاختلافات في محتويات الكربون مرتبطة بالاختلاف المشترك للغطاء النباتي، ومع ذلك فإن الغطاء النباتي هو المحرك الرئيسي للاختلافات في الخصائص التركيبية للمادة العضوية.

Abstract:

To investigate the effect of land use change carbon (C) contents and structural characteristics of organic matter (OM) in soils. Fourier-transform infrared (FTIR) spectroscopy was used. Soil samples from different plantation rubber (Hevea brasiliensis), oil palm (Elaeis guineensis) with different age 5and15 years old, and pasture (Pancium Maximum)) in the Main Range of Peninsular Malaysia were investigated to determine the effects of land use change on soil organic carbon (SOC) contents and structural characteristics of OM. Chemical analyses and structural characteristics of soil samples from 0 to 30 cm were analyzed. FTIR spectra for the surface organic horizons showed an increase of aliphatic band (2920 cm^{-1}) with increasing nitrogen, that resulted from a selective preservation of aliphatic structures derived from original plants with high content of waxes (rubber) and using fertilizer. This study demonstrates that differences in (C) contents is related to co-variation of vegetation; however, vegetation is the major driver of differences in structural characteristics of OM.

Key words: land use change, soil organic carbon, structural characteristics of soil organic matter, FTIR.

Introduction:

It is known that soil organic matter, especially soil organic carbon , plays an important role in repairing and improving many soil properties. Agricultural land is the land most closely associated with the main functions and optimal level of soil organic carbon. Forestry and grazing, in addition to groundwater contamination and carbon sequestration, are areas closely related to the function of soil organic carbon (SOC). A key component of the global carbon cycle are the emissions from land use and land cover change (Gasser et al.,2020), generating around $1.5\pm0.7 PgCyr^{-1}$of the total carbon dioxide (CO_2) emissions around the world (Friedlingstein et al., 2019), and causes to declines in soil organic matter (SOM) that represents the largest terrestrial pool of carbon (C) in the world (Zhu et al., 2016). Land use and land cover change are known to strongly impact the chemical composition of SOC. The changes in the chemical composition of SOC it will strongly effects on the decomposition rate of SOC, which in turn effects on SOC stabilization and global carbon cycle. In Malaysia, human activities, such as land-use change and tree cutting, have significantly altered the natural forests that strongly influence the chemical composition of (SOM). Since the spare of information on the effects of land use change on the structural composition of SOM and, as Fourier transform infrared spectroscopy (FTIR) has served as a valuable tool to characterize qualitatively of chemical groups of which SOM is comprised, therefor it was used in this study to investigate the effects of land use change on SOM composition.

Materials and Methods: Study Area:

This study was conducted in agricultural plantation of rubber plantation (Hevea brasiliensis) that is 15 years old as well as two different aged oil palm plantation (Elaeis guineensis) five and fifteen years old respectively, and Pasture (Pancium Maximum) at the University Putra Malaysia (UPM) farm, Serdang, Selangor, Malaysia, as demonstrated in Figure1. The soil classified as Serdang at UPM. An experimental plot of (100 × 100 m) with three replicates was designed for the field experiment.

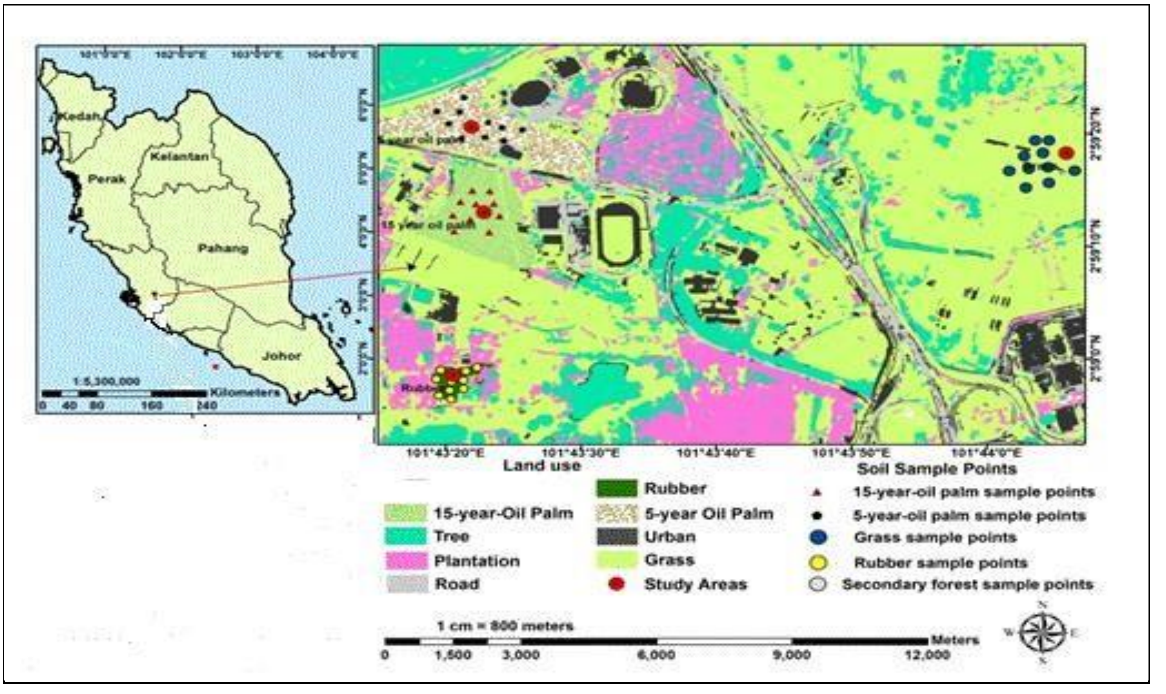

Figure 1: The study area in the University Putra Malaysia (UPM) farm. Selangor State, Malaysia.

The geographic coordinate were shows in Table 1 as determined by Global Positioning System (GPS) Garmin 60CSX.

Soil sampling:

Soils were sampled using steel rings soil sampler, the depth intervals sampled was (0– 30cm),samples were collected from 3 replicate for each sites.

Table 1: General description of the study sites.

Site profile/ Plant information	Geographic coordinate in the study area		Geological information	Family	Soil texture
	Latitude (N)	Longitude (E)	(Jusop et al., 1979)		
1/Rubber plantations	02 58 58.4	101 43 20.2	Typic Paleudlt	isohyperthermic, Typic Paleudlt	Sandy clay loam
2/15 years oil palm	02 59 11.0	101 43 24.6	Tropeptic Haplorthox	Fine loamy, kaolinitic, isohyperthermic	clay
3/5 years Oil palm	02 59 21.7	101 43 23.4	Typic Paleudult.	Clayey, kaolinitic, oxidic isohyperthermic	clay
4/ Pasture	02 59 27.4	101 43 59.3	Tropeptic Haplorthox	Fine loamy, kaolinitic, isohyperthermic	clay

Soil analysis:

Bulk soil samples from all genetic horizons were homogenized, air-dried, gently ground, and passed through 2 mm sieve prior to the physical and chemical analyses. Soil pH was measured using a glass electrode in a supernatant suspension of 1:2.5 soil/water and KCl ratio.OM was analyzed by loss on ignition method according (Heiri et al., 2001), total carbon and nitrogen according to (Zulkifli et al., 2014). For SOM decomposition soil samples were finely ground (<65 μm) and heated at 60 °C for 48 hours to reduce the influence of water content on interpretation of the spectra. FTIR Spectroscopy was used and performed with a Perkin Elmer Spectrum 100 spectrometer (Jafarzadeh-Haghighi et al., 2015). However, (Table 2) shows the main IR absorption bands and their corresponding assignments for the samples of soil.

Statistical analysis:

Regarding the effect of land use change on soil chemical and geo-physical properties, a two way MANOVA was used to analyses the data, with Tukeys post-hoc tests to separate the means.

Table 2: The main IR absorption bands and their corresponding assignments for the samples of soil.

Band(cm^{-1})	Base points for the integrated bands (cm^{-1})	Assignment
3693	3700-3200	Stretching of OH groups (bonded and non-bonded (Wang et al., 2016).
3620		Hydroxyl groups (water molecules alcohols, phenols), (Rumpel et al., 2002).
3446		(Si-O±H vibrations), (Tatzber et al., 2011).
3373		Stretching vibration of hydroxyl bonded and non-bonded groups,(Santana et al., 2013).
2920	2800-3000	Symmetric and asymmetric stretching vibrations, respectively of (aliphatic C-H bonds in methyl and/or methylene b - CH3, CH2, and CH groups of alkyls), (Rumpel et al., 2002; Tatzber et al., 2011).
1778	1700-1790	C=O stretching vibration of carboxyl groups, aldehyde and ketones, (Tatzber et al., 2011(Wang et al., 2016).
1639-1625	1570-1700	C=O stretching vibration of carboxylates and Amides, aromatic C=C stretching vibration aromatic C=C bonds conjugated with C=O bonds of unsaturated ketones or amides, (Santana et al., 2013; Wang et al., 2016).
1398	1330-1400	C–O stretching vibration of C-H bending vibration e, phenolic OH D, CO-CH_3, COO- antisymmetric stretching vibration, (Duboc et al., 2012).
1249	1000-14000	CH and NH (amide II) bending motions, molecule skeletal vibrations and aromatic stretch, to carbon oxygen bond vibrations, (Duboc et al., 2012). C–O stretching vibration of aryl ethers and phenols, (Haberhauer & Gerzabek, (1999).C-O stretching vibration and O-H bending vibration of COOH, (MacCarthy & Rice, 1985).

1112	950-1170	C-O stretching vibration of polysaccharides, Si−O stretching band, (Santana et al., 2013).FC-O vibration of ether groups, (Rumpel et al., 2002).
910-750-690528-414	910, 790, 690, and 540	Bands of inorganic materials, such as quartz minerals and clay, (Tatzber et al. 2011).

Nonetheless, in order to get a clear understanding of the impact of land cover change on the composition of SOM, and to compare differences in the constituents of functional group to the quality of SOM, it's necessary to calculate two band ratios. The two indices employed ratios of bands which are representing functional group types (i.e., aliphatic, O-functional group). In previous studies these were established as indexes of comparative decomposition and resistance or recalcitrance of SOM .

$$\text{Index I} = \frac{\text{aromatic}}{\text{aliphatic}} \ldots [1]$$

$$\text{Index II} = \frac{\text{C function group}}{\text{O function group}} \ldots [2].$$

Index I was postulated or hypothesized to be a metric for decomposition which was taken as the ratio of aromatic to aliphatic functional groups, while ratios of bands that are representing the two functional groups are shown to rise up with increasing degree of decomposition (Margenot et al., 2017). Index II was hypothesized as a ratio of C- to O-functional groups: an increase or the rise of which is associated with higher recalcitrance or resistance of SOM (Margenot et al, 2015).

Results and Discussions:

The chemical properties of PH, TOC, and OM of rubber (R), 15 years oil palm (15Op), 5 years (5Op)oil palm and pasture (P) were studied.

Tables 3 summaries the chemical characteristics of soils under investigation:

Plantation site	pH	TOC	TON
R	4.42±0.4	1±0±0.2	0.08±0.02
OP 15	4.68±0.41	1.34±0.5	0.11±0.05

OP 5	4.36±0.76	1±0.2	0.89±0.02
P	4.39±0.53	1.83±0.9	1.76±0.1

Soil pH :

The analysis showed that, the pH value of all sample was between 4. 36 to 4.68. In general, pH of the Ultisols and Oxisols in Malaysia have low pH values in the range of 4 to 5 would attributed to the high rainfall (≥2000mm), the nature of parent material and the hydrolysis of aluminum as suggestion by (Fatai et al., 2017).

TOC:

The results of the effect of TOC under the land use clarify that, the highest TOC content found in pasture, oil palm 15years, oil palm 5 years and rubber consequently can be attributed to the diverse type of vegetation that produces much litter through the fallen leaves, stem, and branches of trees and plants.

Studies have also demonstrated that the higher TOC under oil palm plantation was due to the decomposition of added plant materials such as the application of empty fruit bunches and fibrous root system . However, higher the below-ground production of photosynthetic and fungal hyphae are probably responsible for the high amount of total organic matter in pasture (Chemeda et al., 2018).

TON:

As seen in Table 3 , the pasture site had significantly greater TON content than the top soil of 15 and 5 years oil palm as well as that in the rubber plantation. In our study, we found that land use type had significant effect on TON distribution. This is because soils with different vegetation cover have different litter decomposition processes which leads to differences in the release of C and N in the soil. Previous investigators (Deng et al., 2016) had reported that tree species with different plant traits and stand properties can impact on retentions of soil organic C and N, for instance on releasing nutrients to soil via mineralization. The pasture and oil palm 15 years had higher TON than rubber plantation, which is likely due to the input of organic matter derived from roots in pasture, and from roots and frond heap in oil palm plantations that compromise higher quantity of nitrogen compounds such as protein and amino acids .Similar results were obtained by(Haron et al. 1998), in Malaysia and by (Frazão et al. 2013) in Brazil.

Meanwhile the 15-year-old oil palm had higher soil N than the oil palm for 5 years, the authors suggest that by increasing the planting age of the oil palm, the amount of C and N storage increased after the change of land use in the soil. These results are in line with (Roslee et al., 2016) who indicated that oil palm sequestered C and N during growth. Furthermore, increasing the pH value under plantation might have increased the OM decomposition in the soil, and hence promote the mineralization processes .

SOM compositions:

Evaluated of soil sample from R, P, OP15, and OP5 were documented by FTIR spectroscopy. The data in Figure 2,3,4 and 5 shows the IR absorption band and related function group of SOM in each site. The resulting infrared spectra of soils from R, P, OP15, and OP5 were found to be similar in their elementary peak assignments, as shown in Figure 2,3,4 and 5.

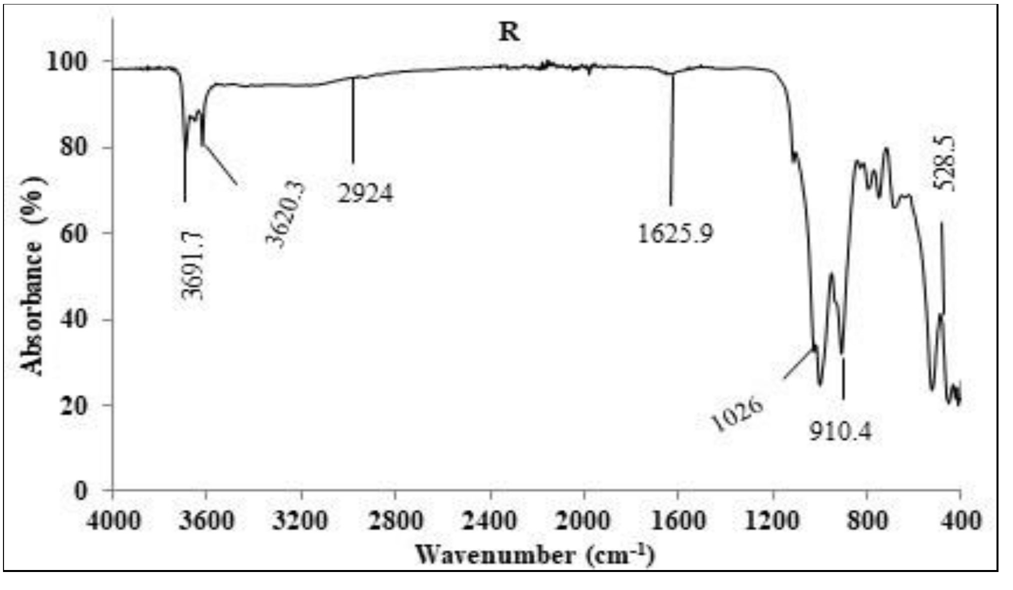

Figure 2: FTIR sample spectra of topsoil from chosen sites (R: rubber plantations). Spectra have been stacked by Y offsets.

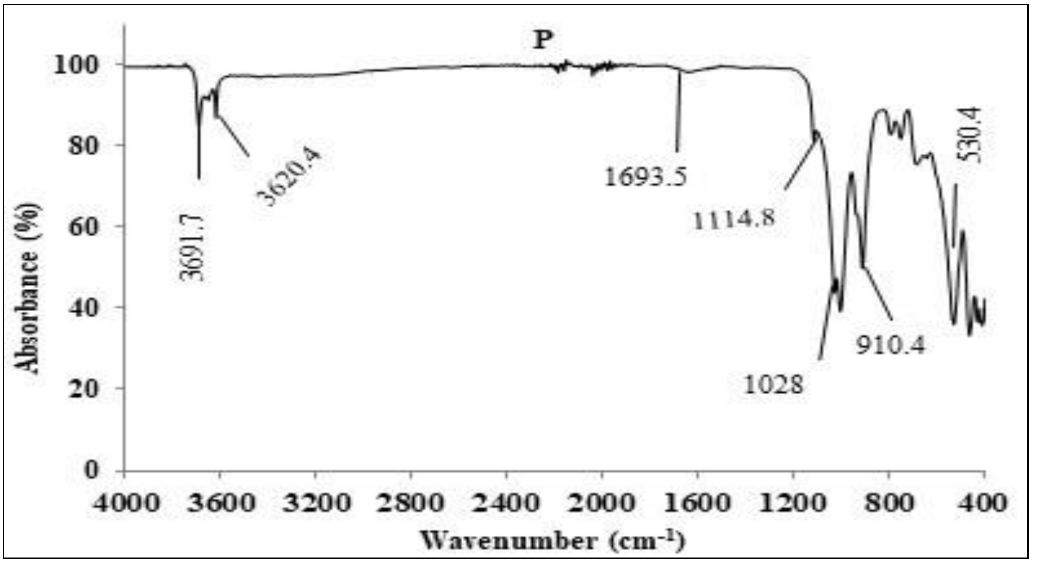

Figure 3: FTIR sample spectra of topsoil from chosen sites (P: pasture). Spectra have been stacked by Y offsets.

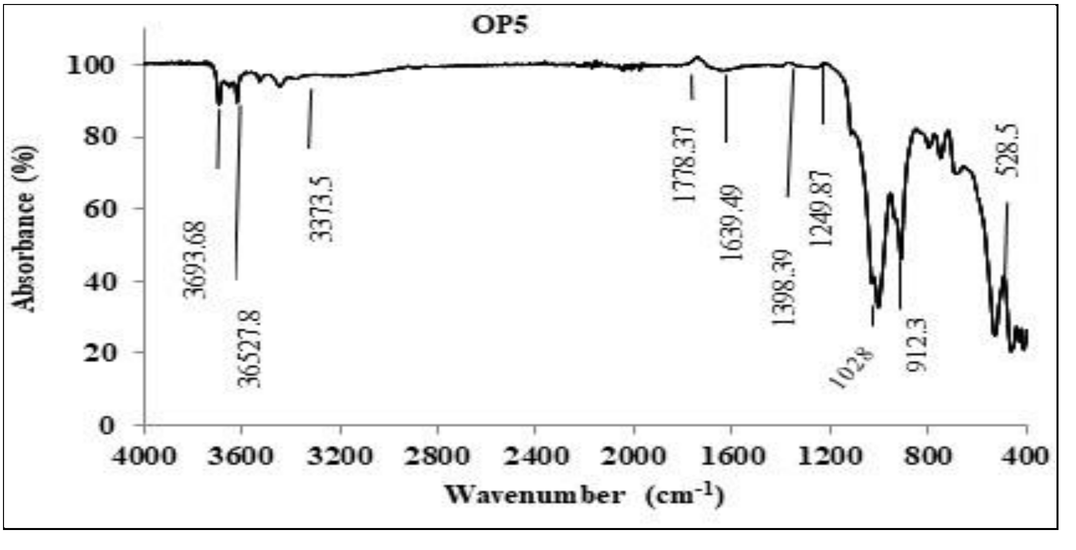

Figure 4: FTIR sample spectra of topsoil from chosen sites (OP5: 5 years old oil palm plantations). Spectra have been stacked by Y offsets.

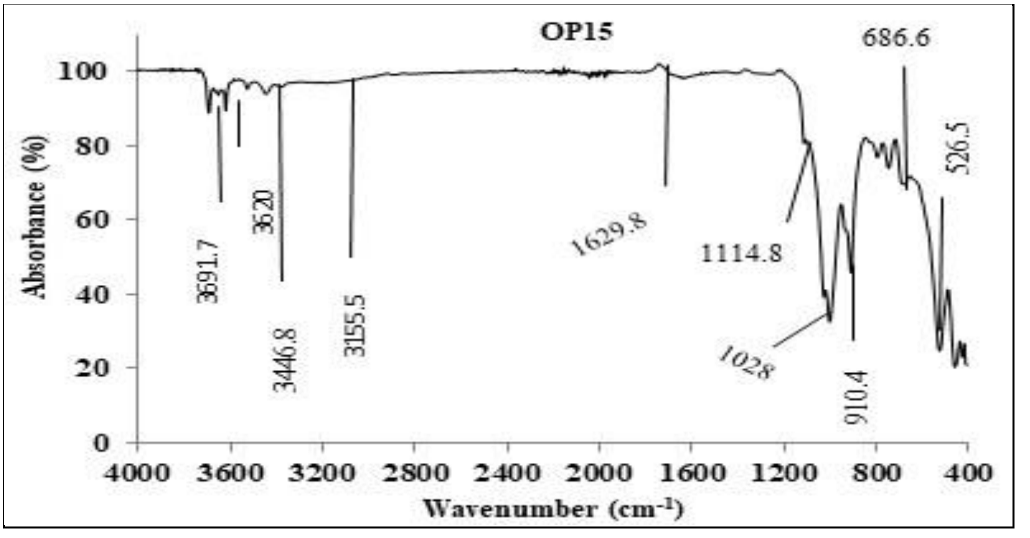

Figure 5: FTIR sample spectra of topsoil from chosen sites (OP 15: 15 year old oil palm plantations). Spectra have been stacked by Y offsets.

Findings in Figure 2,3,4and 5 indicate the peak patterns of the soils spectra at the 4 sites were comparable. The aliphatic group (either C-H stretching vibrations at 2920 cm^{-1} was appeared in R. While, the carboxyl group (C=O) stretching vibration at 1778 cm^{-1} was observed only in OP5. Meanwhile, aromatic (stretch H band at 3693-1630 cm-1), amides and carboxylates groups (C=O) stretching vibration at 1639-1625 cm^{-1}), CH and NH (amide II) bending motions, and aromatic stretch vibration at 1000-1398 cm^{-1} were observed at all study sites. Interestingly, with the presence of peak at 3620 cm^{-1}, which was assigned to hydroxyl group (O–H), stretching vibrations of minerals, indicating existence of kaolinite clay and montmorillonite in the study sites as suggested by (Nguyen et al., 1991). This shows the main mineral constituent in the top soil of study sites are S + C fractions, and it is expected that the small integrated areas for the CH- region came to be as a result of the hydrophobic moderation of aliphatic chains and surfaces of mineral as suggested by (Djomgoue and Njopwouo 2013). The moderation or interaction between mineral surfaces and aliphatic chains have been identified as very important in the materialization of soil aggregates and the stabilization of and gano-mineral complexes (Kleber et al., 2007).

Other bands positioned in the fingerprint area (414-1000 cm^{-1}) at (R, P, OP15 and OP5) sites, were accordingly assigned to couple vibrations. Bands in this type of region indicated the complexity of the studied and analyzed samples as and Jafarzadeh-Haghighi et al., (2015) observed. Top soil indicated higher number of absorption bands, particularly in the fingerprint area as matched to other absorbance band. The range of bands between 1000 and 1026 cm^{-1}, which showed evidence of the presence of polysaccharides in the topsoil, could similarly be assigned to Si-O vibration of minerals in the sample of soil. This observation happens to be in an agreement with the results of humus and mineral layers highlighted by Jafarzadeh-Haghighi et al. (2015), and similar association was noticed by Tatzber et al., (2011). The peak around 600-400 cm^{-1} was linked with unidentified mineral compounds (e.g., oxides, silicate, ond organo-mineral fractions) (Wang et al., 2016).

More pronounced in the sample soil of R is the aliphatic bands. The presence of aliphatic bands and the concentration of aliphatic stretching vibration (band 2920 cm^{-1}) may be linked to the rise in the plant materials decomposition and the process of humification as augmented by the higher index value (I) as shown in Table 4.

Table 4: The index value of SOM rubber (R), pasture (P), 15 years old oil palm (OP15) and 5years old oil palm plantation (OP5).

Land use	Index I = (aromatic/aliphatic)	Index II = (C function group/O function group)
R	1.436	1.93
P	1.625	2.12
OP5	2.974	2.41
OP15	2.005	2.58

Related trend was also detected by Rumpel et al., (2002) for Cambisol and Podzol under spruce and beech forest of Northern Bavaria, Germany by means of ^{13}C NMR spectroscopy. In the same vein, Jafarzadeh-Haghighi et al., (2015) submitted that, the decomposition of residues of plant is predominantly linked with the fall in polysaccharides and or the related accumulation of aliphatic structures.

Nonetheless, the aromatic bands (3690-3373 cm^{-1}) at P and OP15 sites were found to be a good proof on the rising of the resistant or recalcitrant material at the sites, as depicted by the higher value of index II (Table 4), and consequent support for the higher value of SOC at the P and OP15 sites (Table 3). Further, maximum relative proportion of aromatic C showed that organic matter that are mineral-associated and organic matter trapped at sites unreachable to microbial attack, or that are protected physically in soil aggregates, belong to an additionally stable organic matter pools with decades to centuries as a turnover time. Additionally, the lower content of aromatic within soils at R sit and the inverse higher content of aliphatic compounds are likely to be explained by the domination of sand particles (Pisani et al. 2014) corroborated that, long chain-free aliphatic lipids increase as the soil sand content increases.. Furthermore, the pH value at R (Table 3), supported (Pisani et al., 2014) result that, the organic matter associated with mineral in acid sandy soils was reported to be overwhelmed by aliphatic structures. In addition, (Lu etal., 2022) reported that, increased SOC in terrestrial ecosystems was closely associated with decreasd soil pH, which reduced soil C loss by limiting microbial degradation.

In addition, the higher percentage of amine group (3527, 3446 and 3373 cm^{-1}) at OP15 and OP5 sites respectively (figure 4-5), was a sign of the application of fertilizer in the area under study which Yu et al., (2015) reported, or due largely to the activity of enrichment with the microbialderived amide N (amide I and amide II). And this possibly is due to a stabilization of amine group by clay minerals as alluded to by (Helfrich et al., 2006) . The significantly higher content of clay at OP and P back this result. According to Jindaluang et al., (2013) 65–90% of total N assigned to amides was extant in the fine soil fractions (clay & silt). On the same vein, OP15 gave out stretch and broad alkel halide higher than OP5, which was a sign on the higher SOC content. At the same time this also lends support to the previous result, that SOC was raised by increasing the age of plantations of oil palm (Table 3).

Interestingly, the FTIR bands at P, offered broad alkel and amine groups, which are expected to be a valid indicator on the fertility of soil in compare with other sites.

This result in line with Lu et al., 2022 results, which demonstrated that, N-mediated soil acidification is the main increasing SOC under elevated N input soil.

The inherent pattern of accumulation of C functional groups found along the sites that were studied appeared to be altered by changes in land use and nature of the size of particle as well. Therefore, this study infers that the pattern of the accumulation of SOM happened to be stimulated by the quality and quantity of organic matters of input and their rates of decomposition, and characteristics and nature of the size of soil particle as well.

Conclusions:

In this study, we investigated the impact of land-use change, i.e. conversion of rubber to tree plantations or cultivated fields, on soil quality (i.e., SOM, PH ,and TOC) at Serdang State. We found that , the conversion of rubber plantation to oil palm and pasture had positive impact on SOM. In conclusion, to maintain soil fertility, forest managers should avoid forest conversion to agriculture, you have to focus on conversion plantation to another type of plantation. This result supported the FTIR results that showed no difference change for the chemical composition of SOM relating to land use change and concluded that, the relative distribution of SOC, FTIR absorbance can be good indicators of the soil organic matter (SOM) quantity and quality. Moreover, this study recommend that the rubber cover changes into oil palm and pasture resulted in improved content of SOM as a result of addition of plant residue at oil palm plantation.

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