Water Management, Nitrogen rate and Plant spacing effect on Yield and Yield components of Rice

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Abstract

A study was conducted on a calcic vertisol to evaluate the main effects of water management, nitrogen (N) rate and plant spacing and their potential interactions on yield and yield components of rice. The experimental design was a split-split plot with two water treatments as main plots. Continuous flooding (CF) involved repeated ponding to 5 cm height and alternate wetting and drying (AWD) involved ponding to a height of 5 cm after the water level dropped to 25 cm beneath the soil surface. Nitrogen at 0, 90 and 120 kg N ha^{-1} served as subplots and three plant spacing (20 × 15 cm, 20 × 20 cm and 20 × 25 cm) as sub-subplots. The experiment was conducted during the major and minor rainy seasons over two years. A similar panicle density and grain yield was observed between AWD and CF, though AWD was characterized by a reduction in irrigation water used. This resulted in higher water productivity under AWD (0.284-0.899 kg m^{-3}) relative to CF (0.257-0.810 kg m^{-3}). Applying AWD saved between 9.5-11.3 % water relative to CF. There was no yield advantage for 120 kg N ha^{-1} over 90 kg N ha^{-1}. There was no interaction between N rate and water management, suggesting that the effect of N rate was consistent regardless of the water management method. The rice plant did not sufficiently compensate for lower plant population in the minor rainy season compared with the major rainy season. As a result, the lower plant population (20 × 20 cm plant spacing) recorded lower yield than the higher plant population (20 × 15 cm plant spacing) in the minor rainy season. This also indicates that complete yield compensation is difficult or not guaranteed during the minor season at 20 × 20 cm plant spacing. Yield components were higher in the major rainy season resulting in higher yield in the major rainy season (3973 kg ha^{-1}) than the minor rainy season (3550 kg ha^{-1}). Therefore, establishing fields at 20 × 15 cm during the minor rainy season is recommended to increase tiller density to eventually increase or maintain yield. Also, employing AWD and applying N at 90 kg ha^{-1} can help farmers save water, avoid excessive N use and save cost.

Keywords: Rice yield, nitrogen rate, planting distance, water management, water productivity

Introduction

Rice is the staple food for over 50 % of the human race (Khangar et al., 2024). According to USDA (2018), rice consumption (milled grain) in sub-Saharan Africa more than tripled from 9.2 Mt to 31.5 Mt between 1990 and 2018.

In Ghana, rice is the second most important staple after maize, with per capita consumption increasing steadily (MoFA, 2018). However, more than half of the rice consumed in the country is imported. Domestic production has continuously not been able to meet demand, mainly due to limited cultivated area and low agricultural productivity. The high cost of irrigation and fertilizers in Ghana requires a more judicious use of water and fertilizers to save cost and protect the environment. Statistics available indicate total imports of more than 620,000 tons since 2015, with a high annual import bill of about USD 376 million (MoFA, 2018).

Rice is usually grown with a wide range of management practices such as field preparation, seeding rates/plant densities, water and nitrogen management playing a very important role in obtaining optimum yields.

Bouman et al. (2007) noted that, production of rice uses between 34-43 % of the total quantity of water used for irrigation globally. As a result, variable water availability presents a major threat to the sustainability of rice production systems. Humans are now confronted with increased crop production using limited water resources due to competing needs for fresh water for irrigation and use by other water-using sectors. Rice production under lowland conditions is usually characterized by frequent ponding and this consumes a lot of water. According to Bouman and Tuong (2001), less water can be used and water productivity increased when intermittent non-ponded conditions are introduced. Applying water to achieve intermittent ponded and non-ponded conditions, known as alternate wetting and drying (AWD) irrigation (Chu et al., 2014) is one way of using less water. Adoption of AWD by farmers has been observed to maintain or increase yield (Yao et al., 2012). On the contrary, trials with AWD in tropical areas in Asia, such as in India and the Philippines, resulted in lower yields relative to continuous ponding (Tabbal et al., 2002). Belder et al. (2004) noted that, applying AWD in the field is usually characterized by lower yield and that, the level of AWD that produces similar yield as continuous ponding saves between 6 to 14 % water. Consequently, AWD results in 5-35 % higher water productivity relative to continuous ponding whiles characterized by 1-7 % yield reduction. The different results observed when AWD was used may be attributed to differences in soil types, degree of water stress during times of water deficit, and the stage of the life cycle at which water stress was introduced.

Nitrogen is a major nutrient for crops and as such its limited supply leads to reduced crop growth and yield (Linina and Ruza, 2018). Studies have shown that nitrogen fertilization increases growth and yield of different rice varieties (Yin et al., 2014; Amirouche et al., 2019). As a result, application of nitrogen in insufficient quantities and in the wrong manner may reduce potential yields by as much as two-thirds (Alagesan and Raja Babu, 2011). While relatively higher levels of nitrogen may be required to increase yield, nitrogen must be applied in quantities and at times that make it economically reasonable whiles also avoiding environmental contamination (Taddesse, 2009; Harutyunyan et al., 2022).

Plant spacing is a very important factor influencing rice growth and yield, and besides nitrogen, seeding rate is considered as the most important crop management practice that influences plant population, yield and yield stability of rice (Kuai, 2016; Lou et al, 2019). According to Ottis and Talbert (2005), low seeding rates in rice do not necessarily affect rice grain and yield. This is because the ability of the rice plant to produce tillers under good environmental conditions is a compensatory mechanism that allows for some plasticity in seeding rates (Harrell and Blanche, 2010). On the contrary, studies have also shown that low seeding rates can reduce rice yield (Bond et al., 2005, 2008). High seeding rates can also result in overpopulation, which leads to increased lodging potential, reduced leaf area and increased disease potential.

Several studies have been conducted to assess the effect of water management, nitrogen rate and plant spacing either alone or in combination of two of these factors. However, little information exists on the combined effect or interaction of these three factors on growth and yield of rice including the Legon Rice 1 variety. This study was therefore undertaken to assess the effect of varying water use, nitrogen rate and plant spacing and their interactions on rice yield and yield components for two cropping seasons.

Materials and Methods

Two different experiments were conducted for this study. The first field experiment was conducted from March to June 2023 (major rainy season) and from August to December 2023 (minor rainy season). The second experiment was conducted from March to June 2024 and from August to December 2024. Both experiments were conducted at the Soil and Irrigation Research Centre, Kpong (6^0 9’ N, 0^0 4’ E) of the University of Ghana and the rice variety used was the Legon Rice1

(Ex Baika) variety. Legon Rice1 is a medium-duration aromatic medium-grain variety. The experimental design was a split-split plot with two water treatments as main plot: continuous flooding (CF) involved repeated ponding to 5 cm height and alternate wetting and drying (AWD) involved ponding to a height of 5 cm after the water level dropped to 25 cm beneath the soil surface. Nitrogen at 0, 90 and 120 kg N ha^{-1} served as subplots and three plant spacing (20 × 15 cm, 20 × 20 cm and 20 × 25 cm) as sub-subplots. Randomization was restricted within the mainplot, subplot and sub-subplot and the same plots were used while maintaining the treatments over the two years. There were three replicates and plot sizes measured 4m by 3 m. Seedlings were transplanted when they were three weeks old at two seedlings per hill. Triple superphosphate and muriate of potash were used as sources of P_2O_5 and K_2O, respectively at rates of 45 kg ha^{-1}. Urea served as the source of nitrogen. Half of the nitrogen (N) and all P_2O_5 and K_2O was applied 7 days after transplanting and the remaining half N was applied at panicle initiation. Piezometers of length 50 cm and 15 cm in diameter were buried into the soil on all AWD plots, leaving 20 cm above the surface of the soil. Soil was removed from within the piezometers until the end of the piezometer inside the soil was visible. The drop in water level inside the piezometer was monitored and recorded using a ruler (IRRI, 2009). The water level in the piezometers was monitored every 2 days and irrigation interval in the AWD plots ranged between 7-10 days whiles irrigation interval for continuous flooding ranged between 3-5 days. The CF and AWD water management were applied during both the major and minor rainy seasons and the source of irrigation water was the Volta Lake. A distance of 2 m was used to separate main plots (water treatments). A small motorized pump was used to deliver water to plots based on the velocity volume approach (Trimmer, 1994). The pump speed was set to the same delivery rate each time water was delivered to plots. Rainfall data was obtained from a meteorological station on-site to help quantify total water input. Data on the amount of water supplied from pumping was recorded. A 4 m^2 area was hand harvested at maturity from each plot for yield determination and panicle density was determined by counting the number of panicles from a 1 m^2 area. A subsample of 5 hills was selected and dry weights of grain, leaf and straw were obtained. This was used to estimate the harvest index (HI) as the ratio of grain weight to total biomass. A subsample of 10 panicles was also selected and hand threshed to determine filled grains $panicle^{-1}$ and 1000-grain weight. The difference in water input between AWD and CF was used to estimate the amount of water saved. Grain yield per unit of water used provided a measure of water productivity. Data collected was analyzed with Genstat (12th Edition). Where significance was observed, Duncan's Multiple Range Test was used to separate multiple means at 5 % level of probability.

Most of the data points (> 95 %) were within ±2 standard deviations from the mean and a plot of the standardized residuals against the fitted values showed approximately equal variance with no observed pattern in the spread of the residuals. The deviations also followed an approximate normal distribution.

The soils' total organic carbon (TOC) was determined by the Walkley–Black method (Black, 1965). Soil pH was determined using a glass electrode pH metre at a ratio of 1: 2 (w/v) soil to water (Anderson & Ingram, 1993). Available P was determined by the Olsen method (Olsen, 1954), and total nitrogen by the Kjeldahl method (Landon, 1984). Cation exchange capacity was determined using the NH4 OAc method at pH 7. Soil texture was determined using the hydrometer method (Anderson and Ingram, 1993), and bulk density by the cylindrical core method (Arshad et al.,1996). A description of the factors in the experiment is shown in Table 1.

Results

Physical and chemical properties of the soil

Tables 2 and 3 present the properties of the soil used in the study. Soil pH, organic carbon and total nitrogen values were 6.7, 0.81 % and 0.10 %, respectively. The available P was 14.5 mg kg^{-1} with a cation exchange capacity of 34.9 cmol (+) kg^{-1}. Recorded Bulk densities

TABLE 1

Description of water management, N rate and plant spacing treatments for two seasons

Water management	N rate (kg ha^{-1})	Plant spacing
CF	0	15 × 20 cm
	90	20 × 20 cm
	120	20 × 25 cm
AWD	0	15 × 20 cm
	90	20 × 20 cm
	120	20 × 25 cm

CF, continuous flooding; AWD, alternate wetting and drying

TABLE 2

Chemical properties of the soil at the experimental site at Kpong, Ghana

Property	Value
pH in water	6.70
Organic C (%)	0.81
Total N (%)	0.10
Olsen P, mg kg^{-1}	14.5
CEC, cmol(+) kg^{-1}	34.9

TABLE 3

Physical properties of the soil at the experimental site at Kpong, Ghana

Soil depth (cm)	Bulk density (Mg m^{-3})	Sand	Silt	Clay	Textural class
		…………	%................		
0-10	1.43	41.1	2.9	55.0	Clay
10-20	1.41	36.7	2.9	57.6	Clay
20-30	1.48	36.7	2.5	58.9	Clay

were between 1.41 and 1.48 Mg m^{-3} while clay content ranged between 55 and 58.9 %.

From Table 4, harvest index and 1000-grain weight were not affected by the main effects of water management (WM), nitrogen rate (NR) and plant spacing (PS) and their interactions

TABLE 4

Analysis of variance result showing main effects of water management (WM), N rate (NR) and plant spacing (PS) and their interactions on yield and yield components for major and minor growing seasons over 2 years

Season	Effect	Harvest Index	1000-grain weight	Filled grains per panicle	Panicle density	Grain yield
		----------------------------------	p value	----------------------------------		
Major						
	WM	0.078	0.937	0.437	0.376	0.381
	NR	0.299	0.597	0.001	0.001	0.001
	PS	0.673	0.570	0.010	0.001	0.001
	WM × NR	0.253	0.094	0.473	0.108	0.469
	WM × PS	0.911	0.927	0.362	0.191	0.400
	NR × PS	0.071	0.569	0.332	0.134	0.094
	WM × NR × PP	0.611	0.226	0.603	0.256	0.238
Minor						
	WM	0.785	0.775	0.608	0.467	0.260
	NR	0.266	0.137	0.001	0.001	0.001
	PS	0.914	0.981	0.003	0.001	0.001
	WM × NR	0.805	0.599	0.370	0.744	0.305
	WM × PS	0.552	0.510	0.220	0.390	0.239
	NR × PS	0.600	0.998	0.076	0.180	0.100
	WM × NR × PS	0.901	0.522	0.759	0.926	0.232

TABLE 5

Effect of water management (WM), N rate (NR) and plant spacing (PS) on harvest index (HI), panicle density (PD) and filled grains per panicle (FGPP) in the major and minor seasons over 2 years

Effect	Description	Major season			Minor season		
		HI	PD	FGPP	HI	PD	FGPP
			Panicle m^{-2}			Panicle m^{-2}	
WM							
	CF	0.448a	219a	106a	0.441a	196a	106a
	AWD	0.444a	207a	105a	0.442a	198a	105a
	LSD (0.05)	0.005	48	4	0.008	9	4
NR	Kg N ha^{-1}						
	0	0.449a	127a	98a	0.436a	126a	98a
	90	0.448a	254b	108b	0.442a	229b	110b
	120	0.442a	258b	109b	0.447a	236b	109b
	LSD (0.05)	0.011	9	2	0.014	12	2
PS							
	15 × 20 cm	0.445a	217a	105ab	0.442a	222a	103a
	20 × 20 cm	0.449a	236b	103a	0.440a	197b	108b
	20 × 25 cm	0.445a	186c	106b	0.443a	173c	105c
	LSD (0.05)	0.012	15	2		0.013	14

CF, continuous flooding; AWD, alternate wetting and drying

for both major and minor seasons. For the two seasons, filled grains per panicle, panicle density and grain yield were all not altered by water management. Plant spacing significantly influenced panicle density, filled grains per panicle and grain yield for both major and minor seasons. Similarly, the N rate had a significant effect on filled grains per panicle, panicle density and grain yield for the major and minor seasons. All the interactive effects did not influence yield and yield components in both seasons.

Results from Table 5 show that, across all nitrogen rate (NR) and plant spacing (PS), water management (WM) had no effect on harvest index (HI), panicle density (PD) and filled grains per panicle (FGPP) for both major and minor seasons as the differences observed between continuous flooding and alternate wetting and drying were not significant. Nitrogen rate did not influence harvest index when the data was evaluated across water management and plant spacing. However, nitrogen rate significantly influenced panicle density and filled grains per panicle with values ranging between 126-258 panicle m^{-2} and 98-110 FGPP over the major and minor seasons. The PD and FGPP did not differ between 90 and 120 kg N ha^{-1} for both seasons. Applying N at 90 and 120 kg ha^{-1} recorded between 47.5-48.7 % more panicles and 10.0-10.1 % more FGPP compared to the 45 kg N ha^{-1} across the major and minor seasons. Assessing the effect of plant spacing across all water management and nitrogen rates showed that plant spacing did not affect harvest index and 1000-grain weight. On the contrary, plant spacing influenced filled grains per panicle and panicle density for both the major and minor seasons. Generally, lower FGPP was observed for higher panicle densities under PS, but not under NR. During the major season, the plant spacing of 20 × 20 cm recorded significantly higher PD (236 panicle m^{-2}) compared to the 15 × 20 cm and 20 × 25 cm plant spacing which recorded 217 and 186 panicle m^{-2}, respectively. However, during the minor season, the plant spacing of 15 × 20 cm recorded significantly higher PD (222 panicle m^{-2}) compared to the of 20 × 20 cm and 20 × 25 cm plant spacing which recorded 197 and 173 panicle m^{-2}, respectively. Transplanting at 15 × 20 cm and 20 × 20 cm resulted in 16.7-18.2 % more panicles and 1.4-2.3 % less FGPP compared to 20 × 25 cm across the major and minor seasons. Panicle density was relatively higher for the major season than the minor season with average panicle density of 213 and 197 panicle m^{-2}, respectively.

Across all nitrogen rate (NR) and plant spacing (PS), water management (WM) had no effect on 1000-grain weight and grain yield for both major and minor seasons (Table 6). When the data was evaluated across water management and plant spacing, nitrogen rate had a significant effect on grain yield with values ranging between 2227 and 4768 kg ha^{-1}over the major and minor seasons. Applying N at 90 and 120 kg ha^{-1} recorded 47.0 % more grain yield as compared to the 45 kg N ha^{-1} across the major and minor seasons. Similarly, plant spacing significantly influenced grain yield but did not alter 1000-grain weight. During the major season, the plant spacing of 20 × 20 cm recorded significantly higher grain yield (4333 kg ha^{-1}) compared with the 15 × 20 cm and 20 × 25 cm plant spacing which recorded 4029 and 3556kg ha^{-1}, respectively. However, during the minor season, the highest yield was recorded for the 15 × 20 cm plant spacing with a value of 3968 kg ha^{-1}. Transplanting at 15 × 20 cm and 20 × 20 cm resulted in 14.7 % more grain yield as compared to 20 × 25 cm across the major and minor seasons. The major season recorded a relatively higher grain yield than the minor season.

At the lowest N rate of 45 kg ha^{-1}, plant spacing did not affect panicle density and grain yield (Table 7). As N rate increased to between 90 and 120 kg ha^{-1}, plant spacing influenced panicle density and grain yield for both major and minor seasons. During the major season, plant spacing of 20 × 20 cm and 15 × 20 cm had a similar effect on grain yield. However, plant spacing of 15 × 20 cm recorded significantly higher grain yield than 20 × 20 cm during the minor season ove r two years. Generally, the major season recorded higher panicle density and yield than the minor season.

During the major season, irrigation water input was 644 mm for CF and 571 mm for AWD (Table 8). Irrigation water input for CF and AWD during the minor season were 836 mm and 756 mm, respectively. Total water input for the major season for both CF and AWD were higher with values ranging between 1039 and 1112 mm compared with a range of between 948 and 1028 mm for the minor

TABLE 6

Effect of water management (WM), N rate (NR) and plant spacing (PS) on 1000-grain weight (1000-GW) and grain yield in the major and minor seasons over 2 years

Effect	Description	Major season		Minor season	
		1000-GW	**Grain yield**	**1000-GW**	**Grain yield**
		g	kg ha^{-1}	g	kg ha^{-1}
WM					
	CF	26.3a	4082a	26.3a	3584a
	AWD	26.4a	3863a	26.3a	3516a
	LSD (0.05)	0.267	847	0.292	188
NR	Kg N ha^{-1}				
	0	26.4a	2500a	26.4a	2227a
	90	26.4a	4650b	26.4a	4156b
	120	26.3a	4768b	26.2a	4269b
	LSD (0.05)	0.146	181	0.214	157
PS					
	15 × 20 cm	26.4a	4029a	26.3a	3968a
	20 × 20 cm	26.4a	4333b	26.3a	3504b
	20 × 25 cm	26.3a	3556c	26.4a	3180c
	LSD (0.05)	0.192	247	0.223	195

CF, continuous flooding; AWD, alternate wetting and drying

TABLE 7

Panicle density and grain yield of different plant spacing (PS) at various N rates averaged over water management in the major and minor seasons over 2 years

	Panicle density (panicle m^{-2})			Grain yield (kg ha^{-1})		
PS	N0	N90	N120	N0	N90	N120
Major season						
15 × 20 cm	135a	256a	259a	2220a	4888a	4980a
20 × 20 cm	134a	279b	295b	2309a	5264a	5427a
20 × 25 cm	110a	226c	221c	2147a	4265b	4264b
LSD (0.05)	26	19	24	191	418	508
Minor season						
15 × 20 cm	133a	256a	278a	2289a	4660a	4955a
20 × 20 cm	131a	233a	228b	2246a	4090b	4176b
20 × 25 cm	115a	201b	203b	2145a	3718c	3675c
LSD (0.05)	27	24	26	273	284	291

TABLE 8

Water supply under continuous flooding (CF) and alternate wetting and drying AWD) water management averaged over N rate and plant spacing over 2 years

Season	Water	Rain (mm)	Irrigation (mm)	Total water input (mm)	Change (%)
Major	CF	468	644a	1112	
	AWD	468	571b	1039	11.3
	LSD		5		
Minor	CF	192	836a	1028	
	AWD	192	756b	948	9.5
	LSD		11		

AWD = Alternate Wetting and Drying, CF = Continuous Flooding

season. Reduction in water input for AWD relative to CF was between 9.5 and 11.3 %.

Plant spacing generally influenced grain yield with 20 × 20 cm and 15 × 20 cm recording significantly higher grain yield compared with 20 × 25 cm (Table 9) for both major and minor seasons. Nitrogen rate affected grain yield with 0 kg N ha^{-1} recording significantly lower grain yield than 90 and 120 kg N ha^{-1}. Grain yield between CF and AWD for both seasons

TABLE 9

Grain yield of transplanted rice at different plant spacing over 2 years

	Grain yield (kg ha^{-1})					
	CF			AWD		
PS	N0	N90	N120	N0	N90	N120
Major season						
15 × 20 cm	2228a	5219a	4990a	2217a	4557a	4969a
20 × 20 cm	2487b	5258a	5786a	2093a	5271b	5068a
20 × 25 cm	2142a	4339b	4264b	2156a	4190a	4264b
LSD (0.05)	229	487	834	222	548	558
Minor season						
15 × 20 cm	2238a	4731a	5320a	2340a	4589a	4590a
20 × 20 cm	2306a	4077b	4123b	2186a	4104b	4228b
20 × 25 cm	2147a	3658b	3661c	2143a	3778b	3690c
LSD (0.05)	441	509	393	423	370	317

was also similar.

From Table 10, the major season recorded significantly higher mean water productivity (0.656 kg m^{-3}) compared to the minor season (0.448 kg m^{-3}). In the case of water management, AWD recorded significantly higher water productivity values (0.284-0.934 kg m^{-3}) compared to CF (0.257-0.898 kg m^{-3}). Higher water productivity values were also observed for the higher N rates with 90 and 120 kg ha^{-1} recording significantly higher water productivities than 0 kg ha^{-1}.

TABLE 10

Water productivity of transplanted rice at different plant spacing over 2 years

	Water productivity (kg m^{-3})					
	CF			AWD		
PS	N0	N90	N120	N0	N90	N120
Major season						
15 × 20 cm	0.345a	0.810a	0.777ab	0.390a	0.799a	0.870a
20 × 20 cm	0.393b	0.816a	0.898b	0.367a	0.934b	0.899a
20 × 25 cm	0.332a	0.674b	0.663a	0.378a	0.735a	0.747b
LSD (0.05)	0.047	0.071	0.134	0.043	0.098	0.095
Minor season						
15 × 20 cm	0.267a	0.565a	0.637a	0.310a	0.609a	0.610a
20 × 20 cm	0.276a	0.488b	0.493b	0.290a	0.546ab	0.562ab
20 × 25 cm	0.257a	0.438b	0.438c	0.284a	0.501b	0.490b
LSD (0.05)	0.054	0.059	0.049	0.059	0.074	0.075

Discussions

According to Cabangon (2011), mild stress AWD tends to have little or no effect on yield and yield components and this may be responsible for the insignificant differences recorded in harvest index, panicle density, filled grains per panicle, 1000-grain weight and grain yield between CF and AWD. Under limited water availability to plants, the rate of photosynthesis decreases due to reduced evapotranspiration. Panicle density and tiller number are reduced as a result (Kima et al., 2014). Nguyen et al. (2009) in a study that compared different water management options observed similar tiller number and panicle density and therefore, concluded that plant height and leaf area were more sensitive to water deficit than tillering. In another related study, soil moisture had no influence on tiller number and panicles per hill throughout the life cycle of a number of rice cultivars (Akram et al. 2013). According to Surapaneni et al. (2016), moisture stress reduces partitioning intensity to reproductive plant parts and this can reduce grain filling to eventually reduce grain yield. The similar harvest index recorded for AWD and CF shows that the two water regimes had similar grain filling or partitioning to reproductive plant parts. In another study, yield components such as filled grains per panicle, 1000-grain weight and grain filling rate of rice were all observed to be reduced by water stress (Jones et al. 2004). The mild water stress provided by the AWD used in this study is likely responsible for the similar number of filled grains per panicle. Belder et al. (2004) indicated that the main factor which determines whether the rice plant is stressed enough to reduce yield is the level of water stress from AWD. Therefore, the mild water stress from the AWD used may have led to the similar grain yield observed between CF and AWD. Yang and Zhang (2010) also noted that when AWD was practiced throughout the rice life cycle, there was a significant reduction in yield due to reduced soil moisture under AWD. Howell et al. (2015) recorded similar rice yield between CF and AWD which agrees with the results from this study. On the contrary, higher grain yield was recorded under AWD than plants under continuous submergence (Chu et al., 2015). Soil type, frequency and duration of the dry spell can lead to variations in AWD and this could have resulted in the different observations made under AWD (Bouman and Toug, 2001; Belder et al., 2004).

The lack of any difference in harvest index due to N rate is an indication that the partitioning intensity to reproductive plant parts due to the N rates tested was not different (Richards, 2000). Ofori et al. (2017) recorded similar 1000-grain weight at different N rates and this confirms the lack of any difference in 1000-grain weight observed from this study. Ofori et al. (2017) concluded that, the 1000-grain was genetically controlled and that it was not strongly influenced by the environmental conditions that existed. A higher N content of the plants that received higher N rates may be responsible for the higher filled grains per panicle, panicle density and grain yield observed. The significant increase in filled grains per panicle, panicle density and grain yield as a result of higher N application in this study was confirmed by previous research on rice (Awan et al., 2011)

From this study, plant spacing had no effect on harvest index and 1000-grain weight because these traits were mainly under genetic influence (Ofori et al., 2017). According to Deng et al. (2012), an increase in panicle density is usually accompanied by a reduction in grains panicle^{-1}. This trend for increased filled grain panicle^{-1} with declining panicle densities has been described as a yield compensatory measure in rice when plant populations are less than optimum (Bond et al., 2008). Results from this study generally agree with this compensatory measure under plant spacing. During the major season, plant spacing of 20 × 20 cm and 15 × 20 cm had a similar effect on grain yield. However, plant spacing of 15 × 20 cm recorded significantly higher grain yield than 20 × 20 cm during the minor season over two years. Awan et al. (2011) in a study to evaluate different seeding rates planted at different sowing dates under varying N rates made a similar observation where higher seeding rates produced higher yield at one sowing date, but had lower yield relative to lower seeding rates on a different sowing date. They concluded that the higher seeding rate may have produced more primary and secondary tillers during the sowing date on which it produced higher yield, which eventually would have resulted in a higher panicle density to increase yield relative to the lower seeding rate. The results from this study show clearly that a plant spacing of 20 × 25 cm does not provide enough plant stand to give high yield. The results of this research and other findings (Bond et al., 2008) indicate that while rice can produce more tillers in low plant populations to compensate for yield, there exist a threshold population where yield cannot be compensated for by increased tiller production and yield will be reduced. For both major and minor seasons, grain yield increased with increasing plant population. However, the observed differences in yield became less pronounced at higher plant populations.

There was no interaction between the N rate and the two water management strategies, CF and AWD. This suggests that the effect of N rate was consistent regardless of the water management method. The lack of any significant interaction between N rate and plant spacing for both major and minor seasons suggests that very low rice densities emanating from low plant population (wider spacing) cannot be compensated for by increasing N fertilization (Harrell and Blanche, 2010). This observation is in agreement with research conducted with currently grown rice varieties (Bond et al., 2008). On the contrary, other studies using older rice cultivars showed that increased N fertilization had an effect on plant population to increase yield (Wells and Faw, 1978, Counce et al., 1992). It is worth noting that at the higher plant population (15 × 20 cm plant spacing), N rate of 120 kg ha^{-1} had a greater influence on panicle density than 90 kg N ha^{-1} during the minor season compared with the major season. From this study, grain yield was similar between 20 × 20 cm and 15 × 20 cm plant spacing during the major season and this is likely due to environmental conditions that allowed the compensatory ability of rice to come into play more during the major season. However, the significantly higher grain yield (11.6 % more) observed for 15 × 20 cm (higher plant population) than 20 × 20 cm plant spacing in the minor season is likely due to the lower tillering and panicle density generally observed during the minor seasons. As such, the higher plant population (15 × 20 cm spacing) increased panicle density to give a higher yield than the 20 × 20 cm plant spacing.

The lower amount of irrigation water input for the major season is because of the higher amount of rainfall during the major season. This result agrees with Stanslaus et al. (2018) who recorded more irrigation water input during the dry season than in the wet season. Though the minor season used more irrigation water, total water input for both CF and AWD were higher for the major season and this is largely as a result of the higher rainfall water input. There was between 9.5 to 11.3 % reduction in irrigation water input for AWD relative to CF. According to Cabangon (2011), mild stress AWD decreased irrigation water use by 8-20 % and severe stress by 19-25 % compared to CF. This confirms the fact that the AWD employed in this study provided mild water stress and this was further supported by the lack of any significant effect of water management on yield and yield components of rice for both major and minor seasons. The higher water productivity observed for the major season compared with the minor season is due to the relatively higher grain yield for the major season. Also, the lower amount of irrigation water input under AWD resulted in the higher water productivity recorded for AWD. While Chu et al. (2015) recorded higher water productivity for AWD than CF, Dahmardeh et al. (2015) observed no significant difference in water productivity between CF and AWD. Cabangon (2011) attributed the lack of any difference between CF and AWD to mild AWD.

Conclusion

Reducing water use in irrigated rice through AWD technology is becoming more popular with irrigated rice farmers due to water cost and the need to save water. This study was undertaken to evaluate the main effects of water management, N rate and plant spacing and their interactions on panicle density, rice yield and yield components as well as water productivity. There was no reduction in panicle density and rice grain yield from the AWD assessed compared with CF, though irrigation water use for AWD decreased. A higher water productivity was recorded when AWD was used in the field. The lack of any significant interaction between N rate and water management (NR × WM) and plant spacing and water management (PS × WM) is an indication that the effect of N rate and plant spacing between CF and AWD was similar. Applying AWD saved 10.4 % water relative to CF. Increasing N rate increased yield, but with no yield advantage for 120 kg N ha^{-1} over 90 kg N ha^{-1}. Increasing N rate also increased water productivity because of the higher yield observed as N rate increased. During the major season, panicle density and yield were similar between 20 × 20 cm and 15 × 20 cm plant spacing. However, a greater yield increase was observed at 15 × 20 cm plant spacing during the minor season. The similar panicle density and yield between 20 × 20 cm and 15 × 20 cm plant spacing in the major season and the higher panicle density and yield at 15 × 20 cm plant spacing during the minor season is an indication that increased tiller production is a yield compensatory measure under low plant densities. On the contrary, total yield compensation may not be possible under relatively low plant densities and that the environmental conditions can also influence the degree of compensation. Therefore, employing AWD and applying N at 90 kg ha-1 can save water and reduce N loss into the environment. Also, establishing fields at 20 × 15 cm spacing during the minor season which is usually characterized by lower tillering and yield is recommended to increase tiller density to eventually increase or maintain yield.

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