Water Footprint Evaluation of *Oryza sativa L.*Tha Wang Pha District, Nan Province

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Abstract

This study evaluated water requirements for rice plantation (*Orysa sativa L.*) at Tha Wang Pha district, Nan Province covering an area of 690 ha in 8 villages. Water footprint (WF) for rice was evaluated by precipitation which was varied during plantation period. The CROPWAT 8.0 model was used to process important data such as rainfall, atmospheric data, evapotranspiration data, and rice yield and rice types. The results showed the evapotranspiration (ET_o) and crop coefficient (K_c) of rice as 34.55 millimeter per week and 11.09 and ET_c was 33.93 millimeter per week. The cropping calendar covered four months from July to October 2011-2012. Most rainfall occurred in September with 452.7 mm. During the study rice mainly used rainfall so the blue water footprint (WF_{blue}) was not evaluated. The grey water footprint (WF_{grey}) was calculated by using phosphate-phosphorus in the study area and correlated with rice yield of plantation. WF_{grey} for rice was equal to 788.49 m^3/ton. The green water footprint (WF_{green}) should correlate with rainfall data and rice yield at 4 stages of plant development, i.e., land preparation and vegetative growth, reproductive growth, grain development and harvest. The result of WF_{green} for rice was calculated by CROPWAT 8.0 software to be equal to 1,470.33 m^3/ton with the rice yield of 0.48 ton/rai (3 ton/ha). The total water footprint (WF) for rice was 2,258.82 m^3/ton and was related with the rice growth period and rainfall.

Keywords: water management; rice production; water footprint

1. Introduction

Tha Wang Pha district is the important area for rice production in Nan province. *Oryza sativa* L. is one of the types of rice crops that is planted in this area. *Oryza sativa* L. and rice cultivation is carried out in two ways: rain fed and irrigated rice. Rainwater is necessary for rice growth in order to maintain soil moisture and to maintain the standing layer of water over the paddy field. In the major rice producing regions of the world, rice is grown during the wet (monsoon) season, which reduces the irrigation demand by effectively using rainwater.

Rice is one of the major crops feeding the world population and is the most important crop in Thailand. Mainly, rice cultivation uses water from precipitation. In the period 2000-2004, the global average water footprint (WF) of paddy rice was 1,325 m^3/ton (48% green, 44% blue, and 8% grey),

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which is much lower than previous estimates. There is about 1,025 m^3/ton of percolation in rice production. The global water footprint of rice production is estimated to be 784 billion m^3/yr. The ratio of green to blue water varies greatly, both over time and space. In countries like India, Indonesia, Vietnam, Thailand, Myanmar and the Philippines, the green water fraction is substantially larger than the blue water fraction (Chapagain and Hoekstra, 2010).

The WF is the value of water that is used to produce everything, such as crops, products, etc. Sometimes, WF reference is used as a direct or indirect indicator that comes from the process of production or crops (Hoekstra and Chapagain 2007, 2008). This study of the green WF of *O. sativa L.*, or lowland rice production, took into consideration the rainfall only because the study was carried out in the rainy season.

The WF was studied to evaluate rainfall water used in the green WF, to raise awareness in the use of resources and the environment that affect the ecosystems as well as management to achieve the most effective solution. Moreover, from the activities necessary for life, this index is a measure of the ecosystem that is being used in a particular direction.

In assessing the amount of water used by the water footprint for rice, in addition to the green WF a calculation of evapotranspiration of water from the rain for crops is made in order to use WF for assessment of waste. The result from a process of cultivation in the form of water is put into the system so that waste water is discharged into the baseline. The process used is grey WF.

The aim of this study is to estimate the green WF and grey WF of rice product using the method of estimation of rainfall requirement. Green water was calculated using the CROPWAT (FAO, 2003) model in paddy field. The WF can be used to compare water use efficiency of each product particularly during the water shortage period so that the policy can be decided on what plant to be promoted taking into consideration net profit of product, market requirement, labour requirement, etc.

2. Materials and Methods

2.1 Study Area and Data

The study area focuses on Tha Wang Pha District, Northeast of Nan Province. It covers an area of approximately 799 square kilometers or 79,900 ha (Fig. 1). The topography is 90% mountainous and 10% plain area. The average elevation of the area is 234.70 meters above mean sea level with flat areas suitable for planting about 11,503 ha or 14.39% of the total area (LDD, 2010). Flat land is mostly suitable for rice cultivation. Rice growing area in Tha Wang Pha District has a total planted area of 35,619 rai equivalent to 5699 ha (Nan Provincial Agricultural Extension Office, 2556). The area is mostly flat alluvial flood and plains and foothills.

The study area was determined to drain the water out of the paddy field in order to evaluate the phosphate value in the laboratory. The collection of phosphate that was used to evaluate the grey water footprint came from 4 sampling stations in Pha Tong sub-district, Tha Wang Pha District with a recorded ground control point (GCP) at each station.

2.2 Data Used for Model

Data for this study was collected from the Land Development Department (LDD), the Thai Meteorological Department (TMD), and the Royal Irrigation Department (RID). The period of data used was between 2011 - 2012 and detailed data such as meteorological data, hydrological data, crop water requirement, land use, cropping calendar of rice, crop coefficient and evapotranspiration are as shown in Tables 1 and 2.

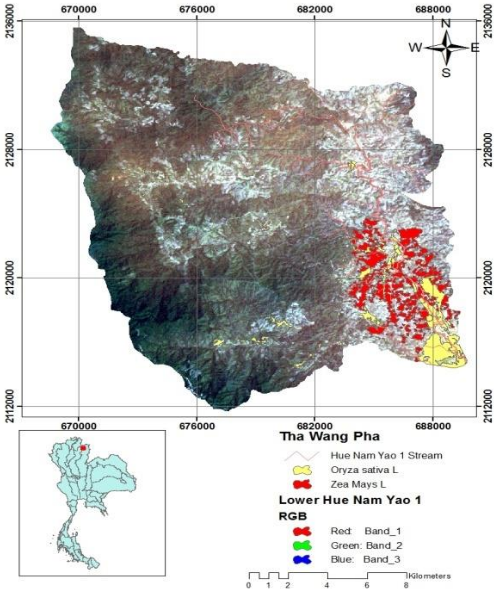


Fig.1. Study area Tha Wang Pha district
Source: LDD (2010).

Table1. Crop coefficient (K_c).

Rice/ Kc	Stage of plant growth (day)			
	Stage 1	Stage 2	Stage 3	Stage 4
Rice (day)	35	21 (60)	35 (95)	26 (120)
K_c	1.13	1.45	1.23	0.86

Source of data: Royal Irrigation Development

Where

K_c = Crop coefficient

Stage 1 = vegetative growth (0 - 35 days)

Stage 2 = reproductive growth (36 – 57 days)

Stage 3 = grain development (58 – 93 days)

Stage 4 = harvest maturity (94 – 120 days)

Table2. Average rainfall (mm/day) and evapotranspiration rate in Nan Province (mm/day).

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average rainfall	7.3	13.1	31.6	96.1	168	133	215	271	197	78.5	20.5	6.8
Evapotrans-piration rate	2.69	3.35	4.20	4.99	4.78	4.34	4.01	3.80	4.01	3.72	3.02	2.52

Source of data: Thai Meteorological Department, (2011 – 2012)

2.3 Evapotranspiration and Crop Coefficient Calculation

The term evapotranspiration (ET) is commonly used to describe two processes of water loss from land surface to atmosphere that include evaporation and transpiration (Lincoln et al., 2009). The K_c factor was selected as follow method for calculation and matching with ET_o by using the Penman - Monteith method as in equation (1) (Teerapon, 2006) and the ET_c was calculated using equation (4).

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{C_n}{T + 273} u_{2(e_s^o - e_a)}}{\Delta + \gamma(1 + C_d u_2)} \quad (1)$$

where ET_o is the crop evapotranspiration (mm/d), R_n is the net radiation at crop surface (MJ m^{-2}/d), G is the soil heat flux (MJ m^{-2}/d), T is the average temperature (^oC), Δ is the slope vapor pressure curve (kPa/^oC), γ is the psychrometric constant (kPa/^oC), U_2 is the wind speed measured at 2 m height (m/s), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), (e_s-e_a) is the saturation vapour pressure deficit (kPa), C_n is the conversion factor, and K_c is the crop coefficient.

2.4 Water Footprint Calculation

The WF of rice is based on Hoekstra and Chapagain (2008). The total WF of growing rices or trees (WF_{rice}) is the sum of the green, blue, and grey components as follows:

$$WF_{rice} = WF_{blue} + WF_{green} + WF_{grey} \quad \text{(unit: } m^3/\text{ton)} \qquad (2)$$

The distinction between blue and green WF is important because direct and indirect impacts (e.g., hydrologic, environmental, and social impacts) and the economic costs of irrigation water used for production differ from the impacts and costs of rainwater (Yoo et al., 2013). The grey WF is defined as the volume of water required to dilute the pollutant loads based on standards of water quality (Hoekstra et al., 2007). The green WF of a product is calculated as the ratio of the total volume of water used (m^3/year) to the quantity of the production (ton/year). This study was to evaluate the WF of *O. sativa L.* or wetland rice. It is available from green water and the values obtained from grey water are replaced by water in bodies of water, waste water and rainfall used in cultivation which is indicative of the rate of water from natural sources and the amount of waste water generated from the fertilizing. That could be attributed by the amount of water cultivation and the rate of the fertilizing. The rate and amount of the fertilizing that is in the ability to get to the area.

WF_{rice} in this study is composed of two parts, green water footprint (WF_{green}) and grey water footprint (WF_{grey}). For this study the water for rice cultivated from precipitation is used for (WF_{green}) calculation. The WF_{grey} was calculated based on the maximum acceptable surface water quality standard of phosphate (0.3 mg/L) (FAO, 2003) and leached phosphorus to surface water. The phosphate value was analyzed by water samples based on the study area with three replications of the experiment for measuring of water in the field in each stage. The WF_{green} could be calculated by the following equations (3), (4) (Chapagain and Hoekstra, 2011).

$$WF_{green} = CWU_{green}/Y \qquad (3)$$

$$CWU_{green} = ET_c$$

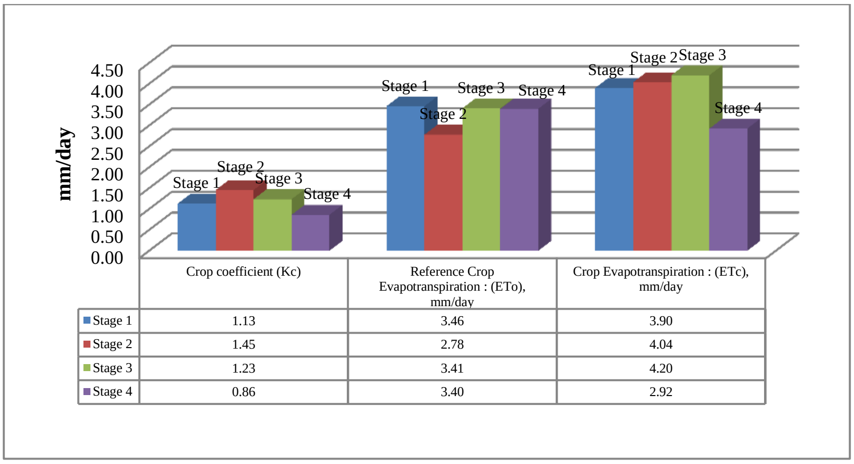
$$ET_c = K_c * ET_o \qquad (4)$$

3. Results and Discussion

Fig.2 shows the result of WF that includes K_c, reference crop evapotranspiration (ET_o), and crop evapotranspiration (ET_c) at each stage of rice development. From Fig 2 it can be seen that K_c, the crop coefficient of rice, has the highest value during where CWU is crop water used and Y is yield of crop product. The WF_{grey} is the pollutant actually released into the water system due to rice production (P_r) unit: mg/l and to the permissible limit of the pollutant (P_l) unit: mg/l follows equation (5):

$$WF_{grey} = P_r/P_l \qquad (5)$$

The component of WF depends on the specific rice evaporation requirement and soil moisture availability in the field. The rice evaporation requirement for a rice (ET_c, mm/day) is calculated using the rice coefficient (K_c) for the respective growth period and reference rice evaporation (ET_o, mm/day) at that particular location and time (see equation 2, 3). The green WF component (WF_{green}, m^3/ton) is calculated as the ratio between green rice water use (CWU_{green}, m^3/ha) and rice yield (*Y*, ton/ha). For the purpose of this study these have been calculated with the CROPWAT model (Allen et al. 1998). The CROPWAT model needs the information on rice calendar and climate data (see in Fig.2) to be input into the model; evapotranspiration and rice water use requirements are calculated for the given set of data on ET_o, monthly rainfall, K_c and the rice calendar. The outputs of the CROPWAT model were ET_o, ET_c, and K_c data which were used as input into the WF equation Stage 2, which is in the range of reproductive growth ET_o, was highest in stage 1 which is in the range of vegetative growth and the ET_c is the maximum during stage 3 which is in the range of grain development stage.



	Crop coefficient (Kc)	Reference Crop Evapotranspiration : (ETo), mm/day	Crop Evapotranspiration : (ETc), mm/day
Stage 1	1.13	3.46	3.90
Stage 2	1.45	2.78	4.04
Stage 3	1.23	3.41	4.20
Stage 4	0.86	3.40	2.92

Fig.2. Parameters for green water footprint.

Remarks**:**
Stage 1 = vegetative growth (0 - 35 days)
Stage 2 = reproductive growth (36 – 57 days)
Stage 3 = grain development (58 – 93 days)
Stage 4 = harvest maturity (94 – 120 days)

The results of the study determined the maximum evapotranspiration (ET_o) and rice maximum coefficient (K_c) of rice calculated from the CROPWAT model as 3.41 at stage 3 and 1.45 at stage 2. ET_c was maximum at stage 3, at 4.20, as shown in Figure 2. The cropping calendar was four months, from July to October. Average rainfall was maximum in August with 271 mm/day (see Table 2.). The grey water footprints WF_{grey} were equal to 788.49 m^3/ton. The green water footprint (WF_{green}) should correlate with rainfall data and rice yield at 4 stages of rice development namely, land preparation and vegetative growth, reproductive growth, grain development and harvest.

The result of WF_{green} rice was calculated by CROPWAT 8.0 software to be 1,470.33 m^3/ton The rice yield was 0.48 ton/rai (3 ton/ha) in 2015. The total water footprint (WF) of rice was 2,258.82 m^3/ton. WF_{green} footprints were 381.52, 394.25, 410.87 and 283.71 m^3/ton during stages 1, 2, 3 and 4 as shown in Fig. 3.

The Fig. 3 WF_{green} varied linearly indicating that the green WF requirement was highest during stage 3 or the period between 9 to 14 weeks of rice development (reproductive growth). The WF requirement drops during stage 3 and 4 of rice development (grain development and harvest maturity, respectively) corresponding to harvesting period in Fig. 3. The variation was described by the equation: $Y = -34.973x^2 + 147.18x+261.93$ and $R^2 = 0.8889$ where Y = WF_{green} (m^3/ton) and X = stage of rice development.

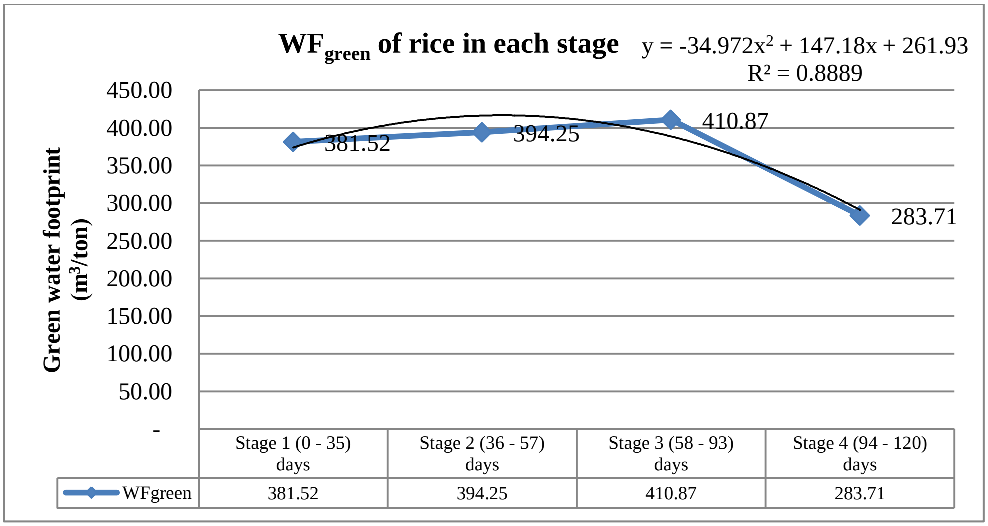


Fig.3. WF_{green} of rice in each stage of development.

In Fig.4 the pie graph of water footprint as calculated by the CROPWAT 8.0 model was divided into three parts: WF_{green} WF_{blue} and WF_{grey}. The WF_{green} for all stages had value equal to 1,470.33 m^3/ton, the value of WF_{blue} was not calculated, and the value of WF_{grey} was equal to 788.49 m^3/ton. The total WF of rice was 2,258.82 m^3/ton. The WF_{blue} was the least because this paddy field mostly used rainfall for cultivation.

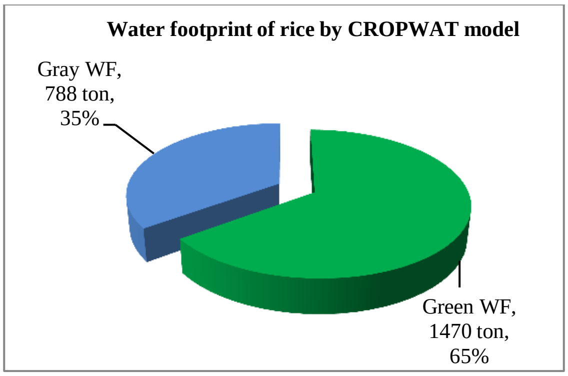


Fig.4. WF of rice calculated by CROPWAT model.

The result of WF calculated from CROPWAT 8.0 models was compared with other sources. The Mekonnen and Hoekstra study Of WF of rice since 2000-2004 indicated the range of WF equal to 638-2,874 m^3/ton for 13 countries. The WF of rice in Tha Wang Pha district, Nan province had total value of 2,258.82 m^3/ton which was a combination of WF_{green}, WF_{blue} and WF_{grey} (see equation (1)). The model output could be used to prepare the result of study which was within the range of WF for rice. Normally, rice used the water 1,200 – 1,400 m^3/crop (average rainfall 150 – 400 mm/month) and the result of water used from study rice produce of Tha Wang Pha province was less than the standard value of water used.

4. Conclusions

The WF as a measure of the impact on water used and water quality can be used to make comparison between products. The WF of rice production and consumption can be compared with values of other countries. However, in these countries most of the water footprints are calculated in the wet season, of that the contribution to water scarcity is relatively low in contrast to our general perception. Globally, there is nearly an equal share of green and blue water used in the total water footprint of rice. In this paper we have used rice only and two WF values (WF_{green}, WF_{grey}) from one area in order to represent this methodology. The green water footprint correlates well with rainfall data and the stages of rice development. The values of green WF obtained should be the maximum values at each stage of rice development. The highest value was reduced in stage 3 to stage 4 which was the final stage of rice development coinciding with the harvest period. The grey WF used acceptable standard phosphate of surface water sampling at 4 stations for paddy field. The phosphate was selected because the reduction of phosphate concentration in surface water could reduce other pollutants (nitrate, ammonia). Also, the phosphate could transform the forms less than nitrate. The efficiency of water used should aim at reducing the amount of water used at each stage of development as well as the reduction of water losses and leach pollutant from surface water. To be more practical the results should cover the entire grey water footprint. Additionally, studies should be conducted for more than one year for comparison as well as to make comparisons with other species such as corn in order to prepare the guidance for water management and take phosphate value tested method for reducing pollutant from water resource. The environmental impact of the green WF and grey WF in rice production depends on the stages of growth and rainfall. Finally, water resource management should use the WF for setting water resource and nutrient loading in regulatory policy management.

5. Acknowledgement

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