Effect of Irrigation Management Methods on Growth, Grain Yield and Water Productivity of Three Lowland Rice (*Oryza sativa* L.) Varieties

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Abstract

It has been predicted that Ghana will face water shortage by the year 2025 due to increased demand of water resources from all sectors of the economy. Rice production will be negatively affected since rice consumes the highest amount of water in the agricultural sector. To develop a strategy to reduce water use for rice production while maintaining or increasing rice yield, a pot experiment was carried out in the screen house at Soil and Irrigation Research Centre - Kpong during 2016 and 2017 cropping seasons to determine the effect of irrigation management methods on growth, yield and water productivity of three rice varieties. A three by five (3 x 5) factorial experiment was laid out in a randomized complete block design and replicated six (6) times. The levels of the variety were: Agra (V_A), Ex Baika (V_B) and a hybrid (V_H). Irrigation management methods included: continuous submergence (I_1), alternate wet and dry soil condition (AWD) from transplanting to panicle initiation (PI) then submergence to harvest (I_2), AWD from transplanting to booting then submergence to harvest (I_3), AWD from transplanting to flowering then submergence to harvest (I_4), and continuous AWD (I_5). Results from the experiment revealed that, I_3 saved 21.7% and 20.4% of water used when compared with I_1 in 2016 and 2017, respectively however, these treatments produced similar growth and yield in both seasons. I_3V_H recorded 21.2% and 20.8% of water saved in 2016 and 2017, respectively however, it produced similar grain yield with I_2V_H and I_1V_H treatments in both seasons.

Introduction

Water is one of the most important components for rice production in the world since it consumes the highest amount of water than any other crop in the agricultural sector (Khan *et al*., 2006). About 34 to 43% of the total world's irrigation water or 24 to 30% of the world available fresh water is used for rice production (Barker *et al.* 1998). Rice plants thrive under flooded conditions due to their aerenchyma cells, which allow the movement of air through the leaves to the roots (Norman *et al*., 1995). About three thousand to five thousand liters of water is required to produce one kilogram of rice (Shashidhar, 2007). Traditionally, rice is cultivated under continuously flooded condition in irrigated areas, which results in high amount of water used. About 75% of the global rice production comes from irrigated lowland areas (Maclean *et al*., 2002). Growing rice under continuous flooded condition suppresses the growth of weeds, which compete with the rice plants for food, water, sunlight and space. According to Ponnamperuma (1984), flooding the field continuously with water adjusts the soil pH to neutral range and therefore nutrients that are not available become available for plants uptake. There is an improvement in the availability of both macro and micro-nutrients when the field is submerged with water (Sahrawat, 2012). However, water productivity, grain yield per unit of water input, is relatively low in irrigated rice ecosystem due to high amount of water loss (Yao *et al*., 2012) through evaporation, percolation, and seepage. Moreover, there is swift decrease in the amount of fresh water available for irrigation for sustainable rice production globally due to high population growth rate (Molden, 2007), expansion of irrigated areas and climate change (Zwart, 2013), increase in the development of urban and industrial areas, high pollution and resource depletion (Belder *et al*., 2004;

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Bouman, 2007). Climate change has decreased the amount of water from rainfall and rivers and increase evaporative demand because of rising temperatures (Smakhtin *et al.*, 2004; De Wit and Stankiewicz, 2006). Moreover, Bindraban *et al.* (2006) estimated about 10% of land used for irrigated rice production to face water scarcity by 2025. Therefore, it is important to reduce water input in irrigated rice ecosystem without affecting grain yield to meet the rising demand of rice globally.

Previous studies have proposed alternate wet and dry (AWD) irrigation management as the best method to reduce water input as well as increase water productivity of rice (Bouman and Tuong, 2001; Belder *et al.*, 2004; Sun *et al.*, 2012; Liu *et al.*, 2013; Chu *et al.*, 2015). In AWD, the field is submerged and allowed to dry for 2 to 7 days after the disappearance of standing water before it is submerged again. The field is re-submerged when plants show visual symptoms of water stress or when hairline cracks appear on the soil surface (Tuong *et al.*, 2005; Bouman *et al.*, 2007). However, the duration for the re-submergence depends on the level of soil water potential (Hira *et al.*, 2002), soil type, depth of groundwater and number of days after disappearance of standing water (Bouman *et al.*, 2007). During the drying period, the soil pores are filled with oxygen, which helps in roots development since the roots get oxygen from both the soil and aerenchyma cells for respiration. This improves plant roots growth and therefore increases water and nutrients accessibility in the soil (Yang *et al.*, 2009). However, some previous studies have reported significant yield losses in AWD management due to reduced soil moisture (Borrell *et al.*, 1997; Yang and Zhang, 2010; de Varies *et al.*, 2010). This study is therefore carried out to determine the exact stage in the rice growth cycle, that reduced soil moisture will significantly affect grain yield as well as to assess the effect of different irrigation management methods on growth, grain yield and water productivity of three lowland rice varieties.

Materials and Methods

Experimental site and materials

The pot experiment was conducted in a screen house at the Soil and Irrigation Research Centre of the University of Ghana, Kpong. The centre is located at a latitude 6° 09^1 N, longitude of 00° 04^1 E, and an altitude of 22 m above mean sea level. The soil (Vertisol) used for the study was collected from an uncultivated field at a depth of 0 – 15 cm. Roots and other plant materials were removed and sieved through 2 mm size mesh to obtain fine earth fraction. Nine kilograms (9 kg) of the soil was weighed into each of the ninety (90) plastic pots with a dimeter of twenty (20) cm and a height of thirty (30) cm. The soil has the following chemical characteristics: pH (8.10), organic carbon (1.77%) and available N, P, K contents were 0.13, 2.05 and 4.96%, respectively. The recommended dose of inorganic fertilizers (90: 45: 45, N P K kg/ha) were applied in two spilt. NPK (15-15-15) fertilizer was used for the basal application before transplanting and urea (N-46%) fertilizer was used to top dress at five (5) weeks after transplanting. Three rice varieties namely: Agra, Ex Baika and hybrid (Arize) were used for the study. The seeds were pre-germinated before nursing them on a wet bed. The seedlings were transplanted at 21 days after emergence and two seedlings were transplanted per pot.

Experimental design

A three by five (3 x 5) factorial experiment was laid out in a Randomized Complete Block

Design (RCBD) and replicated six (6) times. The two factors involved were: irrigation management method and variety. The level of the irrigation management method included: continuous submergence (I_1), alternate wet and dry soil condition (AWD) from transplanting to panicle initiation stage (65 to 70 days after emergence) then submergence to harvest (I_2), AWD from transplanting to booting stage (flag leaf sheath thickens, 75 to 85 days after emergence) then submergence to harvest (I_3), AWD from transplanting to flowering stage (emergence of the panicles from the flag sheath, 82 to 90 days after emergence) then submergence to harvest (I_4), and continuous AWD (I_5). The levels of the variety were; Hybrid (V_H), Agra (V_A), and Ex Baika (V_B). The levels of the factors were factorially combined to form fifteen (1_5) treatments.

Water management

Perforated polyvinyl chloride (PVC) pipes of 30 cm long and a diameter of 1.5 cm were used to monitor soil water level below the soil surface. The pipes were perforated at both sides up to 20 cm long with an interval of 2 cm between perforations as described by Yao *et al.* (2012). The perforated pipes were inserted into all the pots with the exception of the continuous flooded treatments. One-metre measuring cylinder was used to irrigate the plants and the amount of water applied throughout the experiment was recorded. Water was maintained at 5 cm above the soil surface in the continuous flooded treatments. For the AWD treatments, a wooden metre rule was inserted into the perforated PVC pipes to measure the soil water level below the soil surface. When the soil water level dropped to 15 - 18 cm below the soil surface, the pots are submerged five (5) cm above the soil surface (Yao *et al*., 2012).

Data collection and analysis

For the two years; 2016 and 2017, data were taken on the following growth parameters; plant height, number of tillers per pot and above ground biomass accumulation. Plant height was recorded by measuring the height of plants from the soil surface to the tip of the highest leaf. Number of tillers per pot was determined by counting all the tillers formed by the plant in each pot. Above ground biomass accumulation was determined by cutting plant from the soil surface in each pot and oven dried at constant temperature of 70oC for three days to attain a constant weight. After harvest, thousand (1000) grains weight, number of spikelets per panicle, number of panicles per pot, filled grains percentage and grain yield per pot were recorded as yield parameters. Thousand grains weight was recorded by counting one thousand grains manually from each pot and weighed using an electronic balance. Filled grains percentage was calculated by dividing the number of filled grains by the total number of spikelets per panicle and multiply by 100. Number of spikelets per panicle was determined by threshing the panicles and all the spikelets on each panicle were counted manually and their average was recorded. Number of panicles per pot was also recorded by counting all the panicles manually in each pot. Grain moisture content for each treatment was determined by using a moisture meter and grain yield was recorded by weighing all the spikelets in each pot and expressed as g/pot at 14% grain moisture. Water productivity was calculated by dividing grain yield by the amount of water used by the plants. Water use was measured as the total amount of water supplied to the plants from transplanting to harvest. Data collected were computed into Microsoft Excel spreadsheet and then subjected to the analysis of variance (ANOVA) using GenStat statistical software package (12th edition). Least significant difference at 5% probability level was used to separate treatment means.

Results

The main effect of variety significantly ($p<0.05$) influenced plant height at harvest in both seasons (Figure 1a-b). Variety V_A and V_H produced statistically similar and taller plants than variety V_B in both seasons. Both the main effect of irrigation management method and the interaction between variety and irrigation management method did not significantly ($p>0.05$) influence plant height at harvest in both seasons.

Effective tillers were significantly ($p<0.05$) influenced by the main effect of variety in both seasons (Figure 2a-b). Variety V_H and V_B produced statistically similar and higher effective tillers than variety V_A in both seasons. Both Irrigation management method and the interaction between variety and irrigation management method did not affect effective tillers significantly ($p>0.05$) in both seasons.

The main effects of both variety and irrigation management method were significantly ($p<0.05$) influenced by dry matter accumulation at harvest in both seasons (Figure 3a-d). Variety V_H and V_A produced similar and higher dry matter accumulation statistically than variety V_B in both seasons. Plants from I_2, I_1 and I_3 treatments produced statistically similar and higher dry matter accumulation than plants from I_5 treatment in both seasons.

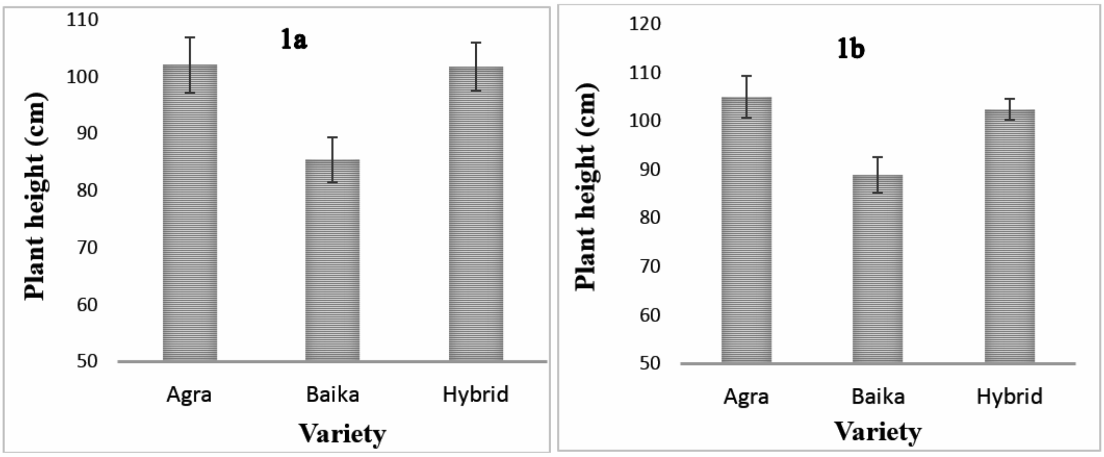

Figure 1a-b: Effect of variety on plant height in 2016 (a) and 2017 (b). Bars represent ± standard error of means at six replications

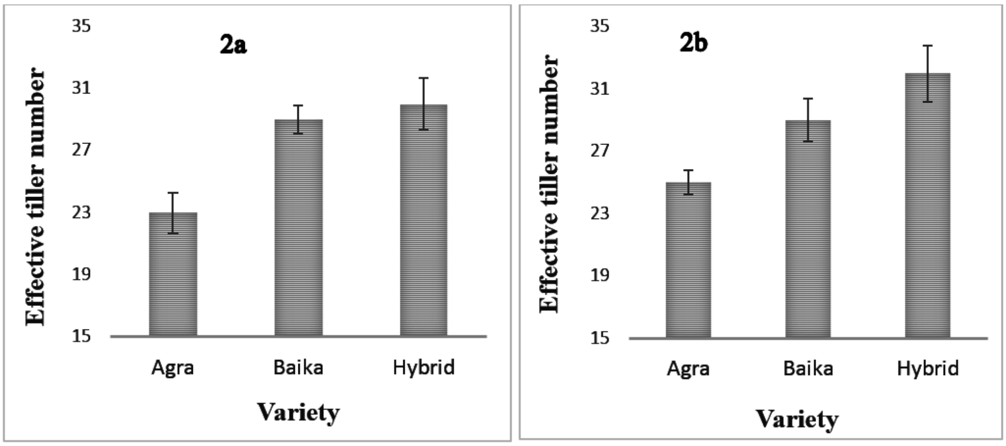

Figure 2a-b: Effect of variety on effective tiller number in 2016 (a) and 2017 (b). Bars represent ± standard error of means at six replications

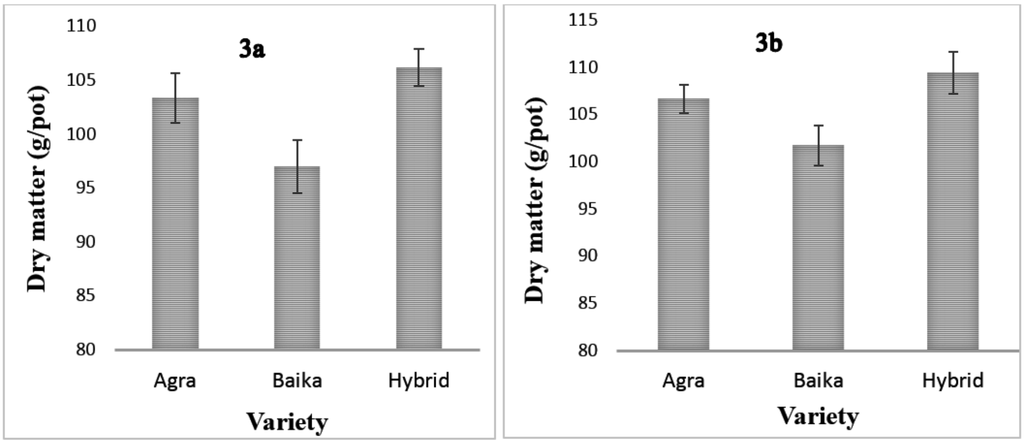

Figure 3a-b: Effect of variety on dry matter in 2016 (a) and 2017 (b). Bars represent ± standard error of means at six replications

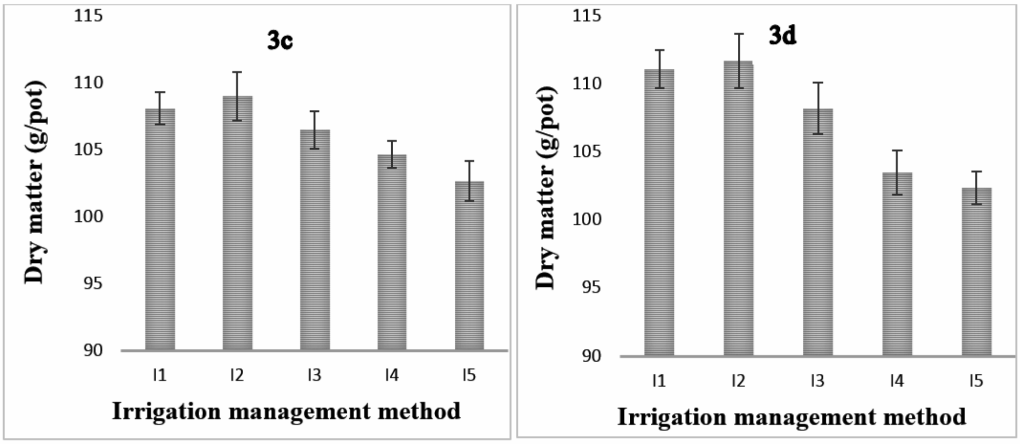

Figure 3c-d: Effect of irrigation management method on dry matter in 2016 (c) and 2017 (d). Bars represent ± standard error of means at six replications

The interaction between variety and irrigation management method did not significantly ($p>0.05$) affect dry matter accumulation in both seasons.

Number of spikelets per panicle was significantly ($p<0.05$) influenced by the main effects of variety and irrigation management method in both seasons (Table 1). Variety V_A and V_H produced statistically similar and higher spikelets per panicle than variety V_B in both seasons. Plants from I_1, I_2 and I_3 treatments recorded statistically similar and higher spikelets per panicle than treatment I_4 and I_5 in both seasons. Moreover, the interaction between variety and irrigation management method significantly ($p<0.05$) influenced spikelets per panicle in both seasons. Plants from I_2V_A and I_5V_B treatment interaction produced significantly the highest and lowest number of spikelets per panicle in both seasons, respectively.

The main effect of variety significantly ($p<0.05$) influenced test weight in both seasons (Table 1). Variety V_A produced significantly the highest test weight in both seasons, followed by V_H and V_B varieties, respectively. Both the main effect of irrigation management method and the interaction between variety and irrigation management method did not significantly ($p>0.05$) influence test weight in both seasons.

Percentage of filled grains was significantly ($p<0.05$) affected by the main effects of variety and irrigation management method in both seasons (Table 1). Variety V_H and V_B produced statistically similar and higher percentage of filled grains than variety V_A in both seasons. Plants from I_1, I_2 and I_3 management produced statistically higher percentage of filled grains than I_5 in both seasons. The interaction between variety and irrigation management method also affected percentage of filled grains significantly ($p<0.05$) in both seasons. Plants from I_1V_H, I_2V_H, and I_3V_H treatment interactions recorded statistically higher percentage of filled grains than both I_5V_A and I_4V_A treatment interactions in both seasons.

Grain yield was significantly ($p<0.05$) influenced by the main effects of variety and irrigation management method in both seasons (Table 2). Variety V_H and V_B produced significantly the highest and lowest gain yield in both seasons. Plants from I_1, I_2 and I_3 management produced statistically similar and higher grain yield than plants from I_5 in both seasons. Moreover, grain yield was significantly ($p<0.05$) affected by the interaction between variety and irrigation management method. Plants from I_2V_H produced the highest grain yield however it was statistically at par with I_1V_H, I_2V_A, I_1V_A, I_3V_H and I_3V_A treatment interactions while

TABLE 1

Effect of variety and irrigation management method on number of spikelets per panicle, test weight and percentage of filled grains of rice in 2016 and 2017 seasons

Variety (V)	**Irrigation mgt.(I)**	**Spikelets per panicle**		**Test weight (g)**		**Filled grains (%)**	
		2016	2017	2016	2017	2016	2017
V_A	I_1	147f	144e	25.5c	25.3c	76.6cd	77.2bcd
	I_2	148f	146e	25.7c	26.0c	76.4cd	78.0bcd
	I_3	144ef	140de	25.4c	25.8c	74.9cd	75.3bc
	I_4	139de	134cd	25.8c	25.1c	70.8ab	73.5ab
	I_5	135cd	133b	25.2c	25.4c	68.3a	70.1a
	Average	**143B**	**139B**	**25.5C**	**25.7C**	**73.4A**	**74.8A**
V_B	I_1	132bc	128bc	22.6b	23.3b	84.4fg	85.8ef
	I_2	135cd	132b	24.3b	24.8b	84.7fg	82.3de
	I_3	130bc	127b	23.0b	23.7b	81.2ef	83.7ef
	I_4	126ab	120a	22.7b	23.5b	77.8de	82.1de
	I_5	123a	119a	23.2b	24.1b	73.4bc	80.8cde
	Average	**129A**	**125A**	**22.9B**	**23.8B**	**80.3B**	**82.9B**
V_H	I_1	144ef	141e	21.4a	21.7a	87.3g	88.9f
	I_2	146f	144e	22.9a	22.8a	88.2g	88.5f
	I_3	142ef	142e	22.1a	20.9a	87.9g	86.6f
	I_4	138cde	133b	21.0a	21.5a	81.7ef	82.1de
	I_5	135c	133b	20.3a	22.1a	76.2cd	77.3bcd
	Average	**141B**	**139B**	**21.5A**	**21.8A**	**84.3B**	**84.7B**

Averages followed by the same letter within a column are not significantly different from each Averages followed by the same letter within a column are not significantly different from each other. I_1: continuous submergence; I_2: alternate wet and dry soil condition (AWD) from transplanting to panicle initiation (PI) then submergence from PI to harvest; I_3: AWD from transplanting to booting then submergence from booting to harvest; I_4: AWD from transplanting to flowering then submergence from flowering to harvest; I_5: continuous AWD. V_H: Hybrid; V_A: Agra; V_B: Ex Baika.

plants from I_5V_B produced significantly the lowest grain yield in both seasons.

The main effects of variety and irrigation management method significantly ($p<0.05$) influenced water use in both seasons (Table 2). Variety V_B and V_H recorded statistically similar and higher water use than variety V_A in both seasons. Plants from I_1 recorded significantly the highest water use, followed by plants from I_2, I_3, I_4 and I_5 management, respectively. Moreover, the interaction between variety and irrigation management method influenced water use significantly ($p<0.05$) in both seasons. Plants from I_1V_H and I_5V_A treatment interactions recorded the highest and lowest water use in both seasons.

Water productivity was significantly ($p<0.05$) influenced by the main effects of variety and irrigation management method in both seasons (Table 2). Variety V_A and V_H significantly recorded higher water productivity than variety V_B. Plants from I_5 management had the highest water productivity followed by I_4, I_3, I_2 and I_1 treatments, respectively. Moreover, the interaction between variety and irrigation management method significantly ($p<0.05$)

TABLE 1

Effect of variety and irrigation management method on number of spikelets per panicle, test weight and percentage of filled grains of rice in 2016 and 2017 seasons

Variety (V)	Irrigation mgt.(I)	Grain yield (g/pot)		Water use (cm^3)		Water productivity (g/cm^3)		Water saved (%)	
		2016	2017	2016	2017	2016	2017	2016	2017
V_A	I_1	47.9bc	48.6bcd	38.9d	39.8fg	1.23b	1.22b	-	-
	I_2	48.8bc	50.1cd	35.4cd	36.1df	1.38c	1.39c	9.0a	9.3a
	I_3	45.3ab	45.9abc	31.8b	32.0cd	1.42d	1.44c	18.3b	19.6c
	I_4	42.8ab	42.6ab	26.9a	26.6ab	1.59fg	1.60e	30.8c	33.2d
	I_5	39.6a	40.7a	24.5a	24.9a	1.62g	1.63e	37.0de	37.4ef
	Average	**44.9AB**	**45.6AB**	**31.5A**	**31.9A**	**1.45B**	**1.46B**	**23.8A**	**24.9A**
V_B	I_1	44.7ab	45.5ab	42.4e	43.1g	1.05a	1.06a	-	-
	I_2	46.6bc	46.2abc	37.7d	37.3ef	1.24b	1.24b	11.1a	13.5b
	I_3	43.7ab	43.3ab	33.5bc	34.2de	1.30bc	1.27b	21.0b	20.6c
	I_4	40.8a	41.2a	27.9a	29.4bc	1.46de	1.40c	34.2d	31.8d
	I_5	39.4a	39.7a	26.8a	27.1ab	1.47de	1.46cd	36.8de	37.1ef
	Average	**43.0A**	**43.2A**	**33.7B**	**34.2B**	**1.31A**	**1.29A**	**25.8AB**	**25.8A**
V_H	I_1	53.0c	52.5d	43.4e	43.7g	1.22b	1.20b	-	-
	I_2	53.3c	53.5d	38.3d	38.8ef	1.39c	1.38c	11.8a	11.2ab
	I_3	46.7bc	48.0bcd	34.2bc	34.6de	1.37c	1.39c	21.2b	20.8c
	I_4	42.1ab	43.1ab	27.2a	27.9ab	1.55fg	1.55de	37.3de	36.2e
	I_5	41.8a	41.4a	26.9a	26.5ab	1.55ef	1.56e	38.0e	39.4f
	Average	**47.2B**	**47.7B**	**34.0B**	**34.3B**	**1.42B**	**1.41B**	**27.1B**	**26.9A**

Averages followed by the same letter within a column are not significantly different from each other. I_1: continuous submergence; I_2: alternate wet and dry soil condition (AWD) from transplanting to panicle initiation (PI) then submergence from PI to harvest; I_3: AWD from transplanting to booting then submergence from booting to harvest; I_4: AWD from transplanting to flowering then submergence from flowering to harvest; I_5: continuous AWD. V_H: Hybrid; V_A: Agra; V_B: Ex Baika.

affected water productivity in both seasons. I_5V_A recorded the highest water productivity however it was at par with I_4V_A, I_5V_H, and I_4V_H, treatment interactions while I_1V_B treatment interaction produced significantly the lowest water productivity in both seasons.

The main effects of variety and irrigation management method significantly ($p<0.05$) influenced percentage of water saved in only 2016 season (Table 2). Variety V_H and V_A had significantly the highest and lowest percentage of water saved in both seasons. Plants from I_5 management recorded the highest percentage of water saved, followed by I_4, I_3, and I_2 management, respectively. Moreover, the interaction between variety and irrigation management method had a significant ($p<0.05$) effect on percentage of water saved in both seasons. Plants from I_5V_H and I_2V_A interactions recorded significantly the highest and lowest percentage of water saved in both seasons.

Discussion

Variety V_H and V_A produced the better vegetative growth in both seasons than variety V_B and it may be due to their genetic mark up. Mohammad *et al.* (2002) asserted that plant height of rice is controlled by both environmental conditions and genetic makeup of the plant. This finding is in conformity with Mannan et al. (2009), Garba *et al.* (2013) and Gagandeep and Gandhi (2015) who reported that vegetative growth of rice is significantly influenced by the type of varieties used. Plants from I_1 treatment produced the highest dry matter accumulation than the other treatments in both seasons and it may be attributed to the absence of water stress on the plants since water was continuously kept above the soil surface throughout the plant cycle. This outcome agrees with previous studies (El-Refaee *et al.*, 2007; Singh *et al.*, 2009). Plants from I_5 produced the poorest vegetative growth and it may be due to the reduced soil moisture from transplanting to harvest. Kropff and Spitters (1991) reported that reducing soil moisture supply limits the movement and absorption of nutrients by plant roots, and therefore reduce rice growth.

Variety had a significant effect on grain yield and it may be attributed to the genetic constitution of the varieties used in the study. Garba *et al.* (2013) and Getachew and Birhan (2015) observed that grain yield and yield components of rice were significantly influenced by the varieties used. Variety V_H produced the highest grain yield due to its higher effective tillers, spikelets number per panicle and percentage of filled grains than the other varieties. Variety V_B produced the lowest grain yield however, it had higher test weight than variety V_H and it may be due to its lowest spikelets number per panicle. Plants from I_3 produced the similar grain yield as plants from both I_1 and I_2 and it may be due to their similar dry matter accumulation, spikelets number of panicle and percentage of filled grains. Anning *et al.* (2018) reported that continuously submerging the field after practicing AWD up to booting stage did not significantly affect grain yield of rice. However, Akram (2013) reported a higher reduction in grain yield when there was water stress at panicle initiation stage than flowing stage. The difference between these findings may be due to the degree of the stress, soil type and the varieties used. Plants from I_4 and I_5 produced the lowest grain yield and it may be due to the reduced soil moisture supply at the flowering stage. Water stress at flowing stage hinder the partition of assimilate during grain filling and consequently reduced grain yield significantly. Sarvestani *et al.* (2008) asserted that water stress at flowering stage significantly reduced grain yield. This outcome is in line with previous studies (Borrell *et al.*, 1997; Yang and Zhang, 2010; de Varies *et al.*, 2010) that, practicing AWD throughout the plant cycle reduces grain yield significantly due to reduced soil moisture. However, Sun *et al.* (2012), Liu *et al.* (2013) and Chu *et al.* (2015) observed a higher grain yield in AWD plants than continuous submergence plants. Moreover, Belder *et al.* (2004), Dong *et al.* (2012) and Howell *et al.* (2015) reported a similar grain yield between AWD and continuous submerged treatments. The discrepancies in these findings may be due to the fact that AWD varies in terms of frequency and duration of drying periods and the type of soil used (Bouman and Tuong 2001; Belder *et al.*, 2004). Plants from I_3V_H produced similar grain yield as I_1V_H and I_2V_H and it may be due to their similar spikelets number per panicle and percentage of filled grains.

Variety V_A recorded the lowest water use which consequently led to its higher water productivity than the other varieties. Variety V_A produced the smallest number of tillers which resulted in its small canopy formation and consequently reduced its transpiration rate. Plants with large canopy formation transpire more water than plants with small copy formation. Plants from I_1 treatment produced the highest water use and it may be attributed to continuous submergence of the plots from transplanting to harvest. Continuous submergence of the plots increases the rate of seepage and percolation (Borrell *et al.*, 1997; Abdul-Ganiyu *et al.*, 2015) and consequently increased the amount of water use. Plants from I_5 treatment recorded the highest water productivity and percentage of water saved due to its lowest water use. AWD reduces the amount of water loss through evaporation, seepage and percolation since water was not always kept above the soil surface and consequently reduced water use and increased the percentage of water saved when compared to the continuous submergence treatment. This outcome agrees with Abdul-Ganiyu *et al.* (2015) and Chu *et al.* (2015) who reported that continuous submergence increased water use and reduced water productivity. Plants from I_5V_A treatment produced the highest water productivity of rice and it may be attributed to their lower water use. Plants from I_1V_H recorded the highest water use due to their higher vegetative growth (canopy formation) and the standing water layer in the pots from transplanting to harvest.

Conclusion

Results from both 2016 and 2017 experiments revealed that, both variety and irrigation management method have significant effect on rice growth, grain yield and water productivity. Continuous submergence from transplanting to harvest significantly decreased water productivity of rice. AWD throughout the plant cycle reduced the amount of water use and grain yield. Reducing moisture supply at flowering stage of rice significantly reduce percentage of filled grains, spikelets number per panicle and grain yield. AWD should be practiced from transplanting to booting stage, then followed by continuous submergence to avoid yield loss while saving more than 20% of water use.

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