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ORIGINAL ARTICLE

Effects of ten year application of empty fruit bunches in an oil palm plantation on soil chemical properties

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Abstract The oil palm empty fruit bunches (EFB), a major waste product of the palm oil mills, were earlier incinerated at the mills and had contributed to air quality problems in Malaysia. This lead to the introduction of the Malaysian Environmental Air Quality Regulation in 1978 which prompted mills to look for alternative management methods in disposal of the EFB. A convenient method is applying the EFB to the oil palm field near the mill for nutrient cycling. A study was conducted to investigate the effects of 10 years of EFB yearly application in an oil palm plantation, as a source of nutrients, on the chemical properties of a well-drained, highly weathered acidic soil, classified as Typic Kandiudult. The experimental plots receiving 3 treatments, i.e. chemical fertilization, without EFB application (CHEM)), application of 150 kg EFB palm^{-1} year^{-1} (EFB150) and application of 300 kg EFB palm^{-1} year^{-1} (EFB300) with four replications, from 1983 to 1992. The EFB was applied in heaps in the middle of every 4 palms. The cumulative addition of EFB had increased the soil pH by two units with application of EFB300 and a one unit increase with EFB150 in the 0–60 cm soil layer, compared to CHEM. The application of EFB even at the lower rate decreased significantly exchangeable Al contents and the cation exchange capacity increased up to 60 cm soil depth. Overall increases in exchangeable bases were also observed in soils treated with EFB. The increase was more evident in EFB300 compared to EFB150. Organic C in the topsoil increased from 1.49 to 2.50% and 2.73% in EFB150 and EFB300, respectively. There was also an increase in total nitrogen with EFB application but only in the topsoil. An overall analysis of the yield response in the 10 year-period shows that EFB300 resulted in higher fresh fruit bunch (FFB) yield than EFB150 and CHEM while the yield of EFB150 was not significantly different from CHEM. This study showed that it is beneficial to dispose the EFB by applying them in the oil palm fields around the mills.

Keywords Soil carbon · Soil nitrogen · Crop waste management · Mulch · Nutrient cycling

Introduction

Malaysia is a producer and exporter of palm oil, with an area of 4.49 million hectares of oil palm cultivation in 2008. One of the main waste products of the

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palm oil industry is the empty fruit bunch (EFB). For every tonne of oil palm fresh fruit bunch (FFB) that goes to the mill, 20–25% is EFB which is the residue after the FFB is steamed and the fruitlets removed for oil extraction. In 2005, there were 395 palm oil mills in the country, producing about 17 million tonnes of EFB (MPOB, 2005).

Traditionally, the EFB was incinerated in the mill as fibre fuel which caused severe air pollution problems. With the introduction of the Malaysian Environmental Air Quality Regulation in 1978, an alternative disposal or management method of the EFB became necessary. As most mills are located in the plantation, a convenient alternative is to transport the EFB to the oil palm estates around the mill and apply as a mulch and nutrient source. Composting of EFB is also a possible alternative but this adds operational cost and requires technology for rapid composting.

Malaysian soils are mostly highly weathered and have low inherent fertility, i.e. low in soil organic matter (SOM), cation exchange capacity (CEC) and exchangeable bases, and high soil acidity which causes low crop productivity. Thus, disposing or application of the EFB as a mulch and nutrient source in nearby oil palm fields may lead to improvement of soil fertility and reduce the use of chemical fertilizers in that field. Application of crop residues not only promotes nutrient recycling and improves soil fertility by adding soil organic matter (Agboola and Unamma 1991; Unger 1997; Makinde et al. 2006) but also promotes C sequestration in soil as a way of mitigating global warming (Feller and Bernoux 2008). Results of field trials have shown that EFB applied as a mulch around the base of the palm from the time when seedlings were transplanted, with addition of minimal rates of chemical fertilizer supplements, increased significantly the vegetative growth of the palm and subsequently the FFB yield compared to plots without EFB mulching (Loong et al. 1987). The maturity period of the palm was also found to be reduced by several months when EFB was applied from the time of field planting (Chan et al. 1991). According to Loong et al. (1987), field trials with mature palms had shown yield responses to rates of EFB mulching up to 55.5 tonnes/ha on an inland soil. However, only marginal yield increases were recorded when EFB was applied on coastal soils. Application of EFB has been found to improve soil structure and water holding capacity and reduce soil temperature (Hoong and Nadarajah 1988). The application of EFB, at 100 kg palm^{-1} around the base of palm seedlings as a mulch at transplanting is currently being practised by most planters. However, for mature palms, the EFB are currently applied only in the estates near the palm oil mill as a convenient and cheap method of disposal. However, the optimum rate and method of application are not standardised.

Although the application of EFB as a nutrient source and mulch in oil palm fields is already a common practice, there is still lack of documented information on the changes in soil chemical properties due to continuous EFB application. In most of the field trials carried out earlier, mainly yield and plant parameter were measured. The EFB was normally applied in a heap between 2 palms or in the middle between 4 palms, as most of the palm roots grow out radially for quite a distance. The feeder roots of the palm also tend to concentrate in areas of high organic matter and moisture. Thus, in 1982, a long-term field trial was established in a plantation by Golden Hope Plantation Sdn. Bhd. to investigate the long-term effects of 2 rates of EFB application as a nutrient source on the oil palm yield, from 1982 to 1993. The EFB in this trial were applied in a heap in the middle between four palms. This paper reports the results of a study conducted in 1992 to investigate the impact of the 10 years application of EFB in this trial on the chemical characteristics of the soil up to 1 m depth in the sites where EFB was applied.

Materials and methods

The study was conducted in an oil palm plantation, Sepang Estate, Golden Hope Malaysia Sdn. Bhd. in Sepang district where a long-term field trial (1982–1992) was already established by the estate to study the oil palm yield response to EFB applied as an alternative nutrient source. The area receives an average annual rainfall of 2,500 mm. The soil is well drained with silty clay texture up to 1 m depth and classified as isohyperthermic Typic Kandiudult. The properties of the topsoil (0–20 cm) are as follows: pH 4.3–4.5, total N 0.120–0.205%, organic C 0.36–0.37% and CEC 7.8–12.4 cmol(+) kg^{-1}.

The oil palms were 8 years old at the time of establishment of the trial in 1982 and the treatments involved were recommended chemical fertilization and zero EFB application rate (CHEM), 150 kg EFB palm^{-1} year^{-1} (EFB150) and 300 kg EFB palm^{-1} year^{-1} (EFB300) application, i.e. 22.2 and 44.4 Mg EFB ha^{-1} year^{-1}, respectively. The plots with EFB application were without chemical fertilization. These treatments were given annually for 10 years, with 4 replications, in a randomised complete block design. The EFB contains 0.65–0.94% N, 0.08–0.12% P, 1.7–3.2% K, 0.11–0.34% Ca and 0.15–0.24% Mg on a dry weight basis; each EFB weighed 1.2–2.1 kg (dry weight basis). The palms were planted at a density of 148 palms per hectare and each treatment plot had 36 palms. The EFBs were placed in a heap in the middle of every 4 palms; each heap amounted to 600 kg (150 kg EFB palm^{-1}) or 1,200 kg (300 kg EFB palm^{-1}) covering an area of about 6 m^2 (see Plate 1). There were nine EFB heaps in each treatment plot. No chemical fertilizers were applied in the EFB plots. In the treatment plots with chemical fertilization, the fertilizers (ammonium sulphate, Christmas Island Rock Phosphate, muriate of potash and kisserite) were applied by broadcasting on the soil surface each year, following the recommended rates according to the age of the palms (see Table 1). In 1993, soil sampling in the EFB heap areas was carried out to investigate the effects of the 10 years application of EFB on the soil properties up to 1 m depth. At the time of sampling, the EFB had completely decomposed.

Four EFB heap sites were randomly selected from each treatment plot for soil sampling. Soil sampling was done with an auger at depths of 0–20, 20–40, 40–60, 60–80 and 80–100 cm. In each treatment plot, samples were taken from three auger points per EFB heap site at the various depths. Altogether, a total of 12 subsamples (3 auger points ×4 heap sites) from each depth per treatment plot were mixed to form one composite sample. In the CHEM plots, the same numbers of subsamples were taken to form a composite sample but they were taken randomly from the area between 4 palms. A portion of the fresh topsoil (0–20 cm) sample was extracted for mineral N analysis and the rest was air dried and sieved through 2 mm mesh for determination of soil chemical characteristics.

Plate 1 Oil palm empty fruit bunches (EFB) applied in a heap in the middle between 4 oil palms in an EFB treatment plot

Table 1 Chemical fertilizer rates applied in the treatment plots with chemical fertilizers (CHEM) from 1982 to 1991

Fertilizer	N (kg ha^{-1} year^{-1})	P (kg ha^{-1} year^{-1})	K (kg ha^{-1} year^{-1})	Mg (kg ha^{-1} year^{-1})
1982	204	44	276	43
1983	204	44	276	43
1984	222	44	257	30
1985	185	44	295	30
1986	185	33	295	36
1987	185	33	295	36
1988	185	33	295	36
1989	207	33	295	36
1990	167	33	295	36
1991	171	33	295	36

Soil pH was measured with a pH meter using soil to distilled water ratio of 1:2.5. Exchangeable aluminium or KCl-extractable Al was determined by the aluminon method using 5 g of soil and 50 ml 1 M KCl as an extractant (Barnhisel and Bertsch 1982). The ammonium acetate at pH 7 method was used to determine the soil cation exchange capacity (CEC) (Anderson and Ingram 1993). In the same analysis, the concentration of exchangeable K^+ in the leachate was determined by flame photometer and exchangeable Ca^{2+} and Mg^{2+} concentrations by atomic absorption spectrophotometer. The Walkley and Black procedure was used for the determination of organic C (Nelson and Somners 1982). Total N was determined by the micro Kjeldahl method (Bremner and Mulvaney 1982) and an autoanalyzer, and mineralizable N was measured according to the short term incubation method (Anderson and Ingram 1993), incubated for 2 weeks under anaerobic condition at 40°C and extracted with 1:5 ratio of soil to 2 M KCl and followed by micro-Kjeldahl digestion to determine the amount of NH_4^+–N liberated. Inorganic N (NH_4^+–N and NO_3^-–N + NO_2^-–N) was also determined by extracting 10 g soil with 2 M KCl (1:4 ratio). Distillation of the extract with magnesium oxide was used to determine NH_4^+–N and Devarda's alloy to determine NO_3^-–N + NO_2^-–N (Keeney and Nelson 1982).

Annual yield data over the 10-year period (1983–1992) were obtained from the Oil Palm Research Station, Golden Hope Malaysia Sdn. Bhd., Banting, Selangor, now known as Sime Darby Research Sdn Bhd R and D Centre.

Statistical analysis

Statistical analysis was done using the Statistical Analysis System (SAS) package. Analysis of variance and mean comparison between treatments at various depths was determined using Duncan's Multiple Range Test and Pearson's Correlation Coefficient analysis was used to determine correlation between the soil chemical properties.

Results and discussion

Yield response

The mean yield produced over the 10 years period ranged from 25.2 to 27.9 tonne FFB ha^{-1}. Statistical analysis of the annual yield data collected over the 10 years period of 1983–1992 shows that there was no significant difference between the treatments CHEM and EFB150. The mean yield of EFB300 was significantly higher than EFB150 but only by about 9.0%. This means that EFB applied alone as a nutrient source at 150 kg $palm^{-1}$ $year^{-1}$ was sufficient to produce the same yield as chemical fertilization.

Effects of EFB application on soil chemical characteristics

Figure 1a–d shows concentrations of the SOC, total N, pH and exchangeable Al in the different soil layers after 10 years of chemical fertilizer and EFB application. There was a significant increase ($P = 0.01$) in soil organic carbon (SOC) in the topsoil with EFB application. In the sub-soils, organic C had also increased significantly ($P = 0.01$) but only with the application of EFB300. The EFB had been reported to decompose rapidly with 50% loss of dry matter weight in 7–15 weeks (Rosenani and Hoe 1996; Rosenani et al. 1996; Rosenani and Wingkis 1999; Lim and Zaharah 2000). Although lignin content of EFB is quite high (25–30%, dry weight basis), total decomposition of EFB in the oil palm field occurs in less than 12 months (Rosenani and Wingkis 1999; Lim and Zaharah 2000). The rapid decomposition is probably because the EFB had undergone a steaming process in the mill to remove the fruitlets. Continuous application of EFB over the 10 years period, particularly with EFB300, obviously had contributed to the significant increase in SOC in the top 0–40 cm layer of this well-drained sandy clay soil compared to soil without EFB application. Burket and Dick (1997), in their review paper on long-term vegetation management in relation to accumulation of C and N, stated that within a certain climate, the amount of SOC that accumulates in aerobic agricultural soils seems to be related more with the amount of C rather than the type of organic residue.

The application of EFB also resulted in significant increase in pH of the topsoil and sub-soils when compared to chemical fertilization (Fig. 1c). Cumulative additions of EFB at 300 kg $palm^{-1}$ $year^{-1}$ increased significantly ($P = 0.01$) the soil pH by about two units; a one unit pH increase was found with the lower EFB rate (EFB150). Although decomposition is generally slower in the very acid soils resulting in only a small difference in pH values, the EFB in this study resulted in significant increase in the soil pH. Soil pH has been shown to increase even after 15 weeks of EFB application, together with increases in exchangeable Ca, Mg and K in the soil (Rosenani et al. 1996; Rosenani and Wingkis 1999). Several processes had been suggested to account for the increase in soil pH by addition of organic materials or plant residues. Noble et al. (1996); Yan and Schubert (2000) and Mokolobate and Haynes (2002) suggested that the ash alkalinity (organic anion content) affects the pH of the soil. However, other workers (Pocknee and Sumner 1997; Tang and Yu 1999; Marschner and Noble 2000; Xu and Coventry, 2003; Li et al. 2008) attributed the increase in soil pH with addition of plant materials to mineralisation of basic-cation-containing compounds. The potassium content of EFB is particularly high and this may be the cause in the increase in pH.

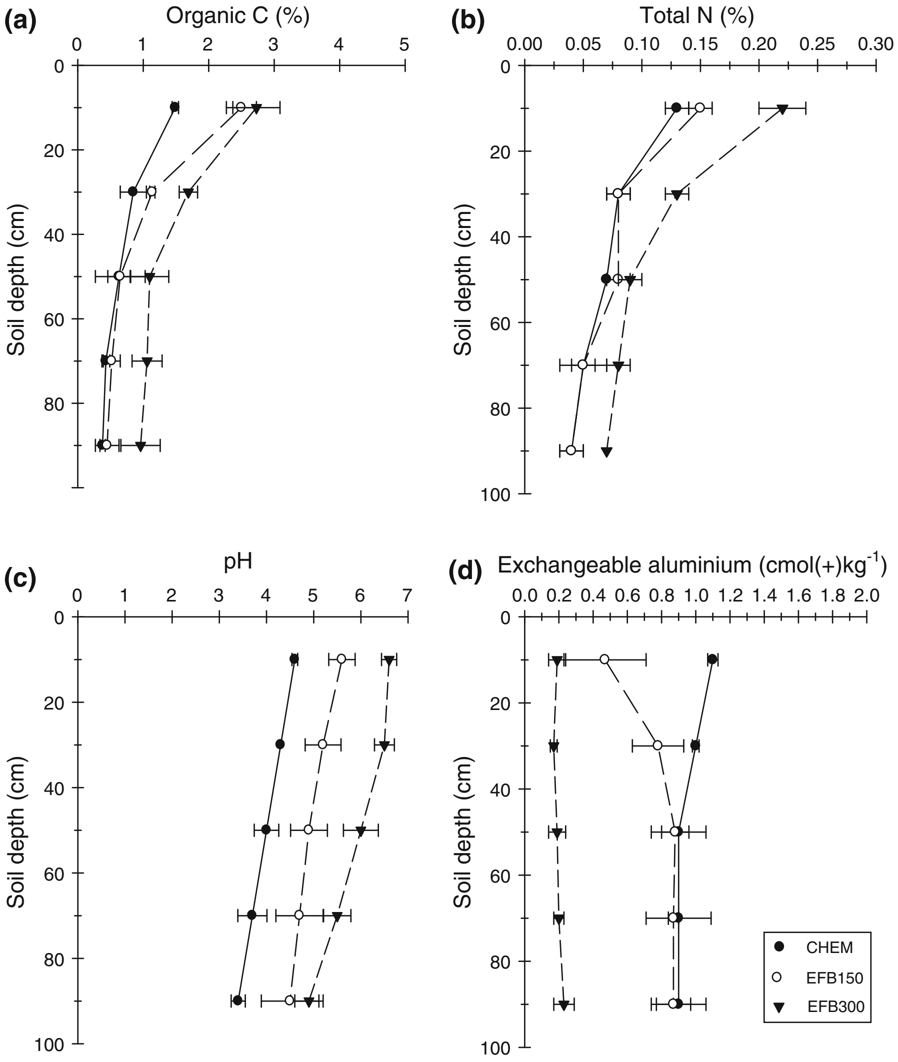

Fig. 1 Organic C (%) (**a**), total N (%) (**b**), soil pH (**c**) and exchangeable Al (cmol(+)kg^{-1}) (**d**) in 0–100 cm soil profile after 10 years application of chemical fertilizers (CHEM), 150 kg EFB palm^{-1} year^{-1} (EFB150) and 300 kg EFB palm^{-1} year^{-1} (EFB300). *Horizontal bars* indicate standard deviation

Exchangeable Al values were predominantly higher in the 0–20 cm soil depth of the CHEM plots than the plots with EFB (Fig. 1d). Application with 150 kg EFB palm^{-1} year^{-1} had resulted in a decrease in exchangeable Al concentration only in the topsoil layer. However, the higher rate EFB300 resulted in significantly ($P = 0.01$) lower exchangeable Al concentrations than the other treatments up to the 1 m soil depth. Pypers et al. (2004) also reported a decrease in salt extractable Al (exchangeable Al) in soil applied with organic amendments. They attributed this to substitution with excess cations and precipitation reactions due to pH increase. Another possible mechanism is complexation reaction with organic compounds (Hoyt and Turner 1975; Hue et al. 1986; Hue 1992). However, the lower rate EFB150 was not sufficient to reduce exchangeable Al in the subsoil.

Application of EFB over the 10 year-period also increased significantly the total N content in the 0–40 cm soil layer in the EFB300 plots (Fig. 1b). No significant difference in total N in the soil profile was observed between the CHEM and EFB150 plots. Other studies also showed an increase in total N content of the soil applied with EFB at only 317 days of application (Rosenani and Wingkis 1999) and with application of oil palm residues such as frond and chipped or shredded trunk at replanting (Khalid et al.

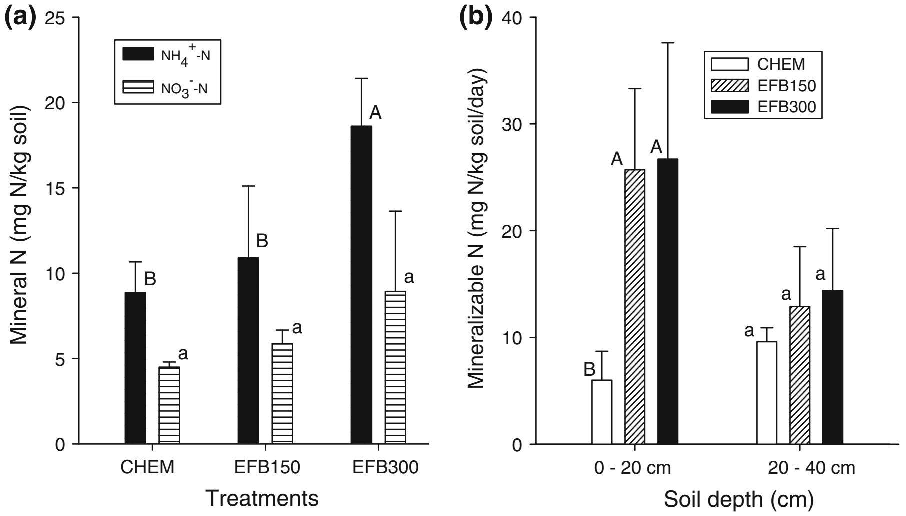

Fig. 2 Mineral nitrogen in 0–20 cm soil layer (**a**) and mineralizable nitrogen in 0–20 and 0–40 cm soil layers, (**b**) as influenced by 10 years application of chemical fertilizers (CHEM), 150 kg EFB palm^{-1} year^{-1} (EFB150) and 300 kg EFB palm^{-1} year^{-1} (EFB300). *Horizontal bars* indicate standard deviation. Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test

1999). Burket and Dick (1997), in their review paper stated that the net stabilization input N is likely to be controlled by soil type and climate. Figure 2a shows the concentrations of mineral N present in the topsoils (0–20 cm) which were quite low; most probably due to plant uptake and leaching. However, the concentration of NH_4^+–N was found to be highest in the topsoil of EFB300. Mineralizable N in the top 20 cm layer soils with EFB applications were significantly higher than in the CHEM soil but not significantly different in the subsoil (Fig. 2b).

Figure 3a shows the effects of long-term EFB application on the cation exchange capacity (CEC) and exchangeable cations of the soil. The soils with EFB application exhibited an overall significant increase ($P = 0.01$) in the CEC throughout the 1 m soil profile. A correlation-coefficient analysis carried out in this study implicated a strong positive relationship between the CEC and SOC (Table 2). According to van Raij and Peech (1972), organic matter or more specifically, humus, is the main component responsible for negative charge development in soils with variable cha. At the same time the CEC seemed to be also correlated to the pH. The CEC in the 0–20 cm topsoil of CHEM was about 8.2 cmol(+)kg^{-1} soil. With the addition of EFB150 and EFB300 over the 10 years period, the pH increased to 5.5 and 6.5 and the CEC increased to 11.0 and 13.3 cmol(+)kg^{-1}, respectively. This may indicate a dependence of the CEC on pH variations which was also demonstrated in a study by Dynia and Camargo (1998), when they investigated the effects of liming and green manuring and phosphate addition for an Oxisol soil from Central Brazil.

There was also an obvious positive long-termed effect of EFB application on the exchangeable cations in the soil profile. Exchangeable K increased from 0.08–0.10 cmol(+)kg^{-1} in the CHEM topsoil to 0.6–1.06 cmol(+)kg^{-1} in the EFB150 topsoil and 1.29–1.18 cmol(+)kg^{-1} in the EFB300 topsoil (Fig. 3b). The concentrations of exchangeable K in the lower depths were quite high, indicating movement of K^+ in the soil profile which was not observed with the exchangeable Ca and Mg (Fig. 3c, d). Although K is easily leached through the soil profile, EFB is rich in K and continuous application of EFB could result in K accumulation in the soil due to increased CEC, as indicated in this study. Substantial accumulation of exchangeable Ca and Mg in the topsoil (Fig. 3c, d) was observed compared to the subsoil, implicating stronger adsorption of these cations than K in the topsoil which also had higher CEC and organic matter. Table 2 also shows that there were positive correlations between these

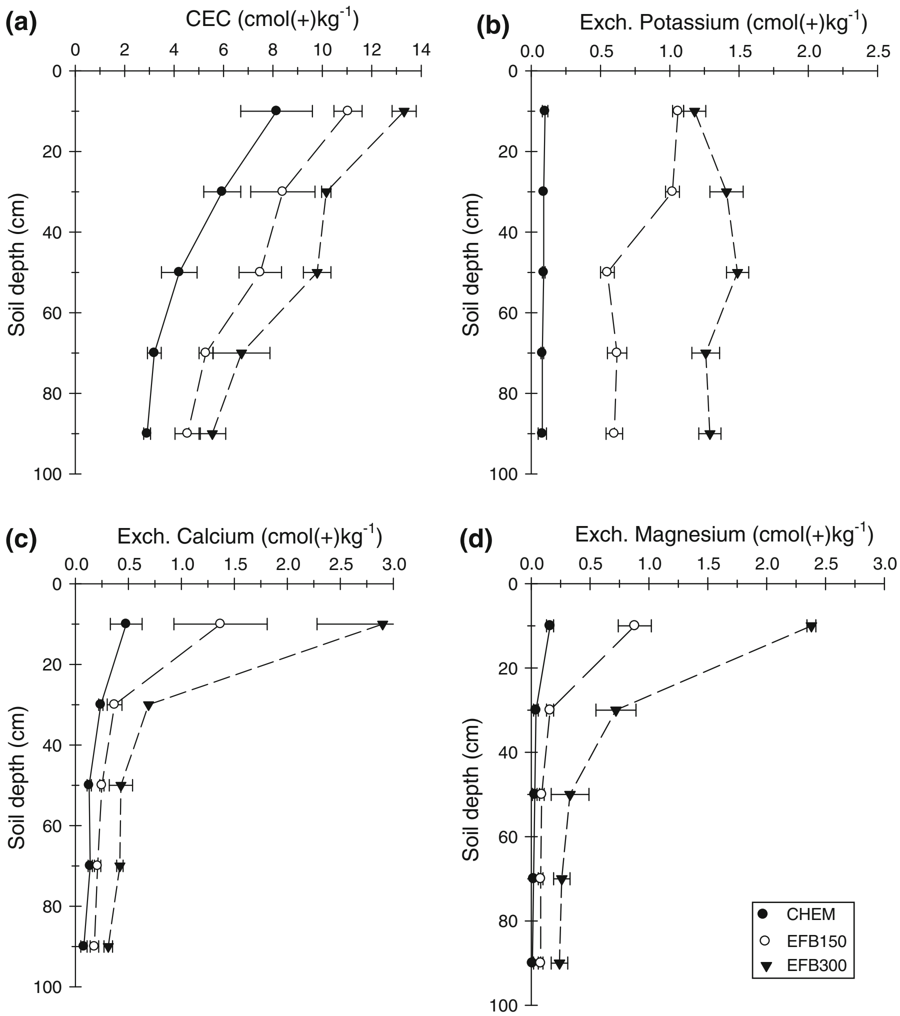

Fig. 3 Cation exchange capacity (**a**) and exchangeable bases (**b**, **c**, and **d**) in 0–100 cm soil profile after 10 years application of chemical fertilizers (CHEM), 150 kg EFB palm^{-1} year^{-1} (EFB150) and 300 kg EFB palm^{-1} year^{-1} (EFB300). *Horizontal bars* indicate standard deviation

exchangeable cations and CEC and between these cations and SOC (Table 2). Khalid et al. (1999), had also reported improvement of total N, CEC and exchangeable K, Ca and Mg in soils that had received application of oil palm residues (shredded or pulverised trunk and frond), after felling of old palms for replanting over a period of only 36 months.

A study with ^{32}P isotope (Zaharah et al. 1989) showed that roots of oil palm grow out radially and laterally to up to 36 m and may absorb nutrients for the entire soil area between the palms. So, although the EFB heap sites cover a small percentage of the soil surface area between the palms, the feeder roots could grow well and absorb nutrients in these areas due to enhanced fertility of the soil with EFB.

We conclude that applying EFB as a mulch and nutrient source in the oil palm field near the palm oil mill is a good and practical alternative method for the disposal and management of the palm oil waste. The application of EFB improves soil fertility and sustains crop production in the long-term. However, the amount of the EFB produced by the mill is only sufficient for application to only 20–25% of the oil palm area around the mill. In practice, the planter may apply the lower rate of EFB over a bigger palm area and reduce fertilizer cost while maintaining the FFB yield or apply the higher rate over a smaller area nearer the mill to reduce transportation cost and produce a slightly higher yield.

Table 2 Correlation coefficient (R) between soil chemical properties in 0–100 cm soil depth after 10 years of yearly application of chemical fertilizers and EFBs

	pH	Exch. Al (cmol (+) kg^{-1})	CEC (cmol (+) kg^{-1})	Exch. K (cmol (+) kg^{-1})	SOC (%)	TN (%)	Exch. Ca (cmol (+) kg^{-1})	Exch. Mg (cmol (+) kg^{-1})
pH								
Exch. Al (cmol (+) kg^{-1})	−0.80***							
CEC (cmol (+) kg^{-1})	0.89***	−0.58*						
Exch. K (cmol (+) kg^{-1})	0.83***	−0.91***	0.62*					
SOC (%)	0.74**	0.54*	0.90***	0.51*				
TN (%)	0.72**	−0.47 ns	0.90***	0.40 ns	0.95***			
Exch. Ca (cmol (+) kg^{-1})	0.67**	−0.50 ns	0.81***	0.41 ns	0.88***	0.91***		
Exch. Mg (cmol (+) kg^{-1})	0.72**	−0.57*	0.80***	0.47 ns	0.85***	0.89***	0.98***	

Significance levels are * 0.05, ** 0.01, *** 0.001, respectively, *ns* not significant

Exch. exchangeable, *CEC* cation exchange capacity, *SOC* soil organic carbon, *TN* total nitrogen

All data obtained from the three treatments in this study were used for this analysis

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