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Alternate Wetting and Drying (AWD) on Rice Irrigation

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ABSTRACT

In Malaysia, numerous methods have been subsequently established subjected to water-saving irrigation aiming to improve the common conventional irrigation system. However, among the most preferred water-saving method, alternate wetting and drying (AWD) irrigation adoption are presently in paddy cultivation yet has very limited information, especially locally. Hence, this study intended to propose two treatments, namely continuously flooded (control) and AWD irrigation, to investigate the feasibility of AWD implementation. The experiment was conducted at the paddy field of Padang Raja Kelantan, Malaysia. From the result, the agronomic performance was evaluated by several attributes under the growth performance evaluation, grain yield performance evaluation, and chlorophyll measurement. Statistical analysis was performed on the obtained data, and both growth, yield performances, and chlorophyll content resulted in no significant difference at $p < 0.05$, a 95% confidence level.

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INTRODUCTION

The water crisis is a major concern in Malaysia as the water demand in growing areas is gradually increasing. Despite having an average rainfall of 3,000 mm, considered

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among the highest rainfall intensity in other Asian countries, the main water sources can no longer meet the increasing demand for the domestic, industrial, and agricultural sectors. In agricultural areas, water is a prime factor and important resource needed for proper crop growth, particularly for water-intensive crops such as paddy. Malaysia has a long and strong history of paddy cultivation. Farmers usually adopt conventional practices where paddy is grown under continuously flooded conditions. This traditional practice commonly requires standing water per season, ranging from 700 mm to 1,500 mm (Oliver et al., 2010). Nonetheless, this practice has a long-term issue concerning the environmental effect of unnecessary irrigation water consumption.

Given water conservation, the most practical approach is water usage optimization. Numerous water-saving techniques have been introduced and documented since time immemorial, for example, intermittent irrigation, drip irrigation, deficit water regime, a system of rice intensification (SRI), and alternate wetting and drying (AWD). AWD is the most popular water-saving technology adopted to improve water use efficiency. In the 90s, International Rice Research Institute (IRRI) introduced a practical and advanced technology approach focusing on water-saving management practice, known as the 'alternate wetting and drying (AWD) technique'. The enforcement of AWD is farmer-friendly.

Water conservation technology only needs a proper field water tube made from a low-cost material, such as bamboo and polyvinyl chloride (PVC). A field water tube is used to monitor the standing water level. The paddy field is flooded with irrigation water and is allowed to dry out to a certain ground depth before the irrigation water is reapplied again. In AWD practices, less irrigation water input is required. Past researchers (Akter et al., 2018; Aziz et al., 2018; Dong et al., 2018; Zhuang et al., 2019) have reported and acknowledged this technique and found that by using AWD practice, there is no significant decrease in yield compared to continuous flooded practice. In AWD irrigation, not only does a reduction of up to 30% of total irrigation water input, but the total water productivity is also increased, and the same goes for the nutrient uptake (Sarkar, 2001).

AWD irrigation has been widely used worldwide and is one of the popular methods in paddy cultivation. AWD has promoted water productivity in rice irrigation relative to conventional irrigation (Akter et al., 2018; Biswas et al., 2021; Busari et al., 2019; Chidthaisong et al., 2018). In addition, Norton et al. (2017) ascertained in their report that AWD increased the total grain mass due to the high number of productive tillers. It was supported by Carrijo et al. (2018) and Sriphirom et al. (2018), who mentioned that the AWD practice positively affects the tiller, panicle numbers, and grain yield.

However, in Malaysia, the farmers' adoption of AWD is still small. It may be due to a lack of information, awareness, expertise, and successful experimental evidence. Based on the previous related research, the study on AWD in paddy growth and grain yield performances has been under research, especially locally. Thus, this study aimed to investigate the feasibility of AWD adoption subjected to agronomic physiology performances in Kelantan, Malaysia.

MATERIALS AND METHODS

Description of the Study Area

Kelantan district experienced a tropical climate divided into the wet and dry seasons. The highest rainfall precipitation can be recorded from November to January, while the highest temperature is observed from February to October (Figure 1). This study was conducted at the end plot of rice cultivation area at the paddy field of the Department of Agriculture Kelantan Research and Developmental Platform Padang Raja Kelantan, Kelantan Malaysia (5°57’44.4”N 102°17’20.3”E). The area is mostly covered with alluvium deposits consisting of unconsolidated to semi-consolidated gravel, sand, clay, and silts. The underlain layer is mainly dominated by granitic and sedimentary/metasedimentary rocks that consist of sandstone, phyllite, slate, and shale (Ilahi et al., 2021).

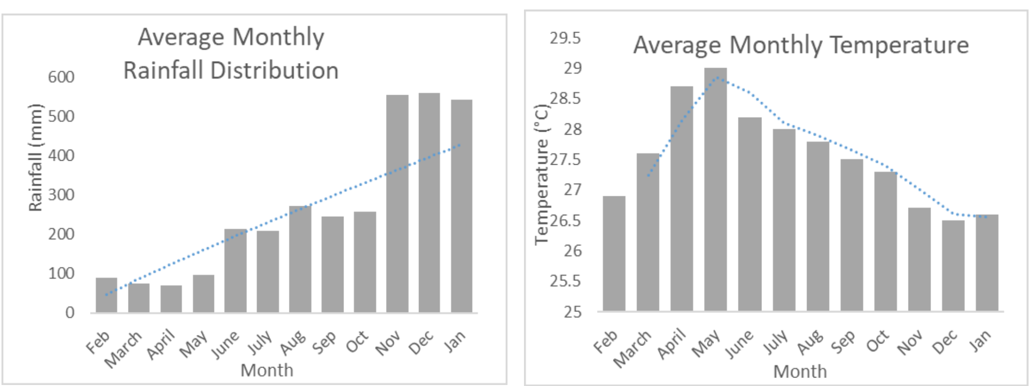

Figure 1. Average monthly rainfall distribution and temperature recorded from the Malaysian Meteorological Department in Kelantan, Malaysia

Experimental Design

Two main water management studies: continuously flooded condition (control) and AWD irrigation, were proposed. The experiment was initiated in 2020 and arranged as a randomized complete block design (RCBD) plot with three replications. Treatment plots were designed to be 46 m x 50 m and separated with compacted earth bunds to minimize and block lateral water seepage between plots. Drainage for outflow water was properly constructed to avoid excessive standing water remaining in the field plot, especially in heavy rainfall. Paddy rice (*Oryza sativa* L.) variety of Mardi Sempadan MR303 was chosen and grown during the wet season (June to September). The direct seeded method was applied for both water management practices. Nutrient management was not a focus in this experiment; thus, the fertilizers and pesticides used for all plots during the whole season of rice cultivation were standardized based on the local farmer's utilization.

A control experiment was proposed by adopting practices from the normal conventional systems by local farmers. The treatment plot was regularly irrigated, keeping 5 cm to 10 cm of standing water starting from 1 day after sowing (DAS). From 85 DAS onwards, plots were not irrigated before harvesting (120 DAS), and soil was allowed to dry out. Following the recommendation by IRRI, the safe-AWD experiment was proposed, in which a low-cost field water tube built from polyvinyl chloride (PVC) pipe was used to monitor the water level at a depth of 15 cm below the ground surface. The field water tube was 15 cm in diameter with 30 cm in height; half of the size was perforated with holes to ensure water could flow in and out of the tube. The 15 cm non-perforated part of the tube protruded above the ground surface, while another half was hammered into the field. The soil inside the tube was removed until the bottom of it could be visibly seen. The plot was regularly irrigated by letting the standing water fluctuate between 5 cm to 10 cm till 30 DAS. It ensures that the paddy crop establishes a stable physiological state before the experiment starts. Afterward, the AWD experiment began by allowing the water level to drop to 15 cm below the ground surface; after that, the irrigation was re-applied till the standing water reached 5 cm above the ground surface. After that, the AWD irrigation was reapplied again till the harvest stage. The AWD experiment started at 30 DAS to suppress weeds from growing and stabilizing the seed from water stress.

Sampling Parameter

Table 1 summarizes the overall sampling parameter and evaluation of samples for both growth and yield performance of paddy crops for two water management (control and AWD irrigation). Daily observations were made for standing water depth in a control experiment to keep it fluctuating from 5 cm to 10 cm. In the AWD experiment, the dates of standing water disappeared, and re-flooded times were recorded. In addition, quantitative measurement was recorded at each growth stage: plant height, tiller number, and average soil plant analysis development (SPAD) measurement between three healthy leaves. SPAD is a tool measuring the chlorophyll content indirectly. SPAD values were measured thrice in each treatment plot, and the average value was recorded using SPAD-502 Plus (Konica Minolta Sensing, Japan).

Evaluation of crop growth performance was evaluated from samples collected at the individual plot of 0.5 m^2 area and at the center of an experimental plot to avoid the border effect. Destructive analysis was conducted for better evaluation of paddy crop samples. Plant samples were separated for grain, leaf, and stem. The plant material afterward was dried till to constant weight.

Grain yield performance was evaluated from five panicles collected randomly. The panicle length, the total number of grains, and the number of filled and unfilled grains were measured and counted. In addition, all grains samples were dried to constant weight, and the dry weight of filled and unfilled grains, the weight of 1,000 grains, percentage grain filing, and harvest index was calculated. The equation involved is shown below:

$$\text{Harvest index (Karki et al., 2018)} = \frac{\text{Economic yield (grain yield)}}{\text{Biological yield (grain yield + straw yield)}} \quad (1)$$

Table 1

List of sampling parameters and evaluation of samples observation for both growth and yield performance of paddy crop for two water management (control and AWD irrigation)

Observation	
Daily observation	
i.	Standing water disappearance
ii.	Re-flooding time
At each growth stage	
i.	Plant height
ii.	Tiller number
iii.	SPAD measurement
Evaluation of crop growth	
i.	Samples were collected at the individual plot of 0.5 m^2
ii.	Samples were separated for grain, leaf, and stem
iii.	Samples were marked
iv.	Samples were dried to constant weight
Evaluation of grain yield	
i.	Samples were collected from five panicles at random
ii.	Samples were measured for their panicle length, the total number of grains, number of filled and unfilled grains
iii.	Samples were dried to constant weight
iv.	The weight of 1000 grains, % of grain filling, and harvest index were calculated

Statistical Analysis

Three replicates were used for each treatment, and the effects of treatments on paddy crop growth and grain yield performance were statistically analyzed by *t*-test using Excel 2011 (Microsoft Corporation, USA). *P*-value was < 0.05, and the differences were considered significant.

RESULTS AND DISCUSSION

Various research and yet ongoing methods were predetermined to improve the current practice of irrigation systems to reduce irrigation water consumption ultimately. The concern of introducing the AWD water management in this study is to investigate the potential effect of the AWD on agronomic traits of crop growth performance, grain yield performance, and chlorophyll content measurement. The crop growth performance for both water management practices was determined by plant height, panicle length, no of filled and unfilled grains, while the grain yield performance was determined by total grain number per panicle, grain filling (%), 1,000-grain weight, and harvest index (Thakur et al., 2018).

Table 2 represents the growth performance between two water management treatments: control and AWD irrigation technique, and was illustrated in the graph as in Figure 2. All values were presented as mean ± standard error (SE) (n = 3) of three replicates at $p < 0.05$ and 95% confidence level. Table 3 represented the grain yield performance between two water management treatments: control and AWD irrigation technique, and was illustrated in the graph as in Figure 3. All values are presented as mean ± standard error (SE) (n = 3) of three replicates at $p < 0.05$ and 95% confidence level. Figure 4 visualizes water level measurement for water management (control and AWD irrigation) throughout the growing season.

Table 2

Growth performance of paddy crop for two water management (control and AWD irrigation). Values are mean ± SE (n = 3) of three replicates at p *< 0.05*

Treatment	Plant height (cm)	Panicle length (cm)	No. of filled grains	No. of unfilled grains
Control	99.78 ± 4.15	24.17 ± 0.55	121.93 ± 8.80	14.00 ± 2.96
AWD	95.00 ± 4.53	22.31 ± 0.58	94.40 ± 5.35	10.93 ± 2.10
Significance	ns	ns	ns	ns

Note. ns = Not significant

Table 3

Grain yield performance and harvest index of plant crop at harvest stage for control and AWD irrigation. Values are mean ± SE (n = 3) of three replicates at p *< 0.05*

Treatment	Total grain number/panicle	Grain filling (%)	1,000-grain weight (g)	Harvest index
Control	135.93 ± 6.17	89.48 ± 2.65	71.15 ± 4.51	0.46 ± 0.03
AWD	105.33 ± 4.90	89.58 ± 2.09	83.42 ± 7.83	0.47 ± 0.03
Significance	ns	ns	ns	ns

Note. ns = Not significant

Based on Tables 2 and 3, the growth performances and grain yield performances result in no significance at *p*-value < alpha value 0.05 subjected to control and AWD treatment, and this was supported by previous studies of Carrijo et al. (2017), Ishfaq et al. (2020), and Yao et al. (2012). Studies show that the reasoning behind the insignificant difference between both treatments was due to no water stress taking place in AWD irrigation as Safe-AWD was utilized. In Safe-AWD, the standing water was allowed to drop until 15 cm below the ground surface, and irrigation was re-applied afterward, keeping it to 5 cm above the ground surface. It ensured the soil water potential was at > -20kPa, indicating the limitation to mild water stress. Moreover, the experiment was conducted during the wet season, when the precipitation rate exceeded the average. It was in agreement with previous research reported by Chidthaisong et al. (2018) and Sriphirom et al. (2019) that specifically mentioned that the implementation of AWD during the monsoon season was rather hard due to the difficulty of managing the level of standing water. Setyanto et al. (2018) further mentioned that if AWD were properly implemented, it would enhance the root growth and eventually increase the grain filling rate by improving the mobilization of reserve carbon to grains.

Figure 5 shows the image of the paddy crop between control and AWD irrigation water management on the growing days at 60 DAS, 90 DAS, and 115 DAS (before harvest time). At the control treatment, the growth performance comprised plant height, panicle length, and numbers of filled and unfilled grains showed higher value than in the irrigation method. On early 60 DAS of paddy crop (Figure 6), the plant height was higher in control than AWD water management, and the results in Table 2 supported this.

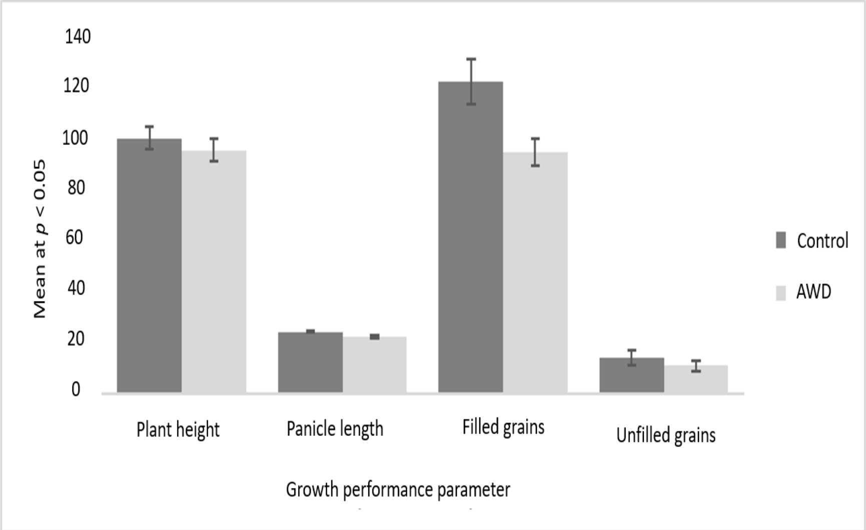

Figure 2. Paddy crop growth performance parameter for two water management (control and AWD irrigation)

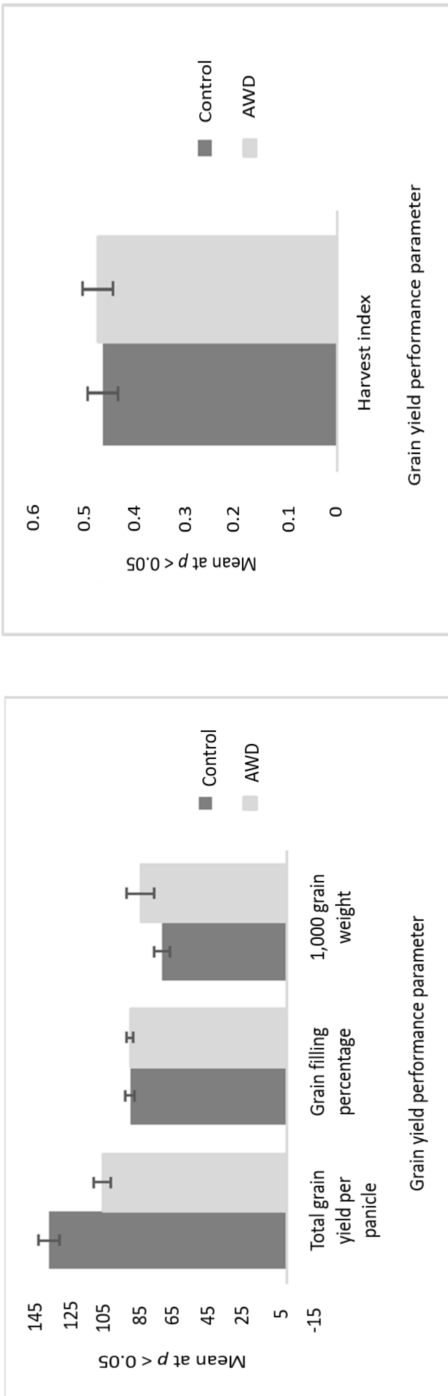

Figure 3. Grain yield performance parameter for two water management (control and AWD irrigation)

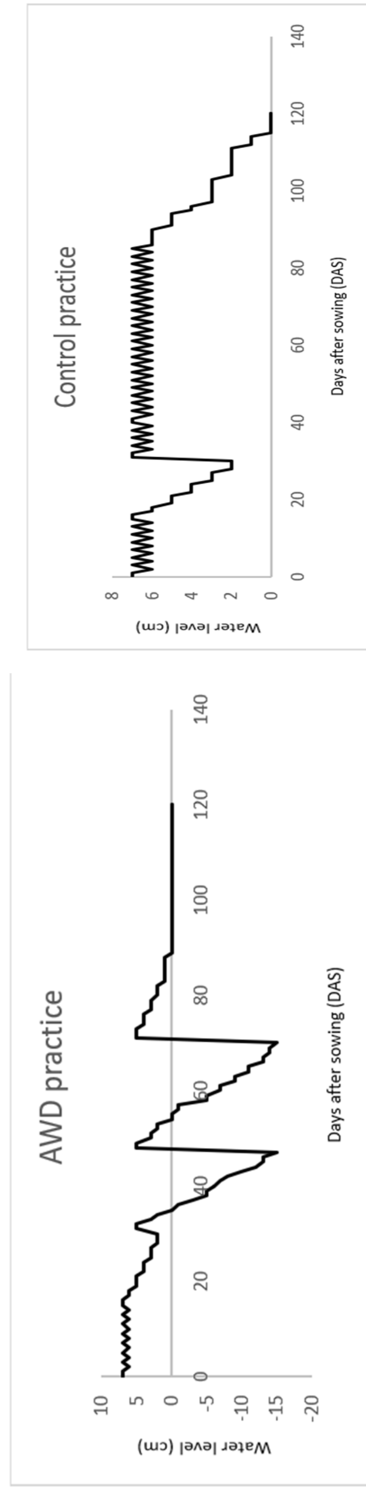

Figure 4. Water level management for two water management (control and AWD irrigation)

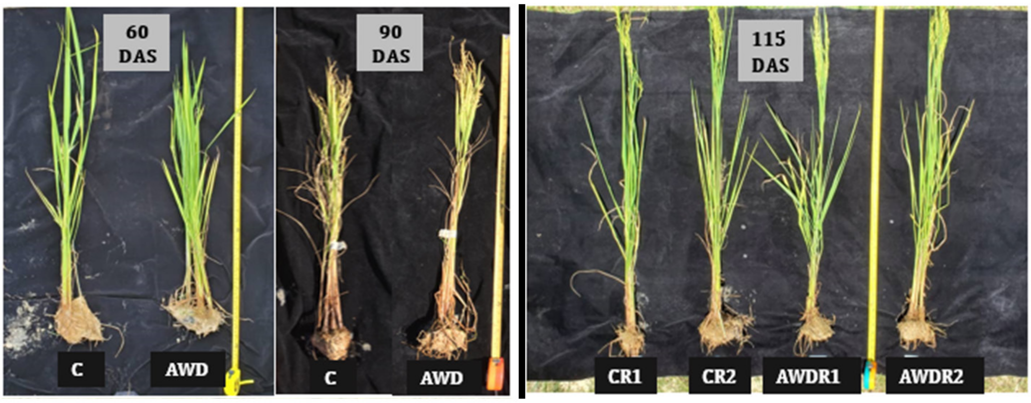

Figure 5. Paddy crop growth comparison between control and AWD irrigation water management at 60 DAS, 90 DAS, and 115 DAS

Nonetheless, on 90 DAS, the plant height was taller in AWD compared to control in a slight difference. As harvest time approached, the plant height was comparative in both treatments. The lower height in AWD irrigation agreed with past studies by Busari et al. (2019) and Fonteh et al. (2013), which have proven that irrigation water management in AWD has significantly reduced the plant height. The plant height and panicle length significantly influence the filled and unfilled number. As plant height increases, so thus the panicle length increases, and the total number of grains increases. Pascual et al. (2017) have mentioned that the number of unfilled grains may increase as water stress increases, thus affecting the grain filling process. It may result to yield reduction as spikelet sterility has been disrupted.

However, at grain yield performances, the percentage of grain filling, 1,000-grain weight, and harvest index show higher value in AWD compared to control. In contrast, the total number of grains per panicle was higher in control than in AWD (Table 3 and Figure 5). AWD method has been proven to have a greater influence on increasing the grain yield (Liu et al., 2013); however, the importance behind the practice was to control the threshold level of soil water potential. As practiced by Ishfaq et al. (2020) and Zhang et al. (2021), results from the safe AWD regime show that re-applied irrigation water at 15 cm to 20 cm of soil depth while maintaining the soil water potential at -20 kPa can avoid paddy crops from experiencing severe water stress. It was supported by Norton et al. (2017), which mentioned the importance of AWD adoption on the drying cycle's duration.

The AWD regime was also believed to increase the percentage of grain filing and 1,000-grain weight, thus increasing the percentage of reproductive tillers and dry matter (Liu et al., 2013). However, this was opposite to the report by Pascual et al. (2017) that mentioned that water stress might affect the reproductive tillers' number and thus may disturb the panicle initiation process.

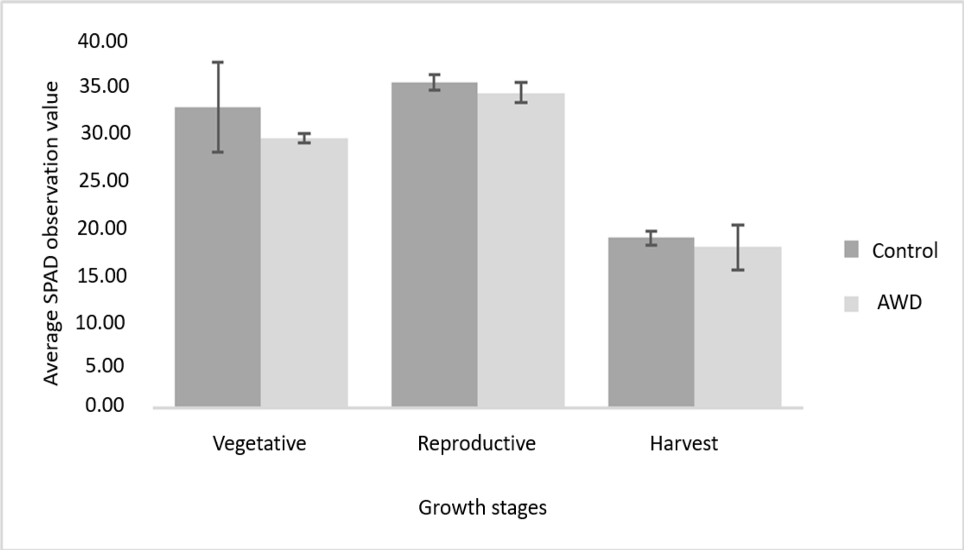

Figure 6. Average SPAD measurement of paddy crop at the vegetative stage, reproductive stage, and harvest stage for control and AWD irrigation

Figure 6 indicates the average chlorophyll content reading measured using the SPAD meter during the vegetative, reproductive, and harvest stages for control and AWD irrigation. SPAD reading observation was measured at three random leaves for both treatments, as represented in Figure 5. Among the vegetative, reproductive, and harvest stage, the average SPAD value was higher in the vegetative stage compared to AWD in all replications. SPAD was used widely to measure chlorophyll content in crop growth stages indirectly. The previous study by Asa et al. (2011) reported that the range difference in SPAD readings was dependent on changes in paddy growth maturity. The higher SPAD value indicates active photosynthesis activities occurred. It was relatable at the early vegetative stage when the crop developed leaves and tillers and increased plant height. While at the reproductive stage, the initial panicle has started to emerge from the stem, and at this stage, the SPAD measurements were recorded consistently at a high value. It indicates that the process of photosynthesis was constantly happening.

CONCLUSION

The irrigation consumption was relatively higher in control than in the AWD technique, as the standing water requirement throughout the season for control was within the range of 5 cm to 10 cm. However, both treatments showed no significance in crop growth performances. However, the AWD irrigation method was preferable in water-saving since the irrigation was scheduled to alternately wet and dry the paddy crop field; thus, the irrigation water consumption is much less than the continuously flooded irrigation. Therefore, Yao et al. (2017) supported the

AWD method as the preferable method, resulting in high grain yield and high-water efficiency.

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