EVALUATION OF WATER REGIMES WITH NITROGEN LEVELS ON WATER USE EFFICIENCY AND YIELD AND YIELD COMPONENTS OF HYBRID RICE (Palethwe-2)

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OCTOBER 2013

EVALUATION OF WATER REGIMES WITH NITROGEN LEVELS ON WATER USE EFFICIENCY AND YIELD AND YIELD COMPONENTS OF HYBRID RICE (Palethwe-2)

A thesis presented
by

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to

A thesis submitted to the post-graduate committee of the Yezin Agricultural University in partial fulfillment of the requirements for the Degree of Master of Agricultural Science (Soil Science)

Yezin Agricultural University

OCTOBER 2013

The thesis attached hereto, entitled **"Evaluation of Water Regimes with Nitrogen Levels on Water Use Efficiency and Yield and Yield components of Hybrid Rice (Palethwe-2)"** was prepared under the direction of the chairman of the candidate supervisory committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil Science).**

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This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

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DEDICATED TO MY BELOVED PARENTS,

U HLA THEIN AND DAW MYINT YI

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge the advice, guidance, helpful assistance, kind permission and administrative support of Dr. Tin Htut, Rector of Yezin Agricultural University (YAU), Pro-rectors Dr. Myo Kywe (Academic) and Dr. Maung Maung Myint (Admin).

I am delighted to express my gratitude to U Kyaw Win, Director General, Department of Agriculture, Ministry of Agriculture and Irrigation for the financial and technical support to study the master course.

I deeply feel much obliged and thankful to our Professor Dr. Soe Soe Thein, Professor and Head of Department of Agricultural Chemistry, YAU for her valuable advice, intellectual and inspiring suggestions, guidance and encouragement throughout the course of this study.

It gives me immense pleasure to express my sincere appreciation and profound gratitude to my thesis advisor Daw Yinn Mar Soe, Assistant Lecturer, for sharing her wise knowledge, resolute guidance, meticulous supervision, interest, encouragement and thought provoking discussion towards the successful completion of my research study and completely writing of thesis.

My deepest gratitude is also due to my advisory committee members, Professor Dr. Nang Nseng Hom, Professor and Head of Department of Agricultural Botany, YAU and external examiner Dr. Khin Mar Htay, Research Officer and Head, Water Utlization Research Section, Department of Agricultural Research, for their constructive comments, valuable suggestions, productive advice and critical reading in this manuscript.

I would like to sincerely thank to all of students and staff of Agricultural Chemistry Department for their kindness and support for providing facilities to complete my research successfully.

I gratefully acknowledge to Republic of the Union of Myanmar Federation of Chambers of Commerce and Industry's (UMFCCI) scholarship for their generous financial assistance for conducting my research work.

The collective and individual acknowledgments are also owed to all of my friends who shared a lot of joy, happiness, hearty encouragement and friendship with me and gave me a hand one way or another during my study period at Yezin Agricultural University. I will remain indebted to them for my progressive life.

Last but not least, words fail me to extend heartiest thanks to my ever-loving parents, my sister and my niece for their heartfelt love, unforgettable sacrifices, patience, eternal support , kindly encouragements, painstaking and prayers provided during my study period since my childhood. Without the efforts and encouragement of my family members, I would have never come to this stage of success.

Evaluation of Water Regimes with Nitrogen Levels on Water Use Efficiency and Yield and Yield components of Hybrid Rice (Palethwe-2)

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ABSTRACT

Pot experiments for two seasons (dry and wet) were carried out in the screen house at the Department of Agricultural Chemistry, Yezin Agriculture University, Nay Pyi Taw, during 2012 and set on three specific objectives: (1) to evaluate the effect of water regimes and nitrogen levels on growth and yield of hybrid rice; (2) to investigate the water use efficiency of hybrid rice; (3) to develop water management techniques with suitable N levels for hybrid rice (Palethwe-2) production. Three water regimes I_1- continuous flooding (CF), I_2- alternate wetting and drying (AWD) during the whole cropping season, I_3- alternate wetting and drying in the vegetative phase (AWDv), followed by continuous flooding until maturity and four levels of nitrogen application rate (0, 75, 150 and 225 kg N ha^{-1}) were laid out in two factor factorial arrangement in completely randomized design (CRD) with four replications.

In this experiment, the highest hybrid rice yield was observed in AWD for dry season. CF produced the maximum yield although there was no significant difference in grain yield for wet season. The maximum value of water use efficiency (WUE) was observed in AWD for both seasons. The application of 225 kg N ha^{-1} level produced the highest grain yield, dry matter production and WUE in both seasons. About 31 % and 23 % more grain yield were recorded for N_4 (225 kg N ha^{-1}) than N_1 (control) during dry and wet seasons. According to the significant positive linear relationship (R^2= 0.9451 and R^2 = 0.9583) between hybrid rice yield and nitrogen application levels, it would increase in 20.75 kg ha^{-1} and 5.15 kg ha^{-1} of grain yield when 1 kg N ha^{-1} was applied in hybrid rice production for dry and wet seasons. Water saving was negatively correlated with tiller numbers, dry matter production and yield of hybrid rice in both seasons. AWD in wet season would save 21 % more water than other water regimes.

Key words: *hybrid rice yield, nitrogen levels, water regimes, water use efficiency (WUE)*

CONTENTS

	Page
ACKNOWLEDGEMENTS	vi
ABSTRACT	viii
CONTENTS	ix
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF APPENDIXES	xv
CHAPTER I. INTRODUCTION	1
CHAPTER II. LITERATURE REVIEW	5
2.1 Importance of Rice	5
2.1.1 Impact of rice production	6
2.1.2 Prospect of hybrid rice production	7
2.2 Agronomic Characteristics of Rice	8
2.3 Soil Requirement for Rice	9
2.4 Climatic Requirements for Rice	9
2.5 Effects of Nitrogen on Rice Growth and Yield	10
2.6 Nitrogen Sources	10
2.7 Nitrogen Management in Rice	11
2.8 Water Use in Rice Production	12
2.9 Effect of Water Regime on Rice Production	12
2.10 Water Management in Rice	13
2.11 Alternate Wetting and Drying	14
2.12 Water Use Efficiency	15
CHAPTER III. MATERIALS AND METHODS	16
3.1 Experimental Site	16
3.2 Experimental Soil	16
3.3 Experimental Design and Treatments	16
3.4 Number, Size and Arrangement of Pot and Condition of Screen House	17
3.5 Fertilization in the Pots	17
3.6 Measurement of Irrigation Water	17
3.7 Measurement Parameters for Growth	18
3.8 Measurement Parameters for Yield and Yield Components	18

3.9 Care and Management 18

3.10 Calculation 19

3.11 Weather Data 19

3.12 Statistical Analysis 19

CHAPTER IV. RESULTS AND DISCUSSION 20

4.1 Experiment I (Dry Season) 20

4.1.1 Effect of water regimes and nitrogen levels on growth parameters and yield and yield components of hybrid rice 20

4.1.1.1 Plant height (cm) 20

4.1.1.2 Number of tillers hill^{-1} 22

4.1.1.3 Number of panicles hill^{-1} 24

4.1.1.4 Number of spikelets panicle^{-1} 24

4.1.1.5 1,000 grain weight (g) 25

4.1.1.6 Filled grain % 26

4.1.1.7 Unfilled grain % 26

4.1.1.8 Grain yield (g plant^{-1}) 26

4.1.1.9 Dry matter production (g) 29

4.1.2 Total water use (mm) 31

4.1.3 Water use efficiency (kg mm^{-1}) 33

4.1.4 Relationship between hybrid rice yield and nitrogen application levels 35

4.2 Experiment II (Wet Season) 37

4.2.1 Effect of water regimes and nitrogen levels on growth parameter and yield and yield components of hybrid rice 37

4.2.1.1 Plant height (cm) 37

4.2.1.2 Number of tillers hill^{-1} 39

4.2.1.3 Number of panicles hill^{-1} 41

4.2.1.4 Number of spikelets panicle^{-1} 41

4.2.1.5 1,000 grain weight (g) 41

4.2.1.6 Filled grain % 42

4.2.1.7 Unfilled grain % 43

4.2.1.8 Grain Yield (g plant^{-1}) 43

4.2.1.9 Dry matter production (g) 46

4.2.2 Total water use (mm) 48

4.2.3 Water use efficiency (kg mm^{-1}) 50

4.2.4 Relationship between hybrid rice yield and nitrogen application levels 52

CHAPTER V. CONCLUSION 55

5.1 Suggestions 56

REFERENCES 57

LIST OF TABLES

Table		Page
4.1	Yield and yield components as affected by different water regimes and nitrogen levels in rice during dry seasons 2012	28
4.2	Mean effect of different water regimes and nitrogen levels on dry matter production during dry season, 2012	30
4.3	Yield and yield components as affected by different water regimes and nitrogen levels in rice during wet seasons 2012	45
4.4	Mean effect of different water regimes and nitrogen levels on dry matter production during wet season, 2012	47
4.5	Benefit cost ratio of hybrid rice production in dry and wet seasons, 2012	54

LIST OF FIGURES

Figure		Page
4.1	Mean value of plant height as affected by different water regimes during the dry season, 2012	21
4.2	Mean value of plant height as affected by different nitrogen levels during the dry season, 2012	21
4.3	Mean value of number of tillers hill^{-1} as affected by different water regimes during the dry season, 2012	23
4.4	Mean value of number of tillers hill^{-1} as affected by different nitrogen levels during the dry season, 2012	23
4.5	Mean value of total water use as affected by different water regimes during the dry season, 2012	32
4.6	Mean value of total water use as affected by different nitrogen levels during the dry season, 2012	32
4.7	Mean value of water use efficiency as affected by different water regimes during the dry season, 2012	34
4.8	Mean value of water use efficiency as affected by different nitrogen levels during the dry season, 2012	34
4.9	Relationship between hybrid rice yield and nitrogen application levels in the dry season, 2012	36
4.10	Mean value of plant height as affected by different water regimes during the wet season, 2012	38
4.11	Mean value of plant height as affected by different nitrogen levels during the wet season, 2012	38
4.12	Mean value of number of tillers hill^{-1} as affected by different water regimes during the wet season, 2012	40
4.13	Mean value of number of tillers hill^{-1} as affected by different nitrogen levels during the wet season, 2012	40
4.14	Mean value of total water use as affected by different water regimes during the wet season, 2012	49
4.15	Mean value of total water use as affected by different nitrogen levels during the wet season, 2012	49
4.16	Mean value of water use efficiency as affected by different water regimes during the wet season, 2012	51
4.17	Mean value of water use efficiency as affected by different nitrogen levels during the wet season, 2012	51

Figure		Page
4.18	Relationship between hybrid rice yield and nitrogen application levels in the wet season, 2012	53

LIST OF APPENDIXES

No.		Page
1.	Nutritional composition of rice	72
2.	Response of the rice plant to various temperatures at different growth stages	73
3.	Mean rainfall, temperature and relative humidity % data at Yezin during two experiments (2012)	74
4.	Field water tube	74
5.	Mean effect of different water regimes and nitrogen levels on plant height, dry season, 2012	75
6.	Mean effect of different water regimes and nitrogen levels on number of tillers $hill^{-1}$, dry season, 2012	76
7.	Mean effect of different water regimes and nitrogen levels on plant height, wet season, 2012	77
8.	Mean effect of different water regimes and nitrogen levels on number of tillers $hill^{-1}$, wet season, 2012	78
9.	Effect of different water regimes and nitrogen levels on grain yield (baskets ac^{-1}) during dry and wet seasons 2012	79
10.	Effect of different water regimes and nitrogen levels on grain yield (t ac^{-1}) and (t ha^{-1}) during dry and wet seasons 2012	80

CHAPTER I

INTRODUCTION

Rice is the major staple food in Asia, where about 92% of the world's rice is produced and consumed (IRRI 2002). Rice is the world's third largest crop, after maize (corn) and wheat. China was the first country to commercially produce hybrid rice in 1964. Hybrid rice was developed by Yuan Long Ping, having about a 30 % yield advantage over conventional pure line varieties (Yuan 1999). Hybrid rice was released for large scale cultivation and commercialization in China during 1976. Development of successful hybrids in a self pollinated cereal crop, which was till then considered an impossibility, was shown to be a reality. It made headlines then and prompted the International Rice Research Institute in Philippines to initiate the research on hybrid rice during 1979. The current global population which is estimated as 6.45 billion is expected to reach 7.54 billion by 2020 and 8.91 billion by 2050 AD. Ninety five percent of this population increase will take place in developing countries, where rice is the staple food. The biggest problem faced by the humanity in the present 21st century is ensuring the food security for the ever increasing population. Adequate food and nutrition is to be made available for the huge global population with the ever shrinking resource base (Prasad 2010). Therefore, to increase production of rice plays a very important role in food security and poverty alleviation.

Myanmar started search on hybrid rice in 1997 and released its hybrid rice to fulfill the needs of consumption for the country (Grain 2005). Growing hybrid rice is a complex process since agronomic management of hybrid rice differs considerably from that of conventional inbred rice varieties in many respects (Ramesh and Chandrasekaran 2007). The life cycles of hybrid and inbred rice are almost similar, but hybrid rice is more vigorous in the vegetative phase, especially at seedling stage. Hybrid rice has higher seedling dry matter content, thicker leaves, larger leaf area and longer root system (BRRI 2000). Hybrid rice can give 10-15% yield advantage over modern inbred varieties through vigorous growth, extensive root system, efficient and greater sink size, higher carbohydrate translocation from vegetative parts to spikelets and larger leaf area index during the grain filling stage (Peng and Cassman 1998). The main reason for higher yield of hybrid rice is vigorous seedlings with tillers. The tillers that emerge in the seedbed produce more spikelets panicle^{-1} than the tillers that emerge after transplanting (Wen 1990). New, front-line agronomic packages such as optimum plant population, seedling number hill^{-1}, optimum dose of N, split application of fertilizers and irrigation management, have a decisive effect on yield potential of hybrid rice. Of these, irrigation and nitrogen management are considered to be the most importance in influencing yields (Jayakumar et al. 2004).

Water is a critical and the most important factor in rice production. Increased efficiency in the use of water is essential for future food security in Asia where rice production has to be increased by 70% of the present amount by the year of 2025. Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice (Guerra et al. 1998). 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 none submerged conditions of several days (Bouman and Tuong 2001). About 55 % of the areas cultivated to rice are under irrigation. It is known that in irrigated systems, more than 4,000-5,000 liters of water are used to produce 1 kg of rice in many areas. It is therefore important to improve water use efficiency in rice production systems through the use of appropriate water control and crop management techniques, with emphasis on irrigation technologies.

Alternate Wetting and Drying (AWD) is a technology developed by the International Rice Research Institute (IRRI). The technology is based on the knowledge that rice tolerates up to 30% reduced water supply during the main growing period compared to conventional irrigation. One of the viable options is the adoption of making better improved applications of irrigation water, e.g., through alternate wetting and drying (AWD) (Bouman and Tuong 2001). Under intermittent irrigation, yields of Sanyou 10 (hybrid rice) and 923 (conventional variety) were 8% and 10% higher, 9.5 and 8.8 t ha^{-1}, respectively, than under flooded conditions (Qinghua Shi et al. 2002). Maintaining shallow water depth (SWD) through AWD or other water management can improve growth conditions and produce higher grain yields (Lin et al. 2004). In AWD, irrigation is applied a few days after water has disappeared from the surface so that periods of soil submergence alternate with periods of non-submergence during the whole growing season (Belder et al. 2007). Alternative wetting and drying irrigation (AWD) has been commonly used as a water-saving practice in many countries including China for more than one decade. Alternate drying and wetting of the fields allows for good aeration of the soil and better root growth thereby increasing rice yield and water use efficiency (Uphoff 2006). The absence of yield reduction in AWD in comparison with CF was consistent with the results obtained in China and the Philippines (Belder et al. 2005b). One strategy to promote water saving for better water resource management in rice production without significant yield losses is by adopting intermittent irrigation (Won et al. 2005).

Nitrogen (N) is the most limiting nutrient to rice growth and yield in almost all environments (Yoshida 1981). Rice grain yield was recorded highest in case the nitrogen application ranged between 90-250 kg ha^{-1} (Bali et al. 1995). Hybrid rice technology aims to increase the yield potential of rice (Chaturvedi 2005). Research data show that hybrids differ from conventional varieties in response to nitrogen fertilizer. Optimum dose of nitrogen fertilization plays a vital role in growth and development of rice plant. Its growth is seriously hampered when lower dose of nitrogen is applied which drastically reduces yield. Nitrogen has a positive influence on the production of effective tillers $plant^{-1}$, yield and yield attributes (Jashim et al. 1984; BRRI 1990). Surekha et al. (1999) found that N application in four splits, coinciding the last with flowering, improved the grain yield of hybrid rice. Nitrogen is normally a key factor in achieving optimum lowland rice grain yields (Fageria et al. 1997). It is worth mentioning utilization especially usage of nitrogen fertilizer is very significant factor in growth of rice. When nitrogen fertilizer used in tillering, paddy yield increased (Bacon 1989). Zhong and Huang (2002) report that grain yield and dry matter increased when application of nitrogen fertilizer increased. In continuous flooding (CS) fields, N is almost solely available as ammonium (NH_4) and N losses are predominantly through NH_3 volatilization (Vlek and Craswell 1981). Allowing the soil to become (temporarily) aerobic will enhance nitrification. If the nitrate (NO_3) is not taken up, it is prone to denitrification losses (Reddy and Patrick 1976; Eriksen et al. 1985) or leaching in more permeable soils (Keeney and Sahrawat 1986).

In the N-fertilized plots, AWD had the highest grain yields, which were significantly higher than those of saturated soil culture on raised beds, which had the lowest yields (Lu et al. 2002). Interactions of irrigation regime and nitrogen level on grain yield and water use efficiency were significant. I_1N_3 (continuous flooding + 120 kg N ha^{-1}) produced maximum yield of hybrid rice. Water use efficiency (WUE) in I_3N_3 (irrigation 8 day interval + 120 kg N ha^{-1}) and I_3N_4 (irrigation 8 day interval + 150 kg N ha^{-1}) were maximum with 1.87 and 1.85 kg m^{-3} and I_1N_1 (continuous flooding + 0 kg N ha^{-1}) had minimum mean value with 0.94 (Ashouri 2011). The study of water use efficiency and physiological response of rice cultivars under alternate wetting and drying conditions indicated that proper water management greatly contributed to grain yield in the late grain filling stage, and it was critical for safe AWD technology (Zhang et al. 2012). The water use efficiency for rice production in Myanmar was investigated at Department of Agriculture Research. Yezin, Myanmar 2011. The result showed that AWD irrigation management practice can save irrigation water up to 30% in comparism with CF.

The objectives of this paper are: (1) To evaluate the effect of water regimes and nitrogen levels on growth and yield of hybrid rice; (2) To investigate the water use efficiency of hybrid rice; (3) To develop water management techniques with suitable N levels for hybrid rice (Palethwe-2) production.

CHAPTER II

LITERATURE REVIEW

2.1 Importance of Rice

Rice is the most important food crop in the world. With the population increase in the world, the requirement for rice yield production increase is more urgent than before. The rice yield should be improved by approximately 1% annually to satisfy the increasing food demand by population growth and economic development (Rosegrent et al. 1995). As a cereal grain, rice is the predominant staple food for 17 countries in Asia and the Pacific, nine countries in North and South America and eight countries in Africa. It is the grain with the second-highest worldwide production, after maize (corn) (FAO 2004b). In Myanmar, rice is the most important agricultural commodity. Myanmar experienced three distinct periods of rice production growth from the latter 1880s to 1985 (Win and Win 1990). The first major period of growth between 1885 and 1910 involved rapid expansion of rice area in Lower Myanmar under British colonization. The second growth period occurred between 1955 and 1965 when rice land abandoned during World War II was returned to production. The third period occurred from 1975 to 1985 as a result of applying new technology in rice production. They stand the highest consumers of rice in the world, with each person averaging more than 180 kg year^{-1}. Rice provides 71% of their daily calorie intake (www.irri.org). Rice is rich in nutrients and contains a number of vitamins and minerals. It is an excellent source of complex carbohydrates, the best source of energy (Appendix 1). Production of rice yield depend on many factor such as geographic factor, climatic factor, land and soil factor, water supply factor and socio- economic factor (FAO 1995).

The major rice-producing regions of Myanmar are in the delta. Ayeyawady, Bago and Yangon regions make up almost half of the country's harvested rice area (MOAI 2011). Myanmar's major rice ecosystems include rainfed lowland rice, irrigated lowland rice, deepwater rice and upland rice. Yields are somewhat lower in the rainfed lowlands, especially those prone to submergence, drought, and salinity. If rice production in Myanmar is increased, poverty may be alleviated and the livelihoods of rural poor would improve, because 73% of the population lives in rural areas. In Myanmar, people eat an average of half a kilogram of rice every day. Rice and its by-products are used for making straw and rope, paper, wine, crackers, beer, cosmetics, packing material, and even toothpaste (FAO 2004). On the basis of mean grain yield, rice crops produce more food energy and protein supply per hectare than wheat and maize. Hence, rice can support more people per unit of land than the two other staples (Lu and Chang 1980). It is, therefore, not surprising to find a close relationship in human history between an expansion in rice cultivation and a rapid rise in population growth (Chang 1987).

2.1.1 Impacts of rice production

Rice, edible starchy cereal grain, is a member of grass family. There are two main cultivated species: *Oryza sativa* L. and *Oryza glaberrima*. Steud.. Of the two cultivated species, African rice (*O. glaberrima* .) is confined to West Africa, whereas common or Asian rice (*O. sativa* L.), is now commercially grown in 112 countries, covering all continents (Chang 2001). Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop for up to 30 years.

Rice cultivation is well-suited to countries and regions with low labor costs and high rainfall, as it is labor-intensive to cultivate and requires ample water. Rice can be grown practically anywhere, even on a steep hill or mountain. Although its parent species are native to South Asia and certain parts of Africa, centuries of trade and exportation have made it common place in many cultures worldwide. The traditional method for cultivating rice is flooding the fields while, or after, setting the young seedlings. While flooding is not necessary throughout the cultivation of rice, all other methods of irrigation require higher effort in weed and pest control during growth periods and a different approach for fertilizing the soil (http://en.wikipedia.org/wiki/Rice).

Rice is the world's most important wetland food crop and the pressure to increase rice production is accelerating. Rice is the only major grain crop that is grown almost exclusively as food. In 30 years, the earth's population may be 8 billion people (UN 2002; Rosegrent et al. 2002) and the number people dependent on rice for food may equal 5 billion (IRRI 2002). Allowing for substitutions of other foods for rice in diets as incomes increase, the world's annual rice production still must increase from 518 million tons in 1990 to 760 million tons. This 47% increase would merely maintain current nutrition levels, which already are inadequate for hundreds of millions of people. More than 90 % of the world's rice is produced in Asia (China and

India account for 50 % of the world rice cultivation area), 3.2 % in Latin America (Brazil and Colombia account for 62 % of that production), 2.1 % in Africa (Egypt and Madagascar account for 48 % of that production), and 2.5 % in the rest of the world (IRRI 1989).

Myanmar has a long tradition of rice production. In the years immediately prior to World War II it was the largest rice-producing nation in the world, and it continues to be one of the ten largest rice-producing countries in terms of total yield (IRRI 2002). Paddy sown area was 8.05 million hectares and production was reached at 33 million metric ton in 2011 (MOAI 2012).

2.1.2 Prospect of hybrid rice production

The word hybrid refers to that it can be produced by crossing two inbred, genetically fixed varieties of a particular crop. These hybrids are special, because they have heterosis or hybrid vigour. If two parents are crossed, which are genetically distinct from each other, the offspring will be superior and produce higher yields. This effect is known as heterosis and it disappears after the first generation (F_1). Therefore farmers cannot save the seeds produced from hybrid crops. They need to purchase new F_1 seeds in every planting season to make use of the heterosis effect (Kuyek et al. 2000). Hybrid technology was successfully developed in China during 1964 to 1975. Today, Hybrid rice covers around 50% of the rice area (30 million ha) in China. Other countries are successively catching up. This hybrid rice technology is being developed in about 20 countries worldwide. Vietnam, India, the Philippines, Bangladesh, Indonesia, Myanmar and the USA are the most important countries which use this technology and in total it covers around 800,000 ha of arable land. Hybrid rice has proven to be more suitable for scare land, large population, and cheap labor areas. Thus hybrid rice technology is very important for the food security (FAO 2004).

Super hybrid rice is a variety, which combines the ideal plant type through hybridization between indica and japonica to achieve super high yields. These two varieties are differing in their forms and characteristics. Japonica rice is more suitable for temperate climate and their grains are round enough cracks or break and it becomes sticky and moist when cooked. In contrast, Indica rice is grown in hot climates and their grains are long and tend to break easily. Rice is fluffy and doesn't stick together, when cooked. Indica rice variety is commonly use in southern Asian countries including India, Thailand, and Southern China for cultivation (Gomez

2009). Hybrid rice technology provides farmers with high yield, and this sector will provide rural employment opportunities to the poorest of the poor people in rural areas. This hybrid rice technology is quite new and many countries have shown their interest to take part in activities to ensure the food security in their countries. A study done by FAO showed that, dissemination of this hybrid rice technology needs strong support and commitment from governments and scientists, cooperation among research programmes, seed productions and extension services and international collaborations and coordination (FAO 2004).

Farmers have to purchase the hybrid seed for every crop season, but in conventional practice for high yielding varieties (HYV) farmers can use some of their own crop harvest for the next season. Labor use is also higher for hybrid rice. In Vietnam the input value of family and hired labor was much higher for hybrid rice. The majority of the rice farmers grew hybrid rice on small plots and they used their own family labor. Hybrid rice has poor resistance to major pests and diseases. Therefore pesticide use was relatively high for hybrid rice. In 1998 researchers in China reported that hybrid is more susceptible to stem borer, white plant hopper, leaf roller, bacterial blight, sheath blight and virus diseases than on inbred rice. They also found outbreak of diseases such as Downey mildew, false smut and kernel smut to occur frequently on hybrid rice. This was the reason hybrid rice farmers had to use more pesticides. Hybrid rice requires 31% more pesticides and 43% more fertilizer compared to inbred rice. Due to this the total cost increase was about 16-23% for hybrid rice (Kuyek et al. 2000).

2.2 Agronomic Characteristics of Rice

Depending on the cultivar and environmental factors, the growth duration of cultivated species may vary from 90 to 180 days. Plant height may range from 0.4 m for most dwarf varieties, to more than 5 m for deep water types. During the vegetative phase of rice growth and development, the major visible activities are tillering and leaf development. Tillering is an intrinsic branching characteristic and important agronomic trait for productivity of plants belonging to the grass family (Moore and Moser 1995). It consists of one or more side shoots which grow independently of the mother culm by developing their own adventitious roots (Briske 1991). In rice and other economic grass plants such as wheat, oats and barley, tillers are specialized potential grain bearing branches whose quality and number are principal determinants of yield (Li et al. 2003).

2.3 Soil Requirement for Rice

Rice can be grown in all type of soils like light to heavy soil, except very sandy. Clay or clay loam soil is the best for rice cultivation due to its high water holding capacity. Slightly acid soils having a pH value of 6 to 7 are better for paddy cultivation. However, it has been found to be grown in a wide range of pH varying from 4 to 8 (www.sikkimagrisnet.org).

2.4 Climatic Requirements for Rice

Rice crop is best suited to tropical and sub-tropical humid climate but it is grown in variety of climate except extreme cold temperate. The climatic factors that affect rice production are temperature, solar radiation and humidity (Yoshida 1981). With irrigation, planting can be adjusted to take advantage of favorable climatic conditions such as optimum temperature and high solar radiation (Datta 1981).

The atmospheric temperature has considerable effect on growth and development of rice plant. Rice needs relatively high temperature for their optimum growth and development. Temperature requirement of rice is different for different growth stages (Appendix 2). For vegetative growth, a temperature range of 25˚C to 30˚C and for grain filling and ripening 20˚C to 25˚C temperature was reported best. For higher grain yield a day temperature of 25˚C to 32˚C and night temperature of 15 to 20˚C is preferable. Temperature beyond 35˚C affects not only pollen shedding but also grain filling. A higher mean temperature ranging between 25˚C to 32˚C per day would reduce the growth duration and accelerate flowering whereas a mean temperature of less than 15˚C would slow during vegetative growth and plants fail to flowers. Therefore, for vigorous vegetative growth moderately high temperature is required. It is well known that mild temperature of night and clear sunny weather during day time is better for high yield of rice, but temperature less than 15˚C is not conducive for panicle initiation as well as for crop growth (Yoshida 1977; 1981) (Appendix 2). Solar radiation is essential for photosynthetic activity of rice plant. As such, the growth, development and yield of rice plants are affected by the level of solar radiation (Nguyen 1998). If irrigation water is available, rice can be grown in the dry season and the grain yield will be higher than in the wet season because of the higher intensity of solar radiation (Datta 1981).

2.5 Effects of Nitrogen on Rice Growth and Yield

Nitrogen, like other essential nutrient elements, is a critical requirement for plant growth and productivity. Correlations between nitrogen accumulation and yield have been reported in many studies on rice (Peng and Cassman 1998; Wang et al. 2001; Murchie et al. 2002; Haefele et al. 2003; Yang et al. 2003b; Huang et al. 2008). In general, about 70 – 90% of the nitrogen accumulated in rice at harvest maturity is said to be absorbed before heading (Ying et al. 1998b). Leaf nitrogen plays a significant role in plant dry matter production since it is closely correlated with the rate of photosynthesis (Hirose and Werger 1987; Evans 1989; Leuning et al. 1995). During the ripening stage of rice, the developing panicles become the major sink for nitrogen wherein large amounts of nitrogen are remobilized from the leaves and stem. At harvest, 30 – 77% of the nitrogen in vegetative plant tissue is reportedly allocated to the grains in the panicle (Witt et al. 1999; Ida et al. 2009). Tillering in rice is known to be very responsive to soil fertility, particularly nitrogen nutrition. However, over application of nitrogen fertilizer at sowing and tillering has been found to result in high tiller abortion after maximum tillering, accompanied by a lowering in the percentage of effective tillers and lower grain yield per unit nitrogen uptake (De Datta and Buresh 1989; Jiang et al. 2005). Excessive nitrogen nutrition is known to promote luxuriant growth, delay the reproductive phase, and encourage lodging and blast in rice (Takebe and Yoneyama 1989). Inadequate nitrogen on the other hand, tends to retard growth, limit photosynthesis and assimilates partitioning, hasten senescence, thereby resulting in low yield (Mae 1997). Efficient management of nitrogen resources is therefore a very critical factor for high yield and it largely depends on the choice, dosage, timing and mode of application of the nutrient carrier or fertilizer. Effective management of crop nutrition entails the provision of adequate minerals in the proper form and amount and at the right time, such that yield returns will be maximized while fertilizer cost is kept at the minimum (Prudente et al. 2009).

2.6 Nitrogen Sources

Plants derive nitrogen nutrition from natural (e.g. biological nitrogen fixation) or artificial (e.g. chemical fertilizer) sources. Plants generally take up mineral nitrogen mainly in the form of nitrate (NO_3^-) or ammonium (NH_4^+) ions (Von Wirén et al. 1997). Basically, all the major forms of nitrogen fertilizers, except urea, are known to contain, ammonium or nitrate, or both (Jensen 2006). Ammonium-based or $NH4^+$ - forming (urea) fertilizers have been deemed to be more useful as nitrogen sources in paddy rice cultures, compared to nitrate fertilizers due to the incidence of denitrification, since nitrate is largely unstable in flooded soils (Prudente et al. 2009).

Furthermore, rice plants are capable of directly absorbing ammonium ions under varying soil moisture conditions (Addiscott et al. 2005). Urea is highly soluble and contains 46% N, which is relatively high in nitrogen and therefore, cheaper compared to other sources of nitrogen except for liquid ammonia which may contain up to 82% N (Dickie 1997). Urea can be applied as granules, or in liquid form like ammonia (Watson et al. 1992). However, plants cannot use urea directly; it has to first be hydrolyzed to NH_4^+ by the enzyme urease which is usually abundant in the soil micro flora; and plants can still absorb the nitrogen when the ammonium is converted to NO_3^- (Reynolds et al. 1985; Kaminskaia and Kostic 1997). The nitrate from the other sources of nitrogen fertilizer can also be taken up by rice and used to produce proteins needed for growth.

2.7 Nitrogen Management in Rice

Timing of nitrogen application is another essential means by which critical growth functions and stages of the rice plant can be enhanced. In transplanted rice, application of nitrogen at 7 days after transplanting has been found to be more beneficial than application at transplanting (Meelu et al. 1987). A reduction in the time interval between nitrogen fertilizer placement and permanent flooding can lead to higher uptake and increased yield (Bacon 1985). Single application of controlled release fertilizer (CRF) at the early seedling stage has been found to not only reduce labor requirement but also increase the ratios of productive tillers and whole grains with lower protein content as compared to a conventional practice that involved topdressing at the panicle development stage (Miura et al. 2009).

Significant yield increases from minimal nitrogen input (of about 50% below the traditional recommended rate) have been reported in places where these instruments were used to inform nitrogen fertilizer input decisions (Reddy and Pattar 2006). Also, soil test and target yield concepts have been found to constitute the basic framework for fertilizer recommendation with the ultimate aim of optimizing nutrient use efficiency (Bera et al. 2006). Soil moisture condition may also have a huge impact on the availability and uptake of nitrogen as well as other nutrient forms irrespective of their source, often with significant consequences for biomass accumulation, tillering and yield of the rice plant. During periods of water stress, nitrogen application may have very little or no effect on growth and tillering; however, uptake may resume after the stress is relieved (Prasertsak and Fukai 1997).

2.8 Water Use in Rice Production

Rice is heavy water consumers which can be produced both rain fed or irrigated. Input of much water on plots is needed to face the water losses by seepage, evaporation, percolation and transpiration. To produce 1 kg of rice, 5000 liters of water is needed. Because of the importance of rice in world's food consumption, food security coheres with water security (www.irri.org). Water plays prominent role in rice production while many other cropping system use water mainly for productive purpose, rice cropping system uses water in a very wide variety of ways both beneficial and non-beneficial. Rice systems need water for three main purposes: (i) evapotranspiration; (ii) seepage and percolation; and (iii) specific water management practices such as land preparation and drainage prior to tillering (FAO 2004c). Water inputs to lowland rice fields are needed to match the outflows by seepage, percolation, evaporation, and transpiration. Seepage is the lateral subsurface flow of water and percolation is the down flow of water below the root zone. Typical combined values for seepage and percolation vary from 1-5 mm day^{-1} in heavy clay soils to 25-30 mm day^{-1} in sandy and sandy loam soils (Bouman et al. 2007). Evaporation occurs from the pounded water layer and transpiration is water loss from the leaves of the plants. Tabbal et al. (2002) stated that typical combined evapotranspiration rates of rice fields are 4-5 mm day^{-1} in the wet season and 6-7 mm day^{-1} in the dry season, but can be as high as 10-11 mm day^{-1} in subtropical regions before the onset of the monsoon. Sound water management practices are needed to use water wisely and maximize rice yield (Bouman and Lampayan 2009).

2.9 Effect of Water Regime on Rice Production

Water is one of the most limiting factors in plant growth. It is essential to plants due to several reasons. First, water transports dissolved minerals through the soil to the roots where they are taken up by the plant, and provides physical support for plants by stimulating internal or turgor pressure within the cells (Nonami and Boyer 1989). Excessive moisture on the other hand, may cause physical and chemical changes in the soil and root environments which may be deleterious to plant performance and final yield (Zaidi et al. 2007). Comparatively, the practice of flooding in rice production, be it continuous or for a short duration, has been reported to contribute to higher tiller number, biomass, and grain yield than non-flooded practices (Juraimi et al. 2009). However, excessive flooding resulting in complete submergence of vegetative tissues poses a real threat to growth, tillering and yield of rice plants since it undermines the very survival of the plants.

Complete submergence at early and active tillering can lead to yield losses due to poor tillering and low panicle numbers. At the booting stage, complete submergence may cause the cessation of panicle development as well as the degeneration of spikelets (Reddy et al. 1985). Efficient management of water has been reported to result in higher yield, and particularly in the case of irrigation, the practice has resulted in less water use. Controlled soil moisture content irrigation techniques can contribute to yield increase and reduce water consumption by 40 - 45% of that used in flooding irrigation (Shizhang et al. 1994). According to these authors, the practice promotes modest rice crop water consumption by reducing transpiration, interplant evaporation and field seepage.

Alternate submergence and non submergence have been found to save water use by 15% of that used in continuously flooded culture with no effect on grain yield, provided ground water remains between 0 - 30 cm (Belder et al. 2004). When imposed alternately, moderate soil submergence and drying may promote grain yield in addition to improved water use efficiency since it enhances root growth and other physiological processes (Zhang et al. 2009a).

2.10 Water Management in Rice

Flooding also helps suppress weed growth, improves the use of nitrogen efficiency and, in some environments, helps protect the crop from fluctuations in temperatures. Under certain conditions, allowing the soil to dry out for a few days before reflooding can be beneficial to crop growth. In certain soils high in organic matter, toxic substances can be formed during flooding that can be removed through intermittent soil drying. Intermittent soil drying promotes root growth which can help plants resist lodging better in case of strong winds later in the season. Intermittent soil drying can also help control certain pests or diseases that require standing water for their spread or survival.

Keep the water level in the fields at 5 cm at all times during reproductive stage. The ripening period of rice crop does not necessarily require flooding. Soil that is 80–90% saturated is sufficient. Draining the fields some 10-15 days before the expected harvest date hastens maturity and grain ripening, prevents excessive nitrogen uptake, and makes the land better accessible (because it is dryer) for harvest operations (IRRI 2009).

2.11 Alternate Wetting and Drying (AWD)

The destructive effects of climate change on the supply of fresh water do not bode well for a growing population that demands a corresponding rise in rice production. It is estimated that 15 to 20 million hectares of irrigated rice may suffer some degree of water scarcity by 2025 (Bouman et al. 2009). Alternate wetting and drying is the process of flooding rice paddy a certain number of days after the disappearance of ponded water. In other words, the field is alternately flooded and dried, a change from the traditional practice of continuous flooding. Farmers wait between 1 and 10 days to irrigate, letting the field drain in the interim. Alternate wetting and drying (AWD) is a type of water-saving rice production system. In this system, the field is irrigated with enough water to flood the paddy for 3-5 days, and, as the water soaks into the soil, the surface is then allowed to dry for 2-4 days before getting re-flooded. Compared with the traditional continuous flooding system, AWD using lowland rice cultivars can reduce water input by 15-30% without yield loss. With drought-tolerant lowland rice cultivars, a longer interval of drying in a cycle and thus more saved water can be expected (Bouman and Lampayan 2009).

AWD practice supplies enough oxygen to the rice-roots and induces an oxidized condition of soil (Feng and Li 2002). The measured values of the oxidation - reduction potential under AWD conditions were always higher after about 30 days of transplanting than those under continuous flooding condition (Zhang et al. 1994b). AWD practices lead to a sound ecological environment for rice. For example, lower temperature at night in paddy-fields due to AWD was favorable for photosynthesis, respiratory metabolism, assimilation and growth of rice-plant (Li and Barker 2004).

The lower temperature at night in paddy fields under AWD was favourable for absorption of nutrients of rice-plant (Li and Barker 2004).

A field water tube, made of bamboo or plastic, helps them assess if it is time to irrigate (Appendix 5). If the water level drops more than 15 cm below the surface in the dry season (20 cm in the wet season), as assessed by the field water tube, it is recommended that farmers flood their field again to a depth of 2-5 cm above the surface (in contrast to 5-10 cm in traditional practice). This cycle continues except for a period of continuous flooding during the flowering stage to prevent sterility (Bouman et al. 2007). In studies on AWD irrigation, grain yield of rice was increased (Li 2001; Tuong et al. 2005; Yang et al. 2007; Zhang et al. 2008a, 2009a) but reduced in others (Mishra et al. 1990; Tabbal et al. 2002; Belder et al. 2004) when compared with continuously submerged conditions.

2.12 Water Use Efficiency (WUE)

Water efficiency is one of the most extensively used terms to evaluate the performance of an irrigation system. In technical, water use efficiency is the mass of agricultural produce per unit of water consumed (Ronald and Marlow 1999). Water efficiency can be increased by increasing yield per unit land area, for example, by using better varieties or agronomic practices, or by growing the crop during the most suitable period. Plant biomass production is linearly coupled with the amount of water transpired, and higher water use efficiency (WUE) is often a trade-off against lower biomass production (Zhang and Yang 2004). Water efficiency and productivity terms should be used complementarily to assess water management strategies and practices to produce more rice with less water (Guerra et al. 1998). In agriculture, many ways of conserving water have been investigated and techniques such as alternate partial root zone irrigation, deficit irrigation, and drip irrigation, have shown that WUE can be enhanced (Graterol et al. 1993; Zhang et al. 1998; Kang et al. 2000; Tabbal et al. 2002; Li et al. 2010). In general, these techniques are a trade-off: a lower yield for a higher WUE (Zhang and Yang 2004).

CHAPTER III

MATERIALS AND METHODS

Experiment I was conducted from February, 2012 to June, 2012 and experiment II was carried out from July, 2012 to October, 2012.

3.1 Experimental Site

Pot experiments were conducted at screen house, Department of Agricultural Chemistry, Yezin Agricultural University (YAU), located at 19˚ 10' N latitude, 96˚ 07' E longitude with the elevation of 102 meters above sea level.

3.2 Experimental Soil

A composite soil sample of 0-15 cm depth from Yezin Agricultural University farm was collected and it was analyzed at the Department of Agricultural Research (DAR). The results were shown in follows:

Soil Texture	- sandy loam
Soil pH	- 6.17
Available N	- 81 ppm (medium)
Available P	- 4 ppm (low)
Available K	- 125 ppm (low)
Field Capacity	- 19.82 %
Permanent wilting point	- 2.61 %
Bulk Density	- 1.07 g cm^{-3}
Organic Matter	- 1.54 %
Cation Exchange Capacity	- 7.2 (low)

3.3 Experimental Design and Treatments

Factorial experiment was used in complete randomized design (CRD) with four replications in pot experiment. The tested variety was hybrid rice (Palethwe-2). Water regimes were assigned as factor A and nitrogen levels as factor B. All treatments were the same for experiment I and experiment II.

Factor A

I_1 - Continuous flooding (CF) at 5 cm above the soil surface from transplanting to harvest

I_2 - Alternate wetting and drying (AWD) during the whole cropping season

I_3 - Alternate wetting and drying in the vegetative phase (AWDv), followed by continuous flooding until maturity

Factor B

N_1 - 0 kg N ha^{-1}

N_2 - 75 kg N ha^{-1}

N_3 - 150 kg N ha^{-1}

N_4 - 225 kg N ha^{-1}

3.4 Number, Size and Arrangement of Pot and Condition of Screen House

A total of 48 plastic pots were used in this experiment. The pots were laid out in the screen house according to design assigned. The size of the pots was 26 cm in height, 30 cm diameter at the top and 21.3 cm at the bottom. The screen house was covered with transparent polyethylene sheet in order to enter sunlight easily into the screen house and to prevent further rainfall. The collected soil was well pulverized and dried in the shade and then passed with 2 mm sieve. The 11.20 kg of soil was filled into plastic pot of 28 cm diameter to a depth of 20 cm. Under puddle condition, 25 day old seedlings were transplanted in each pot.

3.5 Fertilization in the Pots

Nitrogen fertilizer was applied as three equal split applications at active tillering stage, panicle initiation stage and heading stage. Phosphorus fertilizer (70 kg P_2O_5 ha^{-1}) was used as basal. The potassium fertilizer in the form of murate of potash (120 kg K_2O ha^{-1}) was used in three split application at tillering stage, panicle initiation stage and heading stage.

3.6 Measurement of Irrigation Water

Irrigations in pot by using measuring cylinder were done for the treatments that were needed for irrigation. The 5 cm depth of water was maintained throughout the crop growing period for continuous flooding (CF) treatments. For alternate wetting and drying (AWD) treatments, 5 cm depth of water was applied when the water levels of that treatment were 5 cm below the soil surface. For alternate wetting and drying in the vegetative phase (AWDv) treatments, 5 cm depth of water was applied when the water levels of that treatment were 5 cm below the soil surface at vegetative phase and then 5 cm depth of water was maintained until maturity. The amount of water that was applied to each treatment was recorded. Water use efficiency (WUE) was calculated according to Boutraa (2011).

$$\text{WUE (kg mm}^{-1}\text{)} = \frac{\text{Crop yield (usually the economic yield)}}{\text{Water used to produce yield}}$$

3.7 Measurement Parameters for Growth

Growth parameter such as plant height and number of tillers hill^{-1} was recorded one week interval. Plant height was measured from the surface of the soil to the tip of the topmost leaf. The number of tillers hill^{-1}, was recorded until the heading stage. For dry matter production (DMP), plant samples were taken after harvesting, shade dried and then in an oven at 65°C ± 5°C for 48 hours. After that, the oven dry weight was used and computed for dry matter production.

3.8 Measurement Parameters for Yield and Yield Components

The number of panicles hill^{-1}, effective tillers hill^{-1}, uneffective tillers hill^{-1}, spikelets number panicle^{-1}, filled grain %, unfilled grain % and 1000 grain weight were measured at harvest. The grain was harvested from the pot area and hand threshed, winnowed and sun dried. The dried grains from each treatment were weighted and computed to g plant^{-1}.

3.9 Care and Management

Hand weeding was done whenever it was needed in both seasons. Although there was no insect pest damage in the dry season, the incidence of brown plant hopper was found in the wet season. Therefore, Carsumin and Dimethoate were used for the prevention of brown plant hoppers incidence.

3.10 Calculation

Economic analysis for dry and wet seasons was performed as calculation of benefit cost ratio.

$$\text{Benefit-Cost ratio} = \frac{\text{Gross return (Yield} \times \text{Price)}}{\text{Total variable cost}}$$

3.11 Weather Data

All weather data for both seasons were obtained from meteorological station at Department of Agricultural Research in Yezin (Appendix 3).

3.12 Statistical Analysis

The collected data were analyzed by using GenStat (9^{th} edition). Mean comparison was performed by using least significant differences (LSD) at 5 % level. Excel program was utilized for regression analysis.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Experiment I (dry season, 2012)

This experiment was conducted to compare the effect of different water regimes and nitrogen levels on the performance of rice during dry season from February to June.

4.1.1 Effect of water regimes and nitrogen levels on growth parameter and yield and yield components of hybrid rice

4.1.1.1 Plant height (cm)

The data on plant height at 14, 21, 28, 35, 42, 49, 56 and 63 days after transplanting (DAT) were presented in (Figure 4.1). The plant height in all treatments increased continuously from 14 DAT to 63 DAT. There was highly significant difference in plant height among the different water regimes at 14 DAT, 56 DAT and 63 DAT.

At 14 DAT, the plant height was varied from 25.59 cm to 23.34 cm and the maximum value of plant height was observed in CF irrigation among different water regimes. At 56 DAT and 63 DAT, the highest plant height values (86.92 cm and 95.25 cm) were also recorded in AWD irrigation and the lowest values (81.51cm and 89.79 cm) in CF irrigation (Appendix 5). The result agreed with the finding of Maragatham et al. (2010) who observed the plant height of hybrid rice was comparatively higher under the alternate wetting and drying rice cultivation method.

The plant height was not significantly different from nitrogen levels at 14, 21, 28, 35, 42, 56 and 63 DAT (Figure 4.2). The greater plant heights were recorded from N_3 (150 kg N ha^{-1}) and N_4 (225 kg N ha^{-1}). It can be a positive effect of nitrogen on plant height by Reddy et al. (1988). Manzoor et al. (2006) reported that the increase in plant height with increased N application might be primarily due to enhanced vegetative growth with more nitrogen supply to plant. There was no interaction effect on plant height by different water regimes with nitrogen levels at all growth stages.

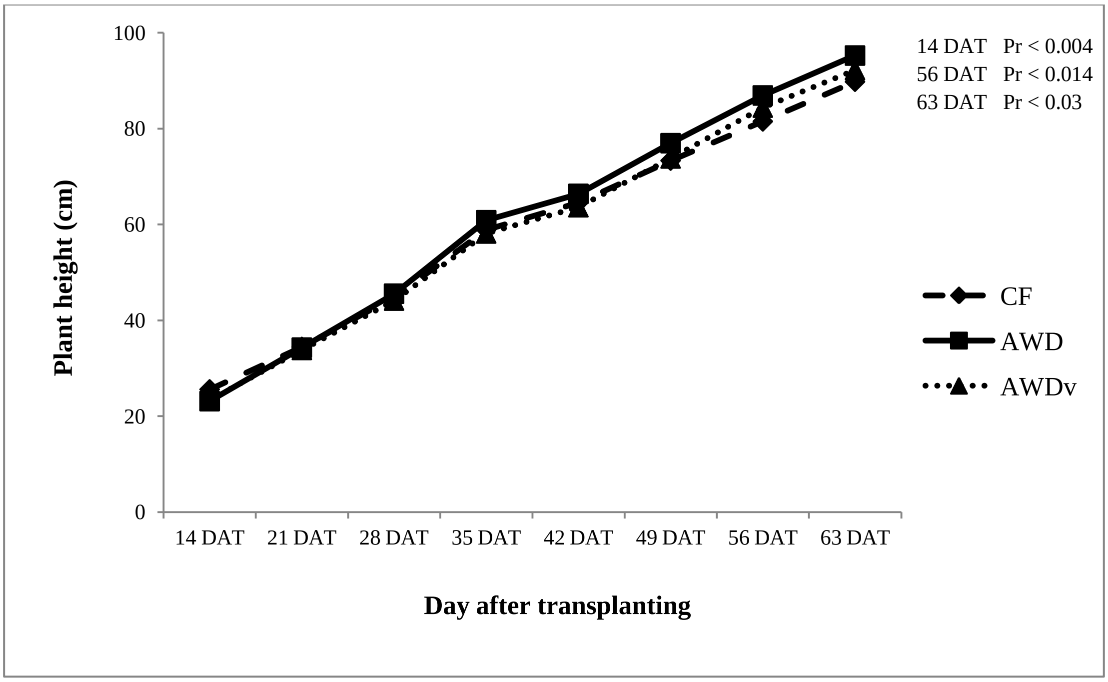

Figure 4.1 Mean value of plant height as affected by different water regimes during the dry season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

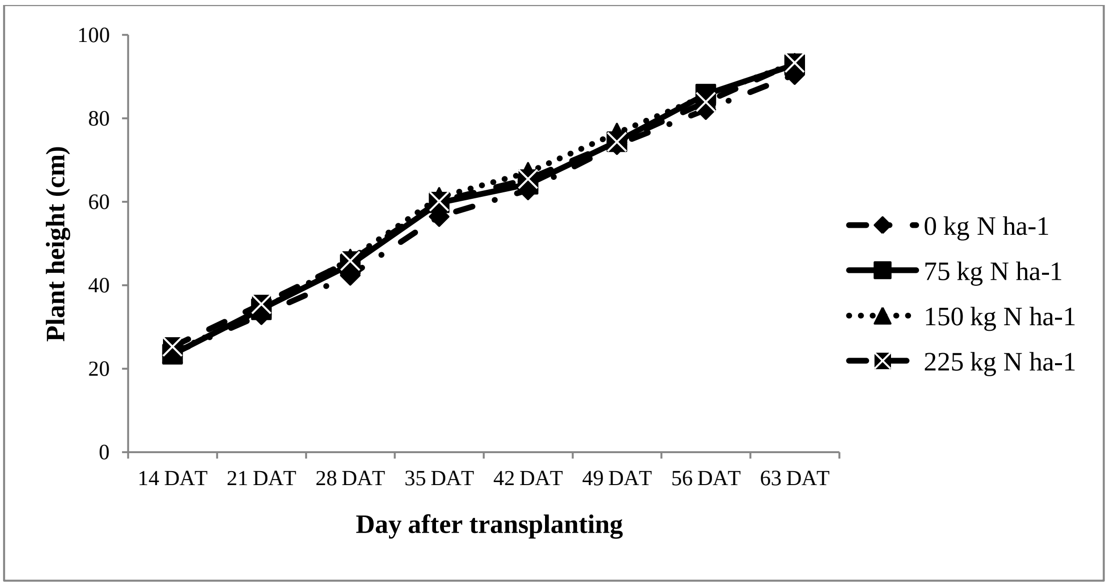

Figure 4.2 Mean value of plant height as affected by different nitrogen levels during the dry season, 2012

4.1.1.2 Number of tillers hill^{-1}

Figure (4.3) shows mean value of number of tillers hill^{-1} as affected by different water regimes during the dry season of 2012. According to the results, the number of tillers hill^{-1} at 49, 56 and 63 days after transplanting (DAT) as affected by different water regimes were highly significantly different at 1 % level but the beginning days were not different at 0.05. The highest number of tillers hill^{-1} (15.56, 21.62, and 23.81) at 49 DAT, 56 DAT, and 63 DAT were recorded from the alternate wetting drying (AWD) of irrigation regimes and the lowest number (9.84, 12.38 and 14.19) were obtained from the continuous flooding (CF) (Appendix 6). It was agreed to the results of Nyamai et al. (2012). This report proved the improved rice tiller growth with alternate flooding and drying as compared to continuous flooding.

Effect of different nitrogen levels on numbers of tillers hill^{-1} was shown in figure (4.4). Significant effect at 5% level was observed in only 56 DAT. Among the different applied nitrogen levels, N_3 (150 kg N ha^{-1}) gave the highest number of tillers hill^{-1} (19.46) and N_1 (control) gave the lowest one (14.17) (Appendix 6). Similarly, YosefTabar (2012) observed that 150 kg ha^{-1} nitrogen treatment gave the maximum tillers (27.6). Number of tillers per unit area is the most important component of yield. The more the number of tillers, especially fertile tillers, the more will be the yield. No interaction effect of different water regimes and nitrogen levels was observed in this result.

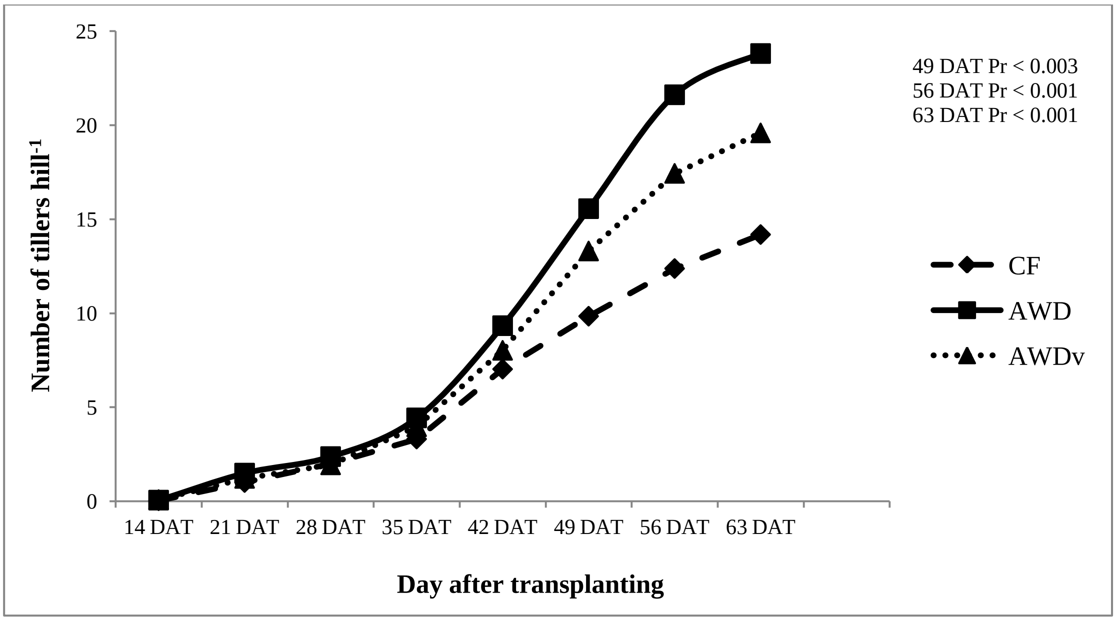

Figure 4.3 Mean value of number of tillers hill^{-1} as affected by different water regimes during the dry season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

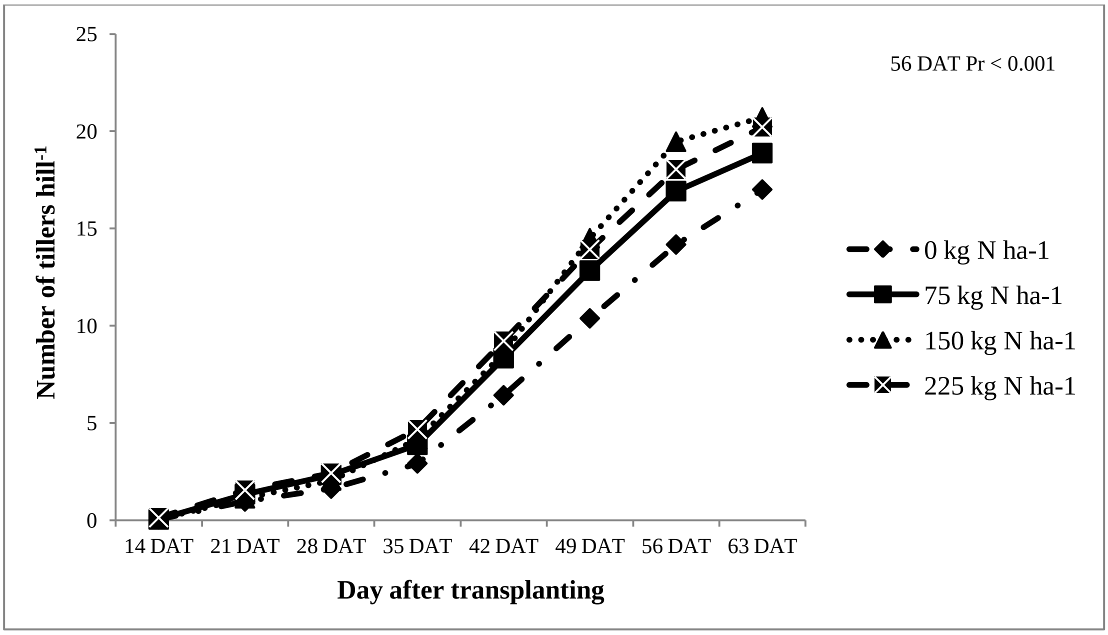

Figure 4.4 Mean value of number of tillers hill^{-1} as affected by different nitrogen levels during the dry season, 2012

4.1.1.3 Number of panicles hill^{-1}

The number of panicles hill^{-1} at harvest was shown in (Table 4.1). Effect of water regimes on panicles number hill^{-1} was statistically significant at 1% level. The greater number of panicle hill^{-1}(17.25) was counted from alternate wetting and drying (AWD) than alternate wetting and drying at vegetative stage (AWDv) which had the less number of panicles hill^{-1}(15.06). Continuous flooding (CF) produced the least number of panicle hill^{-1}(12.69). Similarly, Amod et al. (2011) found that the number of panicles per unit area was also significantly higher under AWD than CF irrigation. There was significant difference in the number of panicles m^{-2} due to AWD irrigation (Nyamai et al. 2012). The lower number of panicle^{-1} in CF was observed that indicates continuous flooding depressed the active tillers during vegetative stage.

Although there was no significant effect on number of panicles hill^{-1} among the application of different nitrogen levels, the maximum number of panicles hill^{-1} (15.83) was observed in N_4 (225 kg N ha^{-1}), and then followed by N_3 (150 kg N ha^{-1}) which had (15.33) panicle hill^{-1} and the minimum number (14.00) was obtained from N_1 (control). The present result explained the increase in application rates of nitrogen increased the number of panicles hill^{-1}. Similarly, Dobermann and Fairhurst (2000) also stated that nitrogen increases panicles number, spikelets number panicle^{-1} and filled spikelets.

The interaction between different water regimes and nitrogen levels was not observed in this parameter, number of panicle hill^{-1}. This result was agreed to Ethan et al. (2012) that water management did not interact significantly with nitrogen rates to influence panicles number.

4.1.1.4 Number of spikelets panicle^{-1}

The statistical result of number of spikelets panicle^{-1}, one of the yield component parameters by different water regimes and nitrogen levels, was presented in (Table 4.1). In general, the number of spikelets panicle^{-1} is more or less directly correlated with rice grain yield.

There was a highly significant difference in numbers of spikelets panicle^{-1} due to different water regimes at 1 % level. It was recorded the highest number of spikelets panicle^{-1} (189.1) in AWDv irrigation which was significantly different from CF irrigation (176.4), but not significantly different from AWD (187.8). According to the result, it can be suggested that water supply in AWDv is more sufficient for rice cultivation to get maximum number of spikelets panicle^{-1} than other water management practices. Although there was no significant difference in number of spikelets panicle^{-1} among the different irrigation method, the maximum number of spikelets panicle^{-1} was obtained from intermittent irrigation (Wardana et al. 2010).

There was no significant difference in number of spikelets panicle^{-1} among the different nitrogen levels. The maximum number of spikelets panicle^{-1} was obtained from N_4 (225 kg N ha^{-1}). Manzoor et al. (2006) noted that the highest numbers of spikelets panicle^{-1} were resulted at nitrogen levels of 175 kg ha^{-1} which remained statistically at par with obtained by nitrogen application levels between 125 to 225 kg ha^{-1}. The more number of grains panicle^{-1} was obtained in treatments receiving higher nitrogen levels than in treatments with lower and little nitrogen levels throughout the growing period. There was no significant difference on number of spikelets panicle^{-1} of different water regimes and nitrogen levels.

4.1.1.5 1,000 grain weight (g)

There was significant difference in 1,000 grain weight (g) due to the responses of different water regimes (Table 4.1). It can be noted that the alternate wetting and drying (AWD) irrigation produced the highest 1,000 grain weight (23.64 g) and it was significantly higher than AWDv (22.98 g) and CF (22.50 g) water regimes. Similarly, Amod et al. (2011) stated that 1,000 grain weight was also significantly higher in AWD irrigation plants than CF irrigation plants.

In different nitrogen levels, there had no significant effect on 1,000 grain weight (g) of hybrid rice. The maximum 1,000 grain weight (23.30 g) was produced by N_2 (75 kg N ha^{-1}) which was not significantly different from N_3 (150 kg N ha^{-1}), N_4 (225 kg N ha^{-1}) and N_1 (control). Shivay and Singh (2003) confirmed this finding by stating that no significant difference was found in 1,000 grain weight due to the application of nitrogen. However, the individual grain weight is usually a stable varietal character and the management practice has less effect on its variation (Yoshida 1981). Islam et al. (2008) reported weight of 1,000 grain of rice was not significantly influenced by N level as it is mostly governed by genetic makeup of the variety. Among the yield components, 1,000 grain weight was less influenced by the treatment combinations because it is more or less genetically controlled characteristics.

4.1.1.6 Filled grain %

According to statistical result, the response of the different water regimes and nitrogen levels on filled grain percentage was presented in (Table 4.1). No significant difference in filled grain % was observed among the different water regimes. It can be pointed out that water saving techniques AWD and AWDv gave the similar filled grain % as CF. Maragatham et al. (2010) reported that filled grains were higher under alternate wetting and drying system of rice cultivation due to better aeration and microbial activity.

In this study, there was also no significant difference in filled grain % among nitrogen levels. The recorded filled grain % was found to be in the range of 81.89 to 85.46 where N_4 gave the maximum filled grain % and N_1 also gave the minimum value. Yang et al. (2008) discussed that grain filling played an important role in grain weight, which is an essential determinant of grain yield in cereal crops, and is characterized by its duration and nitrogen rate. There was no interaction effect between different water regimes and nitrogen levels on filled grain percentage.

4.1.1.7 Unfilled grain %

Table 4.1 shows the effect of different water regimes and nitrogen levels on unfilled grain %. There was no significant difference in unfilled grain % among the different water regimes.

Unfilled grain % was not also affected by different nitrogen levels. Here it can be noted that the maximum unfilled grain % was produced by N_1 (control) and the minimum was by N_4 (225 kg N ha^{-1}). Interaction effect between different water regimes and nitrogen levels was not found on unfilled grain %.

4.1.1.8 Grain yield (g $plant^{-1}$)

According to the dry season results, grain yields as affected by different water regimes and different nitrogen levels were presented in (Table 4.1). It can be clearly seen that there were highly significantly differences on grain yield of hybrid rice due to different water regimes and different nitrogen levels at 1% level. Among the different water regime, the highest grain yield (52.5 g $plant^{-1}$) was produced by alternate wetting and drying (AWD) treatment. Alternate wetting and drying in the vegetative phase followed by continuous flooding until maturity (AWDv) gave the second highest yield (46.4 g $plant^{-1}$). The lowest grain yield (39.2 g $plant^{-1}$) was resulted in continuous flooding (CF) treatment. The yield of AWD was 34% higher than that of CF and 13 % higher than that of AWDv respectively. It proved that there was no need of continuous flooding throughout the growing season of hybrid rice production. Bhuiyan and Tuong (1995) support the finding of a standing depth of water throughout the season that is not needed for high rice yields.

Among the nitrogen application treatments, the maximum grain yield (50.9 g plant^{-1}) was obtained in N_4 (225 kg N ha^{-1}) which was not significantly different form N_3 (150 kg N ha^{-1}) (49.0 g plant^{-1}). N_1 (control) and N_2 (75 kg N ha^{-1}) produced minimum grain yields. At N_4 (225 kg N ha^{-1}), grain yield was 31 % greater than control, 13 % greater than N_2 (75 kg N ha^{-1}) and 4 % greater than N_3 (150 kg N ha^{-1}) for dry season. These results are in agreement with those obtained by Dastan et al. (2012); Kanade and Kalra (1986). Spanu and Pruneddu (1997) reported a highest paddy yield by nitrogen application of 250 kg ha^{-1} for hybrid rice production. Ahmad et al. (2005) also concluded that higher N rates with higher seedling density enhanced the number of tillers that directly contribute to the rice grain yield. Therefore, this rate may be suitable for hybrid rice production. However, according to the benefit cost ratio N_2 (75 kg N ha^{-1}) is an optimum rate for hybrid rice production during dry season (Table 4.5).

Although there was no interaction effect between water regimes and nitrogen levels, the maximum grain yield was observed at N_4 (225 kg N ha^{-1}) nitrogen levels under alternate wetting and drying (AWD) irrigation.

Table 4.1 Yield and yield components as affected by different water regimes and nitrogen levels in rice during dry seasons 2012

Treatments	No. of panicles $hill^{-1}$	No. of spikelets $panicle^{-1}$	1,000 grain weight (g)	Filled grain %	Unfilled grain %	Grain yield (g $plant^{-1}$)
Water regimes						
CF	12.69 c	176.4 b	22.50 b	84.89	15.11	39.2 c
AWD	17.25 a	187.8 a	23.64 a	84.09	15.91	52.5 a
AWDv	15.06 b	189.1 a	22.98 ab	82.81	17.19	46.4 b
$LSD_{0.05}$	1.59	7.89	0.86	3.25	3.25	5.72
Nitrogen levels						
0 kg N ha^{-1}	14.00	183.5	22.84	81.89	18.11	39.0 c
75 kg N ha^{-1}	14.83	181.7	23.30	83.93	16.07	45.2 ab
150 kg N ha^{-1}	15.33	182.9	23.05	84.43	15.56	49.0 a
225 kg N ha^{-1}	15.83	189.6	22.97	85.46	14.54	50.9 a
$LSD_{0.05}$	1.83	9.11	0.99	3.76	3.76	6.60
Pr>F						
Water regimes	<0.001	<0.004	<0.03	0.43	0.43	<0.001
Nitrogen levels	0.23	0.31	0.81	0.29	0.29	<0.004
Water x Nitrogen	0.73	0.52	0.35	0.73	0.73	0.47
CV %	14.7	6.0	5.2	2.4	28.2	17.3

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

4.1.1.9 Dry matter production (g)

Responses of dry matter production from different water regimes were shown in (Table 4.2). In this study, dry matter production in different water regimes was highly significantly different at 1% level. The highest dry matter production (70.8 g) was resulted from AWD irrigation and the lowest (50.0 g) from CF irrigation. Zhang et al. (2010) reported that 6.6% increase in above ground biomass yield with alternate wetting and drying compared to continuous flooding. Maragatham et al. (2010) reported that dry matter productions of hybrid rice were comparatively higher under the alternate wetting and drying rice cultivation method. In addition, AWDv irrigation treatment will save more water than CF to produce dry matter.

The highly significant difference in dry matter production was observed in different nitrogen levels. Maximum dry matter (64.9 g) was obtained from N_4 (225 kg N ha^{-1}) which was not statistically different from N_3 (150 kg N ha^{-1}) whereas N_1 (control) gave the minimum dry matter (53.4 g). Chaturvedi (2005) reported that dry matter accumulation increased significantly with N-fertilizer application in rice at all growth stages of the crop. There was no interaction effect between different water regimes and nitrogen levels for dry matter production.

Table 4.2 Effect of different water regimes and nitrogen levels on dry matter production during dry season, 2012

Treatments	Dry matter production (g)
<u>Water regimes</u>	
CF	50.0 c
AWD	70.8 a
AWDv	61.1 b
$LSD_{0.05}$	6.25
<u>Nitrogen levels</u>	
0 kg N ha^{-1}	53.4 b
75 kg N ha^{-1}	60.1 ab
150 kg N ha^{-1}	64.3 a
225 kg N ha^{-1}	64.9 a
$LSD_{0.05}$	7.21
Pr>F	
Water regimes	<0.001
Nitrogen levels	<0.009
Water x Nitrogen	0.36
CV %	14.4

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

4.1.2 Total water use (mm)

Results of the total water use were presented in (Figure 4.5). In this study, there was a highly significantly difference in total water use among the different water regimes at 1% level. Among the treatments, rice grown under AWD irrigation consumed the largest amount of water. The highest total water use was recorded in AWD (2057 mm), the lower total water use was occurred in AWDv (1920 mm) and the lowest was in CF (1761 mm) respectively. Under the dry season the higher evapotranspiration was associated with AWD and AWDv. Chapagian and Riseman (2011) reported that the highest quantity of water was saved in the AWD irrigation plot during dry period.

Although effect of different nitrogen levels on total water use was not statistically different (Figure 4.6), the highest total water use was found in N_4 (225 kg N ha^{-1}) and the lowest in N_1 (control). It means that rice grown under dry season can absorbed more nutrient together with water and required more water for higher nitrogen levels application. No interaction effect of different water regimes and nitrogen levels was observed on total water use of hybrid rice.

This study points out that no water saving for AWD and AWDv was not observed in the dry season and more water was used 17 % in AWD and 9 % in AWDv when compared with CF. It can probably be that more tillers and more dry matter production of hybrid rice in AWD would require more water in this pot experiment during dry season than others. However, Bouman (2001) reported that AWD practices resulted in both water savings and yield losses of 0 - 70% compared with flooded treatments, depending on the number of days between irrigation and existing soil condition.

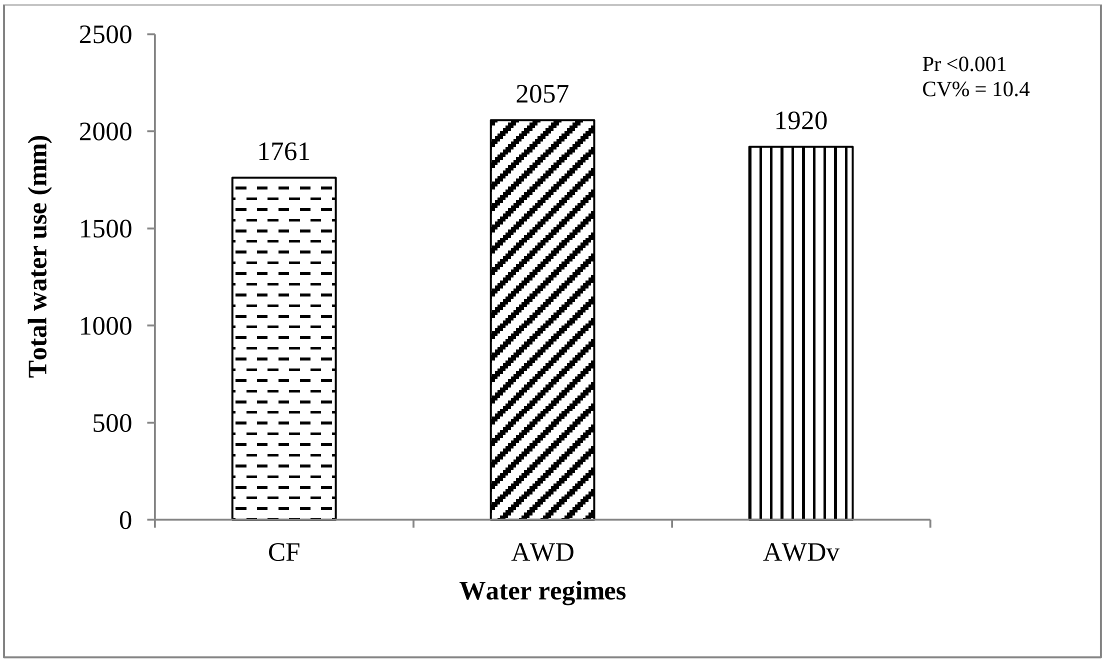

Figure 4.5 Mean value of total water use as affected by different water regimes during the dry season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

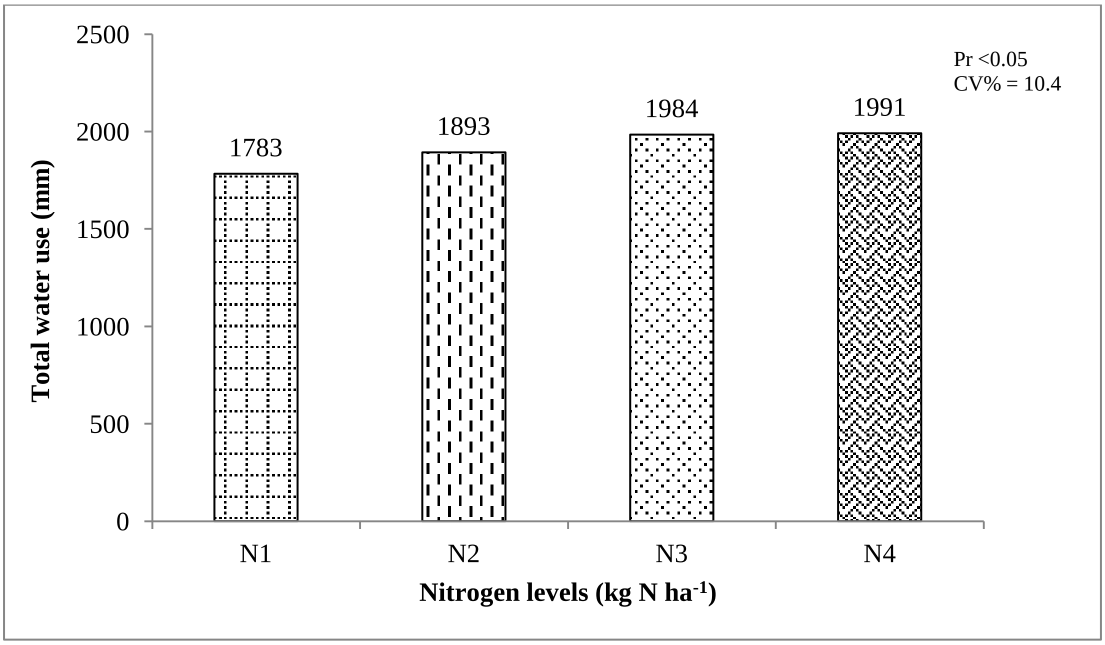

Figure 4.6 Mean value of total water use as affected by different nitrogen levels during the dry season, 2012

4.1.3 Water Use Efficiency (WUE) (kg mm^{-1})

Water use efficiency (kg mm^{-1}) is an indicator commonly used to evaluate the performance of an irrigation system. It is also determined to evaluate the benefit of applied water through economic crop production. WUE for crop is the ratio of the amount of economic yield of desirable crop to the amount of water used by the crop. WUE of hybrid rice as affected by different water regimes was shown in (Figure 4.7).

From the research outcomes, a significant difference at 5 % level was remarked among different water regimes. The highest WUE value (12.72 kg mm^{-1}) was observed in AWD irrigation treatment where CF irrigation was resulted in the lowest WUE value (11.12 kg mm^{-1}). Hatfield et al. (2001) proposed that AWD received higher WUE than CF was due to the decrease in water input. However, this result in pot experiment during dry season proved that WUE in AWD was higher than that of CF and AWDv due to the application of higher input of water enhancing the highest economic grain yield. These results suggested that intermittent irrigation is a suitable way to increase water use efficiency without decreasing yield at the same time. Ramakrishna et al. (2007) reported that maximum irrigation water use efficiency and field water use efficiency were obtained with 3 days drainage followed by 1 day drainage and the least with continuous water submergence in rice.

Effect of different nitrogen levels on WUE was shown in (Figure 4.8). Among the different nitrogen levels, significance was also remarkable at 5 % level. The maximum WUE value (12.64 kg mm^{-1}) was observed from N_4 (225 kg N ha^{-1}) and the minimum WUE value (10.93 kg mm^{-1}) was from N_1 (control). WUE value obtained from N_3 (150 kg N ha^{-1}) and N_2 (75 kg N ha^{-1}) were not different each other. Kibe and Singh (2003) stated that water use efficiency of wheat was increased with addition of N fertilizer to a maximum with 100 kg N ha^{-1}. As the same way, the results showed WUE of hybrid rice increased with increase in application of nitrogen fertilizer. It was observed that there was no interaction between different water regimes and nitrogen levels.

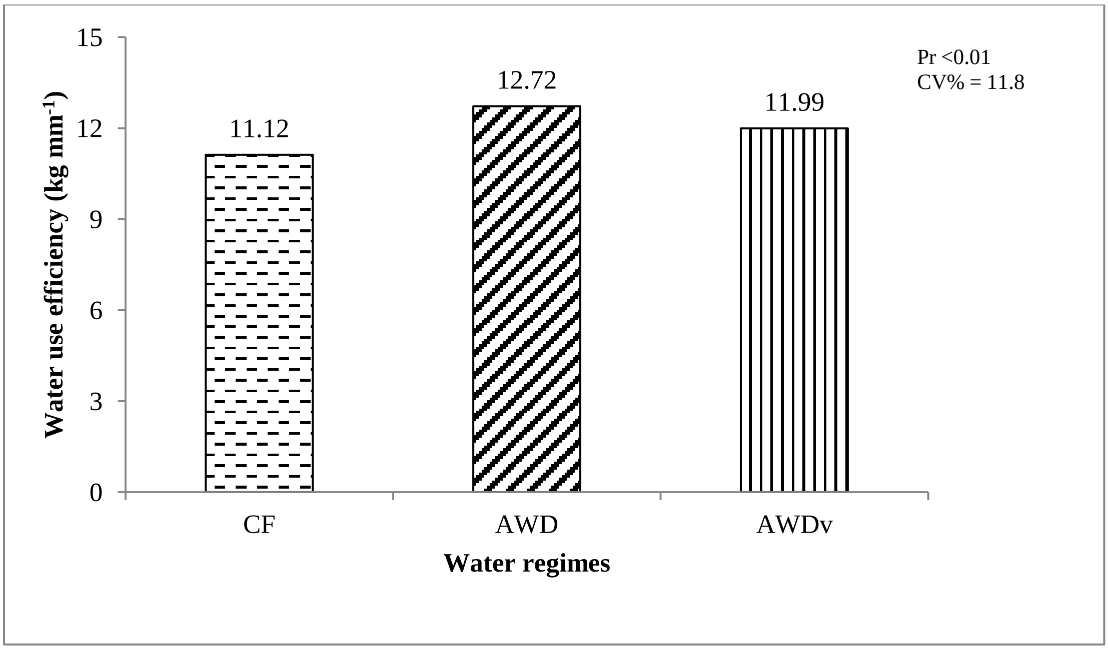

Figure 4.7 Mean value of water use efficiency as affected by different water regimes during the dry season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

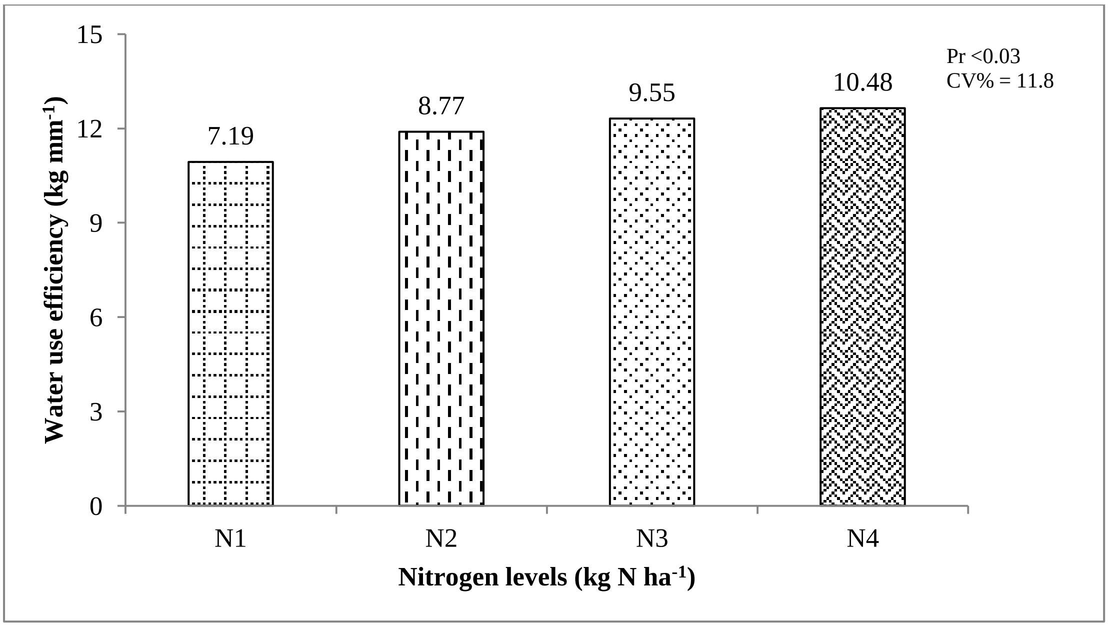

Figure 4.8 Mean value of water use efficiency as affected by different nitrogen levels during the dry season, 2012

4.1.4 Relationship between hybrid rice yield and nitrogen application levels

The positive linear correlation was observed between hybrid rice yield and nitrogen application levels (R^2= 0.9451) in dry season as shown in Figure 4.9. Yields were significantly increased by increasing nitrogen levels. According to nitrogen application levels, the linear regression equation (indicated that hybrid rice yield increased at a rate of 20.75 kg ha^{-1} with an increasing application rate of 1 kg N ha^{-1}in the range of 0 to 225 kg N ha^{-1}. Hence, about 95% variability in grain yield was due to nitrogen levels. Peng-fei et al. (2012) reported that the relation between nitrogen application and yield showed a positive linear correlation within the experimental range, the yield increased 0.5963 kg for each additional 1 kg of the nitrogen application rate, (y= 0.5963x + 5901.5; R= 0.9709).

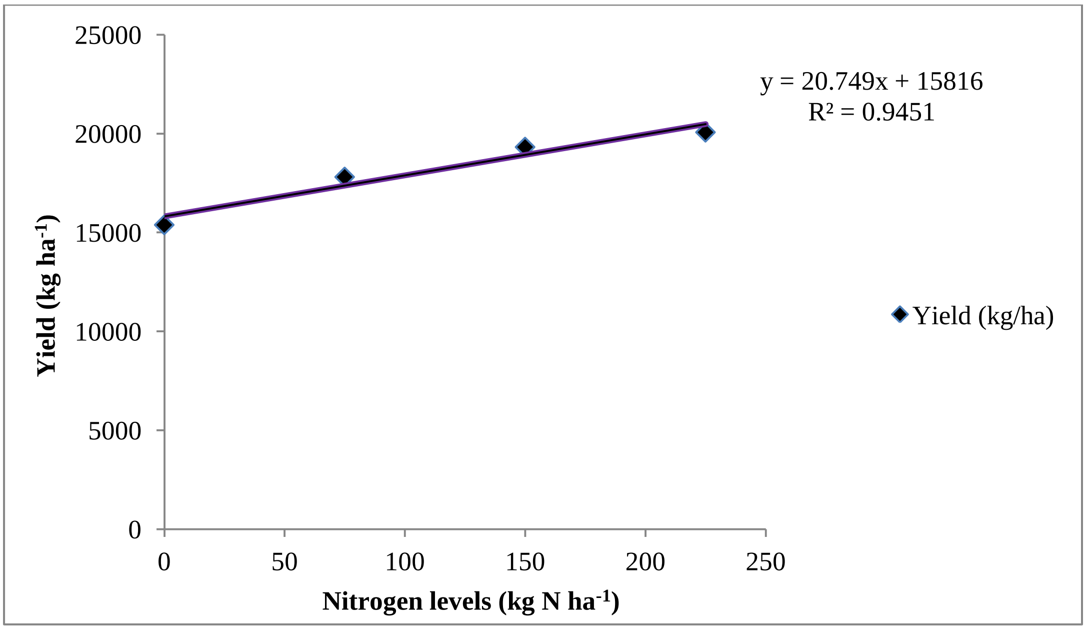

Figure 4.9 Relationship between hybrid rice yield and nitrogen application levels in the dry season, 2012

4.2 Experiment II (wet season, 2012)

This experiment was conducted as the same layout of experiment I to compare the effect of different water regimes and nitrogen levels on the performance of hybrid rice during wet season from July 2012 to October 2012.

4.2.1 Effect of water regimes and nitrogen levels on growth parameter and yield and yield components of hybrid rice

4.2.1.1 Plant height (cm)

Plant height at 14, 21, 28, 35, 42, 49, 56 and 63 days after transplanting (DAT) were presented in Figure 4.10. The plant height in all treatments increased continuously from 14 DAT to 63 DAT. Significant difference was resulted among the different water regimes in 14, 21, 28, 35 DAT at 1 % level and 49 DAT at 5% level. CF irrigation produced the highest plant height at 14, 21, 28, 35 and 49 DAT (Appendix 7). CF irrigation was significantly better than AWD and AWDv. Continuous flooding treatment increased plant height which ultimately resulted in increasing photosynthesis and that reflected the increase in all metabolisms in the plant which led to an increase in grain yield and most of its components (Harbir et al. 1991; Marazi et al. 1993; Awad .2001).

The plant height was not significantly affected by different nitrogen levels at 14, 21, 28, 35, 42, 49, 56 and 63 DAT (Figure 4.11). At 49 DAT the maximum plant height (89.62) got in N_4 (225 kg N ha^{-1}) (Appendix 7). These results corroborated with findings by Fageria and Baligar (2001); Sahrawat (2005) who observed increase in plant height with increase in nitrogen rate. Singh and Sharma (1987); Maqsood (1998); Meena et al. (2003) reported that application of 180 kg N ha^{-1} resulted in higher plant height of rice. Therefore, it can be assumed that the increase in plant height with increased N application might be primarily due to enhanced vegetative growth with more nitrogen supply to plant. The interaction between different water regimes and nitrogen levels was not found in this parameter, plant height.

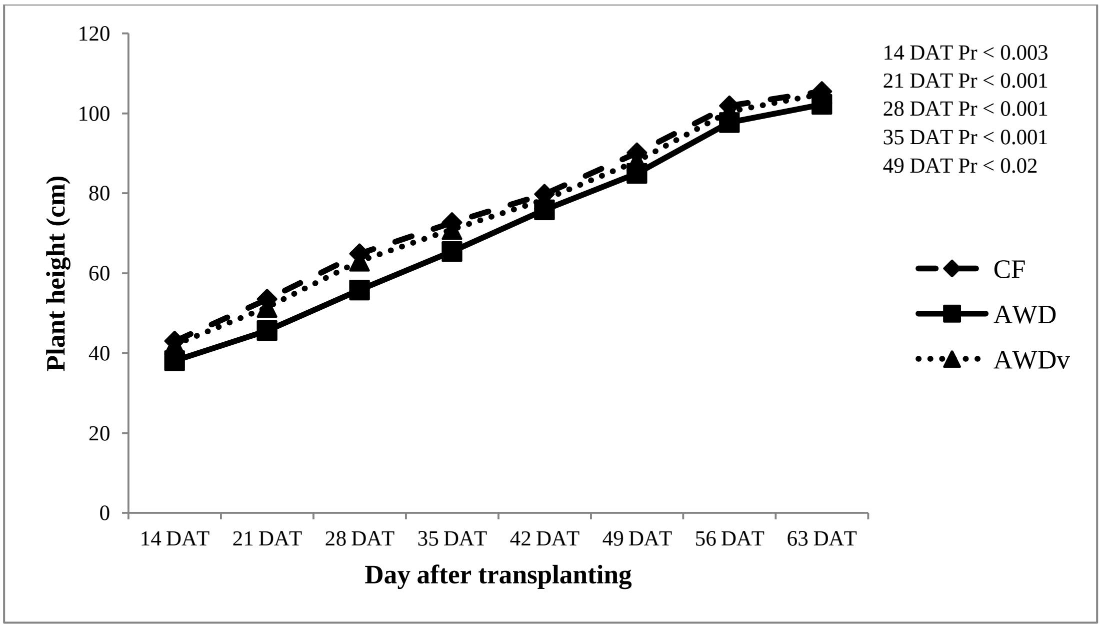

Figure 4.10 Mean value of plant height as affected by different water regimes during the wet season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

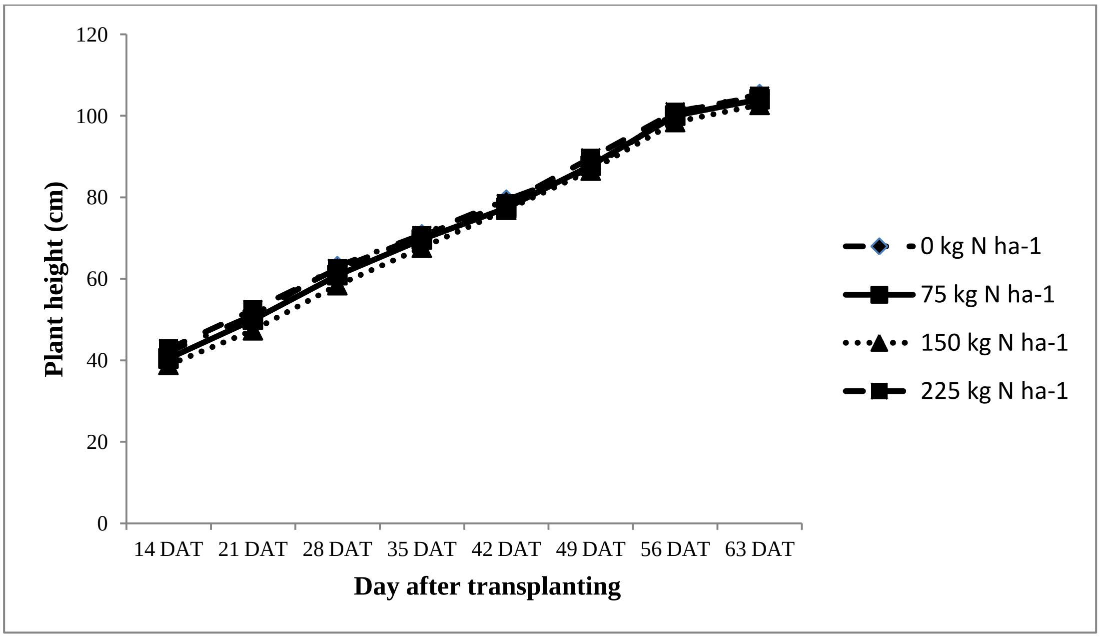

Figure 4.11 Mean value of plant height as affected by different nitrogen levels during the wet season, 2012

4.2.1.2 Number of tillers hill^{-1}

Number of tillers per unit area is the most important component of yield. In this experiment, the number of tillers hill^{-1} of hybrid rice at 14, 21, 28, 35, 42, 49, 56 and 63 DAT were presented in figure 4.12. The significant difference in number of tillers hill^{-1} was observed among different water regimes at 21, 28, 35, 42 and 49 DAT at 5 % and 1 % levels of significance respectively. At 21 DAT, CF irrigation gave the highest number of tillers hill^{-1} and the lowest from AWD irrigation. The maximum number of tillers hill^{-1} (3.09, 4.06, 4.59 and 5.69) was produced from AWDv irrigation at 28, 35, 42 and 49 DAT but these results were not so different from CF irrigation. Minimum number was observed from AWD irrigation at 28, 35, 42 and 49 DAT (Appendix 8). However, Zulkarnain et al. (2009) reported that the more tillers were observed under continuous flooding.

Effect of different nitrogen levels on number of tillers hill^{-1} of hybrid rice was shown in figure 4.13. In this study there was no statistically difference among nitrogen levels at 0.05. At 63 DAT increased nitrogen supply to plant at active tillering stage enhanced tillering. Moreover it was observed that there was a similar tiller-producing trend in this study as Yuan and Fu (1995). In their report, the fast growth of tiller in the vegetable stage and the maintenance of strong tillering ability until heading appeared to be characteristics of F_1 rice hybrid. The present study clearly demonstrated that there was no interaction effect between different water regimes and nitrogen levels on number of tillers hill^{-1}.

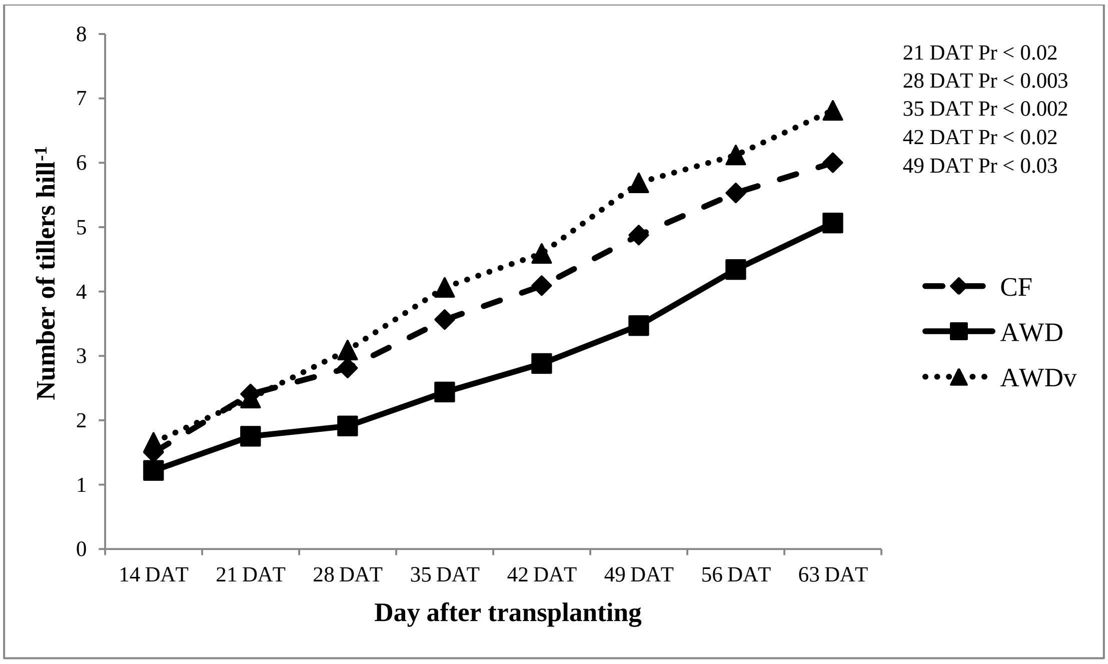

Figure 4.12 Mean value of number of tiller hill^{-1} as affected by different water regimes during the wet season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

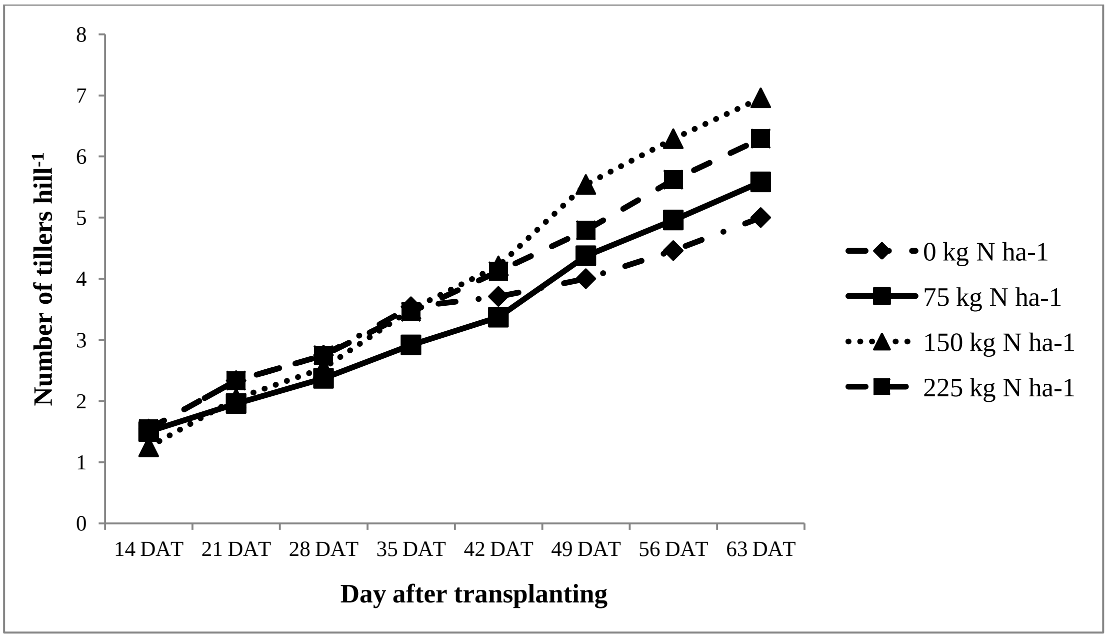

Figure 4.13 Mean value of number of tillers hill^{-1} as affected by different nitrogen levels during the wet season, 2012

4.2.1.3 Number of panicles hill^{-1}

Table 4.3 demonstrated that effect of different water regimes and nitrogen levels on the number of panicles hill^{-1}. Number of panicles hill^{-1} had a significant response to different water regimes at 5% level. Mean value of number of panicles hill^{-1} ranged from 4.31 to 5.47. Among the different water regimes, AWDv irrigation gave the highest number of panicles hill^{-1} (5.47) which was not significantly different from CF irrigation. The lowest number of panicles hill^{-1} (4.31) was found in AWD irrigation.

Number of panicles hill^{-1} was significant affected by different nitrogen levels at 5 % was shown in (Table 4.3). The number of panicles hill^{-1} due to the effect of nitrogen levels was in the range of 4.00 to 5.67. The highest result (5.67) was obtained from N_3 (150 kg N ha^{-1}) which was similar to N_4 (225 kg N ha^{-1}). The lowest number of panicles hill^{-1} (4.00) was collected from N_1 (control). Therefore, the nitrogen application levels (150 kg N ha^{-1}) might be the appropriate levels to produce the more number of panicle hill^{-1} for rice production. There was no interaction for number of panicles hill^{-1} between different water regimes and nitrogen levels.

4.2.1.4 Number of spikelets panicle^{-1}

The statistical result of number of spikelets panicle^{-1} was presented in (Table 4.3). There was no statistically difference among the treatment of different water regimes on number of spikelets panicle^{-1}. Although AWDv irrigation had more spikelets panicle^{-1} than in other treatments; it was not significantly different from these. In the report of Oliver et al. (2008), it was stated that the maximum number of spikelet panicles^{-1} was produced in continuous flooding (CF).

Among the nitrogen levels, no significant difference in number of spikelets panicle^{-1} was observed in the present study. Maximum number of spikelets panicle^{-1} (170.7) was obtained in N_3 (150 kg N ha^{-1}) and it was not significantly different from other three nitrogen levels. In the paper of Abou-Khalifa (2012), it was observed that 220 kg N ha^{-1} gave the highest number of spikelets panicle^{-1}. There was no interaction between different water regimes and nitrogen levels.

4.2.1.5 1,000 grain weight (g)

The data analysis showed that, no significant difference among the treatment was found for 1,000 grain weight (Table 4.3). The effect of different water regimes on

1,000 grain weight was not significantly different with each other. AWD irrigation gave the maximum 1,000 grain weight. The result agreed with the finding of Oliver et al. (2008) who observed the maximum 1,000 grain weight was observed by alternate wetting and drying irrigation stood for on application of 5 cm irrigation water when water level in the pipe fell 20 cm below the soil surface.

1,000 grain weight had no significant different response to different nitrogen levels in this experiment. The maximum 1,000 grain weight was obtained with N_4 (225 kg N ha^{-1}) which was statistically similar with other water regimes. Increase in grain weight at higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development. The result agreed with Huossinzade et al. (2011) and Wilson et al. (1996) findings. In their report the nitrogen fertilizer treatments do not showed any significant effect on 1,000 grain weight which is a genetical character fixed by an individual variety. No interaction effect was observed between different water regimes and nitrogen levels on 1,000 grain weight.

4.2.1.6 Filled grain %

The response of filled grain % to the water regimes and nitrogen levels was clearly demonstrated in (Table 4.3). The result was similar to dry season one and no significant difference in filled grain % was found among the different water regimes. The maximum filled grain % was obtained from AWD water regime but not statistically different among the water regimes. Similar results of Zhang et al. (2010) and Thakur et al. (2011) proved that the filled grains % significantly increased under alternate wetting and drying condition as compared to under continuous flooding.

The statistical result showed filled grain % of different nitrogen levels at 5 % levels of significance. The filled grain % of N_4 (225 kg N ha^{-1}) was significantly superior to other treatments. Alagesan and Babu (2011) found that levels of N and time of application manifested favorable effect on the number of filled grain $panicle^{-1}$ during the periods of study large number of filled grain in a panicle was recorded with the application of 160 kg N ha^{-1}.

There was no significant difference among the combination effect of the water regimes and nitrogen levels on filled grain %.

4.2.1.7 Unfilled grain %

The analysis of variance in Table 4.3 shows the effects of different water regimes on unfilled grain % was not significant. The maximum unfilled grain % (17.0) was observed from AWDv irrigation and minimum (12.8) from AWD irrigation. El-Refaee et al. (2007) reported that the continuous flooding gave the highest unfilled grain %.

Unfilled grain % was not significantly affected by different nitrogen level. Although N_1 (control) gave the highest unfilled grain % (18.7) and it was not significantly higher than those of N_2, N_3 and N_4.

Interaction between different water regimes and nitrogen levels was not found in this parameter.

4.2.1.8 Grain yield (g plant^{-1})

Effect of different water regimes on grain yield of hybrid rice is given in (Table 4.3). In wet season experiment, there was no significant difference among the different water regimes. The grain yield of hybrid rice was ranged from 13.80g plant^{-1} to 15.78 g plant^{-1}. The maximum grain yield (15.78 g plant^{-1}) of hybrid rice was obtained from CF irrigation which was not significantly higher than AWD and AWDv irrigation. The yield of CF was 14% higher than that of AWD and 6 % higher than that of AWDv. Zhang et al. (2012) reported that the grain yield was not significantly different between AWD and CF irrigation in all experiment.

In the wet season experiment, there was significant difference among the different nitrogen levels at 5% level (Table 4.3). The highest grain yield of hybrid rice (16.24 g plant^{-1}) was recorded from N_4 (225 kg N ha^{-1}) which was not significantly superior to N_3 (150 kg N ha^{-1}) (15.3 g plant^{-1}). The lowest grain yield was observed from N_1 (0 kg N ha^{-1}). The yield of N_4 (225 kg N ha^{-1}) was 23 % greater than control, 12 % greater than N_2 (75 kg N ha^{-1}) and 6 % greater than N_3 (150 kg N ha^{-1}) for wet season. Therefore, grain yield of rice was increased with increasing application of nitrogen fertilizer in our study. However, Singh et al. (1996) reported that the highest paddy yield in 150 to 200 kg ha^{-1} nitrogen fertilizer in Philippine. Hollena et al. (2008) showed that the highest grain yield production was 8.53 t ha^{-1} under maximum nitrogen application at 240 kg ha^{-1}. Base on benefit cost ratio, the optimum rate of nitrogen fertilizer for hybrid rice production is N_2 (75 kg N ha^{-1}) in wet season (Table 4.5).

The combination of different water regimes and nitrogen levels had no significant difference in grain yield of hybrid rice. However, the maximum yield was obtained from the treatment of continuous flooding with N_4 (225 kg N ha^{-1}) treatment.

Table 4.3 Yield and yield components as affected by different water regimes and nitrogen levels in rice during wet season, 2012

Treatments	No. of panicles hill^{-1}	No. of spikelets panicle^{-1}	1,000 grain weight (g)	Filled grain %	Unfilled grain %	Grain yield (g plant^{-1})
<u>Water regimes</u>						
CF	5.34 a	163.0	24.19	86.2	13.8	15.78
AWD	4.31 b	151.3	24.39	87.2	12.8	13.80
AWDv	5.47 a	169.6	23.88	83.0	17.0	14.86
$LSD_{0.05}$	0.80	17.74	0.67	5.03	5.03	1.82
<u>Nitrogen levels</u>						
0 kg N ha^{-1}	4.00 b	163.3	23.99	81.3	18.7	12.54 b
75 kg N ha^{-1}	4.92 ab	152.5	24.16	85.2	14.8	14.46 ab
150 kg N ha^{-1}	5.67 a	170.7	24.07	85.7	14.3	15.30 ab
225 kg N ha^{-1}	5.58 a	158.7	24.39	89.6	10.4	16.24 a
$LSD_{0.05}$	0.93	20.48	0.77	5.81	5.81	2.10
Pr>F						
Water regimes	<0.03	0.12	0.30	0.23	0.23	0.10
Nitrogen levels	<0.02	0.34	0.74	0.06	0.06	<0.04
Water x Nitrogen	0.87	0.58	0.10	0.96	0.95	0.43
CV %	27.7	15.3	3.8	8.2	48.2	17.1

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

4.2.1.9 Dry matter production (g)

Result of dry matter production is presented in Table 4.4. In this experiment, it was observed that the different water regimes had highly significant difference on dry matter production. The highest dry matter production (19.36 g) was resulted from AWDv, which was nearly similar with CF irrigation (18.79 g) and the lowest (15.02 g) from AWD irrigation was recorded. Oliver et al. (2008) found that continuous flooding irrigation produced the highest dry matter production.

Significant difference in dry matter production was observed among the different nitrogen levels (Table 4.4). According to different nitrogen levels, N_4 (225 kg N ha^{-1}) treatment had the highest dry matter production, which was not significantly different from N_3 (150 kg N ha^{-1}). The lowest dry matter was achieved from N_1 (control). Prasad (1981) and Park (1987) reported that increased of total dry matter was due to increased nitrogen fertilizer application. In this study, it may be assumed that total dry matter production increased due to nitrogen application at active tillering stage and panicle initiation stage. There was no interaction between different water regimes and nitrogen levels for dry matter production.

Table 4.4 Mean effect of different water regimes and nitrogen levels on dry matter production during wet season, 2012

Treatments	Dry matter production (g)
Water regimes	
CF	18.79 a
AWD	15.02 b
AWDv	19.36 a
$LSD_{0.05}$	2.91
Nitrogen levels	
0 kg N ha^{-1}	15.06 b
75 kg N ha^{-1}	17.14 ab
150 kg N ha^{-1}	18.74 a
225 kg N ha^{-1}	19.96 a
$LSD_{0.05}$	3.36
Pr>F	
Water regimes	<0.009
Nitrogen levels	<0.03
Water x Nitrogen	0.75
CV %	22.9

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

4.2.2 Total water use (mm)

As described in the study of wet season experiment, the effect of water regimes on total water use of hybrid rice was significantly different at 1% level (Figure 4.14). Although Oliver et al. (2008) reported that the highest water used by the plant was found in continuous flooding, the highest total water use in this study during wet season was observed from AWDv irrigation, which was slightly superior to CF irrigation. The lowest value of total water use was recorded from AWD irrigation. During wet season AWD can save more water 21 % than in CF and AWDv. However this water regime was associated with producing grain yield. Bouman and Toung (2001) reported that AWD irrigation resulted in decreased water input, but at the expense of decreased yield.

Total water use as affected by nitrogen levels is summarized in Figure 4.15. Although total water use was not significantly different among nitrogen levels, the maximum total water use was collected from N_4 (225 kg N ha^{-1}). Minimum total water use was obtained from N_1 (control). Interaction between water regimes and nitrogen levels was not found in this parameter, total water use.

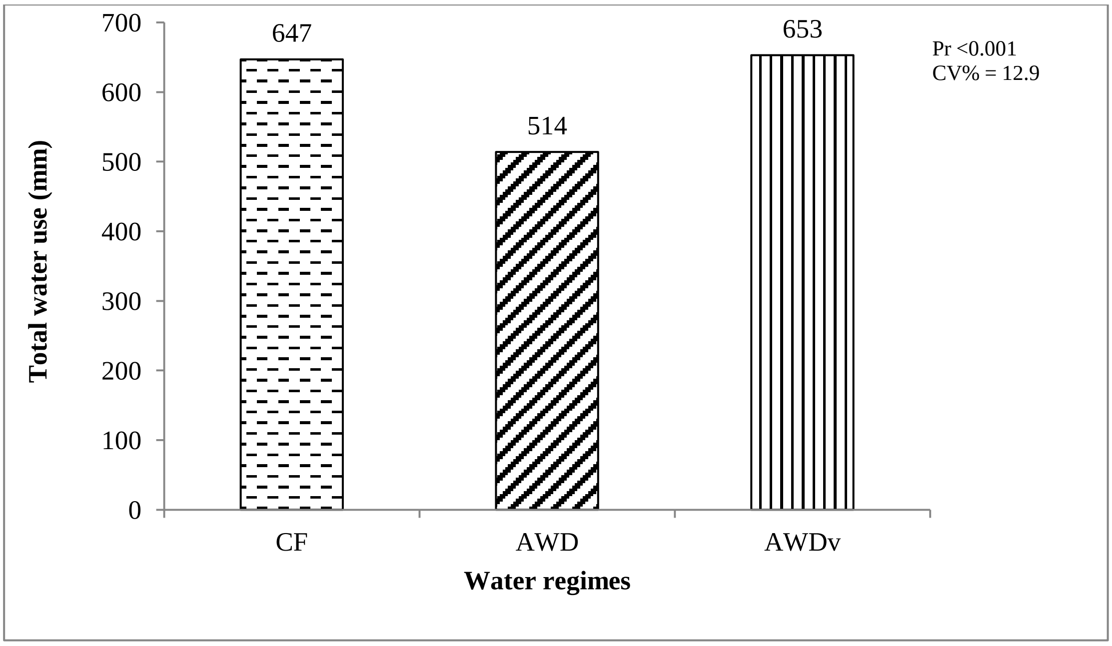

Figure 4.14 Mean value of total water use as affected by different water regimes during the wet season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

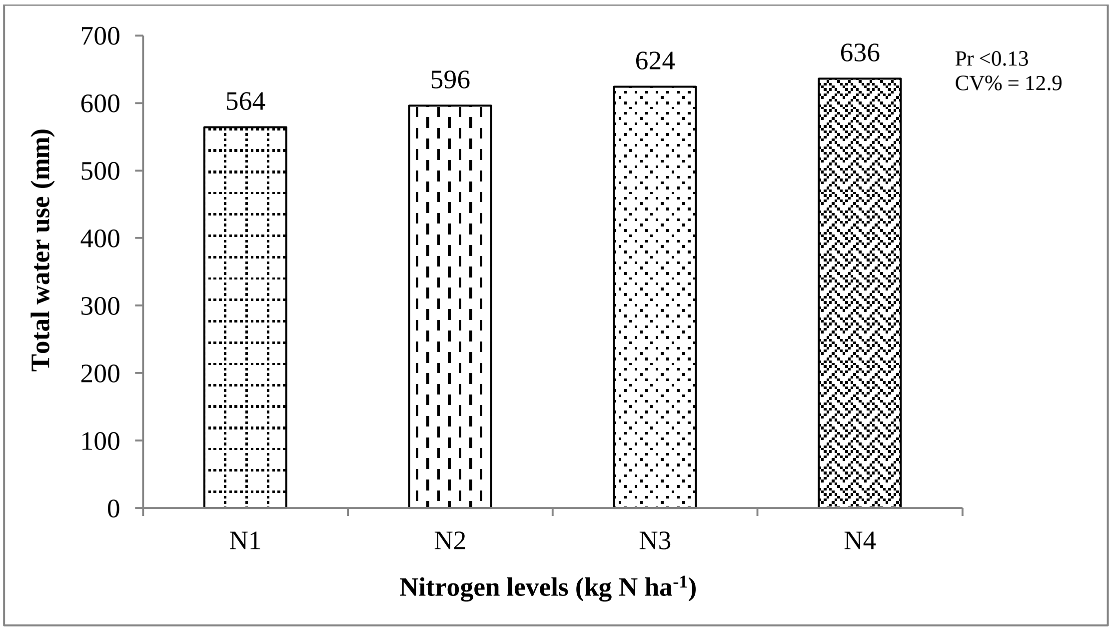

Figure 4.15 Mean value of total water use as affected by different nitrogen levels during the wet season, 2012

4.2.3 Water use efficiency (kg mm^{-1})

(Figure 4.16) showed mean value of water use efficiency as affected by different water regimes. There was no significant difference in WUE was observed among different water regimes. The highest WUE value (12.77 kg mm^{-1}) was observed with AWD irrigation and the lowest from AWDv irrigation. Similar results were also reported by Zhang et al. (2012) state that AWD irrigation higher WUE than CF due to the decrease in water use. Wahab et al. (1996); Luikham et al. (2004); Mehla et al. (2006) reported that increasing water use efficiency of rice crop was with wider irrigation intervals. Base on this finding, it can be assumed that CF water regime is more appropriate than other water regimes for rice production in wet season.

WUE as affected by different nitrogen levels is shown in (Figure 4.17). Among the nitrogen levels, there was no significant difference in WUE in the present study. The maximum WUE value was given by N_4 (225 kg N ha^{-1}), which was not significantly different from N_3 (150 kg N ha^{-1}) and the minimum WUE value was produced from N_1 (control). Kumar et al. (2003) noted that increasing levels of N from 0 to 150 kg ha^{-1} application markedly improved the water use efficiency of pearl millet. Patil and Sheelavantar (2000) reported that application of nitrogen increased water use efficiency of sorghum. There were no significant differences between different water regimes and nitrogen levels.

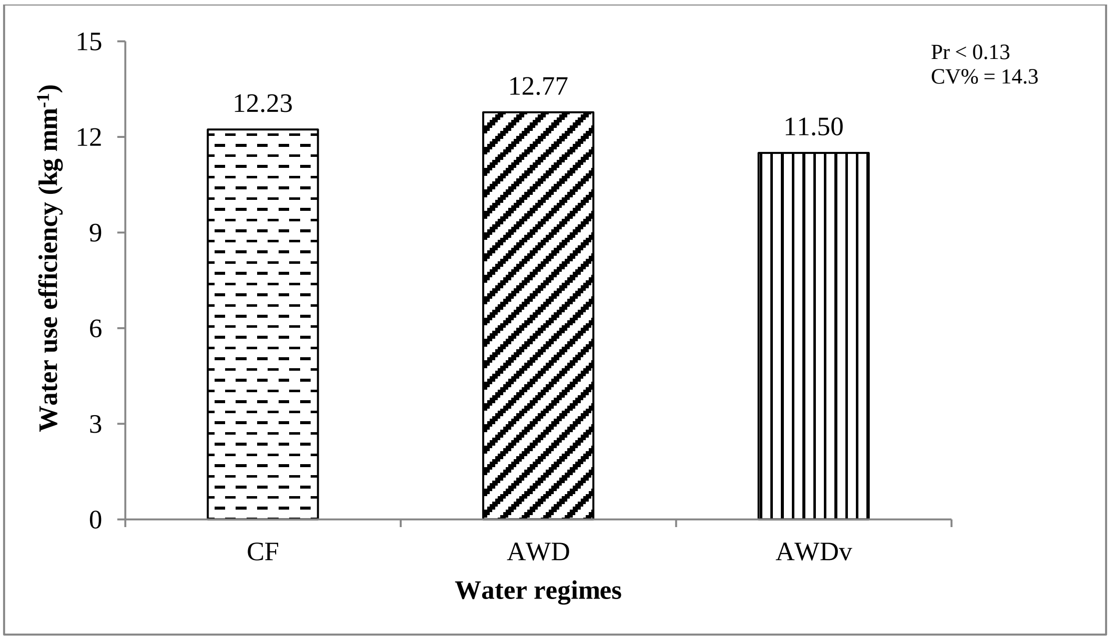

Figure 4.16 Mean value of water use efficiency as affected by different water regimes during the wet season, 2012

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

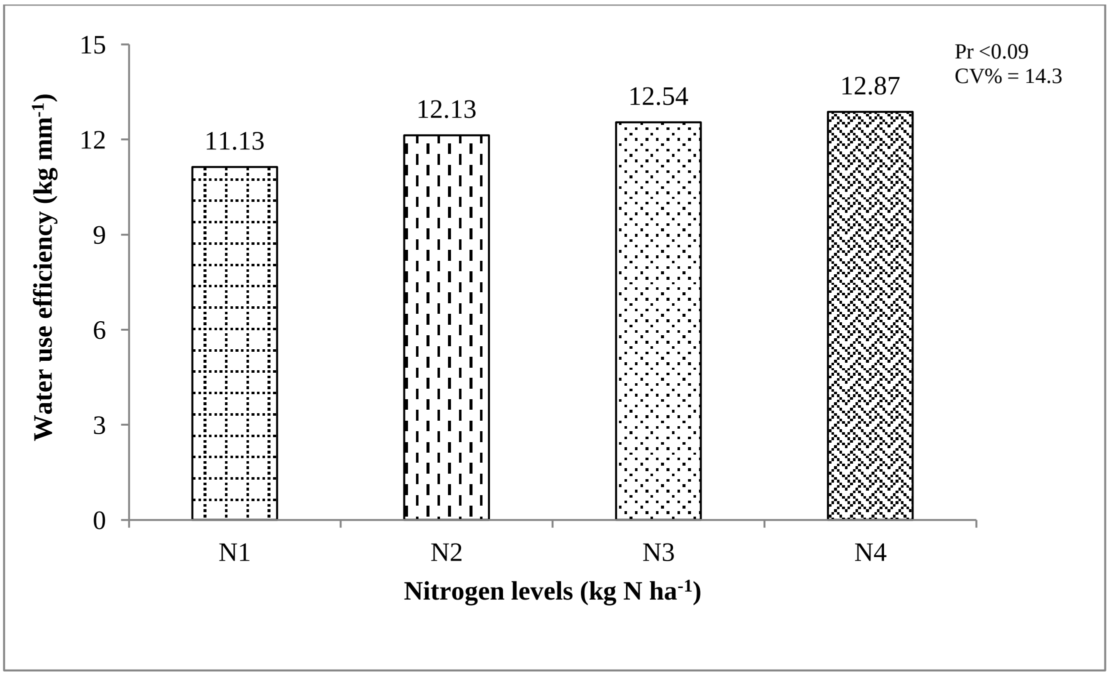

Figure 4.17 Mean value of water use efficiency as affected by different nitrogen levels during the wet season, 2012

4.2.4 Relationship between hybrid rice yield and nitrogen application levels

There was a significant positive linear relationship (R^2 = 0.9583) between hybrid rice yield and nitrogen application levels in wet season as showed in Figure 4.18. In case of nitrogen application levels, the linear regression equation (y= 0.0159x + 12.845) showed hybrid rice yield increased at a rate of 5.15 kg ha^{-1} with an increasing application rate of 1 kg N ha^{-1} in the range of 0 to 225 kg N ha^{-1} applied. A linear regression analysis accounted for 95.83 % variation. Mulbah (2010) stated that a linear regression analysis accounting for about 60% of the variation in the yield response of nitrogen application rate showed a positive linear effect (R = 0.77) of nitrogen on grain yield.

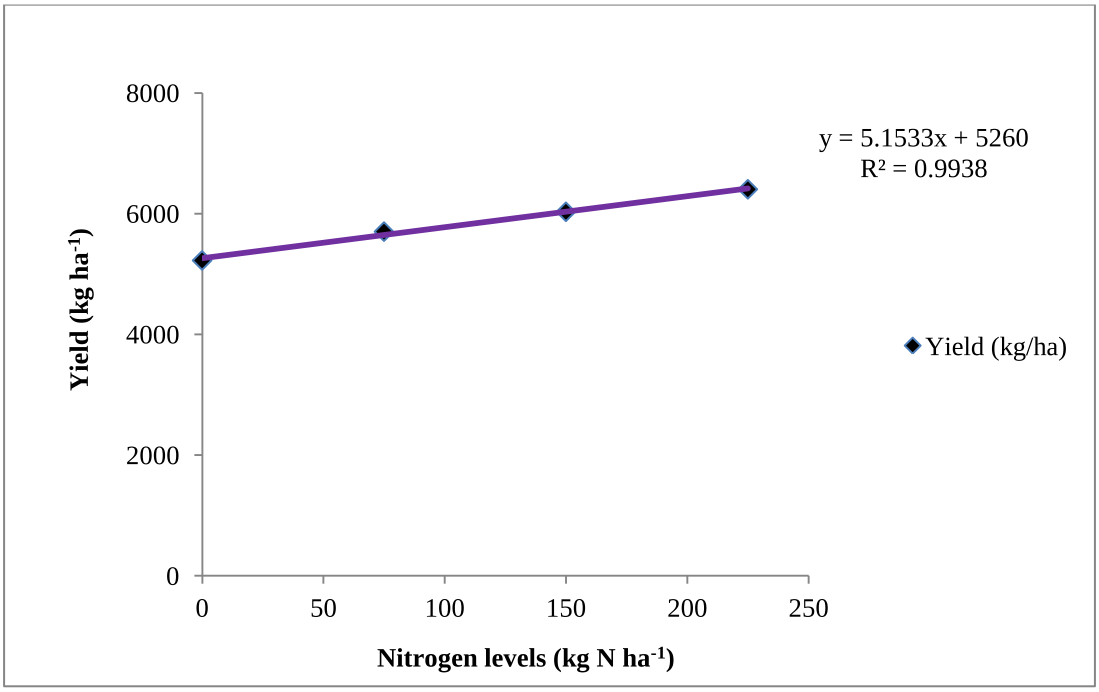

Figure 4.18 Relationship between hybrid rice yield and nitrogen application levels in the wet season, 2012

Table 4.5 Benefit cost ratio of hybrid rice production in dry and wet seasons, 2012

Nitrogen levels	Benefit cost ratio	
	Dry season	Wet season
0 kg N ha^{-1}	-	-
75 kg N ha^{-1}	6.41	1.27
150 kg N ha^{-1}	5.25	1.08
225 kg N ha^{-1}	4.16	1.05

CHAPTER V
CONCLUSION

The present study evaluates the application of different water regimes and nitrogen levels to obtain the highest yield of hybrid rice, to investigate water use efficiency in hybrid rice production in both season, 2012 and then to develop the water saving techniques together with an appropriate nitrogen level.

According to the grain yield results, the highest yield of hybrid rice was observed in alternate wetting and drying (AWD) in dry season and that of CF was the best in wet season. In dry season the yield of AWD was 34% higher than that of CF and 13 % higher than that of AWDv respectively. In wet season, the yield of CF was 14% higher than that AWD and 6 % higher than that of AWDv. In the dry season, growth parameters such as (plant height, tiller numbers and dry matter production) and yield component parameters such as (number of panicle hill^{-1}, and 1,000 grain weight) were maximum in AWD water regime. In wet season, plant height of CF water regime was highest among the other water regimes. In addition, the filled grain % of CF water regimes was higher than AWDv. Although the highest yield component parameters such as (number of panicle^{-1}, number of spikelets panicle^{-1}) was resulted in AWDv, the resulted yield was not as much as the yield of CF.

Based on the WUE, AWD water regime showed the best result in both seasons. It can save more water about 21 % than in CF and AWDv during wet season producing low tillers and low dry matter production, but it can be used more water 16 % and 9 % than in CF and AWDv producing highest grain yield during dry season.

Among the different nitrogen levels, the highest grain yield in both seasons was observed in N_4 (225 kg N ha^{-1}) level which was 31 % greater than control, 13 % greater than N_2 (75 kg N ha^{-1}) and 4 % greater than N_3 (150 kg N ha^{-1}) for dry season and 23 % greater than control, 12 % greater than N_2 (75 kg N ha^{-1}) and 6 % greater than N_3 (150 kg N ha^{-1}) for wet season. The highest filled grain %, and dry matter production were also attained from N_4 (225 kg N ha^{-1}) in both seasons. Based on benefit cost ratio, it can be suggested that N_2 (75 kg N ha^{-1}) is an optimum rates for hybrid rice production recovering 2501 kyats and 496 kyats per 1 kg N used at this level for dry and wet seasons respectively.

Due to yield response to applied N levels of positive linear regression, it was clearly seen that more nitrogen fertilization on hybrid rice production accompanied with more yield showing (4668 kg ha^{-1}) for dry season and (1159 kg ha^{-1}) for wet season under the applied rate of 225 kg N ha^{-1}.

5.1 Suggestions

1. This experiment should be conducted as field trial under multi-location.
2. The phosphorus and potassium fertilizer treatments should be included in this experiment for the future study.

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APPENDIXES

Appendix 1. Nutritional composition of rice

Item	Nutritional value per 100 g of rice	
Energy	1,527 kJ	(365 kcal)
Carbohydrates	80.00 g	
Sugar	0.12 g	
Dietary fiber	1.30 g	
Fat	0.66 g	
Protein	7.13 g	
Water	0.0701 mg	(5 %)
Thiamine (Vitamin B_1)	0.0149 mg	(1 %)
Riboflavin (Vitamin B_2)	1.62 mg	(11 %)
Niacin (Vitamin B_3)	1.1014 mg	(20 %)
Pantothenic acid (B_5)	0.164 mg	(13 %)
Vitamin B_6	28 mg	(3 %)
Calcium	0.80 mg	(6 %)
Magnesium	25 mg	(7 %)
Magnese	1.088 mg	(54 %)
Phosphorus	115 mg	(16 %)
Potassium	115 mg	(2 %)
Zinc	1.09 mg	(11 %)

Percentages are relative to US recommendations for adults.

Source: Adapted from USDA Nutrient data base 2012

Appendix 2. Response of the rice plant to various temperatures at different growth stages

Rice Growth Stages	**Critical Temperature* (˚C)**		
	Low	**High**	**Optimum**
Germination	16 – 19	45	18 – 40
Seedling emergence and establishment	12 – 35	35	25 – 30
Rooting	16	35	25 – 28
Leaf elongation	7 – 12	45	31
Tillering	9 – 16	33	25 – 31
Panicle initiation	15	_	_
Panicle differentiation	15 – 20	30	_
Anthesis (or) Reproduction	22	35 – 36	30 – 33
Ripening	12 – 18	> 30	20 – 29

*Refers to daily mean temperature except for germination

Source: Adapted from Yoshida 1977; 1981

Appendix 3. Mean rainfall, temperature and relative humidity % data at Yezin during two experiments (2012)

Month	Temperature (˚C)		Rainfall	Relative
	Maximum	Minimum	(mm)	Humidity (%)
January	32.8	14.2	0	44
February	36.4	16	0	43
March	38.3	18.8	0	45
April	39.2	23.6	0.73	55
May	38.5	24.85	1.57	60
June	32.6	24.5	4.3	73
July	31.6	23.8	16.94	72
August	31.5	23.5	6.2	72
September	33.22	23.8	7	66
October	34.5	21.9	1.2	62

Appendix 4. Field water tube

Appendix 5. Effect of different water regimes and nitrogen levels on plant height of hybrid rice, dry season, 2012

Treatments	Plant height (cm)							
	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT
Water regimes								
CF	25.59 a	34.45	44.84	58.92	64.59	73.33	81.51 b	89.79 b
AWD	23.14 b	34.32	45.56	60.89	66.39	76.96	86.92 a	95.25 a
AWDv	23.34 b	33.82	44.12	58.12	63.60	73.78	84.39 ab	92.24 ab
$LSD_{0.05}$	1.55	2.63	3.15	4.02	3.81	3.62	3.52	3.93
Nitrogen levels								
0 kg N ha^{-1}	23.68	32.91	42.34	56.41	62.80	73.65	82.04	90.43
75 kg N ha^{-1}	23.45	34.33	44.98	59.74	64.17	74.36	85.75	92.86
150 kg N ha^{-1}	23.72	34.10	46.25	61.03	67.03	76.44	85.41	93.15
225 kg N ha^{-1}	25.26	35.44	45.81	60.05	65.43	74.32	83.88	93.27
$LSD_{0.05}$	1.78	3.04	4.05	4.64	4.40	4.18	4.07	4.53
Pr>F								
Water regimes	<0.004	0.87	0.71	0.37	0.33	0.01	<0.014	<0.03
Nitrogen levels	0.16	0.42	0.22	0.22	0.26	0.56	0.25	0.55
Water x Nitrogen	0.38	0.32	0.15	0.39	0.41	0.48	0.47	0.69
CV %	9.0	10.7	10.9	9.5	8.2	6.8	5.8	5.9

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

75

Appendix 6. Mean effect of different water regimes and nitrogen levels on number of tillers hill^{-1}, dry season, 2012

Treatments	Number of tillers hill^{-1}							
	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT
<u>Water regimes</u>								
CF	0.031	1.00	2.00	3.31	7.03	9.84 b	12.38 c	14.19 c
AWD	0.063	1.50	2.38	4.44	9.34	15.56 a	21.62 a	23.81 a
AWDv	0.094	1.22	1.94	3.97	8.03	13.31a	17.44 b	19.59 b
$LSD_{0.05}$	0.12	0.44	0.69	1.19	2.22	3.19	3.24	2.89
<u>Nitrogen levels</u>								
0 kg N ha^{-1}	0.042	0.96	1.62	2.92	6.42	10.38	14.17 b	17.00
75 kg N ha^{-1}	0.042	1.33	2.33	3.88	8.33	12.83	16.92 ab	18.88
150 kg N ha^{-1}	0.042	1.13	2.04	4.17	8.58	14.50	19.46 a	20.71
225 kg N ha^{-1}	0.125	1.54	2.42	4.67	9.21	13.92	18.04 a	20.21
$LSD_{0.05}$	0.14	0.50	0.79	1.38	2.56	3.68	3.74	3.34
Pr>F								
Water regimes	0.57	0.08	0.39	0.17	0.12	<0.003	<0.001	<0.001
Nitrogen levels	0.53	0.12	0.19	0.09	0.16	0.13	<0.04	0.13
Water x Nitrogen	0.27	0.88	0.44	0.83	0.69	0.77	0.49	0.43
CV %	266.7	49.1	45.8	42.7	38.1	34.5	26.4	21.0

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

76

Appendix 7. Mean effect of different water regimes and nitrogen levels on plant height, wet season, 2012

Treatments	Plant height (cm)							
	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT
Water regimes								
CF	43.02 a	53.51 a	64.87 a	72.67 a	79.76	90.13 a	101.89	105.63
AWD	38.10 b	45.64 b	55.77 b	65.42 b	75.84	84.97 b	97.69	104.88
AWDv	42.09 a	51.44 a	63.00 a	70.92 a	78.42	88.05 a	100.44	102.25
$LSD_{0.05}$	2.85	3.38	3.82	3.28	3.39	3.65	3.86	4.33
Nitrogen levels								
0 kg N ha^{-1}	42.13	51.06	63.08	70.86	79.38	86.99	100.64	105.51
75 kg N ha^{-1}	40.44	49.97	60.88	69.65	77.35	87.73	100.01	104.77
150 kg N ha^{-1}	38.87	47.35	58.42	67.61	76.92	86.54	98.45	104.06
225 kg N ha^{-1}	62.46	52.40	62.46	70.55	78.38	89.62	100.92	102.66
$LSD_{0.05}$	3.29	3.90	4.41	3.79	3.91	4.21	4.46	5.00
Pr>F								
Water regimes	<0.003	<0.001	<0.001	<0.001	0.07	<0.02	0.09	0.26
Nitrogen levels	0.08	0.08	0.16	0.31	0.59	0.47	0.68	0.69
Water x Nitrogen	0.93	0.79	0.55	0.53	0.77	0.44	0.62	0.64
CV %	9.7	9.4	8.7	6.6	6.1	5.8	5.4	5.8

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

77

Appendix 8. Effect of different water regimes and nitrogen levels on number of tillers hill^{-1}, wet season, 2012

Treatments	Number of tillers hill^{-1}							
	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT
Water regimes								
CF	1.500	2.41 a	2.81 a	3.56 a	4.09 a	4.88 ab	5.53	6.00
AWD	1.219	1.75 b	1.91 b	2.44 b	2.88 b	3.47 b	4.34	5.06
AWDv	1.656	2.34 a	3.09 a	4.06 a	4.59 a	5.69 a	6.12	6.81
$LSD_{0.05}$	0.43	0.48	0.68	0.87	1.23	1.59	1.48	1.42
Nitrogen levels								
0 kg N ha^{-1}	1.542	2.33	2.75	3.54	3.71	4.00	4.46	5.00
75 kg N ha^{-1}	1.500	1.95	2.37	2.92	3.37	4.37	4.96	5.58
150 kg N ha^{-1}	1.250	2.04	2.54	3.50	4.21	5.54	6.29	6.96
225 kg N ha^{-1}	1.542	2.33	2.75	3.46	4.12	4.79	5.62	6.29
$LSD_{0.05}$	0.49	0.56	0.78	1.00	1.41	1.84	1.71	1.63
Pr>F								
Water regimes	0.12	<0.02	<0.003	<0.002	<0.02	<0.03	0.06	0.06
Nitrogen levels	0.58	0.40	0.72	0.55	0.61	0.38	0.16	0.10
Water x Nitrogen	0.56	0.44	0.29	0.29	0.47	0.78	0.85	0.86
CV %	41.0	31.1	36.3	36.0	44.3	47.5	38.6	33.1

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

78

Appendix 9. Effect of different water regimes and nitrogen levels on grain yield (baskets ac^{-1}) during dry and wet seasons 2012

Treatments	Grain yield (baskets ac^{-1})	
	Dry season	Wet season
Water regimes		
CF	229.4 c	120.4
AWD	400.5 a	105.4
AWDv	354.4 b	113.4
$LSD_{0.05}$	43.65	13.89
Nitrogen levels		
0 kg N ha^{-1}	298.0 b	101.1 b
75 kg N ha^{-1}	344.9 ab	110.4 ab
150 kg N ha^{-1}	374.2 a	116.8 ab
225 kg N ha^{-1}	388.7 a	124.0 a
$LSD_{0.05}$	50.4	16.04
Pr>F		
Water regimes	<0.001	0.10
Nitrogen levels	<0.004	<0.04
Water x Nitrogen	0.47	0.33
CV %	17.3	17.1

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity

Appendix10. Effect of different water regimes and nitrogen levels on grain yield ($t\ ac^{-1}$) and ($t\ ha^{-1}$) during dry and wet seasons 2012

Treatments	Dry season		Wet season	
	Yield ($t\ ac^{-1}$)	Yield ($t\ ha^{-1}$)	Yield ($t\ ac^{-1}$)	Yield ($t\ ha^{-1}$)
Water regimes				
CF	6.15 c	15.19 c	2.47	6.11
AWD	8.22 a	20.31 a	2.16	5.34
AWDv	7.28 b	17.98 b	2.33	5.75
$LSD_{0.05}$	0.89	2.21	0.29	0.71
Nitrogen levels				
0 kg N ha^{-1}	6.12 b	15.12 b	2.08 b	5.13 b
75 kg N ha^{-1}	7.08 ab	17.49 ab	2.27 ab	5.60 ab
150 kg N ha^{-1}	7.68 a	18.98 a	2.39 ab	5.92 ab
225 kg N ha^{-1}	7.98 a	19.71 a	2.55 a	6.29 a
$LSD_{0.05}$	1.04	2.56	0.33	0.81
Pr>F				
Water regimes	<0.001	<0.001	0.10	0.10
Nitrogen levels	<0.004	<0.004	<0.04	<0.04
Water x Nitrogen	0.47	0.47	0.33	0.33
CV %	17.3	17.3	17.1	17.1

Mean followed by the same letter in each column are not significantly different at 5% LSD

CF - Continuous flooding from transplanting to harvest

AWD - Alternate wetting and drying during the whole cropping season

AWDv - Alternate wetting and drying in the vegetative phase, followed by continuous flooding until maturity