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Effects of soil management practices on soil fauna feeding activity in an Indonesian oil palm plantation

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ABSTRACT

Optimizing the use of available soil management practices in oil palm plantations is crucial to enhance long-term soil fertility and productivity. However, this needs a thorough understanding of the functional responses of soil biota to these management practices. To address this knowledge gap, we used the bait lamina method to investigate the effects of different soil management practices on soil fauna feeding activity, and whether feeding activity was associated with management-mediated changes in soil chemical properties, in a 15-year-old oil palm plantation. We examined the four management zones: (1) empty fruit bunch (EFB) application along the sides of harvesting paths; (2) chemical fertilization within palm circles; (3) understory vegetation with pruned fronds in inter-row areas; (4) no input in the cleared part of the harvesting paths. Our results showed significantly higher soil fauna feeding activity under the EFB application compared to other management practices, and this was associated with improved soil chemical properties and soil moisture conditions. Principal component analysis on soil properties indicated that 71.2% of variance was explained by the first two principal components (PCs). Soil pH, base saturation and soil moisture contributed positively to PC1, while exchangeable aluminum and hydrogen contributed negatively to PC1. The results demonstrate that different soil management practices at the tree-scale have the ability to create spatial complexity in soil fauna feeding activity and soil chemical properties. This suggests that the practice of EFB application plays an important role in enhancing soil ecosystem functioning in oil palm plantations, which may ultimately contribute to sustainable palm oil production.

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1. Introduction

Palm oil is one of the most widely used vegetable oils, with an increasing demand for use in food products, cosmetics, and as a biodiesel feedstock (FAO, 2015; Mukherjee and Sovacool, 2014). Over the past few decades, oil palm plantations have expanded rapidly (Gilbert, 2012). Future projections predict that the expansion will continue in response to increased demand based on global population growth, with further developments in Africa and Latin America (Sayer et al., 2012). The land-use changes associated with the expansion of oil palm cultivation have resulted in the loss of natural vegetation and ecosystem degradation (Foster et al., 2011). This expansion has seen soil ecosystems decline in soil fertility, increase in erosion, and suffer from a loss of soil biodiversity (Comte et al., 2012; Savilaakso et al., 2014). These conditions may be mitigated by optimizing soil management practices within oil palm plantations (Guillaume et al., 2015); however, the effects of these practices on soil ecosystem processes and soil properties are largely unknown.

The spatial arrangements of oil palm planting and the different management practices, which are designed primarily for

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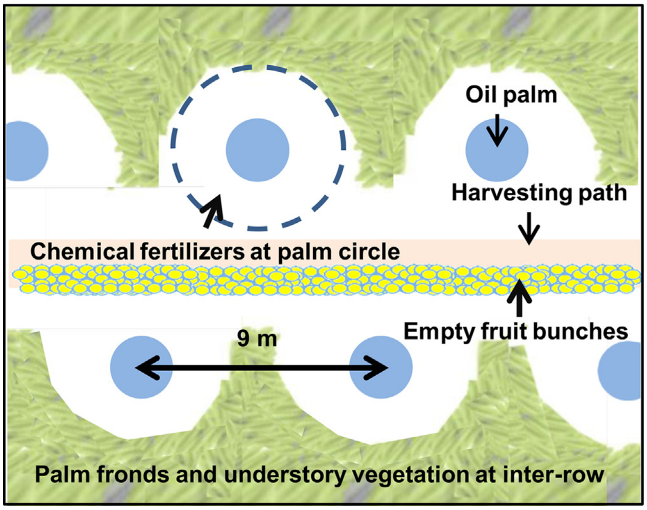

Fig. 1. The layout of an oil palm plantation. Harvesting paths and areas of understory vegetation are in alternate inter-rows. Palm trees are planted in triangular spacing, approximately 9 m apart. The trunks are surrounded by cleared weed-free circles where chemical fertilizers are applied. Empty fruit bunches are applied along one side of harvesting paths.

fertilization and plantation maintenance, create distinct management zones within plantations. This gives rise to spatial heterogeneity in the chemical and physical properties of the soil and variability in microhabitats at the tree scale (Fig. 1). The cleared harvesting paths are used for agriculture-related traffic, resulting in tracks of largely bare soil. In the alternate inter-row areas, understory vegetation is allowed to grow and pruned palm fronds are added regularly to prevent soil erosion and to return organic matter to the soil (Frazão et al., 2013). The palm circle, a weed-free area surrounding each palm with a radius of approximately 2 m, is where chemical fertilizers are applied and provides access for harvesting. A common practice is to apply residues from the palm oil mill, namely empty fruit bunches (EFB), along the sides of harvesting paths (Carron et al., 2015b). The EFB is a wet, cellulose-rich oil palm mill residue that is used as an organic fertilizer and mulch substrate.

The decomposition of crop residues is facilitated by decomposer microorganisms and soil animals. These nutrient mineralization processes are crucial for ecosystem functions and services in agricultural ecosystems, including soil carbon stabilization, nutrient cycling and primary productivity (Hättenschwiler et al., 2005). In oil palm ecosystems, a specific termite species, *Macrotermes gilvas*, is reported as the major litter-dwelling fauna for leaf litter decomposition in Malaysian oil palm plantations (Foster et al., 2011). Other studies reported that the abundance and diversity of soil microorganisms and soil-dwelling fauna such as earthworms, beetles, and earwigs are increased by crop residue application, suggesting a functional role for these organisms in organic matter decomposition (Carron et al., 2015a,b; Situmorang et al., 2014). However, despite an increase in the number of studies of soil fauna within the oil palm ecosystem in the past decade, the functionality of soil-dwelling organisms in litter decomposition remains understudied.

The composition and activity of soil fauna both reflect and are influenced by the availability of nutrients and chemical properties of the soil, such as acidity, cation concentrations and moisture (Lavelle et al., 2006; Ponge, 2013). Soil management practices such as EFB application in oil palm plantations have been shown to increase the soil's organic carbon, nutrient contents and pH (Comte et al., 2013), and these changes are also related to soil macrofauna abundance (Carron et al., 2015b). Further examination of how soil fauna activity responds to changes in soil chemical properties under different management practices is crucial to understand the mechanisms underlying soil management practices and their effects on the functionality of soil fauna.

In this study, we compared four management practices to examine their effects on soil fauna feeding activity and soil chemical properties: (1) empty fruit bunch, (2) chemical fertilization, (3) understory vegetation with pruned fronds and (4) no input. Specifically, we asked: do different soil management practices in oil palm plantations affect soil fauna feeding activity? And do different soil chemical and environmental conditions under these management practices explain soil fauna feeding activity? We hypothesized that EFB and palm frond application would provide favorable conditions (e.g., higher soil nutrient pools and soil moisture conditions) to increase soil fauna activity compared to other management practices.

2. Material and methods

2.1. Site description

The study was carried out on a Roundtable on Sustainable Palm Oil (RSPO)-certified oil palm plantation (0° 32′26.50″ N 101°04′19.80″E) in Riau Province, Sumatra, Indonesia (Supplementary S1). The plantation was established in 1998 and the oil palm trees were 15 years old at the time of sampling. The density of palm trees was approximately 143 palms per ha, planted in staggered lines with palms at the points of a 9 m equilateral triangle. The climate of this region is described as tropical humid, with an average rainfall of 2350 mm/year (226 mm/month during October–March, 166 mm/month during April–September), and the average

Table 1
Application rates of aboveground inputs, the equivalent amount of nutrients applied, and time since the last application of each management practice.

Management practice	Management zone	Aboveground input	Application rate (kg tree^{-1} yr^{-1})	Nutrient application rate (kg tree^{-1} yr^{-1})					Time since the last application (month)
				N	P	K	Mg	Ca	
Empty fruit bunch (EFB)	One side of harvesting path	EFB[a]	210	0.57	0.06	0.17	0.11	0.11	12
		Rock phosphate[a]	0.75	0	0.15	0	0	0	12
Palm frond	Inter-row	Palm frond[c]	237	0.57	0.05	0.71	0.08	0	1
Chemical fertilizer	Within palm circle	Urea[a]	0.50	0.23	0	0	0	0	24
		Kieserite/ dolomite[b]	0.50	0	0	0	0.06	0.10	4
No input	Cleared part of harvesting path	None	–	–	–	–	–	–	–

[a] Mean annual application rate of EFB, rock phosphate and urea. They were applied every 2 years.
[b] Mean annual application rate of kieserite or dolomite. They were applied once or twice per year.
[c] Estimated mean annual application rate of palm frond and its nutrient composition after (Moradi et al., 2014).

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