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Research

Water Footprint and Crop Water Usage of Oil Palm (*Eleasis Guenensis*) Under Varying Crop Ages and Soil Type as an Indicator of Environmental Sustainability

Lisma Safitri [1*], Hermantoro [1], Sentot Purboseno[1], Valensi Kautsar[1], Satyanto Krido Saptomo[2], Agung Kurniawan[3]

[1] Department of Agricultural Engineering, Stiper Agricultural University, Yogyakarta, Indonesia
[2] Department of Civil and Environmental Engineering, Bogor Agricultural University, West Java Province, Indonesia
[3] Research Centre PT Bumitama Gunajaya Agro, Pundu, Kotawaringin Timur, Kalimantan Tengah

* Correspondence: lisma.safitri86@gmail.com; lisma@instiperjogja.ac.id ; Tel. +62 852 2781 2729

Abstract: Various environmental challenges, related to oil palm commodity has became a major environmental challenge to oil palm production. The aim and objective of this study is to analyze the actual water footprint of oil palm based on root water uptake under varying crop age and soil type. The research was conducted in Pundu Village, Central Kalimantan. The methodology adopted in carrying out this study consists of various stages which includes observing soil moisture, rainfall, and water table, ETo, root water uptake and oil palm water footprint. The highest rate of water consumption was the 13 years oil palm on spodosol soil type with an average daily rate of 3.73 mm/day. The lowest evapotranspiration was represented by the 7th year oil palm on spodosol with an average rate of 3.07 mm/day. The total water footprint value obtained was between 0.56 – 1.14 m^3/kg for a variety of plants with various age and soil types. It can be deduced that the water footprint value of oil palm vary for different crop age and soil types on temporal scale. The study also presented that the source of green water from the first root zone of oil palm deliver the highest contribution for oil palm root water uptake.

Keywords: *water footprint, crop water usage, oil palm (Eleasis guenensis), crop ages, soil type, environmental sustainability*

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1. Introduction

The oil palm plantation in Indonesia is well developed from year to year. Based on analysis, it is found that, in 2015, the total area of oil palm in Indonesia was 5,980,982 Ha which increased by about 13.7% in 2017 to 6,798,820 Ha [1]. Various environmental challenges, related to oil palm commodity has become a major challenge to has a more environmental friendly production proses and supports environment sustainability. One of the persistent and reoccurring developing issues, is that of water usage. One of plant water usage efficiency parameter could be approached by water footprint method which indicates the quantity of water used by these plants for each biomass product. Water footprint of plants consists of green water footprint (from rainfall), blue water footprint (from aquifer, river, irrigation, etc.) and grey water footprint (certain quantity of water used to dissolve chemical substances in order to make it appropriate with the environmental threshold) [2]. Water footprint is generally affected by water usage from plant and its generated production. Two techniques are used to determine the rate of plant water usage or water utilization these are using crop water requirement (ETP) and crop water usage (ETA) [2,3].

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Plant water usage using ETA assumes more representatives to the real condition. There are various values of oil palm water footprint which is usually based on geographical location and climate condition. One should also note that the value of water footprint tends to vary based on soil type, plant age, etc.

Nowadays, water footprint has become an indication of environmental sustainability. There is the urgent and necessary need to develop oil palm plantation as a way to sustain plantation and encourage efforts to analyze water footprint condition in each plantation location. Water footprint analysis could be conducted in various methods such as eco-scarcity method, Milai Canals approach, Pfister approach, etc. [4]. The water footprint represents the total sum of water used in a supply chain, which comprises of blue, green and grey water [3].

However, the limitation of climate data which is the main factor used to analyze water footprint in oil palm plantation has become a major challenge. Asides that, the temporary cultivation of crops and the various impacts associated with it, has been neglected in analyzing it with globally [4]. Consequently, an annual assessment might be misleading regarding crop choices within and among different regions. A temporal resolution is therefore essential for proper life cycle assessment (LCA) or water footprint of crop production. For this purpose, we developed a water stress index (WSI) on a monthly basis for more than 11,000 watersheds with global coverage [5].

On the other hand, we calculated water footprint value using evapotranspiration and productivity approach which gave different range of variation between each region [6]. This analysis, was based on geographical location, climate condition, plant condition factors, soil types, etc. As a result of this, and in order to develop water footprint as a factor of environmental sustainability, a description of water footprint value in the specific location with various soil types and plant age is needed. Climate data limitation for analyzing water footprint in a specific timeframe, could be solved by developing a method of water footprint analysis using primary data. However, this is only achievable if plant evapotranspiration and oil palm fresh fruit bunch (FFB) production are in one farm.

Based on the above stated problems, it could be stated that WF variation values for oil palm are developed based on actual climate and production data in specified location. The current study is the first proposing specific development stage used in developing WF for oil palm under varying soil type and crop age in order to provide detailed information about WF oil palm and as an indicator of environmental sustainability in oil palm plantation. An accurate crop water analysis in oil palm stage is needed for a better understanding of the most efficient and precise crop water requirement and in order to reach the optimal productivity range. The varying climate condition, soil properties, crop stage, and water existing in an oil palm cultivation, requires the specific water balance analysis model which can evidence the precision condition of crop water use.

Soil properties is generally based on soil types. Generally, the soil types used for oil palm plantation in Indonesia are spodosols and inceptisols. These soils are spread across Kalimantan and Sumatra Island [7]. Most oil palm plantations in Indonesia are located in Kalimantan and Sumatra, making it quite easy to analyze the spodosols and inceptisols used and its relationship to water footprint.

There are limiting factors associated with the use of spodosols such as the depth of spodic layer, its sandy soil texture and its acidic texture associated with tropical area. The depth of the spodic layer is the main factor contributing to the poor root growth. This is because it depends on the roots to penetrate the soil, whereas the sandy soil texture will reduce the soil ability to retain water and produce greater chance for the soil to leach its nutrients. Other limiting factors that could possibly hinder plant growth include poor drainage and soil acidity.

According to [8], the depth of spodic layer on spodosols ranges from 30 to 70 cm below soil surface. Oil palm requires solum depth greater than or equal to 80 cm without layers of rock for optimal growth and development [9] a minimum depth of 75 cm [10].

Inseptisols is one of the acid mineral soils with low nutrient availability. The productivity of oil palm planted on the soil is low, and there are symptoms of decreased productivity in certain months of the year. The use of insepticols for agricultural purposes has resulted to many physical, biological

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and chemical inconsistencies properties of the soil. The problem associated with its physical properties is coarse texture of the topsoil, which happens to be less coarse in the lower texture. It is, therefore, ideal to say that permeability is rapid on the top surface and lower at the lower layer. The topsoil structure is granular or crumb with a lower unstructured layer. Furthermore, it has a lower density on the surface and an increasing depth. This happens to be one of the problems associated with biological properties such as species, population, and biota activities, while the problems related to chemical properties are high C-organic content (5,06 – 5,39%) low N-total percentage ranging between 0.15 – 0.42% which resulted in a moderate C/N ratio of about 12 – 35%. Cation Exchange Capacity is relatively moderate at about 14.1-17.3 me/100 g, while base saturation is low between the range of 24-29%. This low base saturation results in low nutrient and CEC availability [11].

The oil palm root architecture, consists of primary vertical and horizontal roots, secondary horizontal roots, vertical upward and downward growing secondary roots, superficial and deep tertiary roots and quaternary roots [12-14].

Therefore, in this research study, actual oil palm with various soil type and plant age water footprint analysis were carried out. Furthermore, a detailed description of water footprint value which can be a parameter for environmental sustainability was used as an implication of oil palm plantation in certain regions. The aim and objective of this study is to analyze the actual water footprint of oil palm based on root water uptake with the specific climate condition under varying crop age and soil type.

2. Materials and Methods

The research was conducted in Pundu village, Central Kalimantan from April to May 2017 and from June to August 2017. The tropical average condition observed was (i) average annual rainfall was 3002 mm/year (ii) average annual temperatures varied between 21.4 – 33.8 °C and, (iii) the average sunshine per hour was around 5.9 hours per year (based on the climate data series 2008-2015 from climate station of Pundu Plantation). The observation was carried out on an oil palm field of 22.457,7 hectares. The methodology used in achieving this study was accomplished through the following stages below:

2.1. Observing Soil Moisture, Rainfall, and Water Table of Variation of Crop Age and Soil Type

In order to better understanding the water balance system in oil palm tree, a set of computerized tools were installed to observe the water balance parameters such as rainfall, water table and soil moisture in oil palm root zone. The data was furthermore used to predict the crop water usage of oil palm as a main variable to determine the water footprint. The lateral water flux in and out of the oil palm system was also neglected.

The observation was undertaken on the varying soil types and crop age as shown below:

1. Soil type inceptisol, crop age 8th years
2. Soil type inceptisol, crop age 13th years
3. Soil type spodosol, crop age 8th years
4. Soil type spodosol, crop age 13th years
5. Soil type spodosol, crop age 7th years
6. Soil type ultisol, crop age 9th years

The rainfall was measured using an automatic double tipping bucket rain gauge while the water was measured using an automatic water level. The soil moisture in oil palm tree was observed by soil moisture sensor which spread horizontally and vertically in the root zone based under varying crop age and soil types by referring to oil palm root architecture [15].

2.2 The ETo Analysis by Penman Montheit

The evapotranspiration reference (ETo) is the main parameter of crop water usage. The ETo in this study was calculated using Penman Monteith according to study analysis by [16], [17], [18], [19]

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, [20], and based on the hourly climate data. The climate data which includes solar radiation, sun shine, wind speed, temperature and relative humidity were observed through the Automatic weather station (AWS). This set of climate data was observed from April – May 2017 and June - August 2017. The ETo was predicted using the Equation (1) by the standardization for grass crops [16], [17], [18], [19] , [20].

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \frac{Cn}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + Cd)} \quad [1]$$

ETo = reference evapotranspiration [mm day-1],

Rn = net radiation at the crop surface [MJ m-2 day-1],

G = soil heat flux density [MJ m-2 day-1],

T = mean daily air temperature at 2 m height [°C],

u2 = wind speed at 2 m height [m s-1],

es = saturation vapour pressure [kPa],

ea = actual vapour pressure [kPa],

es - ea = saturation vapour pressure deficit [kPa],

D = slope vapour pressure curve [kPa °C-1],

g = psychrometric constant [kPa °C-1].

Cn = numerator constant for reference type and calculation time step, aerodynamic resistance where the Constanta was 900 for daily, 37 for hourly daytme and nightime

Cd = denominator constant for reference type and calculation time step. Bulk surface resistance, and aerodynamic resistance where the Constanta was 0.34 for daily, 0.24 for hourly daytme and 0.96 for hourly nighttime

2.3 The Root Water Uptake Analysis Under Varying Crop Age and Soil Type

The crop water usage is the major formula used to calculate the water footprint in this research work. The root water uptake in oil palm root zone could be represented by the actual evapotranspiration in each root zone layer. The distribution of this root water uptake could also be determine using the water used by the oil palm which led to the emission of green or blue water. According to [20], there are several methods used for measuring ET (crop water usage)) such as change in soil water, lysimetry, Bowen Ratio Energy Balance (BREB), Eddy Covariance, Water balance and Remote Sensing Energy Balance. Since we have already observed the oil palm in fields as well as the water balance in small scales (plant and root zone), using the Penman Montheit Equation. Following the procedure in [20] and [16] research work, we installed some soil moisture sensor in the root zone layer followed by the result of oil palm root architecture [15] which we used to measure the change in soil water in root zone. The recorded change in soil moisture was then used to adjust the coefficient of oil palm compared to the change in soil moisture using Richard Equation [21], [22], [23], [24].

2.3.1. Calculate The Soil Moisture Change Based on the Richard Equation Model under Varying Soil Type Which Depends on Soil Properties

The soil properties of oil palm field study were denoted on Table 1.

Table 1. Soil properties and Van Genuchten parameter of soil type variation

Soil Type	Ultisol	Spodosol	Inceptisol
Sand (%)	33.3	89.29	52.38

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Soil Type	Ultisol	Spodosol	Inceptisol
Silt (%)	30.32	3.44	16.24
Loam (%)	36.39	7.28	31.38
Bulk Density (g/cm3)	1.33	1.42	1.38
Porosity (%)	49.91	46.59	47.86
Ks (Cm/hour)	10.31	36.49	8.24
Vg Paramaters :			
θs	0.439	0.404	0.418
θr	0.142	0.147	0.169
alpha	0.011	0.009	0.011
n	1.356	1.821	1.605

The distribution of soil moisture in root zone of oil palm was analyzed using The Richard Equation [21], [22], [23], [24], [25], [26] [45] as shown below:

- Water retention calculated by van Genuchten [23]:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_h}{\left(1 + |\alpha h|^n\right)^m}$$

$$m = 1 - \frac{1}{n} \quad [2]$$

- Water capacity (Darcy law and Richards Equation) :

$$C(h) = \frac{d\theta}{dh} = \frac{\alpha^n (\theta_s - \theta_r)(n-1)(|h|)^{n-1}}{\left[1 + (\alpha |h|)^n\right]^{2-1/n}} \quad [3]$$

- Hydraulic conductivity calculated by Muallem model [22]:

$$K(S_e) = K_s \cdot S_e^{\lambda} \cdot \left(1 - \left[1 - S_e^{1/m}\right]^m\right)^2 \quad [4]$$

- S degree of saturation [23]:

$$S_e = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} \quad [5]$$

- Water flux by vertical flow of Richards Equation :

$$J_w = -\left(K \frac{\partial h}{\partial z} - K\right) \quad [6]$$

- Richard Equation (positive downward): 1D vertical flow

$$\frac{\partial \theta}{\partial t} = -\frac{\partial J_w}{\partial z} - S$$

$$\frac{\partial \theta}{\partial t} = -\frac{\partial}{\partial z}\left(-\left(K \frac{\partial h}{\partial z} - K\right)\right) - S$$

$$\frac{\partial \theta}{\partial h} = C_w \quad [7]$$

$$C_w \frac{\partial h}{\partial t} = -\frac{\partial}{\partial z}\left(-\left(K \frac{\partial h}{\partial z} - K\right)\right) - S$$

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Abbreviation:
K = hydraulic conductivity (cm/hour)
h = water pressure head (Pa)
θs = saturated water content (cm^3/cm^3)
θr = residual water content (cm^3/cm^3)
α = air entry value (ha = α-1)
n = curve gradient
λ = pore-size distribution index
C (h) = water capacity
Se = effective saturation / degree saturation
m = empirical parameters
Jw = total flux (cm/hour)
S =sink factor, root water uptake/ accumulative actual evapotranspiration (cm/hour)

2.3.2. Determine The Root Water Uptake Distribution In Root Zone

The value of root water uptake which is considered as the actual evapotranspiration was analyzed by the varied Kc value and reference evapotranspiration (ETo) as showed in Equation (8) below:

$$ET = K_c \times ET_o \quad [8]$$

Abbreviation :
ET = evapotranspiration (root water uptake) (mm/hour)
Kc = crop coefficient
ETo = reference evapotranspiration (mm/hour)

The crop coefficient based on grass crop is the ratio of ET to ETo which depends on nonlinear interactions of soil, crop,atmospheric conditions, and irrigation management practices [16], [20]. A major uncertainty associated with using this approach is that a good number of Kc values used in the literature were empirical and often not adapted to local conditions. Therefore, in this research study, the crop coefficient (Kc) was determined through the calibration between the soil moisture change model based by Richard Equation and soil moisture change observation-based on soil moisture sensor placed in root zone. Based on the study, it can be deduced that the value of Kc varies between 0.68 – 0.7 for different crop age of oil palm (7-13 years). Furthermore, the total root water uptake was partitioned along the root zone of oil palm [15] which was referred to as the root density distribution.

2.4. The Monthly Oil Palm Water Footprint Analysis Under Varying Crop Age and Soil Type

The calculation of water footprint was figured out based [2], [3] research work. The water footprint concept includes green, blue and grey water footprints (Equation 9, 10 and 11). Due to the absence of fertilization during the observation period, the grey water footprint was disregarded. The monthly water footprint of oil palm was determined based on the Equation given below. This involved the root water uptake as evapotranspiration (mm/month) and oil palm yields (kg/month). Furthermore, the calculation of water footprint was done using Equation (12).

$$WF\ green = \frac{10\ x\ ET green}{Y}\ (m^3/ton) \quad [9]$$

$$WF\ blue = \frac{10\ x\ ET blue}{Y}\ (m^3/ton) \quad [10]$$

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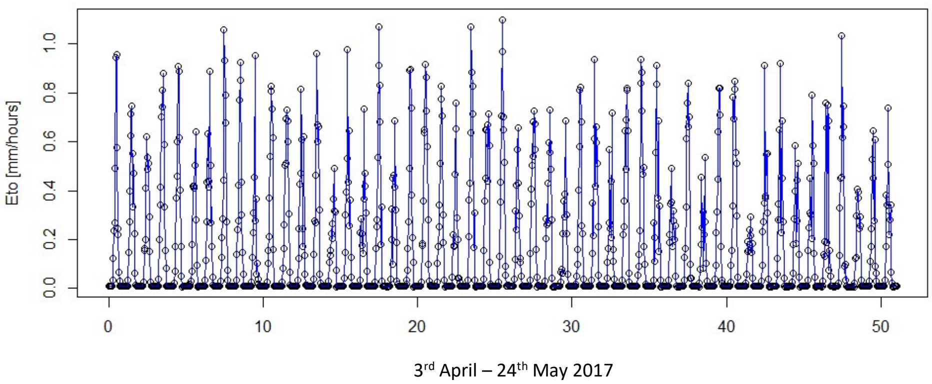
$$WF\ grey = \frac{\alpha\ x\ AR\ /(Cmax - Cnat)}{Y}\ (m^3/ton) \quad [11]$$

$$WF_{Total} = WF_{green} + WF_{blue} + WF_{grey} \quad [12]$$

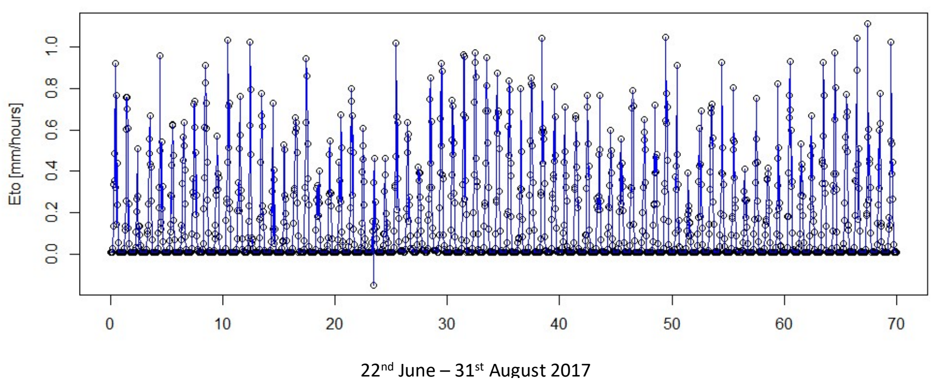
The ET green was considered as root water uptake from rainfall and ET blue from groundwater. The contribution of groundwater to oil palm was neglected because the water level depth was below 10 m which is where the root zone only reaches 2 m maximum. The oil palm absorbed the water from capillary only in shallow ground water in this case < 2 m from top soil. Apart from the value of crop water used, it is required to determine the yields data production of oil palm in order to determine the oil palm water footprint.

3. Results

3.1 Evapotranspiration Reference (ETo) as the Main Parameter of Crop Water Usage



(a)



(b)

Figure 1. The ETo (mm/hour) of oil palm plantation area in Pundu, Central Borneo during (a) April – May 2017, (b) June – August 2017

The ETo is the main factors used to determine the crop water requirements based on the rate of transpiration in the area. Figure 1 (a) dan Figure 1 (b) demonstrates the result of the ETo (mm/hour) in study area for 2 consecutive observations. Figure 1 (a) showed that the ETo (mm/hour) between 3rd Aprill – 24th May 2017 has an average of 0.1(a) 7 mm/hour, with the minimum value recorded during the night and with a maximum value of 1. 099 mm/hour. For daily rate, the average of ETo was 4.18 mm/day. Figure1 (b) pointed out the ETo (mm/hour) during 22nd June – 31st August 2017 on

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the average was 0.16 mm/hour, with the minimumvalue obtained during the night with a maximum value of 1. 114 mm/hour. For daily rate, the average of ETo was 3.87 mm/day.

The maximum hourly reference evapotranspiration was slightly higher between 22nd June – 31st August 2017 than 3rd April – 24th May 2017. The average daily reference evapotranspiration obtained during the first period was slightly higher than the latest. Nevertheless, the maximum hourly reference evapotranspiration was slightly lower. It shows that in the field study which is categorized of the tropical rainforest zone, there's insignificantly different rate of reference evapotranspiration.

3.2 Oil Palm Root Water Uptake (mm/day) Analysis and Its Distribution in Root Zone

The term evapotranspiration (ET) has become more common compared to the term consumptive use. ET is the same as consumptive use, the only difference being that the later includes minor water retained in the plant tissue that is relative to the total ET [20]

In this research study, the term consumptive use was represented by the root water uptake of oil palm which is obtained from water absorption of root spread along the root zone. Many studies such as [27], [28], [29] shows that the highest contribution of root extraction comes from the smaller/ finer root. Among the 4th level oil palm root architecture, the size (primary, secondary, tertiary and quarterly root), the tertiary and quarterly absorbs more water than others [12], [13], [14]. According to [15], a classified oil palm root zone in several types of soil and oil palm crop age in oil palm field in Pundu, Central Borneo as shown in Table 2.

Table 2. The oil palm root zone under varying soil type and crop age

	Soil type and Crop age					
	Inceptisol 8th years	**Inceptisol 13th years**	**Spodosol 8th years**	**Spodosol 13thyears**	**Spodosol 7th years**	**Ultisol 9th years**
Root zone 1 (cm)	0-30	0-50	0-9	0-5	0-9	0-30
Root zone 2 (cm)	30-60	50-150	9-18	5-25	9-18	30-60
Root zone 3 (cm)	60-90	150-200	18-28	25-57	18-28	60-90
Spodic layer (cm)	-	-	56	56	56	-

Furthermore, based on that root zone classification, some field and laboratory works were established to analyze the distribution of root density (gr/cm^3) in oil palm root zone as displayed in Figure 2. The root density represents the mass of oil palm root for each bulk soil volume. With regards to Figure 2, the value of root density can be seen to be varying between 0 – 0.1 gr/cm^3. It also varies with the soil type and crop age.

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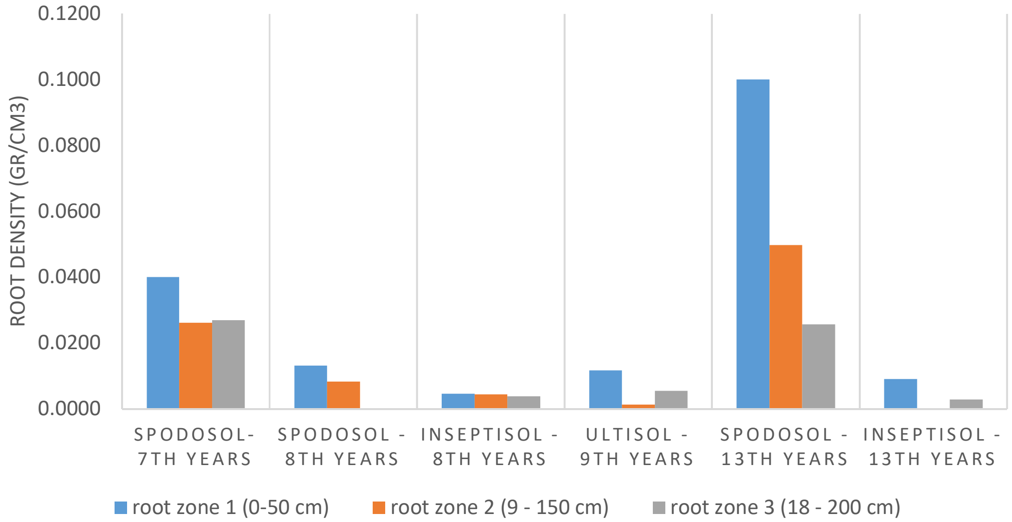

Figure 2. The distribution of oil palm root density under varying soil type and crop age

For example, among all the plants studied, the oil palm with a 13th years lifespan on spodosol has the highest root density which consisted of 0.1001 gr/cm^3, 0.0497 gr/cm^3, 0.0257 gr/cm^3, for 1st, 2nd and 3rd root zone respectively and followed with the oil palm fruit with a lifespan of 7 years on spodosol with 0.0400 gr/cm^3, 0.0262 gr/cm^3, 0.0270 gr/cm^3 in the same order. The lowest root density was obtained by the oil palm 8th years on inceptisol gradually 0.0046 gr/cm^3, 0.0045 gr/cm^3 and 0.0038 gr/cm^3. The root density hereafter was used to determine the contribution of root water uptake in root zone of oil palm.

According to this study, the highest dense root density was on first root zone, followed by the next layer. Among the soil type, it seemed that the spodosol contained denser of root than inceptisol and ultisol. With regards to Table 1, the spodosol is consists of sands (89 %), silt (3%), and loam (7%), while, inceptisol and ultisol dominantly structured by the higher composition of loam and silt. It also could be seen that the root density decrease gradually from the older to the younger oil palm plant in the same soil type.

The root water uptake in this study is calculated based on the standard of reference evapotranspiration and crop coefficient. The root water uptake value illustrates the actual condition for adjusting the Kc value obtained from calibrating the result obtained by the soil moisture change model using Richard Equation [21] and sensor technique. There are a variety of Kc value obtained which are between the range of 0.68 – 0.7. Those values are lower than the KC standard usually used for determining the crop water requirement of palm oil that are between 0.8-0.9. Figure 3 shows the distribution of root water uptake in oil palm root zone.

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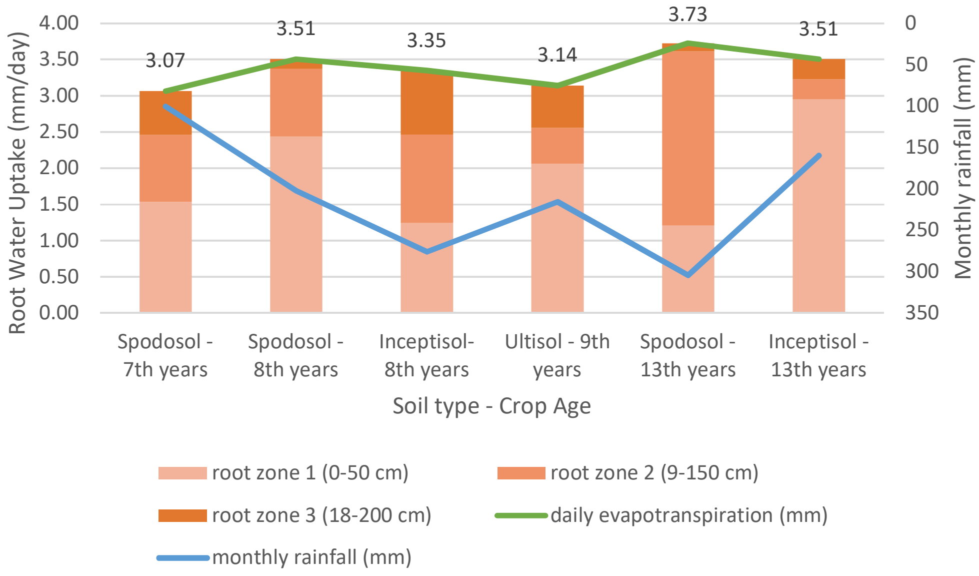

Figure 3. The distribution of root water uptake in oil palm root zone

Based on this study, the average root water uptake in the observation area varies between 3.07 – 3.73 mm/day though this depends on the crop age and soil type. The highest consumptive water used was contributed by the 13th year oil palm with on spodosol and with an average daily rate of 3.73 mm/day, followed by the 8th year oil palm with an on spodosol and 13th years on inceptisol with 3.51 mm/day. The lowest actual evapotranspiration was represented by the 7th year on spodosol by 3.07 mm/day.

The distribution of root water uptake on Figure 3 performed that the first root zone of oil palm contributes more water than the 2nd and 3rd layer. For example, for the oil palm plantation with a lifespan of 13 years on inceptisol, the root water uptake from the 1st root zone reached almost 85% followed by the 8th year spodosol by 69%, 9th year ultisol by 65%, and the 7th year spodosol by 50%. The root water uptake on the 8 years oil palm on inceptisol seemed distributed on the root zone layer (38%, 36% and 26%). While the different case showed by 13th year oil palm on spodosol which has root water uptake distribution mostly contributed on 2nd root zone by 65% and followed by the 1st and 2nd root zone by 32% and 3% respectively.

The analysis of oil palm root water with a variety of soils and ages could also describe the relationship and influence between the parameters. Table 3, shows the correlation test result between the derived variable from soil types such as Ks (*Saturated hydraulic conductivity),* the total available water (TAW) and plat ages such as crop age and yields also the climate factor such as rainfall. From Table 3, it could vividly be seen that there are some strong relations between the parameters with the root water uptake. The total root water uptake value has a positive correlation with the crop age by 0.730. It was also found that the inverse correlations between the root water uptake in zone 3 with the yields.

Table 3. The variable correlations by root water uptake

Variable	RWU total	RWU_z1	RWU_z2	RWU_z3
	cor_est	cor_est	cor_est	cor_est
Precipitation	0.607	-0.476	0.678	-0.069
Sat. hydraulic conductivity (Ks)	0.206	-0.279	0.547	-0.527
Crop age	0.730	0.242	0.257	-0.591
Yields	0.408	0.093	0.383	-0.816

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Total available water (TAW)	-0.466	0.160	-0.442	0.333

3.2 Oil Palm Water Footprint under Varying Crop Age and Soil Type

According to the root water uptake and yield production, the value of oil palm water footprint could be analyzed. Figure 4 denotes the oil palm water footprint (m^3/kg FFB) under varying crop age and soil type. The total water footprint of oil palm varied between 0.56 – 1.14 m^3/kg., with the highest water footprint obtained on the 8th year oil palm on inceptisol by with a value of1.14 m^3/kg. However, the lowest was the 7th year oil palm on spodosol by 0.56 m^3/kg.

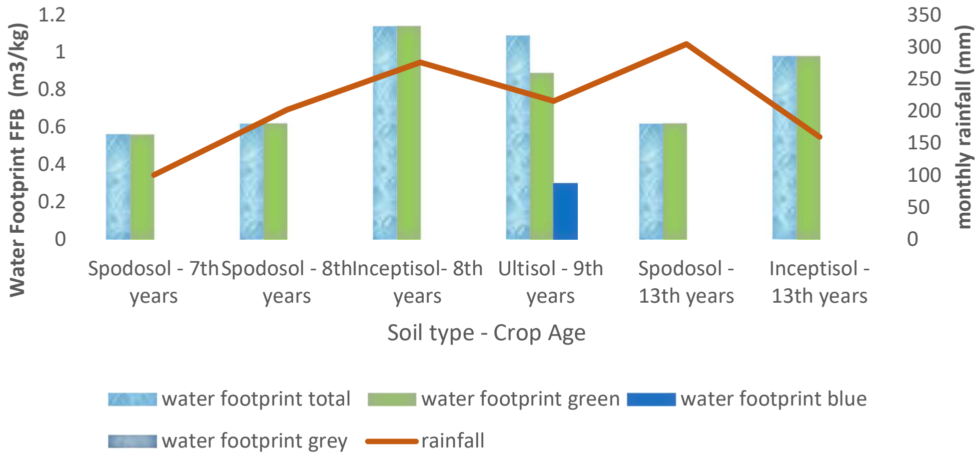

Figure 4. The oil palm water footprint (m3/kg FFB) under varying crop age and soil type

Figure 4 showed that water footprint of oil palm was mostly contributed by the green water which was pointed out by the green water footprint. The only blue water which contributed to oil palm crop water usage was that of the 9th year oil palm on ultisol. The green and blue crop water usage was determined based on the ground water level and the longest root in root zone.

The contribution of groundwater was neglected in area where the water level depth was below 10 m and where the root zone only reaches 2 m maximum for the 8th and 13th years oil palm on inceptisol. The oil palm absorbed the water from capillary only in shallow ground water in this case < 2 m from top soil in case of 9th year of ultisol. For the spodosol, there were a spodic layer which does not allow water to flow both as deep percolation and capillary.

The analyses of oil palm water footprint with various kinds of soil types and ages could also illustrate the influential relation among the parameters. Table 4 shows the correlation test result between the descendant variable from various soil types such as Ks (*Saturated hydraulic conductivity),* the total available water (TAW) and plant ages such as crop age. This also yields some climatic factor such as rainfall. From Table 4, it could be seen that the total value of water footprint and the green water footprint negatively correlate to the Ks value with -0.975. Meanwhile the blue water footprint positively correlated with TAW (Total Available Water) value of 0.977.

Table 4. Varible correlation with water with a total, green and blue footprint

Variable	Yields	WF total	WF green	WF blue
	cor_est	cor_est	cor_est	cor_est
Precipitation	0.147	0.259	0.276	0.038998
Sat. hydraulic conductivity (Ks)	0.619	-0.975	-0.948	-0.407357
Crop age	0.361	0.054	0.103	-0.122859
Yields	-	-0.596	-0.733	0.191347

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Total available water (TAW)	0.026	0.646	0.383	0.977579

4. Discussion

In order to properly calculate the water footprint value of oil palm, adequate information about crop water usage is needed. The crop water usage in this study is calculated based on the reference evapotranspiration standard. Furthermore, the crop coefficient from the calibration process is carried out using the soil moisture change model of Richard Equation [21].

Furthermore, the ETo value was analyzed using Penman Montheit [16], [18], [20].Although there are many modern approaches which could also be used, such as lysimeters, a soil water balance approach, eddy covariance methods, a Bowen ratio energy balance system, or a surface renewal method, the Penman–Monteith combination Equation is widely accepted as the best-performing method for reference evapotranspiration estimates from a well-watered hypothetical grass or alfalfa surface [30].

ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The only factor affecting ETo is climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. According to [16], the FAO Penman-Monteith method is recommended for determining ETo. The method was selected because it closely approximates grass ETo at the location evaluated, it is physically based, and it explicitly incorporates both physiological and aerodynamic parameters.

The climate data for ETo analysis is obtained from AWS using the hourly time step. This analysis could also be the parameter of drought of an area [31], [32], [33], [34], [35]. Therefore, in order to improve water management quality of oil palm fileds, the ETo analysis by hourly time-step for local-temporal scale of data should be evaluated. The calculated ETo using a benchmark such as the application of lysimeter shows the proper result[37]. Similarly, the ETo calculated result is validated using the Kc value which is adjusted to the calculation result of soil moisture. Furthermore, the hourly ETo value is accumulated which resulted to a daily ETo.

The average daily reference evapotranspiration obtained during the first observation period was slightly higher than the latest. However, the maximum hourly reference evapotranspiration was never than the least. This analysis has it that in the field study categorized by tropical rainforest zone, there's different rate of reference evapotranspiration. According to [37] comparing both shows that the average daily reference evapotranspiration in tropical wetland of Northeast India ranges between 2.4 – 3.6 mm/day with the maximum rate during summer (June – September). The ETo analysis in the location study showed a higher result.

This result was, however, influenced by the several factors such as geographical location and the composition of land cover (high dense oil palm cultivation). However, according to FAO-56 data obtained, the average value of ETo for tropical area particularly in humid and sub-humid zones like in Borneo in Indonesia, ranges between 3-5 mm/day for moderate temperature and 5-7 mm/day for warm temperatures [16].

Based on this study, the average root water uptake in the observation area in which varied between the ranges of 3.07 – 3.73 mm/day depends on crop age and soil type. The root water uptake represents the actual evapotranspiration of oil palm in Pundu, Central Kalimantan, Indonesia. This can be compared to the result, obtained in the research work carried out by [38] where the annual crop evapotranspiration of oil palm in Johor, Malaysia was calculated to be between 1100 – 1365 mm/year or similar to 3 – 3.7 mm/day. [39] analyzed several studies and pointed out that the average oil palm crop evapotranspiration was 4.1 mm/ day (between 3.5 – 5.5 mm/day). This actual evapotranspiration in this study referred to oil palm crop water usage.

Comparing this to other types of plant, [40] showed that the maximum value of daily evapotranspiration varies between 3.3 to 5.6 mm / day for rain fed sunflower and 6-7 mm / day for sunflower with optimal irrigation. Similarly, [41] observed that the evapotranspiration of irrigated sunflower and canola varied between 3.6 - 10 mm / day and 2- 11 mm / day respectively. This is

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similar to comparison among the oil corps, with the consumptive water use of oil palm showing a lower rate.

On the other hand, comparing crop water use with forest plants shows that the level of oil evapotranspiration is slightly higher. A one year daily observation in Bornean Tropical rainforest resulted to a varied evapotranspiration between 2.7 - 2.8 mm / day [42]. From the analysis obtained, it could be concluded that oil palm is not a crop with an extreme absorption rate that could be categorized as a waste of water. Even if it could be compared to forest plants with the same location, there water absorption rate is slightly different.

As the plant grow and absorbs more water, the root water uptake increases as the ages of the plant. Similarly, the oil palm on spodosol absorbs more water than ultisol and inceptisol. This is in line with the root density level shown in Figure 1 (b), which happens to be where the spodosol contains a denser root than others. It is also supported by the production data in Table 5. The spodosol soil type is higher than inceptisol. Generally, we also could assume that the highest contribution of root water uptake was on first zone which correlates to the root density distribution.

Table 2. Yield production of FFB (kg/ tree/month) in field study

Soil type	Crop age (year)	Yield FFB (kg/tree/month)
Inceptisol	8	10.73
Spodosol	8	14.69
Spodosol	7	13.06
Ultisol	9	14.19
Inseptisol	13	12.83
Spodosol	13	15.62

This can be said to be similar to [27] research study which showed that the root length density and the potential rate of root extraction decreased with the depth of root zone of oil palm. Meanwhile the soil moisture extraction efficiency (SMEE) value increased with depth and distance from the palm. With regards to other plants, [28] showed that the observed corn field extracted moisture mainly from the upper root dense soil profile when water content is in an optimal range. [29] beamed that the distribution and density of wheat roots increases the water uptake.

The oil palms are often regarded as a wastewater plant capable of absorbing a high amount of water, thereby and threatening the availability of ground water. From the results obtained from this study, it could be seen that the low level of root water uptake when compared to other oil-producing plants such as sunflower and canola, the distribution of the root water uptake of oil palm plants is mainly from the upper root zone layer. In the first layer, the soil moisture comes from rainfall, while in the second layer it comes from 1) the rainwater with deep percolation or 2) the capillary from ground water from a shallow water level with a maximum depth of roots.

Furthermore, the amount of crop water used by the root water uptake is used to analyze the oil palm water footprint with the supported production data listed in Table 5. The water footprint analysis in this research study is location-specific and also based on partial temporal climate data applicable between April – May, and July-August. Various studies related to crop water footprint are mostly provided by the global annual result by ignoring the temporal aspects and other influential factors. In fact, in some areas such as the Kalimantan region, the temporal aspects and local climate data greatly varies and affects the consumption and use of water as a major factor in the crop water footprint.

The pattern of crop water footprint changes considerably with higher temporal resolution [5]. According to their analysis, it can be concluded that, in many regions it is relevant to consider the monthly WSI (water stress index) than the annual ones. The changes are also shown to be sensitive to crop types due to different growth patterns leading to an increasing or decreasing water footprint.

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In line with this opinion, the results of the study show that there are variations in WF values for various conditions that represent the differences in rainfall, soil type and growth of oil palm plantations.

The water footprint of oil palm FFB for soil type of spodosol is lower than inseptisol and ultisol. With the same type of soil, younger plants have a higher water footprint as shown in Figure 4. The crop water footprint is mainly driven by yield trends, while the evapotranspiration plays a minor role in the annual water crop analysis for wheat, rice, and maize and soybean footprint. [43] beams that apart from correlation with yield and irrigation volume, the WF values are not correlated to soil properties. However, it could be seen in Figure 3 that root water uptake (mm / day) varies.

Therefore, if drawn on the annual global scale, there will be a huge significant difference between these variables. The process of root water uptake analysis itself in this study is strongly influenced by climatic factors, soil physical properties and plant coefficient factors. To this analysis, the discovery of variations in root water uptake and water footprint values at the local and temporal scale in this study could enrich the water footprint information on palm oil plants in particular, as well as other types of plants.

Furthermore, another interesting fact worthy of discussion in this research study is the percentage contributions from each element of water (green, blue, and gray) to the total water footprint value of oil palm with variations in age and soil type. As shown in Figure 4, assuming no fertilization occurred during the observation process, the WF gray contribution would be 0%, while the green temporal water footprint reached would be 100% of the total WF for almost all variations except for 9 years oil palm with ultisol. From this, it can be deduced that there is a total of 25% blue water contribution rate out of the total WF due to the presence of shallow ground water with a depth of <2m.

In this oil palm WF analysis, the range of blue water footprint is relatively small. In its annual scope, [15] showed that the green, blue, and gray water footprints were 876.6, 35.9, and 91 m3 ton-1, and the contributions were 87.3%, 3.6% & 9% for case study in oil palm plantation in Pundu, Central Borneo. In addition to this, [44] obtained the composition of green, blue and gray to be 68%, 18% and 14% of the total average of water footprint from several provinces in Thailand.

The crop water footprint for tomato cultivation showed the highest variability found in the WF green component which ranged from 5% to 45.2% [43]. The blue WF ranged from 14.3% to 63.6% and gray WF from 23.8% to 46.5% out of total WF. Therefore, it could be said that the range of groundwater use in oil palm plants in this study is relatively small. With no irrigation activities in the field, the possibility of using blue water only comes from the capillarity of groundwater.

The total value of the water footprint, the use of green and blue water and the distribution of root water uptake in the rooting layers of oil palm could be described as an indication of environmental sustainability. The various negative issues associated with the absorption of water by oil palm plants are inversely proportional to the results obtained in this study. The root water uptake of palm oil is still relatively low compared to other food crops. In addition, the maximum level of water absorbed in the upper root zone also shows that oil palm plants absorb a lot of rainwater (green water) which is fast circle compared to ground water (blue water) which is long circle.

The last interesting analysis is the variation of the water footprint value on various types of soil and plants of all ages. The variation in WF values is derived from the variations of the actual yields which functioned as a maintenance factor and the variations of actual crop water used and which represents the plant water adequacy. Therefore, further research is required to determine the value of oil palm on benchmark water footprint. With the benchmark, the variation in the water footprint value could illustrate whether the plant is lacking water or consumes excess water.

5. Conclusions

1. The average root water uptake in the observation area varied between 3.07 – 3.73 mm/day. This, however, depends on crop age and soil type. The highest consumptive water use was contributed by the oil palm with 13 years life span on spodosol with the average daily rate of 3.73 mm/day. This was followed by the oil plant with a lifespan of 8 years on spodosol and 13th years on

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inceptisol with 3.51 mm/day. The lowest actual evapotranspiration was represented by the 7th year oil plant on spodosol by 3.07 mm/day.

2. The total water footprint value obtained ranges from 0.56 - 1.14 m3 / kg for various plant ages and soil types. With the higher yields, it can be concluded that the water footprint value of oil palm FFB for spodosol soil types is lower than inseptisols and ultisols.
3. Using the same soil type, it can also be analyzed that the plants with younger ages have relatively higher water footprint value. This water footprint value illustrates the efficiency of water use by plants. The higher the productivity, the higher the value of water used.
4. The detailed description of water footprint value could be a parameter for environmental sustainability as an implication of oil palm plantation in certain region. The highest contribution of green water footprint, as well as the highest root water uptake in first root zone.

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Acknowledgments: This research and publication was full supported by Oil Palm Plantation Fund Management Agency (BPDPKS), Indonesia. We also thank our colleagues from PT Bumitama Gunajaya Agro, Indonesia who provided the location, accommodation and the labours that greatly assisted the research. We thank our college doi:10.20944/preprints201809.0561.v1

Peer-reviewed version available at *Water* **2018**, *11*, 35; doi:10.3390/w11010035

Rudyanto and Andiko Putro Suryotomo for assistance with the running data analysis using R in finite different method.

Author Contributions: Conceptualization, Lisma Safitri and Hermantoro Hermantoro; Data curation, Valensi Kautsar; Formal analysis, Valensi Kautsar; Project administration, Agung Kurniawan; Supervision, Sentot Purboseno; Writing – original draft, Lisma Safitri; Writing – review & editing, Satyanto Krido Saptomo.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results".