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Research article

# Input–output optimisation model for sustainable oil palm plantation development

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## ABSTRACT

Due to the increase in global demand for palm oil products, the oil palm industry has continued to expand in the past decades. Continuous production of fresh fruit bunches in oil palm plantation is essential to meet this growing demand. Meanwhile, the productivity of plantations is highly dependent on the supply of resources (e.g., water, fertilisers and sunlight) and on proper plantation management systems. The harvested fresh fruit bunches from oil palm plantations have to be immediately sent to palm oil mills to ensure the quality of the crude palm oil and crude palm kernel oil extracted. In this study, oil palm plantation operations are optimised using an input–output model to determine maximum yield with minimum plantation size and greenhouse gases emissions. Multiple scenarios can be incorporated in the model. To illustrate the proposed approach, a case study of an oil palm plantation supplying fresh fruit bunches for a 60 t/h capacity palm oil mill in Malaysia is presented. Various plantation management practices with different resources supply constraints are considered. Based on the optimised result, the sustainability of a plantation is greatly improved. The plantation area needed to meet the demand is reduced by 24% to meet the requirement of the palm oil mill by using combined organic and inorganic fertilisers. A significant drop in greenhouse gases emissions from 282.95 to 200.73 kt $CO_{2\ eq.}$/y can thus be achieved. This result implies that widespread use of such optimal practices can help meet growing global demand without the need to convert pristine ecosystems into new plantations.

## 1. Introduction

Oil palm (*Elaeis guineensis*) is a plant that originates from the tropical rain forest regions of West Africa, but was later introduced to the Americas, and from there to the Far East (Poku, 2002). Oil palm plantations and downstream processing industries developed rapidly in countries such as Indonesia, Malaysia, Nigeria, Thailand, etc. due to the crop's favourable properties as an agro-industrial commodity (Ekpa, 1995). Compared to other major oilseed crops in the world (i.e., rapeseed, sunflower and soybean), oil palm gives the highest oil yield per hectare of land (SimeDarby Plantation, 2014). According to Malaysian Palm Oil Council (2016), oil palm requires only 0.26 ha/t, which is an order of magnitude lower that land requirement for rapeseed, sunflower and soybean. To date, palm oil accounts for 65 Mt/y out of 215 Mt/y (30%) vegetable oil produced worldwide (R.E.A. Holdings PLC, 2018).

An oil palm tree can typically last for more than 25 years (Goh et al., 2009) before replanting is required due to declining productivity. Adequate yields can be guaranteed, provided that the trees are tolerate abiotic stressors (e.g., episodes of drought or haze) and free from diseases (e.g., brown germ, *Curvularia* leaf blight and *Ganoderma* basal stem rot) (Pornsuriya et al., 2013). As shown in Fig. 1, the growing cycle of an oil palm tree can be generally divided into four phases, starting with immature Phase I (0–3 years). This phase is also known as the nursery phase when the seedlings germinate (Ewulo et al., 2015). Typically, at the age of three, oil palm trees are transferred to the plantation to gradually acclimatise with new surroundings. Up to the age of seven to nine, oil palm trees are considered to be in the immature Phase II, during which the yield of fresh fruit bunches (FFB) increases in a roughly linear pattern. As the oil palm trees mature further, FFB yield peaks in years 7 to 18, which constitute Phase III (Wilmar International, 2018). After this stage, the aging oil palm trees enter Phase IV where FFB yield starts

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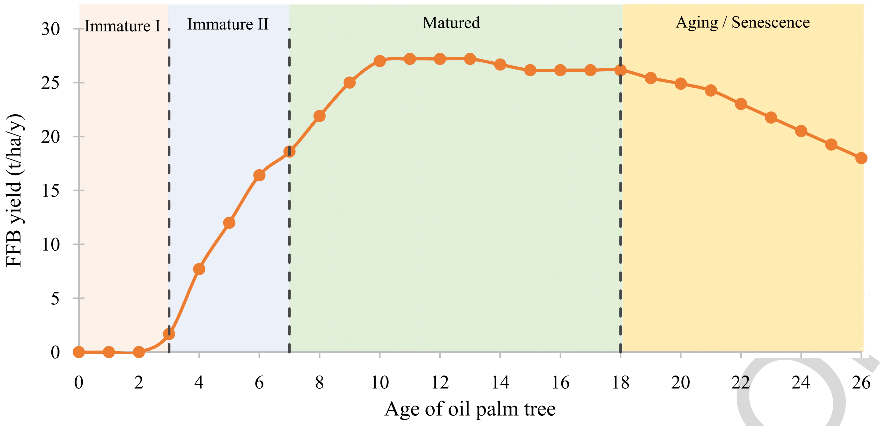

**Fig. 1.** Typical fresh fruit bunch yield by oil palm tree age (Tan, 2014).

**Table 1**
Recommended fertiliser application rate.

| Fertiliser application | Nitrogen, N (kg/ha/y) | Phosphorus, P (kg/ha/y) | Potassium, K (kg/ha/y) | Reference |
|---|---|---|---|---|
| Immature | 35–105 | 42–56 | 42–420 | (Goh et al., 2003) |
| | 45 | 25 | 108 | (FAO, 2005a) |
| | 50–120 | 22–48 | 54–216 | (Von Uexküll, 2007) |
| Matured | 35–245 | 56–98 | 42–420 | (Goh et al., 2003) |
| | 120 | 22 | 286 | (FAO, 2005a) |
| | 120 | 16.1 | 285.6 | (Tarmizi and Tayeb, 2006) |
| | 120–200 | 30–87 | 183–581 | (Von Uexküll, 2007) |

**Table 2**
FFB yields for matured oil palm plantation (Goh et al., 2009).

| Environment | Maximum yield (t/ha/y) | Average yield (t/ha/y) |
|---|---|---|
| Good | 35 | 29 |
| Satisfactory | 30 | 26 |
| Fair | 25 | 21 |
| Poor | 20 | 17 |

to decline. At the age of 25 and above, old trees are felled to initiate another crop cycle in order to maintain plantation productivity and economic viability (Bessou et al., 2017).

During the entire growing cycle of oil palm trees, resources such as sunlight, water and nutrients are required to support photosynthesis for growth and FFB production (Fig. 2). Based on the natural weather patterns in Malaysia, most plantations receive sufficient sunlight and water to support the growth of oil palm tree. In some parts of the plantations, additional water can be supplied via irrigation in areas with low precipitation, or during droughts, to meet the water requirements of the trees (Carr, 2011; TNAU Agritech, 2013a). Similarly, nutrients can be applied through chemical fertilisers, organic fertilisers and/or natural degradation of organic materials. Nitrogen (N), phosphorus (P) and potassium (K) are essential nutrients required by oil palm trees to sustain FFB productivity (Syura and Tsan, 2009; Makinde et al., 2011). Table 1 shows the recommended application rates of fertilisers for immature and mature oil palm trees in a plantation, subject to the surrounding environment conditions (i.e., climate change, soil condition, plantation management, etc.) (Comte et al., 2012; Wijaya et al., 2015). Table 2 summarises the typical FFB yield based on different environmental conditions (Goh et al., 2009).

The productivity of an oil palm plantation is affected by environmental conditions. The most feasible and effective way to achieve high FFB yield is to implement good plantation management in estates. As mentioned previously, fertilisation plays a crucial role in plantation management. Based on the current practice, nutrients are supplied using commercial inorganic or organic fertilisers. Inorganic fertilisers can be divided into straight (single nutrient) and compound (combination of two or more nutrients) fertilisers. These fertilisers are normally made from mineral salts and fossil fuels. Meanwhile, organic fertilisers can be made from animal manure, compost or biosolids (Huntley et al., 1997). Inorganic fertilisers provide several advantages, such as high nutrient content, low absorption time, low odour level, and ease of handling and application (Hasputri et al., 2017). However, excessive application of inorganic fertilisers causes problems such as overfertilisation, soil acidification, hardening of soil, and leaching of excess nutrient which causes ecosystem eutrophication (Ewulo et al., 2015). Furthermore, since inorganic fertilisers are primarily produced from non-renewable sources (i.e., mineral salts and fossil fuels), long-term use of these fertilisers are not sustainable from both resource and carbon footprint standpoints. In addition, most of the inorganic fertilisers are imported from overseas into Malaysia, which exacerbates their supply chain carbon footprint. This carbon footprint then becomes part of the carbon footprint of the palm oil product (Wood and Cowie, 2004).

On the other hand, organic fertilisers can improve soil structure and quality (Bell et al., 2003). Such fertilisers provide tolerance towards moisture stress (Yusuf, 2014), improve nutrients uptake (Rosenani et al., 2016) and improve plant growth (Hasputri et al., 2017) in plantations. Besides, the long-term use of organic fertiliser allows significant increase in soil carbon storage, thus, reduces system carbon footprint (Brown et al., 2011). By reducing the dependence on inorganic fertiliser the sustainability of oil palm plantations can be enhanced (Abdul Aziz et al., 2012). However, the main drawback of most organic fertilisers is their invariably low nutrient contents. Therefore, large quantities are needed to provide sufficient nutrients for optimum growth and FFB yield (Syura and Tsan, 2009).

According to Oil World (2017), oil palm plantations occupy almost 10% of the world's agricultural land (around 300 million hectares) in 2017. It was projected that the required plantation area for oil palm will continue to grow to meet global palm oil demand, by approximately 7% per annum (Business Wire, 2017).

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