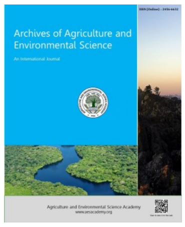
Archives of Agriculture and Environmental Science 2(4): 247-256 (2017)
https://doi.org/10.26832/24566632.2017.020401

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: www.aesacademy.org



ORIGINAL RESEARCH ARTICLE

Physiological parameters and yield differ in rice (*Oryza sativa* L.) cultivars with variable water management systems

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ARTICLE HISTORY

Received: 08 October 2017
Revised received: 07 November 2017
Accepted: 14 November 2017

Keywords

Growth stage
HYV rice
Water stress
Subtropical environment
Water productivity

ABSTRACT

Yield reduction of rice is a severe problem due to the advent of increasing water scarcity and efficiency is relatively low. Physiological attributes and yield performance of high yielding (HYV) rice cultivars need to be assessed by minimizing water loss. Therefore, a glasshouse experiment was conducted in Bangladesh to investigate the impact of cultivars and water management on growth dynamics, biomass production, and yield and water productivity. Ten HYV *boro* (dry season irrigated) rice cultivars along with fivewater management systems were included in the study. The study revealed that cultivars Binadhan-10 had higher value of leaf area index (LAI), root dry weight along with moderate panicle length. Accordingly, the cultivar Binadhan-10 had a higher yield than all other cultivars because of the highest total dry matter (TDM), number of effective tillers hill^{-1}, and number of grains panicle^{-1}. Growth, TDM, and yield were increased with water application up to 8 DAD after which these factors declined with increasing water stress at 10 DAD. The crop grown at CS condition did not increase the yield, rather caused the wastage of irrigation water. The water productivity was the highest (0.252 t ha^{-1}cm^{-1}) in 10 DAD treatments, obviously due to minimum water use but highest yield was observed in 8 DAD because of optimum use of water and non stress condition. Therefore, the present study was useful in the screening of the most efficient cultivars, which could be strongly recommended to rice growers to improve crop yield and reduce the use of water.

Citation of this article: Sarker, U.K., Uddin, M.R., Sarkar, M.A.R., Salam, M.A. and Hasan, A.K. (2017). Physiological parameters and yield differ in rice (*Oryza sativa* L.) cultivars with variable water management systems. *Archives of Agriculture and Environmental Science,* 2(4): 247-256, DOI: 10.26832/24566632.2017.020401

INTRODUCTION

In recent years, agriculture is facing two major challenges that include enhancement of food production sustainably to feed a growing world population and this increment needs to be accomplished under conditions of increasing scarcity of water resources (Bouman, 2007). Rice (*Oryza sativa* L.) is the principal staple food for more than 50% of the world's population (Jahan *et al.,* 2017). The world's farmers have to produce about 60% more rice than at present to meet up the food demands of the expected world population by 2025 (Fageria, 2007). Rice production under irrigated condition is the leading consumer of water in the agricultural sector, and its sustainability is intimidated by increasing water scarcity. In consequence, rice production in Asia is increasingly constrained by water limitation (Arora, 2006) and increasing pressure to reduce water use in irrigated production as a consequence of global water crisis (Tuong and Bouman, 2002). Irrigated lowland rice consumes more than 50% of total freshwater, and irrigated flooded rice requires two or three times more water than other cereal crops, such as wheat and maize (Barker *et al.,* 1998; Sarkar *et al.,* 2017). For 1 kg of rice, it is estimated that farmers use 3 to 4 thousand litres of water whereas it actually needs 1.0 to 1.5 thousand litres only. Thus, for irrigation farmers have to pay about 30-40% of the extra cost. This might be due to their ignorance about the need of water for rice cultivation as well as consequence of misuse of water. In addition, rice production is facing increasing competition with rapid urban and industrial development in terms of freshwater resource (Bouman and Tuong, 2001). The need for "more rice with less water" is crucial for food security, and irrigation plays a greater role in meeting future food needs than it has in the past (Tuong *et al.,* 2005). This issue will necessitate the development of substitute irrigated rice production systems that involve less water than conventional flooded rice (Bouman *et al.,* 2005).

Different water saving techniques for rice production have been evolved by researchers such as alternate wetting and drying (AWD) (Bouman and Tuong, 2001; Belder *et al.,* 2004), saturated soil culture (Tuong *et al.,* 2005), direct dry seeding (Tabbal *et al.,* 2002; Rahman, 2016), and aerobic rice culture (Bouman *et al.,* 2005; Kato *et al.,* 2009). These have been found to be effective in reducing water use and improving water productivity, but there are debates on whether these water-saving techniques will increase or decrease rice yields (Bouman *et al.,* 2007). The lower productivity of rice is associated with drought stress arises from these technologies. This stress has now become a severe threat to ensure food security in the developing world as well as in Bangladesh. Although water is required all over the growth periods of rice plant, there are some critical growth stages when drought stress impacts seriously and create a massive reduction in quantity and quality of yield.

Plants respond to drought stress at the molecular, cellular and physiological levels which vary among species and genotype, length and severity of water stress, crop age and stage of development, organ and cell type and sub-cellular compartment (Yamakawa *et al.,* 2007; Jana *et al.,* 2017). The water stress resulted in significant decreases in chlorophyll content and the leaf relative water content (Naher, 2011). The maintenance of high plant water status and plant functions at low water potential, and the recovery of plant function after water stress are the major physiological processes that contribute to the maintenance of high yield under drought stress (Bouman and Tuong, 2001).

There is limited information on the difference in crop performance under continuous saturation along with other water management systems. Furthermore, physiological basis of yield gap among high yielding rice cultivars has not been studied extensively under Old Brahmaputra Floodplain ecosystem. Such information is vital for identifying the physiological and morphological traits to support the selection and breeding of high yielding rice cultivars. Efforts are few to address the growth, physiological responses and yield of rice (*Oryza sativa* L.) to water stress under tropical environment (Zain *et al.,* 2014). Therefore, in this study, an attempt has been made to assess the influence of water stress as a measure of water saving technique during the subsequent growth period of crop ontogeny and yield.

MATERIALS AND METHODS

Site description: The experiment was conducted (using pots of 12.5-cm diameter) in a glass house under controlled conditions in the Agronomy Department, Bangladesh Agricultural University, Mymensingh, Bangladesh (latitude: 24°42´55´´, longitude: 90°25´47´´) during *boro* (dry) seasons of 2014-15. The experimental site (Mymensingh) is under a humid subtropical monsoon type of climate. The climate is humid subtropical monsoon. The mean minimum and maximum temperature and rainfall for the experimental period are shown in Figure 1. The physicochemical properties of the soil before the beginning of the experiment are shown in Table 1.

Experimental design and treatments: Treatments consisting of five water management systems namely, continuous saturation (CS), water applications made 4, 6,8, 10 days after disappearance of 4 cm ponded water (DAD) and ten high yielding cultivars of rice *viz.,* BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan50, BRRI dhan59, BRRI dhan60, BRRI dhan61, Binadhan-8, Binadhan-10, and Binadhan-14.The selected cultivars were the most popular and high-yielding ones cultivated during the *boro* season. The experiment was conducted following completely randomized design (CRD) and replicated thrice. In each replication,50 pots were placed side by side while maintaining 10 to 25 cm between them. The replicates were separated by 1 m. The parentages of the cultivars tested including their import characteristics are presented (Table 2) to determine their adaptability with specific traits.

Pot preparation and fertilizer application: Each pot was filled with 8 kg of soil and placed in the glasshouse of the Department of Agronomy, BAU, Mymensingh. Extra water was applied to bring the soil moisture to a suitable level for seedlings because the pots were filled with dry soil. Two liters of water were added to saturate the soil. Fertilizer concentrations for pot experiments were applied as 2.7 g, 0.8 g, 1.04 g, 0.9 g, and 0.03 g per pot in the form of Urea, Triple Super Phosphate (TSP), Muriate of Potash (MOP), gypsum, and zinc sulfate, respectively. Whole amounts of fertilizers except Urea were applied during the final pot preparation. One-third of Urea (0.9 g) per pot was applied at 15 days after transplanting (DAT), 40 DAT, and 70 DAT.

Crop and water management: Forty days old seedlings (previously grown in the seedbed) of the cultivars were transplanted in the pot on January 12, 2015. There was 4 cm of standing water during transplanting and after disappearance of this ponded water, different water management treatments were applied. In the continuous saturation treatment, water as applied to saturate the soil (without flood), while for the other treatments, each irrigation was applied according to the time interval specified for the treatment. The irrigation was continued up to 15 days before the harvest of the crop. During the growth period, especially in the early stages, sometimes weeds were observed and uprooted by hand. No major insects were noticed except rice hispa during the growth period. The infestation was controlled by applying insecticides (Fenitrothion 50 EC) in each pot at the tillering stage.

Plant and growth dynamics measurement: In the experiment, phenological observations were done weekly. The anthesis date of rice was observed using the decimal code scale anticipated by Zadoks *et al.* (1974). Anthesis dates were recorded when 50% of the plants reached this periodin each plot. Observations on growth dynamics were made at active tillering (AT), panicle initiation (PI), flowering (FL), and physiological maturity (PM). The parameters to evaluate growth dynamics, such as plant height, leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) were recorded foreachpot through destructive sampling. For each destructive sample, a plant was uprooted and washed with water. The leaf blades were alienated from the leaf sheath and leaf area was measured by a leaf area meter (LI 3100, Licor, Inc., Lincoln NE, USA). Leaf area index was accordingly calculated from leaf area data. After measurement of leaf area, the plant samples were dried in an electric oven at 65°C for 72 hour until they reached at constant weight, and their dry weights were recorded. LAI, CGR, RGR, and NAR were calculated following the standard formulae (Radford, 1967; Hunt, 1978).

Biomass partitioning measurement: Biomass partitioning in the shape of sheath weight, leaf weight, root weight, and total dry matter was calculated for each water management treatment level for all cultivars. The sheath, leaf, and root dry weight was calculated during AT, PI, FL, and PM by placing the plant samples in the oven at 65°C for 72 h. Total dry matter of the plant was determined by adding shoot dry matter, including leaf blade, leaf sheath, Culm, and panicle (when applicable) and root dry matter.

Estimation of irrigation water and water productivity: Amount of applied irrigated water was recorded from seedling establishment and continued up to 15 days before harvest. Water productivity of rice was calculated by dividing the total yield with the total amount of water required during entire crop growth period by following formula (Michael, 1978):

$$\text{Water productivity} = \frac{Y}{WR}\,(\text{t ha}^{-1}\,\text{cm}^{-1})$$

Where,

Y = grain yield (t ha^{-1}), WR = total amount of water used (cm)

Relative water Content (RWC) was calculated according to Smart and Bingham (1974):

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

FW= Fresh leaf weight, TW= Turgid leaf weight, DW= Leaf dry weight; For FW, fresh leaf sample was cut into a small disc and then fresh leaf weight was measured; For TW, the leaf sample (disc shaped) was soaked in distilled water for 4hr in the dark and thereafter the turgid leaf weight was measured and For DW, the leaf was dried at 80° C in an electric oven for 24 hr and then weight was taken.

Measurement of yield and yield components: Maturity date was identified when 90% of grains had matured. At maturity, the whole plant was cut at the ground level with a sickle. The harvested crop from each pot was bundled separately and tagged appropriately. After recording data for plant height and panicle length for each plant, plant materials were sun dried for grain collection. Finally, grain and straw yield and yield contributing parameters were recorded separately.

Data analysis

Data on crop growth, yield components, and yield of rice were compiled and tabulated for statistical analysis. The recorded data on various plant characters were statistically analyzed to find out the significance of variation resulting from the experimental treatments. All the collected data were analyzed following analysis of variance (ANOVA) technique and mean differences were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984) using a computer operated program namely MSTAT-C.

RESULTS AND DISCUSSION

Crop phenology and environmental conditions during crop cycle: Crop duration was interactively determined by the cultivar and environment. Patterns for 10 cultivars with different phenology are shown in Figure 2. In the present study, the average length of life cycle of cultivars was 137 days (d). The greatest difference between the minimal and maximal crop duration for cultivars was 28 d and the smallest difference was 3 d. Crop duration from emergence to FL varied from 92 d to 115 d depending on the cultivar. Grain filling duration exhibited variation based on cultivar from 26 d for Binadhan-14 to 33 for Binadhan-10. It was noted that the cultivar Binadhan-10 matured much earlier than other cultivars along with more grain filling period. The rice cultivars having higher grain filling duration have produced higher yield (Yang *et al.*, 2008). Extension of grain filling duration provided rice plant with more climatic resources such as temperature and solar radiation for prolonged grain growth.

Daily mean temperature for the effective grain-filling period was constant for all cultivars because of the relative stable temperature after FL (Figure 1). Considering phenology, during transplanting, PI, and FL daily mean temperatures were 17°C, 21°C, and 24°C, respectively. At the early stage of crop growth, there was no rainfall; however, at the grain-filling stage and onward, rainfall began, and maximum rainfall (46.6 mm) was recorded during the grain-filling period (Figure 1).

Growth parameters: Significant ($P<0.05$) differences in terms of plant height among the cultivars were observed (Table 3). Cultivar BRRI dhan47 registered highest plant height (93.85 cm) while lowest was in Binadhan-14 (69.79 cm). Plant height was also significantly ($P<0.05$) higher under different water management conditions (DAD) than under CS conditions. A significant reduction in plant height of under CS situation may be due to restriction of plant growth.

A significant variation in plant height and LAI at different growth stage based on cultivars and water management conditions are observed in Figures 3 and 4. Plant height increased progressively over time attaining the highest at PM. The rate of increase, however, varied depending on the growth stages. The cultivar Binadhan-10 recorded maximum plant height at all the growth stages except PM where Binadhan-8 showed highest value and both of which were statistically similar at this stage. The shortest plant height up to PM was observed with Binadhan-14. Among water management conditions, 8-DAD treatment recorded the tallest plants at all the growth stages followed by 10- DAD. The shortest plant height was observed at CS at all the stages of growth except AT.

Cultivars differed significantly in respect of root dry weight $hill^{-1}$ (g) at FL. The highest root dry weight $hill^{-1}$ (1.57 g) was recorded in Binadhan-10 while being lowest in BRRI dhan61. Water management treatments also significantly affected root dry weight $hill^{-1}$at FL. It was enhanced compared to CS, but only in treatments up to 8 -DAD; beyond that, root dry weight was reduced. Panicle length differed significantly under both the cultivars and water management practices and among the cultivars, highest being in BRRI dhan29. Panicle length increased significantly up to 8- DAD treatments compared to CS and then tended to decrease.

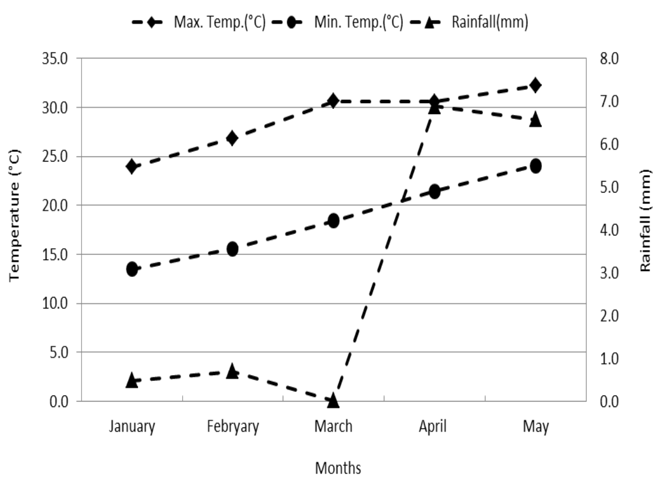

Figure 1. *Temperature (°C) pattern and mean rainfall (mm) at the experimental site (Mymensingh, Bangladesh) during the experimental period.*

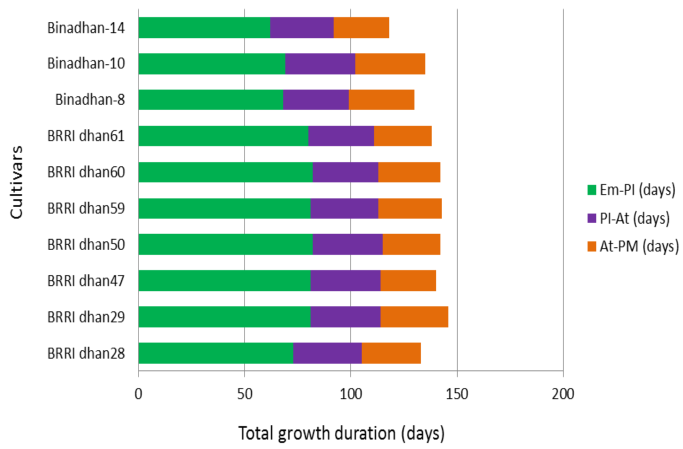

Figure 2. *Crop phenology of high yielding rice cultivars of Bangladesh. Bar shows the length of each development phase: Emergence (Em)-panicle initiation (PI) (green bars), PI-anthesis (At)(purple bar) and At-physiological maturity (PM) (orange).*

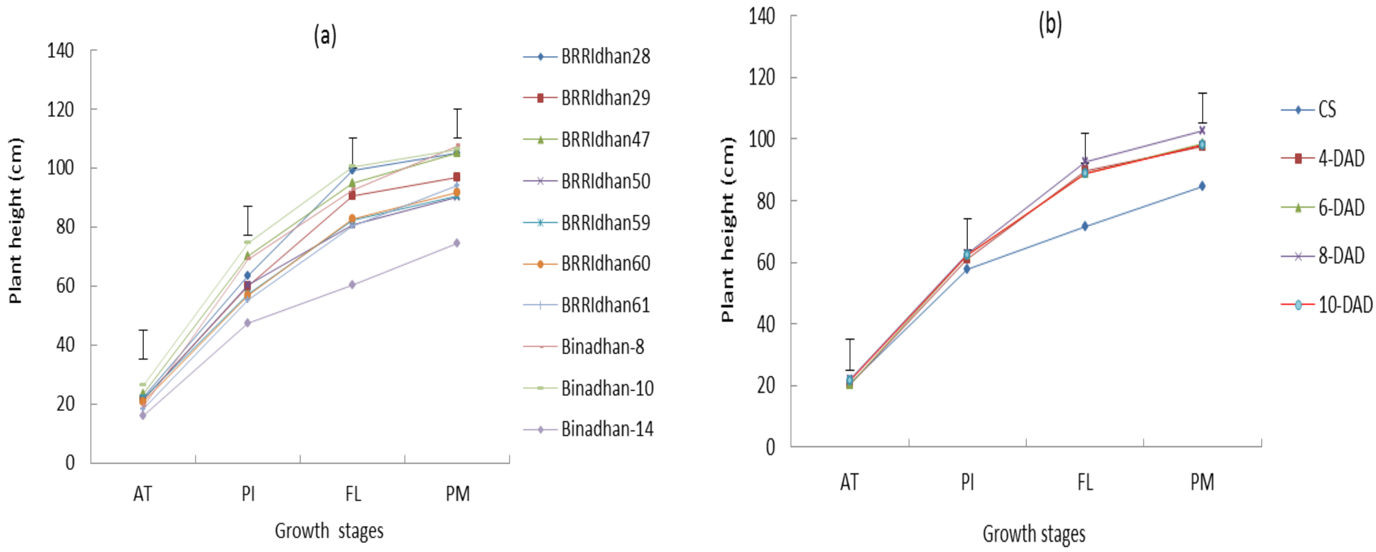

Figure 3. *Plant height of rice as influenced by (a) cultivars (b) water management systems. Vertical bars represent LSD(P=0.05).*

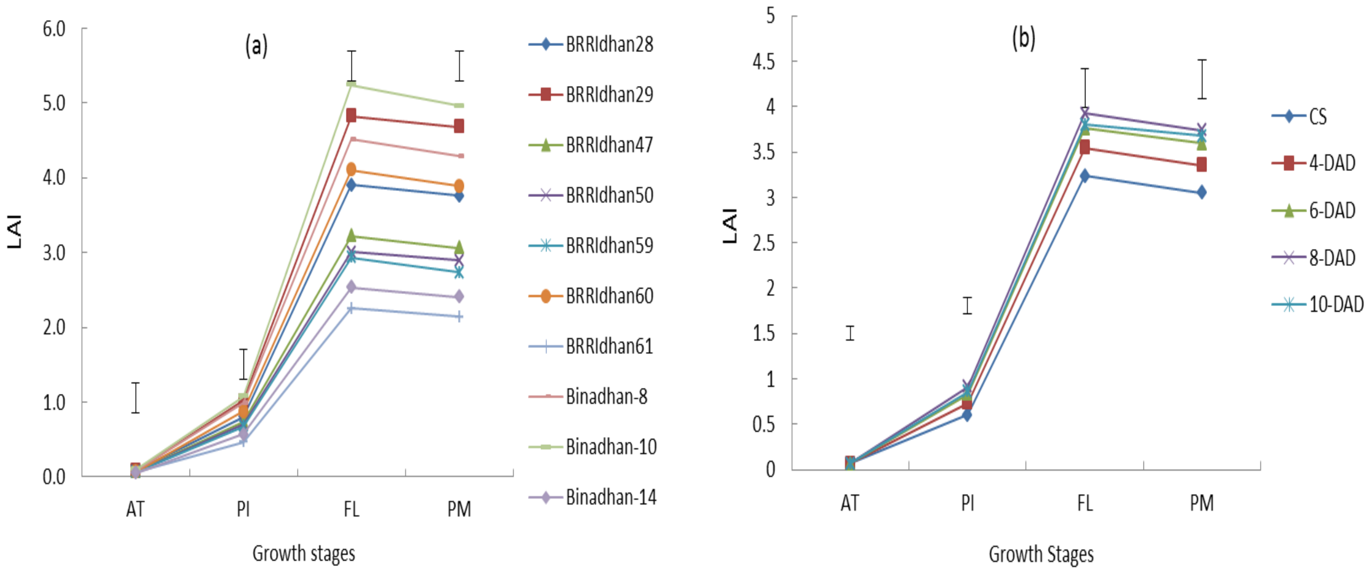

Figure 4. *LAI of rice as influenced by (a) cultivars (b) water management systems. Vertical bars represent LSD(P=0.05).*

TDM increased significantly with increasing plant growth started from AT to PM (TDM at FL only presented, Table 3). It was found significantly highest (*P<0.05*) in Binadhan-10 followed by BRRI dhan29. The lowest TDM was observed in BRRI dhan61. A wide variability in photosynthetic rates exists in rice cultivars (Sharma and Singh, 1994) which may cause difference in dry matter accumulation. Alam *et al.* (2009) found differences in total dry matter accumulation in different genotypes. TDM ranged from 19.88 to 21.99 g plant^{-1}under different water management treatments.8-DAD treatment recorded significantly higher TDM compared to other DAD treatments and lowest TDM was observed under CS condition. Grain yield improvement of lowland rice cultivars released by the International Rice Research Institute (IRRI), Philippines is due to increases in biomass production (Peng *et al,* 1999). Akita (1989) and Amano *et al.* (1993) also stated that higher grain yield from rice was achieved by increasing biomass production.

LAI of rice cultivars with different levels of water management showed substantial differences over the growth stages. LAI is connected to biological and economic yields and enhance in LAI causes higher yield (Singh *et al.,* 2009). Considering growth stage, LAI increased sharply reaching peak at FL and then decreased irrespective of treatment differences. The rate of decrease of LAI after attaining peak was swifter. Maximum LAI (5.24) was attained at FL by Binadhan-10. Similarly, highest LAI was observed at all growth stages and at FL it was maximum (3.92) for 8-DAD treatments. LAI decreased after FL reflecting the loss of some existing leaves through senescence. A significant relationship (R^2=0.92, *P<0.01*) between grain yield and LAI at FL is observed in Figure 5a. Cultivar having more LAI has the possibility to absorb more solar radiation, more photosynthesis and ultimately leads to higher yields.

Regarding CGR, it is observed that parallel to the increase in leaf area over the time, CGR also was raised until FL and then decreased (Table 4). CGR attained maximum of 22.60 g cm^{-2} day^{-1} at FL for Binadhan-10 and minimum was noted at BRRI dhan61. CGR with 4-DAD, 6-DAD and 8-DAD was 7.14, 9.87 and 16.38 % higher, respectively than CS treatments. Irrespective of treatments, RGR was more at early phase and showed a diminishing trend with the progress of plant age. The decline in RGR was possibly due to the raise of metabolically active tissue, which contributed less to the plant growth. Based on the trend of RGR in cultivars, it is stated that Binadhan-10 cultivar had the highest RGR at FL and after that BRRI dhan61 cultivars had the highest RGR at PM. The trend of NAR in both cultivars and water management

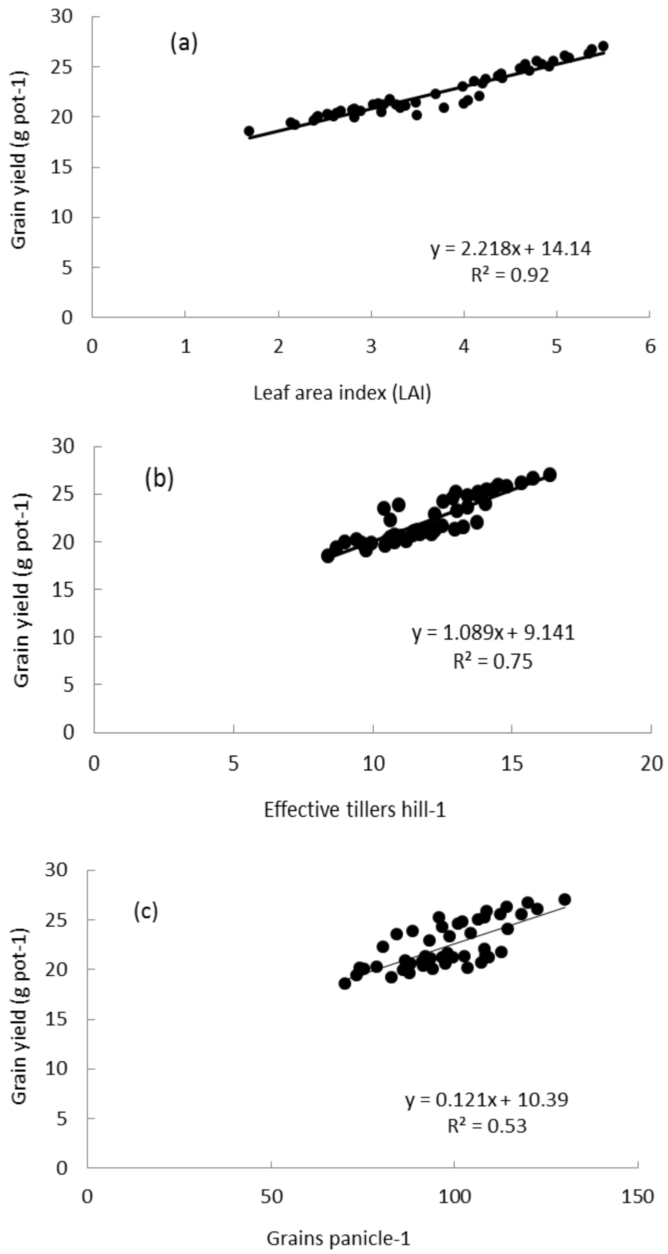

Figure 5. *Relationship between grain yield and leaf area index (a) at flowering, effective tillers hill*$^{-1}$ *(b) and grains panicle*$^{-1}$ *(c) at harvest.*

treatments was relatively equal and downward (Table 4). With LAI increasing, NAR was reduced in all the treatments and it can be due to the more tillering and leaf area development. The percentage of increase in NAR of 4-DAD, 6-DAD, 8-DAD and 10-DAD were 5.83%, 10.37%,11.99% and 14.03 % respectively compared to CS at PI.

Cultivars and water management systems has remarkable effect on RWC. The cultivars having the high RWC (%) have the more capability of tolerance to drought condition. At FL, the highest RWC (91.51 %) was exhibited by Binadhan-10 and lowest RWC (82.06 %) was recorded by BRRI dhan61. At FL and PM of water stress, most of the varieties had a little change in RWC and the similar patterns of RWC as before were observed. Water stress significant reduced RWC at vegetative and flowering stages after a certain period. The result indicated that, 8-DAD treatments showed highest RWC followed by 6- DAD and 4- DAD.

Yield attributes and yield: The cultivar Binadhan-10 produced highest number of effective tillers hill^{-1}closely followed by BRRI dhan29 and Binadhan-8, whereas lowest number was noticed in BRRI dhan61 (Table 5). Grain yield variations for cultivars were significantly positively correlated (R^2=0.75, p<0.01) with effective tillers hill^{-1} (Figure 5b).Similarly, number of grains panicle^{-1}, grain yield and straw yield was higher in Binadhan-10. There was a significant positive correlation (R^2=0.52, p<0.01) between grains panicle^{-1} and grain yield (Figure 5c). Binadhan-8 registered highest 1000 grain weight. A large number of studies have already been done on the relationships between yield components and yield in rice. There were positive correlations between yield and harvest index (HI), grain weight plant^{-1}, and grains panicle^{-1} (Li *et al.,* 2005). Katsura *et al.* (2007) reported that rice yield is mainly dependent on producing ability of dry matter before heading. Moreover, grain number, which is the main part of sink size, is optimistically correlated with yield (Yoshida *et al.,* 2006). In our study, the highest grain yield of Binahan-10 was related with more effective tillers hill^{-1} and greater numbers of grains panicle^{-1}, but the higher grain yield of BRRI dhan29 was mainly attributed to more panicle length. The results also suggest that biomass accumulated at FL has a great involvement to final yield performance. Evidently, the biomass gathered in the stems (and leaf sheath) will be transported into developing grains during filling stage.

Data on yield and yield attributes revealed that different water management (DAD) had significantly (P<0.05) higher values of yield attributes and yield compared to CS except 1000 grain weight and harvest index, which were non-significant for water management practices (Table 5). Grain yield of rice under 4- DAD, 6- DAD, 8- DAD treatments was 2.9%, 4.9 %,7.8 % higher respectively than that recorded under CS condition. Beyond the 8- DAD treatments, the yield tended to decrease and it was 1.2 % lower at 10- DAD treatment compared to 8- DAD and it may be due to encountered moisture stress. The grain yield of rice under 8- DAD treatment was 7.8 % higher than CS condition. Grain yield difference between 8 -DAD and CS condition was also attributed primarily to the difference in sink formation (number of grains panicle^{-1}), TDM accumulation and partly to difference in panicle length. Among yield components, sink size (number of grains panicle $^{-1}$) contributed more towards grain yield and is the most important factor for minimizing yield difference between 8-DAD and CS condition.

Interaction effect revealed that under different water management systems, Binadhan-10 recorded significantly higher yield over all the cultivars (Table 7). The cultivar BRRI dhan61 had lowest yield under different water management practices. Highest grain yield (7.21t ha-^{1}) was recorded in Binadhan-10 along with 8-DAD treatments. The yield reduction ranges from 6.00% to 8.65% in CS condition compared to 8-DAD treatment. This result showed that high yielding cultivars of rice are not suitable for CS condition.

Water requirement and productivity: Water use and water productivity under different water management treatments are shown in Table 6. Across all the water management treatments, irrigation water applied was maximum for CS (118 cm) and minimum for treatment 10-DAD (20 cm) and 8-DAD (24 cm), respectively. These were 83% and 79.6% less water required for 10-DAD and 8-DAD compared to CS. Besides, the water productivity rice cultivars at 8- DAD and 10- DAD were 78.6% and 81.3% higher than that of the rice grown under CS condition. WUE of aerobic rice was higher compared to other establishment methods (Belder *et al.,* 2007; Singh *et al.,* 2008).This means that the water productivity decreased with the increase of irrigation water. Similar results are also reported by Islam and Mondal (1992). Among the treatments in which irrigation water applied, water productivity was the highest (0.252 t ha^{-1} cm^{-1}) in treatment 10-DAD and was found to be minimum (0.047 t ha^{-1} cm^{-1}) in CS.

The adoption of AWD method means that application of irrigation water in fields to renovate flooded conditions on an intermittent basis, only after a certain number of days have passed since the disappearance of ponded (standing) water. The number of days of non-flooded soil before the subsequent irrigation is applied can differ from 1 day to more than 10 days under AWD (Bouman *et al.,* 2007). In our study, most of the physiological and yield parameters showed better performance up to 8- DAD. The differences in the number of days between irrigations and in soil and hydrological conditions cause great variability in the results of AWD (Bouman and Tuong, 2001). However, beneficial effects from practicing AWD over continuous saturation apart from water saving have been reported exclusively. Continuous submergence was not crucial for achieving high rice yields (Sato and Uphoff, 2007). Yang *et al.* (2004) stated that AWD irrigation methods can produce greater and deeper root systems, enhancing nutrient uptake, raising water use efficiency and grain yield (Zhang *et al.,* 2009). Yang *et al.* (2004) also reported that the positive responses of integrated nutrient management for rice yield are significantly declined by waterlogging of rice fields.

Table 1. Physicochemical properties of soil before start of the experiments.

Soil property	Values
Soil texture	Clay loam
pH–H_2O	5.83
EC (µs/cm)	143
Organic carbon (%)	1.125
Total N (%)	0.145
Available P (ppm)	23.3
Available K (ppm)	88.64
Available S (ppm)	59.64

Table 2. Parental line and significant characters of the rice cultivars tested in the experiment.

S.N.	Name of cultivar	Parentage	Year of notification	Duration (days)	Ecosystem	Salient features	Recommended for cultivation
1.	BRRI dhan28	BR6 (IR28) × Purbachi	1994	140	Irrigated lowland	Early maturing and medium slender grain, yield : 6.0 t/ha	Sylhet, Netrakona belt (flash flood area)
2.	BRRI dhan29	BG90-2 × BR51-46-5	1994	160	Irrigated	Very high yield potential and medium slender grain, yield: 7.5 t/ha	All Bangladesh
3.	BRRI dhan47	IR515111-B-B-34-B × TCCP266-2-49-B-B-3	2007	152	Irrigated	Salt tolerant and medium bold grain, yield : 6.0 t/ha	Barisal belt (Saline area)
4.	BRRI dhan50	BR30 × IR67684B	2008	155	Irrigated	Premium quality rice, slightly aromatic and long slender grain, yield: 6.0 t/ha	All Bangladesh
5.	BRRI dhan59	Collected from International Network for Germplasm Evaluation of Rice (INGER)	2013	153	Irrigated	Dwarf, flag leaf erected and deep green, non lodging and medium bold grain, yield:7.1 t/ha	All Bangladesh
6.	BRRI dhan60	BR7166-4-5-3 × BR26	2013	151	Irrigated	Lodging resistant and extra long slender grain, yield : 7.3 t/ha	All Bangladesh
7.	BRRI dhan61	IR64419-3B-4-3 × BRRI dhan29	2013	150	Irrigated	Salt tolerant and medium slender grain, yield : 6.3 t/ha	Barisal belt (Saline area)
8.	Binadhan-8	IR29 x Pokkali	2010	130-135	Irrigated	Semi dwarf, early maturing and medium bold grain, salt tolerant, yield: 7.5-8.5 t/ha	Barisal belt (Saline area)
9.	Binadhan-10	IR42598-B-B-B-B-12 X Nona Bokra	2012	127-132	Irrigated	Deep green and erect flag leaves, trunks and stems are strong, no lodging and no shattering, salt tolerant, medium long and slender grain, yield: 7.5 t/ha	Barisal belt (Saline area)
10.	Binadhan-14	Ashfal mutant (Radiation was applied on Ashfal)	2013	120-130	Irrigated	Shorter, erect and lodging resistant, late planting, long and slender grain, yield: 6.85 t/ha	All Bangladesh

Table 3. Growth parameters of rice as influenced by cultivar and water management systems.

Treatments	Plant height (cm)	Root dry weight /hill^{-1} (g)	Panicle length (cm)	Total dry matter (g plant $^{-1}$)
Cultivars (C)				
BRRI dhan28	78.28g	1.16e	22.24c	21.73e
BRRI dhan29	80.40f	1.45b	24.91a	26.88b
BRRI dhan47	93.85a	0.95f	21.17d	17.92f
BRRI dhan50	72.03i	0.89g	21.19d	16.68g
BRRI dhan59	73.14h	0.86g	21.43d	16.29g
BRRI dhan60	82.84d	1.22d	22.54c	22.84d
BRRI dhan61	81.47e	0.65i	19.96f	12.68i
Binadhan-8	85.68c	1.35c	23.74b	25.15c
Binadhan-10	88.49b	1.57a	23.96b	29.22a
Binadhan-14	69.79j	0.74h	20.49e	14.06h
Water management (W)				
CS	79.60b	0.99d	21.11e	18.27d
4 -DAD	80.50a	1.09c	21.64d	19.88c
6 - DAD	80.94a	1.15b	22.26c	20.56b
8-DAD	81.00a	1.20a	23.16a	21.99a
10 - DAD	80.95a	1.00d	22.63b	21.02b
ANOVA				
Cultivars (V)	**	**	**	**
Water management (W)	**	**	**	**
V × W	NS	NS	NS	NS
CV (%)	1.77	5.38	3.18	5.20

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT); ** Significant difference at P ≤ 0.01, NS- Non-significant.

Table 4. Physiological and bio-chemical parameters of rice as influenced by cultivar and water management systems.

Treatments	CGR (g cm $^{-2}$day^{-1})			RGR (g^{-1}g^{-1}day)			NAR (mg cm^{-2}day^{-1})			RWC (%)			
	AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM	AT	PI	FL	PM
Cultivars (C)													
BRRI dhan28	2.30e	16.75e	8.09cd	47.20de	35.82ab	6.09e	0.3340abc	0.3727	0.0913de	90.20ab	85.43d	88.86abc	87.24ab
BRRI dhan29	2.90b	20.69b	8.72bc	48.85bc	35.54abc	5.42g	0.3413abc	0.3687	0.0813e	91.26ab	85.77d	90.82a	89.45a
BRRI dhan47	2.06f	13.64f	7.33d	46.74ef	34.39b-e	6.60d	0.3260bc	0.3553	0.1020cd	90.04ab	88.52a-d	86.76bcd	84.87bc
BRRI dhan50	1.94g	12.66g	7.51d	46.29efg	34.19cde	7.17c	0.3187c	0.3513	0.1107bc	89.74ab	88.31a-d	85.88cd	83.90cd
BRRI dhan59	1.87g	12.39g	7.53d	45.37g	34.31b-e	7.33c	0.3193c	0.3527	0.1160b	88.93b	89.96ab	85.61cd	83.56cd
BRRI dhan60	2.48d	17.57d	7.91cd	50.40a	35.57abc	5.71f	0.3480ab	0.3687	0.0846e	92.08a	89.52abc	89.36ab	87.79ab
BRRI dhan61	1.51i	9.579i	7.05d	45.67g	33.66de	8.53a	0.3500ab	0.3633	0.1393a	88.94b	91.08a	82.06e	79.64e
Binadhan-8	2.79c	19.27c	9.39ab	47.96cd	35.08a-d	6.11e	0.3347abc	0.3620	0.0926de	90.68ab	89.88ab	90.24a	88.80a
Binadhan-10	3.02a	22.60a	10.16a	45.90fg	36.13a	5.75f	0.3207c	0.3760	0.0873e	89.49b	86.30cd	91.51a	90.22a
Binadhan-14	1.73h	10.59h	7.37d	49.16b	33.30e	8.10b	0.3547a	0.3487	0.1293a	91.41ab	86.78bcd	83.61de	81.35de
Water management (W)													
CS	1.72e	14.29d	7.04b	44.63d	37.12a	6.59bc	0.3087c	0.3893a	0.1043	87.95c	89.20a	85.65b	83.71c
4-DAD	2.12d	15.31c	7.63b	47.20 b	35.55 b	6.52c	0.3267b	0.3733a	0.1017	90.53b	87.13ab	87.74ab	85.96abc
6-DAD	2.34c	15.70bc	8.44a	49.31a	34.18c	6.83a	0.3407ab	0.3480b	0.1043	91.79ab	89.20a	88.42a	86.72ab
8-DAD	2.63a	16.63a	8.95a	45.94c	33.57c	6.75ab	0.3457a	0.3513b	0.1050	92.16a	89.19a	88.90a	87.2a
10-DAD	2.50b	15.94b	8.47a	49.69a	33.58c	6.71abc	0.3520a	0.3477b	0.1020	88.95c	86.04b	86.65ab	84.75bc
ANOVA													
Cultivars (V)	**	**	**	**	**	**	**	NS	**	*	**	**	**
Water management (W)	**	**	**	**	**	**	**	**	NS	**	**	*	**
V × W	**	NS	NS	**	**	**	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.39	6.68	15.66	2.82	5.46	5.36	9.10	10.08	16.57	3.25	4.81	4.97	5.09

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT); *AT* active tillering, *PI* panicle initiation, *Fl* flowering, *PM* physiological maturity, *CGR* crop growth rate, *RGR* relative growth rate, ,*NAR* net assimilation rate, *RWC* relative water content * Significant difference at P ≤ 0.05, ** Significant difference at P ≤ 0.01, NS- Non-significant.

Table 5. Yields attributes and yield of rice as influenced by cultivar and water management systems.

Treatments	Effective tillers hill^{-1}	No. of grains panicle^{-1}	1000 grain weight (g)	Grain yield (g pot^{-1})^{a}	Straw yield (g pot^{-1})^{a}	Harvest Index (%)
Cultivars (C)						
BRRI dhan28	12.50 c	91.90 e	20.45 e	21.17 d	21.32 d	49.85
BRRI dhan29	13.22 b	106.4 b	21.77 d	24.99 b	25.33 b	49.65
BRRI dhan47	11.26 d	92.30 e	25.85 b	20.74 de	20.97 de	49.75
BRRI dhan50	11.01 d	93.27 e	17.26 f	20.79 de	20.97 de	49.83
BRRI dhan59	11.24 d	96.63 d	20.54 e	21.02 d	20.95 de	50.11
BRRI dhan60	12.64 bc	98.40 d	23.35 c	23.23 c	23.57 c	49.63
BRRI dhan61	10.10 e	87.81 f	20.53 e	19.47 f	20.03 f	49.29
Binadhan-8	12.88 bc	102.0 c	27.55 a	24.65 b	25.38 b	49.28
Binadhan-10	15.03 a	113.9 a	26.27 b	26.19 a	26.65 a	49.56
Binadhan-14	10.34 e	91.23 e	21.20 de	20.17 e	20.52 ef	49.54
Water management (W)						
CS	10.04 d	79.69 e	22.30	21.30 d	21.47 d	49.82
4 -DAD	11.65 c	92.22 d	22.47	21.91 c	22.03 c	49.87
6 - DAD	12.42 b	97.68 c	22.36	22.36 bc	22.52 c	49.83
8-DAD	13.24 a	113.6 a	22.91	22.96 a	23.80 a	49.14
10 - DAD	12.76 b	103.7 b	22.34	22.68 ab	23.04 b	49.60
ANOVA						
Cultivars (V)	**	**	**	**	**	NS
Water management (W)	**	**	NS	**	**	NS
V × W	NS	NS	NS	NS	NS	NS
CV (%)	7.17	3.59	6.95	3.97	4.22	2.94

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT) ** Significant difference at P ≤ 0.01, NS- Non-significant; Grain yield and straw yield are at 14 % moisture content.

Table 6. Water use and water productivity under different water management systems.

Treatments	No. of irrigations	Frequency of water application (DAT)	Water used for crop establishment (cm)	Irrigation water applied (cm)	Total water use (cm)	Grain yield (t ha^{-1})	Water productivity (t ha^{-1} cm^{-1})
CS	Continuous saturation	Every alternate day	4	118	122	5.687 d	0.047
4 -DAD	10	30, 36, 42, 48, 54, 60, 66, 72, 78, 84	4	40	44	5.851 c	0.133
6 - DAD	8	30, 38, 46, 54, 62,70, 78, 86	4	32	36	5.970 bc	0.166
8-DAD	6	30, 40, 50, 60, 70, 80	4	24	28	6.130 a	0.219
10 - DAD	5	30, 42, 54,66,78	4	20	24	6.055 ab	0.252
Level of significance						**	
CV (%)						3.97	

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT); ** Significant difference at P ≤ 0.01

Table 7. Interaction between cultivars and water management systems on grain yield and water productivity.

Cultivars	Grain yield (t ha^{-1})					% yield reduction[a]	Water productivity (t ha^{-1} cm^{-1})				
	CS	4-DAD	6- DAD	8-DAD	10-DAD		CS	4-DAD	6- DAD	8-DAD	10-DAD
BRRI dhan28	5.38	5.57	5.68	5.87	5.76	8.35	0.044	0.127	0.158	0.210	0.240
BRRI dhan29	6.37	6.56	6.67	6.94	6.81	8.65	0.052	0.149	0.185	0.248	0.284
BRRI dhan47	5.32	5.46	5.57	5.71	5.62	6.83	0.044	0.124	0.155	0.204	0.234
BRRI dhan50	5.33	5.47	5.62	5.67	5.66	6.00	0.044	0.124	0.156	0.203	0.236
BRRI dhan59	5.39	5.54	5.65	5.79	5.70	6.91	0.044	0.126	0.157	0.207	0.238
BRRI dhan60	5.94	6.12	6.21	6.41	6.32	7.33	0.049	0.139	0.173	0.229	0.263
BRRI dhan61	4.95	5.12	5.22	5.37	5.34	7.82	0.041	0.116	0.145	0.192	0.223
Binadhan-8	6.28	6.47	6.63	6.81	6.72	7.78	0.052	0.147	0.184	0.243	0.280
Binadhan-10	6.72	6.89	7.01	7.21	7.14	6.80	0.055	0.157	0.194	0.258	0.298
Binadhan-14	5.18	5.30	5.43	5.52	5.49	6.16	0.043	0.121	0.151	0.197	0.229
Level of significance	NS	NS	NS	NS	NS						

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT) NS- Non-significant; [a] Compared to 8-DAD treatment.

Conclusions

It is obvious from these results that the cultivar Binadhan-10 with high values of physiological, yield contributing and yield parameters appears to best choice for periodic water stress condition. The cultivar BRRI dhan29 was the next best after Binadhan-10 for cultivation in such condition. The physiological attributes of these two cultivars may be used for breeding a cultivar for a particular environment. On the other hand, AWD had beneficial effects on grain yield compared with CS. Continuous standing water in the rice field, which is a usual practice in Bangladesh, was not found to give optimum yield. The highest grain yield was obtained from 8-DAD and greatest water productivity was found with the 10 -DAD treatment. This indicates that water productivity at 10-DAD are more than 8-DAD due to less water requirement but in respect of yield 8 DAD treatment out yielded 10 DAD due to efficient use of water.

ACKNOWLEDGEMENT

The authors wish to acknowledge Ministry of Science and Technology (MOST), Government of the People's Republic of Bangladesh for funding this research project and technical support.

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