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Evaluation of water footprint of Phitsanulok-2 rice yield under alternate wetting and drying cultivation in dry season

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Abstract

The objective of this research was to assess the Water Footprint (WF) of rice cultivation in Phitsanulok Province, Thailand. In this research, the data were collected by the field research technique in order to access WF in the rice fields for water saving without affecting the yield using Phitsanulok-2 rice. The implementation of two water management strategies under Alternate Wetting and Drying Method (AWD) was tested in comparison with Continuous Flooding Method (CF). The experiment was conducted during the dry season in 2016 and 2017 in the irrigated fields of Irrigation Water Management Experiment Station (Phitsanulok). From the results, it was found that the water delivery to the plots with both AWD techniques used less water than the continuous water supply method at approximately 33.64% in 2016 and about 18.26% in 2017 in the dry seasons and maintaining grain yield. The average WF of AWD1, AWD2 and CF was 883.35 m^3/ton, 912.90 m^3 /ton and 1,150.45 m^3/ton of paddy, respectively. Therefore, the less water cultivation by AWD1 and AWD2 are the appropriate water management strategy for cultivation of irrigated rice and it is an effective way to reduce WF of water used in the agricultural sector for Thailand.

Keywords: water footprint, irrigation, Phitsanulok-2 rice, alternated wet and dry, paddy yield
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1. Introduction

Rice is the most important grown of all crops under irrigation, with as much as 80% of all freshwater resources in Asia dedicated to irrigation, and 90% of the irrigation water is used for rice produce [1]. As a result of climate change, as well as the demands of urbanization and the need for water to maintain industrial production, it is increasingly difficult to maintain the supply for agriculture. It is anticipated that within 5 years, up to 20 million hectares in Asia will be experiencing a severe lack of water [2]. In farming rice, water is necessary to address the issue of evapotranspiration. Water is lost from farms due to seepage or percolation, and this water simply leaves the farm without ever coming into contact with the irrigated crop. Reducing the amount of irrigation water would lead to an improvement in water use efficiency.

Rice agriculture occupies 21.3% of cultivated land in Thailand and production reached 31.9 million tons from 108,960 km^2 of rice paddy during 2016 [3]. Rice cultivation demands a large amount of water usage, while the process generates wastewater which can have a detrimental effect on the environment. In recent decades, attempts have been made to increase yields while reducing water usage in the rice-growing sector. Various innovations have sought to help farmers to avoid water shortages and to manage scarce resources [4, 5]. One approach which has been used across Asia is AWD, which was first employed by the International Rice Research Institute (IRRI) more than twenty years ago. However, AWD techniques have not been widely adopted by Thailand farmers because of constrains in effectiveness and reliability.

The water footprint (WF) concept was initiated by Hoekstra and Hung (2002) and then was developed by Hoekstra and Chapagain (2008), and which serves to assess the way humans use freshwater resources, whether directly or indirectly, and in the capacity of production or consumption. WF therefore can be applied as a tool in managing the use of water in terms of its energy impact, especially when assessing the impact of water usage upon global warming. There are three elements which comprise the WF: blue, green, and grey water. Green water WF describes the rainwater which is evaporated as the rice crop grows. Blue water WF describes the water on and beneath the surface in the specified area which evaporates as the crops grow. Grey water WF shows how much freshwater is

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needed for pollutant assimilation and will depend on the concentrations which occur naturally as well as the ambient water quality [6 – 9].

The aim of this study was to calculate the WF when rice is grown in Thailand using water-saving methods under AWD, making comparisons of the 2015 – 2016 and 2016 – 2017 seasons. The study considers blue, green, and grey WF, and the findings can be used in planning the future usage of water resources and the formulation of policy controlling rice production and the use of water.

2. Materials and Methods

2.1 Experimental site

The field experiment was conducted over two consecutive years (2016, 2017) at irrigation fields of Irrigation Water Management Experiment Station, Phitsanulok Province in the northern region of Thailand. The location of the site chosen for this study is given by 17° 03′ 05′′ N and 100° 13′ 29′′ E. The site elevation above mean sea level stands at 47.5 m. Soil samples were drawn from a depth of around 30 cm and analyzed to determine the pH, texture, organic matter content, permanent wilting point, and field capacity, as indicated by the data in Table 1.

Table 1. Soil characteristics in the studied fields. (Depth 0-30 centimeters).

Property of soil analysis	2016	2017
Sand (%)	8.6	8.8
Silt (%)	11.0	10.3
Clay (%)	80.4	80.9
Texture Class	Clay	Clay
pH	5.0	5.3
Organic Matter (%)	2.5	4.6
Field Capacity	40.8	40.8
Permanent Wilting Point	28.7	27.4
Available P (ppm)	2.4	3.0
Total Extractable K (ppm)	40.0	38.0

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2.2 Treatments of irrigation

The experiment was repeated over seasons using randomized complete block design with three water treatments. The water treatments were: 1) AWD1, in which the paddy plot underwent flooding to 5 cm. Then when the water level declined to 5 cm beneath the ground level, the plot was flooded again for the remainder of the season to 5 cm, although irrigation ceased two weeks prior to harvesting; 2) AWD2, in which the paddy plot received 5 cm of water immediately after transplanting, which was maintained until 25 or 45 days later. If the water level fell to 15 cm beneath the ground level, flooding would once again take place to 5 cm for the remainder of the season, although irrigation ceased two weeks prior to harvesting; 3) A continuous flooding approach (CF), with pond depth of 5 cm for the duration of the season, ceasing irrigation two weeks prior to harvest. The design of the treatments allowed the planting of Phitsanulok-2 by taking rice seedlings aged 21 days and transplanting sections measuring 20 × 25 cm. For each of the treatments, if a single plot required irrigation, all of the three plots for each treatment received irrigation. The plots measured 10 m × 22 m and were separated by a pathway of width 1.0 m. The water was unable to flow laterally due to the construction of 30 cm dikes which were covered with a black plastic film extending 30 cm below the surface of the ground.

In each of the two seasons, the irrigation commenced ten days after transplanting. During those initial ten days, the depth of the water was maintained at 5 cm to allow the plants to consolidate and to prevent the growth of weeds. After this, the water level under the soil surface was checked constantly using perforated field water tubes. Under continuous flooding, this 5 cm depth was sustained for a period from 15 days prior to harvesting. For AWD1 and AWD2, irrigation timings were dependent on the records of water depth obtained from the field water tubes.

The research also recorded the total water input levels (m^3/ha), including both irrigation sources and rainfall. For each season, the amount of water input from irrigation to each plot was measured using a flow meter installed in the irrigation pipeline, whereas rainfall data were collected from irrigation water management experiment station (Phitsanulok).

2.3 Water footprint (WF) assessment

WF is defined as a water resources use indicator, which could be expressed as the water volume used to produce a unit of product (m^3/ton). The total WF (m^3/ton) of crop cultivation is calculated by the sum of green, blue and grey components, as shown below:

$$WF_{Crop} = WF_{Blue} + WF_{Green} + WF_{Grey} \quad (1)$$

Where, WF_{Blue} is the blue WF, refers to the fresh surface and ground water used for production purpose, ground water has not been calculated in this study; WF_{Green} is the blue WF, refers to the volume of rain water used for crop cultivation; WF_{Grey} is the grey WF; grey WF is the water needed to dilute with the pollution. The green and blue WFs can be calculated using the Equation (2) and (3)

$$WF_{Blue} = CW_{Blue}/Y \quad (2)$$

$$WF_{Green} = CW_{Green}/Y \quad (3)$$

Where, CW (m^3/ton) is the crop water use of blue or green, CW_{Blue} is the amount of the water from the irrigation and CW_{Green} is the precipitation consumption. Y (ton/ha) is the crop yield. In the case of grey WF, the

Table 2. Summary of water consumption and paddy yield.

Treatments	Water consumption (m^3/ha)			Yield (ton/ha)
	Irrigation water	Precipitation	Total	
AWD1-2016	4,357.5	735.0	5,092.5	6.5
AWD2-2016	4,926.9	735.0	5,661.9	6.9
CF-2016	6,995.6	735.0	6,995.6	6.6
AWD1-2017	4,843.5	395.0	5,238.5	5.7
AWD2-2017	4,980.1	395.0	5,375.1	5.7
CF-2017	6,008.8	395.0	6,403.8	6.0

calculations were based on the use of nitrogen fertilizers using the application rate given in Equation (4):

$$WF_{Grey} = [(\alpha \times AR)/(C_{max} - C_{naure})]/Y \quad (4)$$

When, α is times the leaching fraction, assumed 10% for nitrogen fertilizers. AR indicates the rate of chemical application for each hectare (kg/ha), while Y is the yield quantity of paddy (ton/ha), C_{max} indicates the highest permissible concentration (kg/m^3) and C_{naure} represents the pollutant's natural concentration (kg/m^3) [6, 7]. The fraction for leaching runoff (α) was 5 mg/l [10], which was the equivalent of the greatest acceptable level of nitrate-nitrogen in the surface water and groundwater on the basis of the water quality standards employed in Thailand. This assumed that in the bodies of water into which this runoff flowed, there was zero natural nitrogen content [7]. The type of soil used will affect the requirements for nitrogen fertilizer, with around 100 kg/ha needed for loam, sandy loam, or sand, while clay or clay loam will require just 50 kg/ha [11].

3. Results and Discussion

3.1 Water usage and paddy yields

In 2016 growing season, water consumption for the CF treatment was 6,995.6 m^3/ha. The AWD1 and AWD2 treatments, water consumption were 5,092.5 m^3/ha and 5,661.9 m^3/ha, respectively. The precipitation or rainfall received 735.0 m^3/ha (73.50 mm). In 2017 growing season, CF, AWD1, AWD2 and precipitation received 6,403.8 m^3/ha, 5,238.5 m^3/ha, 5,375.1 m^3/ha and 395.0 m^3/ha (39.50 mm), respectively. There were significant differences in the way the irrigation water was used when comparing between the approaches ($p < 0.01$). This is presented in Table 2. The total amount of water required for integration was closely dependent on the influence of the water management techniques used in each case ($P < 0.01$). Those plots which were continuously flooded (CF) required the greatest water input level for both seasons under investigation. AWD1 and AWD2 were able to reduce the amount of water required by plots maintained under CF had the highest total water input in both rice growing seasons. The AWD1 and AWD2 irrigation reduced total water input by 30.40% and 21.30% respectively in comparison to CF for 2016, while the reduction was 19.39% and 17.12% respectively when compared to CF in 2017. The AWD technique for saving water was able to reduce the water input required in both years.

When comparing irrigation approaches in 2016 and 2017, the grain yields showed significant differences ($p < 0.01$) as shown in Table 2, with 2016 producing a yield superior to that of 2017. The greatest yield for 2016 was on AWD2 at 6.9 ton/ha, which was higher than AWD1 at 6.5 ton/ha and CF at 6.6 ton/ha. In 2017, the high grain yield was observed in CF at 6.0 ton/ha, which was higher than AWD1 at 5.7 ton/ha and AWD2 at 5.7 ton/ha, respectively. When AWD1 treatments were applied, the average grain yield declined relative to AWD2 and CF, with the yields under the AWD1 treatments declining by 3.17% when compared with AWD2 and CF, respectively. Meanwhile, for 2017, the AWD1 and AWD2 treatments reduced yields by 5.0% when compared to CF. In average yields, a similar trend was observed, with significant decreases found for all AWD1 treatments ($p < 0.01$), ranging from 0.0 – 0.4 ton/ha to 0.1 – 0.3 ton/ha, in comparison to AWD2 and CF covering the two experimental periods. However, it is also known that AWD can reduce rice yields if not implemented correctly and the drying conditions in AWD is the most important factor affecting yield. This might be due to different soil type and other site specific characteristics [12, 13]. Importantly for AWD process, the soil matric potential threshold for triggering the AWD irrigation might be dependent on soil type, management practices and factors related to the local climatic conditions [14]. Even in the same region, the effects of AWD vary with time and intensity of rainfall, type and amount of fertilizer.

3.2 Water footprint of rice production

The WF of rice cultivation in 2016 – 2017 was calculated in this study. Data from Table 3 showed the average total WF of treatments, which can be divided into blue, green and grey, respectively. All treatments, the blue WF was higher than green and grey, which implied that there was a large section of water used for irrigation. In order to reduce the blue proportion in rice cultivation, an alteration to the water-saving technologies was suggested. The result of the average WFs of rice production in experimental site was calculated based on Equation (2 – 4). The results in

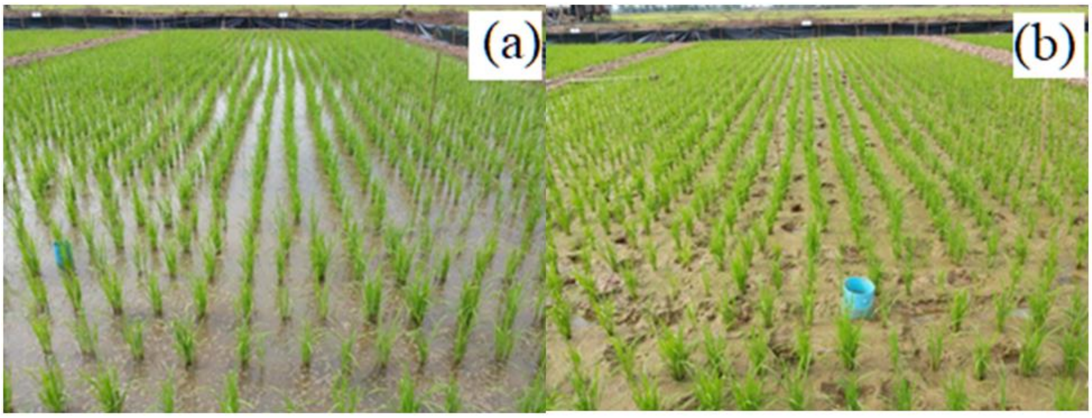

Figure 1: Experimental site of the individual plot of (a) CF period and (b) AWD period.

Table 3. Summary of water footprint.

Treatments	Water Footprint (m^3/ton)			
	Blue Water	Green Water	Gray Water	Total
AWD1-2016	670.4	113.1	29.9	813.4
AWD2-2016	714.0	106.5	28.3	848.8
CF-2016	1,059.9	111.4	29.6	1,200.9
AWD1-2017	849.7	69.3	34.3	953.3
AWD2-2017	873.7	69.3	34.0	977.0
CF-2017	1,001.5	65.8	32.7	1,100.0

Table 4. Previous studies of the water footprint (m^3/ha) for rice cultivation in Thailand.

Treatments	Water Footprint (m^3/ton)			
	Blue Water	Green Water	Gray Water	Total
AWD [15]	1,193.9	24.4	198.9	1,417.1
AWD [16]	711.3	54.5	200.0	965.8
CF [17]	600.0	1,678.0	585.0	3,209.0
CF [18]	1,283.0	11.0	397.0	1,691.0
CF [19]	1,470.3	0.0	788.4	2,258.8

2016 showed the maximum WF in CF-2016 of 1,200.9 m^3/ton with the blue, green and grey WF at 1,059.9, 111.4 and 29.59 m^3/ton respectively which was higher than AWD2-2016 at 848.8 m^3/ton and AWD1-2016 at 813.4 m^3/ton, respectively. Results in 2017 also showed the maximum WF in CF-2017, consisting of blue, green and grey WF of 1,001.5, 65.8 and 32.68 m^3/ton respectively resulting in a total WF of 1,100.0 m^3/ton which was higher than AWD2-2017 at 977.0 m^3/ton and AWD1-2017 at 953.3 m^3/ton, respectively. It was found that WF was significantly higher under CF than AWD in both growing seasons. The average values of WF for CF were higher than AWD1 and AWD2 treatments about 23.22% and 20.65%, respectively. The range of the total WF of rice cultivation in CF were 1,100.0 – 1,200.9 m^3/ton, AWD1 were 813.4 – 953.3 m^3/ton and AWD2 were 848.8 – 977.0 m^3/ton.

From tables 2 – 3, the treatment of AWD1-2016 yielded the lowest WF of 813.4 m^3/ton and the AWD1-2017 WF was 953.3 m^3/ton, while maintaining similar grain yield and the yield was relatively high almost up to CF technique. This implies that an AWD irrigation technique delivers enough water for crop water requirement. From all treatments, the different climatic conditions, water level control, dry period duration and cultivation practices could cause variation of WF.

From the results, both AWD systems reduced irrigation water use during AWD cycle. AWD was a water management technique that reduced irrigation water requirement in paddy field. In the Phitsanulok field, the total amount of water used in AWD was slightly less than CF. Results indicated that AWD might be an effective mean for water saving. Other studies showed a more effective impact of AWD on water saving such as the studies on Table 4. Results of this study showed that the blue component was higher than the green and grey components. Most interactions between rice variety and fertilizer were not significant.

For Paddy, which needs relatively high water inputs, especially irrigation water in dry season, the irrigation efficiency of water use during the growing period is therefore essential to the regions with limited irrigation water. Water productivity of paddy can be improved by developing water management and improving agronomic management, i.e., improving fertilizer management and pest control to enhance yields. Moreover, as the water management practices during the first two weeks from planting are essential to enhance weed suppression, the early flooding of wet seeded rice and the intermittent flooding by AWD method during crop growing can help to reduce water use.

Generally, the water used in rice cultivation from absorbing water in the soil through plant roots. The amount of water that the rice absorbed is only a low quantity of irrigation water for rice. Most of the water is lost from an irrigated field by transpiration, evaporation and percolation. The transpiration and soil water evaporation, collectively known as evapotranspiration, are controlled by the solar radiation or sunshine, temperature, atmospheric humidity and wind, which are factors that depend on the topography factor. In this study, factors that cause differences in irrigated water requirement and yield are climatic condition and water management. The important variables affecting WF are the water level control of flooding in rice cultivation and climatic conditions.

4. Conclusions

This study not only proved the feasibility of assessing WF of rice production with field experiments, but also provided a method for WF calculation based on field water processes. The calculation was made using the methodology proposed in The Water Footprint Assessment Manual, according to which the WF of rice represented the relation between the water saving irrigation techniques and the field productivity.

The AWD is a comparatively new and easy-to-use technique developed for Asian farmers to reduce water input while maintaining yield in irrigated rice production system. Some studies have observed decreased or even increased grain yield under AWD compared with CF [20,21]. In this study, this water saving irrigation technique could be a feasible option in reducing total water input and maintaining grain yield for soil and weather conditions comparable to the present study. By assessing the water footprint of rice cultivation, it could be seen that the input of blue water was lower, while WF was also lower under AWD in comparison to CF. If the period of cultivation could be moved to a time of year which offered slightly higher rainfall, the need for water supplied could be reduced. Alternatively, using a systematic approach of wet and dry farming rather than maintaining a flooded environment might also serve to lower the overall water consumption levels. While the use of green water in the cultivation of rice is not currently a major environmental concern, it is probably the case that in order to reduce the use of blue water, the green water footprint should be cut where possible. The use of green water suggests that rainfall alone is insufficient to generate the required rice yields, and therefore irrigation is necessary. The effects of the WF for green and grey water in rice cultivation will vary with the growth stage and levels of rainfall. The findings report should be of use to those responsible for paddy management with regard to water resources allocations and water supply management practices. By using the concept of the water footprint in the analysis of paddy water usage, it is possible to make savings in terms of blue water, while using green water more efficiently [22]. It is hoped that further studies will be encourage which will examine alternative regions and crops in order to limit the usage of blue water in agriculture in the future.

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