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WATER FOOTPRINT: PART 1 - PRODUCTION OF OIL PALM SEEDLINGS IN PENINSULAR MALAYSIA

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ABSTRACT

The oil palm nursery is the first link in the palm oil supply chain where oil palm seedlings are produced for the cultivation of palms in plantations. The water footprint for this study focuses on the volume of water required for the production of oil palm seedlings in Malaysia, which include direct and indirect water consumption. This study was carried out at 21 nurseries in Peninsular Malaysia for the duration of four years. In this study, the water footprint is expressed as water volume per unit of the product, i.e. m^3 t^{-1} *fresh fruit bunch (FFB). This article outlines the components of water footprint which are associated with the production of oil palm seedlings. The methodology used to calculate water footprint for the production of oil palm seedlings was based on water footprint network. The results showed that the direct blue water footprint was 1.57E-01* m^3 t^{-1} *FFB, contributed by irrigation water using sprinklers and also the water used for pesticides application. The total indirect blue water footprint contributed by all the inputs such as diesel, electricity and polybags was 1.46E-04* m^3 t^{-1} *FFB. Green and grey water footprint was found to be 3.10E-01 and 1.83E-03* m^3 t^{-1} *FFB, respectively. From the analysis, it was found that the water footprint for the production of oil palm seedlings were 1.57E-01, 3.10E-01 and 1.83E-03* m^3 t^{-1} *FFB for the blue, green and grey components, respectively. Therefore, it could be concluded that the volume of polluted water (grey water footprint) associated with the production of oil palm seedlings was very minimal.*

Keywords: water footprint, oil palm seedlings, water footprint network, irrigation.

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INTRODUCTION

The oil palm nursery is the starting link in the palm oil supply chain, followed by oil palm plantation and oil palm mills. In 2009, 2010, 2011 and 2012, the total productions of germinated oil palm seeds in Malaysia were 86.4, 76.5, 72.6 and 75.2 million, respectively (MPOB, 2010; 2012). The productivity of an oil palm plantation depends on many factors, and the most important starting point is the quality of the oil palm seedlings derived from cross pollination of selected parent palms for use in commercial planting. The production of high quality oil palm seedlings is very much dependent on good nursery management and practices. A nursery stage is required because oil palm requires constant close attention during the first 10 to 12 months of its growth and development.

There are two types of nursery practice – single-stage and double-stage. The technique of raising seedlings in large polythene bags (polybags) before transplanting them to the field is known as a single-

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stage nursery system. A double-stage nursery consists of a pre-nursery and a main nursery. In the pre-nursery, seeds are sown in small polybags (15 cm x 23 cm) in which the seedlings are maintained until they are approximately three to four months before transferring them to large polybag (30 cm x 38 cm or 38 cm x 45 cm). All seedlings should get sufficient water at 0.5 litres per polybag per day in the pre-nursery, and 2.0 litres per polybag per day in the main nursery.

Water footprint can be defined as the amount of water that is needed to produce different goods and services (Chapagain and Hoekstra, 2004). A water footprint consists of three components: blue, green, and grey. The blue water footprint is the volume of freshwater that evaporates from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community. The green water footprint refers to consumption of rain water (rain water insofar as it does not become run-off). The grey water footprint is the volume of polluted water associated with the production of all goods and services for the individual or community. The latter can be estimated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains at or above agreed water quality standards (Hoekstra and Chapagain, 2007; Wikipedia, 2013a).

Malaysian palm oil is one of the major exports in the world and Malaysia's income is largely contributed by the palm oil industry. The industry has been constantly asked to prove the sustainability of its products. Sustainability is no longer an option but the primary driver of economic development in the long-term. Sustainability has to be part of the oil palm industry's business strategy. The interest of the oil palm industry will be best served if stakeholders maximise their financial performance by strategically managing their economic, social, environmental and ethical performances. Central to this is the development of the oil palm industry in a sustainable manner which is vital for the long-term profitability of the oil palm business.

In view of the imminent need for the oil palm industry to be accountable for its water consumption, it is very crucial to first quantify the water footprint of the industry and then identify areas of high water intensity. The next step will be to reduce the water consumption as much as possible. In this manner, the oil palm industry will remain competitive and sustainable in the global market. This will also ensure the market access and the ability to compete with other sources of oils and fats.

The water footprint is a new concept and was first introduced by Hoekstra in 2003. In 2004, Chapagain and Hoekstra made a more specific study about the water footprints of nations. Using similar principles, the water footprint can also be calculated for a person or for a business. According to Chapagain and Hoekstra (2004), the water footprint has been developed in analogy to the ecological footprint, which was introduced by Wackernagel and Rees in 1996.

Much research had been carried out to determine the water footprint network. A paper on the water footprints of nation: water use by people as a function of their consumption pattern was studied by Hoekstra and Chapagain (2007). Several studies had been carried out and reported on water footprint of cotton consumption, water footprint of bio-energy and also carbon, and water footprint of soap bar (Chapagain *et al*., 2006; Gerbens-Leenes *et al*., 2009; Francke and Castro, 2013). On top of that, there was a paper on the energy and water trade-off in enhancing food security by Mushtaq *et al.* (2009) and a study on the water footprint of oil palm grown in Thailand was also carried out (Seewiseng *et al*., 2012). There was also a review paper by Kaenchan and Gheewala (2013) on water footprint of biofuel crop production in Thailand. Vijaya *et al.* (2011) has reported an overview of the water footprint for the oil palm industry. However, to date, there are no reports on the water footprint of the oil palm seedlings at the nursery stage. Therefore, there is a need to carry out water footprint assessment at this stage of growth. Hence, the main objective of this article is to study the blue, green and grey water footprint components from cradle-to-gate of oil palm seedlings production based on the water footprint network methodology.

Functional Unit

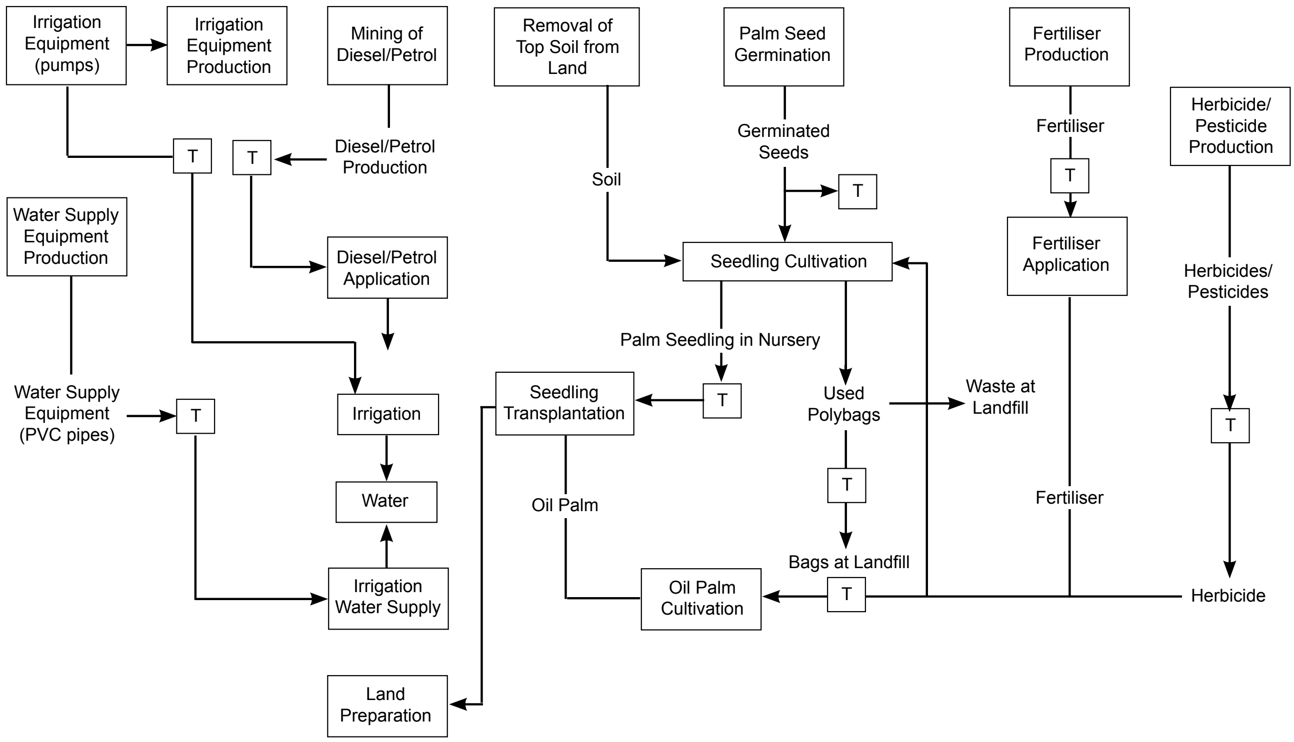
All inputs and outputs have to be related to a common reference unit. The relevant function of the system under study is to provide oil palm seedlings to be transferred to oil palm plantations. Thus, an appropriate functional unit for this study is m^3 water per tonne fresh fruit bunch (FFB).

Data Collection

For this study, 21 oil palm nurseries licensed by the Malaysian Palm Oil Board (MPOB) were selected for collection of inventory data for the production of oil palm seedlings. These oil palm nurseries, located in West (Peninsular) Malaysia, practised the double-stage nursery system. Annual inventory data over a four-year period were collected and analysed to obtain average reading for each parameter.

System Boundary

Figure 1 shows the representation of the production of oil palm seedlings life cycle. This study is a cradle-to-gate system boundary beginning with the transportation of germinated seeds to the nursery



Note: T - transport.

Figure 1. Schematic representation of the production of oil palm seedlings life cycle.

and ending with the transportation of 12-month old seedlings in big polybags to the plantation. The system boundary includes the production of pre-plantation inputs, *i.e.* the cultivation of oil palm seedlings in the nursery.

METHODOLOGY

Calculation of the Green, Blue and Grey Water Footprint of Growing Oil Palm Seedlings

The total water footprint for production of oil palm seedlings (WF_{proc}) is the sum of the blue, green and grey components. The calculation of the green, blue and grey water footprint of growing oil palm seedlings was based on Hoekstra *et al.* (2011).

Blue Water Footprint

Direct water. The water footprint (WF) of the oil palm seedlings growing process (WF_{proc}) was calculated by adding the direct water footprint of the individual and its indirect water footprint:

$$WF_{proc} = WF_{proc,\, dir} + WF_{proc,\, indir} \quad \text{[volume/time]}$$

The direct water footprint refers to the water consumption and pollution that is related to water use at nursery.

Indirect water. The indirect water footprint refers to the water consumption and pollution of water that can be associated with the production of the oil palm seedlings. In this study, the indirect water use was based on data sourced from the Ecoinvent database.

The blue component in crop water use (CWU, m^3 per seedling) was calculated by accumulation of daily evapotranspiration (ET, mm per day) over the complete growing period:

$$CWU_{blue} = 10 \times \sum_{d-1}^{1gp} ET_{blue} \quad \text{[volume/area]}$$

$$WF_{proc,\, blue} = \frac{CWU_{blue}}{Y} \quad \text{[volume/mass]}$$

in which ET_{blue} represents blue water evapo-transpiration. The factor 10 was meant to convert water depths in millimeters into water volumes per land surface in m^3 ha^{-1}. *lgp* stands for length of growing period in days and Y represents crop yield (seedling per hectare).

Green Water Footprint

The green component in crop water use (CWU, m^3 ha^{-1}) was calculated by accumulation of daily evapotranspiration (ET, mm per day) over the complete growing period:

$$CWU_{green} = 10 \times \sum_{d-1}^{1gp} ET_{green} \quad \text{[volume/area]}$$

$$WF_{proc,\,green} = \frac{CWU_{green}}{Y} \quad \text{[volume/mass]}$$

in which ET_{green} represents green water evapo-transpiration. The factor 10 was meant to convert water depths in millimeters into water volumes per land surface in m^3 ha^{-1}. *lgp* stands for length of growing period in days.

Grey Water Footprint

The grey component in the water footprint of growing a crop or tree ($WF_{proc,grey}$, m^3 per seedling) was calculated as the chemical application rate to the field per hectare (*AR*, kg ha^{-1}) times the leaching-run-off fraction (α) divided by the maximum acceptable concentration (c_{max}, kg m^{-3}) minus the natural concentration for the pollutant considered (c_{nat}, kg m^{-3}) and then divided by the crop yield (*Y*, seedling per hectare).

Total Water Footprint

$$WF_{proc,\,green} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Y} \quad \text{[volume/mass]}$$

$$WF_{proc} = WF_{proc,\,green} + WF_{proc,\,blue} + WF_{proc,\,grey} \quad \text{[volume/mass]}$$

In this study, expression of all the processes for water footprint were in m^3 water per tonne FFB.

RESULTS AND DISCUSSION

The boundary determines which unit processes shall be included as direct or indirect blue water consumption in this water footprint study, as shown in *Table 1*.

Based on the previous life cycle assessment (LCA) study (Halimah *et al.*, 2010), it was found that the major problem faced by the oil palm seedling was the attack by fungi. The commonly used pesticides in oil palm nurseries are mancozeb, thiram, carbendazim, maneb and dithane (classified under dithiocarbamates), followed by urea or sulfonylurea (herbicide) and organophosphate (insecticide). Glufosinate ammonium, urea/sulfonylurea and glyphosate are considered as unspecified herbicides. Fungicides and insecticides need not be applied regularly as they are only used when there are attacks by fungi or insects. Application of pesticides is also dependent on the weather where during the wet season more herbicides are needed as compared to the dry season.

Table 2 shows the required quantity of oil palm seedlings and land in the pre-nursery and main nursery.

Table 3 shows the data type and source for the nursery system for transportation and production of fertilisers, polybags, pesticides, seedlings and water. This table also shows where the input data were obtained, and whether they were from background, foreground data sources, or taken from the Ecoinvent database or Malaysian database (SIRIM). Foreground data for each unit process were collected directly from oil palm nurseries through questionnaires. The input data for each unit process were validated by on-site visits, telephone interviews, on-site measurements, communication via e-mail and fax. Foreground data included information on field electricity generation and diesel used to run pumps and consumption of water for irrigation of oil palm seedlings in the nursery. The water used for irrigation was from surface water (river or catchment pond) and ground water (well).

TABLE 1. DIRECT AND INDIRECT BLUE WATER CONSUMPTION

Processing category	Blue water consumption	
	Direct	Indirect
Production of agricultural inputs, *e.g.* polybags and fertilisers (in the form of N, P_2O_5, K_2O)	-	✔
Application of insecticides, herbicides and fungicides	✔	-
Transportation of polybags, fertilisers, insecticides, herbicides and fungicides	-	✔
Water supply	✔	-
Transportation of germinated seeds to nursery	-	✔
Transportation of seedlings to plantation	-	✔
Electricity generation	-	✔
Diesel for running water pump	-	✔

TABLE 2. DETERMINATION OF THE REQUIRED QUANTITY OF OIL PALM SEEDLINGS AND LAND IN THE PRE-NURSERY AND MAIN NURSERY

Calculation of the required number of seedlings	
Required quantity of palm seedlings grown in the main and pre-nursery	Mineral soils
Required palms per hectare in the plantation (palm density)	150 palms
- Loss at planting	8 palms
- Loss of seedlings in the main nursery	10%
Required seedlings in the main nursery	167
- Loss of seedlings in the pre-nursery	15%
Required seedlings in the pre-nursery	196
Calculation of the required land	
Pre-nursery	Land area for 196 seedlings
Pre-nursery (palm density: 563 000 oil palm seedlings per hectare, duration: three months)	0. 87 m^2 yr
Main nursery	Land area for 167 seedlings
Main nursery (palm density: 12 500 oil palm seedlings per hectare, duration: 10 months)	250.5 m^2 yr
Total land use per replanting	251 m^2 yr
Total land use relating to one year out of 25 years	10 m^2 yr

Direct pesticide application, oil palm seedling cultivation and transportation were considered as foreground data. Transportation of raw materials such as fertilisers, insecticides, herbicides, fungicides and polybags to nurseries were also included in the nursery stage as foreground data.

Background data which included information on generic materials were collected from published sources or proxies, *i.e.* same operation but in another country. Some of the data were obtained from published sources including literature, public databases or calculated using published models. Generally, the production of raw materials such as fertilisers, insecticides, herbicides and fungicides for the input were obtained from the Ecoinvent database, while the application of the raw materials was obtained from questionnaires. Electricity and polybags production were Malaysian-based (SIRIM) data.

Generally, there are two stages in oil palm nursery; pre-nursery (four months) and main nursery (eight months). In the pre-nursery stage, water required to irrigate the seedlings were about 11% wheres for the main nursery was about 88.89% (*Table 4*). Since the blue water used for irrigation in oil palm seedling processing is insignificant, therefore, it was not included in this study.

For pesticide application, water was used to prepare the pesticide solution before spraying on the oil palm seedlings. The dilution of the pesticide was prepared according to the method described by Esnan *et al.* (2004). *Table 5* indicates the types of pesticides and blue water consumption, m^3 t^{-1} FFB. Based on *Table 5*, dithiocarbamate contributed the highest amount of pesticide usage (kg ha^{-1}) and required 8.35E-06 m^3 water t^{-1} FFB. The unspecified pesticide has the lowest pesticide usage with 1.70E-02 kg ha^{-1} and the water required for this application was 1.18E-07 m^3 t^{-1} FFB. The overall amount of water used for pesticides application at the oil palm nursery was 1.69E-05 m^3 t^{-1} FFB.

For indirect blue water footprint, the water usage for all inputs, *i.e.* diesel, electricity and polybags were obtained from the Ecoinvent database. In this study, the indirect blue water usage in decreasing order were electricity, polybags and diesel, respectively. The total indirect blue water footprint contributed by all the inputs was 1.46E-04 m^3 t^{-1} FFB (as shown in *Table 6*). Therefore, the total blue water footprint was calculated as the sum of direct and indirect water consumption. It was found that the total blue water footprint was 1.57E-01 m^3 t^{-1} FFB.

Green Water

The parameters needed to calculate crop water usage (CWU) of oil palm seedling (as mentioned in the the Methodology section) for green water footprint include ET, mm per day, multiplying factor of 10 (as equation in the Methodology section) and growth period. The ET, mm per day value was obtained from a study conducted by Mohd Roslan and Haniff (2007). Total CWU green (m^3 ha^{-1}) was 13 286. Based on the CWU value, it was calculated that the total green water footprint per tonne FFB at nursery was 3.10E-01 m^3 (*Table 7*).

TABLE 3. DATA SOURCE FOR NURSERY SYSTEM

Unit process	Process starts	Process ends	Data type (B/F*) /data source
Electricity production	Mining and extraction of fossil fuels	Distribution to the grid at the point of use	B/Malaysian data from SIRIM
Irrigation water supply	Water from river, pond and well	Water at nursery	B/site specific data
Irrigation	Water at nursery	Water applied to germinated seeds/tonne FFB	F/site specific data
Fertiliser production	Acquisition of raw materials	Fertilisers at the production unit gate	B/Ecoinvent database
Transportation of fertilisers to nurseries	Collection of fertilisers from port in Malaysia to nursery	Delivery of fertilisers to nursery	F/site specific data
Fertiliser application	Fertilisers stored at nursery	Fertilisers into soil	F/site specific data
Insecticides production	Acquisition of raw materials	Pesticides at the production unit gate	B/Ecoinvent database
Transportation of insecticides to nurseries	Collection of pesticides from port in Malaysia to nursery	Delivery of pesticides to nursery	F/site specific data
Insecticides application	Pesticides stored at nursery	Pesticides applied to seedlings	F/site specific data
Unspecified herbicide production	Acquisition of raw materials	Herbicides at the production unit gate	B/Ecoinvent database
Transportation of unspecified herbicide to nurseries	Collection of herbicides from port in Malaysia to nursery	Delivery of herbicides to nursery gate	F/site specific data
Unspecified herbicide application	Herbicides stored at nursery	Herbicides applied to soil	F/site specific data
Fungicides production	Acquisition of raw materials	Fungicides at the production unit gate	B/Ecoinvent database
Transportation of fungicides to nurseries	Collection of fungicides from port in Malaysia to nursery	Delivery of fungicides to nursery gate	F/site specific data
Fungicide application	Fungicides stored at nursery	Fungicides applied to soil	F/site specific data
Polybags production	Acquisition of raw materials	Polybags at the production unit gate	SIRIM database
Transportation of polybag to nurseries	Collection of polybags from port in Malaysia to nursery	Delivery of polybags to nursery gate	F/site specific data
Polybags application	Polybags stored at nursery	Polybags used at nursery	F/site specific data
Oil palm seedling cultivation	Acquisition of oil palm germinated seeds	10- to 12- month old oil palm seedlings for planting in plantations	F/site specific data

Note: *B – background data. F – foreground data.

TABLE 4. BLUE WATER FROM SPRINKLERS PER TONNE FRESH FRUIT BUNCH (FFB) AT NURSERY

Stage	Water required per tonne FFB (m^3)
Pre-nursery	1.74E-02
Main nursery	1.39E-01
Total	1.57E-01

TABLE 5. BLUE WATER FROM PESTICIDES APPLICATION

Pesticides	Pesticide (kg ha^{-1})	Water used (m^3 t^{-1} FFB)
Thiocarbamate	1.40E-01	9.74E-07
Pyrethroid	4.40E-02	3.07E-07
Organophosphate	2.50E-01	1.74E-06
Dithiocarbamate	1.20	8.35E-06
Unspecified pesticides	1.70E-02	1.18E-07
Glyphosate	1.11E-01	7.71E-07
Sulfonylurea	2.70E-01	1.88E-06
Total blue water	-	1.69E-05

TABLE 6. INDIRECT BLUE WATER USAGE

Inputs with blue water	Unit/seedling	Water used for the production of input per tonne FFB (m^3)
Diesel	0.004 kg	5.22E-06
Electricity	0.006 kWhr	1.04E-04
Polybag (LDPE)	0.0021 kg	3.65E-05
Total		1.46E-04

Note: FFB – fresh fruit bunch.

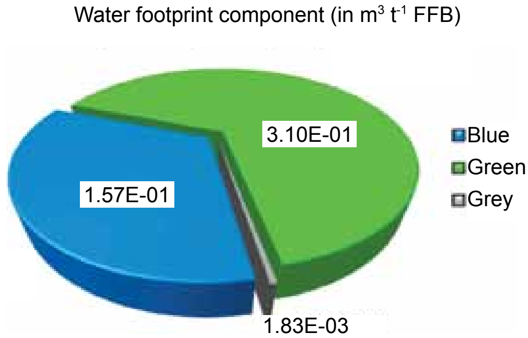
TABLE 7. PARAMETERS FOR CROP WATER USAGE DETERMINATION AND GREEN WATER FOOTPRINT

Parameters	Amount
ET (mm per day)	3.64
Growth period	365 days
Yield (seedling per hectare per year)	12 500
CWU green (m^3 ha^{-1})	13 286
WF green (m^3 t^{-1} FFB)	3.10E-01

TABLE 8. GREY WATER FOOTPRINT PER TONNE FRESH FRUIT BUNCH FOR FERTILISER

Parameters	Application rate (kg ha^{-1})	Grey water footprint (m^3 t^{-1} FFB)
N	6.375	8.87E-04
P	3.25	4.52E-04
K	2.625	3.65E-04
Total		1.70E-03

Note: FFB – fresh fruit bunch.



Note: FFB – fresh fruit bunch.

Figure 2. Blue, green and grey water footprint for production of oil palm seedlings.

Grey Water

The parameters needed to calculate grey water footprint for fertilisers include α= 0.30, chemical application rate (AR), kg ha^{-1} (*Table 8*), C_{max}, kg m^{-3} = 0.05, C_{nat}, kg m^{-3} = 0.00 and Y, seedlings per hectare. In this calculation, the leaching fraction was referred to USDA (2000). The C_{max} and C_{nat} were taken from the Department of Environment (DOE) (2010) and Wikipedia (2013b). The application rate of fertilizers as N, P and K (in kg ha^{-1}) was obtained from Halimah *et al.* (2010) and the data was used to calculate the grey water footprint. Based on the above parameters, it was calculated that the total grey water footprint per tonne FFB for fertiliser at nursery was 1.70E-03 m^3.

The parameters needed to calculate grey water footprint for pesticides include α= 0.005 5.00E-03, AR, kg ha^{-1} (*Table 9*), C_{max}, kg m^{-3} = 1.80E-03, C_{nat}, kg m^{-3} = 0.00 and Y, seedlings per hectare. The application rate of pesticides, *i.e.* thiocarbamate, pyrethroid, organophosphate, dithiocarbamate, unspecified pesticides, glyphosate and sulfonylurea (in kg ha^{-1}) was obtained from Halimah *et al.* (2010) and all the data were used to calculate the grey water footprint. For pesticides, the total grey water footprint per tonne FFB at nursery was found to be 1.31E-04 m^3. The total grey water footprint for fertiliser and pesticides was 1.83E-03 m^3 t^{-1} FFB.

For oil palm seedlings, the total water footprint for WF blue, WF green and WF grey was 4.69E-01 m^3 t^{-1} FFB. From the pie chart, it can be seen that the water footprint, in increasing order is grey WF, followed by blue and green. Green WF is the highest because it depends on accumulation of daily evapotranspiration (ET, mm per day) over the complete growing period. For this study, the grey water footprint was found to be the lowest. Therefore, we can infer that the volume of polluted water associated with the production of oil palm seedlings was very minimal.

TABLE 9. GREY WATER FOOTPRINT PER TONNE FRESH FRUIT BUNCH FOR PESTICIDES

Pesticides	Application rate (kg ha^{-1})	Grey water footprint (m^3 t^{-1} FFB)
Thiocarbamate	1.40E-01	9.01E-06
Pyrethroid	4.40E-02	2.83E-06
Organophosphate	2.50E-01	1.61E-05
Dithiocarbamate	1.20	7.75E-05
Unspecified pesticides	1.70E-02	1.10E-06
Glyphosate	1.11E-01	7.16E-06
Sulfonylurea	0.27	1.74E-05
Total	-	1.31E-04

UNCERTAINTY

The data obtained for this study was based on the inputs provided by nursery practitioners in Malaysia. The nurseries chosen for this study were at different locations and under different rainfall pattern. However, the calculation of the daily evapotranspiration (ET, mm per day) over the complete growing period was based on oil palm seedlings growing in Sintok, Kedah (Mohd Roslan and Haniff, 2007). Therefore, there might be a possibility of uncertainty, whereby the northern part of Malaysia would normally receive less amount of rainfall as compared to other regions in Malaysia. Therefore, the calculation for water footprint might be overestimated. Overall, the amount of water footprint for production of oil palm seedlings is minimal.

CONCLUSION

Based on this study, it was found that the total water footprint for the production of oil palm seedlings to be 4.69E-01 m^3 t^{-1} FFB. This study establishes the baseline for water footprint of oil palm seedling. The information gathered can be used to improve and assess the sustainable production of oil palm seedlings.

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