Research article

Agronomic and Yield Performances of Three Rice Cultivars (*Oryza sativa* L.) under Water Regimes in Dry Season

SAVOEURN LANG*
Faculty of Agronomy, Royal University of Agriculture, Phnom Penh, Cambodia
Email: savoeurnlang@gmail.com

SOPHAONARITH RO
Faculty of Agronomy, Royal University of Agriculture, Phnom Penh, Cambodia

SIRANET ROEURN
Faculty of Agronomy, Royal University of Agriculture, Phnom Penh, Cambodia

LYHOUR HIN
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

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Abstract Rice *(Oryza sativa.* L*)* is widely cultivated in Cambodia, but it consumes considerably more water than any other crops. In the context of water scarcity due to global climate change, rice cultivation in Cambodia has been worsened by the effect of drought. Development of a cultivation technique to minimize yield loss under drought stress or/and limited water resource in rice production is of great strategic value. Therefore, the present study aims to investigate growth and yield performances of three rice genotypes, namely CAR 14, CAR 15 and CAR 16 under different water regimes including drought (at flowering stage), alternative wet and dry (AWD), and flooded conditions. The experiment was conducted from January to October 2019, at the Tonle Bati Agricultural Development Center, located in Bati District, Takeo Province, Cambodia. The soil is clay loam and is classified as Toul Samrong (Soil Classification for Rice Production in Cambodia). Two-way ANOVA was utilized to determine interaction between the genotypes and the water regimes. As a result, the genotype-water regime interaction was detected for grain yield. Water regimes affected grain filling percentage and yield, whereas rice genotypes affected plant height, 50% flowering days, 100% flowering days, number of unfertile grains, grain yield, and 1000 grain weight. Nevertheless, plant density, panicle length, and straw biomass were not affected by either of the factors. In any water regimes, CAR16 grew the tallest at 94.4 cm and blossomed 2 to 4 days later than any other cultivars. In contrast, CAR 15 had the highest yield, observed in permanent flooding and in AWD. Although 27% of irrigation water was saved in AWD, permanent flooding produced more yield. In short, drought conditions affected total yield. Despite that, Car 15 was observed to be more suitable for any water regimes.

Keywords Rice cultivars, AWD, drought, rice yield, straw biomass

INTRODUCTION

Rice belongs to the genus *Oryza sativa* L. and is known as a remarkable semi-aquatic plant which has been cultivated in tropical and subtropical regions for about 10,000 years (IRRI, 2013; Sivapalan, 2015). Maintaining proper water level in paddy fields is critical for rice production, but rice plants will die or suffer yield loss when the water is too deep (Eckardt, 2017). International Rice Research Institute (2013) reported that rice alone provides food for nearly half of the world population that has increased remarkably. Irrigated rice accounts for 55% of the world's harvested rice area and increases by 25% in the next 20 years. Inadequate irrigation causes agronomic problems for intensive rice cultivation (Sivapalan, 2015). It is reported that drought adversely affects rice production by limiting growth and reducing yield by 25.4%, posing a serious threat to global food security (Zhang et al., 2018). The problem is even exacerbated when the demand for clean water is not fulfilled because competition between irrigation and household use has formed.

In Cambodia, rice is grown in both wet and dry seasons depending on availability of water sources. However, prolonged drought has been considered one of the main affecting factors that limit annual rice planting areas. In 2015, severe drought occurred in the country, resulting in dire water shortages and affecting several million people, while in 2012, thousands of hectares of rice fields were destroyed (Climate Change Adaptation, 2019). In response, new rice varieties are studied and bred in hopes of producing drought tolerability. As a result, several varieties such as CAR 14, CAR 15 and CAR 16 have been released, but they are not yet widely available. Besides that, recognizing their effectiveness is still unclear (CARDI, 2019). To address these issues, a proper irrigation technique is required to maintain the yield although drought-tolerant rice varieties are used. A promising solution to rice cultivation with water scarcity is alternative wetting and drying (AWD) designed to irrigate paddy fields when needed, to save water. Large numbers of research results show that AMD significantly reduced water use while maintaining yield (Howell et al., 2015). Therefore, testing different irrigation methods may be beneficial for sustainable rice production within the country.

OBJECTIVE

The research aims to investigate growth and yield performances of the three rice genotypes under different water regimes classified as drought (at flowering stage), alternative wetting and drying irrigation (AWD), and flooded conditions, known as flooding in three rice varieties: CAR 14, CAR 15 and CAR 16.

METHODOLOGY

The experiment was conducted at the Tonle Bati Agricultural Development Center, located in Bati District, Takeo Province, Cambodia, starting from January to October 2019. Three rice cultivars were planted on clay loam, classified as Toul Samroang based on the Cambodian soil classification for rice production. Those cultivars were CAR 14, CAR 15, and CAR 16, and they were planted under three different water regimes designed for drought conditions at flower stage, alternative wetting and drying irrigation (AWD), and flooded conditions, known as flooding. The experimental plots were neatly prepared, bunded, and lined in polythene plastic at the depth of 30 cm. Rice seeds were broadcasted at rates of 125 kg ha^{-1}, with urea and DAP fertilizer applied at rates of 50 kg ha^{-1} each after land preparation and at 100 kg ha^{-1} at the vegetable stage.

In drought conditions, the water level was maintained at 5.0 cm above the ground, but the plots were completely drained at the flowering stage. Draining activities were repeated in case of rain to ensure no water was left in the field. In AWD, PVC tubes were placed in the plots at 40 cm underground and at 20 cm above the ground. The tubes were 40.0 cm in length and 15.0 cm in diameter, perforated with 0.5 cm diameter holes spaced 2.0 cm apart and covered in cloth to prevent clogging. The water level in the AWD plots was maintained at 5.0 cm above the ground and repetitive irrigation was needed when it decreased 5.0 cm below the ground. This practice was discontinued at the flowering stage. In flooding, the paddy fields were kept submerged at 3.0 - 5.0 cm above the ground and then at 5.0 - 7.0 cm until the booting stage. At milking stage, the plots were completely drained.

Three months after planting, the plant height was measured from 10 randomly selected plants within each plot, while plant density was evaluated from 3 random locations within each plot using a 1.0-m^{-2} frame area. In addition, 50% and 100% flowering was evaluated by counting the number of days required from planting to half-full and full blossom. In each plot, panicle length and the number of grains per panicle were measured from 10 randomly selected plants and rice yield from 3 locations using a 4.0-m^{-2} square frame area. Manual threshing was done to collect grains for drying and weighing to calculate the rice yield in all treatments. Then the straw biomass left was dried using an oven at 80^0C for 48 hours. Grain weight was measured based on 1000-grain quantity (Tian et al., 2017). Firstly, grains were dried to reach 14^0C. Then 1000 grains from each plot samples were randomly taken and weighed. Afterwards, grains were split into categories, full or imperfect, and then counted for comparison.

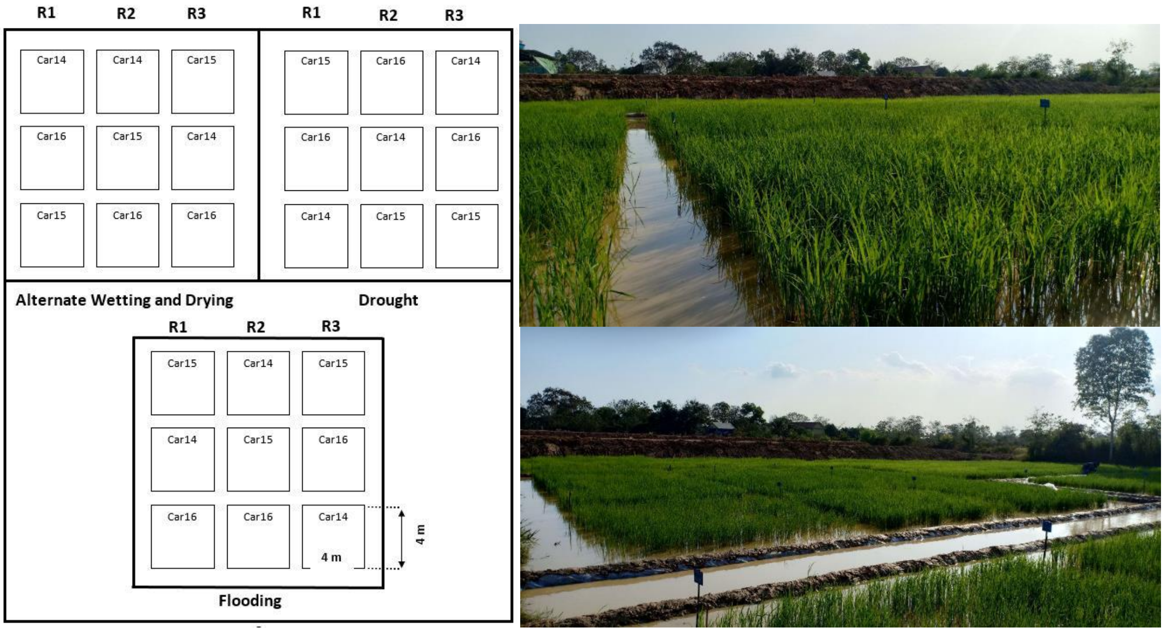

Fig. 1 Experimental plots arranged in RCBD and placed under three water regimes

The experiment arranged for this study was a randomized complete block design comprising three rice cultivars grown in three different water regimes. This combination constituted 6 treatments replicated three times, generating 27 plots. Each plot was 4.0 m by 4.0 m and had spacing of 1.0 m. Two-way ANOVA was performed to determine the interaction between the varieties and the water regime used. Statistical differences were stated by using LSD-test with an error of 5%.

RESULTS AND DISCUSSION

Plant height and Plant density

No significant interactions between the varieties and the water regimes were observed for plant height ($P=0.086$). The water regimes ($p=0.200$) also had no effects on plant height, but there were significant differences among the varieties ($p<0.001$). CAR 16 varieties had significantly higher stems, when compared to CAR 14 and CAR 15, regardless of irrigation techniques. In contrast, CAR 14 had the shortest stems. In addition, the plant height was significantly greater in AWD than in flooding and drought conditions. In Flooding, the plant height for CAR 14, CAR 15, and CAR 16 was 91.0, 90.6, and 96.8 cm, respectively. In AWD, they were 93.5, 91.7, and 98.1 cm, respectively. In drought, the plant stems for different rice cultivars were the shortest, averaging less than 93.0 cm. In short, drought affected rice growth, stunting the stems. Regarding plant density, there were no interactions between the varieties and the water regimes. In addition, no significant differences were found among the two factors. Regardless of the varieties and the irrigation technique used, the plant density ranged from 61 to 73 plants m^{-2}.

Flowering Stage

Days to flowering were counted in this experiment starting from the day of sowing until 50% and 100% blossom. However, no signification interactions between the varieties and the water regimes were observed. Different water regimes also had no significant effects on flowering days, but there were significant differences among the varieties, which means that different rice cultivars started to blossom at different days. It was observed that CAR 14 started to flower faster, when compared to other varieties. In addition, CAR 16 produced flowers at the slowest pace. In all regimes, CAR 14 began to flower 50% at day 64 after planting, followed by CAR 15 and CAR 16 that produced 50%

blossom at days 67 and 68. Full blossom was observed 2 days after 50% flowering. In short, drought did not have effects on flowering dates, and but different varieties did.

Panicle Length

In the experiment, the panicle length of the different varieties was measured at harvest time. There were no significant interactions between the varieties and the water regimes used. In addition, neither of the two factors affected the panicle. These mean that the tested varieties had similar panicle length. Regardless of the water regimes used, the panicle length was observed to lie within the range of 24.8 to 25.9 mm

Table 1 Comparison of vegetative and reproductive growth in three seed varieties planted in three water regimes (Different alphabets mean statistical difference at 5% error)

Water Regime (WR)	Seed variety (SV)	Plant height (cm)	Plant density (plants/m^2)	50% flowering days	100% flowering days	Panicle length (cm)
Drought	Car 14	89.1 cd	64.3	64.7 c	66.7 c	24.8
	Car 15	92.3 b	61.2	67.0 b	69.0 b	25.3
	Car 16	92.9 a	64.9	68.0 a	70.0 a	24.9
AWD	Car 14	89.1 d	65.9	65.0 c	68.0 c	25.9
	Car 15	91.7 bc	66.6	67.0 b	69.0 b	25.6
	Car 16	93.5 b	65.0	68.0 a	70.0 a	25.8
Flooding	Car 14	91.0 bcd	70.9	64.7 c	67.5 c	24.9
	Car 15	90.6 bcd	68.0	67.3 ab	70.0 ab	24.9
	Car 16	96.8 b	73.6	68.0 a	70.3 a	25.0
SE		19.87	4.81	N/A	N/A	2.1
F-test probabilities						
WR		*0.200*	*0.054*	*0.721*	*0.831*	*0.113*
SV		*<0.001****	*0.6167*	*<0.001****	*<0.001****	*0.990*
WR x SV		0.08630	0.76040	0.52150	0.52450	0.965

**Significantly different p at 0.05; **significantly different p at 0.01; and ***significantly different p at 0.001*

Table 2 Comparison of vegetative and reproductive growth in three seed varieties planted in three water regimes (Different alphabets mean statistical difference at 5% error)

Water Regime (WR)	Seed variety (SV)	Yield (Ton/ha)	1000-grain weight (g)	Straw biomass (Ton/ha)	Harvest index (%)	Water used (m^3 ha^{-1})
Drought	Car 14	2.47 e	25.0 c	6.80	26.8	4,824
	Car 15	2.96 cde	28.4 ab	6.98	29.8	
	Car 16	2.62 de	29.8 a	6.90	30.7	
AWD	Car 14	3.12 bcde	24.8 c	5.94	35.1	4,968
	Car 15	4.00 a	27.9 b	7.85	33.9	
	Car 16	2.72 de	28.9 ab	5.51	32.9	
Flooding	Car 14	3.45 abc	25.6 c	8.80	28.2	6,768
	Car 15	3.70 ab	28.8 ab	7.92	31.8	
	Car 16	3.18 bcd	30.0 a	7.85	29.0	
SE		*0.42*	*7.80*	0.72	2.18	N/A
F-test probabilities						
WR		*<0.001****	*0.175*	*0.066*	*0.093*	
SV		*<0.001****	*<0.001****	*0.527*	*0.730*	
WR x SV		*0.021**	*0.980*	*0.517*	*0.807*	

**Significant different p at 0.05; **significant different p at 0.01; and ***significantly different p at 0.001*

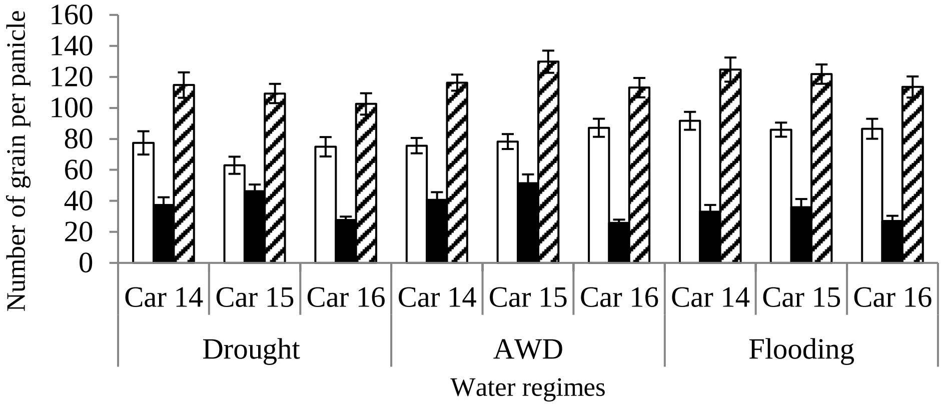

Fig. 2 Comparison of full and imperfect grains for each rice cultivars grown in different water regimes (mean ± SD; n = 30).

Weight in 1000 Rice Grains

After harvest, the grain was sun-dried until they arrived at 14% moisture. Then, 1000 grains were repeatedly taken from the different varieties, weighed and compared. Statistically, no interactions between the varieties and the water regimes were observed (p=0.980). Significant differences in 1000-grain weight were not detected among the water regimes (p=0.175). However, there were significant differences in the weight among the varieties (p<0.001). Regardless of the irrigation conditions, 1000-grain weight was similar between CAR 15 and CAR 16 but was the lowest in CAR 14. On average, 1000 grains of CAR 15 and CAR 16 weighed 28 to 30 g, whereas the same amount of CAR 14 weighed only 25 g.

Number of Panicle Grains

Effects of drought were detected based on separation of full and imperfect grains. No interactions between the varieties and the water regimes were observed for imperfect grains (p=0.377) and for full grains (0.360). Significant differences in imperfect grains were found among the varieties used (p<0.001), but not the water regimes (p=0.081). In contrast, full grains were significantly affected by the water regimes (p=0.001), not by the varieties (p=0.222). Among the varieties planted, CAR 14 had greater numbers of full grains in AWD and drought, compared to other varieties. Likewise, CAR 16 was seen to have more full grains in flooding. Both of these varieties had few imperfect grams than CAR 15 did. Regarding the total grain number, CAR 15 had the most and CAR 16 had the least, while CAR 14 was in the middle.

Rice Yield, Straw Biomass, Harvest Index, and Water Use

Significant interactions between the varieties and the water regimes were observed in rice yield (p=0.021), and these two factors also affected the yield (p<0.001). It can be seen that the yield harvested in the drought treatment was significantly lower than in other treatments, regardless of the varieties used. Similar rice yield was obtained both in AWD and flooding treatments. In drought condition, the yield for the three varieties was less than 3 tons ha^{-1}. Drought reduced the yield was reduced by 28 % for CAR 14, 20% for CAR 15, and 17% for CAR 16. The result was similar in the studies by Zhang et al. (2018), which identified the effect of drought by 25.4%. Besides that, the rice yield of CAR 14 and CAR 15 was lower in this study than in the report by CARDI (2018a & 2018b).

Straw biomass was also collected from all treatments for comparison and for calculating harvest index. Significant interaction between the varieties and water regimes was not observed (p=0.517), nor were there significant differences in straw biomass (p=0.066; p=0.527). It was found that drought had no effects on biomass that varied from 5.5 to 8.8 tons ha^{-1} among all treatments. Significant interaction between the varieties and water regimes were not detected for the harvest index (p=0.093). There were also no significant differences among the two factors (p=0.730; p=0.807). In all treatments, the harvest index averaged 31%. Regarding the water use, it can be seen that the flooding treatment consumed considerably more water than other treatments, while the amount of water used in the drought condition and AWD was quite similar. In this research, the amount of water consumed was 4,824 for drought, 4,968 for AWD and 6,768 m^3 ha^{-1} for flooding. When compared, flooding consumed 26.6% more water than AWD, but the rice yield between these treatments was not much different. Likewise, CGIAR (2014) also mentioned in a report and Kumar and Rajitha (2019) in their studies that using AWD could save water up to 25%.

CONCLUSION

In this research, three different rice cultivars CAR 14, CAR 15, and CAR 16 were planted in three different water regimes, namely drought, AWD, and flooding, to find out their effects on rice growth and yield, as well as aiming to select the most suitable varieties. In the results, CAR 16 produced the greatest plant length among the experimented cultivars, but began to flower a bit late, when compared to other varieties. However, they had similar panicle length. CAR 15 and CAR 16 produced higher yield, regardless of the water regimes although the straw biomass and harvest index among the treatment were not different. In conclusion, drought conditions tend to affect total rice yield, while flooding and AWD were more favorable for rice plants. For drought tolerance, CAR 15 and 16 should be selected for cultivation. For flooded conditions, all of the varieties were suitable and for AWD, CAR 14 and CAR 15 were better.

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