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Effect of four soil and water conservation practices on soil physical processes in a non-terraced oil palm plantation

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ABSTRACT

Mulching materials from oil palm residues such as pruned palm fronds (OPF), empty fruit bunches (EFB), and Eco-mat (ECO; a compressed EFB mat) are often the recommended soil and water conservation practices (CP) for oil palm plantations on hill slopes. Another recommended CP is the construction of silt pits or trenches (SIL) across the hill slope to capture runoff and then return the water and nutrients into the surrounding soil. Although these four CP are recommended practices, their relative effects on improving soil physical properties and on increasing the soil water content have never been compared with one another. Consequently, the objective of this study was to fill in this knowledge gap. A three-year field experiment was conducted in a non-terraced oil palm plantation, and soil samples from 0 to 0.15, 0.15 to 0.30, and 0.30 to 0.45 m depths were collected every three months and analyzed for their soil physical properties. Soil water content up to 0.75 m depth was also measured daily. EFB released the highest amount of organic matter and nutrients into the soil compared to OPF, ECO, and SIL. Hence, EFB was most effective to increase soil aggregation, aggregate stability, soil water retention at field capacity, available soil water content, and the relative proportion of soil mesopores. Due to these improved soil physical properties, EFB also gave the highest soil water content. Unlike ECO that concentrated more water in the upper soil layers, EFB distributed the soil water more uniformly throughout the whole soil profile, but SIL concentrated more soil water in the lower soil layers (>0.30 m) because the water levels in the pits were often below 0.30 m from the soil surface. The large opening area of the silt pits could have also caused large evaporative water losses from the pits. EFB mulching is recommended as the best CP, particularly for oil palm plantations on hill slopes.

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is the world's highest yielding oil crop, producing nearly 5 t ha^{-1} of oil per year which is 13, 8, and 7 times more than the oil produced from soybean, sunflower, and rapeseed, respectively (Chang, 2014). Palm oil accounts for 33% of the world's vegetable oil and 45% of edible oil production worldwide. Moreover, palm oil is the world's largest source for cooking oil and biodiesel (Tye et al., 2011).

Oil palm is a tropical crop, and it is planted in 43 countries over a total land area of 16.4 million ha (FAO, 2014). Malaysia is the second largest palm oil producer, after Indonesia and the area under oil palm in Malaysia has expanded rapidly from 55,000 ha in 1960 to 5.23 million ha in 2013 (equivalent to 16% of Malaysia's total land area) (MPOB, 2013). However, due to limited arable land, new oil palm plantations in some countries such as Malaysia and Indonesia have expanded into marginal land areas such as hill slopes (Moradi et al., 2012; Witt et al., 2005). But hill slopes face high risks of surface runoff and soil erosion which degrade soil physical and chemical properties (Abu Bakar et al., 2011; Teh et al., 2011) and ultimately, lower soil fertility. Degraded soil properties may also cause flooding, sedimentation, and reduction in water supply and quality (Nkonya et al., 2008; Stocking, 2001; Troeh et al., 2004).

Despite the high annual rainfall in the tropics, periodic water stress still occurs in oil palm plantations as a result of uneven rainfall distribution and high atmospheric evaporation demand on the crop due to high air temperatures (Arif et al., 2003). The use of irrigation has shown little promise due to its high installation and maintenance costs (Arif et al., 2003). Therefore,

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proper soil and water conservation practices are needed to increase or conserve soil water, thereby, lowering the risk of water stress and also to reduce soil erosion and maintain soil productivity.

Organic mulching is one effective and established way to conserve soil and water. Utilization of oil palm residues such as pruned oil palm fronds (OPF) and empty fruit bunches (EFB) as a mulching material is a common conservation practice in oil palm plantations especially on non-terraced hill slopes (Anderson, 2008; Moradidalini et al., 2011). The popularity of using oil palm residues as mulching materials is because oil palm produces large amounts of biomass that have to be reused to avoid large amounts of wastes. 96% of oil palm's total annual dry matter production is stored in its above ground biomass (trunk, fronds, and bunches) (Corley and Tinker, 2003), and for every ton of palm oil produced from a fresh fruit bunch, approximately 1 t of EFB, 0.7 t of palm fibers, 0.3 t of palm kernels, and 0.3 t of palm shells are generated, which amounts to a total oil palm biomass of 2.3 t. In 2012, for instance, Malaysia's palm oil industry produced 43 million tons of biomass (Chang, 2014).

Oil palm residues like OPF and EFB contain essential plant nutrients that can be released into the soil during their decomposition, and they also provide organic matter which is a key factor to improve many soil properties. The beneficial effects of EFB and, to a much lesser extent, pruned OPF on soil chemical properties have been well reported. Their application as a mulch has shown to increase many soil chemical properties such as pH, exchangeable K, Ca and Mg, CEC, organic C, total N, and available P (Budianta et al., 2010; Kheong et al., 2010; Lim and Zaharah, 2002; Ortiz et al., 1992; Rosenani and Wingkis, 1999; Zaharah and Lim, 2000; Zolkifli and Tarmizi, 2010). EFB mulching has also led to higher oil palm vegetative growth and yield (Chan et al., 1980; Hamdan et al., 1998; Ortiz et al., 1992) and higher oil palm leaf K and N levels (Lim and Zaharah, 2002).

Nevertheless, one major disadvantage of EFB is it is bulky; thereby, making its storage, transportation, and field application cumbersome and expensive. One recent method to reduce EFB's bulkiness is to comb out the EFB's fibers and compress them into a carpet-like material known as Eco-mat (ECO) (Yeo, 2007). ECO has been shown to increase the vegetative growth of young oil palm trees by 5–14% and their N, P, and K uptake by 10–24% (Khalid and Tarmizi, 2008; MPOB, 2003). ECO has also helped to increase soil water content by 17% and 9% in the 0–200 mm and 200–400 mm soil depth, respectively (Xin-Fu, 2004) and by 44% in the 0–200 mm depth (Liu et al., 2005).

Another common soil and water conservation practice in oil palm plantations is the construction of silt pits (SIL) (Lim, 1989; Soon and Hoong, 2002). SIL are long and wide soil trenches (normally 3–6 m long and 0.5–1 m wide; Lim, 1989; Moradidalini et al., 2011; Soon and Hoong, 2002), and they are usually constructed between planting rows and perpendicular to the hill slope direction. The purpose of SIL is to collect runoff water which contains eroded sediments and nutrients which would otherwise be lost from the field. The collected water and nutrients are then redistributed back into the plant root zone around the pits after the rainfall event. SIL have been shown to be beneficial in several ways such as increasing the forage and oil palm yield by 100% (Schuster, 1996) and 13% (Murtilaksono et al., 2009), respectively; increasing the amount of soil water by 43% (Jahantigh and Pessarakli, 2009); reducing surface runoff by 10–18% (Hickey and Dortignac, 1963) and 23% (Soon and Hoong, 2002); and reducing soil loss by 3 t ha^{-1} (Lim, 1989), 0.52 t ha^{-1} (Soon and Hoong, 2002), and 5–14 t ha^{-1} (George et al., 2003).

Favorable effects of EFB, but to a much lesser extent for pruned OPF, ECO, and SIL, on various soil chemical properties have been well documented by studies conducted in different countries such as in Malaysia (Abu Bakar et al., 2011; Khalid and Tarmizi, 2008; Lee et al., 2012; Lim and Zaharah, 2002; Moradi et al., 2012; Soon and Hoong, 2002); in Costa Rica (Ortiz et al., 1992); in Indonesia (Budianta et al., 2010); in Thailand (Jantaraniyom et al., 2001); and in India (George et al., 2003). However, their effects on the soil physical properties and water conservation, especially on non-terraced hill slopes, have received less attention. Furthermore, there is no single study, to our knowledge, that compares the relative effects of these four recommended soil and water conservation methods on the soil physical properties and on increasing soil water content. Therefore, the objective of this work was to compare the relative effects of these four soil and water conservation practices (OPF, EFB, ECO, and SIL) on the soil physical properties and soil water content in a non-terraced oil palm plantation. Results from this study would be applicable to countries where oil palm is planted in particular for oil palm planted on hill slopes. As stated earlier, oil palm produces large amounts of biomass that needs to be reused. This study would help to determine the benefits of using these oil palm residues (OPF, EFB, and ECO), as well as to compare their benefits with SIL which is not a mulching material.

2. Materials and methods

2.1. Site description and experimental design

A field experiment was conducted in the Balau Estate oil palm plantation (2.9325° N and 101.8822° E), Semenyih, Selangor, Malaysia for three years from December 2007 until September 2010. In the first two years, the effects of four soil and water conservation practices on the soil physical properties and soil water content were evaluated. In the third year, nutrient release from the mulching materials during their decomposition in the field was measured. Results from the third year work were used to explain the results obtained in the first two years. The area was cultivated with eight-year old oil palm (*Elaeis guineensis* Jacq.) trees in a 8 by 8-m triangular spacing on a hill slope of 6°. Average annual rainfall in the area was 2105 mm for the year 2008 and 2009. Daily mean air temperature in the area was 26.9 °C. The soil of the experimental area is classified as a Typic Paleudult (Rengam series) which has a sandy clay loam texture in the topsoil (0–0.15 m depth) and sandy clay in the subsoil layers (0.15–0.30 and 0.30–0.45 m) (Table 1).

Table 1
Initial soil properties at the experimental site.

						Particle size (μm)		
						<2	2–50	>50
Soil depth (m)	pH	EC dsm^{-1}	CEC cmol (+) kg^{-1}	OC g (100 g)$^{-1}$	BD Mg m^{-3}	Clay g (100 g)$^{-1}$	Silt g (100 g)$^{-1}$	Sand g (100 g)$^{-1}$
0.0–0.15	4.79	1.11	7.29	2.65	1.37	28.9	12.6	58.5
0.15–0.30	4.78	0.93	8.33	1.75	1.49	44.1	7.7	48.1
0.30–0.45	4.48	0.84	7.88	1.51	1.40	28.3	7.8	63.8

EC: electrical conductivity; CEC: cation exchange capacity; OC: organic carbon; and BD: bulk density.