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Effects of Flooding and Alternate Wetting and Drying on the Yield Performance of Upland Rice

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ABSTRACT

Water-wise rice cultivation is a growing concern in rice production. We justified the effects of different water levels on rice production of upland variety. A completely randomised design was arranged with four treatments (T1: flooding at 5 cm depth, T2: flooding at 1 – 3 cm depth, T3: saturated to 1 cm flooding, and T4: alternative wetting and drying, or AWD) with five replications. Yield, plants and soil parameters were evaluated. Upland rice variety showed improved yields and yield parameters under flooding at 5 cm depth treatment than alternative wetting and drying treatment. Flooding water significantly increased plant height, tiller numbers, panicle numbers, panicle height, grains per panicle and yield compared to AWD treatment. Chlorophyll (Chl) content increased gradually with increasing plant age but flooding at 5 cm treatment increased Chl content after the secondary tillering. Net photosynthesis rate (Pn) and relative water content (RWC) decreased in plants under alternative wetting and drying treatment than control treatment. Saturated to 1 cm flooding treatment saved 42% of water used in the treatment of flooding at 5 cm depth, which showed a similar water use efficiency (WUE) to alternative wetting and drying treatment. However, treatments of flooding at 1 – 3 cm depth and saturated to 1 cm flooding showed a similar effects on rice yield. Meanwhile, saturated or above soil water condition did not affect soil pH, soil electric conductivity (EC) and phytoavailability of nutrients in the soil. These results suggested that saturated to 1 cm flooding irrigation could increase rice yield of upland variety and save fresh water for other purposes at the same time.

Keywords: Water use efficiency, chlorophyll content, photosynthesis, relative water content, flooding effects, rice yield

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INTRODUCTION

Rice is a staple food which provides about 32% of total calorie uptake and about 90-91% of total rice produced and consumed in Asia (IRRI, 2012). In Asia, irrigated agriculture accounts for about 90% of the freshwater, while rice farming only consumes about 50% of that fresh water (Cantrell & Hettel, 2005). Between 1955 and 1990, water availability per capita dropped by 40-60%, and further dropping at 15 – 54% is expected in the next few years (Gleick, 1993). Malaysia needs approximately 20 billion m^3 by 2020 to fulfil domestic and industrial demands (Keizrul & Azuhan, 1998). In addition, water rationing during rainless situation shows a critical condition for fresh water in Selangor state (Koon & Pakiam, 2014). Therefore, it is important to produce rice that needs less water to cut down water supply for rice cultivation and ensure sustainable rice production.

Plant growth and grain yield are affected by water deficit in soil (Pirdashti et al., 2004). Less water affects transpirational functions to regulate effectively in irrigated rice variety (Vandeleur et al., 2009), while upland rice may persist under less water condition and sustain production (Dahamarudin & Rivaie, 2013). Soil water status that is below saturated condition affects the production of rice (Sariam et al., 2004). Under less water condition, irrigated rice variety shows low tissue water potential (Kato et al., 2004) which may affect net photosynthesis rate. Water and soil stresses affect net photosynthesis rate, photosynthetically active radiation (Inani et al., 2015; Munirah et al., 2015a; Syuhada et al., 2016). Chlorophyll function, on the other hand, is important to regulate light reaction in photosystem II to produce light energy, which might affect crop yield (Jahan et al., 2016). In addition, flooded soil-system reduced oxygen in soil may cause a decline of redox reaction but less water ensures higher redox value in the soil (Sarwar, 2004) that might indicate oxygen availability for root growth and absorb nutrients from soil effectively. Therefore, water in rice cultivation should be applied in a logical way to reduce water use in rice cultivation without affecting yield and plant properties.

Rice production system requires approximately 1900 to 5000 litres of water to produce 1 kg of grain (Haefele et al., 2009). By 2025, about 10% of irrigated rice will face water scarcity (Bouman et al., 2007). Therefore, we need to focus on upland rice production to minimise water use and increase rice production. To date, a lot of research has been done on reducing water use in lowland rice cultivation (Sarwar, 2004; Bouman et al., 2007; Jahan et al., 2013a) but less attention was given to study the effects of different water regimes on upland rice cultivation. Therefore, this study was conducted to find the effects of less water use on rice yield and physiological parameters of upland rice. In this study, we provide information that shows upland rice variety provides higher production and better physiological performance under 1 cm flooding than alternative wetting drying condition.

METHODOLOGY

Plant Materials and Experiment Setup

Four-day old pre-sprouted rice seeds of WAB 96-1-1 were grown in a pot measuring of 25 cm × 25 cm x 35 cm. All pots were filled with soil leaving 5 cm spaces from the top of the pot and two holes were made at 0 cm and 1 cm above the soil level to maintain water levels. There were four treatments [T1: flooding at 5 cm depth (control; irrigate when the water level dropped at 3 cm), T2: flooding at 3 cm depth (irrigate when the water level dropped at 1 cm), T3: flooding at 1 cm depth (irrigate when the soil water level dropped at saturated level) and T4: alternative wetting and drying (AWD; wetting at 5 cm flooding when the water level dropped at drying level of -33 Kpa)] arranged according to the completely randomised design (CRD) with five replications. Soil water potential values were determined by using ECHO soil moisture sensors. The experiment was conducted under a rain shelter. Insect, disease and weeds were controlled according to Sarwar et al. (2004). Fertilisers were applied according to the previous studies (Sarwar & Khanif, 2005; Khairi et al*.,* 2015a).

Measurement of the Parameters

At harvest, yield and yield related parameters were measured according to Jahan et al. (2012, 2013a). A portable SPAD-502 chlorophyll meter (Minolta Technologies, Japan) was used to measure chlorophyll content in leaves (Abdulkadir et al*.,* 2015; Khairi et al*.*, 2015b; Nozulaidi et al*.*, 2015). The second uppermost collared-leaf was used to determine Chl content at different weeks after planting. A CI-340 portable photosynthesis meter (CID Biosciences, Inc., USA) was used to determine net photosynthesis rate (Munirah et al*.,* 2015b). The leaf relative water content was measured according to Chelah et al*.* (2011). It is important to note that water needed for land preparation was not considered in this experiment. This experiment was conducted under rain shelter, therefore, rainwater was considered as zero (0). Water saving was calculated against the control treatment. Water use efficiency (WUE) was calculated from the grain yield divided by the amount of irrigation water applied in the treatments. Meanwhile, soil pH and soil EC were measured using portable Mettler Toledo MP120 pH meter and soil EC meter, respectively. Soil extracts were collected using soil sampler model SPS200, whereas nitrogen (N), phosphorus (P) and potassium (K) were measured according to Sarwar (2004) and Jahan et al*.* (2013a).

Statistical Analysis

The data were analysed for the analysis of variance (ANOVA). The means were compared by using Duncan's Multiple Range Test (DMRT) at 5% level by utilising the SPSS software (Version 17), MS Excel and Minitab 16.

RESULTS

Effects of Flooding Water on Plant Height, Yield and Yield Parameters

Results indicated that different water levels did not affect plant height in the first few weeks but it was affected thereafter (Figure 1A). Plant height gradually increased with increasing plant age regardless of the effects of treatments (Figure 1A). Application of water increased tiller and panicle numbers/hill and panicle height of rice plants compared to alternative wetting and drying treatment (Figure 1B). Seed size did not affect by water stress (data not shown). Flooding water (Treatments T1 to T3) significantly increased total grains and filled grains per panicle (Figure 1C). Furthermore, alternative wetting and drying treatment significantly affected rice yield (Figure 1C) which made the lowest yield, although continuous flooding at 5 cm made the highest yield.

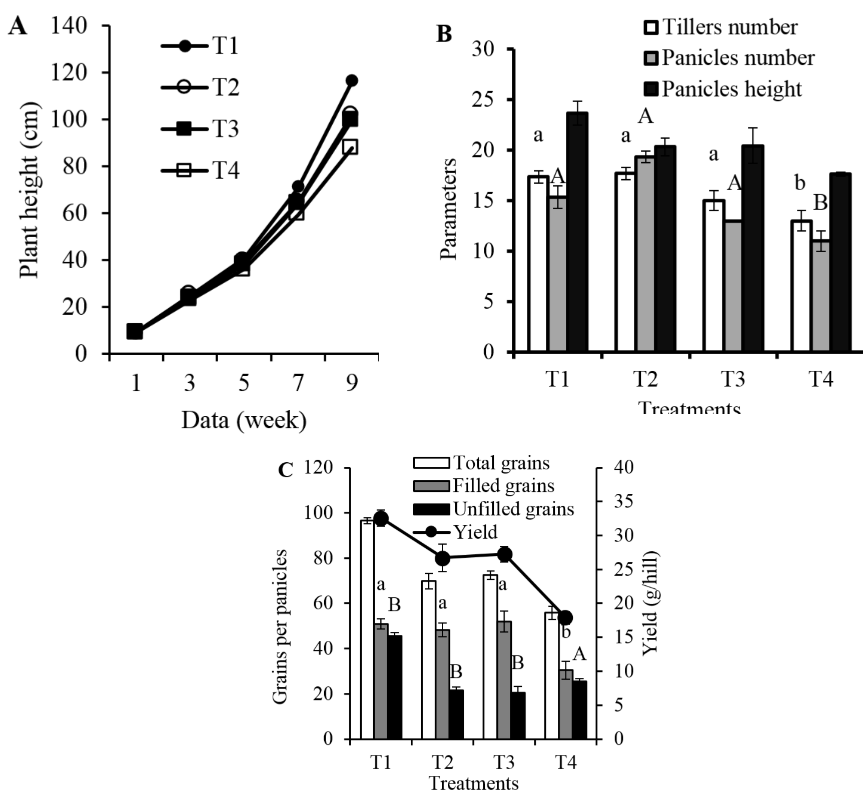

Figure 1. Effects of different water levels on yield and yield parameters of upland rice variety.

A. Plant height was measured at different weeks under different water levels; T1 (closed round), T2 (open round), T3 (closed square) and T4 (open square). B. Plant produced tillers number (open bars), panicles number (gray bars) and panicle height (black bars) under different water regimes. C. Left panel shows total grains per panicle (open bars), filled grains per panicle (gray bars), unfilled grains per panicle (black bars) and right panel shows the yield of rice (line graph). Here, T1 stands for flooding at 5 cm depth, T2 stands for flooding at 1 – 3 cm depth, T3 stands for saturated to 1 cm flooding and T4 stands for alternative wetting and drying.

Effects of Flooding Water on Chlorophyll Content and Net Photosynthesis Rate (Pn) in Leaves

Chlorophyll content did not affect in all treatments for the first five weeks but significantly increased chlorophyll contents afterward (Figure 2). Figure 3 showed that Pn rate decreased with decreasing water input in soil but the decrement was not significant until T3 treatment. Pn rate was significantly higher in plants under different treatments (T1 to T3) than that of plants under T4 treatment.

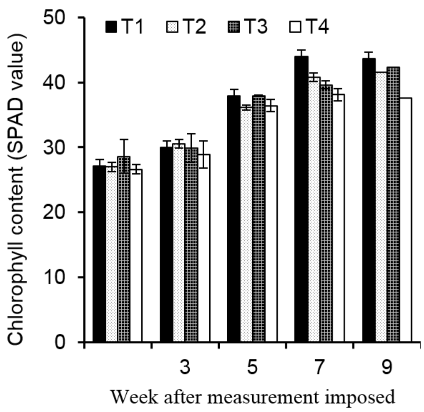

Figure 2. Effects of different water regimes on chlorophyll content in leaves of rice plants.

T1 (closed bars), T2 (dotted bars), T3 (grid bars) and T4 (open bars). Vertical bars indicate standard deviation. Here, T1 is for flooding at 5 cm depth, T2 is for flooding at 1 – 3 cm depth, T3 is for saturated to 1 cm flooding, and T4 is for alternative wetting and drying.

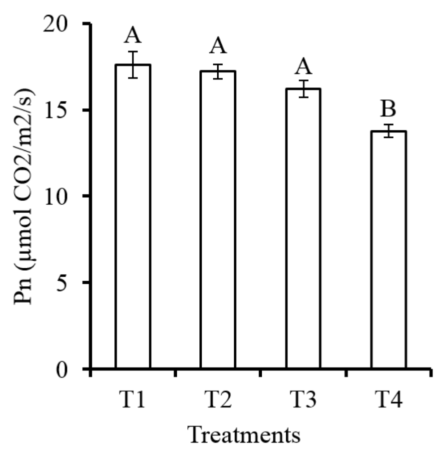

Figure 3. Effects of different water regimes on net photosynthesis rate in leaves of rice plants. Here, T1 is for flooding at 5 cm depth, T2 is for flooding at 1 – 3 cm depth, T3 is for saturated to 1 cm flooding, and T4 is for alternative wetting and drying.

Effects of Flooding Water on Leaf RWC, Water use and WUE

The highest RWC was recorded in T2 treatment and non-significant difference with T1 and T3 (Figure 4A). In contrast, the lowest RWC was recorded in T4 treatment. Water volume used in T3 and T4 treatments was almost similar (Figure 4B) but it was significantly lower than T1 and T2 treatments. Water volume used in rice cultivation increased with increasing depth and duration of irrigation water used (Figure 4B). The potency of water use was found to be the sequence of T1 > T2 > T4 > T3. The treatments T4, T3 and T2 saved water about 43, 42 and 29%, respectively, over the control (data not shown). Figure 4B also shows that water use efficiency in T3 treatment was significantly higher than other treatments, while T2 and T4 treatments showed similar WUE whereas control (T1) showed significantly lower (Figure 4B, line graph).

Effects of Flooding Water on Soil pH and Soil EC Value in Soil

Soil pH and EC readings were determined to justify the effects of flooding water on soil chemical properties (Sarwar, 2004). Flooding water had no significant influence on soil pH until T3 treatment and soil pH significantly decreased in T4 treatment as compared to the control (Figure 5A). On the other hand, flooding water reduced soil EC value compared to AWD treatment, which indicates solute accumulation in soil (Figure 5B).

Effects of Flooding Water on Phytoavailability of Nitrogen, Phosphorus and Potassium in Soil Solution

Figure 6A shows that the concentrations of N and K decreased with time under water stress and even decreased with decreasing water levels (Figs. 6A & 6C). These results are consistent with some previous results by

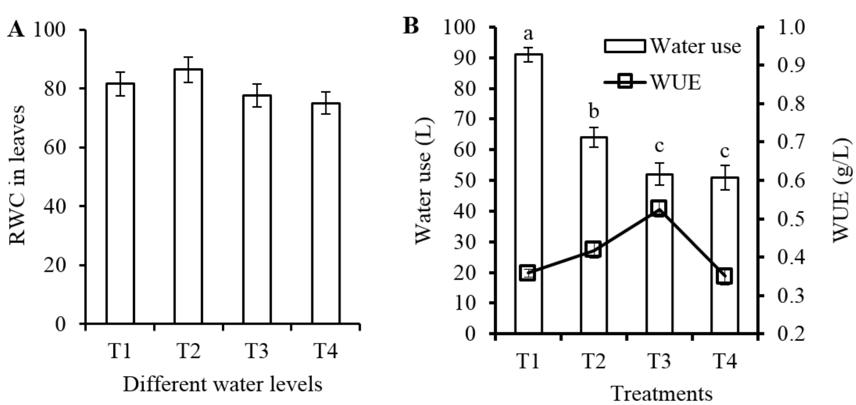

Figure 4. Effects of different water regimes on relative water content and water productivity.

A. Relative water content in leaves of rice plants grown on different water treatments. B. Water use (open bars) and WUE (line graph) under different water treatments. Here, T1 is for flooding at 5 cm depth, T2 is for flooding at 1 – 3 cm depth, T3 is for saturated to 1 cm flooding, and T4 is for alternative wetting and drying.

Jahan et al. (2012, 2013b). Flooding water did not affect P concentration in soil solution except for T4 treatment, which significantly decreased P availability in soil solution. This finding is also consistent with the previous results by Sarwar et al. (2004).

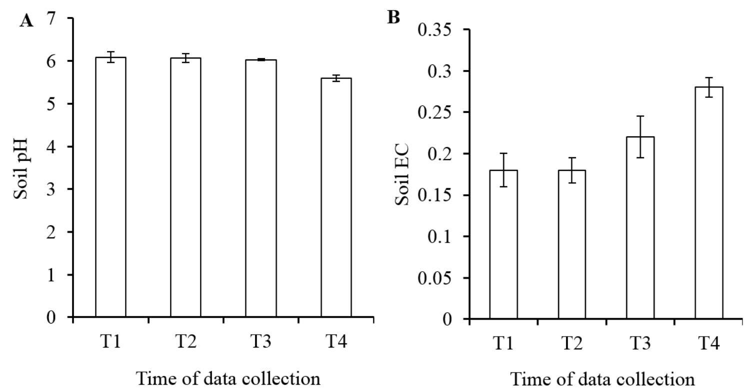

Figure 5. Effects of different water regimes on soil pH (A) and soil electric conductivity (B). Here, T1 is for flooding at 5 cm depth, T2 is for flooding at 1 – 3 cm depth, T3 is for saturated to 1 cm flooding and T4 is for alternative wetting and drying.

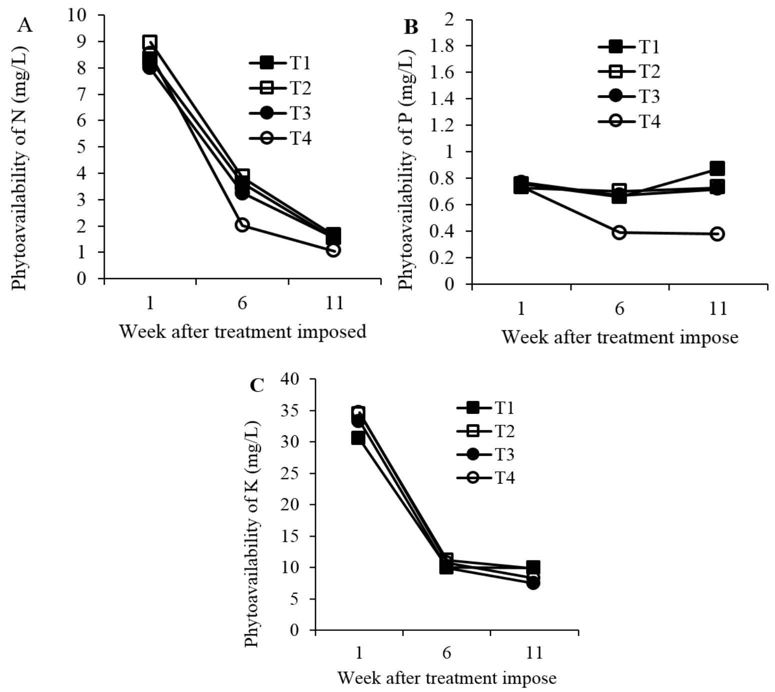

Figure 6. Effects of different water regimes on phytoavailability of nutrients.

Phytoavailability of nitrogen (A), phosphorus (B) and potassium (C) in soil solution different water treatments, T1 (closed square), T2 (open square), T3 (close round) and T4 (open round). Here, T1 is for flooding at 5 cm depth, T2 is for flooding at 1 – 3 cm depth, T3 is for saturated to 1 cm flooding, and T4 is for alternative wetting and drying.

DISCUSSION

Malaysia still practices conventional flooded rice cultivation system, which leads to use higher amounts of fresh water compared to the less water rice production system (Sarwar et al., 2004). This study showed that uses of flooding water increased production of upland rice (Figure 1). Upland plants might enhance physiological function under flooding condition than AWD condition. These results are supported by the effects of AWD treatment on grain filling stage that might lead to a reduction of grain filling per panicle (Figure 1C). In contrast, saturated and above water condition did not affect filled grains per panicle, the finding which is consistent with that of Sarwar et al. (2004). Therefore, these results suggested that upland rice might increase yield and yield parameter when grown under saturated or above soil water condition than alternative wetting and drying condition.

Chlorophyll content in leaves controls crop productivity by modulating physiological function in plants (Jahan et al., 2016). The finding of this study stated that flooding water treatment induced the accumulation of chlorophyll content (Figure 2), which might increase photosynthesis rate in plants (Figure 3). These results suggested that application of flooding water in upland rice variety might affect Chl-functioned plant growth and development (Khairi et al., 2015b). Furthermore, higher Chl content in wild type plants indicates higher GSH content in plants compared to Chl-deficient mutant (Jahan et al., 2011). This also supports that flooding treatments (T1, T2 and T3) might affect GSH content that enhanced physiological function in the plant. In addition, Kura-Hotta et al. (1987) stated that photosynthesis is affected by water stress, which supports this study that saturated or above water condition did not affect Pn rate in upland rice plants (Figure 3).

Drought reduces relative water content in leaves under T4 treatment (Figure 4A). Water use efficiency increased in T3 treatments compared to T4 and T1 treatments (Figure 4B) indicating that less water might ensure sustainable rice production and reduce water use over the control. In contrast, soil pH decreased (Figure 5A) but EC value increased in the soil of T4 treatment (Figure 5B). Under anaerobic condition, bio-chemical reaction might not affect soil pH; this indicates unaffected phytoavailability of nutrients in the soil (Figure 6). Nitrogen decreased in the soil of T4 treatment; this might due to different transformation processes of nitrogen in the soil, e.g. nitrification. P is less deficient in flooded soil than in upland soil due to the highly available forms of P in flooded soils (Thiyagarajan & Selvaraju, 2001), while Olk et al. (1995) suggested that plant-available K decreases after flooding of dry soil due to fixation. These results confirmed that saturated or above water condition did not affect nutrients phytoavailability in the soil.

CONCLUSION

Soil water condition at saturated or above it did not affect water use, Chl content, soil chemical properties and rice production. In addition, T3 treatment reduced water use but increased WUE and rice yield. Farmers could implement irrigation water at saturated to 1 cm flooding to increase rice production by using upland variety without affecting soil and plant parameters but saving a larger amount of fresh water instead.

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