The water footprint of oil palm crop in Phetchaburi province

Lukkanaporn Seewiseng[a]* , Kampanad Bhaktikul[a], Chumlong Aroonlertaree[a] and Wachara Suaedee[b]

[a] Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom 73170, Thailand
[b] Irrigation Development Institute, Royal Irrigation Department, Nonthaburi 11120, Thailand
Tel. +66 (0)83-9178098
***Corresponding author:** Lukkana_bee@hotmail.com

Abstract

This study quantifies the water footprint of oil palm at the Chaipattana-Mae Fah Luang Reforestation Project in 2006-2010. For green, blue and grey WFs of oil palm production (land preparation, cultivation, harvesting and transportation steps) are assessed by the water footprint assessment framework as followed [1]. The crop evapotranspiration is calculated with the CROPWAT version 8.0 models. Considering the water footprint of oil palm crop is 10,150 m^3/ ton; 1333, 4,657 and 4,160 m^3/ton of green, blue and grey WFs, respectively. An oil palm yields average is 3.09 tons/ha (0.49 tons/rai). The crop water used of oil palm is $2.2x10^4$ m^3/ha/year ($3.5x10^3 m^3$/rai/year) and the efficiency of crop water used is 0.2 kg/m^3. The water used in the study area has appeared especially in oil palm growth stage and blue water consumption is higher than rainwater. So the trend of water irrigation demand is increasing. WF value of oil palm can reduce by increasing productivity of oil palm per area as possible because a yield factor can make significantly for WF value too.

Keyword: *water footprint, oil palm, Chaipattana-Mae Fah Luang reforestation project*

1. Introduction

The water footprint (WF) concept was initiated by Hoekstra and Hung (2002) and then was developed by Hoekstra and Chapagain (2008). Green, blue and grey water are the components of water footprint concept. The WFs shows the overview of the water consumption's of products and it indicates the weak spots and the awareness of water used of production. Producer has improved the efficiency of water consumption. WFs concept is considered as an alternative tool to plan and manage the water used for energy properly under the existence of a limited resource on the global warming [1].

A number of products or services were relevant to water used. The water is a key factor in the existence of all things on the earth. Water resources have stressed from climate change, human activities, a rapid increase in population and high technology that makes the temperature and rainwater change. So, these factors are depend on the specific area and the trends of water scarcity in future which is higher [2]. Agricultural water used is dominated the most part of withdrawal water demand, and agricultural water scarcity will result in the loss of agricultural production the same as African and Asian region that shows high sensitive to agricultural water scarcity [3].

Like the energy crisis that is increasing so the alternative energy like 'bio-diesel' is the good choice to produce the renewable energy from oil palm. Thus, the oil resources will be able to continue in the world [4]. An oil palm crop is a popular plant for oil produced. The *Tenera* specie is an oil palm which is planted in the study area because it has high drought tolerance. The crop energy in Thailand has been expanded to support the future demand [5]. Which is the same as raw materials (oil palm) for bio-diesel production needs water to grow. The water consumption demand for plant is increasing as bio-diesel consumption. In Thailand, the Chaipattana-Mae Fah Luang Reforestation Project, Phetchaburi province has the experiment of oil palm plots (100 rai) to produce bio-diesel production where set in rain-shadow area. So water footprint of oil palm crop in rain-shadow area is the thing that we are interested and all of them are the goal of this paper.

The CROPWAT model often use worldwide to estimate evapotranspiration and study demand of crop water requirement based on FAO Penman Montieth equation of Allen et al. (1998) as equation (1). That was developed by the FAO. This model can assess the of crops under rain-fed and irrigation conditions and various irrigation patterns by the crop water requirement options (supposing optimal condition) and the irrigation schedule options (inclusive the feasibility to the specific actual irrigation volume in time) [1] and [6].

$$ET_c = K_C \times ET_0 \quad (1)$$

ET_c is crop evapotranspiration, K_C is crop coefficients and ET_0 is reference of crop evapotranspiration. Monthly climate, crop information, soil type and crop planting date were optimal adjusted for study before take it in model. CROPWAT model can assess output data in term of year by year. So the perennial plant assessment with this model is based on annual output data because it has long life time, see more details [1]. So the CROPWAT model is a good choice for helping in the oil palm crop WF calculating process in this study.

2. Methodology

In term of water footprint (or so called 'virtual water') of oil palm cultivation use the water footprint concept followed by frameworks of [1]. Green WFs named volume of rainwater on land has evapotranspiration and consumption by crop growth. Blue WFs named volume of surface and ground water used (blue water resources) along supply chain. Finally, grey WFs named volume of freshwater that is required to assimilate the load of pollutions based on existing ambient water quality standards [1]. All that as showed in equation (2) and m^3/ton is unit of result that:

$$WF_{oil\ palm} = WF_{green} + WF_{blue} + WF_{grey} \quad (2)$$

Green and blue WF of growing process (WF_{proc}, m^3/ton) is calculated as the green and blue component in crop water use (CWU, m^3/ha) divided by yield of palm fruit (Y, ton/ha) as equation (3):

$$WF_{proc,green} = CWU_{green} / Y \quad (3)$$

A CROPWAT version 8.0 model was applied to simulate the crop water requirement both green and blue WFs; the model runs on the irrigation schedule option using for a medium soil, effective rainfall based on USDA calculation method, refill soil to field capacity of application timing, irrigated at fix interval per 3 day for irrigation timing, 70% irrigation efficiency and the calculated evapotranspiration is called ET_a as equation (4) and (5):

$$CWU_{green\ or\ blue} = 10x\sum_{d=1}^{\lg p} ET_{green\ or\ blue} \quad (4)$$

ET_{green} and $_{blue}$ means green and blue water evapotranspiration. The factor 10 is meant to convert water depth in mm into water volumes per land surface in m^3/ha and *lgp* stands for length of growing period in days.

In rain-fed scenario: ET_{green} (rain-fed) = ET_a (rain-fed), ET_{blue} (rain-fed) = 0
In irrigation scenario: ET_{green} (irrigation supply)= ET_a (rain-fed) – ET_{blue}(irrigation supply) (5)
ET_{blue}(irrigation supply) = min (total net irrigation or actual irrigation requirement)

For grey WFs assessment was calculated by application rate (*AR*) as equation (6):

$$WF_{grey} = \{(\alpha * AR)/(C_{\max} - C_{nat})\}/(Y) \quad (6)$$

When, α is times the leaching fraction, assumed 10% for nitrogen fertilizers, *AR* is chemical application rate per hectare (kg/ha), *Y* is yield of palm fruit (ton/ha), c_{max} is maximum allowable concentration (5 mg/L) and c_{nat} is natural concentration [1]. But this study was analyzed to Nitrate-N used only because nitrogen used is nonpoint source to affect for river as same [7]. So in this paper must study only water footprint of oil palm crop since year 2006-10 but does not means violence or impact of environmental.

Data collecting in this study is secondary data; crop Kc [4], climate data [8], soil type [9], water quality standard and study area [10], yield, fertilizer used rate and cropping pattern from [11] and observation from field in 2006-10 periods.

3. Results and discussion

3.1 Oil palm yields

An oil palm which is planted in the study area was *Tenera* variety (5 years old). Total yield of oil palm (fresh fruits bunch, FFB) in 2008-10 periods were 21, 58 and 69 ton/100 rai respectively, the average yield was 3.06 ton/ha (yield fruit as 2.16 ton/ha) and the highest yield was 4.34 ton/ha in 2010 period as Table 1. Five years old of oil palm yield gave the highest yield in May to August and trend of total yields had a slightly increased as Figure 1.

Table 1 Oil palm yields average in 2006-10 periods

Country	Weather station location	Latitude/longitude	Yield FFB (kg/rai)	Yield FFB (ton/ha)	Yield fruit (ton/ha)
Thailand, Phetchaburi province (2008-2010)	Nhong Plub,Prachuap Khiri Khan province*	12.35N, 99.44 E	490	3.06	2.16**

Remark *Climate data from [8]. **Value calculates, yield fruit as 70% of FFB in oil palm plated at the Chaipattana- Mae Fah Luang Reforestation Project, 2008-10 periods. The palm fruit was used in production only.

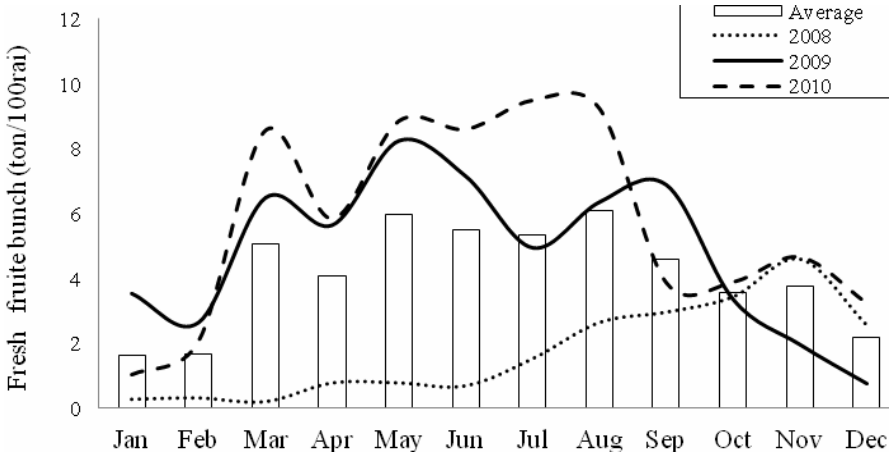

Fig. 1 Total monthly yields of oil palm in 2008-2010 periods

3.2 Crop water used (CWU)

In part of water used of oil palm was born on oil palm growth step. The green and blue water, oil palm had CWU_{green} and $_{blue}$ were 2,880 and 10,060 m^3/ha/year respectively on the irrigation schedule option. Result from Irrigation schedule option was lower than CWR-option results as Table 2. Some grey water used was 8,986 m^3/ha/year and crop water used of oil palm total was 21,926 m^3 /ha/year as Table 3.

Table 2 Green and blue water used (m^3/ha) of oil palm growth using the CWR-option and irrigation schedule option for a medium soil of CROPWAT 8.0 models: 2006-10 periods

CROPWAT option model	ET_{green}	ET_{blue}	ET_a	CWU_{green}	CWU_{blue}	CWU_{grey**}	CWU_{total}
	mm/growing period			m^3/ha			
Irrigation schedule option*	288	1,006	1,294	2,880	10,060	8,986	21,926
Crop water requirement option	704	802	1,506	7,040	8,020	8,986	24,046

Remark *Irrigation schedule option was selected to estimate the crop water used in this study. ** Grey water used was calculated by equation (5).

Table 3 Calculation of the grey WF (m^3/ton) and grey water (m^3/ha) for oil palm crop in the study area: 2006-10 periods

Average fertilizer application rate (kg/ha)	Area (ha)	Total fertilizer applied (ton/yr)	Nitrogen leached to water bodies 10% (ton/yr)	Max. ,nat. conc.* (mg/l)	Total $WF_{proc.grey}$ oil palm (10^6 m^3/yr)	Palm fruit (ton/ha)	$WF_{proc.grey}$ oil palm (m^3/ton)	Grey water (m^3/ha)
339.6	1	0.3	0.03	5, 1.7	0.009	2.16	4,160	8,986

*Source: [10]

For the trend of crop water need, ET_{green} had declined but ET_{blue} had increased. So the trend of the irrigation water supply for oil palm planted had increased as Figure 2.

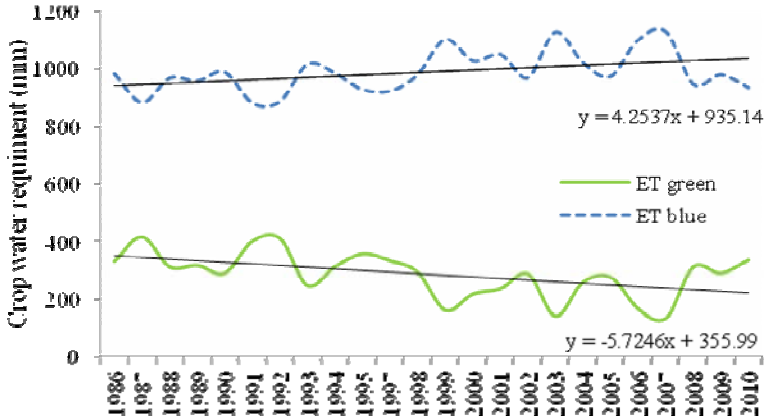

Fig. 2 Trend of green and blue crop water requirement in 1986-2010 periods

3.3 Water footprint of oil palm cultivation

WFs of oil palm crop had 10,151 m^3/ton; green WF 1333, blue WF 4,657 and grey WF 4,160 m^3/ton. WFs which result from Irrigation schedule option had lower than CWR-option results as Table 4 and Figure 3.

Table 4 WFs of oil palm production in 2006-10 periods on the irrigation schedule option and CWR-option results

CROPWAT option model	Palm fruit (ton/ha)	Oil palm WFs (m^3/ton)			
		Green WF	Blue WF	Grey WF	Total WFs
Irrigation schedule option*	2.16	1,333	4,657	4,160	10,150
Crop water requirement option	2.16	3,259	3,713	4,160	11,132

Remark *Output from Irrigation schedule option was representative of this studied.

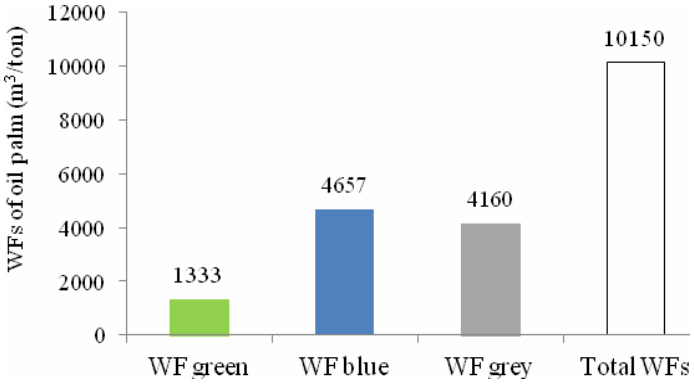

Fig. 3 Total WFs of oil palm crop in 2006-2010 periods; green, blue and grey WFs components

4. Conclusions

The water footprint of oil palm crop at Chaipattana-Mae Fah Luang Reforestation Project was 10,150 m^3/ton in 2006-10 periods; 1,333 green, 4,657 blue, 4,160 grey WF m^3/ton. FFB average yield was 3.09 ton/ha. The blue water (irrigation system) was main source of water used and crop water used was 21,926 m^3 /ha/year for oil palm cultivation. The trend of blue crop water used had increased in year 2015.

For oil palm crop WFs of study area in 2006-10 periods was higher than Lienden et al. (2010) study because the harvested yield in the study area was lower than the normal standard [12] and [4]. Moreover, WFs value was depend on difference factor; agricultural practice, climatic condition, location, soil type and yield as same [1] and [6]. The climatic condition (rain-shadow area), un-richness soil and the oil palm tree was just into the young stage that were main factor which affected on oil palm yield for WFs value. Blue WF was higher than green and grey WFs. An oil palm harvested was important factor to control WFs value so should be increased oil palm productivity per area as possible and fertility of the soil created; if high oil palm yields, the oil palm crop WFs was low value. For next study, the blue water used (irrigation supply) should be collected from site for actual volume; best representative of study area, creating the water footprint label of oil palm, awareness and knowledge for the water footprint concept with people.

Acknowledgements

I wish to express my sincere thanks to Mr.Krotsuwan Phoesuwan (Irrigation Development Institute), Mr.Adisorn Jumpathong (Officers of Regional Irrigation Department) and Officers of Chaipattana Mae Fah Luang Foundation project.

References

[1] Hoekstra, A. Y, Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. (2009). Water Footprint manual state of art 2009. Water footprint Network, Netherlands, *Earthscan*, p.127.

[2] Bhaktikul, K. (2010). Water footprint of crop energy in Thailand Faculty of Environment and Resource Studies, Mahidol University, P.1-4.

[3] Motoshita, M., Itsubo, N. and Inaba, A. (2009). Health Damage Assessment Modeling on Agricul-tural Water Scarcity based on Regression Analysis of Statistical Data National Institute of Advanced Industrial Science and Technology (*AIST*), pp.1-20.

[4] Lienden, A. R., Leenes, G., Hoekstra, A. Y. and Meer, H. V. D. (2010). Biofuels scenario in a water perspective: The global blue and green water footprint of road transport in 2030 UNESO-Institute for Water education. *Research report series*, 43, pp.58.

[5] Khamthep, N. (2010). Study on appropriate area ratio between food crops and energy crop in Thailand Faculty of Technology of Faculty of Technology of Environmental Management, Mahidol University, pp.50-60.

[6] FAO. (2007). Software CropWat 8.0 and Example of the use of CROPWAT 8.

[7] Mekonnen, M. M. and Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop product *Hydrology and Earth system Sciences*, 15, pp.1577-1600.

[8] Thai Meteorological Department. (2011). Meteorological data of Nhong Plub weather station, Prachuap Khiri Khan province.

[9] Office of Soil Survey and Land Use Planning. (2010). The Chaipattana- Mae Fah Luang Reforestation Project, Phetchaburi province. Land Development Department, Ministry of Agriculture and Cooperatives, pp.104.

[10] Regional Irrigation Office 14. (2008). Water quality of Huay Sai Royal Development Study in Phetchabiri province: 2006-10 period. Royal Irrigation Department.

[11] Chaipattana- Mae Fah Luang Reforestation Project. (2010). Annual reporting data. The Chaipattana Foundation.

[12] Chy, C. (2004). Oil palm". Department of Agriculture. *Thai Agricultural Research Journal*, 16, pp. 188.