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Research paper

Effects of best management practices on dry matter production and fruit production efficiency of oil palm

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ABSTRACT

Enhancing dry matter production with higher partitioning to fruit bunches is important for sustainable intensification of oil palm. A series of best management practices including site-specific nutrient management, canopy management, and harvesting has been developed for oil palm plantations. However, the effects of these practices on dry matter production and partitioning, and how the effects vary with climatic and soil conditions of plantation sites, remain largely unknown. We established a four-year field trial including 30 paired commercial blocks across Sumatra and Kalimantan, Indonesia. The paired treatments included site-specific best management practices, and standard estate practices as the control. The annual production of aboveground dry matter was 30.0 ± 0.5 t ha^{-1} yr^{-1} (mean ± se) under best management practices, higher than 28.8 ± 0.5 t ha^{-1} yr^{-1} under standard estate practices. The bunch index, an indicator of the fruit production efficiency, increased by 12% under best management practices compared to standard estate practices. Partitioning of dry matter to the fronds decreased by 8% under best management practices, compared to standard estate practices. The positive effect of best management practices on the annual production of total aboveground dry matter was stronger in the plantation site with higher annual rainfall. These results are useful for optimizing management practices to improve sustainable intensification of oil palm.

1. Introduction

Oil palm (*Elaeis guineensis*) is one of the most important agricultural crops in the tropics. Palm oil and palm kernel oil extracted from fresh fruit bunches accounted for 36% of the global vegetable oil production (FAO, 2015). The area of oil palm plantations is more than 16 million ha, with more than half located in Malaysia and Indonesia (FAO, 2015; Sayer et al., 2012). Land conversion as well as sub-optimal management practices in plantations can result in negative environmental impacts. For example, loss of natural vegetation, reduction in biodiversity, water pollution, and greenhouse gas emissions are critical issues in many oil palm plantations today (Dislich et al., 2016). Implementing management practices that enhance oil palm growth and productivity while minimizing negative environmental impacts is important for sustainable intensification of oil palm (Sayer et al., 2012; Tilman et al., 2011). A series of best management practices (BMP) guidelines has been developed to intensify the oil palm production through a range of agronomic practices, including nutrient management, suitable drainage, optimal canopy management and harvesting schemes (Donough et al., 2009; Fairhurst and Griffiths, 2014). The design and implementation of these practices are adapted to environmental conditions and soil fertility of each commercial estate (Oberthür et al., 2013).

Sustainable intensification of oil palm can be achieved by higher net dry matter production and higher partitioning assimilate into fruit bunches (Fairhurst and Griffiths, 2014). The ratio of fruit bunch weight partitioning to the total aboveground dry matter production, the bunch index (BI), is an indicator for fruit production efficiency (Corley et al., 1971a). Previous studies have shown that applying best management practices in commercial oil palm plantations influenced plant nutrition and fruit bunch production (Donough et al., 2009; Pasuquin et al.,

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2014). However, their effects on dry matter production and partitioning remain largely unknown. Furthermore, it is unclear whether the effects vary with site characteristics, such as climate, soil properties, and palm age (Ng, 1983; Squire and Corley, 1987; Tarmizi, 2000). This information is important to optimize best management practices of oil palm plantations under changing climate and different soil conditions.

To fill the research gaps, we investigated the effects of best management practices on the production and partitioning of aboveground dry matter, and the bunch index. We further examined whether the effects varied with site characteristics. We established a four-year field trial in commercial oil palm plantations at six study sites in Indonesia with a wide range of climates and soils. We compared dry matter production and partitioning under paired treatment blocks of best management practices and standard estate practices. We estimated the aboveground dry matter production (fruit bunch, frond, and trunk) using existing allometric relationships (Corley and Tinker, 2015; Fairhurst and Härdter, 2003). We then examined whether the effects of best management practices depended on key site factors, including soil organic carbon, palm age, and annual rainfall. We hypothesized that 1) oil palms under best management practices would have higher annual production of aboveground dry matter and bunch index, compared to the standard estate practices; and 2) the effects of best management practices on annual production of aboveground dry matter and bunch index would depend on climate and soil conditions of plantation sites.

2. Materials and methods

2.1. Study sites and experimental design

A four-year field trial was established at six study sites in commercial oil palm plantations across Sumatra and Kalimantan. Commercial blocks were used as the treatment unit. The area of a commercial block ranged from 25 to 55 ha. A total of 30 paired blocks with five pairs at each study site were selected. Each pair of blocks consisted of one block treated with best management practice, and one adjacent block treated with standard estate practice as the control. Each paired block had similar soil type and slope, and oil palms with the same age and variety. The location, climatic and soil conditions of the study sites are summarized in Table 1 (see also Pauli et al. (2014) for details). A range of agronomic practices for best management practices and standard estate practices were listed in Table 2 (see also Pauli et al. (2014) for detailed information). The nutrient inputs of nitrogen (N), phosphorus (P), and potassium (K) for both practices were detailed in Supplementary S1.

2.2. Field measurements and estimating dry matter production

Field measurements of vegetative growth parameters were conducted throughout the trial period. Depending on the size of the commercial block, 30–45 palms were selected as sampling palms, to account for 1% of the total number of palms in each block. Every tenth palm of every tenth row, excluding all abnormal palms and palms closest to the roadside, were selected as sampling palms. The annual production of fruit bunch, frond, and trunk dry matter were estimated using allometric relationships reported in Fairhurst and Härdter (2003) (Supplementary S2). The annual production of fruit bunch dry matter was estimated as 53% of the fresh fruit bunch weight (Corley and Tinker, 2015). The annual production of frond dry matter was estimated from the width and depth of frond petioles, and the number of new fronds produced each year. The petiole cross-section was measured from the 17th frond of the sampling palms. The annual new frond production was estimated by marking the first frond as a reference frond in the beginning of the trial, and calculating the order of reference frond at the end of each year. The annual production of trunk dry matter was estimated from the annual increment in trunk volume and trunk density. The trunk diameter was obtained at 1.5 m above ground level. The trunk height was measured each year from the base of a trunk to the marked frond. The annual increment of the trunk height was obtained by subtracting the trunk height from the prior year.

The annual production of total aboveground dry matter and the partitioning to fruit bunches, fronds, and trunk were calculated using formula below:

Annual production of total aboveground DM (t ha^{-1} yr^{-1})**:** Annual DM production of fruit bunches + fronds + trunks (1)

$$\text{Partitioning of annual DM production to fruit brunches(\%)} : \frac{\textit{Annual production of bunch DM}}{\textit{Annual production of total aboveground DM}} \times 100 \quad (2)$$

$$\text{Partitioning of annual DM production to fronds(\%)} : \frac{\textit{Annual production of frond DM}}{\textit{Annual production of total aboveground DM}} \times 100 \quad (3)$$

$$\text{Partitioning of annual DM production to trunks(\%)} : \frac{\textit{Annual production of trunk DM}}{\textit{Annual production of total aboveground DM}} \times 100 \quad (4)$$

where DM stands for dry matter. The bunch index is the partitioning of annual dry matter production to fruit bunches with the range from 0 to 1.

Two site characteristics were measured in this study: soil organic carbon and annual rainfall. The soil organic carbon concentration was measured at the start and the end of the trial. The soil samples were collected from palm circles and the frond stack area at soil depths of 0–20 cm and 20–40 cm for each sampling palm. The soil samples of the same soil depth and management zones were bulked to obtain soil organic carbon concentrations for each treatment block. The annual rainfall for each paired blocks was obtained from the nearest weather stations.

Table 1
Location, climate, and soil conditions of six study sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Location	North Sumatra	North Sumatra	South Sumatra	West Kalimantan	Central Kalimantan	East Kalimantan
Palm age [a]	5–12	8–14	14–17	8–9	8–9	4–13
Annual rainfall [b] (mm yr^{-1})	1705	3323	2413	3112	2099	3796
Annual temperature (∘C) [c]	26.7	26.4	27.1	26.6	26.8	26.6
Main soil texture	Sandy clay loam	Sandy loam clay	Clay	Fine sandy loam	coarse sandy loam	Clay loam
Soil organic carbon (%) [d]	0.7	1.9	1.5	2.0	2.4	0.5
Soil clay content (%) [e]	23.7	35.1	39.1	6.5	10.1	31.1

[a]The range of the oil palm age at the start of the field trial.
[bc]Referred to Pauli et al. (2014).
[de]Values were averaged from soils beneath the palm circles and frond stacks at the depths of 0–20 cm and 20–40 cm, measured in the beginning and at the end of the trial.