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Influence of Flooding Intensity and Duration on Rice Growth and Yield

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ABSTRACT

An experiment was conducted in the glasshouse of the Faculty of Agriculture, Universiti Putra Malaysia (UPM) in 2005 to evaluate the effect of different flooding treatments on rice growth and yield. Five flooding treatments were used, namely T1 = continuously flooded condition until maturity, T2 = early flooding until 55 DAS (day after sowing) followed by saturated condition until maturity, T3 = early flooding until 30 DAS followed by saturated condition until maturity, T4 = continuous saturated condition until maturity, T5 = continuous field capacity condition throughout the experiment period. The results showed that the response of rice plant to water soil availability varies with its growing stage. At an early stage of rice plant growth (15 and 30 DAS), flooding treatments were found to not affect the growth of rice plant significantly. However, from 45 DAS onwards, the effect was significantly pronounced. All flooding regimes (T1, T2 and T3) significantly favoured rice plant height and the number of tillers as compared to non-flooded regimes (T4 and T5). The positive correlation was observed between the grain yield and yield components. The significant higher number of tillers, high spikelets/ panicle and high 1000-grain weight had contributed to higher grain yield of rice in T1, T2 and T3 as compared to T4 and T5. Shorter duration of flooding (T2 and T3) was found to give a similar performance to continuous flooding, and thus, these methods might save on water use without reducing yields, while over watering might just increase vegetative growth.

Keywords: ***Oryza sativa*** **L., minimal water condition, water regime treatments, glasshouse condition**

INTRODUCTION

Rice, *Oryza sativa* L., is one of the most important cereal crops in the world (Wangda *et al.,* 2003). It feeds well in excess of more than 2 billion people in Asia and many in Latin America, providing on average of about 32% of the total calorie uptake (Mclean *et al*., 2002). The lowland rice agriculture is now responsible for 86% of the total world rice crop and the yields are typically in the range of 2.0 – 3.5 t ha^{-1} (Ladha *et al.,* 1997). In Malaysia, rice is the third most important crop, after rubber and oil palm. Rice is mainly grown in the eight granaries in Peninsular Malaysia, covering an area of about 205,548 ha (MOA, 2008).

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However, yield stagnation or even decline has been observed in some rice growing areas of Asia since the early 1980s (Cassman and Pingali, 1994). One of the major factors is the crisis of fresh water. The per capita availability of water resources was found to decline by 40 – 60% in many Asian countries between 1955 and 1990 (Gleick, 1993). Agriculture's share of water will decline at an even faster rate because of the increasing competition from the urban and industrial sectors (Tuong and Bhuiyan, 1994). According to the United Nation's World Food Programme (WFP), the biggest threat to Asia in the future will be the shortage of clean water; this is particularly in Asia as it accounts for 60% of the world's population, but with only 36% of the global freshwater (Sariam, 2004). According to FAO (2000), Malaysia was categorized in Zone 3 in terms of water scarcity in the 20th Century; with the need to increase water management between 25 – 100 % to meet the 2005's water requirement, rice cultivation would be badly affected by this phenomenon. Water is the single most important component for sustainable rice production, especially in the traditional growing areas. Reduction or large withdrawal of water from the field can significantly lower the sustainability of rice production (Belder *et al.,* 2008; Farooq *et al.,* 2006). However, despite the constraints of water scarcity, rice production must rise dramatically to meet the world's food needs. Producing more rice with less water is therefore a formidable challenge for the food, economic, social and water security.

A series of alternate water management in lowland rice have been studied lately, aiming to keep the field not continuously submerged in order to save the water use in rice farming (Farooq *et al.,* 2006). In addition, water inputs can be reduced by introducing periods of non-submerged conditions of several days throughout the growing season unless cracks are formed through the plough sole (Bouman and Toung, 2001). In China, the systems of alternate flooding and drying have been reported to maintain or even increase rice yields and these have widely been adopted by farmers (Belder *et al*., 2008). Previously, Bhuiyan (1982) reported that the rice plants did not suffer from water stress if the soil was saturated and there was no standing water in the field. Similarly, Tabbal *et al.* (1992) also observed the insignificant difference in the yield between rice grown in flooded condition, alternate flooded conditions and saturated condition. In general, rice plant only uses less than 5% of the water observed through roots from soil (Farooq *et al.,* 2006).

Efforts were made in the past to save water by either reducing the depth of water on the soil surface (Bhuiyan and Palanisami, 1987) or by keeping the root zone saturated without a water head (Ghani and Rana, 1992). Tabbal *et al.* (1992) observed no significant yield difference between rice grown in standing water and those grown under saturated field conditions in the 1988-1989 dry seasons; however, yields under saturated soils were lower in the 1990-1991 dry seasons because of more weed growth, as compared to the previous dry seasons. Therefore, there is a need for a thorough investigation for the changes in rice growth and yield brought out by different water conditions. Thus, a study was undertaken to determine the response of rice plant growth and yield under different water regimes under glasshouse condition.

MATERIALS AND METHODS

The experiment was carried out under a controlled environment in the glasshouse of the Faculty of Agriculture, Universiti Putra Malaysia (UPM), Selangor. The glasshouse had 13:11 h day:night photoperiod and a 21 – 36°C temperature range, with no artificial lighting. The average day temperature and light intensity inside the glasshouse were recorded at 1-hour intervals (*Fig. 1*).

Ten kilograms of air-dried sandy clay loam soil of Sogomana Series was taken from the Bertam Rice Research Station experimental field. The Sogomana Series is a member of the family of *fine, mixed, isohyperthermic palid Tipik Tuajelkuts* (Paramananthan, 2000). They were developed over sub-recent riverine alluvium, and characterized by light grey to white clays, showing strong to moderate

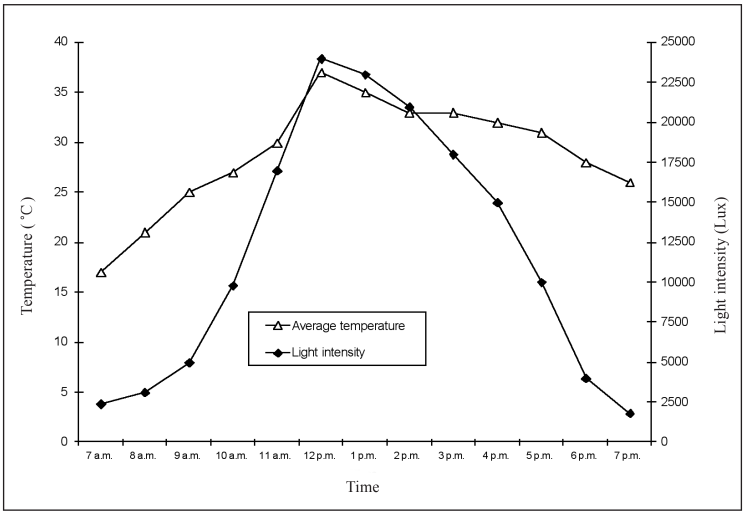

Fig. 1: The average daily temperature and light intensity in the glasshouse

prismatic to coarse angular blocky structures and sticky consistence. The properties of the soil are shown in Table 1. The soils were packed into 20 clay pots. Each pot measured about 32 cm in diameter by 40 cm deep. Pre-germinated rice seeds were sown onto the soil surface at a rate of 500 seeds m^{-2} (approximately 40 seeds per pot). The experiment was begun in May 2005, and completed in September 2005.

The treatments comprised of five flooding treatments, namely T1 = continuously flooded condition (10 cm water level) until maturity, T2 = early flooding (10 cm water level) up to panicle initiation stage (55 DAS – day after

TABLE 1
Physico-chemical properties of Sogomana soil series in MARDI Bertam experimental field

Particle size distribution (%)	
Sand	51.5
Silt	12.0
Clay	36.5
Textural class: Sandy clay loam	
Chemical properties	
pH (1:2.5 in distilled water)	4.49
Cation exchange capacity (CEC), $cmol_c\ kg^{-1}$	7.00
Organic C, %	0.52
Total N, %	0.13
Available P, $mg\ kg^{-1}$	10.38
Exchangeable K, $cmol_c\ kg^{-1}$	0.21
Exchangeable Mg, $cmol_c\ kg^{-1}$	0.52
Exchangeable Ca, $cmol_c\ kg^{-1}$	3.60
Available Cu, $mg\ kg^{-1}$	0.14
Available Mn, $mg\ kg^{-1}$	3.38
Available Fe, $mg\ kg^{-1}$	43.30
Available Zn, $mg\ kg^{-1}$	1.01

sowing), followed by saturated condition until maturity, T3 = early flooding (10 cm water level) for the first month (30 DAS) followed by saturated condition until maturity, T4 = continuous saturated condition until maturity, T5 = continuous field capacity condition throughout the experiment. However, the soil which was maintained under saturated condition during sowing and flooding treatment were only commenced at 7 DAS. For T4 condition, water was only introduced into the soil until saturated (maintain the soil to muddy condition without standing water) to the maximum of 5 mm standing water condition, depending on the temperature inside the glasshouse at that time. Meanwhile, for T5 condition, a water deficit indicator called Tensiometer was placed inside the pots (each pot contained one Tensiometer). The irrigation of T5 was done when the soil water potential fell between -30 to -50 Centibar, as measured by the Tensiometer.

All crop management practices (i.e. fertigation, pest control, weed control) were done according to MARDI's Cultivation Manual (MARDI 2002). However, all the applications were measured and converted according to glasshouse condition and pot size. Water was drained out from all the flooded and saturated pots at 95 DAS and maintained under the field capacity condition until harvesting. The pots were placed close together and another row of extra pots were placed around the entire perimeter to minimize border effects. A Randomized Complete Block Design (RCBD), with 4 replications, was used in this experiment.

The plant height was measured using a measuring tape from the plant base to the tip of the highest leaf. The average of six readings was taken randomly from each experimental unit. The parameter of the plant height was taken at 15, 30, 45, 60, 75 and 90 DAS. Meanwhile, the number of tillers per plant was recorded as soon as tillering was started (when seedlings have 5 leaves) and ended at the panicle initiation stage when the flag leaf emerged. The number of tillers per plant was taken at 15, 30, 45, 60, 75 and 90 DAS. The days to flowering were recorded when the first flower emerged while the days to grain maturity were recorded when the grain colour turned yellow and the leaves started to senesce. The number of panicles, per square meter, was recorded in each pot of the rice plants and converted into number m^{-2}. The number of spikelet per panicle was recorded for fully-filled grains, half-filled and non-filled spikelets. The rice plants were harvested manually using a sickle at 10 cm above the ground. 1000 filled grains weight, rice straw biomass and rice yield per pot of all treatments were converted into ton ha^{-1} at 14% moisture content. The effects of the different water regime treatments on the rice growth and yields were analyzed using the Analysis of Variance (ANOVA). The statistical analysis was done using the SAS statistical software and the means were tested using the Tukey's studentized range test, at 5% level of probability.

RESULTS AND DISCUSSION

Rice Plant Height

Table 2 shows the height of the rice plant at the different growth stages under different water flooding treatments. At 15 and 30 DAS, there was no significant difference observed. The differences were only recorded at the beginning of 45 DAS. The height of the rice plant increased with time in all the flooding treatments until the time of harvest. Generally, the rice plant which was exposed under T4 (continuous saturated) and T5 (continuous field capacity) conditions were significantly shorter than the rice plant which received continuous flooding (T1), T2 (flooded until 55 DAS followed by saturated) and T3 (flooded until 30 DAS followed by saturated) conditions. Therefore, the height of the rice plant was significantly affected by flooding treatment at all growing stages, except at 15 and 30 DAS. At 45, 60 and 75 DAS, the lowest height of rice plant was observed in T5, where rice grown under the field capacity condition was approximately 10 – 15% shorter as compared to the rice plant under other flooding treatments. At 90 DAS, however, rice plants in both T4 and T5 pots were significantly lower as compared to the other flooding treatments.

TABLE 2
The height of rice plant (cm) under different flooding treatments at various growing stages

Flooding Treatments	Day After Sowing (DAS)					
	15-ET	30-AT	45-MT	60-PI	75-Mk	90-D/M
T1	34.25ab	51.00a	83.63a	92.48a	111.25a	117.50a
T2	37.00a	51.75a	78.50ab	86.00ab	111.50a	115.00ab
T3	35.75a	52.75a	76.00ab	90.25ab	105.00b	111.25bc
T4	32.25a	50.50a	81.25a	88.00ab	101.67bc	107.75c
T5	33.75a	50.75a	74.00b	82.50b	96.00c	100.75d

*In a column, means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition. Growth stages: ET = early tillering; AT = active tillering; MT = maximum tillering; PI = panicle initiation; Mk = milking; D/M = dough/maturation stage.

In general, the rice plants grown in T1 were taller than the rice plants grown in other flooding treatments, while reduced water regimes of T4 and T5 restricted rice plant growth. Navarez *et al*. (1979), in the glasshouse experiment in Philippines, also found the same results. However, variable flooding regimes (T2 and T3) also resulted in good performance of the rice plant growth in this study. Meanwhile, the effect of the flooding treatments on the height of the rice plant was not obviously significant in all the pots during the vegetative phase (15 and 30 DAS). This might be due to the few and small rice tillers at the early growing stages, which minimized the competition for available water for growth, even under continuous saturated (T4) and continuous field capacity (T5). IRRI (2008) reported that at vegetative stage, water requirement is the least concern affecting rice growth as compared to weed, nutrition and pest management.

As growth advanced, water requirement increased and reduced water conditions such as T4 and T5 significantly restricted plant height, especially at maturity phases. This is because at reproductive stage, water has become the main factor contributing to the growth and production of rice plant (IRRI, 2008). Beyrouty *et al.* (1992) observed the reduction in the height of plant when flood was delayed. In addition, Anbumozhi *et al.* (1998) also found variable and continuous ponding conditions resulted in better performance in plant height compared to shallow ponding condition. The reduced water condition also enhanced weed emergence and significantly reduced the height of the rice plant (Janiya and Moody, 1991).

Number of Tillers

Table 3 shows the effect of different flooding treatments on the number of rice tillers at different growing stages. The results showed that the flooding treatments did not significantly influence the number of rice tiller in the early growing stage (15 and 30 DAS) in both weeded and unweeded pots. A significant effect was recorded starting only at the beginning of the maximum tillering stage, i.e. 45 DAS onwards. The effect of the flooding treatments on rice plant, during the early tillering stages, was not significantly observed because the tillering process was just about to begin at this stage (Sariam, 2004). The number of tillers reached its maximum potential until 75 DAS and at 90 DAS, and tillering process started to slow down in most of the flooding treatments because the rice plants were found to reach their maturity and only a few small tillers were produced.

The production of tiller at 15 and 30 DAS was not significantly affected by the flooding treatments (Table 3). At 45 and 60 DAS, rice plants grown in T3 (flooded until 30 DAS followed by saturated) produced the highest number of tillers (794 tillers m^{-2} and 878 m^{-2} tillers respectively), while the productions of tiller in T5 (continuous field capacity) were significantly the lowest at 625 tillers m^{-2} and 684 tillers m^{-2}, respectively. Meanwhile, at the reproductive stage (75 and 90 DAS), T2 (flooded until 55 DAS followed by saturated afterward) produced the most tillers (1003 tillers m^{-2} and 972 tillers m^{-2}, respectively) as compared to the other flooding treatments, while T5 produced the lowest number of tillers (769 tillers m^{-2} and 772 tillers m^{-2}, respectively). Jahan (2004) and Sariam (2004) also found that the production of tiller was significantly lower under the field capacity than in the flooded and saturated conditions.

Days to Flowering and Grain Maturity

The variability in the flooding treatment did not significantly affect either the day to flowering or the day to grain maturity in all the pots (Table 4). However, T1 (continuous flooded), T2 (flooded until 55 DAS followed by saturated) and T3 (flooded until 30 DAS followed by saturated) enhanced rice plants to flower earlier than T4 (continuous saturated) and T5 (continuous field capacity). This is because at the flowering stage, water demand is very critical, while low or deficit in water availability will delay and lengthen the time of flowering process (Siti Mardina, 2005; IRRI, 2008). According to Williams *et al*. (1990), earlier heading and flowering might have been a stress reaction where rice grown under submerged conditions showed faster heading and flowering than under shallow and saturated conditions.

Meanwhile, the effect of the different flooding treatments on the days for grain maturity showed the opposite result (Table 4). In more specific, rice planted under T5 condition ripened earlier than the rice grown under other flooding treatments in all the pots. It was then followed by T4, T2 and T3. On the contrary, maturity was delayed in T1 with the longest ripening time. This is because less water is needed in the maturity phase (Siti Mardina, 2005; IRRI, 2008) and delay in draining out the water will cause the rice grain to ripen slower.

TABLE 3
The production of rice tillers (number m^{-2}) under different water regime treatments, at various growth stages

Flooding Treatments	Day After Sowing (DAS)					
	15-ET	30-AT	45-MT	60-PI	75-Mk	90-D/M
T1	500a	575a	700bc	759bc	866ab	922a
T2	500a	578a	750ab	831cb	1003a	972a
T3	500a	625a	794a	878a	928ab	966a
T4	500a	581a	684cd	794ab	897ab	891ab
T5	500a	572a	625d	684c	769b	772b

In a column, means followed by the same letter are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T1 = continuous flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuously saturated condition: T5 = continuous field capacity condition. Growth stages: ET = early tillering; AT = active tillering; MT = maximum tillering; PI = panicle initiation; Mk = milking; D/M = dough/ maturation stage.

TABLE 4
The effect of the different flooding treatments on the day to flowering and the day to grain maturity of rice plant

Flooding Treatments	Days to flowering ± SE	Days to grain maturity ± SE
T1	59a ±1.15	96a ±1.70
T2	62a ±1.88	92a ±1.88
T3	61a ±1.50	93a ±1.36
T4	63a ±1.94	92a ±1.08
T5	63a ±1.82	92a ±1.44

In a column, means followed by the same letter are not significantly different at 5% level by Tukey's Test.
T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition. SE = Standard Error.

The Number of Rice Panicles

Fig. 2 indicates the effect of the flooding treatments on the number of rice panicles m^{-2}. Generally, the responses of rice panicle number m^{-2} were significantly affected by the flooding treatments. The highest number of rice panicles was produced under continuous flooded condition (T1), which produced 434 panicles m^{-2}, followed by T2 (426 panicles m^{-2}), T3 (425 panicles m^{-2}) and T4 (398 panicles m^{-2}), which were not significantly different among each other. Meanwhile, T5 was found to significantly produce the lowest rice panicle number (320 panicles m^{-2}) as compared to the other flooding treatments.

The result showed that the production of the rice panicles was significantly influenced by the flooding treatments, which were in line with the research done by Jahan (2004) and Sariam (2004). According to Sariam (2004) and Siti Mardina (2005), the production of panicles was significantly reduced when rice was grown under field capacity. From the results, higher number of panicles m^{-2} in all flooded regimes (T1, T2 and T3) is believed to be due to the high number of tillers in the same flooding treatments, as shown in 3.2 (Table 3), indicating the positive interaction between the results in rice growth stages and the results in rice maturity stages.

The Number of Spikelets Per Panicle

The response of spikelets number per panicle to different flooding treatments was found to be significantly different (*Fig. 3*). The number of spikelets per panicle was observed to decrease with the reduction in water availability. Nevertheless, there were no significant differences observed between T1, T2, T3 and T4, as well as between T3 and T4, as compared to T5. A significant difference was only found between T1 and T2 as compared to T5. In more specific, T1 and T2 produced 123 and 122 spikelets/panicles respectively, while T5 produced the lowest number of spikelets (107 spikelets/ panicle). It is believed that a high number of panicles also contributed to a high number of spikelets. The results indicated that the number of spikelets per panicle was much lower under the field capacity condition, as compared to the flooded and saturated conditions. These results are in agreement with the ones by Sariam (2004) who observed that the number of spikelets per panicle under continuous flooded conditions had the highest value, followed by the saturated, while

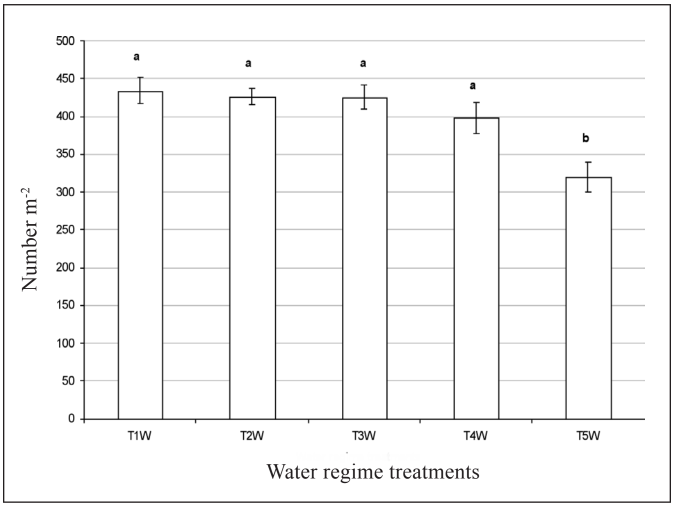

Fig. 2: The effect of different flooding treatments on the number of rice panicles m^{-2}

Means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuous flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition.

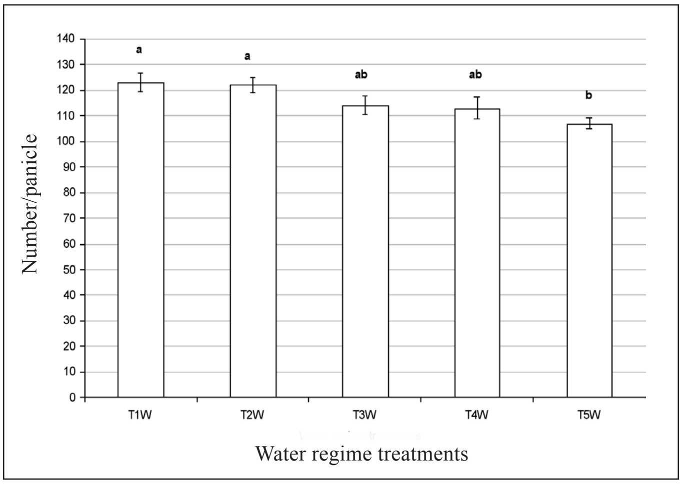

Fig. 3: The effect of different flooding treatments on the number of rice spikelets/panicle

Means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition.

rice under field capacity condition produced the least spikelets per panicle.

Yield Components and Rice Yield

1000-Grain Weight

One thousand grain weight is a genetic character widely used in yield estimation (Mahfuza, 2006). The 1000-grain weight was affected by flooding treatments, where significant differences were observed in both the weeded and unweeded pots. In the weeded pots, a significant difference was found among almost all the flooding treatments, as shown in *Fig. 4*. Higher 1000-grain weight was obtained under all the flooding regimes (T1, T2 and T3), where T1 (continuous flooded) was indicated to produce the highest grain weight (26.76 g). The weight of 1000-grain under reduced water conditions (T4 and T5) was significantly lower as compared to T1, T2 and T3 with T5 (continuous field capacity) which produced the lowest 1000-grain weight (18.39 g).

Jahan (2004), in his study on rice production under glasshouse condition, indicated similar results where no significant difference of 1000-grain weight was observed under the different flooding regimes. Meanwhile, Sariam (2004) reported that 1000-grain weight varied significantly with water management, where lower grain weight was observed under the field capacity condition as compared to the saturated and flooded conditions. According to Dey and Upadhaya (1996), less biomass and number in grain production under the reduced water regimes could be caused by the lack in water availability at the anthesis (flowering) stage, which restricted rice pollination process and caused the rice to produce infertile and empty rice grain.

Rice Straw Biomass (Rice Straw Yield)

The differences in the flooding treatments had significant effects on the yield of rice straw, as shown in *Fig. 5*. Generally, when water availability declined, the straw biomass gradually decreased in both weeded and unweeded pots. The highest rice straw biomass was obtained in T1 (continuous flooded), which yielded 681.32

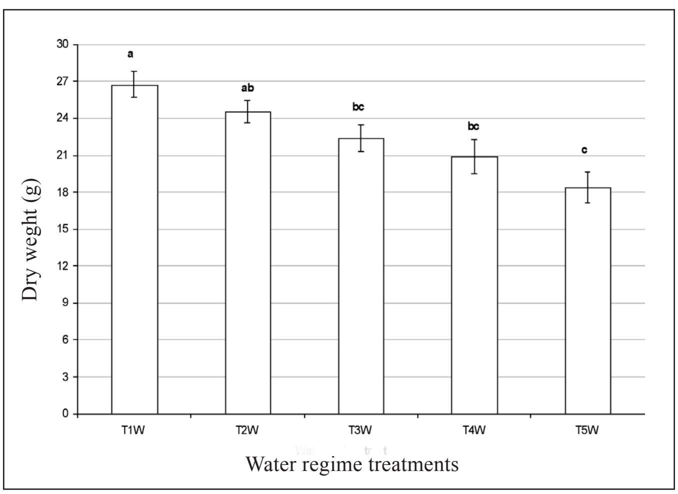

Fig. 4: The effect of different flooding treatments on 1000-grain weight (g)

Means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition.

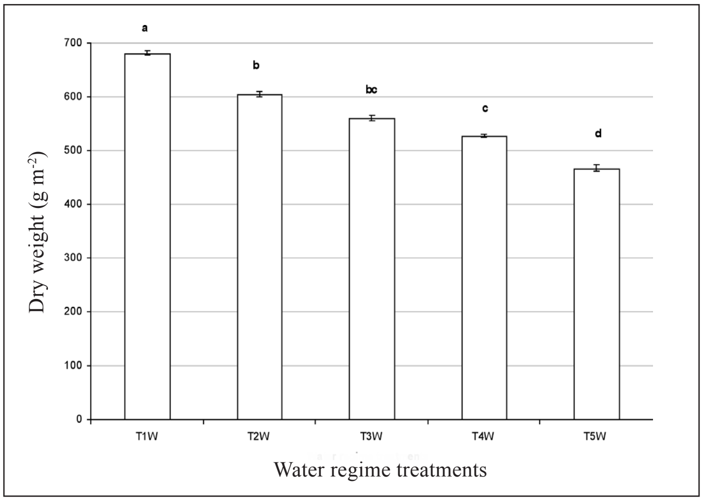

Fig. 5: The effect of different flooding treatments on biomass of rice straw (g m^{-2})

Means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition.

g m^{-2} of rice straw weight, while T5 (continuous field capacity) produced the lowest straw yield of 467.03 g m^{-2}. From the observation, the amount of rice straw yielded in T5 was in average of 20-30% lesser than the rice straw produced under all flooding regimes (T1, T2 and T3) in both the weeded and unweeded pots. Shorter plants (Table 2) and fewer tillers (Table 3) could have attributed to lower straw yield under the field capacity condition. The results are in agreement with the reported findings (Mishra *et al.,* 1991; Beyrouty *et al.,* 1992; Sariam, 2004). According to Dey and Upadhaya (1996), reducing water availability in soil will adversely affect rice growth especially at vegetative and reproductive stages and this can further decrease the rice straw and grain yield.

Rice Yield

Fig. 6 illustrates the effects of different flooding treatments on the yield of rice grains. From the observation, rice yield was found to decrease significantly with reduced water availability in the soil. Generally, there was no significant difference observed between T1, T2 and T3, but all those flooding regimes significantly produced higher rice yield than T4 and T5. The maximum grain production was obtained from T1 (8534.4 kg ha^{-1}), followed by T2 (7870 kg ha^{-1}) and T3 (6840.8 kg ha^{-1}). Under T4, the rice production was significantly reduced to only 6130 kg ha^{-1}, causing a 23.16% reduction as compared to T1. However, the yield obtained from T4 was only significant when compared to T1 and T2, but not significant when it was compared to T3. Meanwhile, T5 produced the lowest rice grains of 3706.2 kg ha^{-1}, which was 56.57% lower than T1.

The result shows that rice grain yield responded differently under different flooding treatments. Continuous flooding (T1) favours rice growth and produces maximum rice yield. However, the results also suggest that it is not necessary to continuously flood the rice field throughout the rice growing period to obtain high grain yield since maintaining a temporary period of flooding, either until 55 DAS (T2) or 30 DAS (T3) resulted only in a non-significant reduction in rice yield of 1.35% and 14.25%.

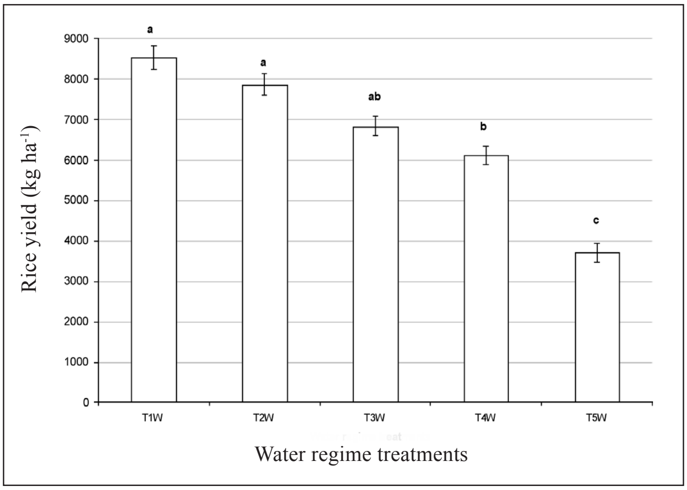

Fig. 6: The effect of different flooding treatments on rice yield (kg ha^{-1})

Means followed by the same letter are not significantly different at 5% level by Tukey's Test.
DAS = Day after sowing: T1 = continuously flooded condition: T2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T3 = early flooding for the first month (30 DAS) followed by saturated: T4 = continuous saturated condition: T5 = continuous field capacity condition.

Similar results were also indicated by Mishra *et al.* (1991) and Sariam (2004).

However, grain yield decreased significantly when water was reduced to continuous field capacity (T5). This finding is in line with the results reported by Beyrouty *et al.* (1992), Anbumozhi *et al.* (1998) and Sariam (2004). Meanwhile, under continuous saturated condition (T4), the yield was not significantly different as compared to the moderate flooding period of T3. However, Sariam (2004), in her study, found dissimilar results when the yield of rice under saturated condition was found to be insignificantly different as compared to the rice yield under continuous flooded condition.

From the results, water management is shown as an important tool in rice planting. Water is the single most important component for sustainable rice production, especially in the traditional rice-growing areas (Williams *et al.,* 1990). Water is a major constituent of tissues, a reagent in chemical reaction, a solvent and mode of translocation for metabolites and minerals within plants and is essential for cell enlargement through increasing turgor pressure (Farooq *et al.,* 2006). However, the effect of water deficits on the growth and yield of rice is dependent on the stage of crop growth, at which the water deficits occur (Farooq *et al.,* 2006).

Water stress during vegetative stage reduces plant height, tiller number and leaf area. Immediately after transplanting, adequate land submergence (five to ten centimetres) is necessary to prevent damage to establishing seedlings from high winds and for root development (Farooq *et al.,* 2006). Following the early rooting stage, a shallow depth of land submergence (two to five centimetres) facilitates tiller production and firm root anchorage in the soil. Water deficit during this stage may reduce plant height, tiller number and leaf area, but the yield is least affected if adequate water is provided to permit recovery of the crop before panicle primordial initiation. However, excessive water depth at this stage will hamper rooting and decrease tiller production (Williams *et al.,* 1990). The reduction in grain yield, due to water deficit, during this stage is more related to the degree and duration of water deficits than to the stage of crop growth (Farooq *et al.,* 2006). Meanwhile, milk to grain maturity stage is the least sensitive to soil moisture stress. After the yellowish ripening stage, there is no necessity for standing water. Water may be drained from the field about 7 – 10 days before harvest so as to facilitate harvesting (Farooq *et al.,* 2006).

Greater yields were observed from flooded rice than rice which was grown under saturated or dry conditions (Castillo *et al.,* 1992). A 10% reduction of rice yield in direct seeded rice flooded at the early reproductive stage was reported afterwards, when compared to the rice grown with a flooding beginning at early tillering (Tanaka *et al.,* 1963). Meanwhile, rice yield was not significantly reduced if water deficit was imposed during vegetative growth, but up to 70% of yield reduction occurred if water deficit was imposed during reproductive period (Lilley and Fukai, 1994).

CONCLUSIONS

The response of rice plant to water soil availability varies with its growing stage and other agronomic practices. At the early stage of 15 and 30 DAS, the flooding treatments did not significantly affect rice growth. However, from 45 DAS onwards, the effect of the different flooding treatments on rice growth was significantly pronounced. All flooding regimes (T1, T2 and T3) significantly favoured the height of rice plant and the production of tillers, while the reduced water regime treatments (T4 and T5) restricted them. Hence, a proper management of water supply, at different growing stages, is important in order to enhance the growth of rice plant to its maximum potential.

The positive correlation between the rice grain yield and rice yield components indicates that the parameters which contribute in producing high grain yield include the number of tillers, number of panicles m^{-2}, number of spikelets/panicle and 1000-grain weight. High rice grain yield, subjected to varying flooding regimes (T1, T2 and T3), was attributed to high number of tillers, high spikelets/ panicle and high 1000-grain weight; whereas, low grain yield under reduced water regimes (T4 and T5) was contributed by the low production of those components. Thus, managing flooding regimes is an important component of the integrated weed management system and to obtain high rice yield.

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