Response of Lowland Rice (*Oryza sativa* L.) to Water Saving Management in the Coastal Savannah Agroecology of Ghana

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Abstract

Water productivity of rice is relatively low especially in irrigated ecosystem due to poor water management which leads to high water loss through seepage, evaporation and percolation. However, the amount of fresh water available for irrigation in the world is decreasing due to climate change, population growth and development of urban and rural areas. This study was therefore conducted at the screen house of Soil and Irrigation Research Centre of the University of Ghana, Kpong, during the cropping season of 2016/2017 to investigate the effect of different water saving management methods on growth, grain yield and water productivity of lowland rice. The study was laid out in Randomized Complete Block Design with seven (7) replications. Five treatments were involved; continuous flooding (T1, control), flooding from transplanting to ten days after complete heading (T2), flooding from transplanting to twenty days after complete heading (T3), alternate wet and dry (AWD) from transplanting to booting, then flooding from booting to ten days after complete heading (T4), and AWD from transplanting to booting, then flooded from booting to twenty days after complete heading (T5). Results from the experiments revealed that, withholding water after complete heading has no significant effect on rice growth. Plants from T5 saved 24.3% and 25.2% of water used in 2016 and 2017, respectively while producing similar grain yield as the control.

Introduction

Rice (*Oryza sativa* L.) is one of the most important staple grain crops in the world and over 50 kg of rice is consumed per capita per year (Food and Agriculture Organization, FAO, 2016). Globally, about 3.5 billion people consume rice as food (International Rice Research Institute, 2013). More than 495 million tonnes of milled rice was produced in 2017/18 and more than 97% of this production was used for domestic consumption (United States Department of Agriculture, 2018). By the end of 2030, the production of rice in the world must increase by 40% to meet increasing demand of rice due to the high population growth (FAO, 2009). Report by the International Fund for Agricultural Development (2012) estimated about 870 million people to suffer from chronic undernourishment in the world and most of these people live in areas where rice is associated with food security. In Ghana, rice is the second most important grain food crop after maize since 1990 (Millennium Development Authority, 2010). The crop is cultivated on 192,000 hectares of land with average annual production of 493,000 tonnes of paddy rice and 322,000 tonnes of milled rice (Ministry of Food and Agriculture, MoFA, 2015). Among all the major food crops grown in the country, rice is the only crop that records a deficit in terms of production and consumption due to low yields and high population growth. About 490,000 tonnes of rice was imported into the country in 2015 to compensate the deficit between production and consumption needs (MoFA, 2015).

Traditionally, rice is cultivated in continuous flooded condition to suppress weeds growth and counter nutrients and water stress. This practice however, leads to high water loss through percolation, evaporation and seepage.

Water productivity is relatively low in irrigated rice ecosystem due to poor water management (Yao et al., 2012). However, fresh water resources available for irrigation in the world is decreasing due to high population growth rate, increase in the development of urban and industrial areas, depletion of resources and pollution (Bouman, 2007). There is a great strain on the Volta River basin due to high population density and large-scale irrigation systems and consequently reducing the availability of the water resources (Ravenga et al., 2000). According to the report by United Nation Environment Program (2008), Ghana is one of the 13 countries in Sub-Saharan Africa to face water stress by 2025 due to increasing demand of water resources from all sectors. Water stress will be intensified by the effects of climate change because of the reduced rainfall as well as elevated temperatures and therefore negatively affect water availability (Smakhtin et al., 2004; De Wit and Stankiewicz, 2006). Thus, the agricultural sector will be negatively affected since it uses the highest amount of fresh water resources and within this sector, rice consumes the highest amount of the fresh water resources (Khan et al., 2006).

Producing more rice with less water to meet the rising food demand has become a global challenge and therefore many water saving techniques have been proposed of which alternate wet and dry (AWD) technique is widely practiced (Belder et al., 2004; Bouman, 2007; Dong et al., 2012; Pan et al., 2017). Moreover, withholding water from 10 days after complete heading to harvest has no significant effect on rice yield (Momo et al., 2013). However, rice varieties response differently to the same water stress intensity and timing (Bourman and Tuong, 2001). Therefore, this study was conducted to assess the effect of water saving management on growth, yield and water productivity of a local rice variety as well as to determine the best time to withhold water after complete heading.

Materials and Methods

Site description

Pot experiment was carried out at the screen house of Soil and Irrigation Research Centre of the University of Ghana, Kpong in 2016 and 2017. The experimental site is located at latitude 6° 09’ N, longitude 00° 04’ E and lies at 22 m altitude above sea level within the lower Volta basin of the Coastal Savannah agroecological zone. The soil (Vertisol) used for the experiment has the following properties; organic carbon (1.77%), total nitrogen (0.13%), phosphorus (2.05%), potassium (4.96%), C/N ratio (13.6) and pH (8.10).

Experimental materials and design

The study was laid out in Randomized Complete Block Design with seven (7) replications. Five treatments were involved; continuous flooding (Control, T1), flooding from transplanting to ten days after complete heading (T2), flooding from transplanting to twenty days after complete heading (T3), alternate wet and dry (AWD) from transplanting to booting, then flooding from booting to ten days after complete heading (T4), and AWD from transplanting to booting, then flooding from booting to twenty days after complete heading (T5). Plastic pots of 10000 cm3 volume were used for the experiment. Soil was collected from an uncultivated field at a depth of 0 – 15 cm and was crushed and sieved through 2 mm size mesh to obtain fine earth fraction, and ten kilograms (10 kg) of the soil was weighed into each plastic pot. Rice variety, Ex Baika, was nursed using a wet bed method for three weeks and then transplanted into the pot at three seedlings per hill and later thinned to two seedlings per hill. NPK (15-15-15) was applied at 45 kg/ha as basal application at one week after transplanting and urea (46% N) fertilizer was applied at 45 kg N/ha as top dress prior to panicle initiation stage (five weeks after transplanting).

Water management

Thirty centimeters (30 cm) long perforated polyvinyl chloride (PVC) pipes with a diameter of 1.5 cm were inserted into the AWD treatments to monitor water level below the soil surface as described by Yao et al. (2012) and Anning et al. (2018). One-litre measuring cylinder was used to irrigate the plants and the total volume of water used to irrigate the plants throughout the experiments was recorded. A wooden meter rule was inserted into the perforated PVC pipes to determine water level below the soil surface. Water was maintained at 5 cm above the soil surface in the continuous flooded treatments. For the AWD treatments, plants were only submerged (5 cm above the soil surface) when water level dropped between 15 – 18 cm below the soil surface (Yao et al., 2012 and Anning et al., 2018).

Data collection

Plant height, tiller number and leaf area index were measured as growth parameters. Plant height was taken by measuring the height from the soil surface to the tip of the highest leaf. Tiller number per pot was recorded by counting all the tillers formed by the plant in each pot. Leaf area index (LAI) was calculated as the ratio of the total leaf area of the plant to the land surface area covered by the plant. Leaf area was determined by measuring the length and width of the leaf and multiplied by a constant (0.75). Yield parameters included; spikelet number per panicle, 1000 grain weight, sterility percentage, grain yield, straw yield and harvest index. Grain moisture content was measured for each treatment using a moisture meter and yield was expressed as g/pot at 14% grain moisture. Straw yield was determined by cutting plant from each pot from the soil surface and oven dried at constant temperature of 70^0C till a constant weight was attained and then weighed using an electronic scale. 1000 grains weight was determined by counting 1000 grains manually from each treatment after harvest and weighed using an electronic scale. Sterility percentage was determined as the ratio of the number of unfilled spikelets per panicle to total spikelets per panicle and multiplied by 100. Harvest index was derived as the ratio of grain yield biomass to the sum of grain and straw yield biomass. Water use was recorded as the total amount of water received by the plants from transplanting to harvest. Water productivity was determined as the ratio of grain yield to water use. Percentage of water saved was calculated as the ratio of the difference between the amount of water applied to continuous flooding treatment and water save management treatments to the amount of water applied to the continuous flooding treatment and multiplied by 100.

Statistical analysis

Means for data set from 2016 and 2017 seasons were subjected to one-way Analysis of Variance (ANOVA) using GenStat statistical software package (12th Edition). Treatment means were separated by using least significant difference (LSD) at 5% probability level.

Result

Effect of water saving management on plant height, tiller number and leaf area index of rice

Water saving management did not significantly ($P>0.05$) influence plant height throughout the plant cycle in both seasons (Figure 1). However, tiller number was significantly ($P<0.05$) affected by water saving management at only maximum tillering stage in both seasons (Figure 2). Tiller number increased from maximum tillering stage to booting and then declined to harvest. Plants from T4 and T5 produced statistically the highest tiller number at maximum tillering stage while plants from T1, T2 and T3 had the lowest number in both seasons. The effect of water saving management on leaf area index was statistically insignificant ($p>0.05$) from mid tillering stage to booting stage in both seasons (Figure 3). Leaf area index increased from mid tillering stage to booting stage in both seasons.

Effect of water saving management on yield components, grain yield and water productivity of rice

Water saving management insignificantly ($p>0.05$) influenced spikelets per panicle and 1000 grain weight in both seasons (Table 1). However, sterility percentage was significantly ($p<0.05$) affected by the water treatments (Table 1). Plants from T2 and T4 treatments recorded significantly the highest sterility percentage while T1, T3 and T5 treatments had similar and the lowest percentage statistically. Grain and straw yields were significantly ($p<0.05$) influenced by water saving management in both seasons (Table 2). Plants from T1, T3 and T5 treatments produced statistically similar and the highest grain and straw yields while T2 and T4 treatments recorded the lowest values in both seasons. Harvest index was significantly ($p<0.05$) influenced by the

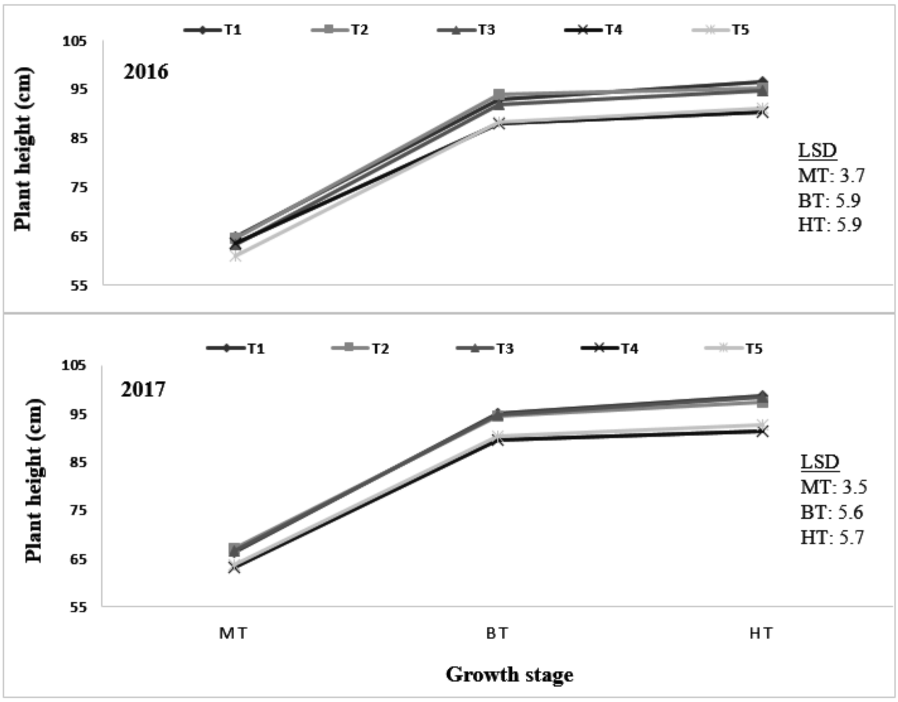

Figure 1: Effect of water saving management on plant height for 2016 and 2017 seasons. MT: maximum tillering stage, BT: booting stage; HT: harvest stage, LSD: Least significant difference

water treatments in only 2016 season (Table 2). Plants from T1, T3 and T5 had the same harvest index while plants from T4 recorded significantly the lowest harvest index.

Water saving management significantly ($p<0.05$) influenced water use, percentage of water saved and water productivity of rice in both seasons (Table 3). Plants from T1 produced significantly the highest water use, followed by T3, T2, T5 and T4, respectively in both seasons. Plants from T4 saved significantly the highest amount of water used, followed

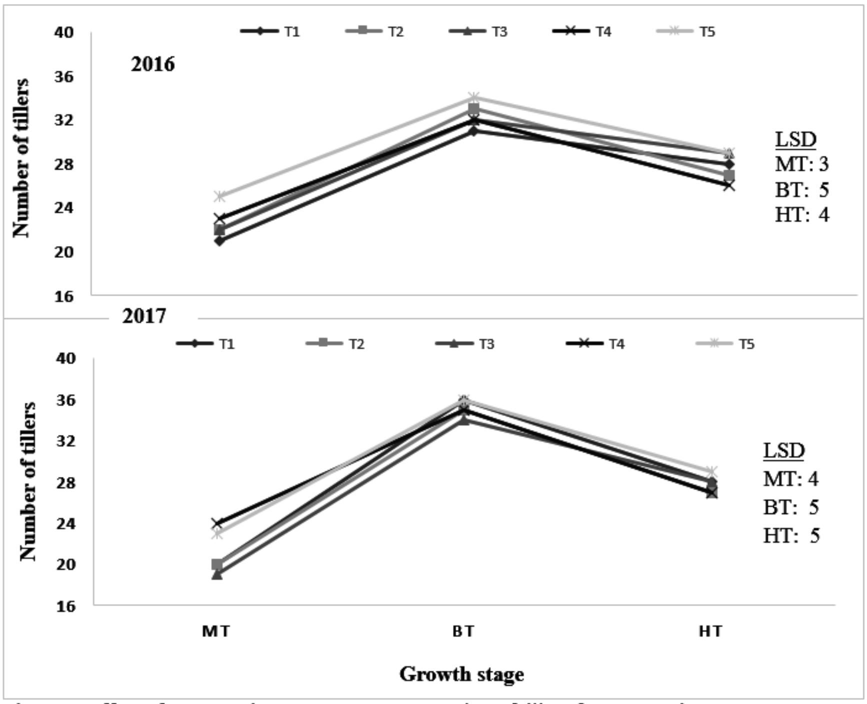

Figure 2: Effect of water saving management on number of tillers for 2016 and 2017 seasons. MT: maximum tillering stage, BT: booting stage; HT: harvest stage, LSD: Least significant difference

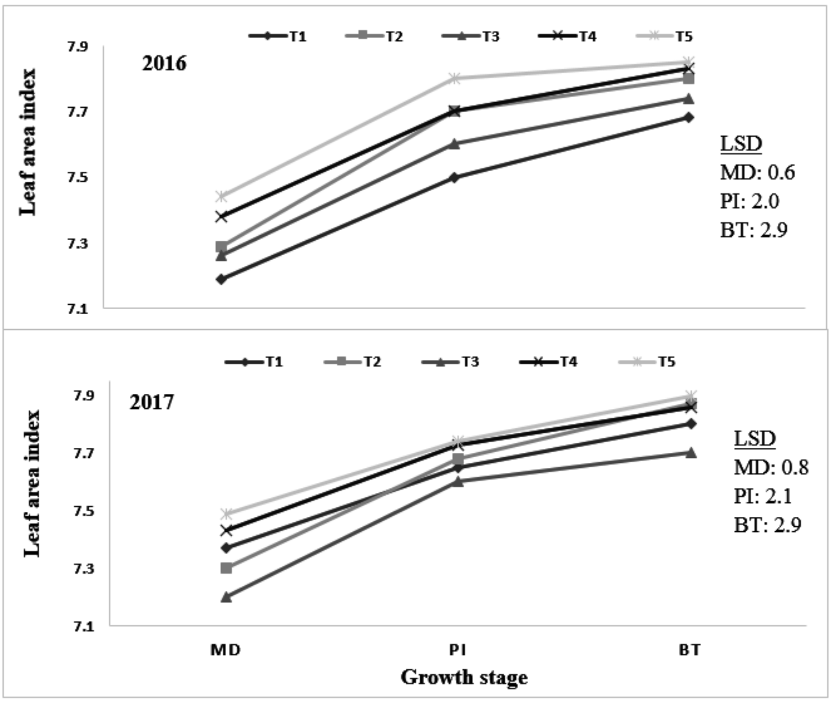

Figure 3: Effect of water saving management on leaf area index for 2016 and 2017 seasons. MD: mid tillering stage, PI: panicle initiation, BT: booting stage; LSD: Least significant difference

by T5, T2, T3 and T5, respectively in both seasons. T4 produced significantly the highest water productivity, followed by T5 however these treatments did not differ significantly from each other in both seasons. Plants from T1 produced the lowest water productivity however it had similar value with plants from T2 and T4 treatments in both seasons.

TABLE 1
Effect of water saving management on spikelets per panicle, sterility percentage and 1000 grains weight of rice for 2016 and 2017 seasons

Treatment	Spikelets per panicle		Sterility percentage (%)		1000 grains weight (g)	
	2016	2017	2016	2017	2016	2017
T1	126a	133a	17.9b	18.2b	26.5a	26.2a
T2	129a	132a	29.7a	32.6a	26.2a	26.4a
T3	126a	134a	18.0b	17.8b	26.4a	26.5a
T4	127a	133a	31.1a	33.4a	26.1a	26.3a
T5	125a	136a	17.2b	16.9b	26.4a	26.7a

Means followed by the same letter within a column are not significantly different from each other

TABLE 2
Effect of water saving management on dry matter accumulation, grain yield, straw yield and harvest index of rice for 2016 and 2017 seasons

Treatment	Grain yield (g/pot)		Straw yield (g/pot)		Harvest index (HI)	
	2016	2017	2016	2017	2016	2017
T1	46.0a	47.3a	17.9b	18.2b	26.5a	26.2a
T2	41.1b	43.6b	29.7a	32.6a	26.2a	26.4a
T3	45.5a	47.1a	18.0b	17.8b	26.4a	26.5a
T4	39.8b	40.9c	31.1a	33.4a	26.1a	26.3a
T5	45.4a	46.8a	17.2b	16.9b	26.4a	26.7a

Means followed by the same letter within a column are not significantly different from each other

Water saving management significantly ($p<0.05$) influenced water use, percentage of water saved and water productivity of rice in both seasons (Table 3). Plants from T1 produced significantly the highest water use, followed by T3, T2, T5 and T4, respectively in both seasons. Plants from T4 saved significantly the highest amount of water used, followed by T5, T2, T3 and T5, respectively in both seasons. T4 produced significantly the highest water productivity, followed by T5 however these treatments did not differ significantly from each other in both seasons. Plants from T1 produced the lowest water productivity however it had similar value with plants from T2 and T4 treatments in both seasons.

TABLE 3
Effect of water saving management on the water use, percentage of water saved, and water productivity of rice for 2016 and 2017 seasons

Treatment	Water use (m^3 m^2)		Water saved (%)		Water productivity (kg/m^3)	
	2016	2017	2016	2017	2016	2017
T1	1.17a	1.21a	-	-	0.98b	0.98b
T2	1.03b	1.06c	12.0c	12.4c	1.00b	1.03b
T3	1.11a	1.13b	5.1d	6.6d	1.03b	1.05b
T4	0.73d	0.77e	37.6a	36.4a	1.37a	1.33a
T5	0.89c	0.91d	23.9b	24.8b	1.28a	1.29a

Means followed by the same letter within a column are not significantly different from each other

Discussion

Alternate wet and dry (AWD) treatments (T4 and T5) produced similar plant height and leaf area index as continuous flooding (CF) treatments (T1, T2 and T3) in both seasons. This may be attributed to the exchange of air between soil and the atmosphere which might have facilitated root growth and nutrient uptake. Bouman et al. (2007) reported that AWD facilitates root growth, accelerates organic matter mineralization and inhibits soil nitrogen immobilization rate. This finding is in conformity with previous studies (Yang et al., 2009; Dong et al., 2012; Tan et al., 2013; Pan et al., 2017). AWD treatments produced the highest tiller number at maximum tillering stage however, they produced similar tiller number as CF treatments at booting due to their higher tiller death because of the drying period during the reproductive phase (panicle initiation). Akram (2013) reported a significant reduction in tiller number when there was a moisture stress at panicle initiation stage. This finding is in line with Yang and Zhang (2010) who asserted that, AWD results in frequent tiller death due to its drying periods.

AWD treatments produced similar spikelet number per panicle as CF treatments in both seasons. This may be due to their high root growth and nutrient uptake because of their drying periods which promoted air exchange between the soil and the atmosphere (Yang et al., 2009; Tan et al., 2013). All the treatments produced similar 1000 grain weight in both season since grain weight is controlled by the genetic makeup of the variety. Yoshida (1981) reported that 1000 grain weight is a genetic trait and therefore the environment has an insignificant effect on it. This outcome is in support of Anning et al., (2018) who asserted that 1000 grain weight is not significantly affected by water stress. Moreover, Momo et al., (2013) reported that withdrawing water after complete heading has no effect on 1000 grain weight. Plants from T1, T3 and T5 produced similar grain yield and it may be due to their similar sterility percentage and straw yield. The absence of yield loss of T3 and T5 may be attributed to the time the water was withheld (20 days after complete heading). The grains were completely filled at the time water was withheld. Akram (2013) reported a significant reduction (9.87%) in sterility percentage when there was a water stress at grain filling stage. This explains why T2 and T4 recorded the highest sterility percentage. This outcome disagrees with Momo et al., (2013) who reported withholding water after complete heading has no effect on grain yield, straw yield and unfilled grain number. Moreover, Sadeghi and Danesh (2011) asserted that withholding water before panicle exertion from the sheath, flowering and seed dough stages has insignificant effect on grain yield of rice. The discrepancy between the current study and the previous study may be due to the type of variety and soil used.

Plants from T1 recorded the highest water use due to the continuous flooding from transplanting to harvest. Continuous flooding increases the rate of percolation and seepage (Borrell et al., 1997; Abdul-Ganiyu et al., 2015) and therefore increases water use of rice. Plants from T4 recorded the highest percentage of water saved (38.0% in 2016 and 36.7% in 2017) and it may be attributed to the alternate wet and dry soil as well as water withheld at 10 days after complete heading. AWD treatments produced higher water productivity than CF treatments and it may be attributed to the higher water use of the latter treatments. This finding is in line with previous studies (Abdul-Ganiyu et al., 2015; Chu et al., 2015; Wang et al., 2016) who reported that continuous flooding of the soil reduces WUE of rice. Plants from T4 and T5 produced the highest water productivity however, T4 recorded higher percentage of water saved than T5. This may be due to the higher grain yield of T5 than T4 treatments.

Conclusion

Results from both experiments revealed that, withholding water after complete heading have no significant effect on plant height, leaf area index, effective tiller number, spikelet number per panicle and 1000 grain weight of rice. Growing rice under continuous flooding (CF) management does not significantly increase rice growth and yield. Alternate wet and dry (AWD) treatments produced significantly higher water productivity than CF treatments. Withholding water at 10 days after complete heading (T2 and T4) significantly decrease grain yield of rice. The study recommends T5 (AWD from transplanting to booting, then flooding from booting to twenty days after complete heading) since it saved 24.3% and 25.2% of water used in 2016 and 2017 seasons, respectively while producing similar grain yield as the control (T1).

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