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Yield gap analysis in oil palm: Framework development and application in commercial operations in Southeast Asia

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ABSTRACT

Narrowing the gap between actual and attainable yields in existing oil palm plantations is perceived as a key to fulfill the growing global demand for vegetable oil. To assess the scope for intensification we need robust estimates of attainable yields, which has been so far rarely done for perennial crops. For this purpose, we evaluated the complexities associated with estimating yield gaps (YGs) in oil palm (i.e. carry-over effect and aging), and adapted the existing framework for YG studies in annual crops. Based on this framework, we analyzed YGs for four sites within oil palm plantations located in Sabah (Malaysia), Central Kalimantan and North Sumatra (Indonesia) using a unique commercial yield data set covering an area of 38,300 ha.

We assessed for each site at plantation scale water-limited potential yield using the PALMSIM simulation model, attainable yield determined by best performing blocks within the plantation as defined by 90th percentile of observed yields and actual yields (blocks representing the median yields). The water-limited potential yield did not differ very much; 35–39 t fresh fruit bunch (FFB) during the plateau phase, the most productive phase in the life time of a palm. This reflected the favorable environmental conditions found in many parts of Sumatra and Borneo for oil palm. Attainable yields were in the range of 26–31 t FFB/ha. The exploitable YG between attainable and actual yield ranged for the four sites from 5 to 7 t FFB/ha/year. For one site (Central Kalimantan), we assessed yield variability due to varying soil conditions at the block scale according to its dominant soil type. This suggested that they were indeed exploitable by management. If the plantation could close the gap between attainable and actual yield this could give about 21,000 t/yr higher FFB. This indicated the large scope for intensification oil palm offers in many parts of insular Southeast Asia.

1. Introduction

Global production of vegetable oil (palm, soy, canola and sunflower) doubled from 73.9 Mt to 141.0 Mt 2000–2013. Production of palm oil increased from 25.0 to 61.1 Mt (2.5 times) over the same period (FAOSTAT, 2015). Oil palm (*Elaeis guineensis*) can produce up to 10 t/ha/yr crude palm oil (CPO) in favorable sites (Corley and Tinker, 2016). Its genetic yield potential is 11–18 t CPO/ha/yr (Barcelos et al., 2015). As global demand for vegetable oils increased, the oil palm industry responded by expanding the planted area. The area planted to oil palm in Indonesia, the world's major producer of palm oil, doubled between 2003 and 2012 (FAOSTAT, 2015). This has led to environmental concerns about the conversion of tropical forests into plantations of oil palm. These include increased CO_2 emissions from deforestation and degradation of peat soils, and loss of biodiversity (Carlson et al., 2012; Koh and Wilcove, 2008). Environmentalists are often at odds with frontier developers, particularly in Southeast Asia (Sayer et al., 2012). There is a global movement to reduce deforestation and restrict new oil palm plantations to low-carbon, degraded land, including land that was cleared from forest in the past (Gingold et al., 2012).

An alternative to expanding the area of oil palm is to increase the productivity of existing plantations (Garnett et al., 2013). But first we need to know how actual yields compare with those that can be obtained with good management, which is called the yield gap (YG) (Connor et al., 2011, p.11). Most analyses of YG have been with annual crops. In their analysis of global crop yields and global food security, Fischer et al. (2014) focus on YGs in food crops, including oil palm. They cite 1011

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references, of which 554 are for annual crops, 448 we could not identify from the reference title, but only 9 were for perennial crops. A further literature search found little work to identify YGs in any perennial crop, far less a perennial crop as important as oil palm.

The aim of this paper was first to outline the complexities associated with estimating YGs in oil palm, and to adapt the existing frameworks for YG assessments to oil palm. Based on the revised framework, we identified YGs for four sites in plantations in Indonesia and Malaysia. We then explored yield variability due to palm age and soil type. We used a data set of yield records from 1198 management blocks covering an area of 38,300 ha for several years. These data provided insights into current productivity of commercial plantations and the scope for improvement in Southeast Asia.

2. Yield gap analysis in oil palm

The first step to analyze YGs was to determine the *potential yield* (PY), which is the "yield to be expected with the best-adapted variety (usually the most recent release), with the best management of agronomic and other inputs, and in the absence of manageable abiotic and biotic stresses" (Fischer et al., 2014, p. 30). Oil palm is rarely irrigated in the tropics where most is currently grown, although we are aware that irrigated oil palm is an option in native savannahs with a dry season. As we focus attention on intensification in established plantations we step down to *water-limited potential yield* (PY_W), which is "the yield obtained with no other manageable limitation to the crop apart from the water supply" (Fischer et al., 2014, p.32). This puts the YG in the context of the climate and soil. *Attainable yield* (AY) is "the yield attained by a farmer from average natural resources when economically optimal practices and levels of inputs have been adopted while facing the vagaries of weather" (Fischer et al., 2014, p. 32). In contrast, *farm yield* (FY) is "the field, district, regional or national average yield given in kilograms or metric tonnes per hectare (kg/ha and/or t/ha)." AY with no subscript implies well-watered or irrigated crops, while AY_W is for rainfed crops. "FY … for all countries are collated annually by … [FAO] and are disseminated through the publicly accessible database FAOSTAT" (Fischer et al., 2014, p. 30). The *YG* is the difference between FY and AY_W for the site and crop cycle under consideration. It is expressed as a percentage of FY since this "is the observed world … production and likely increases are directly linked to FY (not PY)" (Fischer et al., 2014, p. 33).

While the growth cycle of tropical annual crops rarely exceeds six months, commercial oil palm has a sequence of production cycles over at least 25 years. Soil, terrain and plant genetics are fixed for this time and can be analyzed in the same manner as for annual crops. In annual crops, crop performance is affected by variation in weather patterns over the growth cycle of less than six months. In contrast, oil palm fruits take more than three years from flower initiation to harvest maturity. Thus, for example, a dry period at any time over these three years, including the harvest year, may drastically reduce yield. Similarly, any reduced applications of fertilizer over the several years before harvest will decrease yield. These long-term carry-over effects related to the complex physiology of oil palm must be taken into account when assessing YGs.

In addition to these carry-over effects from year to year, harvested yields commonly decline as the palms age. Moreover, the records of harvest yield (*yield taken*) do not always reflect independent estimates of the fruit available for harvest (*yield made*) (see Section 2.2 below). These factors, combined with differing scales of assessment, from smallholder plots to plantation blocks (20–100 ha) to estates (collections of 20–50 blocks) or plantations (collections of estates) make addressing YGs in oil palm a challenge.

2.1. Carry-over effects

Fresh fruit bunch (FFB) yield of oil palm is determined by the number of bunches per ha and their mean weight. The period from flower initiation to harvest is somewhat over three years (Breure, 2003). The sex of the inflorescence differentiates about two years before harvest, when the potential number of flowers is fixed, although inflorescences may abort about 10 months before harvest. Pollination occurs about six months before harvest and the potential number of fruits is determined, although some flowers may abort later while the remaining fruits develop.

During the period from initiation to harvest, variations in rainfall influence the development of the fruit bunches. Stress prior to pollination reduces the sink size, while stress after pollination reduces growth of the bunch (Legros et al., 2009a, 2009b). Estimates of PYw must therefore consider the rainfall quantum and its distribution over the three years prior to harvest.

Cock et al. (2016) showed that extremes of rainfall during the last two years before maturity reduces yield, but we know little about the long-term carry-over effects of water stress on oil palm. A common observation in field trials is that a year of high yields is followed by one or more years of low yield (Breure and Corley, 1992; Corley and Tinker, 2016). Commercial operators confirm this, attributing the yield decline in 2010 in one case to the high levels of production in 2008 and 2009 (United Plantations, 2010). This can be because the number of bunches and the number of fruit per bunch is set by the weather and yield in the two years or so between flower initiation and pollination. Oil palm can therefore yield well in years with dry spells by mobilizing carbohydrate reserves from the trunk during fruit development. Trunk reserves can contribute up to 5 t/ha FFB (Henson et al., 1999; Henson and Dolmat, 2004). There may also be long-term effects from nursery management, but there is little evidence to support this hypothesis.

2.2. Yield taking

The yield taken (fruit harvested) in oil palm is often a lot less than the yield made (fruit produced) due to practical difficulties at harvesting (Cock et al., 2014). Thus, the yield data from commercial plantations often underestimate the actual yield produced. Moreover, the reliability of data of taken yield at the block level depends on how it was done.

Plantations usually record the number of bunches harvested from each block, but they are not weighed. Bunches from several adjacent blocks are collected for transport to the mill where the load is weighed and the average bunch weight of the whole load calculated. This average weight is applied to the number of bunches collected from the relevant blocks to determine the total yield of each block. Because each load may come from several blocks whose mean bunch weight may differ, the calculated block yield may not be accurate. Moreover, the interval between harvest and weighing can very a lot, causing further errors. Nevertheless, errors in the yield of individual blocks are irrelevant in calculating taken yields of whole plantations or estates. They are sufficient to identify the outcome of what good management can achieve in a given region.

2.3. Age effects

Palms yield less as they age. They start to produce bunches three years after planting with the yield increasing rapidly to a plateau phase that starts when the palms are 6 to 7 years old lasting until they are 10 to 12 years old. Increasing yield in the early phase is associated with increasing leaf area index and canopy closure, which leads to greater interception of incident radiation and hence yield. After canopy closure, yields reach a plateau for a number of years, after which productivity declines. Part of the yield decline is attributed to loss of stand, mainly due to diseases, as well as lower yield per palm (Goh et al., 1994). Declining yield may be because old, tall palms are more difficult to harvest and prune (Goh et al., 1994) or because maintenance respiration of the larger trunks of older palms is greater (Henson, 2004). Respiration in other crops is closely related to total photosynthesis and growth (Cheng et al., 2009; Frantz et al., 2004; Thornley, 2011). If