Science of the Total Environment 542 (2016) 521–529

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# Water footprints of products of oil palm plantations and palm oil mills in Thailand

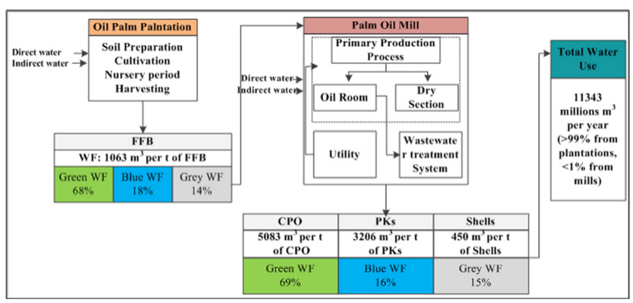
Phetrada Suttayakul [a], Aran H-Kittikun [b], Chaisri Suksaroj [a], Jitti Mungkalasiri [c], Ruthairat Wisansuwannakorn [c], Charongpun Musikavong [a,d,*]

[a] Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Hatyai 90112, Thailand
[b] Department of Industrial Biotechnology, Faculty of Agro-Industry, Prince of Songkla University, Hatyai 90112, Thailand
[c] National Metal and Materials Technology Center, National Science and Technology Development Agency, Pathumthani 12120, Thailand
[d] Center of Excellence on Harzardous Substance Management (HSM), Bangkok 10330, Thailand

## HIGHLIGHTS

- WFs and water deprivation of FFBs and CPO in Thailand were determined.
- Green water of 68 and 69% of WF were found for plantations and mills, respectively.
- In 2013, the CPO production in Thailand required 11,343 million $m^3$ water.
- The planting of oil palm namely Suratthani 7 decreased WF of FFBs by 21.8%.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 24 January 2015
Received in revised form 8 October 2015
Accepted 10 October 2015
Available online xxxx

Editor: S. Pollard

*Keywords:*
Crop water requirement
Crude palm oil
Fresh fruit bunches
Soil texture
Water deprivation

## ABSTRACT

The water footprint (WF) of fresh fruit bunches (FFBs) from oil palm plantations and crude palm oil (CPO) from palm oil mills in southern and eastern Thailand were determined over 25 years. Climatic conditions, soil characteristics, and the characteristics of oil palm growth were considered. The WF of FFBs was 1063 $m^3$/ton (t) on average. Green, blue, and grey waters comprised of 68, 18, and 14% of total WF, respectively. The oil palm plantations in Thailand required smaller amounts of indirect blue water. The average WF for producing a ton of CPO of seven mills was 5083 $m^3$. Most of the waters used in the mills originated from indirect green, blue and grey waters from the plantations. The direct blue water used in the mills had less impact on the total WF, lower than 1% of the total WF. Average percentages of green, blue, and grey waters of 69, 16, and 15% of total WF were determined for the mills, respectively. The water deprivation of the FFBs and CPO ranged from 0.73–12.9 and 3.44–58.3 $m^3$ $H_2O$ eq/t, respectively. In 2013, the CPO production in Thailand including green, blue, and grey waters from plantation and blue water from mills required 11,343 million $m^3$ water. If the oil palm variety Suratthani 7 is used in the plantation, it would increase the yield from 15.2 to 22.8 t FFBs/ha-year and decrease the WF to 888 $m^3$/t FFBs. The average value of the oil extraction rate (OER) of mills was 18.1%. With an increase in the OER of 1%, a reduction of the WF of 250 $m^3$/t CPO or 5.1% of total WF could be obtained.



*Abbreviations:* CPO, Crude palm oil; CWR, Crop water requirement; CWU, Crop water use; DEDE, Department of Alternative Energy Development and Efficiency; DOA, Department of Agriculture; EFBs, empty fruit bunches; FAO, Food and Agriculture Organization of the United Nations; FC, Field capacity; FFB, Fresh fruit bunches; $f_p$, Product fraction; FU, Functional unit; IRR, Irrigation; $K_{sat}$, Conductivity coefficient; LCI, Life cycle inventory; LHV, Lower heating value; MOE, Ministry of Energy; OAE, Office of Agricultural Economic; OER, Oil extraction rate; PEA, Provincial Electricity Authority; PK, Palm kernel; PWP, Permanent wilting point; RID, Royal Irrigation Department; TAM, Total available moisture; USDA, United State Department of agriculture; WF, Water footprint; WSI, Water stress index; WWAP, World Water Assessment Programme.

* Corresponding author at: Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Hatyai 90112, Thailand.
*E-mail addresses:* mcharongpun@eng.psu.ac.th, charongpun@gmail.com (C. Musikavong).

http://dx.doi.org/10.1016/j.scitotenv.2015.10.060

## 1. Introduction

Water is an essential natural resource for food and energy production and other purposes for human use. Water withdrawal for agricultural activities has accounted for 70% of the total amount of water withdrawn by municipal, industrial and agricultural organizations throughout the world (World Water Assessment Programme, WWAP, 2012). In 2014, the total water requirement in Thailand for agricultural activities, balancing ecology, domestic consumption, industry, and live stock was 162,151 million $m^3$. Agricultural activities accounted for 65% of the total amount of water required (Royal Irrigation Department, RID, 2015). Thailand, as a country is one of the largest producers of agricultural commodities. A water management plan on a national and sub-national scale should be prepared immediately to avoid the water scarcity experienced in some regions of Thailand.

Biofuel plays an important role in the alternative energy development plan in Thailand. In 2008, the existing volume of ethanol and biodiesel used were 1.25 and 1.75 million liters per day, respectively. By 2022, the volume targets are 9.0 million liters per day ethanol and 4.5 million liters per day of biodiesel (Ministry of Industry, MOE, 2009). The ethanol and biodiesel industries in Thailand have been and are expanding through increasing demand.

About 56 million t of palm oil and palm kernel oil was produced for both the food and non-food industries in 2012. It accounted for more than 35% of world's production of vegetable oils (Food and Agriculture Organization of the United Nations, FAOSTAT, 2013). The palm oil industry is one of the most important agricultural industries in Thailand. It consists of four major sections: (1) oil palm plantations; (2) crude palm oil (CPO) extraction by mills; (3) the refining of edible oil; and (4) biodiesel production (Kaewmai et al., 2012). Approximately 86.6 and 5.84% of the plantation areas are located in southern and eastern Thailand, respectively (Office of Agricultural Economic, OAE, 2014). Most palm oil mills, therefore, are located in southern Thailand.

In 2013 the area of oil palm plantations was 0.72 million hectares (OAE, 2014). This area had increased from approximately 0.46 million hectares in 2008 (OAE, 2010). The expansion of the plantation areas has led to an increase in the production capacity of mills, refining factories, and biodiesel production plants. The associated activities require larger amount of fresh water. To develop a water management plan for the palm oil industry to support the food and alternative energy markets, direct and indirect water use should be evaluated. The water footprint (WF) concept has been introduced for determining direct and indirect water use in the production of products. It consists of three main components, notably green, blue, and grey waters (Hoekstra et al., 2011). In addition, the hotspots where water use is highest could be determined by WF analysis.

The WF concept is used by researchers to evaluate water use in the production of several agricultural products (Bocchiola et al., 2013; Chapagain and Hoekstra, 2011; Chapagain and Orr, 2009; Gheewala et al., 2014; Jefferies et al., 2012; Lamastra et al., 2014; Mekonnen and Hoekstra, 2010, Shrestha et al., 2013; Wang et al., 2014; Zang et al., 2014) A high variation in water requirement for growing crops has been found in different regions in Thailand (Gheewala et al., 2014). On a country-wide scale, the green, blue, and grey waters accounted for 65.7, 24.2, and 10.4% of WFs for primary crop production in Nepal. A low agricultural productivity, poor efficiency in water use, and lack of improved technology caused higher WFs in primary crop production (Shrestha et al., 2013). Ruini et al. (2013) determined the WF of Barilla pasta. The variations in the WF were attributed to the production site, local environmental conditions, and the agricultural techniques used for cultivating durum wheat.

There are a few published reports about the WF of products from oil palm plantations. The water footprint per ton(t) of palm fruits at national and sub-nation level in Thailand has been determined (Mekonnen and Hoekstra, 2010). The WF of the oil palm on a country-wide scale has been reported for Thailand (Gheewala et al., 2014). However, an evaluation of the WF of oil palm covering the economic life span of oil palm plantations over 25 years at the sub-national level has never been reported or undertaken. Soil textures are an important parameter in calculating the irrigation water needed for growing crops. However, information about the effect of soil textures on the WF of oil palm is limited.

In this present work, data over 25 years has been considered to cover the economic life span of oil palm for the evaluation of WF. The plantation assessments made during 25 years of oil palm include soil preparation, cultivation, a nursery period of 3 years, and harvesting for 22 years. During the soil preparation, cultivation, and nursery periods water was used but there were no products. During the harvesting, water was used and the fresh fruit bunches (FFBs) made up the output. The yield of FFBs production varied according to the age of the oil palm. It was inappropriate to use the yield of FFBs from 1 or 2 years to indicate the total production of FFBs over 22 years. For the evaluation of the WF in this work, the total water use was determined from the sum of the direct and indirect water used for soil preparation, cultivation, and the nursery period together with those used during the harvesting. The total production of FFBs over 22 years was recorded as the output.

From October, 2014 to April 2015, 15.1% of the villages in Thailand have faced problems with drought. These were located in 11 provinces in the northern part, 9 provinces in the northeastern part, 7 provinces in the central region, 5 provinces in the southern part, and 4 provinces in eastern part (Hydro and Agro Informatics Institute, HAII, 2015). The problem of water scarcity, therefore, is of serious concern in Thailand.

A method for quantifying water scarcity in relation to ecosystems and human users at downstream locations in terms of water deprivation has been developed by Pfister et al. (2009). For determining the water deprivation, first the consumptive water use (CWU) of products, services, and organizations must be investigated. Second, the water stress index (WSI) of the watershed where the products have been produced must be determined. The WSI is the ratio between the total annual freshwater withdrawals and the hydrological availability, or available water, in a region or watersheds. Third, water deprivation can be calculated by multiplying the CWU of the products with the WSI of the specific watershed where water is withdrawn for producing products (Pfister et al., 2009). The growing of oil palm and establishing new palm oil mills with low water deprivation values can minimize the water scarcity in ecosystems and by human users at the downstream location.

The WF and water deprivation values of the products of oil palm plantations and palm oil mills that include all the practices have never been determined. To develop a water management plan and national policy for the palm oil industry, the WF and water deprivation of the products of oil palm plantations and palm oil mills that include all the practices need to be investigated. This could help develop methods for reducing the WFs from plantations and mills. In the final stage, WF and water deprivation can be used as the criteria for selecting new areas to site oil palm plantations and for establishing new palm oil mills in Thailand.

## 2. Materials and methods

### *2.1. Goal, system boundary, and sites of studies*

Our work aimed at determining the WF of FFBs from the oil palm plantations. It also aimed at evaluating the WF of CPO as the main product and the WF of shells and palm kernel (PKs) as co-products of mills in Thailand. In addition, the water deprivation of FFBs and CPO were also determined. Plantations and mills in Krabi, Chumphon, Suratthani, and Chonburi were selected as the study sites. These make up over 66% of the total plantation area in Thailand (OAE, 2014).

This present study applied the life cycle assessment method to establish the life cycle inventory (LCI) for the WF calculation. A system boundary of cradle to gate was set (Fig. 1). The functional unit (FU)