Agricultural Sciences, 2019, 10, 92-109
http://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

# Agronomic, Water Productivity and Economic Analysis of Irrigated Rice under Different Nitrogen and Water Management Methods

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**How to cite this paper:** Yakubu, A., Ofori, J., Amoatey, C. and Kadyampakeni, D.M. (2019) Agronomic, Water Productivity and Economic Analysis of Irrigated Rice under Different Nitrogen and Water Management Methods. *Agricultural Sciences*, **10**, 92-109.
https://doi.org/10.4236/as.2019.101008

**Received:** December 9, 2018
**Accepted:** January 18, 2019
**Published:** January 21, 2019



## Abstract

The most limiting factors for irrigated rice farming are water and nitrogen. Efficient water and nitrogen management has remained critical for sustainable rice production in irrigated rice farming system. Due to rapid global population growth and climate change, future rice production will depend heavily on developing strategies and practices that use water and nitrogen efficiently. The study therefore set to evaluate agronomic, water productivity and economic analysis of irrigated rice under various nitrogen and water management methods. To achieve the set objectives, field and pot experiments were carried out at the Soil and Irrigation Research Centre, University of Ghana, Kpong in 2015 and 2016 cropping season. The field experiment was laid in a split plot design with water management treatments as main plots and N fertilizer as subplot treatment. The pot experiment was carried out in a randomized complete block design with five replications. The water management treatments were; continuous submergence (SC), alternate wet and dry soil condition (AWD) and moist soil condition (MC). Nitrogen fertilizer rates were; no N fertilizer (N0), 60 kg N/ha (N1) and 90 kg N/ha (N2). Data such as yield and yield parameters of rice, water use, water productivity, costs and returns were recorded. Results obtained from both pot and field experiments revealed that rice yields were at par in AWD and SC but yields were lower in MC treatment. With N fertilizer, higher yields were observed with 90 kg N/ha. The interaction effect of submerged with 90 kg N/ha gave the highest grain yield. N fertilizer effect on water use and water productivity was ranked as N2 > N1 > N0 while water management effect on water use and water productivity was ranked in this order: SC > AWD > MC and MC > AWD > SC respectively.

**Keywords**

Irrigated Rice, Nitrogen, Water Management, Yield, Water Productivity

## 1. Introduction

Rice (*Oryza sativa* L.) is one of the most consumed cereal crop in most of parts of the world. It is said to be a staple crop for more than half of the world's population [1]. About 79 million ha of irrigated lowlands account for 75% of the global rice production [2]. In Ghana, rice is considered to be the second most important contributor of food security next to maize [3] and the 5th most important source of energy in the diet accounting for 9 percent of total caloric intake [4].

The rice sector is not only the major contributor of food security but also the biggest consumer of freshwater resources. Researchers [5] observed that, lowland rice consumes large volumes of water than any other irrigated crop and it requires up to 2 - 3 times more water compared to other crops.

It is widely acknowledge that rice is grown under continuous submergence to counter nutrient, water and weed stresses by pumping water from the rivers and their tributaries by either small diesel pumps or large electric pumping systems which intern reduce water productivity and farmers' income [6]. Water and energy has therefore emerged to be key elements of sustainability of rice production.

Also, N nutrition drives rice production but there is a spiral increase (50%) in inorganic fertilizer prices in Ghana due to fall of the local currency on exchange market, increase in fuel prices and the removal of government subsidies on fertilizer price [7]. In effect, majority of Ghanaian farmers are unable to apply fertilizer at the required rate for a good crop yield. In addition to high cost of fertilizers, poor nitrogen and water management have also resulted in serious drawbacks in rice production by small-holder farmers who form the majority of the farming population. As a result, fertilizer and water often represent the most expensive input cost for irrigated rice farming.

Furthermore, decreasing water availability for agriculture threatens the production of rice in irrigated system. Worldwide, fresh water resources are threatened by rapid global population growth and climate change. Due to growing demand for water resources from all sectors, it is projected that by 2025, some countries in Sub-Sahara Africa (SSA) including Ghana will face water stress [8]. Water management is therefore critical for sustainable rice production in irrigated rice farming system.

In order to improve water use efficiency and water productivity in irrigated rice, many water management techniques have been proposed [9] [10] [11] [12]. However, considering the spiraling increase in cost of chemical fertilizer and huge competition for water for industrial, domestic and agricultural use, it is essential to identify the most efficient water management methods and optimum N fertilizer level for sustainable increase in rice productivity in irrigated rice farming system in Ghana. Against this backdrop, this work seeks to evaluate agronomic, water productivity and economic analysis of irrigated rice farming under different N levels and water management methods in that only the most cost-effective technologies that mirror the economic capabilities of the Ghanaian farmer can be promoted.

## 2. Materials and Methods

### 2.1. Description of the Study Area

The experiments were carried out at the Soil and Irrigation Research Centre (SIREC) of the University of Ghana in 2015 and 2016 cropping season. Geographically, the experimental area is located between latitudes (00'04"E, 60'09"N), in the Eastern region of Ghana. It is part of the Accra plains and has annual rainfall between 800 and 1100 mm with mean annual temperature of 28˚C. The soils of the experimental site are vertisols, which are characterised by montmorillonitic clay minerals with clay content of 35% - 40%. Initial chemical characteristics of soils of the experimental site (0 - 20 cm depth) are indicated in Table 1.

### 2.2. 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 × 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 10,000 $cm^3$ 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 to attain the field bulk density. The pot experiment was carried out in a randomized complete block design with five replications.

### 2.3. Experiment Design and Treatments

The experiment was carried out in a split plot design with 3 replications. The main plot factors were water management regimes and the sub-plot factors were nitrogen levels. The three water management methods were: alternate wet and dry (AWD), moist soil condition between field capacity and permanent wilting point (MC), and continuous submergence (SC). The nitrogen levels were: 0, 60 and 90 kg N/ha as subplots within each main plot as indicated in Table 2. The main plots were separated from each other by bunds at a distance of 2 m whiles

**Table 1.** Chemical characteristics of soil at 0 - 20 cm depth.

| Depth (cm) | TN% | AP | AK ($mg \cdot kg^{-1}$) | Ca ($mg \cdot kg^{-1}$) | pH | OC% |
|---|---|---|---|---|---|---|
| 0 - 20 | 0.067 | 2.09 | 4.72 | 22.83 | 7.55 | 1.55 |

TN: total nitrogen, AP: available phosphorus, AK: available potassium, Ca: exchangeable calcium, pH: soil reaction, OC: organic carbon.

**Table 2.** Description of treatments.

| Water management | Nitrogen fertilizer level |
|---|---|
| | No nitrogen fertilizer (N0) |
| Alternate wetting and drying (AWD) | Urea 60 kg N/ha (N1) |
| | 90 kg N/ha (N2) |
| | No nitrogen fertilizer (N0) |
| Moist condition between saturation and field capacity (MC) | 60 kg N/ha (N1) |
| | 90 kg N/ha (N2) |
| | No nitrogen fertilizer (N0) |
| Continuous submergence (CS) | 60 kg N/ha (N1) |
| | 90 kg N/ha (N2) |

metallic barriers of size 6 $m^2$ were then buried 30 cm deep in each sub plot to reduce lateral movement of water and nutrients. Rice variety, Ex Baika was used as the test crop. Twenty five days old seedlings were transplanted at spacing of 20 cm within rows and 20 cm between rows with 2 seedlings per hill. During planting, all the plots were kept saturated with irrigated water to prevent transplanting shock.

## 2.4. Fertilizer Application

The nitrogen fertilizer source was Urea. Nitrogen fertilizer was applied two times that is 50% at transplanting and 50% at panicle initiation. Nitrogen fertilizer levels were 0, 60 and 90 kg N/ha henceforth referred to as N0, N1 and N2, respectively. Straight fertilizers of triple Superphosphate ($P_2O_5$) and muriate of potash ($K_2O$) was applied at a rate of 45 kg/ha to all the plots at transplanting of seedlings.

## 2.5. Water Management

After transplanting, all the plots were irrigated to maintain uniform moisture content at saturation for the first week to ensure full establishment of the seedlings. Perforated PVC pipes of about 3 cm in diameter and 45 cm in length were inserted in all except submerged treated plots 15 cm above and 30 cm below the soil surface to monitor soil water levels below the soil surface.

Graduated buckets and cylinders were used to apply water to the plots and pots, and the quantity of water applied throughout the experiment was recorded. The amount of rainfall (rainfall events) during the experimental period was also recorded. A metre wooden rule was used to measure moisture level below and above the soil surface. Water was maintained at 5 cm above the soil surface till ten days to harvest in the continuous submerged treatment. For the moist treatment, soil moisture was kept at 18 cm and 25 cm below the soil surface in the pot and field experiments, respectively. In the AWD treatment, the experimental unit was only submerged (5 cm above the soil surface) when soil moisture dropped to 18 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.

## 2.6. Water Use Measurement

Water was applied through a horse pipe and the amount of water consumed per plot was measured using containers with known volume. Water application was done using graduated containers (10 and 15 liters). The amount of water-use was obtained from daily measurements. Depth of irrigation water (mm) applied was computed by dividing the volume of water applied by the area of the sub-plot. Also, amount of precipitation during the period (rainfall events and amounts) were recorded.

## 2.7. Data Collection

Grain yield was determined by weighing grains from 5 $m^2$ and expressed as t/ha at 14% grain moisture. Ten plants were selected at the center of the plot randomly and used to determine the yield components: test weight, percentage of filled grains, grains/panicle and effective tillers.

**Quantification of water productivity and economic analysis of water use**

Water productivity was estimated according to [13]. The equation for estimating water productivity is given as;

$$WP = \frac{GY}{TWA}$$

where; $WP$ = water productivity (kg/$m^3$), $GY$ = grain yield (kg/ha) and $TWA$ = total water applied (irrigation water and rain water) expressed in $m^3$/ha. Percentage water saving was obtained with reference to the irrigation water and calculated as the difference in irrigation under the two water management regimes divided by the irrigation water applied under the SC regime expressed as a percentage.

Net returns from sales of rice was calculated as;

$$\text{Net returns} = \text{Cost of production} - \text{Gross returns} \tag{1}$$

Benefit cost ratio; $B/C$ was estimated using the formula;

$$B/C = \frac{\text{Gross returns}}{\text{Cost of cultivation}} \tag{2}$$

### 2.8. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) to find out the significance difference due to treatments using GenStat (12th Edition). Mean separation was done using least significance difference (LSD) at 5% level of significance.

## 3. Results

### 3.1. Agro-Hydrological Conditions

The summary for the climatic data presented in **Table 3** was recorded at the University of Ghana Soil and Irrigation Research Center agro-meterological station during research period. The total rainfall during the entire period was 396.8 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 at the experimental site ranged from 23.0% in December to 62.0% in October.

### 3.2. Results from Pot Experiment

#### 3.2.1. Rice Yield and Yield Parameters

Grain yield was significantly ($p < 0.05$) influenced by water management and N fertilizer (**Figure 1**). Grain yield in AWD was at par with SC water treatment, while MC water treatment produced significantly ($p < 0.05$) lower grain yield. Differences in yield among the N levels were in the order: N2 > N1 > N0.

Number of effective tillers/pot was significantly ($p < 0.05$) influenced by both water management and N fertilizer (**Table 4**). Also, the interaction effect of water management and N fertilizer was significant. Number of effective tillers did not differ significantly ($p > 0.05$) between AWD and SC water treatments. However both water treatments were significantly superior to MC water treatment.

Number of effective tillers increased with increased N rate with the lowest number of tillers being recorded in plants treated with no N fertilizer (N0). Interaction effect of N2 and SC produced higher number of effective tillers followed by N2 and AWD interaction. In all, N0 with MC interaction was inferior to all other interaction effect. Number of grains/panicle was significantly ($p < 0.05$) influenced by water management and N fertilizer (**Table 4**). Also, the interaction effect of water management and N fertilizer on number of grains/panicle was significant ($p < 0.05$).

AWD and SC produced similar number of grains/panicle however, MC treated plants produced the lowest number of grains/panicle. With response to N fertilizer, number of grains/panicle increased with increased N application rate with the lowest number produced in N0. Interaction effect of N2 with SC and N0 with moist produced the highest and lowest number of grains/panicle respectively.

Percentage filled grains ranged from 88.3% to 93.7% depending upon treatment combination as indicated in **Table 4**. Percentage filled grains was significantly

**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.

**Table 4.** Effective tillers, grains/panicle, % filled grains and test weight as influenced by nitrogen and water management.

| Parameter | Water mgt. (W) | Nitrogen management (N) | | | | LSD (0.05) | | |
|---|---|---|---|---|---|---|---|---|
| | | N0 | N1 | N2 | Mean | N | W | N × W |
| Effective tillers | AWD | 15 | 20 | 21 | **19** | | | |
| | MC | 12 | 14 | 18 | **14** | 0.9** | 0.9** | 1.6* |
| | CS | 15 | 19 | 22 | **19** | | | |
| | **Mean** | **14** | **18** | **20** | | | | |
| Grains/panicle | AWD | 100 | 106 | 134 | **113** | | | |
| | MC | 91 | 95 | 102 | **99** | 4.1** | 4.1** | 7.1* |
| | CS | 103 | 108 | 135 | **115** | | | |
| | **Mean** | **98** | **103** | **124** | | | | |
| % filled grains | AWD | 89.3 | 93.7 | 92 | **91.7** | | | |
| | MC | 88.3 | 89 | 90 | **92.6** | 1.3* | ns | ns |
| | CS | 91.7 | 93.7 | 92.3 | **89.1** | | | |
| | **Mean** | **89.8** | **92.1** | **91.4** | | | | |
| 1000 grain weight (g) | AWD | 27.4 | 26.9 | 26.5 | **26.8** | | | |
| | MC | 27.1 | 26.6 | 27.1 | **26.9** | ns | ns | ns |
| | CS | 27.3 | 27.5 | 27.4 | **27.4** | | | |
| | **Mean** | **27.3** | **27** | **27** | | | | |

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N·ha$^{-1}$ respectively. LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

($p < 0.05$) influenced by N fertilizer treatments but not by water management. N2 and N1 did not differ in percentage filled grains but lowest percentage filled grains was recorded in N0. The interaction of water management and N fertilizer on percentage filled grains was non-significant ($p > 0.05$).

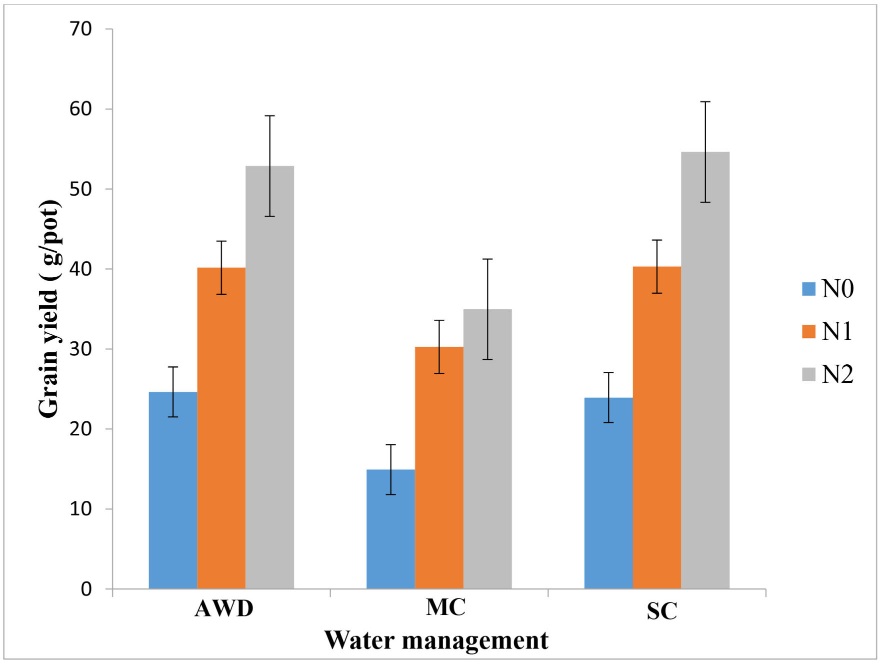


**Figure 1.** Grain yield of rice as influenced by N fertilizer and water management. AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N·ha$^{-1}$ respectively. Bars represent means ± SEM of 3 replicates.

Test weight was not significantly ($p > 0.05$) influenced by both N fertilizer and water management (Table 4). Also, there was no interaction effect of water management and N fertilizer on test weight.

### 3.2.2. Water Use, Percentage Water Saved and Water Productivity

Water use was significantly ($p < 0.05$) influenced by both water management and N fertilizer application rate (Table 5). Interaction effect of water management and N fertilizer significantly ($p < 0.05$) influenced water use. For N fertilizer, the trend of response of water use was N2 > N1 > N0. Water use with regards to water management was ranked in this order: MC < AWD < SC.

Nitrogen did not significantly ($p > 0.05$) influence percentage of water saved. Also there was no significant ($p > 0.05$) interaction effect between water and nitrogen on percentage water saved.

Percentage of water saved was insignificantly ($p < 0.05$) higher under MC treatment than AWD treatment. Both water management treatments and N fertilizer, and their interactions had a significant ($p < 0.05$) effect on water productivity (Table 5). In all cases, water productivity increased with increased N fertilizer application rate. In relation to water management treatments, water productuctivity was ranked in this order: MC > AWD > SC. In general, the interaction effect of N2 with MC water management produced higher *WP* followed by N1 with same water management. The lowest *WP* (0.47 g·cm$^{-3}$) was observed at N0 with SC interaction.

**Table 5.** Water use, percentage water saved and water productivity under various water and nitrogen treatments in rice.

| Parameter | Water mgt. (W) | Nitrogen management (N) | | | | LSD (0.05) | | |
|---|---|---|---|---|---|---|---|---|
| | | N0 | N1 | N2 | Mean | N | W | N × W |
| Water use ($cm^3$) | AWD | 48 | 49.3 | 50.5 | **49.3** | | | |
| | MC | 23.1 | 26.4 | 32 | **27.2** | 0.95** | 0.96** | 1.66* |
| | CS | 50.8 | 53.3 | 57.8 | **54** | | | |
| | **Mean** | **40.6** | **43** | **46.7** | | | | |
| Percentage water saved (%) | AWD | 20.4 | 15.5 | 20.8 | **18.3** | | | |
| | MC | 27.9 | 26.5 | 28.3 | **27.8** | NS | 2.7** | NS |
| | CS | - | - | - | **-** | | | |
| | **Mean** | **24.2** | **21** | **24.6** | | | | |
| Water productivity ($g/cm^3$) | AWD | 0.51 | 0.82 | 1.05 | **0.79** | | | |
| | MC | 0.65 | 1.06 | 1.09 | **0.96** | 0.3** | 0.3** | 0.05** |
| | CS | 0.47 | 0.76 | 0.95 | **0.72** | | | |
| | **Mean** | **0.55** | **0.91** | **1.03** | | | | |

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 $kg \cdot N \cdot ha^{-1}$ respectively. LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

## 3.3. Results from Field Experiment

### 3.3.1. Yield and Yield Parameters of Rice

The effect of various water management and N fertilizer rate on rice yields is shown in **Figure 2**. In water management treatments, grain yield in AWD was at par with SC water treatment, while MC water treatment produced significantly ($p < 0.05$) lower grain yield. Differences in yield among the N levels were in the order: N2 > N1 > N0. With regards to interaction effect, the highest grain yield (6.5 t/ha) was recorded in N2 with SC interaction followed by N2 with AWD interaction which produced grain yield of 6.4 t/ha. The lowest grain yield (2.2 t/ha) was recorded in N0 treated plants in moist water condition.

Number of panicles/$m^2$ was significantly ($p < 0.05$) influenced by water management and N fertilizer as well as their interactive effect (**Table 6**). Number of panicles/$m^2$ in AWD was at par with SC water treatments. However, MC treated plants produced significantly lower panicles/$m^2$. With regards to N fertilizer rates, panicles/$m^2$ varied significantly and was ranked in the order: N2 > N1 > N0. Interaction effect of N2 with submerged produced higher number of panicles/$m^2$ followed by N2 and AWD interaction. In all, N0 with moist interaction was inferior to all other interaction effect.

Number of grains/panicle was significantly influenced by water management and N fertilizer (**Table 6**). Also, the interaction effect of water management and

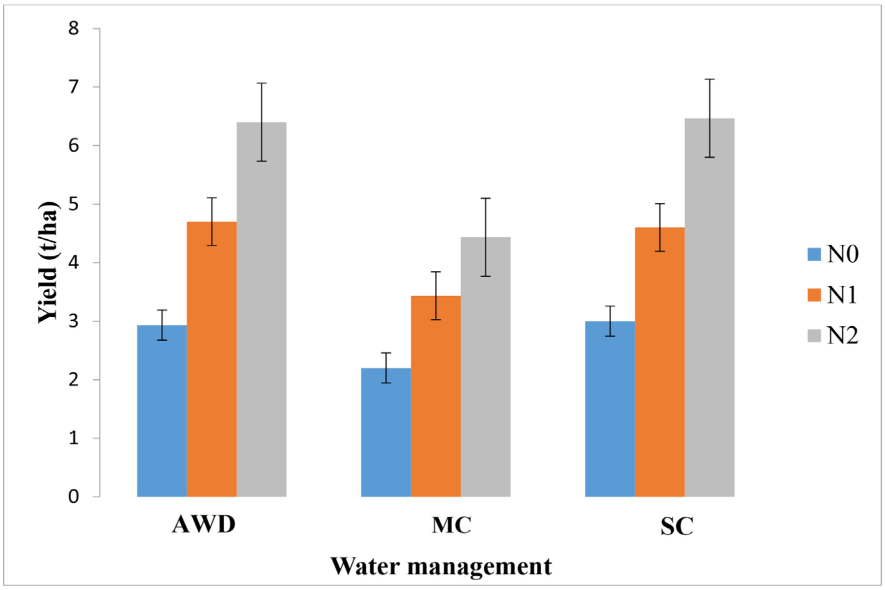


Figure 2. Grain yield of rice as influenced by N fertilizer and water management. AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N·ha$^{-1}$ respectively. Bars represent means ± SEM of 3 replicates.

Table 6. Panicles/m$^2$, grains/panicle, % filled grains and test weight of rice as influenced by water management and nitrogen fertilizer.

| Parameter | Water mgt. (W) | Nitrogen management (N) | | | | LSD (0.05) | | |
|---|---|---|---|---|---|---|---|---|
| | | N0 | N1 | N2 | Mean | N | W | N × W |
| panicle/m$^2$ | AWD | 275 | 369 | 401 | **349** | | | |
| | MC | 232 | 324 | 400 | **319** | 12.3** | 10.2** | 363* |
| | CS | 277 | 271 | 403 | **350** | | | |
| | **Mean** | **261** | **355** | **401** | | | | |
| Grains/panicle | AWD | 113 | 124 | 147 | **127** | | | |
| | MC | 93 | 98 | 102 | **99** | 2.4** | 1.1** | 3.4* |
| | CS | 113 | 124 | 148 | **128** | | | |
| | **Mean** | **106** | **115** | **133** | | | | |
| % filled grains | AWD | 89 | 91.2 | 92 | **90.9** | | | |
| | MC | 90.3 | 86 | 91 | **92.4** | 1.1* | ns | ns |
| | CS | 91.3 | 92 | 94 | **89.1** | | | |
| | **Mean** | **90.2** | **89.9** | **92.3** | | | | |
| 1000 grain weight (g) | AWD | 26.9 | 27.1 | 26.4 | **26.8** | | | |
| | MC | 27.1 | 26.6 | 27.1 | **26.9** | ns | ns | ns |
| | CS | 27.2 | 27.5 | 27.4 | **27.4** | | | |
| | **Mean** | **27.1** | **27.1** | **27** | | | | |

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N·ha$^{-1}$ respectively. LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

N rate on number of grains/panicle was significant ($p < 0.05$). Number of grains/panicle was not significant ($p > 0.05$) among AWD and SC treatment but, moist treated plants produced significantly ($p < 0.05$) lower number of grains/panicle. Based on N fertilizer, the number of grains/panicle varied in the order: N2 > N1 > N0. With interactions, N2 with SC and N0 with MC interaction produced significantly ($p < 0.05$) higher and lower number of grains/panicle respectively.

Percentage filled grains were significantly influenced N fertilizer treatments ($p < 0.05$) and ranged from 86.0% to 94.0% (**Table 6**). Interaction effect of water management and N fertilizer on percentage filled grains was also significant ($p < 0.05$) but effect of water management on percentage filled grains was not significant ($p > 0.05$). N2 and N1 did not differ in percentage filled grains but lower percentage filled grains was recorded in N0. Grain filling was poorer in N1 with moist interaction compared to all other treatment interaction.

N fertilizer and Water management as well as their interaction did not significantly ($p > 0.05$) affect 1000 grain weight (**Table 6**). However, 1000 grain weight ranged from 26.4 to 27.5 g.

#### 3.3.2. Water Use, Water Productivity and % Water Saved

Water use was significantly ($p < 0.05$) influenced by both water management and N fertilizer application rate (**Table 7**). Also, interaction effect of water management and N fertilizer application on water use was significant. Water use based on total water input (irrigation+ rainfall) ranged from 524 mm to 1608 mm depending upon water management and N rate used. In the case of water management, less water was required to produce rice under AWD than submerged. The least water requirement was observed in moist treatment. In case of N fertilizer, water use was in the order: N2 > N1 > N0.

Percentage water saved was significantly ($p < 0.05$) influenced by N fertilizer and water management as well as their interactive effect (**Table 7**). MC treatments saved 65% of water while AWD water management resulted in 34% water. Percentage water saved decreases with increase in N fertilizer application rate.

Both water management treatments and N fertilizer application rates, and their interactions had a significant ($p < 0.05$) effect on water productivity ($WP$) of rice (**Table 7**). $WP$ was greatest in moist followed by AWD treatments. The least $WP$ was recorded in SC treatments. Among the N rates, $WP$ varied significantly in this order: N2 > N1 > N0. The highest $WP$ ($0.73\ kg \cdot m^{-3}$) and lowest $WP$ ($0.2\ kg \cdot m^{-3}$) were observed at N2 with moist interaction and N0 with submerged interaction respectively.

#### 3.3.3. Economic Analysis of Rice

Generally, N2 fertilizer application rate required the higher cost of production followed by N1 fertilizer rate while N0 required the lower cost of production (**Table 8**). In the case of water management, SC required higher cost of production compared to AWD water treatment. MC treatment required least cost of

Table 7. Water use, Percentage of water saved and Water productivity, as influenced by water management and N fertilizer.

| Parameter | Water mgt. (W) | Nitrogen management (N) | | | | LSD (0.05) | | |
|---|---|---|---|---|---|---|---|---|
| | | N0 | N1 | N2 | Mean | N | W | N × W |
| Water use (mm) | AWD | 1031 | 1062 | 1132 | **1075** | | | |
| | MC | 524 | 588 | 604 | **572** | 213** | 235** | 363* |
| | CS | 1514 | 1552 | 1608 | **1558** | | | |
| | **Mean** | **1023** | **1067** | **1115** | | | | |
| Percentage water saved (%) | AWD | 33.83 | 31.84 | 27.34 | **31** | | | |
| | MC | 66.37 | 62.26 | 61.23 | **65** | 3.4** | 2.1** | 5.0* |
| | CS | - | - | - | **-** | | | |
| | **Mean** | **34.33** | **31.51** | **28.43** | | | | |
| Water productivity (Kg/cm$^3$) | AWD | 0.28 | 0.44 | 0.57 | **0.43** | | | |
| | MC | 0.42 | 0.58 | 0.73 | **0.58** | 0.02** | 0.02** | 0.04** |
| | CS | 0.2 | 0.3 | 0.4 | **0.2** | | | |
| | **Mean** | **0.3** | **0.44** | **0.57** | | | | |

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N·ha$^{-1}$ respectively. LSD: least significant difference; * means significant at 5%; ** means significant at 1%; NS means not significant at 5%.

production. Cultivation of rice with N2 under submerged and N0 under moist required the highest and lowest cost of production respectively.

Gross returns increased with increased N fertilizer application rate regardless of the water management regime (Table 8). The highest gross returns ($3996.7) were realized when rice was produced under submerged with N2 fertilizer application rate. In relation to water management treatments, gross return varied in this order: SC > AWD > MC. For interaction effect the lowest gross returns was observed in N0 with moist interaction and the highest gross returns was observed in N2 with submerged interaction.

Average net profit ranged from $688 to $3129.7 across the treatment combinations (Table 8). In all cases, net profit increased with increased N fertilizer application rate. The trend of net profit with regard to water treatments was AWD > SC > MC. For interaction effect, the greatest interaction effect on net profit ($3129.7) was N2 with AWD. Interaction effect of N0 with moist was inferior to other interaction effect of water management and N fertilizer

In Table 8, N fertilizer on benefit cost ratio was ranked as: N2 > N1 > N0. In relation to water management, the trend was AWD > SC > MC. The interaction effect of N2 with AWD gave the greatest benefit cost ratio. The second highest

**Table 8.** Cost of production, gross returns, net profit and benefit cost ratio as influenced by water management and N fertilizer.

| Parameter | Water mgt. (W) | Nitrogen management (N) | | | |
|---|---|---|---|---|---|
| | | N0 | N1 | N2 | Mean |
| Cost of production ($/ha) | AWD | 720.6 | 788.8 | 829.6 | **779.6** |
| | MC | 661.8 | 734.1 | 768.5 | **722.1** |
| | CS | 779.1 | 845.7 | 888.4 | **828.8** |
| | **Mean** | **720.5** | **789.5** | **828.8** | |
| Gross returns ($/ha) | AWD | 1812.1 | 2865.2 | 3959.2 | **2878.9** |
| | MC | 1350.6 | 2122.2 | 2739.5 | **2070.8** |
| | CS | 1855.5 | 2843.4 | 3996.7 | **2898.5** |
| | **Mean** | **1672.8** | **2610.1** | **3565.1** | |
| Net profit ($/ha) | AWD | 1091.7 | 2076.4 | 3129.7 | **2099.3** |
| | MC | 688 | 1388.1 | 1971 | **1349.3** |
| | CS | 1076.4 | 1997.8 | 3108.3 | **2060.8** |
| | **Mean** | **952.4** | **1820.8** | **2736.4** | |
| Benefit cost ratio | AWD | 1.52 | 2.63 | 3.77 | **0.43** |
| | MC | 1.04 | 1.89 | 2.56 | **0.58** |
| | CS | 1.38 | 2.36 | 3.50 | **0.20** |
| | **Mean** | **1.31** | **2.30** | **3.28** | |

AWD: alternate wetting and drying soil condition; MC: moist soil condition between field capacity and permanent wilting point; CS: continuously submerged soil condition; N0, N1 and N2, are 0, 60 and 90 kg·N/ha respectively. The exchange rate is GH₵ 4.46 = $1.00, GH₵ is Ghana Cedi, the local currency.

interaction effect was N2 with SC combination of N fertilizer and water combination. The lowest benefit cost ratio (1.04) was produced at N0 with moist interaction.

## 3.4. Discussion

### 3.4.1. Effect of N Fertilizer on Yield and Yield Parameters of Rice

Plants fertilized with nitrogen had higher grain yield than unfertilized plants. This could also be attributed to efficient use of split application of nitrogen at transplanting and panicle initiation stage. This is in accordance with [14] who observed that nitrogen fertilizer application increased the activity of cell division and expansion of rice which enhanced grain yield. Also, [15] observed that N facilitates efficient mobilization of resources and photosynthesis for grain filling. Higher yields in N2 compared to N1 might be due to its higher availability of nitrogen which is essential for rice yields. This is in agreement with other researchers [16] [17] [18] who all observed that the application of 90 kg N/ha increased rice yield significantly. The finding however, disagrees with [19] who observed that, application of nitrogen fertilizer above 60 kg·N·ha$^{-1}$ did not improve yield. Nitrogen fertilization did not significantly influence test weight of rice. This might be due the fact test weight is a genetic trait and strictly controlled by the hull of a particular variety and therefore cannot grow above the size allowed by the size of the hull [20].

#### 3.4.2. Effect of Water Management on Yield and Yield Parameter of Rice

Yield parameters; panicles/m$^2$, grains/panicles and test weight were higher in SC treatments though not significantly different from AWD treatments. Nonetheless lower yield parameters contributed in reduced yields as observed in the MC treatments. Grain yield showed no significant differences between SC and AWD treatments. Several authors have cited similar grain between SC and AWD indicating that AWD does not restrict water availability to rice plants. Since AWD plots were submerged at booting stage till ten days before harvest, yield penalties are not recorded. This is consistent with previous studies [17] [21] [22] who all observed similar grain yield between AWD and SC treatments. However, [23] observed higher panicle/m$^2$ and grain yield under AWD while [24] [25] found conflicting results. The differences in these findings might be due to different soil types, rice variety, climatic conditions as well as duration of irrigation [10]. Plants grown under MC water management had significantly low yields probably due to poor metabolism as a result of its reduced water availability. Furthermore, reduced yields under MC treatment might be due to inhibition of photosynthesis and less translocation of assimilates due to soil low moisture availability [26]. These results are similar to those reported by [17].

Interaction effect of N2 with AWD had similar yield as in submerged and N2 treatment combination. These observations might also be due to more N transported to the plant when plants were treated with higher doses of N. In all N0 under moist treatment combination gave the lowest grain yield due reduced moisture level at panicle initiation stage, similar to what was reported by [27].

#### 3.4.3. Effect of Water Management on Water Use, Percentage of Water Saved and Water Productivity

Submerged water management received higher amount of water use than AWD and moist treatments due to the standing water layer maintained continuously on the plot from crop establishment till ten days to harvest. According to [28] evapotranspiration was intense under continuous submergence. This probably increased the rate of evapotranspiration and percolation in submerged treatments which in turned increased water use.

The highest water productivity was obtained under MC and AWD. AWD had higher water productivity than submerged treatment due to its lower water use. This finding was also reported by [10] [26] [29] who observed that AWD resulted in higher water productivity than continuous submergence of fields. Researchers [30] reported that, continuous submergence produced optimum rice yield however, required the highest amount of water hence low water productivity. MC treatment had the lowest water use and higher water productivity due to the absence of standing water layer from one week after transplanting to booting stage. This conforms to [31] who reported that reduction in water use increased water productivity of rice. Also, MC and AWD resulted in 60% and 34% water savings respectively compared with SC water management. Likewise, [32] also reported water saving of up to 60% under AWD compared with SC management.

Interaction effect of N2 and submerged water management required higher water use due to higher evapotranspiration rate as a result of its higher leaf area index and evaporation [28]. With regards to water productivity, N2 treated plants under moist water condition gave higher water productivity compared to the rest of the treatment combinations due to its lower water use. Also [31] reported that reduction in water use increased water productivity of rice.

#### 3.4.4. Cost-Effectiveness of Water Use under Various Water Management Methods

The economic analysis from the study revealed that, it was highly economical to produce rice under AWD than the rest of the water management treatments. Although grain yields and gross returns from sales of rice were higher under submerged treatments than AWD water management, cost associated with water under submerged water management reduced net profit since general cost of production was same for all the water treatments. Moist treatment had the highest water productivity but the lowest gross returns from sales of rice due to reduced yields. The outcome agrees with the assertion by [33] [34] who argued that, an increase in water productivity may not result in higher economic benefits. Despite the fact that gross returns was higher in submerged water management than AWD water management, it's economic water use was the least compared to AWD at any given N rate due to significant water cost associated with this water management regime. Continuous submergence and maintaining moisture level at field capacity does not increase crop and economic water productivity [35].

### 3.5. Conclusion

Results from the study revealed that rice yield differed significantly ($p < 0.05$) across the various N and water treatments. Nitrogen application rate of 90 kg/ha enhanced plant growth and development culminating to significant increases in grain yields. AWD resulted in similar yields to submerged water treatments and yields of rice were better with interaction effect of 90 kg N/ha and submerged water treatment. AWD required less water than continuous submergence for rice production and it was more cost-effective to produce rice under AWD than the rest of the water management methods. This indicates that continuous submergence is not an obligation in rice production and farmers could implement AWD and 90 kg N/ha to reduce water use, and increase water productivity while harvesting maximum yields with reduced cost of production.

### 3.6. Recommendation

Basing on the findings from the study, we recommend that further study on nutrient requirement of irrigated rice in Ghana is needed to investigate more nitrogen rates on different soil types and agro ecological zones. Also, future study should include soil moisture monitoring overtime and to quantify N leaching because of the high irrigation requirement of rice.

## Acknowledgements

The authors are most grateful to the Office of Research, Innovation and Development (ORID), University of Ghana, for the sponsorship which has been of immense help in funding both the field work and laboratory analysis. We are also grateful to all those who contributed in diverse ways to make this study possible particularly the technical and support staff at the Soil and Irrigation Center (SIREC). This paper is a product of the research work done by the first author for his Master of Philosophy thesis in Crop Science (Agronomy) at the University of Ghana.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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