

Water Footprint Assessment of Thai Banana Production

Cheerawit Rattanapan and Weerawat Ounsaneha

Abstract—The aim of this research was to assess the water footprint level of Thai banana production. Firstly, the water consumption inventory of banana production was developed. The water consumptions in the banana farms and a case study of banana industry were collected based on the inventory. The results showed that the water consumption of banana plantation was 842.02 m³ including 443.50 m³ of green water, 398.52 m³ of blue water and not found grey water. Moreover, 1638.59 m³/rai was found in the one rai of banana plantation consisted of 863.06 m³/rai of green water and 775.53 m³/rai of blue water. From the finding of this study, the reduction approach of water footprint for banana production should be the reduction of watering the plant in the process of banana growing.

Index Terms—Water footprint, water consumption, banana production, life cycle assessment, Thailand.

I. INTRODUCTION

The banana, belonging to the family Musaceae, is a highly common plant in tropical and subtropical countries [1]. Banana is a potential carbohydrate source for food consumption and could be used to formulate several kinds of desserts and functional foods [2]. About 144 million tons/year of banana is widely produced in the worldwide and over 234,000 tons were produced for demand of Thai and international consumption in 2013 [3], [4]. Besides, Office of Agricultural Economics, Thailand [5] presented that the dominant area of banana plantation with the low chemical use Thailand was found in the central part of Thailand.

The water requirements to grow food, supply industry and sustainable urban and rural populations has led to an increasing shortage of fresh water in many parts of the world [6]-[8]. To date, the increasing pollutant contamination at their water resources and the development of suitable management plan were presented in various countries. The number of global standards is quite limited in order of providing better comparison of different regions of the world [9]. Mekonnen and Hoekstra [10] recommended that the water footprint is the principle measurement for assessing the level of human appropriation of water resources. The total volumes of fresh water consumption and contamination were presented by producers and consumers from both direct and indirect ways throughout supply chain [9]-[11]. This measurement will be performed as a volumetric amount of water, without considering water use impacts on the region, and therefore this paper showed a water footprint inventory

analysis [12].

From the study of Clercx *et al.* [13] mentioned that the average water footprints of banana production in the small banana farmers in Peru and Ecuador were 576 m³/t in Ecuador and 599 m³/t, respectively. These finding presented that the sustainability of the water footprint is questionable in both countries for increasing the water productivity and better quality of banana fruits. Rattanapan and Ounsaneha [4] indentify that the water consumption is the important parameter of life cycle inventory for Thai banana supply chain.

Hence, the aim of this study was assess the water footprint of banana production in Thailand. Firstly, the water consumption inventory was generated and then the volumes of water consumption in banana plantation and industry were collected by life cycle assessment. Finally, the water footprint reduction approach was recommended for proposing the sustainable water consumption in Thai banana production.

II. MATERIAL AND METHODS

A. Goal and Scope Definition

- 1) The water footprint assessment of Thai banana plantation consisted of soil preparation, banana plantation, fertilizer use, pest control and harvesting. The input resources of banana plantation were water, fertilizer and fuel consumption and the output of this process was only the waste generation (Fig. 1).

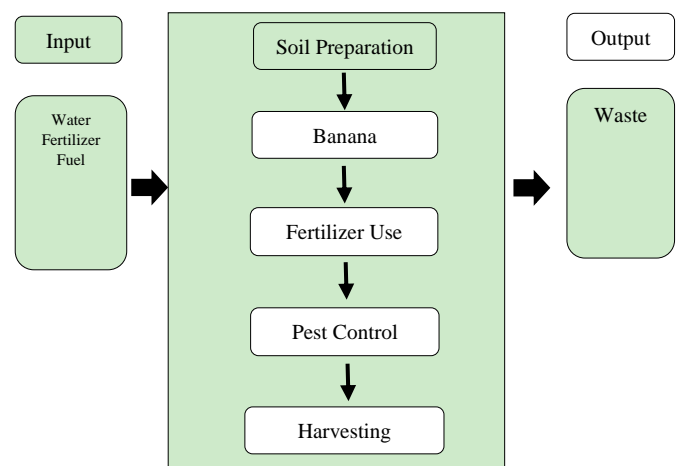


Fig. 1. Diagram of banana plantation.

- 2) The water footprint assessment of Thai banana production consisted of transportation, cutting, cleaning and drying, conveyor belt, screening, packing, and reprinting processes. The input resources of banana production were water, fuel and electricity consumption

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and the output of this process was only the waste generation (Fig. 2).

- 3) The consumption data from a one company and banana farms in the central parts was collected in this study.

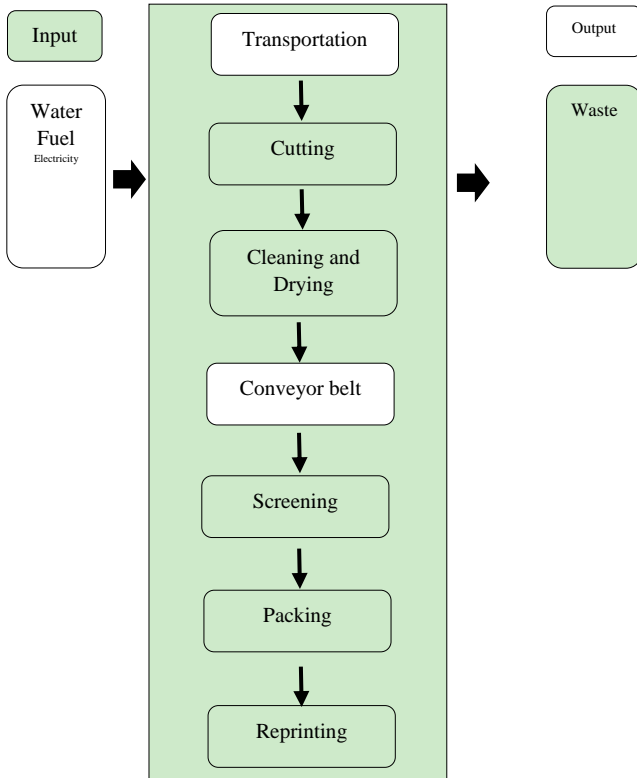


Fig. 2. Diagram of banana production.

B. Water Footprint Inventory

The primary data from banana farms and factor in the central part of Thailand was collection in the period of 2018 by the face-to-face interview and observation. The life cycle resources of banana supply chain including banana plantation, water, fertilizer, fuel, and electricity consumption were conducted. Moreover, secondary data of waster footprint assessment was includes from the related study or report with the scientific references.

C. Water Footprint Assessment

The water consumption inventory was developed from the primary survey and then was used to assess the water footprint performance in the agriculture and industry section. Firstly, the data of soil, climate, plan and map were collected from the literature review and related study and then were used to calculate the crop water use and Crop Evapotranspiration by CROPWAT 8.0 software. The Crop Evapotranspiration; ET was calculated by the green and blue of water footprint values in equation 1. The crop water use was calculated by gray of water based on equation 2 [14].

$$WF_{green} = \frac{CWU_{green}}{Y} \tag{1}$$

$$WF_{blue} = \frac{CWU_{blue}}{Y} \tag{2}$$

$$WF_{grey} = \frac{\alpha \times AR}{Y(C_{max} - C_{nat})} \tag{3}$$

Note:

CWU = Crop water use (m^3/rai)

Y = Crop Yield (kg/rai)

C_{max} and C_{nat} = the maximum concentration and concentration in the nature mass (mass/volume)

The total water footprint was calculated by following equation 4:

$$WF_{proc} = WF_{green} + WF_{green} + WF_{grey} \tag{4}$$

III. RESULT AND DISCUSSION

A. Life Cycle Inventory of Thai Banana Production

The life cycle inventories of Thai banana production consisted of banana plantation and production was shown in Table I and II, respectively. The input of life cycle inventory for the banana plantation collected from two banana farm consisted of root, chemical fertilizer, organic fertilizer, pesticide, herbicide, fuel, electricity, rain water and water use. The main input of banana plantation was the chemical fertilizers as 52.37 kilogram/rai. This finding was consistency with the report of Rattanapan and Ounsaneha [4] because the nitrogen and potassium was the main requirement for banana plantation. Moreover, the water use and rain water for plantation process were 833.70 and 714.24 m^3/ Rai , respectively. Table II showed the life cycle inventory of banana production, the main life cycle of banana production consisted of banana, water use, electricity, bag, tape, sticker and acetylene gas. The electricity use was the main input of this process because the electricity is used mainly for lighting and for operating pumps that extract water from wells and bananas is also transported within the facility on conveyor belts powered by electricity [15].

TABLE I: LIFE CYCLE INVENTORY OF THAI BANANA PLANTATION

Order	Inventory	Quantity	Unit
Input			
1.	Root	300	Root/Rai
2.	Chemical Fertilizer	52.37	kg/Rai
	0-0-60	2.5	kg/Rai
	46-0-0	6.5	kg/Rai
	15-15-15	34.5	kg/Rai
	21-0-0	8.87	kg/Rai
3.	Organic Fertilizer	25	kg/Rai
4.	Pesticides	7	kg/Rai
5.	Herbicide	0.40	L/Rai
6.	Fuel		
	Diesel	78.46	L/Rai
	Benzene	164.25	L/Rai
7.	Electricity	6.79	Kwh/ Rai
8.	Rain water	833.70	m^3/ Rai
9.	Water use	714.24	m^3/ Rai
Output			
1.	Banana	1.9	Ton/ Rai

B. The Parameter Information for Banana Production by CROPWAT 8.0

The objective of this research was to assess the water footprint of banana production with the calculation of water volume in the real banana plantation. From the comparison with the water consumption of banana (Etc) with the rain

consumption (P_{eff}), The ET_c value can be calculated by the plant coefficient from the report of Allen multiply with the reference of the water consumption from the CROPWAT 8.0 software. The meteorological data during 2013 – 2018 from Phra Nakhon Si Ayutthaya meteorological station was used to compute in this study. The detail of the rain consumption by USDA was following:

1) Climate and water consumption of banana (climate/ET₀)

The water consumption of banana (ET₀) was assessed by CROPWAT 8.0 with Penman-Monteith equation. The result found (Table III) that the maximum and minimum of water consumptions were 4.85 mL/day in May and 3.51 mL/day in December, respectively. This value was lower than the reference standard (3.51 mL/day) because of the humidity and high temperature in the plantation area in this study.

TABLE II: LIFE CYCLE INVENTORY OF THAI BANANA PRODUCTION

Order	Inventory	Quantity	Unit
Input			
1.	Banana	2625	Ton
2.	Water use	0.04	m ³ / Prodcut
3.	Electricity	0.042	kWh./ Prodcut
4.	Bag	0.00007	kg/Rai
5.	Tape	0.000006	kg/Rai
6.	Sticker	0.000001	kg/Rai
7.	Acetylene gas	0.00078	kg/Rai
Output			
1.	Banana Product	2348	Ton
2.	Waste	1.23	kg/Rai

TABLE III: CLIMATE AND WATER CONSUMPTION OF REFERENCE PLANT

Months	Minimum Temperature (°C)	Maximum Temperature (°C)	Humanity (Percentage)	Wind Speed (M/S)	The length of sunlight (H)	Water consumption of reference plan
Jan	20.1	32.7	70	66	7.4	3.53
Feb	21.9	34.4	69.3	65	7.4	4.00
Mar	24.2	36.2	72.3	63	7.4	4.56
Apr	24.9	37.1	71.8	64	7.2	4.82
May	25.2	37.2	72.4	64	7.1	4.85
Jun	24.6	35.5	76	64	4.9	4.05
Jul	24.3	34.4	78	63	3.7	3.62
Aug	23.9	34.0	80.3	56	3.4	3.45
Sep	23.7	33.5	83.3	49	4.6	3.60
Oct	23.2	33.6	81.6	53	5.9	3.68
Nov	22.4	33.6	76.5	72	7.2	3.75
Dec	20.4	32.1	69.1	82	7.1	3.51
AVG	23.2	34.5	75	63	6.1	3.95

Source: CROPWAT 8.0

2) Rainfall (P_{eff}) and Rainy

The rainfall consumption (E_{ff,rain}), P_{eff} was conducted by USDA method with the assumption on over and lower of 250 Mm of rainy value. The result showed that the rainfall and rainy consumptions were 1048.00 mm and 833.70 mm (Table IV).

3) Plan parameter of banana plantation

The period of banana plantation consisted of 4 periods including Period 1: offshoot to plan pot, Period 2: early growth (found leaves), Period 3: initial growth (found blossom) and Period 4: final growth (from blossom to production). The detail of plan parameter in each period of banana plantation was shown in Table V.

TABLE IV: RAINFALL AND RAINY CONSUMPTION

Months	Rainy (mm/months)
Jan	7.80
Feb	12.90
Mar	58.90
Apr	51.90
May	92.10
Jun	124.60
Jul	134.00
Aug	170.00
Sep	190.00
Oct	127.90
Nov	62.90
Dec	14.90
AVG	1048.00

Source: CROPWAT 8.0

TABLE V: PLANT PARAMETER OF BANANA PLANTATION

Plan parameter of banana plantation	each period			
	period 1	period 2	period 3	period 4
Days	90	165	45	30
Plan coefficient	0.50	0	1.10	1.00
Root depth	0.30	0	0.90	0.90
Dehydration crisis	0.55	0	0.45	0.45
Adjusting value	1.00	1.00	1.00	1.00
Height	0	0	3.00	0

Source: CROPWAT 8.0

4) Soil parameter

The soil parameters in this study were the total of humanity, the highest rate of penetration of water through soil, the highest of depth root, the initial decrease of soil moisture and the initial of total humanity. The details of soil parameter were shown in Table VI.

TABLE VI: SOIL PARAMETER OF BANANA PLANTATION

Soil parameters	Values	Unit
Total of humanity	200	Mm/m
Highest rate of penetration of water	30	Mm/day
Highest of depth root	900	centimeter
Initial decrease of soil moisture	50	Percentage
the initial of total humanity	100	Mm/m

C. Water Footprint of Thai Banana plantation

The water footprint of Thai banana plantation was assessed by the data collection from banana farm of Ayutthaya province, Thailand. The details of water footprint assessment are following:

1) Crop Coefficient (K_c)

In this research, Crop Coefficient of banana plantation was investigated by Crop Coefficient in each period of banana growth. The Crop Coefficient of each period was shown in Table VII.

TABLE VII: CROP COEFFICIENT OF WATER CONSUMPTION IN EACH GROWTH PERIOD FOR BANANA PRODUCTION

Growth period	Crop Coefficient (K _c) of banana plantation	Months
period 1	0.50	Jan-Mar
period 2	0	Apr-Sep
period 3	1.10	Oct-Nov
period 4	1.00	Dec

Source: CROPWAT 8.0

2) Reference Crop Evapotranspiration (ET₀)

The Reference Crop Evapotranspiration in this research was assessed by the Penman Monteith method. The

Reference Crop Evapotranspiration per months was shown in Table VIII.

TABLE VIII: THE REFERENCE CROP EVAPOTRANSPIRATION OF BANANA PLANTATION

Months	Crop Coefficient (K _c)	ET ₀ (MM/days)	ET ₀ (MM months)
Jan	0.50	109.43	54.71
Feb	0.50	112	56
Mar	0.50	141.36	70.68
Apr	0	144.6	0
May	0	150.35	0
Jun	0	121.5	0
Jul	0	112.22	0
Aug	0	106.95	0
Sep	0	108	0
Oct	1.10	114.08	125.48
Nov	1.10	112.5	123.75
Dec	1.00	108.81	108.81

Crop Water Requirement (CWR) =11.4

Source: CROPWAT 8.0

3) Effective Rainfall and Weighted Rainfall

The effective rainfall and weighted rainfall were assessed by the difference value between crop water requirement and effective rainfall. The detail of factor use for calculation was shown in Table VIII.

TABLE VIII: THE FACTOR OF RAINFALL ASSESSMENT

Weighted Rainfall WRFL(MM)	Effective Rainfall Peff (MM)
0-10	0
11-100	WRFL×0.80
101-200	WRFL×0.70
201-250	WRFL×0.60
251-300	WRFL×0.55
301-up	WRFL×0.50

From the average of rainfall value in this area, the effective rainfall was selected and then multiplied for calculating the rainfall. The result showed that the collection data area was the high value of rainfall per year as 1,048.00 mm/year. Over 72.31 percent of rainfall value was found in the September for initial growth period. The detail of rainfall value calculation for banana plantation was shown in Table. Form the result finding, the values of rainfall value as CWU_{green} and CWU_{blue} of Thai banana plantation were 757.25 mm and 80.78 mm, respectively (Table X-XII). Moreover, the values of rainy value as CWU_{green} and CWU_{blue} were 863.06 MM/area and 775.53 MM/area. Hence, total water consumption of banana plantation was 1638.59 MM/area.

D. Water Footprint of Thai Banana Production

TABLE X: THE RAINFALL VALUE CALCULATION OF BANANA PRODUCTION

Months	WRFL (MM/months)	Factor value	Pe (MM/months)
Jan	7.80	0	0
Feb	12.90	0.80	10.32
Mar	58.90	0.80	47.12
Apr	51.90	0.80	41.52
May	92.10	0.80	73.68
Jun	124.60	0.70	87.22
Jul	134.60	0.70	94.22
Aug	170.00	0.70	119
Sep	190.00	0.70	133
Oct	127.90	0.70	89.53
Nov	62.90	0.80	50.32
Dec	14.90	0.80	11.92
Total	1048.00	-	757.85

From the field of observation form the 400 rai of banana farms with the 1.946 ton/rai of banana productivity, the water footprint was assessed by three categorized above.

TABLE XI: THE RAINFALL VALUE OF THAI BANANA PRODUCTION

Months	Pe	CWR	Rainy consumption	Irrigation water consumption
Jan	0	54.71	1)CWR=0	0
Feb	10.32	56	1)CWR=10.32	56
Mar	47.12	70.68	1)CWR=47.12	70.68
Apr	41.52	0	2)Pe=0	0
May	73.68	0	2)Pe=0	0
Jun	87.22	0	2)Pe=0	0
Jul	94.22	0	2)Pe=0	0
Aug	119	0	2)Pe=0	0
Sep	133	0	2)Pe=0	0
Oct	89.53	125.48	1)CWR=89.53	125.48
Nov	50.32	123.75	1)CWR=50.32	123.75
Dec	11.92	108.81	1)CWR=11.92	108.81
Total	757.85	539.73	751.25	484.72

TABLE XII: THE RAINY VALUE OF THAI BANANA PRODUCTION

Months	Rainy consumption	Irrigation water consumption	Rainy consumption for banana use	Irrigation water consumption
Jan	54.71	0	87.53	0
Feb	56	56	89.6	89.6
Mar	70.68	70.68	113.08	113
Apr	0	0	0	0
May	0	0	0	0
Jun	0	0	0	0
Jul	0	0	0	0
Aug	0	0	0	0
Sep	0	0	0	0
Oct	125.48	125.48	200.76	800.76
Nov	123.75	123.75	198	198
Dec	108.81	108.81	174.09	174.09
Total	539.73	484.72	863.06	775.53

1) Green Water Footprint was the water volume in the pattern of humidity in soil. The green water footprint of banana plantation was assessed by the ratio of crop water use and plantation area. The assessment of green water footprint for banana production was following:

$$WF_{green} = \frac{863.06}{1.946} = 443.50 \text{ m}^3/\text{ton}$$

2) Blue Water Footprint was the natural water from the production and service use. The blue water footprint of banana production was assessed by the ratio of natural volume for banana production and banana volume for plantation area. The assessment of blue water footprint for banana production was following:

$$WF_{blue} = \frac{775.53}{1.946} = 398.52 \text{ m}^3/\text{ton}$$

3) Grey Water Footprint was the water volume use in the process of wastewater treatment from the production and service process. Form the observation in the banana farm found that the chemical and fertilizer in the process of banana plantation was not contamination in the environment. Hence, the grey water footprint was not the

scope of this study.

- 4) Water footprint of product was the water use volume of production in the life cycle for the product and service. Water footprint of production was assessed by the total water use of the whole process of the 1 ton of banana product. The assessment of water footprint for banana production was following:

$$\begin{aligned} \text{WFTotal} &= \text{WFgreen} + \text{WFblue} + \text{WFgrey} \\ &= 443.50 + 398.52 + 0 \\ &= 842.02 \text{ m}^3/\text{ton} \end{aligned}$$

From the result finding, the water use volume of 1 ton of banana production in this study was 842.02 m³, which consisted of 443.50 m³/ton of rain water use (53 % of total water use) and of 398.52 m³/ton of natural water use (47 % of total water use). Hence, water use volume of 1 rai of banana plantation area was 863.06 m³/rai, (53 % of total water use) and 775.53 m³/ton of natural water use (47 % of total water use)

The comparison of water footprint value for banana plantation with other countries was shown in Table XIII. The result found that the water footprint value of Thai banana production was lower than Indonesian banana because the climatic pattern of Indonesia was shown in the high water volume in the rainy season and Iceland area. However, the water footprint of Peru banana was lower than Thai banana the climatic pattern of Peru was presented in the high humanity and high water volume in the rainy season.

TABLE XIII: THE COMPARISON OF WATER FOOTPRINT VALUE FOR BANANA PLANTATION WITH OTHER COUNTRIES

Area	Water Footprint (m ³)
Thai banana (This study)	842.02
Indonesian banana	875
Peru banana	576

Source: L. Clercx [13]

E. Management Approach of Water Use Reduction for Banana Production

From the finding of water footprint assessment for Thai banana product, the main source of water use for banana plantation was watering process. Then, the reduction of watering process in each growth period of banana plantation should be proposed and concerned. In the industry process, the cleaning process of raw material as banana should be considered and reused for other process in the industry.

IV. CONCLUSION AND RECOMMENDATION

This study was to present the results of the water footprint assessment for Thai banana production. The production chains of Thai banana production process consisted of banana plantation and banana production in the industry, which was assessed based on 1 ton of banana production. The results showed that the water footprint of banana plantation was 842.02 m³ including 443.50 m³ of green water, 398.52 m³ of blue water and not found grey water. Moreover,

1638.59 m³/rai was found in the one rai of banana plantation consisted of 863.06 m³/rai of green water and 775.53 m³/rai of blue water. From this finding, the main source of water use for banana plantation was watering process. Hence, the reduction of watering process in each growth period of banana plantation and the water reused from the clearing process to other process in the industry should be recommendation of water footprint reduction.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, and methodology, C.R.; data collection and data analysis, W.O.; and writing, W.O.

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