INCREASING WATER PRODUCTIVITY OF IRRIGATED RICE THROUGH VARYING NITROGEN AND WATER MANAGEMENT METHODS

BY

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DECLARATION

In exception of references to the works of researchers which have been duly cited, this thesis is the result of my own work produced from research undertaken under supervision.

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DEDICATION

I dedicate this work to my late father, Adamu Abdulai

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ABSTRACT

Globally, rice (*Oryza sativa* L.) is the third largest cultivated cereal crop with about 79 million hectares of irrigated lowlands providing 75% of the world's rice production. Its productivity depends on many factors including Nitrogen (N) fertilizer and water management. This study was conducted to determine the effect of water management and N fertilizer on growth and yield of rice. The study also sought to evaluate the cost effectiveness of water use under various water management methods. To achieve the set objectives, pot and field experiments were conducted at Soil and Irrigation Research Centre (SIREC), Kpong between July, 2015 and January, 2016. The pot experiment was designed as randomized complete block (RCBD) in factorial arrangement of three water management treatments namely; continuous submergence (submerged), alternate wet and dry (AWD) and moist soil condition (moist) and three nitrogen fertilizer rates; no N fertilizer (N0), 60 kg N/ha (N1) and 90 kg N/ha (N2). In the field experiment, a split plot design with water management treatments as main plot and the three N-fertilizer treatments as subplots was used. Data including tiller numbers, leaf area index, above biomass accumulation, leaf chlorophyll content, days to 50% flowering, grains/panicles, panicles/m^2, 1000 grain weight, grain yield and harvest index were collected. In addition, data on water use, water productivity, nitrogen uptake, nitrogen use efficiency, cost and benefit analysis were also recorded. Results obtained from both experiments revealed that, plant growth, yield and yield parameters were significantly influenced by water management and N fertilizer and their interaction except 1000 grain weight and days to 50% flowering. Analysis of variance further revealed that plant growth and yields were at par in AWD and submerged but yields were lower (3.4 t/ha) in moist treatment. N fertilizer had positive effect on rice growth and yields with higher yields (5.8 t/ha) observed when plants were treated with 90 N kg/ha. The interaction effect of submerged with 90 kg/ha N gave the highest grain yield (6.5 t/ha). For both pot and field experiments, N fertilizer effect on N uptake, water use and water productivity was ranked as N2 > N1 > N0. N uptake was found to be higher in AWD than moist but was at par with submerged treatment. Water management effect on water use and water productivity was ranked in this order: Submerged > AWD > Moist and Moist > AWD > Submerged respectively. AWD treatment had the highest net profit (9341.7 GH₵/ha) and thus making it most cost effective water management method for irrigated rice farming.

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CHAPTER ONE

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population (Kumar *et al*., 2015). The number of consumers is expected to increase in future due to increasing population, rapid urbanization and change in diets (Wassmann *et al.*, 2009). About 79 million ha of irrigated lowlands account for 75% of the global rice production (Maclean *et al*., 2002). In Sub-Saharan Africa (SSA), although domestic production is disproportionate to consumption demand, the role of rice production still remains cardinal in improving food security for the growing population and contributing to poverty alleviation (Otsuka and Kijima, 2010). Traore (2005) estimated that, Africa produces about 14.6 million tons of rice per year on 7.3 million hectares. Out of the vast land available, West Africa has the largest planted rice area of about 1.1 million hectares (Traore, 2005), yet production levels are not able to meet local demands. As a result, SSA is said to account for a third of global rice imports to fill the gap in local demand at an alarming cost of more than US$4.3 billion per year, an amount which otherwise could be used in other areas of development (Nakano *et al*., 2011).

According to Angelucci *et al*. (2013), most of the rice produced in Ghana is by smallholder farmers with farms of less than one hectare in size. Rice is considered to be the second most important staple grain food next to maize (MOFA, 2009) and the 5th most important source of energy in the diet accounting for 9 percent of total caloric intake (FAOSTAT, 2012). Rice now competes with vegetables and plantation crops such as citrus, oil paslm, cocoa and mango in lowland agriculture (Buri *et al*., 2012). Local rice production in Ghana satisfies only about 30 percent and the nation currently spends about US$450m annually to import rice to make up for the shortfall in supply (MOFA, 2010). Traditionally, lowland rice is grown under rain-fed with little or no water management from crop establishment to close to harvest. Many farmers rely mainly on rainfall and without any proper water management which makes the efficiency of fertilizer very minimal. In addition to high cost of fertilizers, poor water and nitrogen management have resulted in serious drawbacks in rice production by small-holder farmers who form the majority of the farming population.

Nitrogen is the most essential nutrient element for rice growth and development. Though N supply drives rice production, low nitrogen use efficiency (NUE) is a key challenge in irrigated rice farming (Cassman *et al*., 1998). Nitrogen fertilizer under submerged water condition is subject to considerable changes due to chemical, physical, and biological processes, which lead to high losses via volatilization, denitrification, surface runoff and leaching. Nitrogen dynamics in submerged water management are different from that of that of alternate wet and dry water management regime (AWD) or moist soil condition. Studies conducted by Cabuslay and Alejar (2002) showed that, alternative wetting and drying increase nitrogen application efficiency compared to continually submerged water. On the contrary, nitrogen use efficiency was found to be less in AWD water management compared to submergence condition (Pirmoradian and Sepaskhah, 2006). Though Nitrogen plays vital role in rice cultivation, more dosage than necessary level causes' harm to the environment and even decreases yield (Manzoor *et al*., 2006). Knowledge of N transformations in various water management regimes is essential not only to reduce the N fertilizer losses but also to minimize the environmental impacts.

Rice is generally 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 (Sing *et al*., 2002). Water and energy has therefore emerged to be key elements of sustainability of rice production. According to Sing *et al*. (1990) irrigation consumes about 82 % of the total operational energy input in rice cultivation. Moreover, worldwide fresh water resources are threatened by rapid global population growth and climate change. For instance, Orange and Limpopo River basins in Southern Africa and the Volta River basin in West Africa, are pressured with population densities and large-scale irrigation systems which put great strains on water resources availability in these areas (Ravenga *et al*., 2000). Furthermore, due to growing demand for water resources from all sectors, it is projected that by 2025, some countries in SSA including Ghana will face water stress (UNEP, 2008). Increasing competition from domestic and industrial users has further compounded the problem of water scarcity. Khan *et al*. (2006) envisaged that lesser amount of water will be available for agriculture and especially for rice, the crop that consumes the largest amount of freshwater. 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, such as internal drainage (Ramasamy *et al*., 1997), AWD (Belder *et al*., 2004), soil water potential (Yang *et al*., 2005), continuous soil saturation (Borrell *et al*., 1997), and non-flooded mulching cultivation (Zhang *et al*., 2009). Considering the spiralling increase in cost of chemical fertilizer and huge competition for water for industrial, domestic and agricultural use, it is essential to identify efficient water management methods and optimum N fertilizer level for sustainable increase in rice productivity in irrigated rice farming system. In view of this, the research work was carried out to evaluate the effect of different water management methods and nitrogen fertilizer application rates on the growth and yield of irrigated rice in Ghana.

The specific objectives of the study were;

i. To determine the effect of different water management methods and different rates of nitrogen (N) fertilizer on growth and yield of rice in irrigated rice system.
ii. To assess the effect of water management and N fertilizer on nitrogen uptake by rice in irrigated rice system
iii. To evaluate water productivity and cost-effectiveness of water use under various water management methods.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Origin and distribution of rice

Rice (*Oryza sativa* L) is a grass (Gramineae) and belongs to the genus *Oryza*. Between 8000 and 15000 years ago, rice as a crop was first cultivated in south - East Asia, India and China (Normile, 2004). Nguyen *et al*. (2009) estimated that about 85% of the total rice production is mainly for human consumption. Rice is cultivated across all continents except Antarctica (Li and Li,2010). Archeological data revealed that *Oryza.-sativa* was domesticated some 7,000 years ago in Asia (Carney, 2000), although its antiquity and place of the origin is not well documented. Portères (1956), who discovered two loci of *O. sativa* introduction along the West African coast observed that rice varieties from Asia were easily adopted and integrated into rice farming systems in Africa since farmers in these areas were already familiar with rice cultivation.

2.2 Importance of rice

Today, rice feeds more than half of the people on earth. It is the second most important cereal in the world today and provides together with wheat a large proportion (95%) of the total nourishment of the world’s population (FAO, 2004). David (1991) stated that Asia accounts for about 90 % of rice production in the world. Furthermore, Li (2003) estimated that the 155 million hectares planted throughout the world produce about 596.5 million metric tons of paddy rice per year. Per capita consumption and consumer demands for a given rice type also differ from region to region (Webb, 1991). Undoubtedly rice is now a major staple food for millions of people in West Africa (Basorun, 2003). Annual demand for rice in the Sub-Region is estimated at over 8 million metric tonnes and with rapid population growth (estimated at 2.6% per annum), increasing urbanization and the relative ease of preservation and cooking have influenced the growing trend in rice consumption (Khumbanyiwa 2003). Unfortunately, West Africa does not produce the quantity of rice needed to meet its demand and to fill that gap, rice has to be imported. Sub-Saharan Africa is said to account for a third of global rice imports to fill the gap in local demand at an alarming cost of more than US$4.3 billion per year, an amount which otherwise could be used in other areas of development (Nakano *et al.*, 2011). Imports of this magnitude is worrying and represent a major setback for broader development and poverty reduction efforts in this sub region (Khumbanyiwa 2003). In Ghana, rice is considered to be the second most important staple grain food next to maize. According to Buri, *et al*. (2012), rice is now competing with other crops such as citrus, oil palm, cocoa, mango and vegetables in lowland crop cultivation. Local rice production in Ghana satisfies only about 30 percent and the nation currently spends about US$450m annually to import rice to make up for the shortfall in supply (MOFA, 2010). The increase in demand for imported rice is primarily attributed to increased income, good storability and ease of cooking (Shabbir *et al*., 2008). Rice consumption increased by over 20% per year in the 1990s, with the increased demand being met by imports from the Far East and the Americas (Berisavljevic *et al*., 2003). It has been reported that imported rice, which is also perceived to be of better quality than local rice, is generally sold at higher prices (Berisavljevic *et al*., 2003). Total rice consumption in Ghana in 2005 amounted to about 500,000 metric tonnes which is equivalent to per capital consumption of 22 kg per person (Tomlins *et al.*, 2005). Furthermore, irrigated rice yields in Ghana are known to vary from 3.5 t/ha to 7 t/ha with an average yield of 4.6 t/ha on formal irrigation schemes (FAO, 2005). Despite the increases in rice production, Ghana still depends largely on imported rice to make up the deficit in rice supply. The self-sufficiency ratio of rice in Ghana has declined from 38 % in 1999 to 24 % in 2006 (Andriesse and Fresco, 2009).

2.3 Irrigated rice farming system

Irrigated rice is mostly cultivated in bunded and puddled rice fields with one or more crops planted each year. According to George *et al*. (1992) lowland rice or irrigated rice usually refers to rice grown on both flat and slopping bunded fields with surface flooded during most of growing season. Usually, irrigation is the main water source in the dry season and is also used to supplement rainfall in the wet season. Mostly, water diversion from rivers and pump irrigation from wells are major sources of irrigation water. According to Humphreys *et al*. (2005) rice in the irrigated system is usually cultivated with water supplied by ground irrigation to supplement rainfall such that the standing depth of water maintained about 15 cm from crop establishment to close to harvest. Of all the different rice ecosystems, such as rainfed lowland and upland rice, irrigated rice farming system is the most dependable in Africa in terms of productivity. However, large areas in West Africa lacks fully developed irrigation system. A gradual increase in the 231, 000 ha observed in the irrigated ecosystem in 1980-84 had been expected (WARDA, 1993). Some African countries especially Egypt, Niger, Mauritania and Madagascar have large amounts of irrigated land planted to rice (WARDA, 2004). Main drawbacks linked to the irrigated systems include; nutrient deficiencies, poor water and nitrogen management, acidity, weeds, diseases including, Rice Yellow Mottle Virus (RYMV), blast, sheath rot, and bacterial leaf blight and insect pests (Traore, 2005). Rice yield of about 5000 to 7000 kg/ha can be realized if farmers employ optimum input management such as fertilizer, pesticide, seed, and appropriate water management in irrigated rice farming system (WARDA 1993). Lowland rice is mostly transplanted in puddled soil and farmers try to keep a fixed depth of ponded water on soil surface throughout the cropping season. Most often this modifies the soil structure considerably which may have adverse effect for all the succeeding cereal crops such as wheat, soybean and peanut

(Hobbs & Gupta, 2003; Timsina and Connor, 2001). In lowland rice-based cropping systems fine texture soils are mostly used which are characterized by low percolation rates that allow an extended period of submergence. Under continuous submergences, soils become anaerobic which reduces nitrification and therefore allowing accumulation of NH_4^-N which is essential for growing lowland rice (De Datta, 1995).

2.4 Importance of nitrogen in rice plant nutrition

Nitrogen is the most essential element in determining the yield potential of rice (Cassman *et al.*, 1996). Rice plants require N as much as possible at early and mid tillering to maximize panicle production. Nitrogen is also required at the reproductive and ripening stages in order to enhance number of grains/panicles plant and grain filling (Datta *et al.*, 1986). Amount of N removal is estimated between 16 to 17 kg for the production of one ton of rough rice, and straw (Dobermann and Fairhurst, 2000). The efficiency of nitrogen uptake differs from 20 to 60 % based on the environmental conditions (soil type, water control, pH and water temperature), doses and modes of supply (split or not) as well as varieties (Karres *et al.*, 1999). Conversion of nitrogen in nitrogenous fertilizer to ammonium is vital in the nutrition of irrigated rice (Gu *et al.*, 2009), although rice can also remove the nitrate-N (Martens, 2001). According to Singh *et al.* (2002) ammonium-N fertilizer sources are highly recommended because the NH_4^+ is stable under flooded soil conditions. Excessive N availability in the soil does not only cause higher transpiration rates but also reduces available soil water especially during flowering and grain filling stage that may reduce grain yield (Song *et al*, 2010). In most cases, it is recommended to apply 120 – 180 kg of N per hectare at pre-flood to achieve a target nitrogen uptake of 130-150 kg N/ha at panicle initiation to obtain 12 t/ha rice yield (Nangia *et al.*, 2008).

2.4.1 Effect of nitrogen fertilizer on plant growth

2.4.1.1 Plant height

Application of optimum dose of nitrogen to rice is gaining importance because nitrogen plays a cardinal role in crop production. It is therefore crucial for individual farmer as well as to the country to get the optimum economic benefit out of a huge recurring expenditure in fertilizer. In an experiment to assess the effect of water stress and N fertilizer on growth and yield of rice, El-wahab *et al*. (2007) observed that, plant heights were significantly affected by N fertilizer application. The tallest plants were recorded when plants were treated with high N fertilizer rate. Plant height increased with increased N fertilizer application rate with plots without N fertilizer producing shorter plants. In a field experiment to evaluate the growth and yield responses of lowland rice with 4 nitrogen levels (0, 40, 80 and 120 kg ha^{-1}) and placement methods, Lawal and Lawal (2002) concluded that plant height increased significantly up to 80 kg nitrogen ha^{-1}. Similarly Hussain and Sharma (1991) reported that application of nitrogen up to 40 kg ha^{-1} increased plant height. However, at 80 kg and 120 kg ha^{-1}, plant heights were non-significant among the treatments. Taller plants were obtained when plants were treated with 120 kg N/ha and the shorter ones from the control plots (Raju and Reddy 1992). Dahatonde (1992) concluded that N fertilization significantly influenced plant height. Also, in a field trial to determine the effect of different nitrogenous (N) fertilizers on growth, yield and quality of hybrid rice Variety, Chaturvedi and Chaturvedi (2005) found that, application of N fertilizers increased plant height significantly. The increase in plant height in response to application of N fertilizers was attributed to availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulting in more dry matter accumulation. According to Malik *et al.* (2014), application of nitrogen level (140 kg N ha^{-1}) increases plant height and there was a decrease in plant height with N rate below this rate. They argued that, although plant height is not a yield component especially in grain crops, it indicates the influence of various nutrients on plant metabolism. One of the most important functions of N in rice is the promotion of rapid growth through increase in height.

2.4.1.2 Number of tillers

Number of tillers per unit area is one of the most important components of yield. The more the number of fertile tillers, the more the yield. Chaturvedi and Chaturvedi (2005) observed that, number of tillers / hill at 20 days after transplanting (DAT) were not significant among N fertilizer treatments. However, at 40, 60 and 80 days after transplanting the numbers of tillers / hill increased significantly (especially between 40-60 days after transplanting). There after a gradual decline was observed up to 80 days after transplanting. Studies by Gonzalez-dugo *et al.* (2010) on effect of nitrogen fertilizers on growth, yield and quality of hybrid rice (oryza sativa) revealed that, tiller production / hill was significantly affected by levels of nitrogen at all stages. Also, tiller number increases with increased nitrogen application rate. More number of tillers /m2 might be due to the more availability of nitrogen that played a vital role in cell division. Mannan *et al.*, (2012) observed that tiller numbers varied significantly at different growth stages due to variation of N levels and genetic potentiality of variety. In their study they observed that, number of tillers decreases with decreased N fertilizer rate with the lowest number recorded in plots where N application was absent. Furthermore, El-wahab *et al.*, (2007) revealed that tiller numbers at booting was significantly influenced by N fertilizer rate. The highest number of tillers were recorded when plants were treated with higher doses of nitrogen compared to lower N rates. Panda (1996) conducted a field experiment to assess the effect of nitrogen application as basal (45, 60 and 80 kg N ha^{-1}) and top dressing (10, 30 and 45 kg ha^{-1}) on the yield and yield components of Japonica rice and obtained high effective tillers hill^{-1} percentage of ripened grains and high grain yields from 45 kg ha^{-1} (basal) and 45 kg ha^{-1} (top dressing). Similarly, Idris and Matin (1990) in their field experiment revealed that application of 140 kg N ha^{-1} produced maximum number of tillers hill^{-1} which was statistically identical to 60, 80, 100 and 120 kg N ha^{-1}. Minimum tillers hill^{-1} was recorded from the control plots (0 kg N ha^{-1}). Maske *et al*. (1997) concluded that, plant height, leaf area hill^{-1}, number of tillers hill^{-1}, dry matter hill^{-1} and grain yield increased significantly with increased N levels.

2.4.1.3 Leaf area index (LAI)

Application of nitrogen fertilizer is believed to significantly influenced leaf area index of rice. According to Chaturvedi and Chaturvedi, (2005), application of higher dose of nitrogen produced higher leaf area index at flowering stage of plant growth compared to plots where there was no N application. They further observed that LAI decreases with decreased nitrogen application rate. They attributed these phenomena to possible improvement of nutrients availability and enhanced growth of plant by nitrogen application. Haque and Haque (2016) indicated that, leaf area index (LAI) was affected noticeably by adding nitrogen fertilizers at various growth stages of rice. Leaf area index progressively increased and achieved its maximum value (4.17) at 45 days after transplanting when fertilized with 100 kg N ha^{-1} whilst the lowest value (1.90) was recorded at control treatment (Haque and Haque 2016). A research conducted by Azarpour *et al.*, (2014) revealed that, LAI values at lower nitrogen levels were lesser than higher levels. It was also observed that, maximum LAI was obtained at flowering stage (65 days after sowing) and then it reduced significantly. Leaf area increased as N application increased from 30, 60 and 90 kg/ha nitrogen which were significantly higher compared to the control treatment (Abou-khalifa, 2012). These were attributed to the positive effect of nitrogen on both leaf development and leaf area duration. According to Russo (1996), nitrogen enhances vegetative plant growth and to a certain extent large LAI leads to absorption of more solar radiation by plants. This promotes photosynthesis and ultimately leads to higher yield. LAI is related to the biologic and economic yields and increase in LAI causes higher yield (Singh *et al.*, 2009).

2.4.1.4 Biomass accumulation

According to Chaturvedi and Chaturvedi (2005), dry matter accumulation increased significantly with N fertilizer application in rice at all the growth stages of the crop. Biomass accumulation significantly increase due to nitrogen fertilizer throughout the measurement period. Significantly higher dry-matter accumulation (15.51 tonnes/ha) was obtained from 140 Kg N ha^{-1} at 95 days after transplanting (Rezaei *et al*., 2009). Ye *et al.* (2013) observed that dry matter accumulation increased at slow rate up to 30 days after transplanting and thereafter increased at faster rate up to harvest. Significantly higher dry-matter accumulation (11.41 tonnes/ha) was obtained from urea treatment at 95 days after transplanting which was superior to the control plots. The highest dry matter of nitrogen treated plants was attributed to the positive effect of nitrogen in some important physiological processes. Studies conducted by Rezaei *et al*. (2009) on the effects of irrigation and nitrogen management on yield and water productivity of rice revealed that N fertilizer application rate significantly influenced biomass accumulation. Application of higher dose of N produced higher biomass than lower application rate of N. Also, higher dry matter accumulation was attributed to increase in length and number of leaves, increase in number of tillers, elongation of stem and panicles and causing overall increase in vegetative growth of plant.

2.4.1.5 Leaf chlorophyll content

Chlorophyll is a key pigment involved in photosynthesis which is the global biological process which supply energy for plants and other living things (Shpilyov *et al*., 2013). Kingori (2016) attributed higher leaf chlorophyll content in plants to increase availability of nitrogen to plants as nitrogen is essential for chlorophyll formation by plants. There was an increase in chlorophyll content of rice when nitrogen was applied. This resulted in increased photosynthesis process which led to more sugar formation (Dikshit and Paliwal, 1989). Work done by Verma *et al*. (2004) revealed that chlorophyll content in the third leaf of rice increased with increased nitrogen levels. Total chlorophyll content was gradually increased with increased N levels with 0 kg/ha to 200 kg/ha (Verma *et al*., 2004).

2.4.2 Effect of N fertilizer yield parameters of rice

2.4.2.1 Number of panicles

In a study to investigate growth and yield of basmati and traditional aromatic rice as influenced by water stress and nitrogen level, Mannan *et al*. (2012) reported that yield parameter varied significantly due to variation of fertilizer N levels. Maximum number of panicles which were longer in length were found in the plots where higher doses of N was applied. On the contrary, lower number of panicles which were shorter in length were observed in plots where N was absent (Russo, 1996). Furthermore, Haque and Haque (2016) observed the highest number of panicle per hill (8.8) when 60 kg N ha^{-1} was applied and the lowest (7.07) from control treatment. Malik *et al*. (2014) revealed that, application of 120 kg N ha $^{-1}$ gave the highest number of grains per panicles and longer panicles among the nitrogen levels. However lower values were recorded with decreased N levels. Studies conducted by Singh and Singh (1993) revealed that application of nitrogen fertilizer increases the number of grains per panicle as well number of productive tillers. Similarly, Jamil and Hussain, (2000) observed that application of 92 kg ha^{-1} N gave 114.75 numbers of grains per panicle which was significantly higher than the control. This probably was due to reduced competition for resources with these treatments compared to plots where there is no N fertilizer application. According to Ritesh *et al*. (2014) more number of productive panicles per m^{2} (364.71) as well as longer panicles (27.68 cm) were produced when plants were treated with 160 kg N ha^{-1} which remained statistically at par with that obtained by nitrogen application levels between 40 to 120 kg N ha^{-1}.

2.4.2.2 Panicle length

Field experiment conducted by Singh and Singh (1993) revealed that, panicle m^{-2}, panicle length and grains/panicle increased due to application of 60 kg N ha^{-1}. Similarly, Azad *et al*. (1995) stated that panicle length increased significantly when nitrogen rate was increased from 0 to 75 kg/ha. Mannan *et al*. (2012) observed longer panicles when rice plants were treated with higher doses of nitrogen. Idris and Matin (1990) concluded that the rate of nitrogen application influenced panicle length positively.

2.4.2.3 Number of grains/ panicle

Hussain and Sharma (1991) stated that application of nitrogen fertilizer up to 80 kg N ha^{-l} increased number of grains panicle^{-1}. Nitrogen application at the rate of 120 kg ha^{-1} did not significantly affect the grains panicle^{-1}. The highest number of grains panicle^{-1} produced at 80 kg N ha^{-1} and the lowest was produced at the 0 kg N/ha. In a field experiment to determine growth and yield of basmati and traditional aromatic rice as influenced by water stress and nitrogen level, Mannan *et al*. (2012) observed that grains panicle^{-1} increased with increased nitrogen application rate regardless of the water management treatments. They observed that more number of grains panicle^{-1} were produced when plants were treated with 120 kg N ha^{-1} which was significantly superior to the control treatments. In a similar study, Abou-khalifa (2012) revealed that application of N fertilizers significantly increased the yield attributes of rice with 220 kg N ha^{-1} producing the highest value of grains per panicle (94.6), while unfertilized plants gave the lowest value of grains panicles^{-1}. Chander and Pandey (1996) stated that a significant increase in grains panicle^{-1}, tillers m^{-2} and grain yield were obtained from application of 120 kg N/ha compared to 60 kg N/ha. Tayefe *et al.*(2011) concluded that, increasing rates of applied N increased plant height, panicle m^{-2}, grains panicle^{-1} and grain yield significantly.

2.4.2.4 1000-grain weight

Field experiment conducted by El-wahab *et al*. (2007) showed that, nitrogen levels did not significantly influence 1000 grain weight of rice. They further suggested that, the genetic traits of the variety supersede that of the environmental conditions of which the plants were exposed to. Similarly, Jamil and Hussain (2000) concluded that, nitrogen rate had no significant influence on 1000-grain weight of rice. On the contrary, Islam *et al*. (1990) observed an increasing trend of 1000-grain weight with an increase in levels of nitrogen up to 80 kg ha^{-1}. The lowest 1000 seed weight was recorded from application of 69 kg ha^{-1} N (22.7 g) while the highest of 26.3 was recorded when nitrogen rate was115 kg ha^{-1} N

2.4.2.5 Grain yield

Field experiment conducted by Azarpour *et al*. (2014) revealed that, maximum grain yield (4328 kg/ha) was obtained from 90 kg/ha nitrogen fertilizer level with the minimum of 2734 kg/ha being obtained from the non-fertilizer treated plants. These showed that non application of nitrogen fertilizer decreases yield components and physiological indices. Singh *et al*. (2000) stated that incremental dose of N (100 kg N ha^{-1}) gave significantly higher yields (2647 kg ha^{-1}). According to Jamil and Hussain (2000) rice paddy yields were 1.91, 2.66 and 3.03 t ha^{-1} when nitrogen was applied 0 kg, 50 kg and 100 kg N ha^{-1} respectively. Chaturvedi and Chatusrvedi (2005) concluded that increasing nitrogen rate significantly enhanced paddy yield. Rice yield increased when N was applied of nitrogen up to 100 kg ha^{-1} and then decreased with increasing rate of nitrogen (Maskina *et al*. 1996). Application of nitrogen from 120 to 160 kg N ha^{-1} significantly reduced the yield, which was assumed to be due to excessive vegetative growth followed by lodging after flowering (Abou-khalifa, 2012). Similarly, application of nitrogen fertilizers had a significant effect on yield components with 80 and 120 kg N ha^{-1} markedly improved the grain yield by 17 and 45%, respectively (Raju and Reddy, 1992). Similarly, Singh and Pillai (1994) observed that, increased doses of nitrogen increased grain yield significantly up to 90 kg ha^{-1}, after which it declined.

According to Hossain *et al*. (1995), application of nitrogen up to 120 kg ha^{-1} significantly increased grain yield of rice. They observed with 40, 80 and 120 kg N ha^{-1} there was increase in yield over the control with 24, 33 and 34%, respectively. Similar, Thakur (1993) found that grain yield increased from 80 up to 120 kg N/ha. They recorded significantly higher yields with 80 and 120 kg N ha^{-1} than 0 and 40 kg N/ha. Hari *et al.* (1999) pointed out that grain yield increased as nitrogen application increase from 0 to 150 kg/ha, although a further increase up to 200 kg ha^{-1} did not increase grain yield. Kumar *et al*. (1996) observed higher grain yield at 160 kg N ha^{-1} over the control by 42.0 per cent. In a field experiment to investigate the best Irrigation method and nitrogen application on yield and productivity of rice at The Rice Research Institute of Iran during cropping season of 2006 and 2007, Rezaei *et al*. (2009) concluded that, best nitrogen practice was application of 60 kg/ha. They pointed out that using nitrogen more than 60kg/ha did not increase rice yield. Also, all the growth and yield forming characters increased linearly up to

60 kg N ha^{-1} and thereafter grain yield increased marginally. According to Mannan *et al*. (2012) grain yield of rice varied significantly due to the variation of nitrogen levels. Highest grain yield (4.22 t ha^{-1}) was produced at higher doses of N application.

2.4.2.6 Straw yield

According to Patel and Mishra (1994) application of 30, 60, 90 kg N ha^{-1} increased straw yields. Khanda and Dixit (1996) observed that straw yields were significantly influenced by increased levels of nitrogen. The maximum straw yields of 4.58 and 6.21 ha^{-1}, respectively were obtained at 90 kg N ha^{-1} and 120 kg N ha^{-1}. Murty *et al*. (1992) observed grain yields of 3.5, 4.2, 5.1, 5.5 t/ha and the straw yields were 4.2, 4.8, 6.0, 6.4 t ha^{-1}, respectively by applying 0, 40, 80 and 120 kg N ha^{-1}. Furthermore, Mannan *et al*. (2012) observed that straw yield was significantly influenced by N fertilizer and increasing levels of nitrogen increased the yield of grain and straw of rice.

2.4.3 Effect of Nitrogen fertilizer on uptake and nitrogen use efficiency (NUE) of rice

As one of the most important staple foods for human nutrition, recent studies on rice have mostly focused on improving NUE especially in irrigated rice system. According to Husan *et al*. (2014) agronomic nitrogen use efficiency (ANUE) is a term used to describe the relative balance between the quantities of fertilizer N applied and yield produced. Study conducted by Duhan and Singh (2002) revealed that uptake of nutrients increased significantly with increasing N levels. Moreover, the application of nitrogen along with various green manuring (GM) showed additive effects on yield and uptake of nutrients. Under all green manuring treatments, the yield and uptake were always higher with 120 kg ha^{-1} than with lower level of nitrogen (Ritesh *et al*., 2014). Husan *et al*. (2014) observed that Nitrogen content, uptake, apparent N recovery and NUE were influenced significantly by the application of prilled urea and urea super granule alone or in combination with organic manure. They suggested that, application of Urea Supergranule (USG) in combination with poultry manure could be considered more effective for increasing the yield and NUE of rice. Experiments conducted by Ponnamperuma (1984) revealed that, even in the case of high yields of rice, about 76 to 80% of the total nitrogen uptake is derived from the soil in a single cropping season of rice. Also, N use efficiency (dry weight/N uptake) in grain is influenced by the sources of N fertilizers (Fageria *et al.*, 2011). Haque and Haque, (2016) observed highest grain yield (5.36 t ha^{-1}) when rice variety was fertilized with 60 kg N ha^{-1}. Similarly Application of 60 kg N ha^{-1} also showed the highest nitrogen use efficiency (344.50 kg grain/kg N applied) of the variety. Jamil and Hussain, (2000) revealed that, among nitrogen levels, (0, 50 and 100 kg N ha^{-1}), application of 100 kg N ha^{-1} resulted in maximum paddy sand total biomass yield of 3.03 and 9.74 t ha^{-1}, respectively. They pointed out that, N uptake in both grain and straw increased significantly with increase in nitrogen application levels. Jing *et al.*(2007) revealed that, grain yield was enhanced linearly with the increasing N content of the upper two leaves, but hindered by the high N content of lower leaves. They further observed linear relationship between N uptake and leaf N content on a dry matter basis in all the leaves as N application rate increases.

2.5 Water management practices in irrigated rice systems

About 70% of global fresh water resources are used by irrigated agriculture (FAO, 2007). Rapid population growth and increase in demand for extra water as a result of industrialization is forcing the agricultural sector to seek ways of using irrigation water more efficiently to produce more food (Suriadi, 2010). Moreover Smith (2008) suggests that, defining prudent planning and management of limited water resources in the sector of agriculture should be a regional and global interest. Rice is one of the principal users of the world’s freshwater resources due to continuous submergence of rice fields from crop establishment close to harvest (Bouman and Toung 2001, Toung and Bouman, 2003). However, current rice production is threaten by water scarcity due to competition for water and climate change (Belder *et al*., 2004). Bouman *et al*. (2007) envisaged that about 15-20 million hectares of irrigated rice will experience some degree of water scarcity by the year 2025. Similarly, Tuong (2003) predicted that less water will be available for rice cultivation in the near future, due to increase competition for water among agricultural, domestic, hydropower and industrial water users. Wassmann *et al*. (2009) concluded that several areas which largely depend on rainfall for rice farming are already prone to drought under current erratic weather conditions and due to climate change, these areas are more likely to experience severe and frequent drought events in the near future. Increasing water productivity is especially vital because many processes in rice production area are related to water (Bouman, 2007). Therefore, efforts to increase water productivity by reducing water use are of great importance in irrigated rice farming. Most irrigated rice especially in the tropics are raised in a seedbed and then transplanted into a main field (De Datta, 1981). Main field Preparation often consists of soaking, plowing and puddling (i.e. harrowing under shallow submerged conditions). In irrigated rice farming, puddling is mostly done to control weeds and also to increase water retention and reduce soil permeability for easy leveling of the top field and transplanting of seedlings (De Datta, 1981). Between 25-50% water could be saved by intermitted irrigation during the vegetative stage without any adverse effect on rice yield (Anchal and Shiva, 2014). Various water management options for irrigated rice farming practices and their influence on performance of rice reported by different authors are presented below.

2.5.1 Rice response to submerged water management

2.5.1.1 Plant growth

The rice crop grows better under continuously submerged soil conditions than other crops probably due to the fact that its root can tolerate the anaerobic soil condition (Suraidi, 2010). This practice in most cases keeps the rice field continuously submerged with water from crop establishment to close to harvest (Suriadi, 2010). Saied and Zoghdan (2012) observed that, plant height and number of tillers were significantly higher in continuous submerged treated plots than AWD water management. Similar trend was observed by Shirazi *et al*. (2014),where maximum plant height was recorded in 300mm irrigation treatment and shortest in the control. They pointed out that availability of well distributed soil moisture at different growth stages due to irrigation enhanced the growth of plant. Also research conducted by Khairi, *et al.* (2015) to effect of various water regimes on rice production in lowland irrigation revealed that, there were not significance differences in plant heights and tiller numbers when plants were grown under submergence and AWD water managements. Similarly, plant heights and tiller numbers were not statistically different under continuous submerged and AWD water management (Rezaei *et al*., 2009). A screen house experiment conducted by Nguyen *et al*. (2009) revealed that, mean plant height and tiller numbers of 6 rice cultivars were not significantly different when plants were treated with continuous submerged water management and intermittent water management system. They further point out that, dry matter accumulation for the initial harvest in the continuous submerged treatments was less than in the intermittent water treatment although these differences were not statistically significant. Glass house experiment conducted by Juraimi *et al.* (2009) revealed that, plant height at 15 and 30 DAS, did not show any significant difference. Differences in plant height were only recorded at the beginning of 45 DAS. The height of the rice plant increassd with time in all the flooding treatments until the time of harvest. Generally, rice plant which was exposed under continuous saturated and continuous field capacity conditions were significantly shorter than the rice plant which received continuous submergence (Saied and Zoghdan, 2012). However, effect of the submerged treatments on the height of the rice plant was not obviously significant in all the pots during the vegetative phase (15 and 30 DAS). This was attributed to the few and small rice tillers at the early growing stages, which minimized the competition for available water for growth, even under continuous saturated and continuous field capacity. Similar trend was observed in the case of effect of the continuous submerged treatments on rice tillering, during the early tillering stages, significant differences were not observed because the tillering process was just about to begin at this stage (Sariam, 2004). Mostly, number of tillers reached its maximum potential until 75 DAS and at 90 DAS, and tillering process start to slow down in most of the submerged treatments because the rice plants were found to reach their maturity and only a few small tillers were produced (Weerakoon *et al*., 2010). Weerakoon *et al*. (2010) further observed that, there was a significant increase of the total biomass in treatments where there is no moisture stress to the rice plant. Therefore maintaining rice plants under continuous submergence throughout the growing period resulted in a significant increase of the total biomass. Similarly, Zubaer *et al*. (2007) revealed that, dry matter accumulation as well as LAI were higher in continuous submergence plots than water stress plots at booting and harvest stages of plant growth.

2.5.1.2 Yield and yield parameters

Effective panicles, the number of spikelets per panicle, the percentage of filled grains, and grain weight are the main yield factors. Khairi *et al*. (2015) observed higher number of effective tillers m^{-2} with continuous flooding followed by AWD water management. However, both were significantly superior to that obtained with continuous saturation. According to Zhang *et al*. (2009) the responses of rice panicle number m^{-2} were significantly affected by the submergence treatments. The highest number of rice panicles was produced under continuous submergence condition (434 panicles m^{-2}), while the lowest was recorded when water kept at field capacity**.** A pot experiment conducted by Juraimi *et al*. (2009) to evaluate the effect of different flooding treatments on rice growth and yield revealed that, variability in the continuous submergence treatment did not significantly affect either the number of days to flowering or the number of days to grain maturity in all the pots. This according to Mardina (2005) and IRRI (2008) was due to the fact that at the flowering stage, water demand is very critical while low or deficit in water availability will delay and lengthen the time of flowering process. Research conducted by Belder *et al*. (2004) revealed that biomass, yield and yield components were statistically the same under AWD and continuous submerged water management regimes at regardless of levels for both the hybrid and inbred rice varieties. Similarly Khairi *et al.* (2015) observed higher yields in continuous flooding water treatments than AWD although the differences were not statistically different. Pot experiment conducted by Juraimi *et al*. (2009) revealed that, differences in the flooding treatments had significant effects on the yield of rice straw. They observed a general decreased in straw biomass and yield when water availability declined.

2.5.2 Rice response to Alternately Wet and Dry (AWD) water management

2.5.2.1 Plant growth

In AWD irrigation technique, water is applied to the field a number of days after disappearance of ponded water. This differs from the traditional water management practice of continuous submergence of fields (Rejusus, 2011). This means that the rice fields are not kept continuously submerged but are allowed to dry intermittently during the rice growing stage (Rejesus, 2011).

Field and pot experiments conducted by Vries *et al*.(2010) revealed that, AWD improved soil conditions and this encourages the development of tiller. It was also found that, there was no significance differences in biomass accumulation between AWD treatments and continuous submergence water condition. Nguyen *et al*. (2009) observed that, plant heights and tiller numbers in alternate wet and dry water treatments were not significantly different from continuous submergence treatments.

2.5.2.2 Yield and yield parameters

According to Tan *et al*. (2013), alternate wetting and drying of fields enhance air exchange between the soil and the atmosphere and hence these condition promotes root growth and nitrogen uptake by rice. The performance of AWD in terms of rice yield are similar with submerged water management because AWD do not restrict water availability to plants (Belder, 2004). AWD technique depends much on other environmental factors such as soil type, water table depth and the number of days of absence of floodwater (Suriadi, 2010). During alternate wet and dry, water table coincides with root zone and therefore during the drying period plants may not experience water stress. They therefore produced similar yields as with continuously submerged conditions. Belder *et al*. (2004) reported that, aboveground biomass accumulation and rice yields were significantly similar under AWD and continuously submerged water management. AWD results in a better water productivity than submergence due to higher amount of water required. It was observed that with AWD at the vegetative stage of rice about 25-50% water could be saved without any significant reduction in rice yield (Ramamoorpy *et al*., 1993, Tajima, 1995). Boonjung and Funkai (1996) argued that, at the vegetative stage of the rice plant, rice growth was not adversely influenced when exposed to limited water condition. Hence AWD is preferable since at the vegetative stage of growth, rice adopts osmotic adjustment which enhanced dehydration tolerance in the rice plant (Steponkus *et al*., 1980). However, any water stress at late stages of growth can reduce rice yields significantly especially during early reproductive phase of rice (Kobata and Takami, 1981). In irrigated rice farming, continuous submergence is not necessary to obtain high yields (Guerra *et al.* 1998). According to Rezaei *et al*. (2009), rice plants grown under AWD water management conditions can give a yield 5-10% higher than continuous submergence.

2.5.3 Rice response to moist water management

2.5.3.1 Plant growth

In moist soil condition, soil moisture is kept as close to saturation as possible by shallow irrigation so that about 2-cm floodwater depth is obtained every day (Tuong *et al.*, 2005). According to Tabbal *et al*. (2002) moist water management can save about 30- 60% water compared with the conventional practice of continuous submergence while reduction of yield was only 4-9%. Because the water inputs decreased more than the yields, water productivity (calculated as the ratio of yield over total water input) increased by 30−115%. However, implementation of moist water management practice requires assured water supply throughout the growth period at the field level but frequent shallow irrigation is labour intensive (Suaridi 2010). Moist soil condition can be tedious to accomplish in coarse-textured soil due to its higher percolation rates compared with fine-textured soil (Suaridi 2010). According to Kukal *et al.* (2010) water deficit imposed during vegetative growth did not reduce yields while water stress during reproductive growth resulted in 20±70% less grain yield than well-irrigated rice. On the other hand, moist water conditions at late vegetative stage resulted in reduction in number of panicles per plant, percentage of filled grains and 1000- grain weight (Boonjung and Fukai, 1996). Again, Nour *et al*. (1994) observed that water stress during tillering and panicle initiation for 36 days significantly reduce plant height, tillering, total dry matter, and grain yield. It has been well established that water deficit reduces plant growth, primarily due to a reduction of the stomatal conductance that inhibits the carbon assimilation (Gonzalez-dugo *et al*., 2010)

2.5.3.2 Yield and yield parameters

Under moist soil condition, water stress may develop in the rice plant, which will adversely affect crop growth and ultimately crop yield (Suriadi, 2010). The effect of water stress on rice yield and yield parameters largely depends on crop species or the variety. It also depends on the magnitude and the time of imposing water deficit. The effect of the magnitude and timing of water supply on crop growth and yield are of major importance (FAO, 1986). According to Andreas and Karen (2002), the most common effect of water stress is a decreased rate of growth and development of foliage. This has a cumulative effect through the season as plant stress early in crop development results in a reduced leaf area. This means that light interception is reduced, carbon assimilation is reduced and therefore the rate of leaf growth is reduced. Water level kept between field capacity and permanent wilting point had significant effect on yield and yield parameters of rice (Moutonnet, 2002).

2.5.4 Effect of water management on uptake and nitrogen use efficiency

According to Olk and Senesi (2000) when fields are continuously submerged it brings about changes in the quality of soil organic matter. However, this practice enhances capacity of adequate nutrient-supply and soil carbon (soil organic matter) and yield (Dawe *et al*., 2000). Work done by Belder *et al*. (2004) reported that N uptake and NUE were similar when plants were treated under submerged and AWD management in their experiments. Usually, nitrogen uptake in both grain and straw in continuous submergence of fields was not significantly different from intermittent irrigation water management (Rejesus *et al*., 2011). Availability of nutrients such as nitrogen in crop field is largely influenced by partial aerobic soil conditions created by AWD. Tabbal *et al*. (1992) reported that, the level of ammonium was lower but nitrate levels were higher under AWD than under continuous submerged conditions. They pointed out that, in continuous submergence of fields nitrate could be leached or undergo denitrification losses making N uptake lower in continuous submergence than under AWD water management. Contrary to this, Bouman *et al*. (2006) observed significant decrease in NUE from 66-68% under flooded treatment to 40.2 % under AWD and 34.6% under saturated culture. Nitrogen use efficiency increased from 23.03 kg of grain/kg of N for rain-fed treatment to 30 kg of grain/kg of nitrogen for 100 % soil moisture deficit (SMD) irrigation treatment. Also higher nitrogen use efficiency is promoted at higher levels of water attributed to the better N mineralization and least nitrogen loss through leaching and volatilization at optimum soil moisture condition. This ultimately leads to better nitrogen uptake by rice (Blumenthal *et al*.,2008).

2.6 Water and nitrogen interaction

Water management and N fertilization strategies are two of the most important factors for increasing plant biomass, grain yield, water use efficiency and nitrogen use efficiency of rice (Ye *et al*., 2013). According to Rezaei *et al*. (2009) maximum yield and water productivity are determined by minimum and optimized amount of nitrogen application. Similarly, El-wahab *et al*. (2007) observed yield of 10.86 t/ha when plants were treated with 120 kg N ha^{-1} under continuous submerged water condition. Nitrogen and water management and their interaction can support tactical decision making process in other to improve rice production (Belder *et al.*, 2005). Water management with N fertilizer interaction still remains cardinal in rice production with regards to optimum yields, less water use and in increasing water productivity. Interaction of irrigation regime and nitrogen level on grain yield has been found to produce higher yieldswith the highest grain yield (7542 kg/ha) obtained when plants were treated with 120 kg N/ha under continuous submergence water condition. On the other hand, a lower grain yield of 4804 kg/ha was recorded with no fertilizer application under AWD water management regime. On the contrary, Cabangon *et al*. (2011) observed no interaction effect of water and nitrogen on rice yield, total N uptake, and N-use efficiencies. They concluded that, the principal effects of nitrogen management on rice under AWD are similar to those under continuous submergence conditions. Water treatment and nitrogen rate interaction for total N uptake was significant with 150 kg N/ha nitrogen rates under continuous submergence giving the higher uptake of nitrogen (Dunn and Gaydon, 2011)

2.7 Water productivity

As far as agriculture is concerned, water productivity relates to the yield (biomass or grain) derived from using a specific quantity of water. Water productivity (WP) is the ratio of grain yield and total amount of water input (irrigation + rainfall) from time of transplanting till harvest (Molden, 1997). The factors which affect WP include; crop type, water availability and soil, agronomic and economic factors (Ali and Talukder, 2008). In an experiment, rice yields reduced significantly under AWD compared with continuously submerged water management. However, water productivity with respect to total water input was higher in AWD than continuous submergence because the yield reduction was lower than the amount of water saved (Bouman and Tuong, 2001). Many researchers suggest that, the total water input could decrease by 15 – 30

% without any significant impact on the grain yield (Cabangon *et al*., 2011; Belder *et al*., 2004). In an experiment conducted by Juraimi *et al*. (2009) it was observed that about 24 – 35 % and 70 % irrigation water could be saved if the field is either maintained at saturated condition or saturate to dry situation respectively. Aguilar and Borjas (2005) indicated that irrigated rice can be easily cultivated using 8000 to 10000m^3/ha of fresh water. According to Bouman *et al*. (2006), modern rice cultivars when grown under flooded conditions, have water productivity (with respect to transpiration for grain yield (WPY/Tr)) of about 2 kg/m^3, while water productivity with respect to total water input (irrigation plus rainfall) was around 0.4 kg/m^3. Conventional water management in lowland rice aims at keeping the fields continuously submerged. Water inputs can be reduced and water productivity increased by introducing periods of non-submerged conditions of several days throughout the growing season unless cracks are formed through the plough sole (Belder *et al*., 2004). Water productivity in Sub-Saharan Africa ranges from 0.10 to 0.25 kg/m^3. In the developed world water productivity is average at 0.47kg/m^3. Compared to the developing world of 0.39kg/m^3 (Kadigi, 2003). Bouman and Tuong (2001) found typical water productivities of 0.3–1.1 kg/m^3 in the Philippines under continuous submergence water regime whilst water productivities in water-saving treatments were as high as 1.9 kg grain m^{-3}. Since water scarcity is now of global concern, the aim of agriculture is to produce more rice with less amount water. Water is a scarce commodity, since we pay for the cost of water use and in many cases pay for the enormous environmental costs (Ali and Talukder 2008).

2.8 Water use economy

Workdone by Rejesus *et al*. (2011) revealed that, alternate wetting and drying (AWD) decreases the frequency of irrigation to about 38%, without significant decrease in rice yields and net profits. Irrigation companies supply water to rice growers at a cost of about US$10 per ML and this cost is constantly increasing as the irrigation companies need to be economically viable (Bouman *et al*., 2002). The cost of pumping water from a river and its tributaries to rice growers is about $5 while the cost to growers of groundwater supplied to the crop is approximately $12 (Bouman *et al*., 2002). Globally, water productivity of rice ranged from 0.39 kg/m^3 to 0.52 kg/m^3 while in other cereals it ranged from 0.67 kg/m^3 to 1.01 kg/m3 (Ximing and Rodegrant, 2003). According to Abdul-Ganiyu *et al.* (2015) it is more water productive to produce rice under intermittent irrigation than continuous submergence of fields since the amount in kg of rice grain produced per unit volume of water (m^3) used was higher in intermittent irrigation than continuous submergence water management. According to Bouman *et al.* (2007) total water inputs, including rainfall, ranged from 965 mm for continuous submergence in rice cropping season. Barker *et al*. (1990) reported that, traditional irrigated rice production system not only leads to wastage of water, as it consumes 3000–5000 litres of water to produce 1 kg of rice but also causes environmental degradation and reduces fertilizer use efficiency. Saied and Zoghdan (2012) observed that, water productivity under saturated condition was higher than continuous submergence and half the amount of water was saved with comparable yield production. According to Aguilar and Borjas (2005) discontinuous submergence of fields brought about a reduction in pumping time, resulting in a relevant energy saving, and an important reduction in the overall costs. However, efficient utilisation of the applied N via fertilisers remains very low, that is only 20-40%. Mostly, increase in water productivity may or may not result in higher economic benefits (Visperas *et al.*, 2005)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at the Soil and Irrigation Research centre (SIREC) of the University of Ghana which is about 8 km away from the Kpong. The area lies 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 1100mm. The major rainy season begins from April to mid-July while the minor rainy season from early September to mid-November. It is characterized by an average annual temperature of 28 ˚C and relative humidity between 59%-93%. Monthly climatic data of the study area during the experimental period is presented in Table 1.

Table 1: Monthly climatic data of the study area during the experimental period

Month	Rainfall (mm)	Relative humidity	Maximum temperature (^{0}C)
July 2015	97.0	37.4	31.0
Aug	22.3	34.9	31.0
Sept	21.9	59.0	32.2
Oct	106.4	62.0	32.6
Nov	96.0	60.2	33.8
Dec	N/A	23.0	34.2
Jan 2016	33.2	34.7	34.7

N/A- indicates data not available; Source: Ghana Meteorological Agency, Soil and Irrigation Research Center (SIREC), Kpong

3.2 Soils of the study area

The soils in the study area are mainly the vertisols of the Accra plains. These are characterized by montmorillonitic clay minerals with clay content of 35–40%. The soils characteristically swell and become sticky when wet. When dried, they become harden and crack extensively which makes it difficult to cultivate with simple farm implements. Also, due to their narrow moisture range, tilling operations can be tedious with simple implements, e.g. hoe or with tractor drawn implements. Same soils were used for the pot experiments.

3.3 Soil sampling and preparation for analysis

Soil was sampled at depth of 0-20 cm across the experimental field for laboratory analysis. In the laboratory, the soil samples were air-dried, crushed using mortar and pestle and then sieved through a 2 mm sieve and analyzed at the University of Ghana soil science laboratory.

3.4 Soil Analysis

3.4.1. Soil pH

Ten grams of soil was weighed into beaker and 10 mL of distilled water was added to give a 1:1 (soil to water) ratio. The mixture was then stirred many times for about 30mins and left to stand for 1hr to allow most of the clay particles in suspension to settle. Two different buffer solutions of pH 4.0 and 7.0 were used to standardize the grass electrode pH meter- CG818, Schott Great. The electrode was then rinsed with distilled water, immersed into the partly settled suspension and the pH reading on the meter was recorded.

3.4.2 Determination Nitrogen (N)

Total N in soil samples was measured following digestion using the micro – Kjeldahl digestion method. The micro- Kjeidahl digestion method results in direct oxidation of organic matter through use of a digestion mixture that contains concentrated sulphuric acid, (H_2SO_4), 30% hydrogen peroxide (H_2O_2), lithium sulphate (Li_2SO_4) and selenium (Se) powder. Selenium powder is used as a catalyst and Li2SO4 raises the boiling point of the mixture. An air dried soil sample weighing 0.5 g was weighed into a digestion tube followed by addition of 4.4 ml of digestion mixture. The resultant mixture was placed on a digester at 360 ºC for 2 hours. The solution was allowed to cool and 25 ml of 40 distilled water added. A further 75 ml of distilled water was added and the solution was allowed to settle.

Total N in the sample was then determined colorimetrically at an absorbance of 655 nm. The % N in the sample was calculated as follows:

% N = {(absorbance of sample – absorbance of blank) x F x 0.01}/sample weight

Where F = the mean of (concentration of standards (ppm)/absorbance of standards)

3.4.3 Determination of Phosphorus (P)

Sample digestion for total P was the same as in determination of total N (see section 3.3.3). After digestion, 5 ml of sample were pipetted into a 50 ml volumetric flask followed by 20 ml of distilled water. To the mixture, 4 ml ascorbic acid ($C_6H_8O_6$) was then added and the resultant solution mixed well. Distilled water was added to the mark and the solution left for 1 hour for full colour development. The samples and standards were read at 880 nm wavelength. The % P in the sample and standards was calculated as follows: P = C x 0.05 x W

Where C = concentration of P in sample; W = weight of sample.

3.4.4 Determination of available Potassium (K)

Ten grams (10g) of soil that has been sieved through 2mm sieve was weighed into 200mL extraction bottle, 100mL of 1N ammonium acetate (NH_4OAC) solution buffered at pH 7.0 was added to the soil the extraction bottle. The bottle and its content were placed in a mechanical shaker and shaken for 1hr, and the centrifuge in a centrifuge at 3000 rpm for 20 min. The solution was then filtered through Whatman No 42 filter paper into a clean bottle. An aliquot was taken from the filtrate in the bottle and used for determination of K. The atomic Absorption Spectrometer was used for reading the content of K in the solution and quantity in the soil determined.

3.4.5 Organic carbon determination

Soil organic carbon was measured using the wet oxidation colorimetric method (Anderson and Ingram, 1993). One gram of soil sieved through a 2 mm sieve was weighed into a conical flask followed by addition of 10 ml potassium dichromate ($K_2Cr_2O_7$). The resultant mixture was gently swirled until the sample was completely wet. To the mixture, 20 ml of concentrated H_2SO_4 were added from an automatic dispenser and the resultant mixture gently swirled. The mixture was allowed to cool in a fume cupboard followed by addition of 50 ml 0.4% $BaCl_2$. The mixture was swirled again and left to stand overnight, so as to get a clear supernatant solution. Total organic C in the sample and standards was then measured calorimetrically using a 42 BUCK Scientific 100 VIS spectrophotometer at 600nm wavelength. The % organic C in the sample was then calculated as follows:

% organic C = (K x 0.1)/ (W x 0.74)

Where K = sample concentration – mean blank concentration

W = weight of soil.

Table 2: Chemical characteristics of soil at 0-20 cm depth

Depth (cm)	N%	Available P	Available K	Exchangeable Ca	pH	OC
0-20	0.067	2.09	4.72	22.83	7.55	1.55

3.5 Pot Experiment

The pot experiment was conducted as a preliminary study to help fine-tune the cultural practices and general management of the experiments.

3.5.1 Soil sampling and pot filling

Soils for the pot experiment was taken from the soil and irrigation Research field (from a depth of 0-30 cm). Stones, debris and other foreign materials were carefully removed from the soil samples. The soil were sun-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh. 9.0 kg sample was weighed into pots of volume 1,000 cm^3. The soils in the pots were then submerged with water before transplanting.

3.5.2 Transplanting of seedlings

The rice (*Oryza sativa* L.) variety used was *Ex Baika*. Two seedlings per pot were transplanted. During transplanting, all pots were kept saturated with water to prevent transplanting shock.

3.5.3 Design and layout of experiment

A 3 x 3 factorial experiment was carried out in Greenhouse using a RCBD. In all 45 pots comprising of 9 treatments and 5 replications were used. The treatments used in the pot experiment are described in Table 3.

Table 3: Description of treatments used in the pot experiment

No.	Treatment	Code
1.	**Alternative Wet And Dry + 0kg N ha^{-1}**	**AWDN0**
2.	**Alternative Wet And Dry+ 60kgN ha^{-1}**	**AWDN1**
3.	**Alternative Wet And Dry + 90Kg N ha^{-1}**	**AWDN2**
4.	**Moist soil Condition + 0kgN ha^{-1}**	**MoistN0**
5.	**Moist soil Condition + 60kgN ha^{-1}**	**MoistN1**
6.	**Moist Condition + 90kgN ha^{-1}**	**MoistN2**
7.	**Continuous Submergence + 0kgN ha^{-1}**	**SubmergedN0**
8.	**Continuous Submergence + 60kgN ha^{-1}**	**SubmergedN1**
9.	**Continuous Submergence + 90kgN ha^{-1}**	**SubmergedN2**

3.6 Field Experiment

3.6.1 Land preparation

The field was cleared with a cutlass and all vegetation and debris were removed. It was then flooded with irrigation water for about three (3) days to soften the soil to facilitate tillage. The field was then puddled to a depth of 15-20 cm by a rotovator in order to reduce water percolation and soften the soil for transplanting.

3.6.2 Field Layout

A split plot design with water management treatments as main plot and N fertilizer treatments in subplots was used. The three water management methods were: Alternate wet and dry (AWD), moist soil condition between field capacity and permanent wilting point (Moist), and continuous submergence (submerged). The nitrogen levels were: 0, 60 and 90kgN ha^{-1} as subplots within each main plot. The main plots were separated from each other by bunds at a distance of 2m whiles metallic barriers of size $6m^2$ were then buried 30 cm deep in each sub plot to reduce lateral movement of water and nutrients. The treatments used are described in Table 4.

3.6.3 Transplanting and gap filling

Rice variety, *Ex Baika* was used as the test crop. Seedlings were raised in the seedbed on 19th June, 2015. Twenty five days old seedlings were transplanted onto the field at spacing of 20 cm within rows and 20 cm between rows at 2 seedlings per hill. During planting, all the plots were kept saturated with irrigated water to prevent transplanting shock.

Table 4: Description of treatments used in the field experiment

Water management	**N fertilizer level**
Continuous submergence (submerged)	**No nitrogen fertilizer (N0)**
	60 kg N ha^{-1} (N1)
	90 kg N ha^{-1} (N2)
Alternate wetting and drying (AWD)	**No nitrogen fertilizer (N0)**
	60 kg N ha^{-1} (N1)
	90 kg N ha^{-1} (N2)
Moist soil condition (soil moisture content between field capacity and permanent welting point) (Moist)	**No nitrogen fertilizer (N0)**
	60 kg N ha^{-1} (N1)
	90 kg N ha^{-1} (N2)

3.7 Fertilizer application

Same nitrogen treatments were used for both pot and field experiments. The nitrogen fertilizer source was Urea. Nitrogen fertilizer was applied two times that is 50% at transplanting and 50% at panicle initiation for both pot and field experiments. 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^{-1} as basal for all treatments in both pots and field after two weeks after transplanting of seedlings.

3.8 Water Management Treatments

Water management treatments were the same for both experiments. 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 20 cm in diameter and 45 cm in length were inserted in all plots except the submerged treated plots. The pipes were 15 cm above and 30 cm below the soil surface to monitor soil water levels in each plot.

3.8.1 Submerged water condition

In the submerged water treatment, the depth of water was kept at 3 cm just after transplanting and increased gradually to 5–10 cm at active tillering (AT) stage and maintained until 10 days to harvest.

3.8.2 Moist soil condition

In the moist water management regime, soils were just kept moist. This was achieved by ensuring that, the moisture level in the inserted tube within the plot is at 25 cm and 16 cm below the soil surface in the field and pot experiments respectively. All plots were continuously submerged at panicle primordial initiation stage until 10 days before harvest.

3.8.3 Alternate wet and dry condition (AWD)

In the AWD water management regime, soils were kept inundated at 3 cm depth of water after transplanting. Plants were only irrigated when the water level in the pipe dropped to 25 cm and 16 cm below the soil surface in the field and pot experiments respectively. All plots were completely submerged at panicle primordial initiation stage until 10 days before harvest.

3.9 Insect-pest management

Insecticide (dursban) was sprayed at vegetative stage to control stem borer infestation. The experimental field was covered with nylon nets from flowering stage till harvesting to prevent birds attack.

3.10 Weed management

Pre- emergence herbicide (stump) was applied just after transplanting and followed by post-emergence herbicide (propagold = proppanil + 2, 4-D) application, 21 days after.

3.11 Harvesting and threshing

The crop plot area was harvested manually using sickle. Harvested plants were sun dried for 5 days. Threshing was done manually, and grains were obtained by winnowing and were weighed at 14% moisture content.

3.12 Data collection

3.12.1 Growth parameters of rice

The following growth data were collected: Plant height, leaf area index (LAI), number of tiller per plant, above ground biomass accumulation, leaf chlorophyll content and days to 50 % flowering.

3.12.1.1 Plant height (cm)

Five healthy plants were tagged in each plot on which measurements were made. For juvenile plants, plant height was measured from ground level to the tip of the topmost leaf. For mature plants, however, plant height was measured from ground level to the tip of topmost panicle with a meter rule. The average value was considered to be the plant height for each treatment.

3.12.1.2 Number of tillers

The number of tillers hill^{-1} were counted from five tagged plants in each experimental unit.

3.12.1.3 Dry matter accumulation

Aboveground biomass was determined through destructive sampling of 3 hills per plot. The plant samples were put in brown paper envelopes and then oven dried at 60 ^{0}C for 48 hours to determine their dry matter weight.

3.12.1.4 Leaf Area Index

Leaf area index were estimated by measuring the length and average width of leaf and multiplying by a factor of 0.75 followed by Yoshida (1981).

3.12.1.5 Determination of leaf chlorophyll content

Chlorophyll content of leaves were recorded using SPAD value meter (Minolta Japan). The SPAD value of leaves was determined at flowering stage of the rice plant. For each plot, 15 leaves were randomly selected for measurement per treatment.

3.12.1.6 days to 50 % flowering

Days to 50% flowering was recorded when about 50% of the plants within a plot had flowered.

3.13 Yield and yield parameters of Rice

3.13.1 Number of panicles m^{-2}

Number of panicles m^{-2} per plot were recorded within each plot just before harvesting the crop. The average values were used to obtain the panicles m^{-1} per treatment.

3.13.2 Length of panicle (cm)

The length of panicles were taken from five hills of each plot by random selection just before harvesting. Panicle length was recorded from the basal node of the rachis to the apex of each panicle with a centimeter rule. The means were calculated for each experimental unit.

3.13.3 Number of grains per panicle

Just before harvesting panicles were taken from five hills of each plot. The numbers of filled and unfilled grains were counted to determine the number of filled grains per panicle.

3.13.4 Percentage filled grains

Total filled grains were obtained in the panicles from five hills and this was used to determine percentage filled grains as per the formula. % filled grains = (Number of filled grains×100)/ Total number of grains

3.13.5 1000- grain weight (g)

One thousand clean dried grains were counted from the seed stock obtained from five sample plants of-each plot and weighed by using an electronic balance.

3.13.6 Grain yield

A 5 square meter area within each plot was used to grain yield in kg/ha. Grains obtained from each unit plot were sun dried and weighed carefully at 14% grain moisture content. The grain yield was finally converted to t/ha.

3.13.7 Straw yield

Straw obtained from each unit plot $5m^2$ were dried in sun and weighed to record the straw yield/plot and finally converted to t /ha.

3.13.8 Harvest index

Harvest index (HI) was determined using the formula;

$$\text{Harvest index } = \frac{\text{Grain yield}}{\text{Grain yield} + \text{straw yield}}$$

3.14 Nitrogen uptake and Nitrogen Use Efficiency (NUE)

Tissue N concentration in both grains and straws samples were determined by micro Kjeldahl digestion, distillation, and titration to calculate aboveground total N uptake. Agronomic and physiological nitrogen efficiencies were calculated.

3.14.1 N uptake

Nitrogen uptake were calculated as follows;

Nitrogen uptake by grain (kg ha^{-1}) = % N in grain ×Grain yield (kg ha^{-1})

Nitrogen uptake by straw (kg ha^{-1}) = % N in straw ×Straw yield (kg ha^{-1})

Total nitrogen uptake (kg ha^{-1}) = Nitrogen uptake by grain (kg/ha) + Nitrogen uptake by straw (kg/ha).

3.14.2 Physiological N use efficiency (PNUE)

Physiological N use efficiency (PNUE) was calculated as follows;

$$\mathrm{PNUE} = \frac{\mathrm{YF} - \mathrm{YC}}{\mathrm{NUF} - \mathrm{NUC}}$$

Where; YF = Yield of fertilized plot (kg/ha), YC = Yield of control plot (kg/ha), NUF =Total N uptake in fertilized plot, and NUC = Total N uptake in control plot.

3.14.3 Agronomic N use efficiency (ANUE)

Agronomic N use efficiency (ANUE) was calculated as;

$$\mathrm{ANUE} = \frac{\mathrm{YF} - \mathrm{YC}}{\mathrm{FN}}$$

Where; YF = Yield of fertilized plot (kg/ha), YC = Yield of control plot (kg/ha) and FN = Fertilizer N applied (kg/ha).

3.15 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. 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 subplot. Also, amount of precipitation during the period (rainfall events and amounts) were recorded.

3.16 Water productivity

Water productivity was calculated using the following equations; $\mathrm{WP} = \frac{\mathrm{GY}}{\mathrm{TWA}}$

Where; WP = water productivity (kgm^{-3}), GY = grain yield (kg/ha) and TWA = total water applied (irrigation water and rain water used) expressed in m^{3}ha^{-1}.

3.17 Statistical 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 at 5% level of significance.

3.18 Economic analysis for rice production

Only the field experiment was considered for the economic analysis.

3.18.1 Cost of cultivation

Cost of agro inputs such as fertilizer and pesticides, labour, and other materials used in the field experiment were recorded. Water costs associated with water management techniques was also estimated.

3.18.2 Gross return

Grain yield was converted into gross return from grain yield (GH₵/ha) based on prices of the local market.

3.18.3 Net return

Net returns from sales of rice was calculated as;

Gross returns - Cost of production

3.18.4 Benefit Cost ratio

Benefit cost ratio was estimated using the formula;

$$\text{Benefit cost ratio} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

CHAPTER FOUR

RESULTS

4.1 Pot Experiment

4.1.1 Vegetative Growth

4.1.1.1 Plant height

The data presented in Table 5 revealed that, plant height generally increased up to harvest stage ranging from 46.6 to 100.9 cm depending on water management and N fertilizer level used. The increment in plant height was most intense between active and maximum tillering stage. Plant height was significantly influenced by water management treatments ($p<0.05$) only at booting and harvest stages, while N fertilizer influenced plant height significantly ($p<0.05$) from active tillering to harvest. The interaction effect between water management and N fertilizer was significant at booting and harvest only ($p<0.05$). At active and maximum tillering stage, plant height was not influenced ($p>0.05$) by water management treatments. At booting, AWD and submerged water treatments produced significantly taller plants than plants treated with moist water management. The same pattern was observed at harvest. At active and maximum tillering, N1 and N2 treated plants produced significantly ($p<0.05$) taller plants, while plants that were not treated with N fertilizer (N0) produced shorter plants. At harvest, plant height significantly increased with increased N rate. There was significant interaction effect between water management and N fertilizer at booting and harvest stages. At both stages, the interaction effect of N2 with submerged water management produced significantly taller plants followed by N2 treated plants under AWD water management. The interaction effect of N0 and moist water management resulted in significantly shorter plants.

4.1.1.2 Number of tillers

The mean values of the number of tillers across the treatments (Table 5) showed that tillering increased up to maximum tillering stage and thereafter gradually declined. The number of tillers were significantly influenced by N fertilizer ($p<0.05$) at all stages. Also, number of tillers was significantly influenced by water management ($p<0.05$) at all stages except at active tillering. There was significant effect ($p<0.05$) of interaction between water management and N fertilizer on number of tillers except at active tillering stage. At maximum tillering, booting and harvest stages, tillering, was not significant ($p>0.05$) among AWD and submerged treated plants. However, moist water treatments produced significantly lower number of tillers. With regards to N fertilizer, tillering was similar in N1 and N2 treatments in all growth stages except at harvest. At harvest, tiller number was significantly higher in N2 treated plants than N1. N0 treated plants produced significantly lower number of tillers in all stages of growth. At booting and harvest, interaction effect of N2 with submerged water management produced higher tillers followed by N2 treated plants under AWD water management. In all, tillering was significantly lower in N0 and moist interaction of fertilizer and water management.

Table 5: Effect of water management and N rate on plant height (cm) and number of tillers

Treatment	Plant height (cm)				Tiller numbers			
	Active tillering	Maximum tillering	Booting	Harvest	Active tillering	Maximum tillering	Booting	Harvest
Water (W)								
AWD	47.4	72.3	88.2	88.7	6	22	20	19
Moist	46.6	70.8	71.9	85.0	5	20	17	14
Submerged	47.8	71.6	88.8	89.4	6	22	20	19
LSD (P=0.05)	NS	NS	0.59	1.0	NS	0.5	0.8	0.9
Fertilizer (N)								
N0	45.3	69.7	76.3	76.8	5	17	15	14
N1	47.6	72.1	81.5	87.0	7	23	21	18
N2	48.9	73.0	91.2	99.3	7	24	22	20
LSD (P=0.05)	1.2	1.4	0.59	1.0	1.3	1.1	1.1	0.9
Interaction								
AWD×N0	45	70.0	80.7	77.8	5	18	17	15
AWD×N1	47.6	72.8	86.0	87.4	6	23	22	20
AWD×N2	49.6	74.1	98.0	101	7	24	22	21
Moist×N0	45.4	66.0	69.1	74.2	5	14	12	12
Moist×N1	47.0	71.3	72.1	85.8	6	22	19	14
Moist×N2	47.4	72.2	76.9	95.1	6	23	21	18
submerged×N0	45.4	70.1	81.4	78.5	6	19	17	15
submerged×N1	48.1	72.2	86.5	87.7	7	24	22	19
submerged×N2	49.7	72.6	98.6	102	7	25	23	22
LSD (P=0.05)	NS	NS	1.1	1.78	NS	0.9	1.4	1.6

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05.

4.1.1.3 Aboveground biomass accumulation

Biomass accumulation across the treatment increased from mid-tillering up to harvest (Table 6). Biomass accumulation ranged from 5.4 g to 79.2 g across the treatment combinations. Biomass accumulation was significantly influenced by water and as well as N fertilizer at mid-tillering, booting and harvest. Also the interaction effect between water management and N fertilizer was significant at booting and harvest only. At mid-tillering and booting, AWD and submerged treated plants produced similar biomass accumulation with the least biomass accumulation recorded in moist water treatments. At harvest however, biomass accumulation was significantly varied in this order: submerged > AWD > moist. At mid- tillering and booting, N1 and N2 treated plants produced higher biomass accumulation than plants that were not treated with N fertilizer (N0). At harvest, biomass accumulation significantly increased with increased N rate. Interaction effect of N2 with submerged water treatments produced higher biomass accumulation followed by N2 fertilized plants under AWD water management at booting and harvest stages.

4.1.1.4 Leaf area index

Leaf area index across all treatments increased from booting to flowering and ranged from 3.6 to 7.6 (Table 6). Leaf area index was significantly influenced by both water management and N fertilizer as well as interaction effect of these two factors at both growth stages. At booting, leaf area index was similar in AWD and submerged treated plants. At flowering stage, submerged water treatments was superior to all the other water treatments. For both growth stages, the lowest leaf area index was recorded in moist water management. Based on N fertilizer rate, leaf area index varied significantly ($p<0.05$) and ranked as N2 > N1 > N0. At booting, the interaction effect of N2 with submerged water treatment produced higher leaf area index followed N2 and AWD combination. However at flowering, interaction effect of N2 with AWD produced higher leaf area index followed by N2 with submerged water treatments. Interaction effect of N0 and moist was inferior to all other treatment combinations.

4.1.1.5 Leaf chlorophyll content

Leaf chlorophyll content ranged from 30.6 µmol/m^2 to 55.6 µmol/m^2 across the treatment combinations as presented in Table 6. Both water management and N fertilizer as well as interaction effect of water and N fertilizer significantly influenced leaf chlorophyll content. At flowering, leaf chlorophyll content was significantly higher in submerged treatments than the other water treatments. Moist treated plants produced the lower chlorophyll content at flowering stage. Leaf chlorophyll content significantly ($p<0.05$) increased with increased N rate. The interaction effect of N2 with submerged water treatments produced higher leaf chlorophyll content followed by N2 and AWD interaction at flowering stage. In all, interaction effect of N0 with moist produced the lowest chlorophyll compared to all the other treatment combinations.

4.1.1.6 Days to 50% flowering

The data on days to 50 % flowering are also shown in Table 6. Water management and N fertilizer application as well as their interaction did not significantly ($p>0.05$) influenced days to 50% flowering.

Table 6: Variation in above biomass accumulation, leaf area index, leaf chlorophyll content (SPAD values) and days to 50% flowering as affected by water management and N fertilizer rate

Treatment	**Above biomass accumulation (g)**			**Leaf area index**		**Leaf chlorophyll content**	**Days to 50% flowering**
	Mid tillering	Booting	Harvest	Booting	Flowering		
Water (W)							
AWD	7.3	49.2	60.4	5.8	5.8	42.5	84
Moist	6.2	34.2	46.2	4.7	4.7	38.3	84
Submerged	7.6	49.8	64.5	5.9	6.0	43.9	85
LSD (P=0.05)	0.46	0.84	0.77	0.16	0.14	0.94	NS
Fertilizer (N)							
N0	6.4	27.2	44.3	4.3	4.3	33.5	84
N1	7.3	52.7	57.0	5.2	5.2	39.9	84
N2	7.5	53.4	69.9	6.9	7.0	51.3	84
LSD (P=0.05)	0.45	0.84	0.77	0.15	0.14	0.94	NS
Interaction							
AWD×N0	6.8	29.6	48.3	4.5	4.5	34.5	83
AWD×N1	7.6	58.7	56.9	5.6	5.6	39.7	84
AWD×N2	7.6	59.5	76.1	7.3	7.6	53.4	84
Moist×N0	5.4	21.9	35.7	3.6	3.6	30.6	84
Moist×N1	6.6	40	48.4	4.6	4.6	39.4	84
Moist×N2	6.7	40.7	54.4	5.9	5.9	44.9	85
submerged×N0	6.9	30	48.8	4.8	4.8	35.4	85
submerged×N1	7.7	59.5	65.6	5.6	5.6	40.7	85
submerged×N2	8.1	59.9	79.2	7.4	7.5	55.6	84
LSD (P=0.05)	NS	1.5	1.33	0.27	0.25	1.64	NS

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05.

4.1.2 Yield and yield parameters

4.1.2.1 Effective tillers

Average number of effective tillers per pot across all treatments ranged from 12 to 22 depending on water management and N fertilizer used (Table 7). In general, the number of effective tillers/pot was significantly influenced by both water management and N fertilizer (p<0.05).

Also, the interaction effect of water management and N fertilizer was significant. Number of effective tillers did not differ significantly between AWD and submerged water treatments. However both water treatments were significantly superior to moist 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 submerged produced higher number of effective tillers followed by N2 and AWD interaction. In all, N0 with moist interaction was inferior to all other interaction effect.

4.1.2.2 Panicle length

Panicle length differed significantly with water management and N fertilizer as well as interaction effect of water management and N fertilizer ($p<0.05$) as shown in Table 7. Panicle lengths were at par in AWD and submerged water treatments but significantly shorter in moist water treatments. The trend of panicle length with regard to N fertilizer was N2 > N1 > N0. Interaction effect of N0 with moist water produced the shortest panicle length in all the treatment combinations. Interaction effect of N2 with submerged was significantly ($p<0.05$) superior to all the other interaction effects.

4.1.2.3 Number of grains per panicle

Data on the number of grains per panicle are presented in Table 7. Number of grains/panicle was significantly ($p<0.05$) influenced by water management and N fertilizer. Also, the interaction effect of water management and N fertilizer on number of grains per panicle was significant ($p>0.01$). AWD and submerged produced similar number of grains/panicle however, moist 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 submerged and N0 with moist produced the highest and lowest number of grains/panicle respectively.

4.1.2.4 Percentage filled grains

Percentage filled grains ranged from 88.3 to 93.7 % (Table 7) depending upon treatment combination. Percentage filled grains was significantly ($p<0.05$) 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 ($p>0.05$).

4.1.2.5 1000 grain weight

Thousand grain weight was not significantly influenced by both N fertilizer and water management (Table 7). Also, there was no interaction effect of water management and N fertilizer on 1000 grain weight. However, moist and AWD water management regime produced higher 1000 grain weight (26.9 g) although not significantly ($p>0.05$) different from submerged water treatment. N1 and N2 treated plants produced 1000 grain weight of 27.0 g which was not significantly ($p>0.05$) different from plants with no N application (27.3 g). The highest weight (27.5 g) was recorded in N1 treated plants under submerged although not significantly different from the other treatment combinations. The lowest weight (26.5 g) was recorded in N2 treated plants under AWD water management.

Table 7: Effective tillers, panicle length, grains/panicle, % filled grains and 1000 grain weight as influenced by water and N fertilizer

Treatment	Effective tillers	Panicle length(cm)	Grains/panicle	% filled grains	1000 grain weight(g)
Water (W)					
AWD	19	22.6	113	91.7	26.9
Moist	14	21.3	96	92.6	26.9
Submerged	19	22.7	115	89.1	27.4
LSD (P=0.05)	0.9	0.59	4.1	NS	NS
N Fertilizer (N)					
N0	14	20.8	98	89.8	27.3
N1	18	22.2	103	92.1	27.0
N2	20	23.8	124	91.4	27.0
LSD (P=0.05)	0.9	0.59	4.1	1.3	NS
Interaction					
AWD×N0	15	20.8	100	89.3	27.4
AWD×N1	20	22.6	106	93.7	26.9
AWD×N2	21	24.5	134	92.0	26.5
Moist×N0	12	20.1	91	88.3	27.1
Moist×N1	14	21.4	95	89.0	26.6
Moist×N2	18	22.4	102	90.0	27.1
Submerged×N0	15	20.83	103	91.7	27.3
Submerged×N1	19	22.7	108	93.7	27.5
Submerged×N2	22	24.8	135	92.3	27.4
LSD (P=0.05)	1.6	1.1	7.1	NS	NS

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05.

4.1.2.6 Grain yield

The effect of different water management and N fertilizer rate on rice yield for the pot trial is shown in figure 1. Grain yield was significantly influenced by water management and N fertilizer. Also, the interaction effect of water management and N fertilizer on grain yield was significant. Grain yield ranged from 14.9 to 54.6 g/pot. The effect of N fertilizer on rice yield was ranked as: N2 > N1 >N0. AWD and submerged produced similar yields. Grain yield was lowest in moist treated plants. Interaction effect of N2 with submerged water management gave higher yields followed by N2 with AWD interaction. N0 with moist interaction was significantly (P<0.01) inferior to all other interaction effect of water management and N fertilizer.

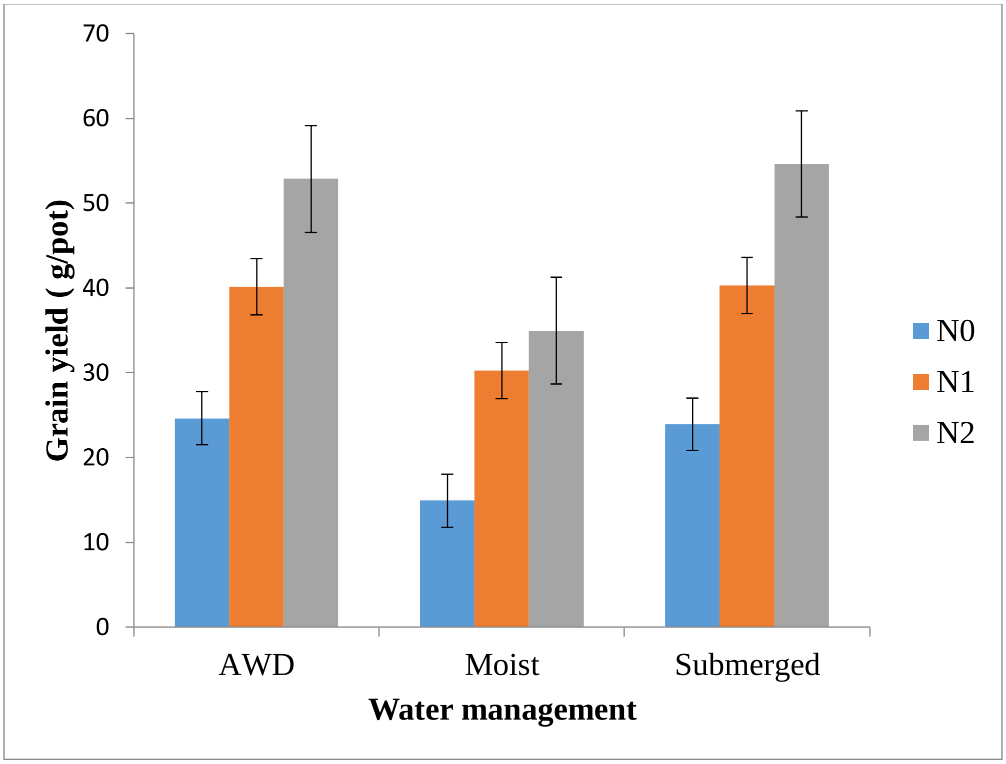

Figure 1: Grain yield of rice as influenced by water management and N fertilizer (Pot Experiment).

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively.

4.1.2.7 Straw yield

Straw yield ranged from 35.7 to 79.2 g/pot across the treatment combinations as presented in Table 8. Both water management and N fertilizer significantly influenced straw yield. The water management effect on straw yield was ranked in the order: submerged > AWD > moist. For N fertilizer, the trend of straw yield was N2 > N1 > N0. Interaction effect of N2 with submerged and N0 with moist gave significantly (p<0.01) higher and lower straw yields respectively

4.1.2.8 Harvest index

Both water management and N fertilizer application rate significantly ($p<0.01$) influenced harvest index of rice (Table 8). There was interaction effect of water management and N fertilizer on harvest index of rice. Harvest index ranged from 0.29 to 0.41 across the treatment combinations. Harvest index increased significantly ($p<0.05$) with increased N fertilizer rate. With respect to water managements, AWD produced the greatest harvest index which was significantly ($p<0.01$) different from submerged and moist water treatments. Moist water treatments produced the lowest harvest index than submerged treatments. Interaction effect of N1 treated pots with AWD proved significantly ($p<0.05$) superior to all other interaction effect of N fertilizer and water management.

4.1.3 Water use (WU)

Water use was significantly ($p<0.05$) influenced by both water management and N fertilizer application rate (Table 8). Interaction effect of water management and N fertilizer significantly ($p<0.05$) influenced water use. Water use ranged from 23.1 cm^3 to 57.8 cm^3 depending upon water management and N fertilizer used. 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: Moist < AWD < submerged. With interaction effect of water management with N fertilizer, more water was required (57.8 cm^3) with submerged and N2 interaction followed by N1 with submerged interaction. The lowest WU (23.1 cm^3) was recorded at N0 treatment under moist water management.

4.1.4 Water productivity (WP)

Both water management treatments and N fertilizer, and their interactions had a significant ($p<0.05$) effect on water productivity (Table 8). Water productivity ranged from 0.47 to 1.09 g cm^{-3} across the treatments combinations. In all cases, water productivity increased with increased N fertilizer application rate. In relation to water management treatments, water productivity was ranked in this order: moist > AWD > submerged. In general, the interaction effect of N2 with moist 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 submerged interaction.

Table 8: Straw yield, harvest index, water use and water productivity of rice as affected by water management and N fertilizer

Treatment	Straw yield (g)	Harvest index	Water use (cm^3)	WP (g/cm^3)
Water (W)				
AWD	60.4	0.39	49.3	0.79
Moist	46.2	0.36	27.2	0.96
Submerged	64.5	0.37	54	0.72
LSD (P=0.05)	0.77	0.04	0.95	0.3
N Fertilizer (N)				
N0	44.3	0.32	40.6	0.55
N1	57.0	0.39	43.0	0.91
N2	69.9	0.4	46.7	1.03
LSD (P=0.05)	0.76	0.04	0.96	0.3
Interaction				
AWD×N0	48.3	0.34	48	0.51
AWD×N1	56.9	0.41	49.3	0.82
AWD×N2	76.1	0.41	50.5	1.05
Moist×N0	35.7	0.29	23.1	0.65
Moist×N1	48.4	0.38	26.4	1.06
Moist×N2	54.4	0.39	32.0	1.09
Submerged×N0	48.8	0.33	50.8	0.47
Submerged×N1	65.6	0.38	53.3	0.76
Submerged×N2	79.2	0.41	57.8	0.95
LSD (P=0.05)	1.33	0.07	1.66	0.05

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively.

4.1.5 Grain N uptake

Grain N uptake was significantly ($p<0.05$) influenced by both water and nitrogen fertilizer (Table 9). Also, interaction effect of water management and N fertilizer on grain N uptake was significant ($p<0.05$). With regards to N rate, uptake increased with increased N rate. Response of N uptake in grain with regard to water management was ranked in the order: AWD > submerged > moist. Interaction effect of N2 with AWD gave higher uptake followed by N2 with submerged interaction.

4.1.6 Straw N uptake

The effects of water management and N fertilizer on straw nitrogen uptake are presented in Table 9. Both water and N fertilizer and their interaction significantly ($P<0.05$) influenced N uptake in straw. N uptake in straw ranged from 0.15 to 0.72 g pot^{-1}. N uptake with regards to N fertilizer was ranked as: N2 > N1 > N0. Among the water treatments, N uptake was ranked in this order: submerged > AWD > moist. Interaction effect of N2 with submerged recorded higher uptake followed by N2 with AWD interaction effect of N fertilizer and water management.

4.1.7 Agronomic nitrogen use efficiency (ANUE)

ANUE was significantly ($p<0.05$) influenced by both nitrogen fertilizer and water treatments as well as interaction effect of water management and N fertilizer (Table 9). Agronomic N use efficiency ranged from 25.9 to 34.9g/g across the treatments combinations. ANUE of rice was significantly higher in N2 than N1, whereas based on water treatments ANUE varied in the order: submerged > AWD > moist. For the interaction effect, ANUE was significantly ($p<0.05$) higher (34.9g/g) in N2 with submerged followed by N2 with AWD interaction.

4.1.8 Physiological nitrogen use efficiency (PNUE)

Data presented in Table 9 showed that, both water management and N fertilizer as well as interaction effect of water management and N fertilizer had significant ($p>0.05$) effect on PNUE. PNUE ranged from 29.6 to 48.2g/g across the treatment combinations (Table 9). PNUE decreased with increased fertilizer rate with the highest recorded in N1. In case of water management, PNUE in AWD was at par with submerged. PNUE in moist was superior to AWD and submerged water treatments. Interaction effect of N1 with AWD as well as N1 with moist had the highest PNUE (48.2g/g) followed by N1 with submerged interaction.

Table 9: Grain N uptake, straw N uptake ANUE and PNUE as influenced by water management and N fertilizer.

Treatment	Grain N uptake (g/pot)	Straw uptake (g/pot)	ANUE(g/g)	PNUE(g/g)
Water (W)				
AWD	0.37	0.43	19.5	25.9
Moist	0.2	0.34	16.3	32.1
Submerged	0.34	0.45	20.9	25.8
LSD (P=0.05)	0.04	0.05	0.93	5.4
N Fertilizer (N)				
N0	0.12	0.20	-	-
N1	0.29	0.34	26.7	50.4
N2	0.51	0.62	29.9	33.4
LSD (P=0.05)	0.04	0.05	0.93	3.6
Interaction				
AWD×N0	0.14	0.28	-	-
AWD×N1	0.34	0.36	26.3	48.2
AWD×N2	0.63	0.70	32.1	29.6
Moist×N0	0.08	0.15	-	-
Moist×N1	0.22	0.26	25.9	48.2
Moist×N2	0.31	0.45	22.8	37.6
Submerged×N0	0.13	0.23	-	-
Submerged×N1	0.33	0.41	27.7	44.3
Submerged×N2	0.57	0.72	34.9	33.0
LSD (P=0.05)	0.07	0.09	1.6	6.5

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively.

4.2 Field experiment

4.2.1 Vegetative Growth

4.2.1.1 Plant height

In the field experiment, plant height was recorded from active tillering up to harvest stage and its value ranged from 43.4 to 101.4 cm (Table 10). The plant height increased faster from active to maximum tillering stage. Plant height was significantly ($p<0.05$) influenced by water management treatments at all growth stages except active tillering, while N fertilizer influenced plant height significantly ($p<0.05$) from active tillering to harvest. The interaction effect between water management and N fertilizer was significant at booting and harvest only. At active and maximum tillering stage, plant height was not influenced ($p>0.05$) by water management treatments. At maximum tillering and booting, plant height in AWD was at par with submerged water treatments, while plants treated with moist water management produced significantly shorter plants. Plant heights were similar in N1 and N2 while N0 produced shorter plants. At harvest the trend was in the order: N2 > N1 > N0. Interaction effect between water management and N fertilizer was significant only at booting and harvest stages. At both stages, the interaction effect of N2 with submerged water management produced significantly taller plants followed by N2 treated plants under AWD water management. On the other hand, the interaction effect of N0 and moist water management resulted in significantly shorter plants.

4.2.1.2 Number of tillers

Tillering increased up to maximum tillering and thereafter gradually declined till harvest (Table 10). The number of tillers were significantly influenced by N fertilizer at all stages. Also, number of tillers was significantly influenced by water management at all stages except active tillering. AWD and submerged water treatments produced similar tillers at booting and harvest stages. Moist water treatments produced significantly lower number of tillers ($p<0.05$). With regards to N fertilizer, tillering was at par in N1 and N2 treatments in all growth stages except at harvest. At harvest stage, tiller number was significantly ($p<0.05$) ranked in the order: N2 > N1 > N0. In all, N0 treated plants produced significantly lower number of tillers. At booting and harvest, interaction effect of N2 with submerged water management produced higher tillers followed by N2 treated plants under AWD water management. In both cases, tillering in N0 with moist interaction was inferior to all other interaction effects.

Table 10: Dynamics of plant height (cm) and tillering of rice as influenced by water management and N fertilizer rate.

Treatment	**Plant height (cm)**				**Tillers/m^2**			
	Active tillering	Maximum tillering	Booting	Harvest	Active tillering	Maximum tillering	Booting	Harvest
Water (W)								
AWD	46.3	70.8	95.7	97.3	139	475	408	369
Moist	44.8	68.8	77.5	79.6	131	414	319	281
Submerged	46.9	70.9	95.8	97.8	158	486	414	356
LSD (P=0.05)	NS	1.13	0.57	0.6	NS	24.4	15.4	14.8
Fertilizer (N)								
N0	43.7	68.6	85.4	85.8	119	350	308	267
N1	46.4	70.6	91.8	93.3	147	503	336	317
N2	47.9	71.5	92.0	95.6	161	522	497	422
LSD (P=0.05)	1.9	2.0	0.46	0.75	17.5	20.4	9.2	10.5
Interaction								
AWD×N0	42.9	68.7	90.4	92.3	117	383	325	300
AWD×N1	46.7	70.9	98.3	98.7	142	508	358	358
AWD×N2	49.3	73.0	98.6	100.7	158	533	542	450

Moist×N0	43.4	67.4	75.2	72.2	100	275	267	225
Moist×N1	45.5	69.5	78.5	82.1	142	475	283	258
Moist×N2	45.4	69.5	78.9	84.6	150	492	408	358
submerged×N0	44.7	69.5	90.5	92.9	142	392	333	275
submerged×N1	47	71.4	98.4	99.2	158	525	367	333
submerged×N2	49.2	72.0	98.6	101.4	175	542	542	458
LSD (P=0.05)	NS	NS	0.76	1.14	NS	33.7	17.7	18.4

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05

4.2.1.3 Biomass accumulation

Data presented in Table 11 showed that, biomass accumulation across the treatment increased from active tillering up to harvest. Biomass accumulation ranged from 125g to 1405.2g across the treatment combinations. Biomass accumulation was significantly influenced by water and N fertilizer at maximum, booting and at harvest. Also the interaction effect between water management and N fertilizer was significant ($p<0.05$) only at booting and harvest. At maximum tillering and booting, AWD and submerged treated plants produced similar biomass with the least biomass recorded in moist water treatments. At harvest however, biomass accumulation significantly ($p<0.05$) varied in this order: Submerged > AWD > moist. At maximum tillering and booting stage, similar trend was observed in N1 and N2 treated plants while plants treated without N fertilizer (N0) produced lower biomass. At harvest, biomass accumulation significantly increased with increased N rate. At both booting and harvest stage, interaction effect of N2 with submerged water treatments produced higher biomass accumulation followed by N2 fertilized plants under AWD water management.

4.2.1.4 Leaf area index (LAI)

Leaf area index increased from booting to flowering and ranged from 3.1 to 7.4 (Table 11). Leaf area index was significantly ($p<0.05$) influenced by both water management and N fertilizer as well as interaction effect of both factors. At both stages, leaf area index was similar in AWD and submerged treated plants but the lowest leaf area index was recorded in moist water treatments. Based on N fertilizer rate, leaf area index varied significantly ($p<0.05$) and ranked as N2 > N1 > N0 at both growth stages. The interaction effect of N2 with submerged was at par with interaction effect of N2 with AWD. In all cases, interaction effect of N0 and moist was significantly ($p<0.01$) inferior to all other treatment combinations.

4.2.1.5 Leaf chlorophyll content

At flowering, Leaf chlorophyll content ranged from 30.1 to 55.6 $\mu mol/m^2$ across the treatment combinations as presented in Table 11. Both water management and N fertilizer as well as interaction effect of water and N fertilizer significantly ($p<0.05$) influenced leaf chlorophyll content. Leaf chlorophyll content varied significantly with regards to water management treatments and ranked as follows: Submerged > AWD > moist. Leaf chlorophyll content significantly ($p<0.05$) increased with increased N rate with the lowest chlorophyll content recorded in N0 treated plant. The interaction effect of N2 with submerged water treatments produced higher (42.7 $\mu mol/m^2$) leaf chlorophyll content followed by N2 and AWD interaction at flowering stage. In all, interaction effect of N0 with moist produced the lowest (30.1 $\mu mol/m^2$) chlorophyll compared to all the other treatment combinations.

4.2.1.6 Days to 50% flowering

Water management and N fertilizer application as well as their interaction did not significantly influence days to 50% flowering (Table 11). Generally it took between 83 and 85 days for the test variety Ex. Baika to reach 50 % flowering, when various water management and N fertilizer treatments were imposed.

Table 11: Above biomass accumulation of rice, Leaf area index, Leaf chlorophyll content (SPAD values) and days to 50 % flowering as affected by water management and N fertilizer.

Treatment	**Above biomass accumulation (g)**				**Leaf area index**		**Leaf chlorophyll content**	**Days to 50% flowering**
	Active tillering	Maximum tillering	Booting	Harvest	Booting	Flowering		
Water (W)								
AWD	144.2	329.7	526.1	1329.5	5.3	5.8	37.4	84
Moist	137.7	232.2	430.5	1083.9	4.2	4.8	33.9	85
Submerged	140.3	349.7	533.8	1341.6	5.5	5.9	38.2	85
LSD (P=0.05)	NS	71.3	9.5	16.82	0.3	0.27	0.3	NS
Fertilizer (N)								
N0	133.9	271.1	346.1	1088.3	3.9	4.3	32.1	84
N1	136.9	315.0	570.7	1330.3	4.7	5.3	36.6	84
N2	151.1	325.6	573.2	1336.4	6.5	6.9	40.8	84
LSD (P=0.05)	NS	39.2	5.33	10.11	0.13	0.21	0.48	NS
Interaction								
AWD×N0	137.5	273.3	377.5	1186.7	4.2	4.4	32.6	83
AWD×N1	144.2	348.3	598.3	1400.0	4.9	5.6	37.7	84
AWD×N2	150.8	367.5	602.4	1401.9	6.9	7.4	42.0	84
Moist×N0	125.0	239.2	270	868.3	3.1	3.8	30.1	84
Moist×N1	138.3	224.2	509.8	1185.8	4.1	4.5	33.8	85
Moist×N2	149.2	233.3	511.6	1197.6	5.5	6.0	37.7	85
submerged×N0	139.2	300.8	391.7	1210.0	4.4	4.5	33.7	85
submerged×N1	128.3	372.5	604.1	1405.2	5.1	5.7	38.2	85
submerged×N2	153.3	375.8	605.7	1409.7	7.0	7.4	42.7	84
LSD (P=0.05)	NS	NS	10.62	16.82	0.31	0.35	0.66	NS

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are

0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05.

4.2.3 Yield and yield parameter

4.2.3.1 Number of panicles/m^2

The effect of different water management and N fertilizer rates on number of panicles/ m^2 are shown in Table 12. Mean number of panicles/m^2 ranged from 232 to 403 depending on water management and N fertilizer used. Number of panicles/m^2 was significantly ($p<0.05$) influenced by both water management and N fertilizer. Interaction effect of water management and N fertilizer was significant ($p<0.05$). Number of panicles/m^2 in AWD were at par with submerged water treatments. However, moist 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.

4.2.3.2 Panicle length

Variation of panicle length as influenced by water and N fertilizer ranged from 20.1 to 24.3 cm (Table 12). Interaction effect of water management and N fertilizer on panicle length was significant ($p<0.05$). Panicle lengths were similar in AWD and submerged water treatments but significantly ($p<0.05$) shorter in moist water treatments. The trend of panicle length with regard to N fertilizer was N2 > N1 > N0. Interaction effect of N0 with moist water produced the shortest panicle length in all the treatment combinations. Interaction effect of N2 with submerged produced longer panicles compared to all the other treatment combinations.

4.2.3.3 Number of grains per panicle

Data on the number of grains/panicle are presented in Table 12. Number of grains/panicle was significantly influenced by water management and N fertilizer. Also, the interaction effect of water management and N rate on number of grains per panicle was significant ($p<0.05$). Number of grains/panicle was not significant among AWD and submerged 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 submerged and N0 with moist interaction produced significantly ($p<0.05$) higher and lower number of grains/panicle respectively.

4.2.3.4 Percentage filled grains

Percentage filled grains were significantly influenced N fertilizer treatments ($p<0.05$) and ranged from 86.0 to 94.0 % (Table 12). 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. Interaction effect of N2 with submerged gave the best grain filling followed by N0 with submerged interaction. Grain filling was poorer in N1 with moist interaction compared to all other treatment interaction.

4.2.3.5 1000 grain weight

The effect of water management and N fertilizer on 1000 grain weight is presented in Table 12. N fertilizer and Water management as well as their interaction did not significantly ($p>0.05$) affect 1000 grain weight. However, 1000 grain weight ranged from 26.4 to 27.5 g.

Table 12: Panicles/m2, panicle length, grains/panicle, % filled grains and 1000 grain weight as influenced by water and N fertilizer.

Treatment	Panicle/m^2	Panicle length (cm)	Grains/panicle	% filled grains	1000 grain weight (g)
Water (W)					

AWD	349	22.2	127	90.9	26.8
Moist	319	21.3	99	92.4	26.9
Submerged	350	22.6	128	89.1	27.4
LSD (P=0.05)	10.2	0.48	1.1	NS	NS
N Fertilizer (N)					
N0	261	22.8	106	90.2	27.1
N1	355	23	115	89.9	27.1
N2	401	23.1	133	92.3	27
LSD (P=0.05)	12.3	0.37	2.4	1.1	NS
Interaction					
AWD×N0	275	20.1	113	89.0	26.9
AWD×N1	369	22.6	124	91.2	27.1
AWD×N2	401	24	147	92.0	26.4
Moist×N0	232	20.1	93	90.3	27.1
Moist×N1	324	21.3	98	86.0	26.6
Moist×N2	400	22.4	105	91.0	27.1
Submerged×N0	277	20.8	113	91.3	27.2
Submerged×N1	271	22.7	124	92.0	27.5
Submerged×N2	403	24.3	148	94.0	27.4
LSD (P=0.05)	18.7	0.63	3.4	2.2	NS

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at $P > 0.05$.

4.2.3.6 Grain yield

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 submerged water treatment, while moist water treatment produced significantly lower grain yield ($p<0.05$). Differences in yield among the N levels was in the order: N2 > N1 > N0. With regards to interaction effect, the highest grain yield (6.5 t/ha) was recorded in N2 with submerged 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.

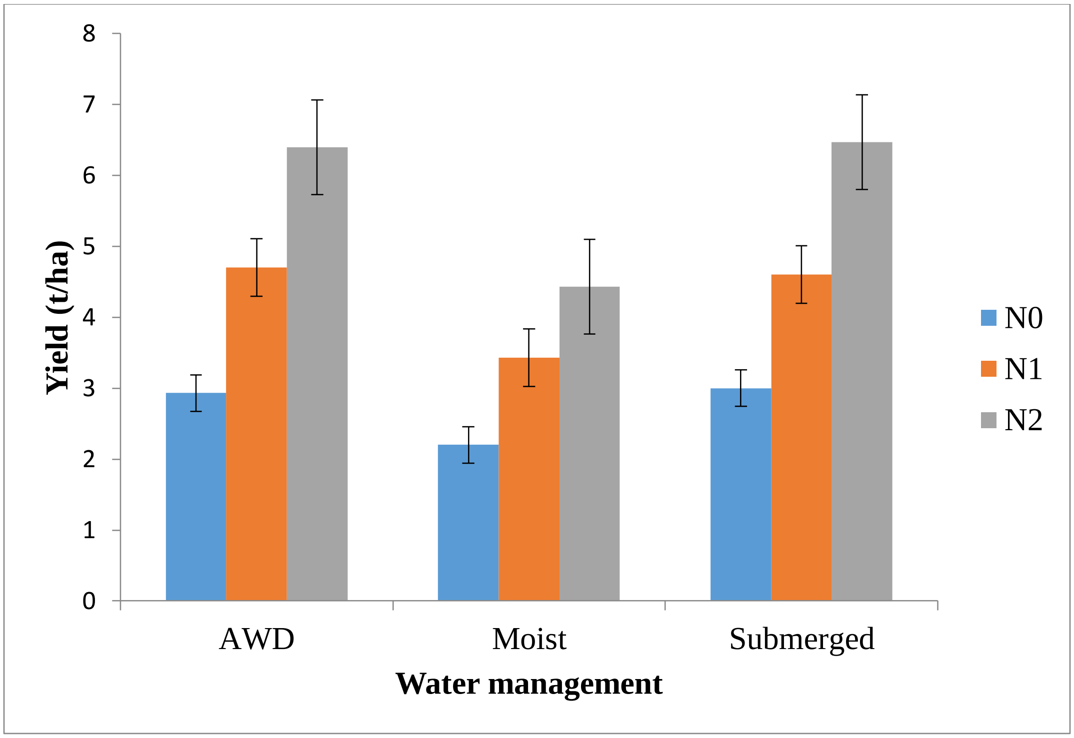

Figure 2: Grain yield of rice as influenced by water management and N fertilizer (Field Experiment).

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively.

4.2.3.7 Harvest index

The influence of water management and N fertilizer application rates on harvest index (HI) of rice is presented in Table 13. HI was not significantly (p>0.05) influenced by water management and N fertilizer but interaction effect of water management and N fertilizer on harvest index of rice was significant. Harvest index ranged from 0.47 to 0.51 across the treatment combinations. The greatest harvest index (0.51) was recorded in N0 with moist interaction followed by interaction effect of N1 with AWD and N2 under moist water condition which recorded harvest index of 0.50.

4.2.4 Water use

Water use was significantly ($p<0.05$) influenced by both water management and N fertilizer application rate (Table 13). 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 524mm 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. For interaction effect, water use was lower (524 mm) in N0 with moist interaction while N2 with submerged recorded the highest water (1608mm)

4.2.5 Water productivity

Both water management treatments and N fertilizer application rates, and their interactions had a significant ($p<0.05$) effect on water productivity of rice (Table 13). It ranged from 0.20 to 0.73 kg m^{-3} across the treatments. With water treatments, WP was greatest in moist followed by AWD treatments. The least WP was recorded in submerged treatments. Among the N rates, WP varied significantly in this order: N2 > N1 > N0. The highest WP (0.73 kg m^{-3}) and lowest WP (0.2 kg m^{-3}) were observed by N2 and moist interaction and N0 and submerged interaction respectively.

4.2.6 Grain N uptake

N uptake in grain was significantly influenced by both water and N fertilizer as shown in Table 13. Also, interaction effect of N fertilizer and water management on grain N uptake was significant. Grain N uptake ranged from 11.45 to 89.61 kg N ha^{-1} across the treatments combinations. Grain N uptake in AWD was similar to submerged treatments. The lowest was recorded in moist treatment. Grain N uptake significantly increased with increased N rate. With regards to interaction effect, grain N uptake was higher (89.61 kg N ha^{-1}) in N2 with AWD interaction followed by N2 with submerged interaction. Interaction effect of N0 with moist produced the lowest grain N uptake.

4.2.7 Straw N uptake

The effect of water management and N fertilizer on N uptake in straw is presented in Table 13. Water management, N fertilizer and interaction effect of water and N fertilizer significantly influenced N uptake in straw. N uptake in straw ranged from 6.72 to 61.70 kg N ha^{-1}. N uptake in AWD was at par with submerged treatments but significantly ($p<0.05$) lower in moist. For N fertilizer rate, the trend was: N2 > N1 > N0. With interaction effect, N2 with submerged and N0 with moist interaction produced the highest and lowest straw N uptake respectively.

4.2.8 Agronomic nitrogen use efficiency (ANUE)

ANUE was significantly influenced by nitrogen fertilizer and water treatments as well as their interaction effect (Table 13). Agronomic nitrogen use efficiency ranged from 20.6 to 38.5g/g across the treatments combinations. ANUE in AWD and submerged water treatments were not statistically different ($p>0.05$). ANUE was significantly lower in moist treatments ($p<0.05$). For N fertilizer, the trend of ANUE of rice was N2 > N1 > N0.

4.2.9 Physiological nitrogen use efficiency (PNUE)

N fertilizer significantly influenced PNUE but water management and interaction effect of water management and N fertilizer was non-significant (Table 13). Mean PNUE ranged from 29.6 to 52.0g/g across the treatments combinations. Among the N fertilizer rate, PNUE increased with decreased N rate.

Table 13: Harvest index water use, water productivity, Grain N uptake, straw N uptake, ANUE, and PNUE as affected by water management and N fertilizer

Treatment	Harvest	Water	Water	Grain	Straw	ANUE(g/g	PNUE(g/g

	index	use (mm)	productivity (kg/m^3)	uptake (kg/ha)	uptake (kg/ha)	)	)
Water (W)							
AWD	0.49	1075	0.43	48.6	33	22.7	27
Moist	0.49	572	0.58	26.7	20.7	15.1	28
Submerged	0.48	1558	0.2	46	33.9	21.7	25
LSD (P=0.05)	NS	213	0.02	2.93	0.77	3.59	NS
N Fertilizer (N)							
N0	0.49	1023	0.3	15.7	10.4	-	-
N1	0.48	1067	0.44	33.2	25.2	25.6	47.3
N2	0.49	1115	0.57	72.4	52.1	33.9	31.9
LSD (P=0.05)	NS	235	0.02	2.35	0.73	2.92	3.36
Interaction							
AWD×N0	0.47	1031	0.28	18.2	13	-	-
AWD×N1	0.5	1062	0.44	38.1	27.1	29.4	52.0
AWD×N2	0.49	1132	0.57	89.6	59	38.5	29.5
Moist×N0	0.51	524	0.42	11.5	6.7	-	-
Moist×N1	0.47	588	0.58	25.1	19.8	20.6	46.0
Moist×N2	0.48	604	0.73	43.5	35.6	24.8	36.7
submerged×N0	0.49	1514	0.2	17.4	11.4	-	-
submerged×N1	0.47	1552	0.3	36.4	28.7	26.7	44
submerged×N2	0.48	1608	0.4	84.1	61.7	38.5	29.6
LSD (P=0.05)	0.02	363	0.04	3.94	1.16	4.88	NS

Submerged is continuous submergence; AWD is alternate wet and dry; N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively. NS = not significant at P > 0.05

4.2.10 Cost of cultivation

The data in Table 14 showed that the cost of cultivation of rice ranged from GH₵2945 to GH₵3953.3 across the treatments in the field experiment. In general N2 fertilizer application rate required the higher cost of production followed by N1 fertilizer rate while N0 required the lowest cost of production. In the case of water management, Submerge water condition required higher cost of production compared to AWD water treatment. Moist water treatment required least cost of production. Cultivation of rice with N2 under submerged and N0 under moist required the highest and lowest cost of production respectively.

4.2.11 Gross return

The data in the Table 14 showed that average gross return ranged from GH₵6010 to GH₵17785.3 across the treatment combinations. The highest gross returns (GH₵17785.3) were realized when rice was produced under submerged with N2 fertilizer application rate followed by N2 treatments under AWD water management which recorded gross returns of GH₵17618.3.Gross returns increased with increased N fertilizer application rate regardless of the water management regime. In relation to water management treatments, gross return varied in this order: submerged > AWD > moist. For interaction effect the lowest gross returns was observed in N0 with moist interaction.

4.2.12 Net profit

The influence of water management and N fertilizer application rate on net profit is indicated in Table 14. Average net profit ranged from GH₵3065 to GH₵13926.7 across the treatment combinations. In all cases, net profit increased with increased N fertilizer application rate. The trend of net profit with regard to water treatments was AWD > submerged > moist. For interaction effect, the greatest interaction effect on net profit (GH₵13926.7) was N2 with AWD. Interaction effect of N0 with moist was inferior to other interaction effect of water management and N fertilizer

4.2.13 Benefit cost ratio

The effect of water management and benefit cost ratio of rice production is presented in Table 14. Benefit cost ratio ranged from 1.04 to 3.77 across the treatment combinations. During the field experiment, N fertilizer on benefit cost ratio was ranked as: N2 > N1 > N0. In relation to water management, the trend was AWD > submerged > moist. The interaction effect of N2 with

AWD gave the greatest benefit cost ratio. The lowest benefit cost ratio (1.04) was produced at N0 with moist interaction.

Table 14: Cost of production, gross returns, net profit and benefit cost ratio as influenced by water management and N fertilizer

Treatment	Cost of production(GH₵/ha)	Gross returns(GH₵/ha)	Net profit(GH₵/ha)	Benefit cost ratio
Water (W)				
AWD	3469.4	12811.1	9341.7	2.64
Moist	3213.3	9214.9	6004.4	1.83
Submerged	3688.2	12898.4	9170.6	2.41
N Fertilizer (N)				
N0	3206.2	7443.9	4238.0	1.31
N1	3513.3	11615.8	8102.4	2.30
N2	3688.2	15864.8	12177	3.28
Interaction				
AWD×N0	3206.7	8064	4858.0	1.52
AWD×N1	3510	12750	9240.0	2.63
AWD×N2	3691.7	17618.3	13927.0	3.77
Moist×N0	2945	6010.0	3065.0	1.04
Moist×N1	3266.7	9444.0	61773.0	1.89
Moist×N2	3419.7	12190.7	8771.0	2.56
submerged×N0	3467	8257.0	4790.0	1.38
submerged×N1	3763.3	12653.3	8890.0	2.36
submerged×N2	3953.3	17785.3	13832.0	3.50

Submerged is continuous submergence; AWD is alternate wet and dry;

N0, N1 and N2, are 0, 60 and 90 kg N ha^{-1} respectively.

CHAPTER FIVE

DISCUSSION

5.1 Plant growth

Results from both the pot and field experiments showed that, plant height, biomass accumulation and leaf area index increased from active tillering till harvest. Tillering on the hand, increased up to maximum tillering stage and thereafter declined gradually till harvest. The decrease in tillering of rice could be attributed to the death of some of the last tillers as a result of their failure to compete for light and available nutrients (Fageria, *et al.*, 1997). Further explanation for this observation might be that during the panicle initiation stage, competition for assimilates existed between developing panicles and young tillers. Consequently, growth of many young tillers were suppressed, which might have led to tiller senescence. Similar observations were made by Dofing and Karlsson (1993).

5.1.1 Effect of N fertilizer on plant growth

In both experiments, application of N fertilizer influenced vegetative growth significantly. Application of N1 and N2 enhanced the growth of plants better than the unfertilized plants. Probably low level of native N in the soil may explain the poor growth of rice in the unfertilized plants compared with N treated plant under same water treatments. The increased in vegetative growth with N fertilization might be due to the effective role of nitrogen in vegetative growth which enhanced the overall growth and physiology of rice (Snyder and Slaton, 2002). The result obtained agrees with that reported by El-wahab *et al*. (2007) and Khairi *et al*. (2015) who observed that application of nitrogen fertilizer usually produce more vegetative growth than plant treated with no N fertilizer. Also, increased biomass accumulation and LAI with increased N fertilizer rate might be due to the effectiveness of photosynthesis of the crop which depends on large and efficient assimilating area for adequate supply of solar radiation and carbon dioxide (Reddy and Reddi, 2002). These results are in agreement with Rezaei *et al*. (2009) who reported that increasing fertilizer nitrogen rate increases dry matter accumulation in rice crop by promoting nitrogen uptake. Ye *et al*. (2013) also stated that increased dry matter could be attributed to increase in length, number of tillers, elongation of stem and panicles. Similarly, Pradhan *et al*. (2013) reported that, application of nitrogen promotes rapid growth through increasing plant height, improve tillering and leaf area index. At flowering, leaf chlorophyll content of plants treated with higher N rate was higher than those that received lower N rate and no N application. The higher chlorophyll content in the treatment could be attributed to increased availability of nitrogen which essential for chlorophyll formation to the plants as reported by Kingori (2016).

5.1.2 Effect of water management on plant growth

Plants under submerged had the highest vegetative growth. This could be due to the higher nutrient availability to plant roots as a result of the adjustment of soil pH to neutral range as observed by Ponamperuma (1984). Saharawat (2012) reported an improvement in availability of micro and macro nutrients such as nitrogen, phosphorus, potassium, magnesium and silicon under submerged soil condition. Plants treated under AWD water treatment produced vegetative growth similar to the submerged treatments. This could be due to the fact that AWD treatment does not restrict water availability to rice plant roots (Belder *et al*. 2004). Also it could be due the fact that AWD promotes root growth as result of air exchange between the atmosphere and the soil (Tan *et al*., 2013). Moist treated plant showed poor growth due to low moisture availability. In low water condition plant cannot absorb nutrients from the soil efficiently due to insufficient moisture, consequently crop growth became stunted (Mannan *et al*., 2012). Also, biomass accumulation and leaf area index (LAI) decreased with moist water condition. Reduction in plant growth could be attributed to the reduction in plant height, tillering and death of the lower leaves which could have been affected by low moisture condition. This finding is in line with Andreas and Karen (2002) who reported that reduced soil moisture at vegetative stage of rice decreased growth and development of foliage. This observation as explained by Sabbor *et al*. (2007) is attributed to the fact that cumulative effect of water stress on plants grown under moist water management is similar to plants stressed early in crop development resulting in reduced leaf area index. Light interception and carbon assimilation are reduced and hence the rate of leaf development and expansion reduces. Furthermore, relatively low available soil moisture which characterizes moist treated plants might lead to reduction of cell division and enlargement of different plant tissues which in turn depressed the vegetative growth and dry matter accumulation (Sabbour *et al*., 2007). These results are in agreement with those obtained by El-wahab *et al.* (2007) who found a reduction in leaf area index and biomass accumulation due to reduced soil moisture level.

5.1.3 Interaction effect of water and N fertilizer on plant growth

Interaction effect of N2 with AWD resulted similar plant growth with N2 under submerged water management. The observed results could be attributed to availability of adequate moisture and nutrient for plant growth. Similar results were reported by Belder et al. (2004). Furthermore, Tan *et al*. (2013) revealed that AWD promotes root growth and nitrogen uptake due to gaseous exchange between the soil and the atmosphere. Plants under moist water management (N) without fertilizer showed poor growth. This confirms a report by Akram *et al*. (2013) who found out that plant growth reduced when water stress was imposed during panicle initiation stage of rice.

5.2 Effect of N fertilizer on yield and yield parameters

Plants fertilized with nitrogen had higher grain yield than unfertilized plants due their higher grains/panicle and panicles/m^2. Split application of nitrogen fertilizer at transplanting and panicle initiation stage ensured efficient use of fertilizers. This results agrees with Witt *et al*.(2002) who observed that nitrogen fertilizer application increased the activity of cell division and expansion of rice which enhanced grain yield. Also, Cabangon *et al*. (2011) observed that N fertilizer helps in efficient mobilization of resources and photosynthesis for the purpose of grain filling. N2 had higher rice yield and yield parameters than N1 and it might be attributed to its contribution to higher number of panicle/m^2, grains/panicle and panicle length. This could also be due to its higher availability of nitrogen which might have resulted in higher grains/panicle and panicles/m2 and consequently led to higher yields than N1. Similar reports were made by Singh and Pillai (1994), Mannan *et al*. (2012) and Azarpour *et al*. (2014) who all observed that the application of 90 kg/ha N increased rice yield significantly. The finding however, are contrary to report by Rezaei *et al*. (2009) in which application of nitrogen fertilizer above 60 kg N ha^{-1} did not improve yield significantly. Nitrogen fertilization did not significantly influence 1000 grain weight of rice. This might be due to the fact that 1000 grain weight is a genetic trait strictly controlled by the hull of a particular variety and therefore cannot grow above the size allowed by the size of the hull (Mae, 1997).

5.3 Effect of water management on yield and yield parameters of rice

In both experiments, differences in yield and yield parameters between AWD and submerged was not statistically significant. Similar observation was made by Belder et al. (2004), who argued that AWD does not restrict water availability to rice plant. This also explains the fact that, during AWD, water table was within the root zone of the plant and therefore the drying period may not sufficiently expose the rice plant to water stress to give comparable rice yield as with continuously submerged conditions (Guerra *et al.*, 1998). Also, Plant adopts osmotic adjustment at the vegetative stage which contributes the mostly noticeable mechanism of dehydration tolerance in the rice plant, though any drought stress at early reproductive phase can cause great loss (Subramanian 2008). Since AWD plots were submerged at booting stage till ten days before harvest, no yield penalties were recorded. Rezaei *et al*. (2009) observed that continuous submergence of rice fields does not significantly increase yield over AWD. The results from this study is consistent with previous studies by Tuong (2003) , Mannan *et al*. (2012) and Khairi *et al*. (2015) who all observed similar grain yield between AWD and submerged treatments. However, Bouman and Tuong (2001) and Belder *et al*. (2004) observed higher panicle/m^2 and grain yield under AWD. Harbir *et al*. (1991), Marazi *et al*. (1993), and Awad (2001) however reported that, AWD reduced grain yield significantly. The different in responses of water can be attributed to different soil types, rice variety, climatic conditions as well as duration of irrigation (Belder, 2004). Plants grown under moist water management had significantly lower grain yields. This also could be due to poor metabolism as a result of its reduced water availability and therefore led to reduction in grain yields. Furthermore, reduced yields under moist soil condition might be due to inhibition of photosynthesis and less translocation of assimilates due to soil low moisture availability (Tabbal *et al*., 2002). Results from this current study are similar to those reported by Mannan *et al*.(2012) who observed reduction in number of grains panicle^{-1} and shorter panicles due to less soil moisture. According to Akram *et al*. (2013) water stress at flowering stage reduced percentage of filled grains and 1000 grain weight significantly. Since all the water treatments in both field and pot experiments were submerged from booting stage to ten days before harvest, there was no water stress at flowering stage and therefore water management treatments did not significantly affect 1000 grain weight and percentage filled grains.

5.4 Interaction effect of water and N fertilizer on yield and yield parameters

Interaction effect of N2 with AWD had similar yield as in submerged and N2 treatment combination as both resulted in similar panicle length, grains/panicles and panicles/m2. This observation might also be attributed to more nitrogen being transported to the plant when plants were treated with higher doses of N. Overall N0 under moist treatment combination gave the lowest grain yield due reduced moisture level at panicle initiation stage. (Akram et al., 2013) reported similar observation.

5.5 Effect of N fertilizer on N uptake and nitrogen use efficiency

N-uptake in both grain and straw increased with increased nitrogen rates across the treatments. N2 had the highest N uptake and agronomic nitrogen use efficiency (ANUE) as a result of higher above ground biomass accumulation and larger leaf area index. Large leaf area index results in higher rate of transpiration and consequently increase nitrogen uptake by plant roots (Haefele *et al*., 2008). Kumar and Rao (1992) and Panda *et al*. (1996) also reported that the uptake of N by rice crop and concentration in the tissues increased by increased N rate. Reduced N uptake in N0 might be due its lower transpiration rate as a results of its small leaf area index and reduced aboveground biomass. This assertion is given credence by earlier reports by De wit (1958) who reported that lower transpiration rate reduced biomass accumulation and consequently lower nitrogen uptake by plant.

5.6 Effect of water management on N uptake, ANUE and PNUE of rice

Submerged water treatment had the highest N uptake and ANUE due to higher availability of nitrogen. According to Ponamperuma (1984) unavailable nutrients become available to plant under submerged condition due to the adjustment of soil pH to neutral range. In addition submerged condition improves the delivery of nutrients to plant roots through mass flow and diffusion mechanisms (Ponamperuma 1984). Ye *et al*. (2013) who reported that N uptake increased when plants were grown under submerged water management regime. AWD treatment had similar N uptake and ANUE because AWD creates aerobic conditions which enhance root growth and therefore better surface area for uptake of nutrients. According to Reddy and Reddi,

(2002) nutrient uptake by plants largely depends on the increment of the nutrient ion to the absorbing root surface or on the roots' ability to reach the zone of nutrient availability. The results from the study agrees with the studies conducted by Belder *et al*. (2005) who observed that nitrogen use efficiency (NUE) in AWD water management was not significantly different from submerged condition. The study however disagrees with Zare *et al*. (2014) who found NUE to be significantly higher in AWD water management than submergence condition. Moist treatment was statistically inferior due its smaller leaf area index which limits N uptake possibly as a result of lower transpiration rate. This agrees with Haefele *et al*. (2008) who reported that small leaf area index reduced transpiration rate and therefore decreased nitrogen uptake by plant roots. It can also be due to reduced soil moisture from crop establishment to booting stage which might have reduced N uptake by rice roots.

5.7 Interaction effect of water and N fertilizer on N uptake and NUE

Interaction effect of submerged water management with N2 rate gave higher N uptake. This can be due to its higher aboveground biomass accumulation compared with the other treatment combinations. Moist with N0 interaction gave the lowest N uptake and NUE due to its lower leaf area index. These are in line with Haefele *et al*. (2008) who revealed that small leaf area index reduced transpiration rate and therefore decreased nitrogen uptake by rice plant.

5.8 Effect of N fertilizer on water use and water productivity of rice

From both experiments, higher water productivity with N2 treatment than the other treatments can be associated with its higher grain yield. Pandey *et al*. (2001) reported that, N fertilization increased water productivity due to increased yield than unfertilized plants. The lower water productivity in N0 was due to reduced yields as a results of grains/panicle and panicle per m^2. N2 had the highest water use due to its higher transpiration rate as results of it higher vegetative growth. Mannan *et al*. (2012) observed that vegetative growth as a result of higher photosynthesis and metabolism led to more water requirement by plants in order to carry out their physiological functions. Lower water use in N0 could be attributed to less water loss through transpiration as a result of its lower leaf area index. This is in line with Song *et al*. (2010) who observed that large leaf area index results in higher water loss through transpiration.

5.9 Effect of water management on water use and water productivity

Comparing the different treatments of water management in both trials, it was observed that 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 Odhiambo and Murthy (1996) evapotranspiration was intense under continuous submergence including evaporation of free water from the standing pool of water. This probably increased the rate of evapotranspiration and percolation in submerged treatments which in turned increased water requirement. However, AWD had higher water productivity than submerged treatment due to its lower water use. This finding is in agreement with Tabbal *et al.* (2002), Belder *et al*. (2004), Kato *et al*. (2009). Wardana *et al*. (2010) observed that AWD resulted in higher water productivity than continuous submergence of fields. Also Talpur *et al*. (2013) reported that, continuous submergence produced optimum rice yield however, required the highest amount of water hence low water productivity. Moist 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 Dahmardeh *et al*. (2015) who reported that reduction in water use increased water productivity of rice.

5.10 Interaction effect of water management and N fertilizer on water use and water productivity

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 of free water from the standing pool of water (Odhiambo and Murthy 1996). 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. Dahmardeh *et al*. (2015) who reported that reduction in water use increased water productivity of rice.

5.11 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 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 due to reduced yields. The outcome agrees with the assertion by Barker *et al*. (2002) and Visperas, *et al*.(2005) 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. Ganiyu, *et al*.(2015) suggested that, continuous submergence and maintaining moisture level at field capacity does not increase crop and economic water productivity.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Water and nitrogen are the two most important factors for increased rice growth, yield, nitrogen uptake and water productivity in irrigated rice farming system. On the basis of the findings, the following conclusions can be drawn:

- Application of N fertilizer positively influenced rice growth and yields with highest yields observed in application of 90 kg/ha.
- AWD resulted in similar growth and yields compared to submerged water treatments. Growth and yield of rice were better with interaction effect of 90 N kg/ ha and submerged.
- Nitrogen uptake increased with increased N fertilizer rate and application of 90 N kg/ha gave higher uptake. N uptake in AWD was at par with uptake in submerged water treatment but lower in moist water management.
- Water productivity was higher under moist water management due to the less amount of water required.
- AWD required less water than continuous submergence for rice production and it was cost effective to produce rice under AWD over the rest of the water management methods.

6.2 Recommendation

- AWD and 90 kg N/ha combination holds promise and seem to be better option to efficiently manage water and N fertilizer where water availability at the farm level is too low, or where water is too expensive to grow irrigated rice.
- The research is one-season one-location experiment. It needs to be repeated with time and locations to increase the validity of the findings made.
- Further studies should be conducted on nutrient requirement of irrigated rice under different soil types and agro ecological zones.
- The response of different varieties of rice should also be investigated under the various water management and N fertilizer levels used in the experiment.

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APPENDICES

Appendix A: ANOVA for parameters in pot experiment

Appendix A1: ANOVA for plant height at active tillering

	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	17.634	5.878	2.82	
Water	2	8.602	4.301	2.06	0.149
N fertilizer	2	80.351	40.175	19.27	<.001
Water. N fertilizer	4	8.654	2.164	1.04	0.408
Residual	24	50.028	2.085		
Total	35	165.27			

Appendix A2: ANOVA for plant height at maximum tillering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	3.266	1.089	0.39	
Water	2	12.934	6.467	2.33	0.119
N fertilizer	2	68.151	34.075	12.25	<.001
Water.N ferttilizer	4	2.634	0.659	0.24	0.915
Residual	24	66.734	2.781		
Total	35	153.719			

Appendix A3: ANOVA for plant height at booting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1.7719	0.5906	1.22	
Water	2	2209.785	1104.893	2273.14	<.001
N fertilizer	2	1369.732	684.8658	1409	<.001
Water.N_Levels	4	94.1533	23.5383	48.43	<.001
Residual	24	11.6656	0.4861		
Total	35	3687.108			

Appendix A4: ANOVA for plant height at Harvest(cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1756	0.0878	0.1	
Water	2	428.207	214.103	238.92	<.001
N fertilizer	2	1839.08	919.541	1026.15	<.001
Water. N fertilizer	4	45.8444	11.4611	12.79	<.001
Residual	16	14.3378	0.8961		
Total	26	2327.65			

Appendix A5: ANOVA for tiller numbers at active tillering stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	2.75	0.9167	2.59	
Water	2	2.3889	1.1944	3.37	0.051
N fertilizer	2	12.0556	6.0278	17.02	<.001
Water. N fertilizer	4	1.2778	0.3194	0.9	0.478
Residual	24	8.5	0.3542		
Total	35	26.9722			

Appendix A6: ANOVA for tiller numbers at maximum tillering stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	6.9722	2.3241	5.43	
Water	2	56.1667	28.0833	65.58	<.001
N fertilizer	2	340.6667	170.3333	397.75	<.001
Water. N fertilizer	4	12.6667	3.1667	7.39	<.001
Residual	24	10.2778	0.4282		
Total	35	426.75			

Appendix A7: ANOVA for tiller numbers at booting stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	10.3333	3.4444	3.65	
Water	2	78.5	39.25	41.56	<.001
N fertilizer	2	318.5	159.25	168.62	<.001
Water.N fertilizer	4	13	3.25	3.44	0.023
Residual	24	22.6667	0.9444		
Total	35	443			

Appendix A8: ANOVA for tiller numbers at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.6296	1.8148	2.12	
Water	2	109.8519	54.9259	64.13	<.001
N fertilizer	2	176.0741	88.037	102.79	<.001
Water.N fertilizer	4	10.3704	2.5926	3.03	0.049
Residual	16	13.7037	0.8565		
Total	26	313.6296			

Appendix A9: ANOVA for aboveground biomass at mid- tillering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.3472	0.3472	3.06	
Water	2	6.0844	3.0422	26.81	<.001
N fertilizer	2	4.2544	2.1272	18.75	<.001
Water. N fertilizer	4	0.2022	0.0506	0.45	0.773
Residual	8	0.9078	0.1135		
Total	17	11.7961			

Appendix A10: ANOVA for aboveground biomass accumulation at booting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	1.0272	1.0272	2.58	
Water	2	938.2878	469.1439	1177.36	<.001
N fertilizer	2	2681.121	1340.561	3364.25	<.001
Water. N fertilizer	4	110.6056	27.6514	69.39	<.001
Residual	8	3.1878	0.3985		
Total	17	3734.229			

Appendix A11: ANOVA for aboveground biomass accumulation at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.9607	0.9804	1.65	
Water	2	1675.22	837.612	1411.81	<.001
N fertilizer	2	2954.32	1477.16	2489.79	<.001
Water. N fertilizer	4	196.193	49.0481	82.67	<.001
Residual	16	9.4926	0.5933		
Total	26	4837.19			

Appendix A12: ANOVA for leaf area index at booting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.02	0.00667	0.19	
Water	2	11.3372	5.66861	158.19	<.001
N fertilizer	2	40.9306	20.4653	571.12	<.001
Water. N fertilizer	4	0.42111	0.10528	2.94	0.041
Residual	24	0.86	0.03583		
Total	35	53.5689			

Appendix A13: ANOVA for leaf chlorophyll content at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.123	2.5615	2.87	
Water	2	151.95	75.9748	85.06	<.001
N fertilizer	2	1460.67	730.336	817.71	<.001
Water. N fertilizer	4	78.2837	19.5709	21.91	<.001
Residual	16	14.2904	0.8931		
Total	26	1710.32			

Appendix A14: ANOVA for days to 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.7407	1.3704	3.33	
Water	2	1.4074	0.7037	1.71	0.213
N fertilizer	2	1.1852	0.5926	1.44	0.266
Water. N fertilizer	4	1.7037	0.4259	1.03	0.42
Residual	16	6.5926	0.412		
Total	26	13.6296			

Appendix A15: ANOVA for effective tillers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.6296	1.8148	2.12	
Water	2	109.8519	54.9259	64.13	<.001
N fertilizer	2	176.0741	88.037	102.79	<.001
Water. N fertilizer	4	10.3704	2.5926	3.03	0.049
Residual	16	13.7037	0.8565		
Total	26	313.6296			

Appendix A16: ANOVA for grains/panicles

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	48.3	24.15	1.4	
Water	2	2020.52	1010.26	58.63	<.001
N fertilizer	2	3394.74	1697.37	98.5	<.001
Water. N fertilizer	4	624.81	156.2	9.07	<.001
Residual	16	275.7	17.23		
Total	26	6364.07			

Appendix A17: ANOVA for percentage filled grains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.222	0.111	0.06	
Water	2	57.556	28.778	16.58	0.083
N fertilizer	2	26	13	7.49	0.005
Water. N fertilizer	4	13.111	3.278	1.89	0.162
Residual	16	27.778	1.736		
Total	26	124.667			

Appendix A18: ANOVA for Panicle length (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.02667	0.01333	0.26	
Water	2	11.50889	5.75444	113.2	<.001
N fertilizer	2	47.70889	23.85444	469.27	<.001
Water.N fertilizer	4	2.06889	0.51722	10.17	<.001
Residual	16	0.81333	0.05083		
Total	26	62.12667			

Appendix A19: ANOVA for 1000 grain weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0052	0.0026	0	
Water	2	1.1852	0.5926	1.08	0.364
N fertilizer	2	0.3585	0.1793	0.33	0.727
Water. N fertilizer	4	1.4815	0.3704	0.67	0.62
Residual	16	8.8081	0.5505		
Total	26	11.8385			

Appendix A20: ANOVA for grain yield (g/pot)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.2067	0.6033	2.23	
Water	2	968.46	484.23	1790.68	<.001
N fertilizer	2	3157.91	1578.95	5838.97	<.001
Water. N fertilizer	4	116.124	29.0311	107.36	<.001
Residual	16	4.3267	0.2704		
Total	26	4248.03			

Appendix A21: ANOVA for straw yield (g/pot)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.9607	0.9804	1.65	
Water	2	1675.22	837.612	1411.81	<.001
N fertilizer	2	2954.32	1477.16	2489.79	<.001
Water. N fertilizer	4	196.193	49.0481	82.67	<.001
Residual	16	9.4926	0.5933		
Total	26	4837.19			

Appendix A22: ANOVA for harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00018	8.94E-05	5.79	
Water	2	0.00407	0.00204	131.82	<.001
N fertilizer	2	0.03654	0.01827	1183.5	<.001
Water. N fertilizer	4	0.00157	0.00039	25.4	<.001
Residual	16	0.00025	1.54E-05		
Total	26	0.0426			

Appendix A22: ANOVA for Nitrogen uptake in grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000114	5.69E-05	3.37	
Water	2	0.145217	0.072608	4300.52	<.001
N fertilizer	2	0.679885	0.339943	20134.49	<.001
Water. N fertilizer	4	0.062745	0.015686	929.09	<.001
Residual	16	0.00027	1.69E-05		
Total	26	0.888231			

Appendix A23: ANOVA for Nitrogen uptake in straw

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.001153	0.000576	21.38	
Water	2	0.152116	0.076058	2821.38	<.001
N fertilizer	2	0.815343	0.407671	15122.57	<.001
Water.N fertilizer	4	0.037017	0.009254	343.29	<.001
Residual	16	0.000431	2.7E-05		
Total	26	1.00606			

Appendix A24: ANOVA for agronomic nitrogen use efficiency

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1111	0.0555	0.06	
Water	2	101.1602	50.5801	59.04	<.001
N fertilizer	2	4851.685	2425.843	2831.49	<.001
Water. N fertilizer	4	145.6264	36.4066	42.49	<.001
Residual	16	13.7078	0.8567		
Total	26	5112.291			

Appendix A25: ANOVA for physiological nitrogen use efficiency

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.771	0.386	0.33	
Water	2	234.887	117.443	100.13	<.001
N fertilizer	2	11822.63	5911.316	5039.78	<.001
Water. N fertilizer	4	194.757	48.689	41.51	<.001
Residual	16	18.767	1.173		
Total	26	12271.81			

Appendix A26: ANOVA for water use (cm^3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.9991	0.4996	0.54	
Water	2	3691.184	1845.592	2000.12	<.001
N fertilizer	2	170.5473	85.2736	92.41	<.001
Water. N fertilizer	4	34.6556	8.6639	9.39	<.001
Residual	16	14.7638	0.9227		
Total	26	3912.15			

Appendix A27: ANOVA for water productivity (g/cm^3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.001324	0.000662	0.7	
Water	2	0.275418	0.137709	146.48	<.001
N fertilizer	2	1.137127	0.568564	604.8	<.001
Water. N fertilizer	4	0.077825	0.019456	20.7	<.001
Residual	16	0.015042	0.00094		
Total	26	1.506736			

Appendix B: ANOVA for parameters in field experiment

Appendix B1: ANOVA for Plant height at active tillering (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16.062	8.031	4.46	
Water	2	22.602	11.301	6.27	0.058
Residual	4	7.209	1.802	0.51	
N fertilizer	2	83.536	41.768	11.78	0.001
Water. N fertilizer	4	16.216	4.054	1.14	0.383
Residual	12	42.536	3.545		
Total	26	188.16			

Appendix B2: ANOVA for lant height at maximum tillering (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.854	4.427	5.9	
Water	2	26.261	13.13	17.51	0.011
Residual	4	2.999	0.75	0.2	
N fertilizer	2	40.903	20.451	5.37	0.022
Water. N fertilizer	4	5.017	1.254	0.33	0.853
Residual	12	45.7	3.808		
Total	26	129.734			

Appendix B3: ANOVA for plant height at booting (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.6763	0.8381	4.49	
Water	2	1999.612	999.8059	5361.42	<.001
Residual	4	0.7459	0.1865	0.94	
N fertilizer	2	256.8896	128.4448	650.05	<.001
Water. N fertilizer	4	26.5593	6.6398	33.6	<.001
Residual	12	2.3711	0.1976		
Total	26	2287.854			

Appendix B4: ANOVA for plant height at harvest (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.8422	1.9211	9.27	
Rep.Water stratum					
Water	2	1923.962	961.9811	4642.27	<.001
Residual	4	0.8289	0.2072	0.39	
N fertilizer	2	471.8289	235.9144	438.99	<.001
Water. N fertilizer	4	19.1956	4.7989	8.93	0.001
Residual	12	6.4489	0.5374		
Total	26	2426.107			

Appendix B5: ANOVA for Number of tillers at active tillering stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	879.6	439.8	0.93	
Water	2	3657.4	1828.7	3.85	0.117
Residual	4	1898.1	474.5	1.64	
N fertilizer	2	8101.9	4050.9	14	<.001
Water. N fertilizer	4	509.3	127.3	0.44	0.778
Residual	12	3472.2	289.4		
Total	26	18518.5			

Appendix B6: ANOVA for number of tillers at maximum tillering stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3888.9	1944.4	5.6	
Water	2	27222.2	13611.1	39.2	0.002
Residual	4	1388.9	347.2	0.88	
N fertilizer	2	160138.9	80069.4	203.47	<.001
Water. N fertilizer	4	6388.9	1597.2	4.06	0.026
Residual	12	4722.2	393.5		
Total	26	203750			

Appendix B7: ANOVA for Number of tillers at booting stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1805.56	902.78	6.5	
Water	2	50555.56	25277.78	182	<.001
Residual	4	555.56	138.89	1.71	
N fertilizer	2	187222.2	93611.11	1155.43	<.001
Water. N fertilizer	4	5555.56	1388.89	17.14	<.001
Residual	12	972.22	81.02		
Total	26	246666.7			

Appendix B8: ANOVA for number of tillers at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	324.1	162	1.27	
Water	2	41157.4	20578.7	161.64	<.001
Residual	4	509.3	127.3	1.22	
N fertilizer	2	113518.5	56759.3	544.89	<.001
Water. N fertilizer	4	2314.8	578.7	5.56	0.009
Residual	12	1250	104.2		
Total	26	159074.1			

Appendix B9: ANOVA for Aboveground biomass accumulation at active tillering (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.3785	1.6893	39.66	
Water	2	0.323	0.1615	3.79	0.119
Residual	4	0.1704	0.0426	0.07	
N fertilizer	2	2.4319	1.2159	1.96	0.184
Water. N fertilizer	4	0.9104	0.2276	0.37	0.828
Residual	12	7.4578	0.6215		
Total	26	14.6719			

Appendix B10: ANOVA for aboveground biomass accumulation at maximum tillering (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	85	42	0.01	
Water	2	71138	35569	11.98	0.02
Residual	4	11878	2969	2.04	
N fertilizer	2	15006	7503	5.15	0.024
Water. N fertilizer	4	10969	2742	1.88	0.178
Residual	12	17479	1457		
Total	26	126554			

Appendix B11: ANOVA for aboveground biomass accumulation at booting (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	11.46	5.73	0.11	
Water	2	59658.9	29829.45	561.03	<.001
Residual	4	212.68	53.17	1.98	
N fertilizer	2	305369.5	152684.7	5680.08	<.001
Water. N fertilizer	4	781.55	195.39	7.27	0.003
Residual	12	322.57	26.88		
Total	26	366356.6			

Appendix B12: ANOVA for aboveground biomass accumulation at harvest (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1087.19	543.59	6.15	
Water	2	380645.6	190322.8	2152.64	<.001
Residual	4	353.65	88.41	0.91	
N fertilizer	2	360429.4	180214.7	1858.85	<.001
Water. N fertilizer	4	18774.52	4693.63	48.41	<.001
Residual	12	1163.39	96.95		
Total	26	762453.7			

Appendix B13: ANOVA for Leaf area index at booting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00519	0.00259	0.05	
Water	2	8.94296	4.47148	86.86	<.001
Residual	4	0.20593	0.05148	3.16	
N fertilizer	2	31.1119	15.5559	954.57	<.001
Water. N fertilizer	4	0.27926	0.06981	4.28	0.022
Residual	12	0.19556	0.0163		
Total	26	40.7407			

Appendix B14: ANOVA for Leaf area index at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.08667	0.04333	1.05	
Water	2	6.64222	3.32111	80.78	<.001
Residual	4	0.16444	0.04111	1.02	
N fertilizer	2	32.3356	16.1678	402.33	<.001
Water. N fertilizer	4	0.55556	0.13889	3.46	0.042
Residual	12	0.48222	0.04019		
Total	26	40.2667			

Appendix B15: ANOVA for Leaf chlorophyll content at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0563	0.0281	0.55	
Water	2	94.2007	47.1004	914.9	<.001
Residual	4	0.2059	0.0515	0.26	
N fertilizer	2	334.6319	167.3159	839.69	<.001
Water. N fertilizer	4	2.9837	0.7459	3.74	0.034
Residual	12	2.3911	0.1993		
Total	26	434.4696			

Appendix B16: ANOVA for Days to 50% flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.963	0.4815	0.59	
Water	2	5.4074	2.7037	3.32	0.141
Residual	4	3.2593	0.8148	1.52	
N fertilizer	2	0.5185	0.2593	0.48	0.629
Water. N fertilizer	4	1.037	0.2593	0.48	0.748
Residual	12	6.4444	0.537		
Total	26	17.6296			

Appendix B17: ANOVA for panicles/ m^2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	300.07	150.04	3.83	
Water	2	4681.41	2340.7	59.71	0.001
Residual	4	156.81	39.2	0.73	
N fertilizer	2	104006.7	52003.37	965.34	<.001
Water. N fertilizer	4	2229.48	557.37	10.35	<.001
Residual	12	646.44	53.87		
Total	26	112021			

Appendix B18: ANOVA for grains/panicles

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.074	4.037	10.9	
Water	2	5183.63	2591.815	6997.9	<.001
Residual	4	1.481	0.37	0.07	
N fertilizer	2	3450.296	1725.148	321.23	<.001
Water. N fertilizer	4	513.259	128.315	23.89	<.001
Residual	12	64.444	5.37		
Total	26	9221.185			

Appendix B19: ANOVA for panicle length (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1919	0.0959	0.71	
Water	2	8.7696	4.3848	32.26	0.003
Residual	4	0.5437	0.1359	1.04	
N fertilizer	2	46.743	23.3715	178.51	<.001
Water. N fertilizer	4	2.2059	0.5515	4.21	0.023
Residual	12	1.5711	0.1309		
Total	26	60.0252			

Appendix B20: ANOVA for percentage filled grains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.185	4.593	1.94	
Water	2	50.074	25.037	10.56	0.25
Residual	4	9.481	2.37	2.13	
N fertilizer	2	31.63	15.815	14.23	<.001
Water. N fertilizer	4	40.37	10.093	9.08	0.001
Residual	12	13.333	1.111		
Total	26	154.074			

Appendix B21: ANOVA for 1000 grain weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2452	0.1226	0.37	
Water	2	1.7163	0.8581	2.56	0.192
Residual	4	1.3415	0.3354	0.88	
N fertilizer	2	0.0741	0.037	0.1	0.908
Water. N fertilizer	4	1.2793	0.3198	0.84	0.527
Residual	12	4.58	0.3817		
Total	26	9.2363			

Appendix B22: ANOVA for grain yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.03185	0.01593	0.47	
Water	2	10.57852	5.28926	156.93	<.001
Residual	4	0.13481	0.0337	0.78	
N fertilizer	2	42.01407	21.00704	484.78	<.001
Water. N fertilizer	4	1.58593	0.39648	9.15	0.001
Residual	12	0.52	0.04333		
Total	26	54.86519			

Appendix B23: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.97E-05	2.98E-05	0.16	
Water	2	0.000571	0.000286	1.5	0.327
Residual	4	0.000762	0.000191	1.33	
N fertilizer	2	0.000366	0.000183	1.27	0.315
Water. N fertilizer	4	0.00422	0.001055	7.35	0.003
Residual	12	0.001722	0.000144		
Total	26	0.0077			

Appendix B24: ANOVA for Nitrogen uptake in grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.546	3.273	0.65	
Water	2	2586.338	1293.169	258.08	<.001
Residual	4	20.043	5.011	0.96	
N fertilizer	2	15169.55	7584.776	1448.93	<.001
Water. N fertilizer	4	1605.769	401.442	76.69	<.001
Residual	12	62.817	5.235		
Total	26	19451.07			

Appendix B25: ANOVA for nitrogen uptake in straw

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.855	4.9275	14.18	
Water	2	986.8198	493.4099	1419.91	<.001
Residual	4	1.39	0.3475	0.7	
N fertilizer	2	8060.181	4030.091	8090.87	<.001
Water. N fertilizer	4	455.6105	113.9026	228.67	<.001
Residual	12	5.9772	0.4981		
Total	26	9519.834			

Appendix B26: ANOVA for agronomic nitrogen use efficiency

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.127	3.064	0.41	
Water	2	303.589	151.795	20.18	0.008
Residual	4	30.087	7.522	0.93	
N fertilizer	2	5628.624	2814.312	347.73	<.001
Water. N fertilizer	4	196.068	49.017	6.06	0.007
Residual	12	97.119	8.093		
Total	26	6261.614			

Appendix B27: ANOVA for Physiological nitrogen use efficiency

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	30.33	15.17	0.89	
Water	2	49.99	25	1.47	0.332
Residual	4	68.08	17.02	1.41	
N fertilizer	2	10483.14	5241.57	435.29	<.001
Water. N fertilizer	4	157.49	39.37	3.27	0.05
Residual	12	144.5	12.04		
Total	26	10933.53			

Appendix B28: ANOVA for water use (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.25E+01	1.63E+01	6.14	
Water	2	4.38E+06	2.19E+06	8.26E+05	<.001
Residual	4	1.06E+01	2.65E+00	0.51	
N fertilizer	2	3.80E+04	1.90E+04	3627.23	<.001
Water. N fertilizer	4	2.39E+03	5.97E+02	113.96	<.001
Residual	12	6.29E+01	5.24E+00		
Total	26	4.42E+06			

Appendix B29: ANOVA for water productivity (cm^3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.57E-05	1.78E-05	0.07	
Water	2	0.353933	0.176966	683.46	<.001
Residual	4	0.001036	0.000259	0.55	
N fertilizer	2	0.319308	0.159654	338.07	<.001
Water. N fertilizer	4	0.010041	0.00251	5.32	0.011
Residual	12	0.005667	0.000472		
Total	26	0.69002			

Appendix C: Economics analysis for rice production

Appendix C1: General cost of rice production (GH₵/ha) under different water management and Nitrogen treatment combinations during July to November 2015 at Soil and Irrigation Research Centre, Kpong

General cost of production	**Amount (GH₵/ha)**
Land preparation	150
Bund making and digging	100
Cost of herbicide	30
Labour for application of herbicide	20
Cost of pesticide	30
Labour for application of pesticide	20
cost of muriate of potash (K20)	157.5
cost of triple Superphosphate (P2O5)	205.4
Cost of seeds	220
Cost of transplanting of seedlings	200
Labour for scaring of birds	300
Harvesting and threshing	900
Total cost	**2333**

Appendix C2. Variable cost of rice production (GH₵/ha) under different water management and Nitrogen treatment combinations during July to November 2015 at Soil and Irrigation Research Centre, Kpong

Treatment	Expenditure	Total (GH₵/ha)
AWDN0	General cost of cultivation	2333
	cost of water	1200
	Total	**3533**
AWDN1	General cost of cultivation	2333
	cost of water	1200
	cost of Urea	273
	Total	**3806**
AWDN2	General cost of cultivation	2333
	cost of water	1200
	cost of Urea	409.5
	Total	**3942.5**
MCN0	General cost of cultivation	2333
	Cost of water	600
	Total	**2933**
MCN1	General cost of cultivation	2333
	Cost of water	600
	Cost of Urea	273
	Total	**3206**
MCN2	General cost of cultivation	2333
	Cost of water	600
	Cost of Urea	409.5

	Total	**3342.5**
CSN0	General cost of cultivation	2333
	Cost of water	1600
	Total	**3933**
CSN1	General cost of cultivation	2333
	cost of water	1600
	cost of Urea	273
	Total	**4206**
CSN2	General cost of cultivation	2333
	cost of water	1600
	cost of Urea	409.5
	Total	**4342.5**