Evaluation of Four Soil Conservation Practices in a Non-Terraced Oil Palm Plantation

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ABSTRACT

In Malaysia, four soil conservation practices are often recommended for non-terraced oil palm (*Elaeis guineensis* Jacq.) plantations. These practices are oil palm empty fruit bunches (EFB), Ecomat (a compressed EFB mat; ECO), and pruned oil palm fronds. These three oil palm residues are used as organic mulching materials. The fourth method is silt pits (SIL) which are soil trenches to collect nutrients from runoff water and later redistribute them back into the soil. Nonetheless, the relative effectiveness of these four methods in improving soil and oil palm properties have never been studied. A 3-yr field experiment was consequently conducted to determine their relative effects on increasing soil chemical properties (pH, cation exchange capacity, organic C, total N, available P, and exchangeable K, Ca, and Mg) and oil palm nutrition levels (N, P, K, Ca, and Mg). Biomass decomposition rate and nutrients release rate in the field by the three mulching materials were also determined. Results showed that EFB mulching was significantly better than the other three soil conservation practices in improving nearly all of the measured soil and plant parameters. Empty fruit bunches was most effective partly because of the combined effects of higher amounts of dry matter added and the higher nutrient concentrations in the EFB than in other mulching materials. Silt pitting was found not to be as effective as EFB because SIL could only trap and return nutrients back into the soil, whereas EFB could do both: trap nutrients and release additional nutrients into the soil as it decomposes.

Oil palm is the most important crop in Malaysia with 4.85 million ha of cultivated area (MPOB, 2010). Nearly one-fifth of Malaysia's total land area is covered by this crop alone. The land area for oil palm plantations in Malaysia have increased rapidly, but today, oil palm cultivation is limited to marginal areas such as hilly, sloping lands where they comprise about 65% of the marginal land areas in Malaysia. Due to slope steepness and high rainfall in Malaysia, sloping lands face soil erosion and nutrient and water losses through runoff which would in turn decrease soil fertility (Hashim et al., 1995; Hartemink, 2006). Any reduction in soil fertility would adversely affect oil palm nutrition, growth, and yield (Ng et al., 1999; Corley and Tinker, 2003). Therefore, proper soil conservation practices are needed to reduce soil nutrients and water losses.

To reduce soil erosion and hence nutrient and water losses on sloping lands, terraces are often built. However, terracing the hill will compact the soil (due to the use of heavy machineries) and reduce soil fertility because the fertile top soil layer would be removed from the area. Consequently, some plantations choose to plant oil palm trees without constructing any terraces. However, non-terraced hill slopes often have low inherent soil fertility, characterized by low soil chemical properties such as organic C, cation exchange capacity (CEC), pH, and exchangeable bases (Abu Bakar et al., 2011).

Utilization of oil palm residues as mulching materials and the construction of SILs are among the often recommended soil conservation practices for non-terraced sloping lands. Oil palm EFB and pruned fronds are common oil palm residues used for mulching because they contain essential plant nutrients that can be released into the soil during their decomposition. Furthermore, they provide organic matter which is a key factor to improve soil fertility properties.

From the palm oil milling process in Malaysia, more than 70 Tg of waste materials are produced every year. The EFB is the main solid waste of the oil palm fresh fruit bunches (FFB) after oil milling process and accounts for 20 to 25% of the oil palm FFB (Chan et al., 1980; Lim and Zaharah, 2000; Budianta et al., 2010; Abu Bakar et al., 2011). In the past, EFB was treated as a waste and incinerated, but now, EFB is used mostly as a mulch in response to the Malaysian government policy on cleaner air quality (Lim and Zaharah, 2000; Abu Bakar et al., 2011).

The application of EFB as mulch has shown to increase soil properties such as pH, exchangeable K, Ca and Mg, CEC, organic C, total N and available P (Ortiz et al., 1992; Rosenani and Wingkis, 1999; Zaharah and Lim, 2000; Lim and Zaharah, 2002; Budianta et al., 2010; Kheong et al., 2010; Zolkifli and Tarmizi, 2010) as well as oil palm leaf K and N levels (Lim and Zaharah, 2002). The EFB mulching has also led to higher vegetative growth parameters (such as leaf area and rachis length)

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Published in Agron. J. 104:1727–1740 (2012)
doi:10.2134/agronj2012.0120

Abbreviations: CEC, cation exchange capacity; CON, control; CP, conservation practices; ECO, Ecomat; EFB, empty fruit bunches; FRD, oil palm fronds; LFT, leaflets; MPOB, Malaysian Palm Oil Board; RAC, rachis; RCBD, randomized completely block design; SD, soil depths; SIL, silt pits; T, soil sampling time.

and subsequently higher oil palm yield (Chan et al., 1980; Ortiz et al., 1992; Hamdan et al., 1998).

Despite the beneficial effects of EFB on soil fertility and oil palm growth and yield, EFB's main disadvantage is it is bulky; thereby, making its storage, transportation, and field application more cumbersome and expensive. Therefore, its usage as a mulch is often limited to areas where the plantations are close to the palm oil mills.

One recent method to reduce EFB's bulkiness is to compress the EFB into a carpet-like material known as Ecomat (ECO). According to Yeo (2007), ECO is produced by shredding the EFB into its raw fiber and then combed out, after which EFB undergoes a high-pressure hydraulic press to remove impurities such as water, sludge, and oil traces. The EFB is then dried, using high temperature, to about 15% gravimetric water content before being trimmed to the desired size. Ecomat is less bulky, more flexible (e.g., can be rolled up), and easier to handle than EFB.

Unfortunately, research on the effects of ECO on soil fertility and oil palm nutrition are very limited. MPOB (2003) and Khalid and Tarmizi (2008) reported that ECO significantly increased the vegetative growth rate and the N, P, and K uptake by young oil palm trees planted on hill terraces. Using ECO as mulch resulted in 14% higher leaf area and increased frond length by 5%. The N, P, and K uptake by the young oil palm trees were respectively 10, 20, and 24% higher under ECO mulch than without it. Nonetheless, these studies did not compare the effectiveness between ECO and EFB on increasing soil fertility and oil palm nutrition and growth.

Another oil palm residue used as mulch is the pruned oil palm fronds. Pruning is a normal and essential field practice where one or two fronds are pruned before harvesting. The pruned fronds are then stacked on the ground to decompose and to release their nutrients, so as to improve soil fertility and plant productivity.

In oil palm fields in Malaysia, it is a de facto or normal practice to prune about 24 fronds per tree annually (Chan et al., 1980; Corley and Tinker, 2003; Sulaiman et al., 2012). Based on this number of fronds, Chan et al. (1980) calculated that 11.7 t ha^{-1} yr^{-1} dry matter of fronds would be produced in the field and which would release a total of (in kg ha^{-1}) 138 N, 12 P, 114 K, 25 Ca, and 47 Mg. However, due to the prevalent surface runoff in the tropics, the amount of nutrients returned to the soil would most probably be lower than that calculated. Nevertheless, data from Mohd Ali (1997) suggested that pruned palm fronds increased soil organic matter content, aggregate stability, and available water, as well as decreased bulk density in the 0- to 0.15-m soil depth.

The construction of SIL is another recommended soil conservation method for non-terraced oil palm plantations. Silt pits are trenches constructed in the soil between planting rows and in perpendicular to the hill slope direction. The idea is so that silt pits collect runoff water and eroded soil sediments, containing nutrients, which would then be redistributed back into the plant root zone after a rainfall event. In an experiment performed in India by George et al. (2003), SIL was effective in reducing soil loss by 13.94 t ha^{-1} and in conserving soil N, P, and K by some 34, 18, and 25 kg ha^{-1}, respectively. Results also showed that while SIL increased these three soil nutrients, SIL did not however increase plant growth rate, leaf nutrient content, and yield of rubber over a period of 18 mo. Soon and Hoong (2002) found that stacked pruned palm fronds reduced soil loss via surface runoff, but when stacked pruned fronds was combined with SIL, soil loss was further decreased by 11%. Compared to the number of studies on EFB, much less have been studied on the effects by ECO, pruned fronds, and SIL on the soil chemical properties and oil palm nutrition. Moreover, there is no single study so far that compares the relative effects of these four methods. Despite the lack of research on ECO, pruned oil palm fronds, and SIL, these three methods, together with the much studied EFB, are still often recommended as soil conservation practices for non-terraced oil palm plantations in Malaysia. We hypothesize that these soil conservation practices have different effects on the soil chemical properties and oil palm nutrition. Therefore, the main objective of this study was therefore to answer which of these four methods best improved the soil chemical properties, linked to soil fertility, and oil palm nutrition on a non-terraced oil palm plantation.

MATERIALS AND METHODS

The first part of this study was a field experiment to determine the effects of four soil conservation practices on the soil chemical properties and oil palm leaf nutrient levels. The second part was to measure the mulching materials' decomposition rate, as well as their nutrient contents and release pattern into the soil. Results from the second part of study would help to explain the results obtained in the first part.

Site Description and Experimental Design

A field experiment was conducted in Balau Estate oil palm plantation (2.9325° N and 101.8822° E), Semenyih, Selangor, Malaysia, for nearly 3 yr from December 2007 to September 2010. The area was cultivated with 8-yr-old oil palm trees in a 8 by 8-m triangular spacing on a hill slope of 6°. Average annual rainfall in this area was 2105.2 mm, and the daily mean air temperature was 26.9°C. The soil of the experimental area is classified as Typic Paleudult (Rengam series), which has a sandy clay loam texture in the topsoil (0–0.15-m depth) and sandy clay and sandy clay loam texture in the 0.15 to 0.30 and 0.30 to 0.45 m, respectively (Table 1).

The field experiment layout was a split-split block arranged in a completely randomized block design with three replications.

Table 1. Initial soil properties of the experiment site.

Depth	pH	EC†	CEC	OC	BD	Particle size distribution		
						<2 μm	2–50 μm	>50 μm
m		dS m^{-1}	$cmol_c$ kg^{-1}	%	Mg m^{-3}	%		
0.00–0.15	4.79	1.11	7.29	2.65	1.37	28.88	12.55	58.49
0.15–0.30	4.78	0.93	8.33	1.75	1.49	44.11	7.71	48.07
0.30–0.45	4.48	0.84	7.88	1.51	1.40	28.25	7.82	63.84

† EC, electrical conductivity; CEC, cation exchange capacity; BD, bulk density.

The conservation practices (CP) were allocated to the whole plot, where CP consisted of mulching the soil with EFB, ECO, and pruned oil palm fronds (the fronds were stacked on the soil surface) and the construction of SIL. Pruning is a conventional practice, done in all of the mature oil palm plantations in Malaysia. Consequently, the pruned oil palm fronds was considered as control (CON) in this study. Soil sampling times (T) and soil depths (SD) were considered as sub- and sub-subplot, respectively. Each experimental unit consisted of four oil palm trees. Each of the three blocks was located at different hill elevations but having the same slope steepness of 6°.

The first application of EFB and ECO treatments and the construction of the SIL were done in January 2008. Empty fruit bunches were applied as a single layer in the middle of each EFB treatment plot at a rate of 1000 kg plot^{-1} yr^{-1}. This EFB rate followed the conventional field practice in Malaysia (Chan et al., 1980; Lim and Zaharah, 2000). Four factory pre-cut ECO pieces, measuring 1 by 2 by 0.02 m, were placed as a single layer on the soil surface in the middle of each ECO treatment plot. The EFB and ECO were re-applied in January 2009. The silt pits were constructed by digging a trench across the hill slope direction. Each SIL had a dimension of 4.0, 1.0, and 0.5 m in length, width, and depth, respectively. The SIL were also located in the middle of each SIL treatment plot. Like the EFB and ECO plots, the SIL were rebuilt in January 2009. Two fronds were pruned each month at fruit bunch harvesting stage (following field practice), and the pruned fronds were stacked on the soil surface between the trees in alternate rows. This means that there were 24 pruned fronds per palm added to the fronds heap annually.

Sampling and Sample Preparation

Mulch

Five pruned palm fronds, EFB, and ECO were sampled randomly, weighed, and analyzed for their respective chemical composition. To determine the ratio of leaflet to rachis, each palm frond was separated for leaflet and rachis and then weighed separately. The samples were subsequently placed in labeled plastic bags, transferred to the laboratory, and cleaned by wiping with a moistened towel. The EFB, ECO, and the leaflet and rachis samples were then cut into small pieces and dried overnight in an oven at 70°C. After oven drying, the samples were ground by using a grinding machine (Retsch SM100) fitted with a 1-mm sieve and placed in labeled plastic bags and stored in the refrigerator before further analyses. To determine the moisture content, a subsample of each EFB, ECO, rachis, and leaflet was placed in the oven at the same temperature until constant weight was reached.

Soil

Disturbed soil samples from each treatment plot were randomly taken at three soil depths (0–0.15, 0.15–0.30, and 0.30–0.45 m) by using an auger. Sampling was done once every 3 mo for 2 yr from December 2007 to December 2009. The samples were transported to the lab and spread on plastic to be air dried for a week. To determine the soil chemical properties, a part of each air dried sample was taken. Stones and plant roots were discarded. The samples were then crushed and passed through a 2-mm sieve and analyzed for chemical properties: pH, CEC, organic C, total N, available P, and exchangeable K, Ca, and Mg. For total N and C determination, the soil samples were first passed through a 0.25-mm sieve.

Plant

To determine the nutrient status of the oil palm trees, frond no. 17 of the palms in each plot was sampled once every 6 mo. The fronds were cut into three approximately equal sections and the mid-section was selected and separated for rachis and leaflet. Twelve leaflets from both sides of the rachis were sampled and placed together in a labeled plastic bag and transferred to the laboratory. The leaflets were then cut into three equal parts and the mid-section was selected, wiped with a moistened towel, and separated from the midribs. The remaining part of the leaflets (lamina) were cut into about 20-mm pieces and kept in trays to be air dried. The samples were dried at 70°C overnight and ground using a grinding machine (Retsch SM100) fitted with a 1-mm sieve, placed in labeled plastic bags, and stored in the refrigerator before the further analyses. Rachis samples were prepared in the same manner as the leaflets.

Chemical Analyses

Soil pH was measured in a soil-water suspension with soil/water ratio of 1:2.5 (Mc Lean, 1982) using a pH meter (Metrohm, 827pH Lab). Soil organic C was measured by the combustion method (Skjemstad and Baldock, 2008) by using the 412-Leco Carbon Auto-Analyzer. Soil total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Cation exchange capacity and exchangeable K, Ca, and Mg were measured by the leaching method by using neutral 1 M ammonium acetate (NH_4OAc) solution (Thomas, 1982) and soil available P by the Mo blue method according to the Bray and Kurtz no. 2 extracting solution (Olsen and Sommers, 1982).

The mulch and plant samples were oven dried at 105°C for 2 h and then analyzed, following Jones (2001), for nutrient status by the dry ashing method and N by the Kjeldahl method.

Decomposition of Mulching Materials

To study the decomposition and subsequent nutrient release patterns of the oil palm residues, an experiment was conducted at the same field site. The EFB, ECO, and pruned oil palm fronds were applied in January 2010 in the same experimental units and at the same application rates as done in the previous experiment. Two pieces of EFB were randomly selected and placed in a screen bag. One piece of 0.4 by 1 m ECO was also placed in another bag. The bags were clipped with wire and placed on the soil surface in the center of each EFB and ECO treatment plots.

Three pruned oil palm fronds were also randomly selected and each one separated for leaflet and rachis before weighing each part separately. The leaflets and rachis were then placed together in each screen bag and left on the soil surface in the middle of each frond heap.

To determine the dry matter mass losses, all the screen litter bags were weighed monthly. In the case of oil palm fronds, the litter bags were opened and weighed for the leaflet and rachis separately.

To determine the moisture and nutrient contents, four EFB located at different places within each EFB treatment plot were randomly selected and sampled. Ecomat samples were also taken from four randomly selected places within each ECO treatment plot. The samples were then mixed to obtain composite samples and oven dried at 70°C, ground, and used for nutrient concentration analyses. A subsample from each composite sample was also taken and oven dried to reach constant weight and then its moisture content was determined gravimetrically.

For the oil palm fronds, each litter bag was opened and separated for leaflet and rachis. The leaflet and rachis were sampled from each bag and the remaining parts were placed back into the bag and clipped. The samples were cleaned and cut into smaller pieces, oven dried at 70°C until constant weight to calculate their water content and then ground and used for their chemical composition.

Dry matter remaining (%) every month was calculated using the following equation:

$$D_t\,(\%) = W_t/W_0 \times 100 \qquad [1]$$

where D_t is the percentage of dry matter remaining at time t; and W_0 and W_t are the initial weight and the weight of dry matter (g) remaining at time *t*, respectively. Mass loss (%) for each oil palm residue was calculated simply by $(100 - D_t)$.

Decomposition rate constants (*k*) for different mulching materials were calculated based on an exponential decay function (Olson, 1963):

$$W_t = W_0 \exp(-kt) \qquad [2]$$

where W_0 and W_t are the initial amount and the amount of dry matter remaining at time *t* (g), respectively.

Nutrient release (%) by the oil palm residues was calculated using the following equation:

$$\mathrm{NR}_t\,(\%) = (N_0 - N_t)/N_0 \times 100 \qquad [3]$$

where NR_t is the percentage of nutrient released by the mulch at time *t*; and N_0 and N_t are the initial content and the nutrient content (g) of the mulch at time *t*, respectively. Nutrient content at time *t* was calculated from

$$N_t\,(\mathrm{g}) = (C_t/100) \times W_t \qquad [4]$$

where C_t and W_t are the nutrient concentration (%) and dry matter weight (g) of the mulch at time *t*, respectively.

Statistical Analysis

Data for the mulches' chemical analyses were analyzed according to a randomized completely block design (RCBD). The oil palm leaf nutrient analyses and the data obtained from decomposition experiment (percentage of dry matter and nutrient remaining) were subjected to ANOVA according to a split block experiment arranged in a completely randomized block design with mulch type as the main plot and sampling time as the subplot. The changes in the soil properties due to the four soil conservation practices (CP) were subjected to ANOVA according to a split split block arranged in a completely randomized block design with three replications, where CP was the main plot, time the subplot, and soil depth as the sub-subplot. All data were analyzed statistically using the ANOVA Procedure in SAS version 9.2 (SAS Institute, Cary, NC) and means separation test was done by the protected least significance difference (LSD) test. The SAS command codes based on Federer and King (2007) were used to analyze the split block and split split block experimental designs, and the LSD tests were based on Carmer and Walker (1982).

RESULTS

Chemical and Physical Characteristics of the Mulching Materials

Compressing EFB to create ECO resulted in the loss of nutrients and water, decreased porosity, and saturated hydraulic conductivity but increased bulk density (Table 2). The EFB had significantly higher K and Mg compared with palm frond,

Table 2. Mean chemical and physical characteristics of empty fruit bunches (EFB), Ecomat (ECO), and palm frond.

Property†	Frond	EFB	ECO
C, %§	49.94a	48.64b	48.47b
N, %	1.24a	0.87b	0.60c
C/N	41.38c	56.15b	82.09a
P, %	0.05a	0.05a	0.03b
K, %	1.51b	1.89a	1.13c
Ca, %	0.64a	0.20b	0.17b
Mg, %	0.07b	0.12a	0.05b
Water content, w/w, %	65.57a	64.17a	12.58b
Weight, kg	10.50	3.65	7.39‡
Length, m	6.91	0.41	2.00
Width, m	2.01	0.24	1.00
Thickness, m	0.04	0.15	0.02
Bulk density, Mg m^{-3}¶	n/a#	0.11	0.24
Porosity, %¶	n/a	91.53	81.54
Saturated hydraulic conductivity (mm s^{-1})¶	n/a	5.40	3.50
Slope of the water retention curve (slope based on a power function)¶	n/a	–0.13	–0.23

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

‡ Mean weight of one Ecomat precut in factory to size 1 by 2 by 0.02 m.

§ The values for nutrient concentrations are on a dry weight basis.

¶ Data from Teh et al. (2010).

n/a, data not available.

Table 3. Decomposition rate constant (*k*) for different oil palm residues, where higher *k* values denote faster decomposition rate.

Oil palm residue	*k*
	% mo^{-1}
Leaflets	0.26d‡
Rachis	0.12a
Frond	0.15ab
EFB†	0.20c
ECO	0.18bc

† EFB, empty fruit bunches; ECO, Ecomat.

‡ Values with the same letter are not significantly different from one another at 5% level of significance according to the LSD test.

but its C, N, and Ca concentrations were significantly lower than the palm frond. The P concentration in palm frond were not significantly different from EFB. The palm frond had significantly higher concentrations for most nutrients than ECO. The C/N ratio of the mulches were in the ascending order of palm frond < EFB < ECO. Both EFB and palm frond had statistically similar water content, and both of them had significantly higher water content than ECO. Empty fruit bunches had about 2.2 times lower bulk density than ECO. Saturated hydraulic conductivity of EFB was about 1.5 times higher than that of ECO. Finally, the slope of water retention curve which represents how strongly the mulching materials could hold onto water was higher for EFB than ECO. This means that EFB would hold its water stronger and releases its held water more gradually than ECO.

Decomposition of Mulches and Their Nutrients Release

The pattern of dry matter mass loss for all of the mulches had an initial rapid phase lasting for 5 mo, followed by a slower decomposition phase (Fig. 1). The loss of dry matter was the fastest for leaflet and the slowest for the rachis and frond compared to other materials. There was no significant difference in mass loss between the EFB and ECO and also between ECO and oil palm fronds. However, the mass loss was significantly higher for EFB than for the oil palm fronds.

The decomposition rate, *k*, was the highest for the leaflet and the lowest for the rachis (Table 3). Although *k* for EFB was statistically similar to that for ECO, EFB decomposed at a faster rate than the rachis and oil palm fronds but at a slower rate than the leaflets. There was no significant difference between the decomposition rate between ECO and oil palm fronds.

Empty fruit bunches released significantly higher amounts of K than fronds, rachis, and ECO after 8 mo of decomposition in the field (Table 4). Unlike K, the amount of N released by EFB and ECO were significantly lower compared with oil palm fronds. The amount of C released by EFB was significantly higher than by the oil palm fronds after 6 and 8 mo of the decomposition. This was due to the rapid decomposition of leaflets and slow decomposition of rachis which led to an increase in the relative proportion of the rachis to leaflets over time, which in turn resulted in a lower quality, as reflected by the C/N ratio, of the oil palm fronds. Although the C/N ratio of the leaflets was significantly lower than the rachis, fronds, and ECO after 3 mo of decomposition, it was not significantly different from EFB.

Table 4. Mean mass loss and nutrient release (in percent) by different mulching materials at 3, 6, and 8 mo of their decomposition in the field.

Period	Properties	Oil palm residue: Leaflet	Rachis	Frond	EFB†	ECO
mo						
3	Mass loss	51.0a‡	23.2d	33.0c	43.9b	39.8b
	C	67.3a	44.3c	52.6bc	57.4b	54.8b
	N	49.0a	2.3b	36.7a	9.7b	2.8b
	C/N	14.7a	64.7c	34.2b	26.0ab	38.5b
	P	42.9a	14.8c	35.4ab	19.2bc	15.2c
	K	65.2a	37.1d	45.0cd	55.5b	50.8bc
	Ca	48.8a	18.6c	36.9ab	28.3bc	22.8bc
	Mg	43.3a	14.7b	36.8a	36.6a	27.6ab
6	Mass loss	80.2a	51.1d	61.5c	72.7b	66.9bc
	C	88.7a	64.2d	73.3c	82.7ab	78.4bc
	N	84.2a	12.9d	66.1b	38.7c	36.5c
	C/N	16.8a	48.7c	35.5bc	15.8a	27.2ab
	P	83.4a	27.6c	67.7a	49.2b	45.8b
	K	93.2a	72.9c	78.4bc	87.3ab	78.2bc
	Ca	87.3a	54.5b	73.5a	53.1b	45.5b
	Mg	81.1a	22.7d	67.3ab	61.9bc	47.4c
8	Mass loss	86.3a	58.0d	68.1c	78.9b	75.0b
	C	92.6a	73.8c	80.8bc	87.6a	86.4c
	N	90.0a	25.4d	72.9b	48.9c	43.1c
	C/N	18.0ab	40.6c	33.0bc	13.7a	20.1ab
	P	90.4a	36.4d	75.3ab	57.8bc	54.1cd
	K	95.5a	78.9b	83.3b	95.5a	86.0b
	Ca	91.5a	56.8b	77.4a	60.3b	58.2b
	Mg	89.8a	40.0d	77.8ab	70.2bc	55.7cd

† EFB, empty fruit bunches; ECO, Ecomat.

‡ In the same row, values with the same letter are not significantly different from one another at 5% level of significance according to the LSD test.

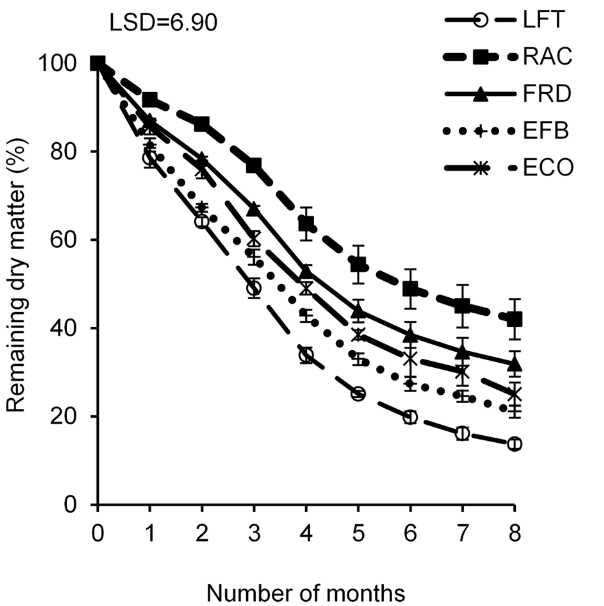

Fig. 1. Temporal change in remaining dry matter for different mulching materials. LFT, RAC, FRD, EFB, and ECO denote leaflet, rachis, palm fronds, empty fruit bunches, and Ecomat, respectively. Vertical bars are the standard error of means.

According to Brady and Weil (2002), C/N ratio is one of the most important indices denoting plant residue quality because C/N ratio determines the pattern and rate of residue decomposition. The lower the C/N ratio, the higher the residue quality. Therefore, residues with low C/N ratio such as leaflets (with an initial C/N ratio of 22.5) would decompose faster than residues having a high C/N ratio such as rachis (with an initial C/N ratio of 112.7). At the beginning of the experiment, oil palm fronds had a ratio of leaflet to rachis of 0.54. Since leaflets decomposed faster than rachis, this ratio decreased as decomposition progressed. For instance, the ratio between leaflet to rachis reduced to 0.27 and 0.18 at 5 and 8 mo, respectively. Therefore, with decreasing leaflets/rachis ratio, the frond quality (i.e., C/N ratio) will decrease. In turn, over time, frond decomposition and its nutrients release will be increasingly more

Table 5. Significant treatment effects on the soil chemical properties.

Source of variation	Soil chemical property							
	pH	CEC†	C	N	P	K	Ca	Mg
CP‡	**	ns§	ns	*	*	**	**	**
T	**	**	**	**	**	**	**	**
SD	**	ns	**	**	**	*	**	**
CP × T	**	ns	ns	ns	ns	**	*	**
CP × SD	**	ns	**	**	ns	**	**	**
T × SD	**	ns	*	*	**	ns	*	**
CP × T × SD	**	ns	*	*	*	ns	ns	ns

* $p < 0.05$.
** $p < 0.01$.
† CEC, cation exchange capacity.
‡ CP, T, and SD denote conservation practices, time, and soil depth, respectively.
§ ns, not significant.

regulated by the rachis than the leaflet characteristics. At 6 and 8 mo, EFB released 82.7 and 87.6% of its original C, respectively. These values were 12.9 and 8.4% higher than the C released by the oil palm frond in the 6 and 8 mo, respectively. This is almost in accordance with Zaharah and Lim (2000) who reported that about 75% of the C content in EFB was released within 25 wk of field decomposition.

Generally, there were no significant differences in C, N, P, Ca, and Mg release between the EFB and ECO. However, as stated earlier, EFB released significantly higher amounts of K than ECO.

Compared oil palm fronds, ECO released significantly less N and P, and the amounts of Ca and Mg released by the ECO were significantly lower than that by the oil palm fronds at 6 and 8 mo of decomposition. There were no significant differences in C and K release between the oil palm fronds and ECO.

Changes in Soil Properties

Analysis of variance revealed that the interaction effect of CP × T × SD on soil pH, organic C, total N, and available P, and the interaction effects of CP × T and CP × SD on exchangeable K, Ca, and Mg were significant (Table 5). There were no significant effects due to the conservation practices and its interaction with time and soil depth on soil CEC. This is in accordance with

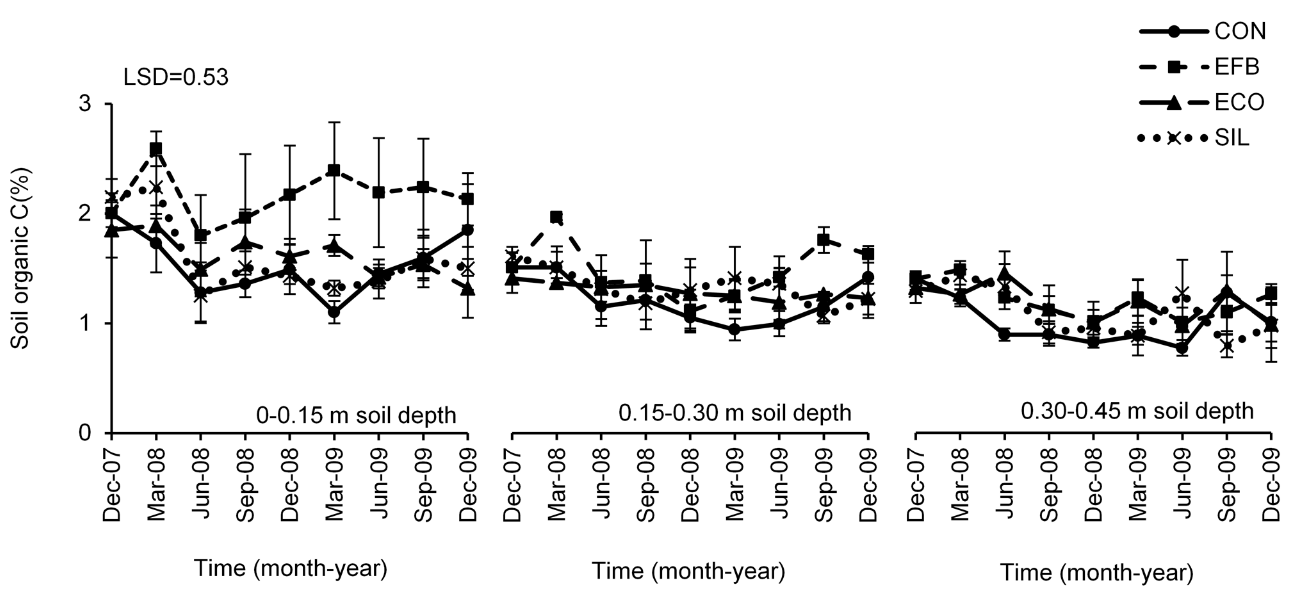

Fig. 2. Changes in soil organic C due to different conservation practices over time for three soil depths. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

Table 6. Soil pH, averaged across all time and soil depths, due to different conservation practices.

Conservation practice	pH
CON†	4.25c‡
EFB	5.72a
ECO	4.67b
SIL	4.39c

† CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively.

‡ Values with the same letter are not significantly different from one another at 5% level of significance according to the LSD test.

Budianta et al. (2010) and Kheong et al. (2010) who found that application of EFB mulch did not affect soil CEC significantly.

Soil Organic Carbon

Soil organic C was significantly affected by the conservation practices only at 0- to 0.15-m depth (Fig. 2). At this depth, EFB treatment had significantly higher soil organic C compared with other soil and water conservation practices for most of the periods. Neither ECO nor SIL was effective in increasing soil organic C as there were no significant differences in soil organic C between the ECO, SIL, and CON treatments. The average soil organic C at 0- to 0.15-m soil depth for EFB was 2.21% which is 38.13% higher than SIL (1.60% C) and CON (1.60% C), and 36.43% higher than ECO (1.62% C). Significant increase in soil organic carbon due to EFB mulching was likewise reported by other researchers (e.g., Hamdan et al., 1998; Zaharah and Lim, 2000; Abu Bakar et al., 2011).

Soil pH

Soil pH was significantly higher in EFB than other conservation practices for nearly all of the time and for all soil depths (Fig. 3). However, there were no significant differences between ECO, SIL, and CON. Soil pH due to EFB mulching, averaged across all time and soil depths, was 5.72, which was

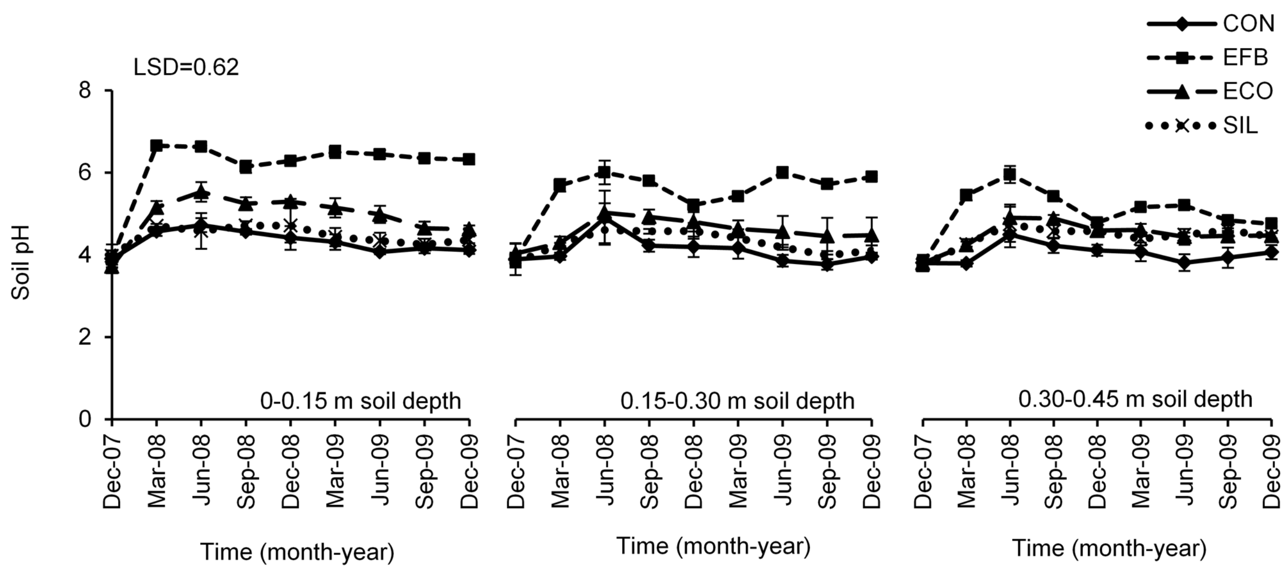

Fig. 3. Changes in soil pH due to different conservation practices over time for three soil depths. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

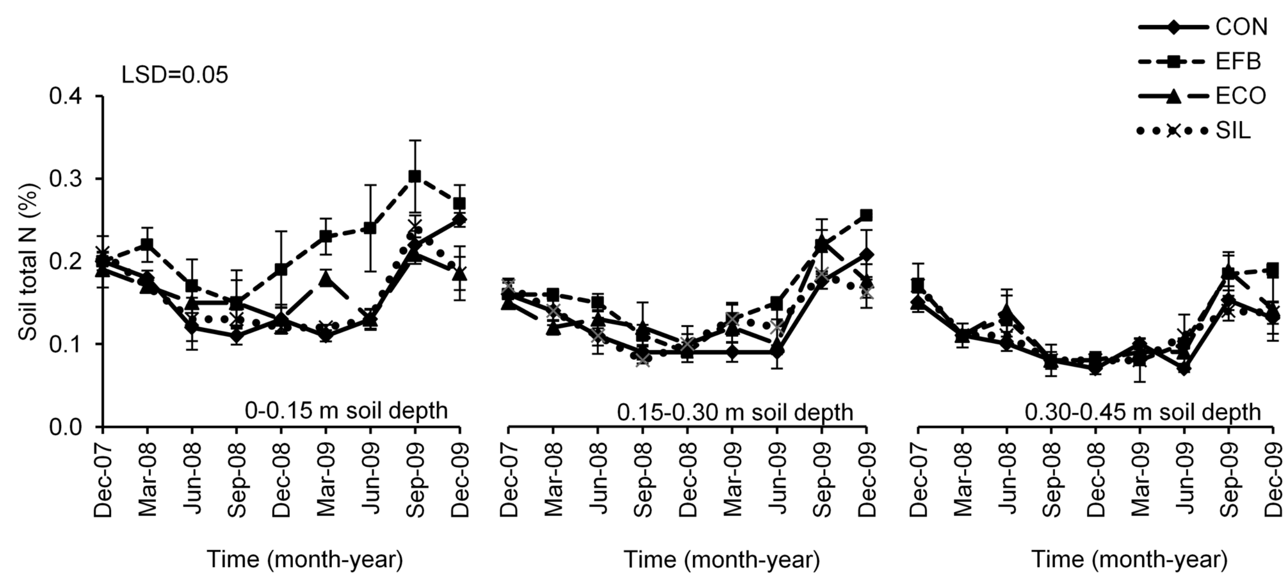

Fig. 4. Changes in soil total N due to different conservation practices over time for three soil depths. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

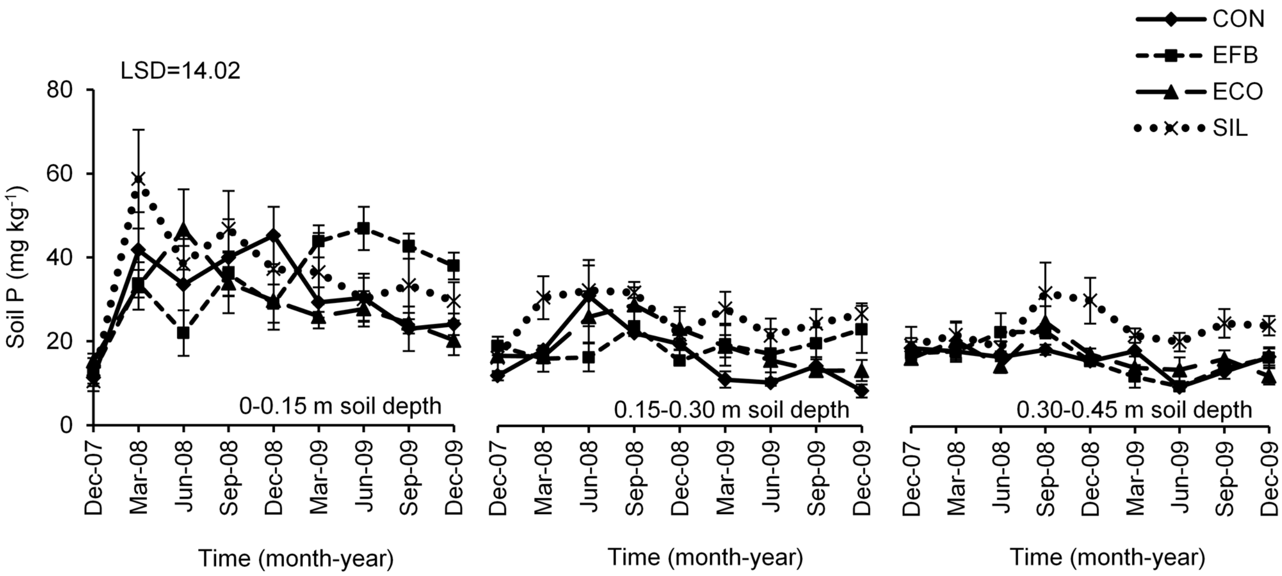

Fig. 5. Changes in soil available P due to different conservation practices over time for three soil depths. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

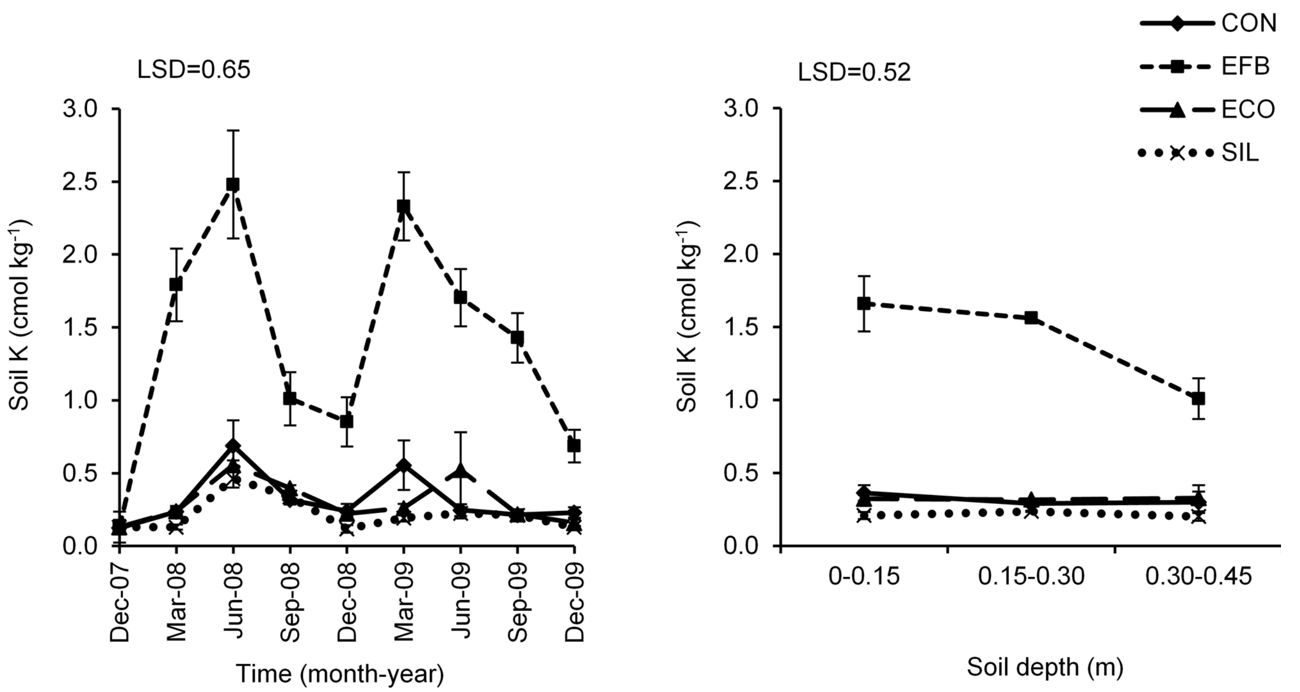

Fig. 6. Changes in soil exchangeable K due to different conservation practices over time (left) and in three soil depths (right). CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

significantly higher than ECO (4.67), SIL (4.39), and CON (4.25) (Table 6). In comparison to control, EFB increased soil pH by an average of 1.48 units, while the increase in soil pH due to the ECO and SIL treatments were only 0.43 and 0.15 units, respectively. Increase in soil pH, as a result of EFB mulching, was also reported by other researchers (e.g., Ortiz et al., 1992; Rosenani and Wingkis, 1999; Zaharah and Lim, 2000; Lim and Zaharah, 2002; Budianta et al., 2010; Kheong et al., 2010).

Soil Total Nitrogen

Similar to soil C results, most of the changes in soil total N occurred in the 0- to 0.15-m depth, and there were no significant differences between the conservation practices in the lower 0.15- to 0.30- and 0.30- to 0.45-m soil depths (Fig. 4). For the 0- to 0.15-m depth, there were no significant differences in soil N between the conservation practices until after December 2008. After this period, soil N was significantly higher in EFB than the other treatments. There were no significant effects on soil N due to ECO and SIL as the total N in both these treatments were not significantly different from the soil N in the CON treatment.

Soil Available Phosphorus

Like soil C and N results, most of the changes in soil available P also occurred in the 0- to 0.15- m depth (Fig. 5). For this depth,

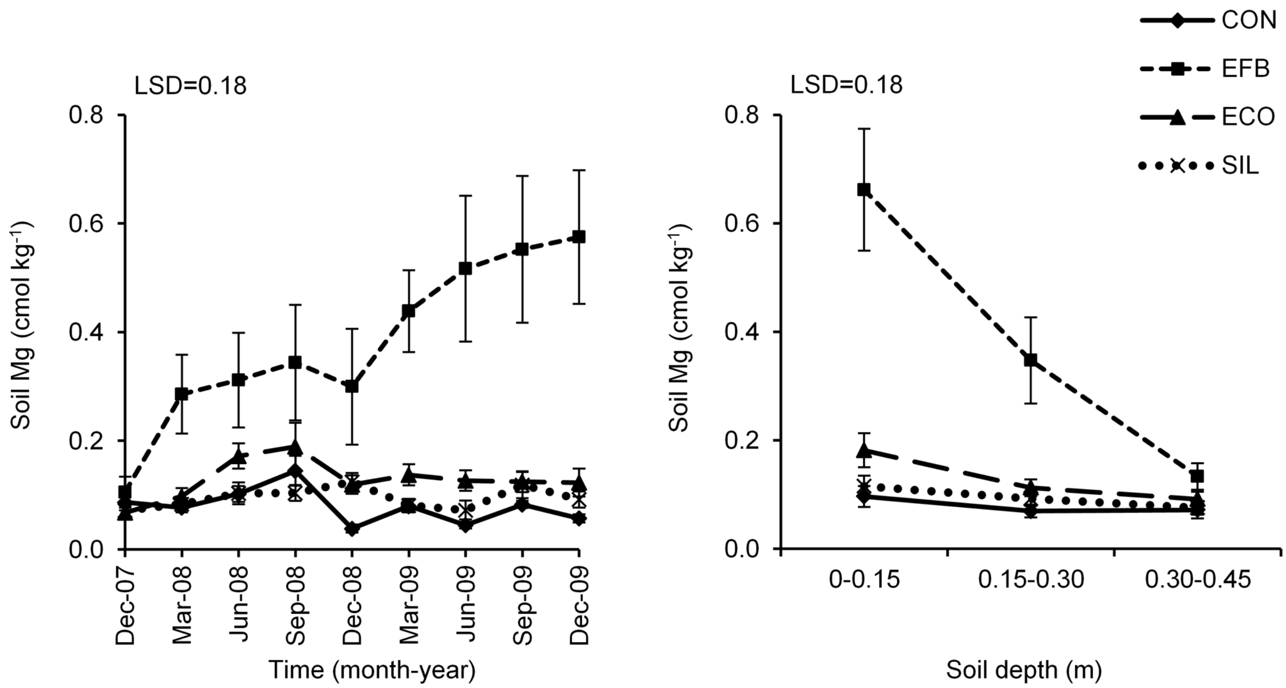

Fig. 7. Changes in soil exchangeable Mg due to different conservation practices over time (left) and in three soil depths (right). CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

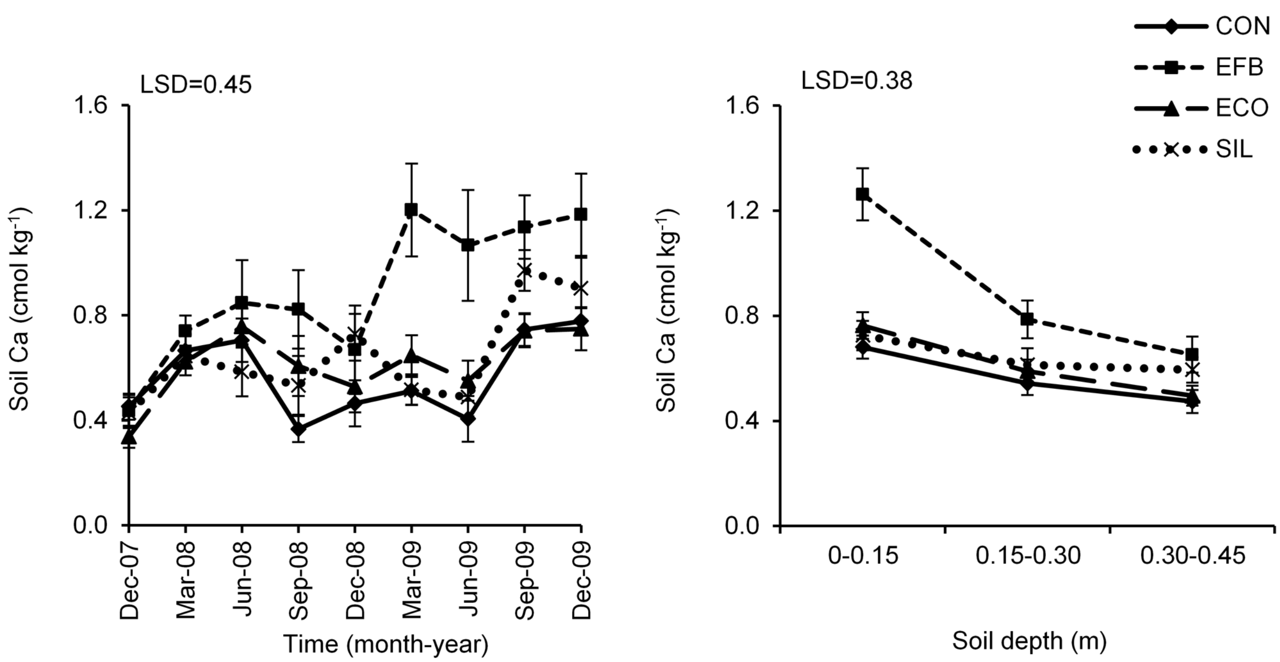

Fig. 8. Changes in soil exchangeable Ca due to different conservation practices over time (left) and in three soil depths (right). CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

except in March 2008 where soil available P was significantly the highest in SIL, there were no significant differences between the conservation practices until after March 2009; thereafter, soil available P was significantly higher in EFB compared with ECO and CON. Both ECO and CON were also not significantly different from SIL in this period. Although there were no significant differences between the conservation practices in the 0.15- to 0.30- and 0.30- to 0.45-m soil depths, soil available P tended to be higher in SIL treatment plots compared to the other conservation practices, especially in 0.30- to 0.45-m soil depth.

Soil Exchangeable Potassium

Soil exchangeable K was significantly and noticeably higher for EFB than for other conservation practices in all periods and in all three soil depths (Fig. 6). Soil exchangeable K in EFB treatment showed some fluctuation over time and decreased with increasing soil depth. Soil exchangeable K was not appreciably changed in CON, ECO, and SIL treatments, but for EFB, exchangeable K increased during the first 6 mo of the experiment and then decreased until the end of the first year. After EFB application was renewed in January 2009, soil K increased

Table 7. Significant treatment effects on the oil palm leaf nutrient levels.

Source of variation	Nutrient				
	N	P	K	Ca	Mg
CP†	ns‡	ns	*	ns	*
T	**	**	**	**	**
CP × T	*	*	ns	ns	ns

* $p < 0.05$.

** $p < 0.01$.

† CP and T denote conservation practices and time, respectively.

‡ ns, not significant.

again as a result of renewed K release from EFB. There were no significant differences between CON, ECO, and SIL over all time and all soil depths.

Soil Exchangeable Magnesium

There were no significant differences in soil exchangeable Mg between CON, ECO, and SIL treatments, but Mg was significantly higher in EFB than the other conservation practices for nearly all periods and in the 0- to 0.15- and 0.15- to 0.30-m soil depths (Fig. 7). Increase in Mg by EFB mulching was also reported by other researchers (e.g., Rosenani and Wingkis, 1999; Lim and Zaharah, 2002; Budianta et al., 2010). Magnesium decreased with soil depth, particularly for the EFB treatment.

Soil Exchangeable Calcium

There were no significant differences in soil exchangeable Ca between the conservation practices for the first 9 mo of the experiment; thereafter, Ca was increasingly higher in the EFB treatment than in the ECO, SIL, and CON treatments (Fig. 8). However, the differences in soil Ca between the four soil conservation practices were not statistically significant from one another in September and December 2009.

Most of the changes in soil exchangeable Ca due to the EFB occurred in the 0- to 0.15-m soil depth (Fig. 8). At this depth, soil exchangeable Ca was significantly higher in the EFB than the ECO, SIL, and CON treatments. There were no significant differences between the conservation practices in the 0.15- to 0.30- and 0.30- to 0.45-m depths.

Changes in Leaf Nutrient Contents

Analysis of variance showed that the main effect of CP on leaf K and Mg concentrations and the interaction CP×T effect on leaf N and P levels were significant (Table 7). Leaf Ca concentrations were not affected significantly by the conservation practices.

Leaf Nitrogen Level

There were no significant differences in N concentration in the oil palm leaf between the conservation practices in the first year; thereafter, EFB increased the N concentration in the oil palm leaf significantly higher than the other treatments (Fig. 9). Nonetheless, the leaf N concentrations due to all of the soil conservation practices were higher than the critical level of 2.3% as reported by Fairhurst and Mutert (1999), a threshold level of N below which indicates N deficiency.

Leaf Potassium and Magnesium Levels

Leaf K and Mg levels were significantly higher in the EFB treatments than other conservation treatments (Fig. 10). For Mg levels, ECO was statistically similar to EFB. There were no significant differences between CON, ECO, and SIL for K, and for Mg, between ECO and SIL. Average K level in the rachis for EFB, ECO, SIL, and CON were 1.32, 1.09, 1.05, and 0.9%, respectively. According to Foster and Prabowo (1996), these four measured values are ranked as adequate, marginal, marginal, and low, respectively. They classified the K status in the rachis of frond no. 17 as high when K is >1.60%, adequate when K is 1.31 to 1.60%, marginal when K is 1.01 to 1.30%, and low when K is <1.01%.

Average Mg level in the leaflet for the EFB, ECO, SIL, and CON were 0.23, 0.19, 0.20, and 0.15%, respectively. According to the Fairhurst and Mutert (1999), the critical leaf Mg level for a 6-yr-old or older oil palm is 0.20%. Therefore, the leaf Mg concentrations in all of the conservation practices, except for EFB, were lower than the critical level. Mulching the soil with EFB resulted in an increase in leaf Mg level above the critical level; hence, correcting for Mg deficiency.

Leaf Phosphorus Level

The P level in oil palm leaves was generally higher in the EFB treatment than the other practices in July 2008 and July 2009 which were 6 mo after EFB mulch annual application (January 2008 and January 2009) (Table 8). Although leaf P concentration was higher in the EFB treatment, it was not significantly different from SIL except in July 2009. The critical level of P as reported by Fairhurst and Mutert (1999) is 0.14%. Except for CON, leaf P level in generally all of the conservation practices was higher than the critical level at 6 mo after initiation of the experiment. It means all of the conservation practices resulted in an improvement of P deficiency in oil palm leaf as compared to the CON treatment.

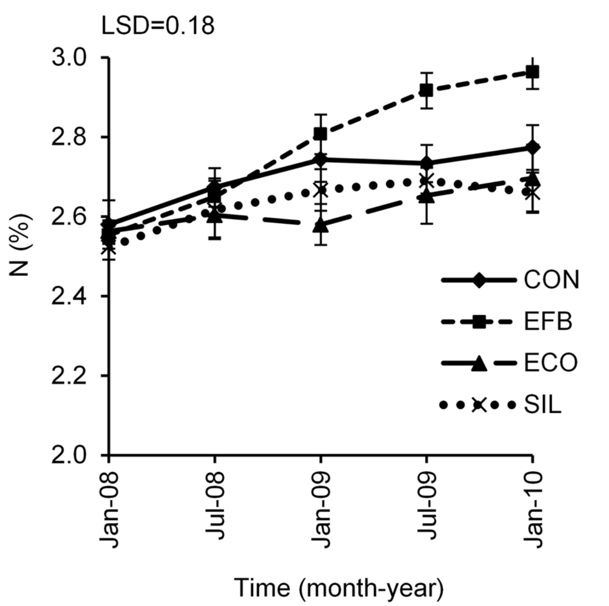

Fig. 9. Oil palm leaf N level due to different soil conservation practices. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

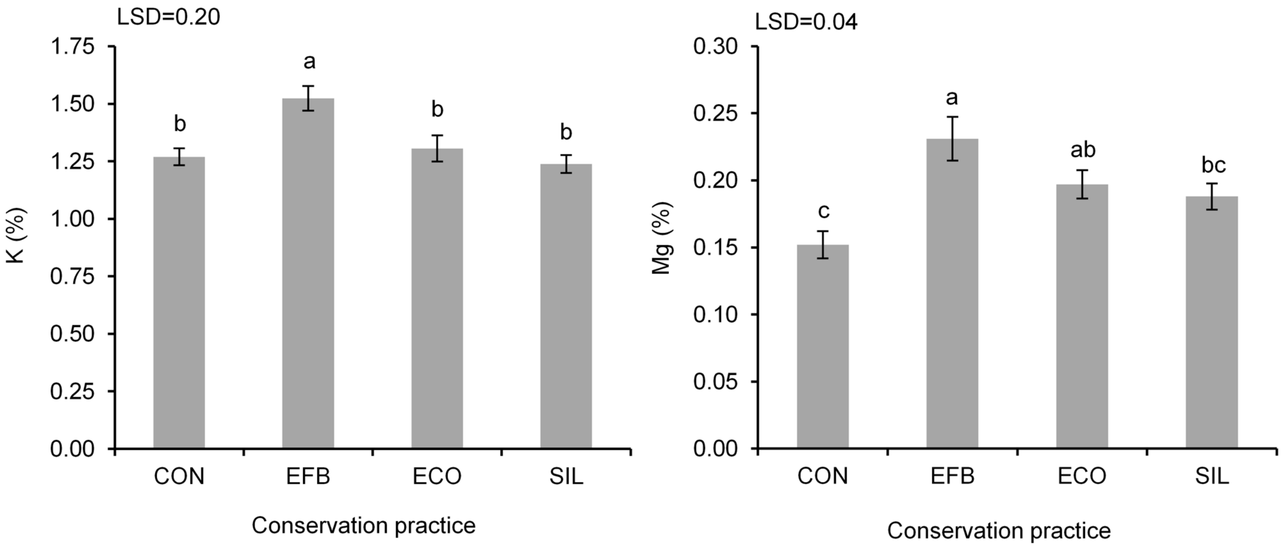

Fig. 10. Oil palm leaf concentration for K (left) and Mg (right) for different soil conservation practices. CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively. Vertical bars show standard error of means.

DISCUSSION

Soil organic C, total N, available P, and exchangeable Ca were significantly affected by the conservation practices at only 0- to 0.15-m depth, being the highest in EFB treatment, especially during the second year.

Nonsignificant changes in these four soil elements in the lower soil depths is probably because the experiment only had two annual mulch applications over a period of nearly 3 yr. This short period length and the only two annual application rates could be why significant increases could not be observed for the C, N, and P contents at the lower soil depths (Fig. 2). Moreover, soil N and P levels are in close relationship with soil organic C levels because more than 90% of soil N and at least 50% of soil P exist as organic forms. Results here correspond to those obtained by Budianta et al. (2010) who did not find any significant increase in soil organic C and available P in the 0- to 0.40-m soil depth even though 40 t ha^{-1} of EFB mulch was applied every year for 4 yr, and that soil total N also did not increase significantly for the first 2 yr.

Unlike the previous four soil elements, soil exchangeable K and Mg and soil pH were affected in all the three soil depths. Chemical analyses revealed that EFB contained higher K concentration compared to N and P (Table 2). The decomposition study further revealed that K was released at a much faster rate than N and P from the EFB (Table 4). Unlike N and P, K is not a structural element of plant cells but available as ions in cells sap. Thus, K would be released much faster than the other elements during plant residue decomposition (Swift et al., 1979; Khalid et al., 2000).

Table 8. Oil palm leaf P concentration (%) due to different conservation practices.

Conservation practice	Time Jan. 2008	July 2008	Jan. 2009	July 2009	Jan. 2010
CON†	0.13a‡	0.13b	0.14b	0.13b	0.15b
EFB	0.13a	0.21a	0.22a	0.24a	0.22a
ECO	0.13a	0.14b	0.22a	0.16b	0.14b
SIL	0.14a	0.16ab	0.25a	0.17b	0.19ab

† CON, EFB, ECO, and SIL denote control, empty fruit bunches, Ecomat, and silt pit, respectively.

‡ In the same column, values with the same letter are not significantly different from one another at 5% level of significance according to the LSD test.

Most of the plant residues' K content was released within a few months of their mulch application. This is in accordance with Zaharah and Lim (2000) who found that the pattern of nutrients release from EFB during its decomposition period was gradual for N, P, Ca, and Mg, but very rapid for K. Zaharah and Lim (2000) reported that while 90% EFB-K content was released within 6 mo of decomposition, there was nearly no N release from EFB even after 10 mo. Increase in concentrations in soil K and, to a lesser extent, Mg in the lower soil depths by EFB mulching caused the soil pH to be affected as well. These basic cations increase soil pH by producing hydroxyl ion via hydrolysis in water.

As stated earlier, Zaharah and Lim (2000) observed nearly no N release by EFB even after 10 mo of EFB decomposition. In this study, there was no significant differences in soil N between the conservation practices during the first year. It was only in the second year that the soil N due to EFB application was significantly higher than the other soil conservation practices. This trend is due to the low N release by EFB as a result of a high initial C/N ratio (Table 2). This is in accordance with Moore et al. (2006) who reported that materials having high C/N ratios are more stable, retaining a greater proportion of their N at a given decomposition stage than materials with low C/N ratios. Like that observed in this study and Zaharah and Lim (2000), data from Rosenani and Wingkis (1999) suggested that only 50% of EFB-N release occurred within 9 mo of EFB decomposition.

Although there was no significant difference in soil available P between EFB and SIL in the topsoil, it was slightly higher in SIL in the subsoil layers especially in 0.30- to 0.45-m depth (Fig. 5). This is because P is less mobile in soil than other macronutrients, and P is lost mostly through surface water runoff rather than deep percolation (Sharpley and Rekolainen, 1997). This study was conducted on a hill slope, and in the SIL treatment plots, the SIL could collect the runoff which contained sediments and hence, P. The collected P was then redistributed into the soil profile around the pits, increasing the soil P level, as observed in this study.

Unlike other soil chemical properties, soil CEC was not increased significantly by any of the soil conservation practices. Mulching materials can increase soil CEC by increasing the soil organic matter and/or soil pH. Although EFB increased soil C and pH, their amounts of increase might not be sufficient or more time might be required before a significant increase in CEC can be detected. Eshetu et al. (2004) observed that the CEC of tropical forest soils were strongly related to the amounts of organic C only when the amount of organic C was higher than 2%, below which soil CEC did not respond to soil organic C. Similarly, Budianta et al. (2010) and Kheong et al. (2010) reported EFB mulching did not significantly increase soil CEC.

The differences in the effectiveness of the EFB, ECO, and pruned oil palm fronds (CON) treatments in improving the soil chemical properties can be attributed to the amount of nutrients released from these mulching materials. The amount of nutrients released into the soil would depend on one or more of the following: (i) differences in the amount of mulching material added, (ii) differences in the nutrient concentrations in the mulches, and (iii) differences in the decomposition rates and hence, the nutrient release patterns of these mulches.

The amount of EFB applied to each plot was 1000 kg which was placed on a 30-m^2 area in the center of each EFB treatment plot. As the EFB had an average water content of 64.17% (Table 2), the amount of dry matter added by the EFB was 11.93 kg m^{-2} yr^{-1}. The amount of ECO applied to each plot was 29.55 kg (four pieces of 1 by 2 m, where each piece weighed 7.39 kg) and placed on a 8-m^2 area in the center of each ECO treatment plot. Because the ECO had an average moisture content of 12.58% (Table 2), the amount of dry matter added by the ECO was 3.23 kg m^{-2} yr^{-1}. The moisture content of palm fronds was 65.57% (Table 2), and with 3552 fronds pruned annually and each frond weighing 10.50 kg, about 12,840 kg ha^{-1} dry matter was added through pruned palm fronds annually. This amount of pruned palm frond was applied on about 60% of the land surface in every other row, therefore the amount of dry matter added to the unit area of the land surface by the pruned oil palm frond was 4.28 kg m^{-2} yr^{-1}.

As mentioned earlier, the amount of dry matter added by EFB, ECO, and oil palm fronds to the soil were 11.93, 3.23, and 4.28 kg m^{-2}, respectively. By multiplying these values by the corresponding nutrient concentrations (Table 2) and by the percentage of nutrient released over a given period (Table 4), the amount of nutrient released from the EFB, ECO, and CON treatments were calculated. For example, multiplying the amount of dry matter added from each mulch type onto the soil surface by the N concentration of the mulch (Table 2) revealed that the N applied by EFB, ECO, and oil palm fronds were 0.15, 0.02 and 0.04 kg m^{-2}, respectively. From the decomposition experiment, it was found that at 8 mo of the decomposition, EFB, ECO, and pruned oil palm fronds released 48.9, 43.1, and 72.9% of their N, respectively. Therefore, the amount of N released from EFB at 8 mo of decomposition was 0.07 kg which was 2.3 times higher than that by the oil palm fronds (0.03 kg) and 7.0 times higher than ECO (0.01 kg). The amounts of nutrient released by different mulches are shown in Table 9.

There were no significant differences between the ECO, SIL, and CON treatments for most of the soil nutrients. In contrast, EFB increased soil C, N, K, Mg, and Ca significantly higher than the other conservation practices. This is mostly due to the higher amount of nutrients released from the decomposition of EFB into the soil compared to the other treatments (Table 9).

Compared to ECO, the better performance by EFB in increasing soil N, P, and Mg was due to the combined effects of having higher amounts of dry matter added and having higher N, P, and Mg concentrations in the EFB. The higher soil K concentration in the EFB plots was due to same aforementioned combined effects as well as EFB having a higher K release rate than ECO. However, the higher soil C and Ca concentrations in the EFB plots were only due to the higher dry matter added from the application of EFB than the ECO treatment.

Compared to palm fronds mulching material (CON), the combined effects of a higher amount of dry matter addition, higher K release rate by the EFB mulch, and higher K and Mg concentrations in EFB resulted in a higher soil K and Mg concentrations in the EFB plots compared to CON plots. The EFB had slightly lower C concentration than in palm fronds (Table 2), but the higher amount of dry matter addition and the higher percentage of C release by EFB resulted in a higher soil C concentration in the EFB plots compared to CON plots. The soil N and P concentrations in the EFB plots were higher than in CON plots because of the higher amount of EFB added to the soil, even though N and P were released into the soil at a higher rate by the pruned fronds than that by EFB (Table 4). However, the amount of Ca released by EFB was lower than that by the oil palm fronds. The higher soil Ca concentration in the EFB plots (Fig. 8) revealed that the Ca released from the oil palm fronds was lost from the soil, so oil palm fronds could not increase soil Ca higher than EFB.

Empty fruit bunches treatment plots had higher soil nutrient concentrations than in the SIL plots. This is because, unlike the three organic materials, SIL is not an organic residue and hence does not add any nutrients into the soil via a decomposition process. Silt pits prevent nutrient losses by trapping and collecting runoff water, which contains these nutrients, and redistributing the nutrients back into the soil profile around the pits after rainfall events. Empty fruit bunches, in contrast, is an organic material (0.15 m in initial thickness) which would not only prevent nutrient losses via runoff water, but also release additional nutrients into the soil as EFB decomposes.

Soil pH was increased the highest by the EFB treatment which was due to EFB releasing the highest amounts of K, Mg, and Ca and its subsequent improvement in soil exchangeable bases. Increase in soil pH will enhance microbial activity and therefore increase nutrient availability for plant uptake. It can

Table 9. Total amount of nutrients released from different oil palm residues after 8 mo of decomposition.

Total nutrient released	Oil palm residue		
	Frond	EFB†	ECO
kg m^{-2} ground			
C	1.730	4.990	1.350
N	0.030	0.070	0.010
P	0.002	0.006	0.001
K	0.041	0.215	0.031
Ca	2.128	1.675	0.306
Mg	0.002	0.010	0.001

† EFB, empty fruit bunches; ECO, Ecomat.

also eliminate or reduce the risk of Al toxicity and the need for liming practices.

Empty fruit bunches increased oil palm leaf N, P, K, and Mg levels significantly higher than the other treatments. Their higher concentrations can be contributed to the higher N, K, and Mg levels in the soil in the EFB plots. This is in accordance with Lim and Zaharah (2002) who found that when N and K concentrations in the soil were increased, N and K concentrations in the oil palm leaves were increased as well. Likewise, Claassen and Wilcox (1974), Al-Kanani et al. (1989), and Hudska (1990) reported that nutrient concentrations in the soil correlated with the amount of their uptake by the plants.

Although EFB significantly increased oil palm leaf N, P, K, and Mg levels, EFB did not do so for Ca. This was due to the higher K concentration in the soil and oil palm leaf in the EFB treatment. According to Lazaroff and Pitman (1966) and Freeman (1967), high K concentration reduces Ca uptake by plants. In this study, the effect of EFB on increasing soil Ca concentration (Fig. 8) was not as large as EFB's effect on increasing the soil K concentration (Fig. 6). Subsequently, the increase in soil Ca concentration by EFB might not be enough to make a significant increase in plant Ca concentration or to overcome the antagonistic effect by the increased soil K concentration.

Improvement in the soil physical properties, including soil water content (Moradidalini et al., 2011), and soil microbial activity (Goh et al., 2011) with EFB mulching could be the other reasons for the higher N, P, K, and Mg levels by this treatment. Other researchers (Lim and Zaharah, 2002; Kheong et al., 2010) also reported that the improvement of soil physical and chemical properties resulted in a higher nutrient uptake by oil palm roots. An increase in oil palm root mass as a result of EFB mulching (Kheong et al., 2010) could be another reason for the higher nutrient uptake in the EFB treatment. Although soil P was not affected by the EFB treatment compared to the SIL treatment, P was significantly higher in the oil palm leaf in the EFB treatment. The higher oil palm leaf P level in EFB may be attributed to the increase in oil palm root mass and density by EFB mulching (Kheong et al., 2010) and higher N concentration in the oil palm leaf. The P moves through the soil via diffusion which is a slow process, where the diffusion rate of P is between 10^{-12} to 10^{-15} $m^2\ s^{-1}$ (Schachtman et al., 1998). Therefore, uptake of P by plant roots is highly dependent on root mass and root activity. Besides root activity, N has a synergistic effect on P uptake by plants. According to the Potash and Phosphate Institute (1994), P is more available for plants when soil is applied with N than without N. Fujita et al. (2010) likewise concluded that increased soil N resulted in a higher P uptake by grass.

CONCLUSIONS

Empty fruit bunches mulching was shown to be significantly better than the other three recommended soil conservation practices: ECO, stacked pruned oil palm fronds, and silt pitting in improving almost all of the measured soil chemical properties and oil palm leaf nutrient status. Compared to ECO, the better performance of EFB in increasing soil chemical properties and oil palm leaf nutrient levels was due to the combined effects of higher amounts of dry matter added by EFB mulching and the higher nutrient concentrations in the EFB than in ECO. Although compressing EFB to create ECO reduces EFB's bulkiness, ECO is not recommended for the purpose of increasing the soil chemical properties and hence soil fertility. This is partly because, compared to EFB, ECO had lower nutrient concentrations which were lost during its manufacturing process. Silt pitting had nearly the same effect as EFB mulching in increasing soil available P level, but it was not as effective as EFB in increasing the levels of other soil chemical properties and oil palm leaf nutrients.

ACKNOWLEDGMENTS

This research is funded by the Ministry of Science, Technology and Innovation, Malaysia (Project no.05-01-04-SF0632). We are grateful to Mr. Subra and his field workers at Balau Estate, Petronella Gerald Ah Tung at Applied Agriculture Research Sdn. Bhd., Sungai Buloh, and the laboratory staff at the Dep. of Land Management, Universiti Putra Malaysia for their help in this research.

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