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Effect of various water regimes on rice production in lowland irrigation

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Abstract

Water-wise rice production is the current concern. To justify whether less water affects rice production, rice plants were cultivated under different water regimes. Four treatments, T1: flooding at 5 cm depth, T2: flooding at 1 – 3 cm depth, T3: saturated to 1 cm flooding, and T4: alternative wet and dry (AWD), were arranged as completely randomized design with five replicates. Yield and yield parameter, plants physiological, and soil chemical properties were evaluated. Treatment of AWD significantly decreased plant height (9%), tillers number ($p \leq 0.04$), panicles number ($p \leq 0.024$), filled grains ($p \leq 0.037$), yield ($p \leq 0.001$) and harvest index (≤ 0.005) but increased unfilled grains ($p \leq 0.011$) compared to the control. Chlorophyll (Chl) content ($p \leq 0.003$) and Chl fluorescence ($p \leq 0.012$), net photosynthesis rate (Pn; $p \leq 0.0001$), stomatal conductance (SC; $p \leq 0.0001$), transpiration rate (TR; $p \leq 0.0001$), and photosynthetically active radiation (PAR; $p \leq 0.001$) decreased in plants under T4 treatment than control treatment. Soil pH decreased ($p \leq 0.0001$) but soil electric conductivity (EC) increased ($p \leq 0.041$) in soil of T4 treatment than that of in soil of control treatments. Nitrogen (N; $p \leq 0.012$), phosphorus (P; $p \leq 0.038$), potassium (K; $p \leq 0.024$) and relative water content (RWC; $p \leq 0.003$) decreased under T4 treatment. Treatment T3 saved 45% of water use in T1 treatment and showed higher water use efficiency (WUE) but produced rice yield similar to T1 and T2 treatments. These results suggested that saturated to 1 cm flooding water could easily be implemented in rice cultivation by the farmers which might not affect rice production, plant and soil characters.

Keywords: Rice, water productivity, chlorophyll content, photosynthesis, harvest index, transpiration.
Abbreviation; AWD_alternative wet and dry; Chl_chlorophyll content; Pn_net photosynthesis rate; SC_stomatal conductance; TR_transpiration rate; PAR_photosynthetically active radiation; WUE_water use efficiency; RWC_relative water content; Fo_the minimum fluorescence; Fm_the maximum fluorescence; Fv/Fm_quantum yield in photosystem II; EC_electric conductivity; N_Nitrogen; P_phosphorus; K_potassium; IRRI_international rice research institute.

Introduction

Rice provides approximately 32% of total calorie uptake and about 90-91% of 455 ton of rice produced and consumed in Asia (IRRI, 2012). In Asia, irrigated agriculture uses 80 - 90% of the freshwater and about 50% of that is used in rice farming (IRRI, 2001). In many Asian countries, per capita water availability declined by 40-60% in between 1955 and 1990, and expected to decline further by 15-54% in the next 35 years (Gleick, 1993). In Malaysia, water demand is increasing about 4% annually and approximately 20 billion m^3 will be needed by 2020 to fulfil the annual domestic and industrial water demands (Keizrul and Azuhan, 1998). Malaysia imports 30% of the country's rice requirement (Ismail, 2014) and recent water rationing in Selangor state shows a critical condition for fresh water (Koon and Pakiam, 2014). Therefore, it is important to cut down water supply for rice cultivation but without effecting rice yield. Soil water lower than saturated condition reduced rice yield (Tuong and Bouman, 2003). Water deficit affected plant growth, flowering and grain yield by 21%, 50% and 21% respectively (Pirdashti et al., 2004). Irrigated rice is more susceptible to drought and unable to regulate transpirational functions effectively (Vandeleur et al., 2009) and shows low tissue water potential (Kato et al., 2004) which may affect net photosynthesis rate. Chlorophyll functions on light antenna in photosystem II and plays an important role in plant growth and development (Jahan et al., 2014). Water stress affects chlorophyll content in leaves of rice (Sheela and Alexander, 1996) which may lead to affect photosynthetic units and inactivation of photosynthesis (Kura-Hotta et al., 1987). In addition, oxygen depleted in the flooded soil-system results oxygen is quickly anaerobiosis causes soil reduction and affects soil health (Sarwar and Khanif, 2005a). Therefore, it is important to present a logical use of less water in rice cultivation which would not affect plant physiological and soil chemical properties. Current rice production systems require about 1900 to 5000 liters of water to produce 1 kg of grain. By 2025, about 10% of irrigated rice will face water scarcity (Bouman et al., 2007). Even a short period of water deficit is highly sensitive to rice farming and rice productivity (O'Toole, 2004). To date, many researches have been done on reducing water use in rice cultivation but less attention was paid on suitability of implementation by the farmers. Therefore, farmers did not use some innovations on less water use in rice cultivation. In this study, we provide information on low water use in rice cultivation which could be easily adopted by the farmers.

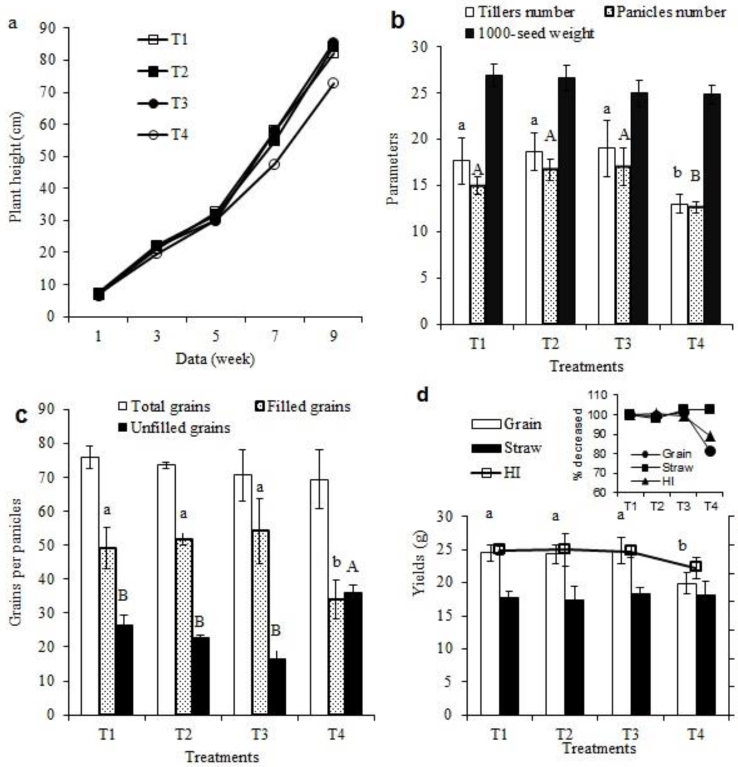

Fig 1. Effect of different water levels on yield and yield parameters. a, Plant height at different weeks,T1 (open square), T2 (close square), T3 (close round) and T4 (open round) showed different water conditions. b, Plant produced tillers number (open bars), panicles number (dotted bars) and 1000-seed weight (close bars) under different water conditions. c, Total grains (open bars), filled grains (dotted bars) and unfilled grains (closed bars) per panicle. d, The production of rice (open bars) and straw (closed bars). Inset picture showed percentage of rice production and harvest index.

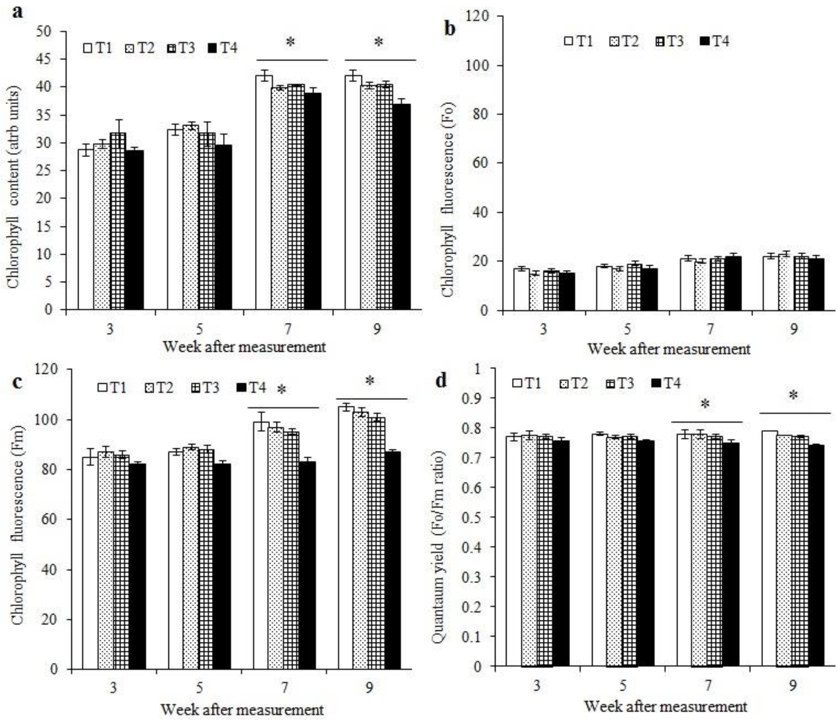

Fig 2. Effect of different water levels on chlorophyll related data. Chlorophyll content (a), minimum chlorophyll fluorescence (b), maximum chlorophyll fluorescence (c), and quantum yield in PSII (d) in leaves of rice plants grown on different water treatments, T1 (open bars), T2 (dotted bars), T3 (grid bars) and T4 (closed bars).

Results

Effect of different water treatments on yield and yield parameters of rice plants

To test the effects of low input water on yield and yield parameters, rice was cultivated under different soil water regimes. Figure 1a showed that different treatments did not affect plant height in the first five weeks. However, T4 treatment significantly reduced plant height after 5^{th} week. In addition, plants' height gradually increased with increasing plant age regardless of treatments' effect. Plants grown under T4 treatment produced significantly lower tiller and panicle numbers than that of plants grown under other treatments (Fig. 1b). A weight of 1000-seed was found to be insignificantly different and was in the range from 24.82 to 26.89 g (Fig. 1b). T4 treatment significantly decreased filled grains per panicle but increased unfilled grains per panicle than other treatments (Fig. 1c). Furthermore, T4 treatment significantly affected rice yield ($P \leq 0.05$) but not straw yield (Fig. 1d). Harvest index significantly ($P \leq 0.05$) decreased in plants grown under T4 treatment compared to other treatments (Fig. 1d). Inset Figure in Figure 1d showed the percentage of yield production, straw production and harvest index in different water treatments as compared to control. Where 19% of grain yield and 10.5% of harvest index decreased in plants grown under T4 treatment compared to the control treatments while straw yield showed no difference.

Effect of different water treatments on Chl content and Chl fluorescence in leaves

Chl contents and Chl fluorescence parameters, Fo, FM and Fv/Fm ratio, in leaves of the rice plants were measured to justify whether low input water affects Chl related parameters. Different treatments did not affect Chl content in the first five weeks then thereafter T4 treatment significantly decreased Chl contents than other treatments (Fig. 2a). Minimum and maximum Chl fluorescences and quantum yields results were found similar to Chl content under different water treatments (Fig. 2 b, c and d).

Effect of different water treatments on Pn rate, PAR, TR and SC

To justify the effects of low water on plants' physiological parameters, we measured Pn, PAR, TR and SC in rice plants. Figure 3A showed that Pn rate decreased with decreasing water input in soil. In addition, T4 treatment significantly decreased Pn rate in leaves of rice plants compared to other treatments. Treatment T3 significantly increased Pn rate than T4 treatment but decreased compared to T1 and T2 treatments (Fig. 3a). Furthermore, PAR ($mmol/m^2/s$) in plants decreased in T5 treatment but insignificantly different in other treatments (Fig 3a). Figures 3b and 3c indicated that T4 treatment significantly affected TR and SC in leaves of rice plants than other treatments while the effects of T3 treatment on TR (Fig. 3b) and SC (Fig. 3c) in plants were similar to Pn rate.

Effect of different water treatments on RWC, water use, water saving and WUE

Figure 4A showed that different treatments affected RWCs differently, while T4 showed insignificantly different with T3 but significant lower than T1 and T2 treatments. Water volume used in T3 and T4 treatments was insignificantly different (Fig. 4b). Water volume used in rice cultivation decreased with decreasing depth and duration of irrigation water used (Fig 4b; open bars). The potency of water use was according to the following sequence T1 > T2 > T3 > T4. Alternatively, water saving was reversed of water use in different treatments. Inset Figure in Figure 2b indicates the percentage of water saving under different treatments. Where, T4 treatment saved about 46% (53 liters), T3 treatment saved 45% (51.7 liters) and T2 treatment saved 30% (34.5 liters) over control (115 liters). In addition, T3 and T4 treatments saved significantly higher water volume than T2 treatment. Figure 3B also showed that water use efficiency was significantly higher in T3 treatment compared than other treatments while WUE was similar in T2 and T4 treatments and control (T1) showed significantly lower (Fig. 4b, line graph).

Effect of different water treatments on soil pH, Soil EC value in soil

Figure 5A showed that soil pH was found to be similar under different water treatments before transplanting. However, at the middle age of plants and after harvest, T4 treatment significantly decreased soil pH compared to other treatments (Fig. 5a). Soil EC value was similar under different water treatments except T4 treatment, which significantly increased soil EC at the middle age of plants and after harvest (Fig. 5b).

Effect of different water treatments on phytoavailability of nitrogen, phosphorus and potassium in soil solution

Figure 6a presented the effects of different water regimes on NH_4^+ phytoavailability in soil. A sharp decrease of NH_4^+ concentration was observed in soil solution after flooding throughout the growing period of rice plants. Though, after few weeks of flooding, T4 treatment decreased NH_4^+ concentration in soil solution than other treatments (Fig. 6a). Figure 6b showed phosphorus phytoavailability in soil solution. There was no significant effect of different irrigation treatments except T4 treatment on P concentration in soil extract was observed at different growing stages (Figure 6b). Conversely, T4 treatment decreased P in soil solution after few weeks of plane age (Fig. 6b). Potassium content, on the other hand, gradually decreases with increasing plant age until ripening stage. The T4 treatment did not affect K concentration in soil extracts (Fig. 6c).

Discussion

Rice can grow in a wide range of hydrological situations, soil types and climates. In Malaysia, the rice environment is known as conventional flooded rice cultivation system which leads to use greater amounts of fresh water compared to the water-wise rice production system (Sarwar et al., 2004; Sariam et al., 2004). In this study, soil water level at saturated or above did not affect yield and yield parameters (Fig. 1). Under AWD condition, plants might suffer for a degree of water stress under which water level goes below than saturated level to reduce rice yield. These results were supported by Sariam et al. (2002) that saturated condition did not affect vegetative growth, grain yield, root length and root weight. In addition, T4 treatment increased unfilled grains per panicle (Fig. 1) indicates that the effects of water stress on grain filling stage might lead to a reduction of filled grains per panicle. It was also stated that saturated and above water condition (1 cm flooding) did not reduced filled grains per

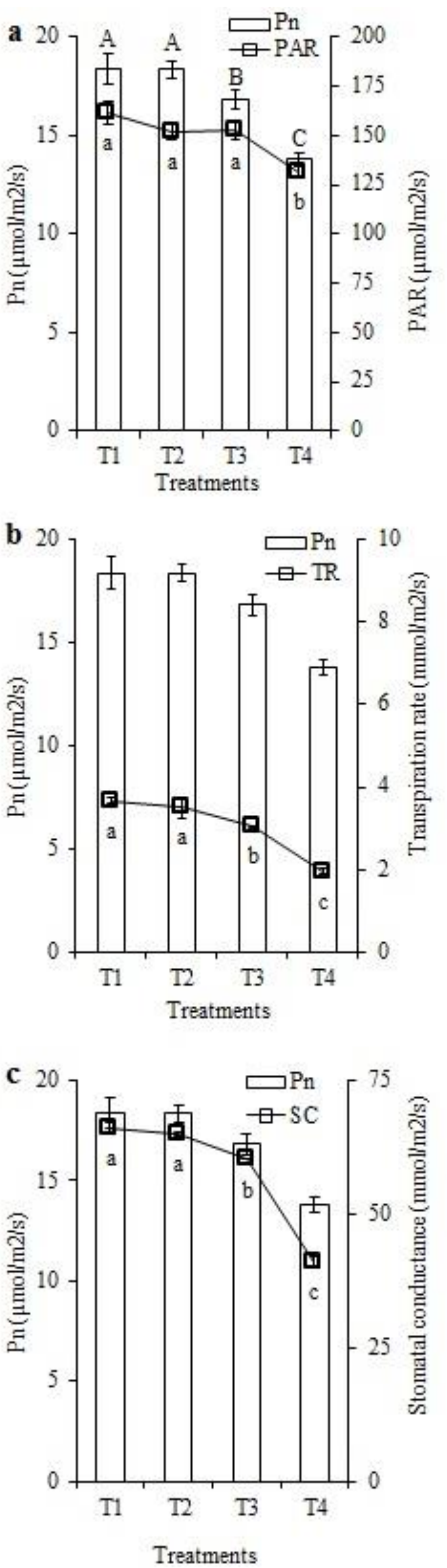

Fig 3. Effect of different water levels on plant physiological parameters. PAR, TR, and SC were presented as compared with Pn rate in different graphs; a, Pn (open bars) and PAR (line graph), b, Pn (open bars) and TR (line graph), and c, Pn (open bars) and SC (line graph

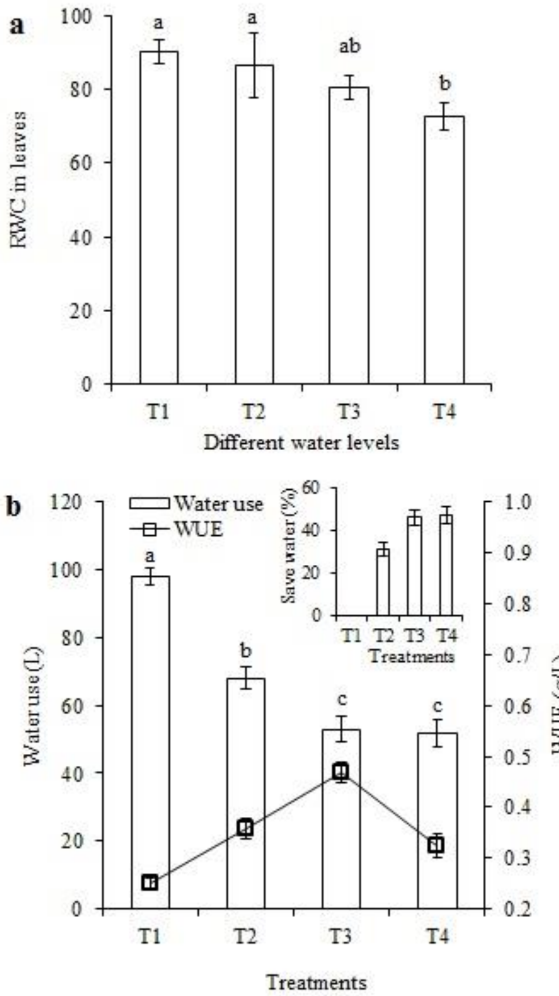

Fig 4. Effect of different water levels on water productivity. a, Relative water content in leaves of rice plants grown on different water treatments. b, Water use (open bars), WUE (line graph) and water saving (inset graph) under different water treatments.

panicle (Sarwar et al., 2004), therefore, yield and yield parameters in T3 were similar to T1 and T2 treatments but higher than T4 treatment (Fig. 1). In this relation, harvest index dropped in T4 treatment and decline rice production while saturated or above water conditions (T2 and T3) did not affect harvest index as well as yield (Fig. 1d). Taken together, these results suggested that saturated or above soil water condition did not affect the production of rice. Water stress reduced chlorophyll content in leaves and controls crop productivity through CO_2 assimilation (Sheela and Alexander, 1996; Awal and Ikeda, 2002). These results were consistent with this study that plants accumulated lower Chl content (Fig. 2a) under AWD condition and reduced chlorophyll fluorescences (Fig. 2b, c) and quantum yield in photosystem II (Fig. 2d). These results suggest that water stress might affect Chl-related plant growth and development (Jahan et al., 2014). In addition, reduction of Chl content indicates lower GSH content presence in plants (Jahan et al., 2011) and supports that T4 treatment might affect GSH content in plant. Besides, Kura-Hotta et al., (1987) stated that water stress affects photosynthesis rate which supports to a reduction of Pn rate in plants grown under AWD conditions but saturated or above water condition did not affect Pn rate

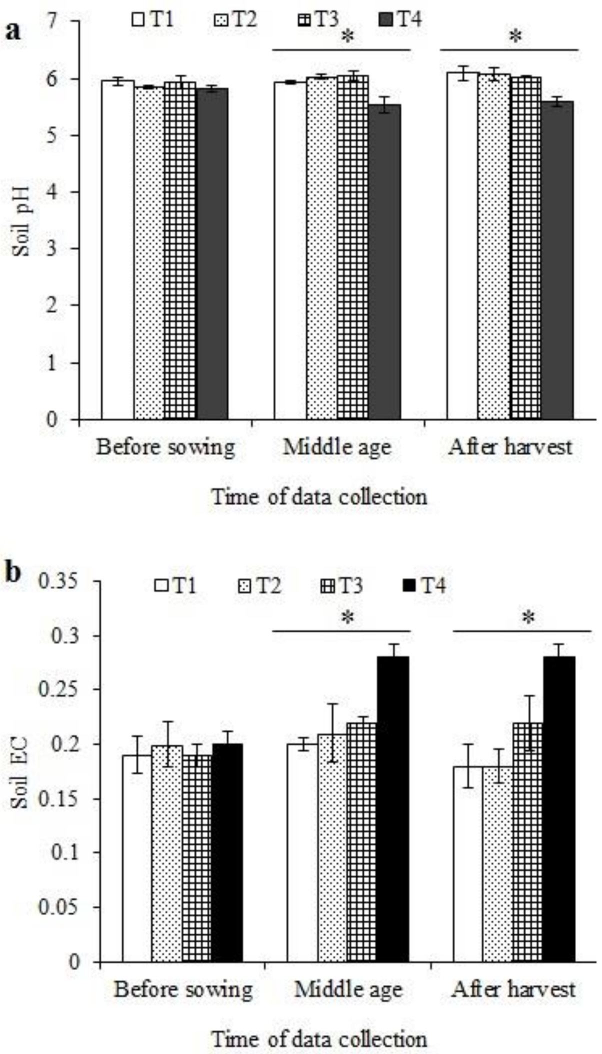

Fig 5. Effect of different water levels on soil pH and soil electric conductivity. Soil pH (a) and soil EC (b) in soil under different water treatments, T1 (open bars), T2 (dotted bars), T3 (grid bars) and T4 (closed bars).

(Fig. 3a). Transpiration rate and stomatal conductance reduced in rice plants are attributed by AWD condition which might function in abscisic acid-induced stomatal movement in water stress condition (Jahan et al., 2008; Okuma et al., 2011). Previous study also stated that the reduction of chlorophyll content indicated lower stomatal opening (Jahan et al., 2014) but not by the effects of intracellular GSH (Jahan et al., 2013a).

Drought affects rice plants and reduces transpirational water loss (Vandeleur et al., 2009), induces abscisic acid sensitivity (Jahan et al., 2011, 2014) and reduces tissue water potential (Kato et al., 2004). These results suggest the reduction of relative water content in leaves under such water stress condition, nevertheless soil water status at saturated or more did not affect relative water content (Fig. 4a). Therefore, soil water condition is important to uptake nutrients by roots (Garg, 2003) as well as functioning in the cell. Water use efficiency, on the other hand, increased in T3 treatments compared than T4 and T1 treatments (Fig. 4b, line graph) indicates that less water use compared to the traditional application could be accounted for sustainable rice production and managed to save about 45% of fresh water over control (Fig. 5b, inset picture). On the other hand, T4 treatment saved fresh water over T3 treatment but showed lower performance in terms of water productivity (Fig. 4b) and rice production (Fig. 1d). In contrast, soil pH level approximately 0.5 units decreased (Fig. 5a) but EC value increased in soil of T4 treatment (Fig. 5b). Under saturated or flooding condition, the anaerobic condition and bio-chemical reaction might not affect soil pH indicating unaffected the phytoavailability of nutrients in the soil (Fig. 6). Nitrogen decreased in soil of T4 treatment might due to different transformation processes of nitrogen in the soil, e.g. nitrification. It is because, in flooded soils, NH_4-N is the main source of nitrogen for plant uptake (Godshalk and Wetzel, 1978). This study stated that P content in the soil of T4 treatment decreased compared to other treatments (Fig. 6b) suggest that flooded soil shows less response to P content in the soil (Mitsui, 1960) and less deficient in flooded soil than in upland soil due to more available forms of P in flooded soils (Thiyagarajan and Selvaraju, 2001). Different water treatments did not affect K phytoavailability in soil (Fig. 6c) which was supported by Olk et al. (1995) that plant-available K decreases after flooding of dry soil due to fixation. Taken together, these results confirmed that saturated or above water condition did not affect nutrients phytoavailability in soil (Fig. 6).

Materials and Methods

Plant materials

Four days old pre-sprouted rice seeds of MR219 variety were cultivated on a pot measuring of 25 cm x 25 cm x 35 cm.

Experimental setup

All pots were filled by soil leaving 5 cm spaces from the top of the pot. The soil was in silty clay with mechanical analysis of 12.2% sand, 39.5% silt and 48.3% clay on average, soil pH of 5.8, cation exchange capacity of 25 cmol(+)/kg soil and organic matter of 3.31%. Two holes were made at the side wall of pots at 0 cm and 1 cm from the soil level to maintain water treatments. There were four treatments, T1: flooding at 5 cm depth (control; irrigate when water level dropped at 3 cm), T2: flooding at 3 cm depth (irrigate when water level dropped at 1 cm), T3: flooding at 1 cm depth (irrigate when soil water level dropped at saturated level), and T4: alternative wet and dry (AWD; wetting at 5 cm flooding when water level dropped at drying level of -33 Kpa), were arranged according to the completely randomized design (CRD) with five replications. ECHO soil moisture sensors were placed in the soil to determine soil water potential value. The experimental pots were placed under a rain shelter. Standard agronomic practices were maintained to control insect, disease and weeds according to Sarwar et al. (2004).

Fertilizer and irrigation

Fertilizers were applied according to the previous studies (Sarwar and Khanif, 2005a, b). Irrigation water was applied through a plastic tube attached to the water tank.

Measurement of yield and yield components

Yield and yield parameters were measured according to Jahan et al. (2012, 2013b). Harvest index was calculated as

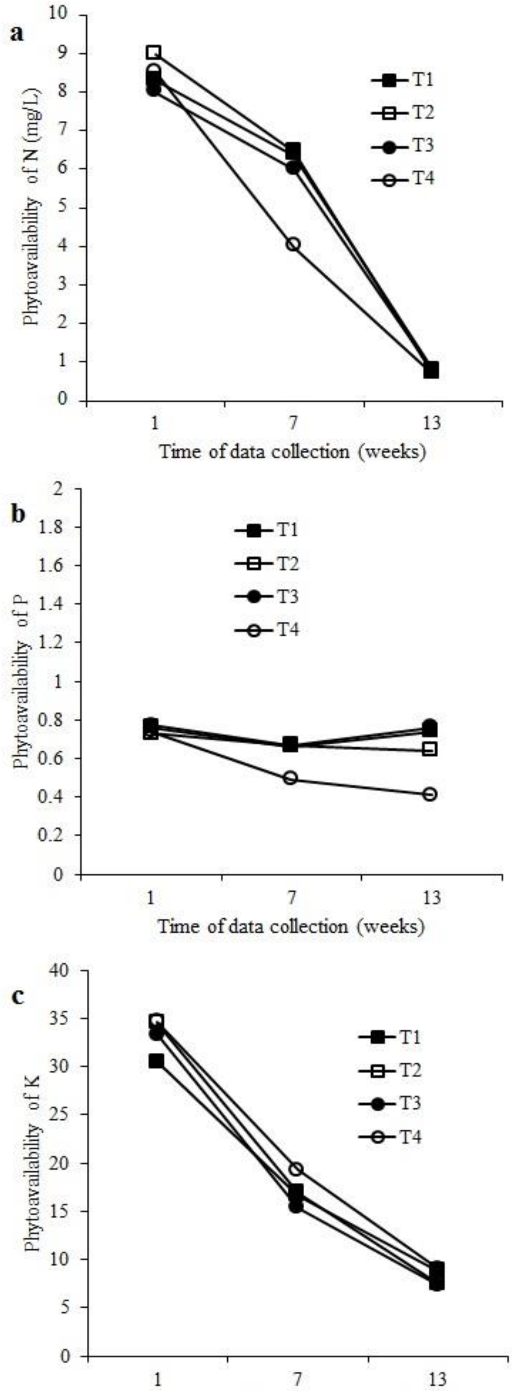

Fig 6. Effect of different water levels on phytoavailability of nutrients. Phytoavailability of nitrogen (a), phosphorus (b), and potassium (c) in soil solution different water treatments, T1 (closed square), T2 (open square), T3 (close round) and T4 (open round).

the ratio of grain weight to the total above ground crop dry weight.

Measurement of chlorophyll content and chlorophyll fluorescence in leaves

A portable SPAD-502 chlorophyll meter (Spectrum Technologies, USA) and Junior-PAM chlorophyll fluorescence monitoring meter (Walz, Germany) was used to acquire a rapid estimation of *in situ* leaf Chl content and Chl fluorescence respectively (Jahan et al., 2014, 2013b). The minimum fluorescence (Fo), maximum fluorescence level (Fm) and quantum yield in photosystem II (Fv/Fm) in leaves of rice plants were estimated.

Determination of net photosynthesis rate, photosynthesis active radiation, transpiration rate, and stomatal conductance

A CI-340 portable photosynthesis meter (CID Biosciences, Inc.) was used to determine Pn, PAR and SC (Syuhada et al., 2014). A quantum sensor in the measuring cell was attached and PAR reading was taken together with Pn data. Data were taken from 11 am to 1 pm on each operational day.

Measurement of relative water content, water use, water saving and water use efficiency

The RWC was measured according to the following formula {RWC (%) = (fresh weight – dry weight) / (turgid weight – dry weight) X 100} (Chelah et al., 2011). 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 control treatment. Volume of water was measured using a measurement cylinder before watering. Water use efficiency (WUE) was calculated from the grain yield divided by the amount of irrigation water applied in treatments.

Measurement of electric conductivity and Soil pH

Electric conductivity (EC) was determined using a portable Field Scout direct soil EC meter (Spectrum Technologies, USA). Soil pH was measured using a portable soil pH meter (HANNA Instruments, USA). Both EC and soil pH meters were calibrated before using.

Collection of soil solution extracts and analyzed for nutrients

A soil sampler model SPS200 was used to collect soil extract from the root zone as previously described (Sarwar et al., 2004). The soil extracts were treated with phenyl-mercuric acetate solution to stop microbial activity. Water samples were collected after land preparation, at middle of plant age and after harvest then were analyzed for nutrients (N, P, and K) by using auto analyzer and atomic absorption spectrophotometer.

Statistical analysis

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

Conclusion

Soil water condition at saturated or above did not affects water productivity, light related parameters, soil chemical properties and plant parameters and production. In addition, T3 treatment saved 45% of fresh water which was similar to AWD over control but increased WUE and rice production. Farmers could implement irrigation water at saturated to 1 cm flooding in their field for rice cultivation to sustain rice roduction without affecting soil and plant parameters but saving a larger amount of fresh water.

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