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WATER FOOTPRINT: PART 2 - FFB PRODUCTION FOR OIL PALM PLANTED IN MALAYSIA

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ABSTRACT

Water accounting across the production of fresh fruit bunch (FFB) in the oil palm's life cycle is gaining momentum arising from the importance placed on the need to quantify water footprint (WF). This article quantifies the WF of FFB production from oil palms grown in some areas in Malaysia, from an inventory data gathered from 2009-2012. The WF methodology of Hoekstra et al. *(2009) was applied for calculating WF of FFB production. The data for crop evapotranspiration (ET) of 5.5 mm per day (Roslan and Mohd Haniff, 2004) was used to calculate green and blue WF. The results showed that for oil palm, the FFB yield average of 25-year life span was 20.7 t ha^{-1} yr^{-1}. The FFB production WF was 1166 m^3 t^{-1} FFB (WF_{green}, 1055; WF_{blue}, 3.56; and WF_{grey}, 107 m^3 t^{-1}). The results showed that the green WF was higher than the grey or the blue WF as planting of oil palm in Malaysia is without irrigation. Oil palm requires a lot of green water (rain water), but when the amount of rain water is lower than ET, it becomes necessary to determine the water deficit of the soil in the oil palm-growing areas. This is to ensure that any shortcoming of water can be provided through irrigation.*

Keywords: water footprint, oil palm, sustainability.

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INTRODUCTION

Oil palm has become an increasingly attractive crop to meet the world's demands for oils and fats as it has a much higher yield than other oil crops. It can grow in marginal soil conditions, and in many cases have helped eradicate rural poverty through creation of jobs. In Malaysia, the oil palm planted areas in 2013 reached 5.23 million hectares, an increase of only 2.9% against 5.08 million hectares recorded in 2011, mainly due to the increase in planted areas in Sarawak (MPOB, 2014).

The requirement to quantify carbon footprint, or greenhouse gas (GHG) emission, has become mandatory for responsible palm oil producers. We have reported on the carbon footprints at various stages of palm oil production (Halimah *et al*., 2010; Zulkifli *et al*., 2010; 2009; Vijaya *et al*., 2010; Tan *et al*., 2010; Puah *et al*., 2010). Of equal importance is the requirement to quantify water footprint (WF). WF is an approach to provide information on how much water is being used at specific processes in the life cycle of a product. In fact, WF can have an impact on the crop's use as a feedstock for biodiesel. In the case of jatropha, for example, the crop can be converted to biofuel and is suitable as diesel substitute but its high WF, as reported by Gerben *et al*. (2009), led the authors to conclude that jatropha is not a suitable feedstock for biodiesel production. This concern on WF has made it as important as the carbon footprint as one of the indicators for choosing a green product.

Climate change has an impact on the amount and distribution of rainfall, which subsequently has an effect on the amount and timing of water availability

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for fresh fruit bunch (FFB) production. Therefore, it is very crucial to quantify the WF of FFB production and to identify areas of high water requirement. The next step will be to reduce the water consumption as much as possible. This will ensure that palm oil remains competitive and sustainable in the global market. This will also ensure the market access and the ability to compete with other vegetable oils as shown in *Table 1.*

Mekonnen and Hoekstra (2011) used the grid-based dynamic water balance model to compute a daily soil water balance and calculated the crop water requirements, actual crop water use (both green and blue) and actual yields. The model was applied at a global scale using a resolution of 5 by 5 arc minute (Mekonnen and Hoekstra, 2010). They estimated the water footprint of 146 primary crops and more than 200 derived products which were grown in only a few countries, using CROPWAT 8.0 model.

One of the biggest problems with water around the world is its scarcity. Currently, about one-third of the world's population is threatened by a lack of freshwater to meet their daily needs (IWMI, 2007). This shortage is due to a variety of factors such as high population growth, pollution of existing resources, climate change, urbanisation, and changing lifestyles (Donna Jefferies *et al*., 2012). This information is critical to develop strategies for efficient water use. With regard to palm oil, not many reports on the WF of oil palm cultivation are available in the literature. To date, only the WF of oil palm cultivation in Thailand (Piyanon Kaenchan *et al.,* 2013) and Indonesia (FAOSTAT, 2013) have been reported (*Table 2*). This could be due to the fact that some of the regions in these two countries may have insufficient rainfall to grow oil palm; and they have to resort to irrigation water instead. Oil palm is usually grown in tropical regions with adequate rainfall, and therefore, there are currently no pressing issues with the sustainable use of water resources in these regions. It is for this reason that the study on the WF of oil palm is lacking. The objective of this study was to estimate a complete WF (blue, green and grey) for the production of FFB in the oil palm plantation. This article is linked with WF analysis for the production of oil palm seedlings in Malaysian oil palm nurseries – part 1 where the WF from the nursery is one of the inputs in the plantation (Halimah *et al*., 2014).

BACKGROUND OF FFB PRODUCTION AND WATER USE FOR OIL PALM

In Malaysia, the commercial oil palm planted is the *tenera* variety, a hybrid cross between the *dura* and the *pisifera* varieties (Corley and Tinker, 2003). The *tenera* variety yields an average of about 4-5 t of crude palm oil per hectare per year and about 1 t of palm kernels per hectare per year (Corley and Tinker, 2003). Oil palm seedlings from the nursery are transferred and planted in the field when they are approximately 12–13 months old. The palms are planted at a density of 136 palms per hectare (inland) to 148 palms per hectare (coastal) on mineral soils. Before the palms are planted, the soil is ploughed and a legume cover is sown. The cover crop prevents erosion and fixes nitrogen from the atmosphere in their root nodules. When the palms are young and the shading effect by the foliage is minimal, the growth of the cover crop is luxurious. A palm circle with no vegetation is established around each palm to prevent encroachment of weeds. Later, when the palm matures, the circle allows easy access for harvesting and picking of loose fruits.

TABLE 1. THE GREEN, BLUE AND GREY WATER FOOTPRINT OF SOME OIL CROPS*

Product (refined oil)	Global oil yield (t ha^{-1})	Global average water footprint (m^3 t^{-1} oil yield)			
		Green	Blue	Grey	Total
Soyabean oil, refined	0.38**	3 980	137	73	4 190
Rape oil, refined	0.67**	3 226	438	636	4 301
Palm oil, refined	3.74**	4 787	1	182	4 971
Sunflower seed oil, refined	0.48**	6 088	299	405	6 792

Source: *Mekonnen and Hoekstra (2011).
**Oil World (2007).

Note: Blue water footprint – volume of surface and groundwater consumed as a result of the production of oil crop.
Green water footprint – volume of rain water consumed during the production process, where it refers to the total rain water evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop.
Grey water footprint – the grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

TABLE 2. WATER FOOTPRINT (WF) OF OIL PALM CULTIVATION FOR TOP PRODUCING COUNTRIES IN SOUTH-EAST ASIA

Country	FFB yield ($t\ ha^{-1}$)	Green + blue ($m^3\ t^{-1}$)
Indonesia	17.9*	802*
Thailand	5.5-16.0**	965-2 353**
Malaysia	20.7 (this study was based on inventory data)	1 059 (this study was based on inventory data)

Note: Grey water was excluded in * and **. FFB – fresh fruit bunch.
Source: *FAOSTAT (2013). **Piyanon Kaenchan *et al*. (2013).

Herbicides are applied to keep the palm circle free from weeds. An oil palm bears its first FFB within two to three years after planting and continues to do so throughout its economic life of 20–25 years. Each palm produces 1 FFB every 10–21 days. Harvesting of ripe FFB is carried out manually every 10–15 days. Normally, progressive pruning is done during harvesting and the pruned fronds are placed in the field between the palm rows for mulching. Detached FFB are placed by the roadside to be collected by the in-field transporters and later transferred to lorries for transport to a nearby mill within 24 hr.

The most common fertilisers applied in the oil palm plantation are muriate of potash, ammonium sulphate, kieserite and rock phosphate. Herbicides are usually required only when the palms are immature and the canopy is insufficient to prevent sunlight from reaching the weeds. In such a situation, the weed's growth is prolific. Most herbicides are water-based formulations and manually applied using knapsack sprayers. Insecticides and rodenticide are the major pesticides required for oil palm cultivation. However, their use is comparatively minimal in oil palm plantations. The application of chemical insecticides for bagworm control is very site specific and is carried out by spraying or trunk injection. Often, the use of insecticides and rodenticides is reduced by integrated pest management, where natural predators or bioagents, such as barn owls, BT, fungi, viruses, *etc.*, are used instead of pesticides (Norman and Basri, 2010; Ramle *et al*., 2009; Mohd Najib *et al*., 2009). Replanting of oil palms is carried out when palms are 20-25 years old because of the difficulty in harvesting tall palms. Old palms also give low FFB yield. The palms are felled, chipped and left in the plantation as a nutrient source for replants. The felled palms contain about 95 t of dry weight per hectare (Khalid *et al*., 2000; 2009) which would decompose within two years.

The largest user of water worldwide is agriculture. Another large water consumer, but often overlooked, is the industrial sector. Currently, the agricultural sector accounts for about 85% of global fresh water consumption (Shiklomanov, 2000; Hoekstra and Chapagain, 2007). Crop water requirements depend on crop type and climate, and the water can be supplied from either rainfall or irrigation water. Oil palm is best grown in areas that have a well-distributed rainfall throughout the year. In Peninsular Malaysia, only some regions, *e.g.* the northern region, experiences seasonal dry period, whereas other regions have rainfall throughout the year. Oil palm crop productivity is also dependent on the availability of water. The actual water requirement of oil palm and the minimum amount required to obtain good yield, are relatively unknown. However, the plant can grow and yield well in areas receiving rainfall of at least 1800 mm, provided it is evenly distributed throughout the year without any chronic water deficit in the soil (Hartley, 1988; Roslan and Haniff, 2004).

In Malaysia, the common practice of oil palm growing is by using only the soil moisture provided by rainfall. Corley and Tinker (2003) made it clear in their review on the role of water in the productivity of oil palm, that there is no simple relationship between rainfall totals and yield. The commonly accepted way of comparing sites and seasons is to use the concept of a soil water deficit, a measure of the relative dryness of the soil. The critical value of the deficit above which yield is lost varies with the soil type and the depth and density of rooting, and also with the stage of growth of the palm. When this moisture is insufficient, then only water supplied through irrigation is required. Some rain or irrigation water evaporates without benefiting the plant, while some transpires through the plant's tissues during photosynthesis and returns to the atmosphere. Water stress is associated with high incidence of juvenile, fused pinnae and retarded growth of seedlings that are discarded at the end-of-nursery culling (Sime Darby, 2011). Water stress reduces photosynthesis and practically stops oil palm growth (Corley, 1976; Ochs and Daniel, 1976; Roslan and Haniff, 2004).

THE NEED AND CONCEPT OF WATER FOOTPRINT

Water is essential for the survival of every living thing. It is an unevenly distributed resource that must be used in a sustainable manner. It is all up to mankind to protect this precious resource. Water use in crops includes both the blue water resources in irrigated agriculture (diverted water) and the green water resources (soil moisture from infiltrated rainfall) in rain-fed agriculture.

WF is an important concept to communicate and manage the way our water consumption patterns affect the environment. The concept of WF, introduced by Hoekstra (2003) and subsequently elaborated by Hoekstra and Chapagain (2008), provides a framework to analyse the link between human consumption and the appropriation of the globe's freshwater. The WF purports to measure human appropriation of freshwater resources and is aimed toward a variety of goals including identification of business, process or product level water consumption, and promoting sustainable use of water resources (Hoekstra *et al.*, 2011). When applied at a product level, the WF provides an inventory of water consumption throughout a product life cycle (the virtual water content). Water consumption is normally determined for a single catchment or a river basin, although Hoekstra *et al.* (2011) suggest that the method can be used at any scale.

The WF for a crop-based product is defined as the volume of fresh water used for production at the place where it was actually produced (Hoekstra and Chapagain, 2008). In general, the actual water content of products is negligible compared with their WF, and the water use in product life cycles is dominated by the agricultural production stage. Calculations of a WF are made by summing up daily crop evapotranspiration (mm per day) over the growing period of a crop. This provides information on the crop water requirement.

The WF consists of three components: the green WF, the blue WF, and the grey WF (Hoekstra and Chapagain, 2008). The green WF refers to rain water that evaporates during production, mainly during crop growth. The blue WF refers to the volume of surface and groundwater for irrigation that evaporates during crop growth. The grey WF is the volume of water that becomes polluted during production, defined as the amount of water needed to dilute pollutants discharged into the natural water system to the extent that the quality of the ambient water remains above agreed water quality standards (Mekonnen and Hoekstra, 2010).

Blue water use (m^3 ha^{-1}) over the length of the growing period is calculated as the sum of the daily volumes of irrigation-water evapotranspiration. In the case of rain-fed crop production, like oil palm, blue crop water use is zero. Green crop water use (m^3 ha^{-1}) is calculated by summing up the daily values of ET (mm per day) over the length of the growing period, using the method developed by Hoekstra and Chapagain (2008). The green and blue WF of oil palm (m^3 t^{-1}) are calculated by dividing the total volume of green or blue water use (m^3 yr^{-1}), respectively, by the quantity of the FFB yield (t yr^{-1}). The grey WF of FFB production, which is an indicator of the volume of fresh water pollution, is calculated by quantifying the volume of water needed to assimilate the nutrients that reach the ground or surface water. Nutrients leaching from agricultural fields are a main cause of non-point source pollution of surface and subsurface water bodies. In this study, we have quantified the grey WF related to the usage of fertiliser and pesticide. The grey component of the WF (m^3 t^{-1}) is calculated by multiplying the fraction of fertilisers/pesticides that leaches or runs off by the fertiliser/pesticide application rate (kg ha^{-1}) and dividing this by the difference between the maximum acceptable concentration of nitrogen (kg m^{-3}) and the natural concentration of nitrogen in the receiving water body (kg m^{-3}) and by the actual crop yield (t ha^{-1}).

MATERIALS AND METHODS

System Boundary

The system boundary of WF for FFB production covers the agricultural phase where oil palm seedlings are grown in the nursery and then transplanted to the field until the FFB reaches palm oil mill (*Figure 1*). This article is linked with WF analysis for production of oil palm seedlings in Malaysian oil palm nurseries – part 1 (Halimah *et al*., 2014).

Functional Unit

In the nursery where the function is to produce seedlings for oil palm cultivation, the functional unit of WF is m^3 per seedling, while the functional unit for FFB production is m^3 t^{-1} FFB.

Calculation of WF

Water consumption is divided into three categories as shown in *Figure 2*. All calculations of the WF of FFB production use the following steps:

Step 1: the calculation of the crop water requirement of oil palm (CWR[c], m^3 ha^{-1}). This is calculated by accumulation of daily crop evapotranspiration (ETc, mm per day) multiply by factor 10 as in Equation (1) (Gerbens-Leenes *et al*., 2009; Chapagain and Hoekstra, 2004a):

$$CWR[c] = 10 \times \sum_{d=1}^{lp} ETc\,[c,d] \qquad (1)$$

where the factor '10' is applied to convert the unit from mm into m^3 ha^{-1}, and 'lp' stands for the length of growing period in days. ETc is measured over the growing period of crop from Day 1 to the final day of growing period using CROPWAT model developed by the Food and Agriculture Organisation of the United Nations (FAO) which is based on the FAO

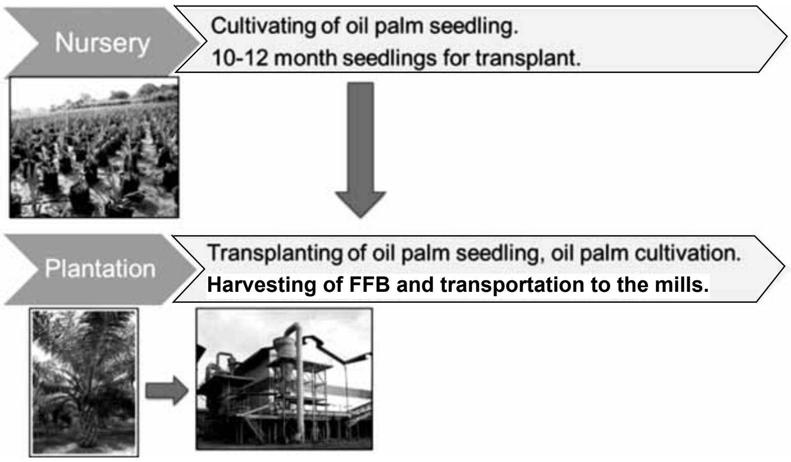
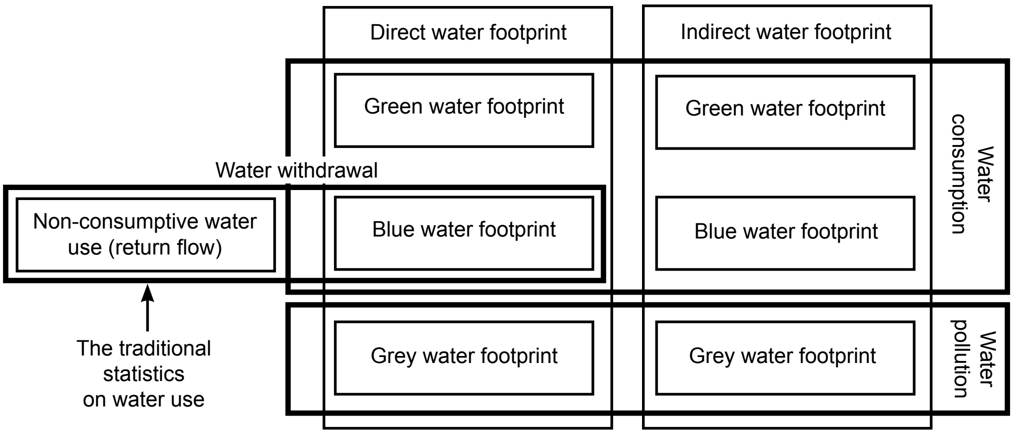


Figure 1. System boundary.



Source: Hoekstra *et al.* (2011)

Figure 2. Water footprint categories.

Penman-Monteith method (Piyanon Kaenchan and Shabbir Gheewal, 2013). ETc can be derived from Equation (2) (Chapagain and Hoekstra, 2004a):

$$ETc = Kc \times ET_0 \quad (2)$$

where Kc is the crop coefficient that includes effects that distinguish evapotranspiration of field crops from grass, and ET_0 is the reference crop evapotranspiration (mm per day) of a hypothetical surface covered with grass not short of water (Gerbens-Leenes *et al.*, 2009; Chapagain and Hoekstra, 2004a, b).

Crop water requirement is classified into green and blue water use. The green water use is equal to the sum of daily volume of rainwater evapotranspiration provided by the rainwater stored as soil moisture. Then, the blue water use (irrigation water) can be known by subtracting the green water from the total amount of crop water requirement as calculated in the Equation (1)(Gerbens-Leenes *et al.*, 2008; Babel *et al.*, 2011). In the case of rain-fed oil palm area, the ET blue equals to 0.

Step 2: The calculation of the green and blue WF for growing the crop (WF, $m^3\ t^{-1}$). These are calculated as the green or blue water use ($m^3\ ha^{-1}$) divided by the crop yield (Y, $t\ ha^{-1}$) (Piyanon Kaenchan and Shabbir Gheewal, 2013):

$$WF\ green = \frac{\text{Green water use}}{Y} \quad (3)$$

$$WF\ blue = \frac{\text{Blue water use}}{Y} \quad (4)$$

Step 3: the grey WF (WFgrey, $m^3\ t^{-1}$) is calculated for the growing crop by multiplying the chemical application (*i.e.* fertilisers, pesticides, *etc.*) rate per hectare (Appl, in $kg\ ha^{-1}$) with the leaching-run-off fraction (α) divided by the maximum acceptable concentration (cmax, $kg\ m^{-3}$) minus the natural concentration for pollutant considered (cnat, $kg\ m^{-3}$) and then dividing by the crop yield (Y, t ha^{-1}) (Piyanon Kaenchan and Shabbir Gheewal, 2013):

$$WF_{grey} = \frac{(\alpha \times Appl)/(cmax - cnat)}{Y} \quad (5)$$

Note: Values for α and cmax were taken from:

(i) Wikipedia (2013). Drinking water quality standards. http://en.wikipedia.org/wiki/Drinking_water_quality_standards. Accessed on 13 June 2013.

(ii) Department of Environment (2010). Annex: National Water Quality Standards for Malaysia. *Malaysia Environmental Quality Report 2009*. Jabatan Alam Sekitar.

Step 4: the total water footprint of the FFB production (WF Total) is the sum of green, blue, and grey WF and its unit is m^3 t^{-1} FFB (water volume per mass) (Piyanon Kaenchan and Shabbir Gheewal, 2013):

$$\text{WF Total FFB production} = WF_{green} + WF_{blue} + WF_{grey} \quad (6)$$

RESULTS AND DISCUSSION

Data Collection

The inventory data obtained from 281 plantations covered an area of approximately 440 000 ha. This represents approximately 10% of the area under oil palm cultivation in Malaysia in the year 2012. The agricultural operation for oil palm includes activities related to cultivation of oil palm in the field during the mature and immature phases of the palms. The FFB yield refers to the average yield obtained from the survey and the characteristics of the plantations used in the study and the direct and indirect blue water consumption are shown in *Tables 3* and *4*, respectively. The amount of herbicides/insecticides used in the plantation, the amount of water used for herbicides/insecticides application, and the amount and types of fertilisers used in the plantation were also obtained from questionnaires which also included the number of palms per hectare as well as the FFB yield per hectare per year (Zulkifli *et al.*, 2010). The collected data were averaged to derive a set of generic data representing Malaysian oil palm plantation on mineral soils.

WF of FFB Production

The WF of FFB production in Malaysia from inventory data obtained from 281 plantations covered an area of approximately 440 000 ha is 3.56 blue,1055 green, and 107 grey m^3 t^{-1} FFB, respectively (*Tables 5, 6* and *7*). The results show the green WF was higher than grey and blue WF (*Table 8*) as planting oil palm in Malaysia is without irrigation. Oil palm requires a lot of green water (rain water); but, as per data collected from the survey, the amount of rain water is much higher than ET. Thus, oil palm planted from the areas (survey data) indicates that irrigation is not required.

Water management is a very important aspect of oil palm cultivation. Deficit or surplus of water would create stress to oil palm and adversely affect yield of the crop. To realise full oil palm yield potential, focus should be given to ensuring adequate water and moisture in the soil throughout the year in tandem with other agronomic practices. To prevent the degradation of the soil and to conserve fertility and moisture, several measures such as terracing and construction of soil pits are done to reduce the length of slope and to trap soil and plant nutrients. Another measure is the establishment of legume cover crops (LCC). The planting of the LCC such as *Mucuna bracteata* is now the standard practice to act as nitrogen fixing as well as to recycle large amount of organic matter, to improve soil structure, to reduce erosion, and to promote infiltration of rain water. Placement of the pruned fronds along the slopes on terrace planting is also done to minimise soil erosion and fertiliser loss.

Continuous soil moisture availability encourages vigorous growth and increases yield of oil palm. Adequate supply of water, good soil depth and good water holding capacity contribute to water availability. In oil palm, as water deficiency increases, stomata will remain closed and the development and opening of spear leaves will be inhibited. Water deficiency adversely affects flower initiation and sex differentiation. It will therefore, result in low sex ratio due to the production of more male inflorescences. It is established that oil palm requires 120 - 150 mm of water to meet its monthly evapotranspiration needs. In some dry areas, irrigation is required in order to improve yield.

Uncertainty

It is stressed that the data collected in this study are based on the survey of fresh water requirements, insecticides/pesticides and fertilisers use in oil palm plantations. Each plantation has the weather regime and the soil characteristic unique to that particular site. Based on the rainfall data gathered from the survey, the plantations seemed to experience drought-free condition.

Another important uncertainty is that the WF estimations are based on water requirement of crops (CWR[c]) which normally refers to the evapotranspiration under optimal growth conditions as in Equation (1). Thus, there could probably be over estimation in cases where the actual water availability is lower than the crop water requirement. In other words, the calculated WF are overestimated since there are water deficiency conditions in reality, and crops are still able to be grown under those conditions (Chapagain and

TABLE 3. BRIEF DESCRIPTION AND CHARACTERISTICS OF PLANTATIONS USED IN THE STUDY

Parameter	Amount	Unit/remark
Area	438 320	ha
Plantations	281	Estates
Yield (FFB)	20.7	t FFB ha^{-1}
Growth period	25	Years
Rainfall	2 747	mm yr^{-1} (average from 281 estates)
Herbicide and pesticides used	0.744*	kg t^{-1} FFB
Water use for herbicide/pesticide	450	litre ha^{-1}

Note: * Based on inventory data without segregating their usage according to disease or pest infestation area.

TABLE 4. DIRECT AND INDIRECT BLUE WATER CONSUMPTION

Processing category	Blue water consumption	
	Direct	Indirect
Production of polyvinyl chloride for pipes	-	✔
Production of agricultural inputs *e.g.* polybags and fertilisers (in the form of N, P_2O_5, K_2O)	-	✔
Application of pesticides, herbicides and fungicides	✔	-
Transportation of polybags, fertilisers, pesticides, herbicides and fungicides	-	✔
Water supply	✔	-
In-field transportation	-	✔
Transportation of FFB to the mill	-	✔

TABLE 5. TOTAL BLUE WATER FOOTPRINT (WF) TO PRODUCE PER TONNE FRESH FRUIT BUNCH (FFB)

Parameters	Amount	Unit/remarks/calculations
Total herbicide and pesticides used	0.744	kg t^{-1} FFB (from inventory data)
Water use for herbicide/pesticides	450	litre ha^{-1} (assumption)
Total direct blue water used for herbicides/pesticides application	0.2232	m^3 t^{-1} FFB [calculated from Equation (1)]
Indirect blue water of diesel for traction use	0.000014	m^3 t^{-1} FFB (from Ecoinvent database)
Indirect blue water for production of fertilisers	3.18	m^3 t^{-1} FFB (from Ecoinvent database)
Total blue water from nursery	0.157	m^3 t^{-1} FFB (Halimah *et al.*, 2014)
Total WF_{blue}	3.56	m^3 t^{-1} FFB

TABLE 6. TOTAL GREEN WATER FOOTPRINT (WF) PER TONNE FRESH FRUIT BUNCH (FFB)

Total WF_{green} from nursery	0.31	m^3 t^{-1} FFB (Halimah *et al.*, 2014)
Evapotranspiration rate	5.5	mm per day (Roslan and Haniff, 2004)
Total WF_{green}	1 055	m^3 t^{-1} FFB [calculated from Equation (1)]

TABLE 7. TOTAL GREY WATER FOOTPRINT (WF) PER TONNE FRESH FRUIT BUNCH (FFB)

Parameter	Grey WF (m^3 t^{-1} FFB)
Nitrogen (N)	20.93 [calculated from Equation (5), Wikipedia (2013) and DOE (2010)]
Phosphate (P)	16.81 [calculated from Equation (5), Wikipedia (2013) and DOE (2010)]
Potassium (K)	69.00 [calculated from Equation (5), Wikipedia (2013) and DOE (2010)]
Herbicides/pesticides	0.10 [calculated from Equation (5); Wikipedia, (2013) and DOE (2010)]
From nursery	0.0018 (Halimah *et al*., 2014)
Total	107

TABLE 8. TOTAL WATER FOOTPRINT (WF) OF FRESH FRUIT BUNCH (FFB) PRODUCTION BASED ON THE INVENTORY DATA

FFB yield ($t\ ha^{-1}$)	WF of FFB production (m^3 t^{-1} FFB)				Total W_{blue} + W_{green} m^3 ha^{-1}
	Blue	Green	Grey	Total	
20.7	3.56	1 055	107	1 165	21 912

Hoekstra, 2004a, b; Hoekstra and Hung, 2002). The results of this study, however, are still able to contribute useful information for the formulation of suitable guidelines for managing water resources in oil palm plantations in Malaysia.

CONCLUSION

The WF of FFB production in Malaysia based on inventory data obtained from 281 plantations covered an area of approximately 440 000 ha is 3.56 blue,1055 green, and 107 grey m^3 t^{-1} FFB, respectively. The green water was the main source of water used and the crop water used was approximately 22 000 m^3 ha^{-1}. Since water is a scarce resource, and that there will be the requirement of more water for both biofuel feedstock and food production, appropriate water management is critical to avoid the conflict between 'water for food' and 'water for energy'. The information from this study can provide guidance for the policy-makers and planters with regard to water management planning for sustainable FFB production in oil palm plantations in Malaysia. The WF of oil crop varies across both crops and countries. The variation is due to differences in crop yields across countries and crops, differences in energy yields across crops, and differences in climate and agricultural practices across countries.

FUTURE RESEARCH RECOMMENDATION

The suggestion for further study is to improve the water footprinting approach by taking into account the water availability along with the water consumption pattern. This approach will provide a better idea on the possible occurrence of water stress. There is a need to quantify the volumes of water consumed as well as the availability of water in the study areas. Through this, the impact of the water consumption can be ascertained. There are techniques, such as in life cycle assessment (LCA), that attempt to correlate the water consumption in a region with the water availability. Such a technique may give more information on water scarcity that could lead to social and environmental impacts. Under the LCA method, the water stress characterisation factors are added into the water footprint calculation, which will provide the comparable impact of water consumption for different sites (Ridoutt *et al*., 2010; Nilsalab *et al.*, 2012).

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