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Water Footprint Analysis of Oil Palm (Case Study of the Pundu Region, Central Borneo)

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ABSTRACT

The rapid expansion of oil palm plantation areas in Indonesia is taking place every year. The impact is the emergence of various issues and opinions regarding the high environmental damage caused by excessive use of water by the crops. The water footprint scenario can be used to explain the usage of water for the oil palm. This is defined as the volume of water used to obtain one ton of fresh fruit bunches (FFB) in m^3 $yield^{-1}$ unit. The water footprint includes the green (water from precipitation), blue (water from surface and ground water resources) and grey water footprints (water used to dissolve fertilizers, pesticides and other chemical compounds). Based on these issues, this study was conducted to obtain the value of oil palm water footprint, in the case study area in Pundu, Central Borneo. Data used include climate, FFB production and the use of fertilizers and pesticides. The results show that the water footprint of oil palm is 1002.1 m^3 ton^{-1} with the following plantation conditions: productivity was about 13.41 ton ha^{-1}, the use of fertilizer was 0.12 ton ha^{-1}, irrigation was assumed only given to pre-nursery and nursery activities. The green, blue, and grey water footprints was 876.7, 35.9 and 89.5 m^3 ton^{-1}, respectively. The oil palm in the research area were grown with the main source of water coming from precipitation, not from groundwater (blue WF is only 3.6% of total WF). The Grey WF was 8.9 % which is lower than the average Grey WF of oil crops worldwide.

Keywords: *Elaeis guinensis*, productivity, water balance

INTRODUCTION

An accurate water usage analysis of oil palm at every stage of growth is needed to obtain efficiency and precision in crop water requirement for increasing optimum yield or productivity. Oil palm water usage can be expressed in water footprint units. The water footprint is a concept to quantify the environmental impacts associated with water. The water footprint of an agricultural product is the total volume of water used crop water usage (CWU) for each crop yield (kg ton^{-1}), either direct and indirect water footprint (Hoekstra *et al.* 2009). The direct

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water footprint includes water footprint green (water from precipitation), blue (water from surface and ground water resources), and grey (water used to dissolve fertilizers, pesticides, and other chemical compounds) (Bulsink *et al.* 2009; Hoekstra *et al.* 2009; Mekonnen & Hoekstra 2010; Hoekstra *et al.* 2011).

Several studies related to the oil palm water footprint in Indonesia show varying values. Bulsink *et al.* (2009) and Kongboon & Sampattagul (2012) presented the results of oil palm water footprint for green, blue and grey values respectively: 802 m^3 ton^{-1}, 0 m^3 ton^{-1} and 51 m^3 ton^{-1} and the total water footprint for oil palm based on the climate and production data during 2002-2004 was 853 m^3 ton^{-1}. Another study from Mekonnen & Hoekstra (2010) which analysed the oil palm water footprint based on the general data of oil palm (not for a specific location) have shown that the green water footprint was 1057 m^3 ton^{-1}, blue 0 m^3 ton^{-1}, grey 40 m^3 ton^{-1} and the total was 1097 m^3 ton^{-1}.

The use of local climate data showed different values of oil palm water footprint. Mungkalasiri *et al.* (2015) presented a comparison of fresh fruit bunches (FFB) water footprint in the same region in Thailand from two different data sources: 1070.65 m^3 ton^{-1} for CLIMWAT 2.0 and 1168 m^3 ton^{-1} for local climate data. Furthermore, the comparison of the FFB water footprint between two different provinces in Thailand provided the difference between each water footprint values (above 300 m^3 ton^{-1}). Based on the previous studies, it can be seen that the differences in climatic characteristics and climate data sources on water footprint analysis have brought about the difference in values of oil palm water footprint. Therefore, it is necessary to analyse the water footprint of oil palm from specific data which represent the oil palm plantations in Indonesia. Thus, the objective of this research was to obtain the water footprint value of oil palm in a case study of oil palm plantations in Pundu, Central Borneo. The results obtained from the research will provide the water fotprint value from data of specific locations in the Pundu region.

MATERIALS AND METHODS

The research was conducted in the oil palm plantation Pundu, Central Borneo with climate conditions as follows (i) average annual rainfall is 3002 mm $year^{-1}$, (ii) average annual temperatures varies between 21.4–33.8 °C and, (iii) the average sunshine hours is around 5.9 hours of sunshine per year.

Data used in this research were climate data series from the local station for 2012-2015 and rainfall data from the climate station in the Pundu region from 2008 to 2015 which ranged from 11 to 254 mm $month^{-1}$, FFB production data for 2011-2014 of total area was 3239.58 ha (Pantai Mas Estate). The general data of soil type is black clay soil in the nurseries and red sandy loam in the plantations including the infiltration rate and total available moisture (TAM), fertilizer and pesticide usage data from 2014-2015, and plant characteristics data such as planting dates, the value of crop coefficient (Kc) of oil plants, growing stages or age (year), rooting depth, critical depletion, and high crop yield response. The planting date was determined by the start of the rainy season. The research includes: oil palm evapotranspiration actual analysis using Cropwat version 8.0.

The CWU of oil palm was considered as actual evapotranspiration (ETa). The ETa calculation of oil palms was done by calculating the evapotranspiration standard (ETo) using CropWat 8.0 with climate data input using a formula from Penman Monteith (FAO 1998; Allen *et al.* 2006; FAO 2006). Furthermore, monthly rainfall data from 2008 to 2015 were obtained and processed into dependable rainfall >75%. The results of monthly rainfall data P>75% as the input for Cropwat 8.0 and used to process effective rainfall data using fix percentage (FAO 2007). The ETa value obtained by the water balance analysis with the main input of potential evapotranspiration (PET), effective rainfall and soil moisture content in total available water (TAW). PET was calculated based on the value of Kc and ETo (FAO 2007). Further analysis of the water balance to get the value in Cropwat 8.0 ETa was calculated based on the equation which is a daily water balance analysis to predict rrigation water requirements (FAO 2007).

$$Dr,i = Dr,i\text{-}1 - (P - RO)i - Ii - CRi + ETc,i + Dpi \cdots (1)$$

where:

Dr,i, root zone depletion at the end of day i (mm);

Dr,i-1, water content in the root zone at the end of the previous day, i-1 (mm);

Pi, precipitation on day i (mm);

ROi, runoff from the soil surface on day i (mm);

Ii, net irrigation depth on day i that infiltrates the soil (mm);

CRi, capillary rise from the groundwater table on day i (mm);

ETc,i, crop evapotranspiration on day i (mm);

Dpi, water loss of the root zone by deep percolation on day i (mm).

According to the equation, ETa was obtained from the difference between Dr,i and Dr,i-1 or similar to daily water content change.

Water Footprint Analysis of Oil Palm

The calculation of the water footprint (WF) according to SO 14046 (2010) and Hoekstra *et al.* (2011) consists of calculation in equation:

$$\text{CWU green} = 10 \times \text{average ET green} \cdots (2)$$

$$\text{CWU blue} = 10 \times \text{average ET blue} \cdots (3)$$

$$\text{WF green} = \frac{\text{CWU green}}{Y} \ (m^3\ ton^{-1}) \cdots (4)$$

$$\text{WF blue} = \frac{\text{CWU blue}}{Y} \ (m^3\ ton^{-1}) \cdots (5)$$

$$\text{WF grey} = \frac{\alpha \times AR/Cmax\ Cnat}{Y} \ (m^3\ ton^{-1}) \cdots (6)$$

where:

ET green, annual actual evapotranspiration during immature and mature stages over 2-15 years ($m^3\ year^{-1}\ ha^{-1}$);

ET blue, annual actual evapotranspiration during the nursery stage age in the first year ($m^3\ year^{-1}\ ha^{-1}$);

CWU green, crop water usage for green water ($m^3\ ha^{-1}$);

CWU blue, crop water usage for blue water ($m^3\ ha^{-1}$);

Y, annual average production of oil palm from Pundu Plantation (ton $year^{-1}$ ha^{-1});

α, nitrogen's leaching fraction

AR, chemical application rate per hectare (ton ha^{-1});

Cmax, maximum allowable concentration (mg L^{-1});

Cnat, natural concentration (mg L^{-1}).

Note that the assumption of nitrogen's leaching fraction is 10% whereas the maximum allowable concentration is 10 mg L^{-1}. Furthermore, the calculation of the FFB water footprint was done using equation:

$$\text{WF total} = \text{WF green} + \text{WF blue} + \text{WF grey} \cdots (7)$$

RESULTS AND DISCUSSION

Oil Palm Evapotranspiration Analysis Using Cropwat Version 8.0

For annual crops, the CWU is considered to be the value of the annual average evapotranspiration throughout the crop lifetime (Hoekstra *et al.* 2011).

Therefore, the value of annual oil palm crop evapotranspiration was simulated over a period of 15 years in terms of plant productivity. The different input characteristics of the palm trees in each stage was adopted to obtain the average annual evapotranspiration.

Available climate data used as input to obtain the estimation of daily solar radiation was used to calculate the ETo value (mm day^{-1}) as the standard evaporation in the Pundu region. Based on Cropwat analysis, the ETo value varied from 3.51 to 4.06 mm day^{-1} with an average value of 3.68 mm day^{-1}.

The analysis of annual crop water requirement using Cropwat 8.0 presented the simulation result of oil palm ETa (mm $year^{-1}$) and the water contribution from the precipitation rate (ETa green) as well as groundwater through irrigation (ETa blue). ETa, ETa green and ETa blue data are listed in Table 1.

Table 1 ETa green, ETa blue, ETa values of oil palm plantations

Age	ETa green	ETa blue	ETa
(year)	(mm)		
1	340.7	723.4	1064.1
2	948.7	0	948.7
3	1043.3	0	1043.3
4	1095.5	0	1095.5
5	1245.8	0	1245.8
6	1282.6	0	1282.6
7	1323.7	0	1323.7
8	1314.6	0	1314.6
9	1307.0	0	1307.0
10	1300.9	0	1300.9
11	1295.3	0	1295.3
12	1241.3	0	1241.3
13	1302.3	0	1302.3
14	1298.1	0	1298.1
15	1294.1	0	1294.1
Average	1175.6	48.2	1223.8

ETa: actual evapotranspiration
Source: Author's calculation using CropWat 8.0

It can be seen that the value of ETa shows the actual water usage of oil palms ranging from 948.7 to 1323.7 mm $year^{-1}$ with an annual average of 1223.8 mm $year^{-1}$ (Table 1).

Compared to this result, Yusop *et al.* (2008) calculated the annual crop evapotranspiration of oil palm in Johor, Malaysia to be between 1100–1365 mm $year^{-1}$ or similar to 3–3.7 mm $year^{-1}$. It is known that crop evapotranspiration represent the crop water requirement while the actual evapotranspiration (ETa) shows the actual crop water usage. This could be the same or less than crop evapotranspiration. From the results, it seems that the range of actual evapotranspiration was within the range of crop evapotranspiration of the case study in Malaysia which has similar climate conditions. It also means that the oil palms in the observation area did not have any significant water deficit. A review of several studies carried out by Carr (2011) revealed that the average of crop evapotranspiration was 4.1 mm day^{-1} (between 3.5–5.5 mm day^{-1}).

The value of ETa green was between 340.7-1323.7 mm $year^{-1}$, while ETa blue was between 0-723.4 mm $year^{-1}$. The ETa data in Table 1 show that the use of groundwater by plantations, represented by the value of ETa blue, is lower than the use of precipitation (ETa green). The use of groundwater through irrigation methods in oil palm plantations is only done when the crops are in the prenursery and nursery phases (Corley & Tinker 2016). As for crops in the immature and mature phases between the ages of 2-15 years continue to grow by relying on rainfall only.

Oil Palm Water Footprint Analysis

The average annual value of ETa, ETa green and blue of oil palm in mm $year^{-1}$ was obtained through the analysis of crop water requirement in Cropwat 8.0 which was subsequently converted to CWU value (m^3 ha^{-1}). The CWU value describes the volume of water used by crops per hectare of oil palm plantation.

Besides green and blue CWU, another parameter of water requirement needed to calculate the total water footprint was the grey CWU calculated specifically in Table 2 based on the data of average annual use of fertilizer in oil palm plantations. The value of the grey WF was calculated based on the equation (6) where the amount of fertilizer applied in the field was multiplied by the percentage rate of pollutants that were considered to flow freely into the water body (10%) divided by the difference between the standard limits of pollutants still acceptable by the environment (maximum acceptable concentration, Cmax) which is 10 mg L^{-1} with a natural concentration (Cnat) assumed to be zero (Hoekstra *et al.* 2009). Referring to Table 2, the grey CWU value was 1200.06 m^3 ha^{-1} which means it took as much as 1200.06 m^3 of water to dissolve a 0.12 ton of fertilizer used in 1 ha area so that the concentration of fertilizer will not contaminate the water body around the estate.

Furthermore, after each value of CWU green, blue and grey was obtained, the water footprint of FFB was calculated using equation (7) and the results are presented in Table 3. To obtain the value of the oil palm water footprint, the CWU value of the annual average obtained from the evapotranspiration data of crop aged 0-15 years of simulation divided by the average oil production (ton ha^{-1}) of mature crops ranging from 2-15 years old. This is based on the calculation of annual plants where the water footprint evapotranspiration values used are for lifetime crop evapotranspiration, whereas the crop production data is taken from the productive age (Hoekstra *et al.* 2009).

The value of total FFB water footprint on soil consisting of black clay and red sandy loam, crop productivity 13.41 ton ha^{-1}, the use of fertilizers contained nitrogen at 0.12 ton ha^{-1}, by assuming irrigation is given only for prenursery and nursery is 1002.1 m^3 ton^{-1} which consisted of 876.7, 35.9 and 89.5 m^3 ton^{-1}, for WF green, blue, and grey respectively. The water footprint value obtained in this study is higher than that of the Bulsink *et al.* study (2009) in which the WF during the research from 2002 to 2004 was around 853, 802,

Table 2 Calculation of oil palm grey water footprint

Average fertilizer applied	Nitrogen leached to water bodies 10%	Max conc	Natural conc	Total WF proc grey oil palm	Yield	WF grey	CWU grey
(ton yr^{-1} ha^{-1})	(ton yr^{-1})	(mg L^{-1})	(mg L^{-1})	(106 m^3 yr^{-1})	(ton ha^{-1})	(m^3 ton^{-1})	(m^3 ha^{-1})
0.12	0.012	01	0	0.0012	13.41	89.49	1200.06

Source: Author’s calculation

Table 3 Oil palm water footprint (m^3 ton^{-1} fresh fruit bunches)

CWU green	CWU blue	CWU grey	Oil palm production	WF green	WF blue	WF grey	WF total
	(m^3 ha^{-1})		(ton ha^{-1})		(m^3 ton^{-1})		
11756	482	1200.06	13.41	876.7	35.9	89.5	1002.1

Source: Author’s calculation

and 52 m^3 ton^{-1} for WF green, blue, and grey respectively. Additionally, the water footprint of oil palm was also calculated, repectively 1057, 0 and 40 m^3 ton^{-1} for each green, blue and grey water footprint, and 1098 m^3 ton^{-1} for total oil palm water footprint (Mekonnen & Hoekstra 2010).

The difference in water footprint values which generally ranges between 600-1300 m^3 ton^{-1} (Lovarelli *et al.* 2016) was strongly influenced by the type of oil palm plantation land, the climatic conditions of the local area as well as the conditions represented by the palm tree plant productivity (tons ha^{-1}). In comparison, Suttayakul (2016) analyzed the average water footprint of several provinces in Thailand. Using the crop water requirement scenario, the total water footprint was found to be 1063 m^3 ton^{-1} which consisted of 772 m^3 ton^{-1} green water footprint, 124 m^3 ton^{-1} blue water footprint and 166 m^3 ton^{-1} grey water footprint.

Suttayakul (2016) also calculated the average water footprint based on the actual evapotranspiration under varying soil textures (silt, loam, clay and a combination). In this scenario, the total water footprint was between 942-1206 m^3 ton^{-1} which consisted of 583-806 m^3 ton^{-1} green water footprint, 73-286 m^3 ton^{-1} blue water footprint and 69.9-294 m^3 ton^{-1} grey water footprint.

Based on the FFB water footprint in Pundu, Central Borneo, it can be seen that the water footprint of the oil palm is still much lower than that of other oil-producing crops such as sun flower seeds (3366 m^3 ton^{-1}), olives (3015 m^3 ton^{-1}), castor oil seeds (9896 m^3 ton^{-1}), coconut (2687 m^3 ton^{-1}) and rapeseed (2271 m^3 ton^{-1}) (Lovarelli *et al.* 2016). This shows that the water usage of the oil palm to produce FFB per ton is relatively lower and more efficient compared to other oil-producing crops. This can be the basis of scientific evidence showing that the oil palm is not a ‘water-hungry’ plant.

Moreover, the issue of high water absorption by the oil palm that could endanger groundwater reservoirs can also be proven untrue through this research. From the composition of the water usage of the oil palm, it can be seen that the green water footprint (WF 87.5% of the total) is more dominant than the value of the blue water footprint (WF 3.6% of the total). This indicates that the oil palm is grown using precipitation as the main source of water while the use of groundwater is less than 5% of total water use. Furthermore, the value of the water footprint could contribute as part of the total ecological footprint of the oil palm (Wackernagel & Yount 1998; Wiedmann & Barrett 2010). Musikavong & Gheewala (2016) concluded that rainwater and irrigation as the source of crop water usage is responsible for more than 90% of total ecological footprint analyses of oil palm and rubber plantations. In detail, the oil palm plantations need a slightly higher amount of water from the ecosystem than rubber plantations. Changes in the consumptive water footprint is possible. Chukalla *et al.* (2015) compared the reduction in the water footprint among different types of irrigation techniques and results show that the blue water footprint is higher in full irrigation systems than in rainfed agricultural systems. Nevertheless, they concluded that due to the increase in yield, the total water footprint tended to decrease which means a high efficiency of water usage.

Finally, the data of the grey water footprint can also be used to prove that the use of fertilizers in palm plantations is still relatively low i.e. only around 8.9% of the water is used to dissolve the fertilizers in order not to contaminate the environment. Related to this grey water footprint, the contribution of 8.9% grey water footprint of the oil palm in this research was lower than oil crops worldwide (11%) according to Mekonnen & Hoekstra (2015). Among the crops, cereals contribute the highest grey water footprint (18%), followed by vegetables (15%) (Mekonnen & Hoekstra 2015).

Overall, the contribution of oil palm green, blue and grey water footprint were 87.5%, 3.6% and 8.9% respectively. Referring to another case, Suttayakul (2016) concluded that the composition of green, blue and grey were 68%, 18% and 14 % respectively of the total average water footprint from several provinces in Thailand.

CONCLUSION

Based on the results of this study, it is concluded that the water footprint of the oil palm in the plantation in Pundu, Central Borneo is 1002.1 m^3 ton^{-1} and the value of the green, blue and gray water footprints are 876.7, 35.9 and 89.5 m^3 ton^{-1}, respectively. Soil types are black clay and red sandy loam, crop productivity 13.41 ton ha^{-1}, fertilizer usage 0.12 ton ha^{-1}, and irrigation is used only for pre-nursery and nursery plants. This result can be used as a reference for plantation managers regarding the precision of crop water requirement and in addition optimizing production. This research also proves that, the oil palm has a lower water footprint and is relatively not a 'water-hungry' crop compared to other oil-producing crops such as sun flowers, olives, castor, coconut and rapeseed. The value of the green and blue water footprints can distinguish between the main source of water usage, i.e. rain water or groundwater, for oil palm. The oil palms in research area are grown with precipitation as the main source of water not groundwater (blue WF is only 3.6% of the total WF). The grey WF is 8.9% which is lower than the grey WF of oil crops worldwide.

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