EFFECT OF WATER MANAGEMENT AND NITROGEN FERTILIZER SOURCES ON YIELD AND WATER USE EFFICIENCY OF LOWLAND RICE

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Abstract
Field and pot experiments were carried out at the Soil and Irrigation Research Centre, University of Ghana, Kpong in 2015 and 2016 cropping seasons to assess the effect of different water regimes and nitrogen fertilizer sources on yield and water use efficiency of lowland rice. The field experiment was laid out in a split plot design with three replications. Water regimes and nitrogen sources were the main plot and sub-plot factors, respectively. The pot experiment was however, laid out in a randomized complete block design with five replications. Levels of water regimes included continuous submergence (CS), alternate wetting and drying (AWD) and moist soil condition between field capacity and permanent wilting point (MC). The levels of fertilizer nitrogen sources were absence of N fertilizer application (control, N0), application of 90 kgN/ha mainly from urea fertilizer (N1), application of 90 kgN/ha from 12.8 tonnes of compost (N2) and 45 kgN/ha from urea fertilizer + 45 kgN/ha from 6.4 tonnes of compost (N3). Lowest water-use efficiency (WUE) of rice was observed under continuous submergence, while treatment combination of N3 x AWD produced the highest WUE and grain yield in both pot and field experiments. The study concluded that 45 kgN/ha from compost should be applied with 45 kgN/ha urea fertilizer to have a positive effect on rice yield.

Keywords
Alternate wetting and drying, compost, continuous submergence, urea, and water use

Introduction

Rice (*Oryza sativa* L.) is an important staple grain crop and is consumed by approximately 3.5 billion people worldwide (International Rice Research Institute, 2013). Over one hundred countries cultivate rice globally with annual production of above 715 million and 480 million tonnes of paddy and milled rice, respectively Food and Organization (2013). In Sub-Saharan Africa, rice production contributes significantly in achieving food security and socio-economic development. The consumption of rice in the region is estimated to increase from 19.8 million tonnes in 2010 to 35 million tonnes in 2020, thus about 14 million tonnes of milled rice will be imported into the region in 2020 to meet the increasing rice demand (Africa Rice Center, 2011). In Ghana, rice contributes 13.75 percent of the total cropped area planted to cereals, however it occupies only 5.48 percent of the total cropped area planted to food crops (Ministry of Food and Agriculture, 2014). Ghana is food self-sufficient in all major food crops apart from rice. Rice production increased by 6.06 percent in 2014 as compared to the average production from 2008 to 2013, even though the domestic food supply and demand showed a deficit of 285 metric tonnes (Ministry of Food and Agriculture, 2014). The production of rice in the country has been consistently less than consumption needs due to rapid population growth and changing consumer preferences (Millennium Development Authority, 2010).

Generally, poor nitrogen and water management practices are the main cause of low rice yields in Ghana (Buri et al., 1999). Nitrogen is the most important and limiting nutrient in rice production and a kg of nitrogen is needed to produce 11 to 22 kg of rice (Duxbury et al., 2000). Nitrogen is highly mobile in soils and it is subjected to different types of losses especially in irrigated rice system. Inorganic N fertilizers are used to supplement the low native N concentration of the soils for a good crop yield. However, the price of inorganic fertilizers in the country has increased rapidly by 50% due to weakness of local currency on exchange market, increase in fuel prices and the removal of government subsidies on fertilizer prices (Ministry of Food and Agriculture, 2014). As a result, most farmers in the county cannot apply inorganic N fertilizers at the recommended rate for a good crop yield. Generally, farmers burn rice residues within and outside their rice fields after harvest which leads to a massive nutrient loss and mining especially in an intensive rice cropping system (rice- rice pattern). However, these crop residues can be composited and used to improve the soil properties. The amount of fresh water available for irrigation for sustainable rice production is decreasing as a result of increasing population growth (Molden, 2007), climate change and expansion of irrigated areas (Zwart, 2013). Report by United Nations Environment Programme United Nations Environment Programme (2008) noted that Ghana will face water stress by 2025 due to increase demand for water resources from all sectors. This will affect rice production since it requires the highest amount of water than any other crop in the agricultural sector (Khan et al., 2006). Therefore, numerous water-saving management methods for rice such as continuous soil saturation (Borrell et al., 1997), alternate wetting and drying (Bouman and Tuong, 2001) and aerobic rice system (Bouman et al., 2005) have been suggested. However, these water management options vary significantly between different seasons and years (Mandal et al., 2009), rice varieties used, soil types, and the frequency and duration of drying periods (Belder et al., 2004; Bouman and Tuong, 2001). Unfortunately, information on water and nitrogen management options for increased yield, water use efficiency and physiological parameters of lowland rice is scanty in the country. This work ought to assess the effect of different water and nitrogen management methods on yield and water use efficiency of lowland rice.

Materials and Methods

Description of the experimental site

The study was conducted at the Soil and Irrigation Research Centre, University of Ghana – Kpong in the Eastern Region of Ghana. The Centre is located within the lower Volta basin of the Coastal Savannah agro-ecological zone at latitude 6°09' N, longitude 00 °04' E, and an altitude of 22 m above mean sea level. It experiences a bi-modal seasonal rainfall pattern with an annual precipitation of about 1200 mm and a mean annual temperature of 27.2 °C. The soil at the experimental area was tropical black clay and it belongs to the Akuse series. Chemical analysis of the soils used for the field and pot experiments are presented in Table 1.

Land and pot preparation

The land was prepared by ploughing to bury all vegetation, submerged with water and puddled to reduced percolation of water. Experimental units of 2 m x 3 m were measured out using a measuring tape, garden line and pegs. Sixty (60) cm high metallic barriers were inserted in each unit at a depth of 30 cm to prevent lateral movement of nutrient and water in and out of the plots. The size of each of the metallic containers was 2 m × 3 m and they were sprayed with anti-rust paint to prevent rusting.

For the pot experiment, plastic pots with 10000 cm^3 volume were used. 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. Nine kilograms (9 kg) of the soil was weighed into each plastic pot.

Design and layout of experiment

A 3 × 4 factorial experiment was laid out in a split plot design and replicated three times for the field experiment. The water management regime was the main plot factor while nitrogen fertilizer source was the sub-plot factor. The sub-plot treatments were completely randomized in each main plot while the main plot treatments were also completely randomized in each replication. Randomized complete block design (RCBD) was used for the pot experiment due to the unidirectional gradient in the screen house, and the treatments were replicated five times. Water management regimes included (1) continuous submergence (CS), (2) alternate wetting and drying (AWD) and (3) moist condition of soil between saturation and field capacity (MC). The levels of nitrogen fertilizer sources were (1) application of 90 kgN/ha of urea fertilizer, (2) 12.8 t/ha (90 kgN/ha) of compost (3) 45 kgN/ha of urea plus 6.4 t/ha (45 kgN/ha) of compost and (4) a control (no N application) as showed in Table 2.

Fertilizer application and crop establishment

Compost was prepared with water hyacinth (*Eichhornia crassipes*), rice straw (*Oryza sativa* L.), ash, cow dung, *Leucaena leucocephala* leaves, and top soil. The matured compost (12 weeks old) had the following chemical properties; total nitrogen 0.7%, available phosphorus 0.4%, available potassium 0.5 mg kg^{-1}, organic carbon 8.9%, pH 6.5 and C/N ratio 12.7. The compost was broadcasted and incorporated into the experimental units one week before transplanting of rice seedlings. An amount of 12.8 tonnes of compost were incorporated as per treatment to supply 90 kgN/ha. Where compost and inorganic N were applied as nitrogen combination, 6.4 tonnes of compost, thus half ½ recommended N (45 kgN/ha), was incorporated into the soil as basal. Recommended rate of inorganic N (90 kgN/ha) was split (50%) and applied for both basal and top-dress. Triple Superphosphate (P_2O_5) and muriate of potash (KCl) were applied at 45 kgN/ha each on all the experimental units at two weeks after transplanting of seedlings. Rice seeds (Ex Baika variety) were pre-germinated and broadcasted into a wet bed nursery. The 21- day old seedlings were transplanted to each plot at a planting distance of 20 cm × 20 cm. In the pot experiment, two seedlings were transplanted per hill in each pot.

Water management

Perforated polyvinyl chloride (PVC) pipes of 30 cm long with a diameter of 2 cm were used for the pot experiment while perforated PVC pipes of 60 cm long with a diameter of 3 cm were used for the field experiment. The pipes were perforated with an electric soldering iron up to 25 cm long in the pot experiment and 30 cm long in the field experiment with 2 cm intervals between perforated holes. The pipes were inserted in all the experimental units except the continuously submerged units to monitor soil moisture level below the soil surface by dipping a wooden metre rule into the perforated pipes. Graduated plastic buckets (10 and 15 litres) were used to measure irrigation water in the field experiment, while plastic cylinders (1 litre) were also used to measure irrigation water in the pot experiment. The quantity of water applied throughout the experiments was recorded. The amount of rainfall (rainfall events) during the experimental period was also recorded. Water was maintained between 5 cm to 7 cm above the soil surface till ten days to harvest in the continuous submerged treatment. For the moist treatment, soil moisture was kept between 15 cm to 18 cm below the soil surface in the pot experiment, and between 20 cm to 25 cm below the soil surface in the field experiment. In the AWD treatment, the experimental unit was only submerged (5 cm above the

Table 1. Chemical properties of the soils used for the field and pot experiments

Site	Depth (cm)	TN (%)	AP (%)	AK ((mgkg-1)	Ca (mgkg-1)	Mg (mgkg-1)	pH (H2O) 1:1	OC (%)	C/N ratio
Field	0 - 15	0.07	2.09	4.72	22.80	1.26	7.88	1.63	24.3
Pot	0 - 15	0.13	2.05	4.96	31.14	1.31	8.10	1.77	13.6

TN: total nitrogen, AP: available phosphorus, AK: available potassium, Ca: exchangeable calcium, exchangeable magnesium, pH: soil reaction, OC: organic carbon, C/N: carbon/nitrogen, OM: organic matter, EC: electrical conductivity

Table 2. Description of treatments

Water regime	Nitrogen source	Treatment
Alternate wetting and drying (AWD)	Control (0 kgN/ha)	AWD x N0
	Urea 90 kgN/ha	AWD x N1
	Compost 12.8 t/ha (90 kgN/ha)	AWD x N2
	Compost 6.4 t/ha (45 kgN/ha) + Urea 45 kgN/ha	AWD x N3
Moist condition between saturation and field capacity (MC)	Control (0 kgN/ha)	MC x N0
	Urea 90 kgN/ha	MC x N1
	Compost 12.8 t/ha (90 kgN/ha)	MC x N2
	Compost 6.4 t/ha (45 kgN/ha) + Urea 45 kgN/ha	MC x N3
Continuous submergence (CS)	Control (0 kgN/ha)	CS x N0
	Urea 90 kgN/ha	CS x N1
	Compost 12.8 t/ha (90 kgN/ha)	CS x N2
	Compost 6.4 t/ha (45 kgN/ha) + Urea 45 kgN/ha	CS x N3

soil surface) when soil moisture dropped to 18 cm and 25 cm below the soil surface in the pots and field experiments, respectively. All the treatments were continuously submerged at booting stage to ten days to harvest.

Data collection

Ten plants were selected randomly with the exception of the border plants from each plot and used to determine the yield components: test weight, percentage of filled grains, spikelet number per panicle and effective tillers. Grain yield was determined by weighing grains from 5 m^2 and expressed as t/ha at 14% grain moisture. Harvest index was derived as the ratio of grain yield biomass to the sum of grain and straw yield biomass. Water use was determined as the sum of the total amount of water received by the plants from both irrigation and rainfall. Water saved percentage was calculated as the ratio of the difference between the amount of water applied to continuous submerged treatment and water save technique (AWD or MC) to the amount of water applied to the continuous submerged treatment, and multiplied by 100. Water-use efficiency (WUE) was determined as the ratio of grain yield to water use. Mathematically, it was calculated as;

$$WUE = \frac{Grain\ yield}{Water\ use} \quad (1)$$

Data analysis

The data collected on various parameters were entered into Microsoft excel spreadsheet for treatment means and subjected to Analysis of Variance using GenStat statistical software package (12^{th} Edition). Least significant difference (LSD) at 5% was used to separate the treatment means.

Results

Weather

The climatic condition during both pot and field experiments is shown in Table 3. The total rainfall during the entire period was 343.6 mm. October recorded the highest rainfall while December had the least rainfall. Monthly maximum temperature ranged from 31 °C in both July and August, 2015 to 34.7 °C in January, 2016. Mean relative humidity varied over the period, generally increasing from the beginning in July and peaking in October, then decreasing afterwards.

Results from pot experiment

Grain yield and yield parameters

The interaction between water and nitrogen treatments significantly ($p < 0.01$) influenced grain yield (Figure 1). N3 × CS and N0 × MC produced the highest and lowest grain yield, respectively. The main effects of water and nitrogen treatments significantly ($p < 0.01$) influenced grain yield. Grain yield was ranked as $CS > AWD > MC$, respectively in the water treatments and $N3 > N1 > N2 > N0$, respectively in the nitrogen treatments. Percentage of filled grains was significantly ($p < 0.01$) influenced by only the main effect of nitrogen fertilizer (Table 4). Percentage of filled grains followed this trend: $N0 > N2 > N3 > N1$, respectively. Both the

Table 3. Total monthly rainfall, mean monthly maximum temperature and humidity of the experimental site during the experimentation

Month	Rainfall (mm)	Maximum temperature (°C)	Relative humidity (%)
July	97.0	31.0	37.4
August	22.3	31.0	34.9
September	21.9	32.2	59.0
October	106.4	32.6	62.0
November	96.0	33.8	60.2
December	N/A	34.2	23.0
January	33.2	34.7	34.7

N/A: not available. Source: Agrometeorological station, SIREC- Kpong.

main effects of water and nitrogen treatments, and their interaction significantly ($p < 0.05$) affected number of spikelet per panicle (Table 4). N3 × CS produced significantly the highest number of spikelets per panicle while N0 × MC produced the lowest number. Number of spikelets per panicle was ranked as: CS>AWD>MC, respectively in the water treatments and $N3 > N1 > N2 > N0$, respectively in the nitrogen treatments. Test weight was insignificantly ($p > 0.05$) influenced by the main effects of water and nitrogen treatments, and their interaction (Table 4). The main effects of water and nitrogen treatments, and their interaction significantly ($p < 0.01$) influenced harvest index (Table 4). N0 × MC had significantly the highest harvest index. The AWD and MC treatments had significantly higher harvest index than CS. Harvest index was ranked in the nitrogen treatments as: $N0 > N2 > N3 > N1$, respectively.

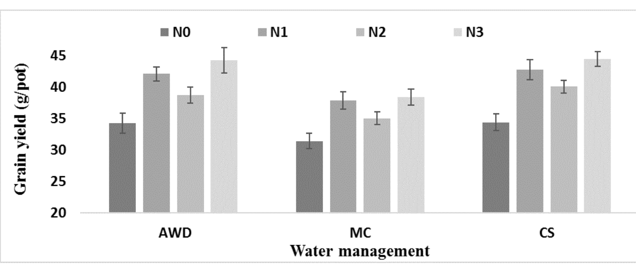

Figure 1. Figure 1: Mean grain yield of rice (g/pot) under various water and nitrogen treatments. AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent point; CS: continuous submerged soil condition; N0: no nitrogen fertilizer; N1: urea fertilizer; N2: compost fertilizer; N3: combined compost and urea fertilizer. Bars represent means + SEM of 3 replicates. LSD: least significant difference.

Water use, percentage of water saved and water use efficiency

There was no significant ($p > 0.05$) interaction effect between water and nitrogen treatments on water use (Table 5). However, significant ($p < 0.01$) effects of both water and nitrogen treatments on water use were recorded. Treatments CS and MC had the highest and lowest water use, respectively. Water use followed the trend: $N1 > N3 > N2 > N1$, respectively in the nitrogen treatments. The interaction between nitrogen and water treatments did not significantly ($p > 0.05$) affect water use efficiency (WUE) and percentage of water saved (Table 5). However, the main effects of water and nitrogen treatments significantly ($p < 0.01$) influenced water use efficiency. MC recorded the highest WUE followed by AWD and CS treatments, respectively. WUE was ranked as: $N3 < N2 < N1 < N0$, respectively in the nitrogen treatments. Only the main effect of water treatments was significantly ($p < 0.01$) influenced by percentage of water saved. MC saved a higher percentage of water than AWD.

Results for field experiment

Grain yield and yield parameters

The main effects of water and nitrogen treatments, and their interaction significantly ($p < 0.01$) influenced grain yield (Figure 2). The N3 × CS produced significantly the highest grain yield while N0 × MC had the lowest yield. CS produced significantly the highest grain yield, followed by AWD and MC treatments, respectively. Influence of nitrogen treatments on grain yield was ranked as: $N3 > N1 > N2 > N0$, respectively. Percentage of filled grains was significantly ($p < 0.01$) influenced by the interaction between water and nitrogen treatments and the main effect of nitrogen treatments (Table 6). N0 × MC recorded significantly the highest percentage of filled grains while N3 × CS produced the lowest percentage. Percentage of filled grains was ranked as: $N0 > N2 > N3 > N1$, respectively in the nitrogen treatments. Spikelet number per panicle was significantly ($p < 0.01$) influenced by the interaction between water and nitrogen, and their main effects (Table 6). N3 × CS produced the highest spikelet number per panicle while N0 x MC had the lowest spikelets number. Spikelet number per panicle followed the trend: $CS > AWD > MC$, respectively in the water treatments and $N3 > N1 > N2 > N0$, respectively in the nitrogen treatments. There was no significant ($p > 0.05$) interaction between the two factors as well as their main effects on test weight (Table 6). The interaction effect between water and nitrogen treatments and the main effect of nitrogen sources did not significantly ($p > 0.05$) influence harvest index (Table 6). However, the main effect of water regime had a significant effect on harvest index ($p < 0.05$). MC had significantly higher harvest index than treatments AWD and CS.

Water use, percentage of water saved and water use efficiency

There was no significant ($p > 0.05$) interaction between water and nitrogen treatments on water use (Table 7). The main effects of water and nitrogen treatments however had a significant ($p < 0.01$) effect on water use. CS and MC treatments recorded the highest and lowest water use, respectively. Water use followed this tread; $N1 > N3 > N2 > N0$, respectively in

Table 4. Mean percentage of filled grains, test weight and harvest index of rice under various water and nitrogen treatments

Parameter	Water mgt. (W)	Nitrogen management (N)				Mean	LSD (0.05)		
		N0	**N1**	**N2**	**N3**		**N**	**W**	**N x W**
Percentage filled grains (%)	AWD	84.6	71.8	77.6	76.6	**76.4**	5.9*	NS	NS
	MC	79.5	74.5	80.0	76.9	**79.0**			
	CS	76.4	70.5	77.6	73.5	**74.5**			
	Mean	**80.5**	**73.2**	**78.4**	**75.7**				
Number of spikelets per panicle	AWD	101	134	116	141	**123**	3.4**	2.1**	5.0*
	MC	97	123	108	126	**114**			
	CS	106	139	121	144	**128**			
	Mean	**101**	**132**	**115**	**137**				
Test weight (g)	AWD	26.0	27.0	26.3	27.3	**26.3**	NS	NS	NS
	MC	26.7	26.3	26.7	27.3	**26.8**			
	CS	26.3	26.7	26.3	26.7	**26.5**			
	Mean	**26.3**	**26.7**	**26.4**	**27.1**				
Harvest index	AWD	0.51	0.45	0.51	0.49	**0.49**	0.02**	0.02**	0.04**
	MC	0.53	0.47	0.49	0.46	**0.49**			
	CS	0.44	0.44	0.44	0.47	**0.45**			
	Mean	**0.49**	**0.45**	**0.48**	**0.48**				

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0: no nitrogen application (control); N1: urea nitrogen application; N2: compost nitrogen application; N3: combined compost and urea nitrogen application; LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

Table 5. Mean water use, percentage of water saved and water use efficiency under various water and nitrogen treatments in rice

Parameter	Water regime (W)	Nitrogen sources (N)				Mean	LSD (0.05)		
		N0	N1	N2	N3		N	W	N x W
Water use (dm^3)	AWD	31.9	38.0	31.7	35.9	**34.4**	1.7**	1.5**	NS
	MC	28.9	33.1	28.6	30.8	**30.4**			
	CS	40.4	45.1	40.3	43.0	**42.2**			
	Mean	**33.7**	**38.7**	**33.5**	**36.6**				
Percentage of water saved (%)	AWD	20.4	15.5	20.8	16.5	**18.3**	NS	2.7**	NS
	MC	27.9	26.5	28.5	28.3	**27.8**			
	CS	-	-	-	-	**-**			
	Mean	**24.2**	**21.0**	**24.6**	**22.4**				
Water use efficiency (kg/m^3)	AWD	1.11	1.16	1.29	1.29	**1.21**	0.07**	0.06**	NS
	MC	1.15	1.21	1.30	1.31	**1.24**			
	CS	0.88	1.00	1.05	1.08	**1.00**			
	Mean	**1.05**	**1.12**	**1.21**	**1.23**				

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0: no nitrogen application (control); N1: urea nitrogen application; N2: compost nitrogen application; N3: combined compost and urea nitrogen application; LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

the nitrogen treatments. Only the main effect of water treatments significantly ($p < 0.01$) influenced percentage of water saved (Table 7). MC recorded significantly higher percentage of water saved than AWD. WUE was significantly ($p <$

Table 6. Mean percentage of filled grains, spikelet number per panicle, test weight and harvest index of rice under various water and nitrogen treatments

Parameter	Water mgt. (W)	Nitrogen sources (N)				Mean	LSD (0.05)		
		N0	N1	N2	N3		N	W	N x W
Percentage of filled grains (%)	AWD	90.0	88.0	89.1	87.9	**88.8**	2.8**	NS	3.6**
	MC	93.7	89.3	93.0	90.3	**91.6**			
	CS	90.3	87.7	91.0	87.0	**89.3**			
	Mean	**91.3**	**88.7**	**91.0**	**88.4**				
Spikelet number per panicle	AWD	101	138	107	135	**120**	5.0**	8.4**	9.1**
	MC	93	101	98	108	**100**			
	CS	109	140	121	141	**128**			
	Mean	**101**	**126**	**109**	**128**				
Test weight (g)	AWD	26.4	26.2	26.7	26.7	**26.5**	NS	NS	NS
	MC	25.9	26.4	26.8	26.6	**26.4**			
	CS	26.7	26.4	26.7	27.1	**26.7**			
	Mean	**26.3**	**26.3**	**26.7**	**26.8**				
Harvest index	AWD	0.43	0.46	0.46	0.45	**0.45**	NS	0.02*	NS
	MC	0.48	0.45	0.45	0.49	**0.47**			
	CS	0.46	0.45	0.45	0.43	**0.45**			
	Mean	**0.46**	**0.45**	**0.45**	**0.46**				

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0: no nitrogen application (control); N1: urea nitrogen application; N2: compost nitrogen application; N3: combined compost and urea nitrogen application; LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

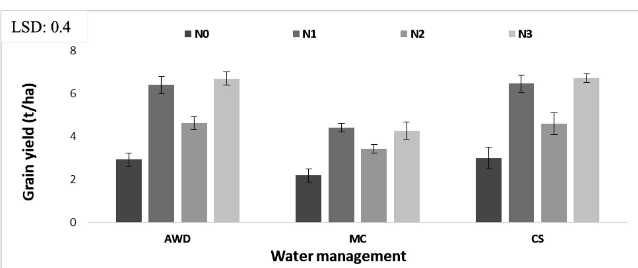

Figure 2. Mean grain yield (t/ha) under various water and nitrogen treatments. AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent point; CS: continuous submerged soil condition; N0: no nitrogen fertilizer; N1: urea fertilizer; N2: compost fertilizer; N3: combined compost and urea fertilizer. Bars represent means ± SEM of 3 replicates; LSD: least significant difference

0.05) affected by the interaction between water and nitrogen treatments, and their main effects (Table 7). N3 x MC had the highest WUE while N0 x CS recorded significantly the lowest value. MC had significantly the highest WUE, followed by AWD and CS treatments, respectively. WUE was ranked as; $N0 > N3 > N1 > N2$, respectively in the nitrogen treatments.

Discussion

Effect of water and nitrogen management on rice yield and yield components

The control recorded higher percentage of filled grains than nitrogen fertilized treatments due to its lower spikelet number per panicle and panicle per m^2. This confirms the finding of Sun et al. (2012) and Liu et al. (2013) who observed that, the higher the spikelet number per panicle, the lower the percentage of filled grains. Among the nitrogen fertilized treatments, combined compost and urea fertilizer (N3) treatment produced the highest grain yield and it may be due to the continuous release of plant nutrients from the compost to the plants along with the instant release of N from the urea fertilizer to the soil Omar Hattab et al. (2000). The application of nitrogen fertilizer did not affect test weight in both experiments since test weight is a genetic trait which is controlled by the size of the hull (Mae, 1997; Yoshida, 1981). The absence of yield loss under alternate wetting and drying (AWD) treatment compared with continuous submergence (CS) treatment might be attributed to the fact that AWD does not restrict soil water availability (Belder et al., 2004; Howell et al., 2015; Singh et al., 2009). Treatment N3 x CS and N3 x AWD had the highest grain yield due to the additional nitrogen from the fertilizers to the soil as well as adequate soil moisture avail-

Table 7. Mean water use, percentage of water saved and water use efficiency of rice under various water and nitrogen treatments

Parameter	Water mgt. (W)	Nitrogen sources (N)				Mean	LSD (0.05)		
		N0	N1	N2	N3		N	W	N x W
Water use (mm)	AWD	1041	1122	1011	1081	**1064**	23.7**	17.5**	NS
	MC	524	604	513	581	**556**			
	CS	1514	1608	1487	1570	**1545**			
	Mean	**1026**	**1112**	**1004**	**1077**				
Percentage of water saved (%)	AWD	31.2	30.2	32.0	31.2	**31.2**	NS	1.74**	NS
	MC	65.3	62.4	65.5	63.0	**64.1**			
	CS	-	-	-	-				
	Mean	**48.3**	**46.3**	**48.8**	**47.1**				
Water use efficiency (kg/m^3)	AWD	0.28	0.57	0.46	0.62	**0.48**	0.02**	0.03**	0.06*
	MC	0.42	0.73	0.67	0.74	**0.64**			
	CS	0.20	0.40	0.31	0.43	**0.33**			
	Mean	**0.30**	**0.57**	**0.48**	**0.60**				

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0: no nitrogen application (control); N1: urea nitrogen application; N2: compost nitrogen application; N3: combined compost and urea nitrogen application; LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

ability. N0 x MC produced the lowest grain yield due to the absence of additional N to the soil and the dryness of the top soil layers Kropff and Spitters (1991) from one week after transplanting to booting stage. Wopereis et al. (1996) and Belder et al. (2005) reported that, water stress at the vegetative phase of the rice plant reduced the sink size and therefore reduced grain yield.

Effect of water and nitrogen management on water use, percentage of water saved (%) and water use efficiency (WUE)

Nitrogen fertilized treatments had significantly higher water use efficiency (WUE) than the control in both experiments due to their higher grain yield. This is in conformity with Cabuslay et al. (2002) and Sun et al. (2012) who asserted that WUE is significantly increased when nitrogen fertilizer is applied. N3 treatment recorded the highest WUE in both experiments and it might be attributed to its high grain yield and low water use. However, compost (N2) treatment produced similar WUE as N3 treatment in the pot experiment and it could be due to the fact that water use reduced more than the corresponding reduction in its grain yield. N2 treatment had the lowest water use and it could be attributed to its improved soil physical properties. Bhattacharyya et al. (2008) asserted that organic fertilizer application improves soil structure, water stable aggregate and water holding capacity as a result of increased number of total storage pore of the soil. CS treatment recorded the highest water use due to the standing water layer that was kept continuously on the field till ten days before harvest. Submerging the field continuously increases the rate of evaporation, transpiration, seepage and percolation which in turn increases water use. This finding is supported by Borrell et al. (1997) and Abdul-Ganiyu et al. (2015) who found that the rate of percolation and seepage increased when the soil was continuously submerged. MC treatment had the highest WUE even though it produced the lowest grain yield. This might be attributed to its significant low water use. This outcome is in line with Sun et al. (2012) who asserted that, keeping the field moist at the vegetative phase reduced grain yield and increased WUE significantly. N3 x MC had higher WUE than N2 x MC treatment even though the latter saved more water than the former. This could be attributed to the higher grain yield recorded by the latter as a result of the instant release of N from the urea fertilizer.

Conclusion

Results from both experiments (pot and field) revealed that submerging the field continuously throughout the growing season did not significantly increase grain yield but rather reduced water use efficiency. Also maintaining soil moisture content between field capacity and permanent wilting point from transplanting to booting stage reduced grain yield significantly. In terms of water use efficiency, alternate wetting and drying water management technique with combined compost and urea fertilizers at equal ratio proved superior to other treatment combinations. The study also showed that the application of 45 kgN/ha from compost plus 45 kgN/ha in urea produced the optimum grain yield.

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