Research article

Water Footprint of Energy Crops under the Rain-Fed and Irrigated Cultivation in Eastern Thailand

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Abstract Under the current 15-year Renewable Energy Development Plan (REDP) of 2008-2022, Thailand's Ministry of Energy promotes the production and use of ethanol to substitute fossil oil. Two major crops used to produce ethanol in Thailand are sugarcane and cassava. This research assesses the water footprint (WF) of sugarcane and cassava under the rain-fed and irrigated agriculture in the eastern provinces of the Kingdom. The data on crop evapotranspiration, use of fertilizer, and yield are required for the estimation of the water footprint in crop production, the approach of which is based on *The Water Footprint Assessment Manual* of Hoekstra et al. The results of this study show that the average WF's of sugarcane in rain-fed and irrigated cultivation are respectively 171 m^3/ton (89% green, 11% grey) and 162 m^3/ton (83% green, 7% blue, 10% grey). For cassava, the average WF's in rain-fed and irrigated agriculture are 387 m^3/ton (85% green, 15% grey) and 413 m^3/ton (81% green, 5% blue, 14% grey), respectively. Rainfall is still a key factor in the cultivation of sugarcane and cassava taking into consideration the proportion of water use. The sugarcane yield in the rain-fed fields is lower than that in the irrigated fields, while the yield of cassava in both environments is similar. The findings not merely would be of use to stakeholders and policymakers for better water management but also could be used as basis data of sub-national water footprint for crop production.

Keywords water footprint, sugarcane, cassava, energy crops, Thailand

INTRODUCTION

Ministry of Energy of Thailand , has since 2008 implemented the current 15-year Renewable Energy Development Plan (REDP 2008-2022) with the goal to increase renewable energy use to 20% of the total energy consumption by 2022. In addition, the present government, to expedite the realization of the REDP, has tasked the Energy Ministry with the drawing up of the Renewable and Alternative Energy Development Plan (AEDP 2012-2021) to identify the framework and direction of Thailand's renewable energy development. Encouraging collaboration among the community people in greater production and use of renewable energy is one of six strategies to promote AEDP. The target of ethanol production output is 9 Ml/day by 2021 through improvement of average yields of sugarcane and cassava to not less than 15 and 5 t/rai/yr (6.25 rai=1 ha). Moreover, other alternative energy crops such as sweet sorghum are promoted.

Based on the aforementioned policies, the data on the amount of water consumption is important for policymakers in the promotion of ethanol production and use. In this regard, the aim of this research is to assess the water footprint (WF) of sugarcane and cassava under the rain-fed and irrigated agriculture in the eastern part of Thailand.

METHODOLOGY

Study area: The eastern region is an important cultivation area of fruits, maize, sugarcane and cassava. Provinces of Chachoengsao, Chonburi, Prachinburi and Sakaeo (i.e., 4 out of 7) were selected as the study area (Figure 1).

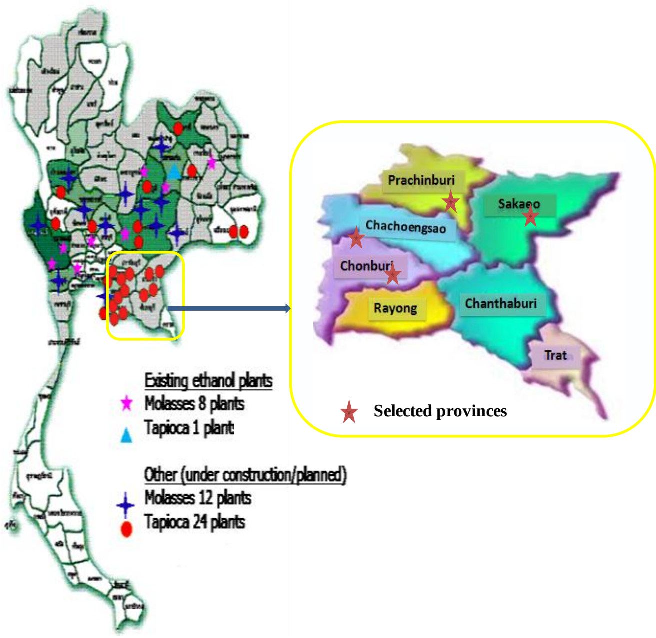

Fig.1 Ethanol plants in Thailand and study area
Source: (DEDE, 2008)

Research methodology: Calculation of water footprint of sugarcane and cassava under the rain-fed and irrigated conditions in this research follows the Water Footprint Assessment Manual of Hoekstra et al. (2011). The data on crop evapotranspiration, use of fertilizer, and yield are requisites for the estimation of the water footprint in crop production.

The water footprint concept: Water footprint (WF) is an indicator of freshwater use that takes into account both direct and indirect water use of a consumer or producer. It consists of three components: green, blue, and grey water footprints. The green water footprint is the volume of rainwater consumed during the production process, the blue water footprint refers to consumption of natural water resources (surface and groundwater) along the supply chain of a product, and the grey water footprint is defined as the volume of freshwater required to assimilate the load of pollutants to meet the water quality standards (Hoekstra et al., 2011).

Calculation of green and blue water footprint: Green and blue water evapotranspiration during crop growth can be estimated with CROPWAT 8.0 model based on the Food and Agriculture Organization (FAO, 2009). According to Hoekstra et al. (2011), this research selects the irrigation schedule option to determine the crop evapotranspiration. The calculated evapotranspiration is called ET_a, which is calculated as the crop evapotranspiration under optimal conditions (ET_c) times a water stress coefficient (Ks) as shown below:

$$ET_a = K_s \times ET_c = K_s \times K_c \times ET_o \quad (1)$$

Where ET_a is the actual crop evapotranspiration, ET_C the crop evapotranspiration, ET_o the reference evapotranspiration, K_c the crop coefficient, and K_s a water stress coefficient with a value between 0 and 1.

The green and blue components of crop water use (CWU) are calculated by accumulation of daily evapotranspiration over the complete growing period. The total ET_{green} and ET_{blue} in mm are converted to crop water use in m^3/ha by a factor 10.

Calculation of the green, blue and grey water footprint for crop production: Calculations of the water footprint (WF) of crop growing process are shown in Eq. (2) and (3). The total water footprint of the crop growing process is the sum of the green, blue, and grey components as shown in Eq.(5).

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \tag{2}$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \tag{3}$$

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \tag{4}$$

$$WF_{proc} = WF_{proc,green} + WF_{proc,blue} + WF_{proc,grey} \tag{5}$$

Where CWU is crop water use (m^3/ha), Y crop yield (ton/ha), α leaching-run-off fraction (%), AR chemical application rate (kg/ha), C_{max} the maximum acceptable concentration (kg/m^3), and C_{nat} the natural concentration for the pollutant considered (kg/m^3).

Data collection: Primary and secondary data were obtained from various sources. Primary data were collected using interviews and questionnaires while secondary data, such as land use map, climatic data, soil type etc., were taken from reports and publications. Additional details about the methods used in this study are indicated below:

Climate data: The climate data for a 30-year period (1981-2010) were taken from the Thai Meteorological Department.

Soil types: Based on the Land Development, Department classification, soil types are mostly sandy loam suitable for cassava and sugarcane production.

Crop parameter: Farmers from the four selected provinces were interviewed with the questions from the questionnaire. Data on household size, age structure, water source for crop production, cropping pattern, crop yield, and fertilizer application were part of the questionnaire.

Ambient water quality standard: Based on the Notification of the National Environment Board No. 8, the maximum acceptable concentration for nitrate in surface water quality standards is 5 mg/l.

Crop coefficient (kc): Crop coefficients of sugarcane and cassava were taken from the Royal Irrigation Department (RID, 2010).

RESULTS AND DISCUSSIONS

Calculation of green and blue WF under the rain-fed and irrigated conditions in this research employed irrigation scheduling based on actual water use from field survey. In the case of irrigated condition, irrigation schedule option of without irrigation was used to determine the water use by crop. The sugarcane yield in the rain-fed fields is lower than that in the irrigated fields, while the yield of cassava in both conditions is similar. The outputs of sugarcane and cassava for rain-fed and irrigated conditions are respectively shown in Tables 1 and 2.

The grey WF is estimated based on the application of nitrogen fertilizer to crops. The average nitrogen fertilizers applied to sugarcane and cassava are 66.21 and 68.23 kg/ha, respectively. The leaching run off fraction is assumed at 10% of the application rate (Chapagain et al., 2006). Due to surface quality standards (DEQP, 1994), the maximum allowable concentration is 5 mg/l. The natural concentration in the receiving water body is assumed to be zero. The grey WF is calculated based on Eq.(4). The outputs of the grey WF of sugarcane and cassava for rain-fed and irrigated conditions are respectively shown in Tables 3 and 4.

Table 1 Components of green and blue water footprint for sugarcane production

Province	ET_{green} (mm)	ET_{blue} (mm)	ETa (mm)	CWU_{green} (m^3/h)	CWU_{blue} (m^3/h)	CWU_{total} (m^3/ha)	Y (ton/ha)	$WF_{proc,green}$ (m^3/ton)	$WF_{proc,blue}$ (m^3/ton)
Rain-fed									
Chonburi	944.4	0.0	944.4	9444	0.0	9444	70.0	134.9	0.0
Prachinburi	1105.7	0.0	1105.7	11057	0.0	11057	65.9	167.7	0.0
Sakaeo	1111.2	0.0	1111.2	11112	0.0	11112	70.6	157.3	0.0
Irrigated									
Chonburi	944.4	280.5	1224.9	9444	2805	12249	96.9	97.5	29.0
Prachinburi	1105.7	46.0	1115.3	11057	460	11153	70.3	157.4	1.4
Sakaeo	1111.2	2.2	1113.4	11112	22	11134	72.3	153.4	0.3

Table 2 Components of green and blue water footprint for cassava production

Province	ET_{green} (mm)	ET_{blue} (mm)	ETa (mm)	CWU_{green} (m^3/ha)	CWU_{blue} (m^3/ha)	CWU_{total} (m^3/ha)	Y (ton/ha)	$WF_{proc,green}$ (m^3/ton)	$WF_{proc,blue}$ (m^3/ton)
Rain-fed									
Chonburi	832.5	0.0	832.5	8325	0.0	8325	25.0	333.0	0.0
Prachinburi	709.2	0.0	709.2	7092	0.0	7092	23.3	305.0	0.0
Sakaeo	773.3	0.0	773.3	7733	0.0	7733	25.0	309.3	0.0
Chachoengsao	742.8	0.0	742.8	7428	0.0	7428	20.3	396.0	0.0
Irrigated									
Chonburi	832.5	33.6	866.1	8325	336	8661	24.9	333.8	13.5
Prachinburi	709.2	129.1	838.3	7092	1291	8383	23.7	299.4	54.5
Sakaeo	773.3	35.5	808.8	7733	355	8088	25.1	308.5	14.2
Chachoengsao	742.8	24.9	767.7	7428	249	7677	19.5	394.0	13.0

Table 3 Water footprint of sugarcane production in Eastern Thailand

Province	Rain-fed (m^3/ton)				Irrigated (m^3/ton)			
	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}
Chonburi	134.9	0.0	18.0	152.9	97.5	29.0	13.0	139.4
Prachinburi	167.7	0.0	22.3	190.0	157.4	1.4	20.9	179.7
Sakaeo	157.3	0.0	14.2	171.5	153.7	0.3	13.8	167.8
Average	153.31	0.0	18.17	171.48	136.18	10.21	15.90	162.29

Table 4 Water footprint of cassava production in Eastern Thailand

Province	Rain-fed (m^3/ton)				Irrigated (m^3/ton)			
	WF_{green}	WF_{blue}	WF_{grey}	WF_{proc}	WF_{green}	WF_{blue}	WF_{grey}	WF_{proc}
Chonburi	333.0	0.0	61.6	394.6	333.8	13.5	61.8	409.1
Prachinburi	305.0	0.0	58.3	363.4	299.4	54.5	57.3	411.2
Sakaeo	309.3	0.0	53.9	363.2	308.5	14.2	53.8	376.5
Chachoengsao	396.0	0.0	60.1	426.0	394.0	13.0	62.6	456.0
Average	335.8	0.0	58.5	386.8	393.9	23.8	58.9	413.2

Table 5 Comparison of this study result, Mekonnen and Hoekstra's (2011) and global average water footprint

Area/Farming system	Sugarcane (m^3/ton)				Cassava (m^3/ton)			
	WF_{green}	WF_{blue}	WF_{grey}	WF_{proc}	WF_{green}	WF_{blue}	WF_{grey}	WF_{proc}
Eastern Thailand								
Rain-fed	153	0	18	171	336	0	56	387
Irrigated	136	10	16	162	334	24	59	413
Mekonnen and Hoekstra (2011)								
Rain-fed	164	0	13	176	-	-	-	-
Irrigated	120	104	14	238	-	-	-	-
Global Average	139	57	13	210	550	0	13	564

The estimated total water footprint of crop production process (WF_{proc}) is the summation of the green, blue, and grey water footprint as Eq.(5). The water footprints of sugarcane and cassava production in eastern Thailand under rain-fed and irrigated agriculture are illustrated in Tables 3-4.

The results show that the average WF's of sugarcane in rain-fed and irrigated cultivation are 171.48 m^3/ton and 162.29 m^3/ton, respectively. For cassava, the average WF's in rain-fed and irrigated agriculture are 386.8 m^3/ton and 413.2 m^3/ton, respectively.

As shown in Table 5, water footprint of sugarcane of eastern Thailand of the irrigated condition (162) is lower than that of rain-fed (171), those of rain-fed (176) and irrigated cultivation (238) of Mekonnen and Hoekstra, and that of global average (210). In the same table, water footprints of cassava of eastern Thailand (387 and 413 for rain-fed and irrigated respectively) are lower than that of global average (564).

CONCLUSION

This paper deals with the assessment of water footprint (WF) of sugarcane and cassava under the rain-fed and irrigated agriculture in the eastern part of Thailand. The results show that the average WF's of sugarcane in rain-fed and irrigated cultivation are 171 m^3/ton (89% green, 11% grey) and 162 m^3/ton (83% green, 7% blue, 10% grey), respectively. For cassava, the average WF's in rain-fed and irrigated agriculture are 387 m^3/ton (85% green, 15% grey) and 413 m^3/ton (81% green, 5% blue, 14% grey), respectively. The average WF of sugarcane in rain-fed is higher than that in irrigated agriculture because the rain-fed yield is lower than the irrigated yield. The yields of cassava in both conditions are very similar, but crop water use of irrigated cassava is higher than rain-fed cassava, thereby leading to the lower average WF of cassava in rain-fed than in irrigated agriculture. With the proportion of water use taken into account, rainfall remains a key factor in the cultivation of sugarcane and cassava. The WF reduction in the eastern region is achievable through adoption of part or all of the following suggestions in combination: 1) increase yield through improved agricultural practice; 2) improve the irrigation schedule by optimizing timing and volumes of application; 3) support investments in irrigation systems and techniques that conserve water; and 4) reduce the use of chemical fertilizers, pesticides and insecticides. The findings of this study not only would be of great use to both stakeholders and policymakers for better water management but also could be further used as basis data of sub-national water footprint for crop production.

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