STUDY ON YIELD PERFORMANCE OF *BORO* RICE UNDER DIFFERENT WATER MANAGEMENT SYSTEM

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CERTIFICATE

This is to certify that thesis entitled, "**STUDY ON YIELD PERFORMANCE OF *BORO* RICE UNDER DIFFERENT WATER MANAGEMENT SYSTEM**" submitted to the Department of Soil Science, Sher–e–Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **SOIL SCIENCE,** embodies the result of a piece of *bona fide* research work carried out by MD. ANARUL ISLAM**, Registration No. 07–02573** under my supervision and guidance. No of part of the thesis has been submitted for any other degree of diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Professor Mst. Afrose Jahan
Department of Soil Science
Supervisor

Dated:

Dhaka, Bangladesh

DEDICATED

TO

MY BELOVED PARENTS

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STUDY ON YIELD PERFORMANCE OF *BORO* RICE UNDER DIFFERENT WATER MANAGEMENT SYSTEM

ABSTRACT

An experiment was conducted to evaluate the performance of *Boro* rice under different water management systems at the research farm of SAU, Dhaka, Bangladesh during the *Boro* season of 2012–13. The experiment consisted of two factors; Factor A: three rice varieties (V_1: BRRI hybrid dhan2; V_2: BRRI hybrid dhan3 and V_3: Heera 4) and Factor B: three types of water management systems (I_1: continuous wetting, I_2: alternative wetting and drying (AWD) and I_3: irrigation only at critical growth stages). The experiment was laid out in split-plot with three replications. Irrigation was assigned in the main plot and Variety in the sub plot. In case of the main effect of variety, BRRI hybrid dhan3 was the most production variety than that of other HYV varieties. Among the HYV varieties and irrigation management systems, BRRI hybrid dhan3 and AWD method highly influencing the studied whole traits as singly or their interaction. In case of the BRRI hybrid dhan3 and alternate wetting and drying (AWD) method exhibited the tallest plant (108.80 and 106.80 cm), more effective tillers hill^{-1} (25.14 and 25.24), more grains panicle^{-1} (226.80 and 221.90), highest grain yield (8.18 and 7.90 t ha^{-1}) while NPK content and uptake by grain and straw were also highest in BRRI hybrid dhan3 and AWD system. In case of interaction effect, BRRI hybrid dhan3 grown under alternate wetting and drying (V_2I_2) also produced the highest plant height (112.0 cm), more effective tillers hill^{-1} (26.87), longest panicle (33.03 cm), more grains panicle^{-1} (244.0 0), highest weight of 1000–grain (36.74 g), highest yield of grain, straw and biological (8.72, 9.04 and 17.75 t ha^{-1}, respectively) compare other interaction treatments of the study. Interaction treatment of V_2I_2 further produced the highest content of NPK in grain (1.084, 0.395 and 0.373%, respectively) and straw (0.884, 0.273 and 1.276%, respectively) while the highest uptake of N (94.51 and 79.90 kg ha^{-1}), P (34.46 and 24.71 kg ha^{-1}) and K (32.57 and 115.40 kg ha^{-1}) in grain and straw, respectively was also obtained in V_2I_2. NPK availability in postharvst soil had also highest (0.960 ppm, 38.05 ppm and 0.0497 meq 100 g^{-1}) in V_2I_2.

Above observing results of the present study it could be concluded that the alternate wetting and drying (AWD) would be the most advantageous irrigation system for rice.

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ABBREVIATIONS

µM	=	Micro mol
AEZ	=	Agro–Ecological Zone
ANOVA	=	Analysis of variance
AWD	=	Alternate wetting and drying
BARC	=	Bangladesh Agricultural Researcher Council
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
BRRI	=	Bangladesh Rice Research Institute
BSMRAU	=	Bangabandhu Sheikh Mujibur Rahman Agricultural University
CF	=	Continuous flooding
CRD	=	Completely randomized design
CW	=	Continuous wetting
DAS	=	Days after sowing
DAT	=	Days after transplanting
DMRT	=	Duncan's Multiple Range Test
e.g.	=	Exempli gratia (by way of example)
EMSD	=	Early Mid–Season Drainage
et al.	=	And others
FAO	=	Food and Agriculture Organization
HI	=	Harvest index
HRC	=	Horticulture research center
i.e.	=	edest (means That is)
IRRI	=	International Rice Research Institute
LSD	=	Least significant difference

mgL^{-1}	=	Milligram per litre
MSD	=	Mid–season drainage
NICS	=	National Institute of Crop Science
RCBD	=	Randomized Complete Block Design
RD	=	Recommended dose
RDF	=	Recommended dose of fertilizer
RFD	=	Recommended fertilizer dose
SA	=	Soil application
SAU	=	Sher–E–Bangla Agricultural University
spp	=	Species (plural number)
var.	=	Variety
Viz.	=	Namely

CHAPTER 1

INTRODUCTION

Bangladesh is an excellent habitat for rice (*Oryza sativa* L.), a semi–aquatic annual grass plant belongs to Graminae family. It is also the most important food crop and a major food grain for more than a third of the world population and 50% of the global population (Zhao *et al*., 2011). Bangladesh is the 4th largest producer (FAOSTAT, 2012) and 3rd largest consumer (FAPRI, 2009) of rice in the world and it covers about 82% of the total cropped land of Bangladesh (Alam *et al*., 2012). Alam (2012) also reported that the rice accounts for 92% of the total food grain production in Bangladesh and provides more than 50% of the agricultural value addition employing about 44% of total labour forces. According to the latest estimation made by BBS (2012), per capita rice consumption is about 166 kg year^{-1} and it alone provides 76% of the calorie intake and 66% of total protein requirement which shares about 95% of the total cereal food supply (Alam, 2012). At present, rice covered an area of 28.49 million acres with a production of 33.54 million M tons in Bangladesh with an average yield of 1.18 T tons acres^{-1} under the diverse ecosystems subject to irrigated, rainfed and deep water conditions in three distinct seasons in Bangladesh. Among the three rice crops, it covers the largest area of 11788 (41.38%) T acre (local 195 + HYV 9968 + HYB 1625 T acre) with a production of 1.86 million tons (55.50%) and the average yield is about 1177 kg acre^{-1} during 2010–11 (BBS, 2012). According to the FAO of the UN, 80% of the world rice production comes from 7 countries (UAE/FAO, 2012).

The population of Bangladesh is growing by two million every year and may increase by another 30 million over the next 20 years. Thus, Bangladesh will require about 27.26 million tons of rice for the year 2020 (BRRI, 2011). During this time total rice area will also shrink to 10.28 million hectares. Rice yield therefore, needs to be increased by 53.3% (Mahamud *et al*., 2013). On the other hand, agricultural land is decreasing day by day. About 220 hectares agricultural lands are decreased per year due to urbanization, industrialization, housing and road construction purposes. Fifty lakh acres of agricultural land decreased during last 20 years. Food deficit has been also increasing in Bangladesh at an alarming rate due to increase in population growth and low yield of food crops achieved per unit area. Therefore, emphasis should be given to increase the yield of rice through selection of high yielding variety by adopting proper and intensive water management, fertilizer management and other improved technologies.

Use of local cultivars is one of the most important reasons for low yield. So, we have to think how to solve the food problem of the country. Since there is little scope of horizontal expansion of the rice area in the country attempt should be made to increase the yield per unit area. However, the potential for increasing rice production strongly depends on various factors like as cultivar, fertilizer application, adoption techniques with different management practices, planting methods, sowing time, seed rate etc. Among them, selection of a better cultivar concerning the regional condition of the cultivated area and adapting with other factors, proper doses of fertilizer, more types of techniques, etc. are the most important features for maximizing the rice yield. So, cultivar selection is the most important factor for enhancing the rice production. Recently, use of high yielding variety (HYV) has been increased remarkably in recent years and the country has almost reached a level of self sufficiency in food. BRRI as the designated organization for carrying out research and development of high yielding modern rice technology has so far successfully developed and released as many as 59 modern rice cultivars suitable for growing in different seasons (Alam, 2012). Despite this impressive achievements made by BRRI, the Bangladesh Institute of Nuclear Agriculture (BINA) has also developed few high yielding rice cultivars. BRAC, the biggest non–government development organization has so far developed six high yielding hybrid rice cultivars to boost rice production through adoption of high yielding modern rice cultivars (MVs) along with improved production technologies (Alam, 2012). Ella, *et al*., (2011) reported that the use of genotypes that better tolerate flooding during emergence can enhance crop establishment in flood–prone areas. Cultivation of improved varieties is the most effective means to achieve the goal. So, therefore the attempts should be taken to increase the yield per unit area by applying improved technology and management practices in this study.

Water is one of the most important requirements of paddy rice production while water shortage during the *Boro* season in Bangladesh is a growing problem due to climatic change and upstream water regulation of the major rivers in Bangladesh. Paddy rice is usually grown in lowland areas under continuous flooded conditions. It is estimated that over 75% of the world’s rice is produced using continuous flooding water management practices (Van der Hoek *et al*., 2001). According to Sharma (1989) the CF method is very inefficient as about

50–80% of the total water input is wasted. Moreover, high emissions of methane (Wassmann *et al*., 2009), greater vulnerability to water shortages than other cropping systems (Wassmann, 2010), leaching of soluble nutrients, reduced soil microbial activities, and reduced mineralization from the soil complexes (Uphoff and Randriamiharisoa, 2002) are the negative impacts of CF in rice fields. Besides, cultivation of rice in flooded fields requires about 2500–3000 m^3 water to produce one ton of rice grain (Bouman *et al*., 2002). Therefore, the paddy production is always blamed for being a high consumer of water (900–2250 mm per season) compared to other cereals (400–600mm) (Van Dung N, 1999). Producing more rice with less water is therefore a formidable challenge for achieving food, economic, social, and water security for the region (Facon, 2000). Water stress caused by non–continuous submergence not only affects the amount of used water but also, by reducing absorption of nutrients by plant and reduction of photosynthesis (Zumber *et al*., 2007), causes reduction in number of tiller, leaf surface, distribution of dry matter, number of grain in panicle, weight of 100 grain and finally yield (Pirmoradian *et al*., 2006; Amiri, 2006; Rezaei and Nahvi, 2008). It is advised that in order to prevent increasing in water use, lengthening the non–submerged period should be avoided (Rezaei and Nahvi, 2008). Alternative wetting and drying, 8–day interval irrigation or irrigation 3 days after disappearance of water from the field surface, have been certified by many researchers (Amiri, 2006). Reports have certified resistance of rice to low water potential caused by applying alternative wetting and drying in root zone up to –10 to –30 KPa (Belder *et al*., 2005). Although it is believed that water stress until field capacity or 80% of saturation will not cause yield loss, water reduction more than this has negative effect on the rice yield (Razavipor, 2007 and Belder *et al*., 2005).

So water saving is the main issue in maintaining the sustainability of rice production when water resources are becoming scarce (Arif *et al*., 2012). In the face of this troubling reality, the International Rice Research Institute (IRRI) has developed several water–saving technologies to help farmers cope better with water scarcity in their paddy fields; intermittent irrigation or alternate wetting and drying (AWD) is one of those recently introduced in Bangladesh to reduced water consumption (Akter, 2014) and to reduce the incidence of malaria due to fewer mosquitoes, reduce methane production, and improve grain quality based on sucrose to starch conversion (Belder *et al*., 2004). AWD increases the water use efficiency in rice field by reducing water loss processes viz. seepage, percolation and evapotranspiration. It is reported that 10% reductions in water consumption of rice irrigation system save 150 M m3 of water in the world (Cabangon *et al*., 2004). In rice–growing areas, drainage water from paddy fields contaminated with N and P is thought to be the main cause of agricultural non– point–source pollution. AWD significantly reduces the amount of surface and deep (beyond the root zone) drainage from paddy fields (Mao, 1997). This in turn may reduce pollution from N and P in the drainage water and improve fertilizer–use efficiency (Belder *et al*., 2005). Liu *et al*. (2010) also reported that the alternate wetting and drying (AWD) irrigation causing alternating oxic and anoxic conditions in top soil but it may lead to increased N losses from coupled nitrification–denitrification. In the AWD method, irrigation water is applied in certain intervals (vary from 1 to more than 10 days depending on the specific management regime and soil/climate conditions) leading to episodes of non–flooded soil conditions in the fields. Hence the benefits of AWD can be summarized as: increased water use efficiency (WUE), increased productivity, reduced vulnerability to drought, decreased methane emission and increased food security (Fonteh, *et al*., 2013).

Therefore, considering the above points the present study was conducted to determine the effect of water management on growth dynamics, yield and yield contributing characters of BRRI hybriddhan2, BRRI hybriddhan3 and Heera 4. Therefore, the present study was undertaken to achieve the following objectives:

i. To find out the most suitable HYV variety to deterring the higher production and best qualitative (nutritional) grain;

ii. To select the most advantageous irrigation system on the aspect of higher vegetative growth and better production including higher qualitative grain during *Boro* season;

iii. To identify the best productive variety in relation to advantageous irrigation system for getting the optimum production during Boro season.

CHAPTER 2

REVIEW OF LITERATURE

In Bangladesh, there are many research work are available on the performance of variety under different agro–ecological zone, but research work regarding to water/irrigation management on yield production including integrated nutrient availability are very scanty. Therefore, an attempt has been made in this chapter to present a brief and relevant review of many research works in relation to the effects of varieties and different types of irrigation on growth development, yield potentialities and nutrient availability of rice in Bangladesh perspective and also in the other parts of the world. Some of the pertinent research works related to the present study have been reviewed in this chapter under the following headings:

2.1 Varietals performance on growth, yield and yield attributes of rice

2.1.1 Plant height

Haque and Pervin (2015b) were evaluated some rice varieties on yield and yield contributing characters of rice. They found that the variety BRRI dhan51 showed highest plant height (129.0 cm) followed by Shakorkura (128.0 cm) while Moulata showed the lowest plant height (126.0 cm).

Haque and Pervin (2015a) reported that the variety Shakorkura produced significantly the tallest plant (134.6 cm) than those of varieties. However, another two varieties such as Moulata and BRRI dhan51 produced statistically similar result regarding to plant height (124.5 and 123.8 cm, respectively), but BRRI dhan 1 produced comparatively shorter plant among the varieties.

Shaha (2014) studied on the effect of varieties where the effect of variety on plant height was significant at all sampling dates. Remarkable higher plant height was observed in BRRI dhan56 at all sampling dates and identical with BRRI dhan57 at 15 and 30 DAT. Plant height of BR11 was shorter at all sampling dates than other two varieties (BRRI dhan56 and BRRI dhan57). The tallest plant (107.50 cm) was found in Br 11 and the second tallest plant (106.32 cm) was found in BRRI dhan57. The shortest plant (100.93 cm) was obtained from BRRI dhan56. Variation in plant height might be due to difference in genetic make–up.

Sarkar (2014) found that the plant height was significantly influenced due to variety at all the DATs. Plant height in all the varieties increased progressively with the advancement of time from 25 to 85 DAT. BRRI dhan34 was observed as the tallest plant at all the DATs. The highest plant height (115.8cm) was recorded in BRRI dhan34 at 85 DAT, which showed superiority in plant heights followed by BRRI dhan38 (114.1cm) and BRRI dhan37 (112 cm) at the same DAT. At harvest, the plant height ranged from 121.7 cm to 142.7 cm where the highest plant height was recorded from BRRI dhan34 followed by BRRI dhan38 and BRRI dhan37. The variation in plant height among the varieties was probably due to heredity or varietal characters.

Roy *et al*. (2014) evaluated 12 indigenous *Boro* rice varieties where the plant height at different DAT varied significantly among the varieties up to harvest. At harvest, the tallest plant (123.80 cm) was recorded in Bapoy and the shortest (81.13 cm) in GS.

Rahman and Bulbul (2014) found that the analysis showed that varietal effect on plant height was statistically significant at 1% probability level. The tallest plant (107.00cm) was found in BRRI hybrid2 (V_2). The shortest plant (101.95cm) was found in BRRI hybriddhan29 (V_1). Variation in plant height might be due to the differences in the genetic make–up of the varieties.

Sarker *et al*. (2013) found that the BRRI dhan 28 was shorter in plant height, having more tillering capacity, higher leaf number which in turn showed superior growth character and yielded more than those of the local cultivars.

Uddin *et al*. (2010) found that the plant height did not significantly influenced by single effect of variety in his study. Among the variety, Lalchicon produced the tallest plant (147.03

cm) where as BRRI dhan41 produced the shortest plant (82.90 cm). This may be due to genetic variability.

Alam *et al*. (2012) studied on the effect of variety, spacing and number of seedlings hill^{-1} on the yield potentials of transplant aman rice where three high yielding varieties viz. BRRI dhan32, BRRI dhan33 and BR11, four levels of spacing viz. 10cm × 25cm, 15cm × 25cm, 20cm × 25cm and 25cm × 25cm and four levels of number of seedlings hill^{-1} viz. 2 seedlings hill^{-1}, 3 seedlings hill^{-1}, 4 seedlings hill^{-1}and 5 seedlings hill^{-1} were used. Variety exhibited significant difference on plant height. Among the varieties BRRI dhan33 gave significantly the tallest plant (113.17cm), which is statistically identical with BR 11 (111.25cm). The shortest plant was found in BRRI dhan32 variety (105.07cm). The results consistent with the findings of Bisne *et al*. (2006) who observed plant height differed significantly among the varieties.

Sadeghi and Danesh (2011) found that the studied variety had significant effect on plant height. The highest plant height of 102.90 cm was found from the variety Binam (V_2) while the lowest plant height with 91.08 cm was obtained from Rezajo (V_3) variety.

Bakul *et al*. (2009) reported that the highest height was observed in one genotype BINA 250^{-1}24 (17.78 cm) which was significantly higher than that of BINA 250–83 (117.33 cm), BINADhan4 (111.59 cm) and BRRI dhan32 (100.52 cm). Genotype BRRI dhan32 showed the lowest plant height of all. Genotype BINA 250^{-1}24 and BINA 250–83 appeared statistically non significant.

Islam *et al*. (2007) showed significant variation in plant height in different genotypes where the genotype Q–31 showed longer plant height structure throughout the whole growth period, and the genotype MR–219 showed the intermediate status. The genotypes Q–31 and Y^{-1}281 showed its susceptibility to salinity stress. Q–31 showed the best performance over the varieties only plant height, but yield is very low.

Ghosh (2001) worked with four rice hybrids (CNAR3, Pro Agro 6201, PDSH 35 and GK 5006) and four high yielding cultivars (MW10, IET 4786, IR 50 and Pari) and concluded that hybrids have higher plant height.

2.1.2 Number of effective tillers hill^{-1}

Haque and Pervin (2015b) found that the highest number of effective tillers hill^{-1} (7.85) was produced from the variety BRRI dhan51 than that of Shakorkura (7.26) and Moulta (6.65).

Haque and Pervin (2015a) found that the maximum number of effective tillers hill^{-1} (8.523) was recorded in BRRI dhan51. In contrast, the minimum number of effective tillers hill^{-1} (6.381) was observed in Moulata which was statistically similar with Shakorkura (6.848) to produce effective tillers hill^{-1}. This result revealed that there was significant difference in number of effective tillers hill^{-1} between them. It was also appeared that BRRI dhan51 produced greater number of effective tillers hill^{-1} than Moulata and Shakorkura for their genetic variability and the adaptability in studied area. The response of difference in producing bearing tillers hill^{-1} might be due to the variation in genetic makeup of the variety.

Singh *et al*. (2014) conducted an experiment to study the effect of different N levels on different rice cultivars. Among the cultivars, Hybrids SVH 027, SVH 005 and variety PR 115 did not significantly influence the number of effective tillers m^{-2} during both the years.

Shaha (2014) reported that the effective tillers have direct effect on productivity of cereals. Effective tiller is the major factor to increase grain yield in cereal production. Analysis of variance shows that the effective tillers hill^{-1} was significantly affected by the variety. The highest number of effective tillers hill^{-1} (9.41) was found in BR 11 which was statistically identical with BRRI dhan56. The lowest number of effective tillers hill^{-1} (7.18) was produced in BRRI dhan57.

Sarkar (2014) also found that the variety had significant effect on number of effective tillers hill^{-1}. The number of effective tillers hill^{-1} ranged from 9.4 to 10.02. The results indicated that BRRI dhan34 produced higher number of effective tillers hill^{-1} (10.02) followed by BRRI dhan38 (9.61). The probable reasons of difference in producing the number of effective tillers hill^{-1} was mainly genetic makeup of the variety. The lowest number of effective tillers hill^{-1}(9.4) was recorded in BRRI dhan37.

Rahman and Bulbul (2014) found that the highest number of total tillers hill^{-1} (10.96) was found in BRRI hybriddhan2 and the lowest (10.63) in BRRI dhan29. The variation in number of total tillers hill^{-1} might be due to varietal characteristics. The highest number of effective tillers (9.11) was found in BRRI hybriddhan2 and the lowest number of effective tiller hill^{-1}(8.68) was found in BRRI dhan29. The highest number of non–effective tillers (1.95) was found in BRRI hybriddhan2 and the lowest number of non–effective tiller hill^{-1} (1.85) was found in BRRI hybriddhan2.

Roy *et al*. (2014) evaluated 12 indigenous *Boro* rice varieties where the number of effective tillers hill^{-1} at different DAT varied significantly among the varieties up to harvest. The maximum effective tillers hill^{-1} (43.87) was recorded in the variety Sylhety *Boro* while Bere ratna produced the lowest effective tillers hill^{-1} (17.73).

Mondal and Puteh (2013) conducted a field experiment during the period of December 2011 to May 2012 to evaluate the effect of spacing on assimilate availability, yield attributes and yield of modern rice varieties. Among the varieties, BRRI dhan29 recorded the higher effective tillers (56.2 m–2) that that of other varieties.

Garba *et al*. (2013) conducted an experiment on the effects of variety, seeding rate and row spacing on growth and yield of rice. Between the varieties, variety Ex–China produced significantly ($P<0.05$) higher numbers of tillers plant^{-1} than other variety.

Alam *et al*. (2012) also reported that the number of effective tillers hill^{-1} was significantly influenced by varieties where BR 11 produced maximum number of effective tillers hill^{-1} (8.62) and the minimum was obtained from the variety BRRI dhan32, which is statistically identical with the variety BRRI dhan33.

Sadeghi and Danesh (2011) found that the studied variety had significant effect on effective/bearer tillers. The maximum number of bearer tillers with 256 was found from Khazar variety (V_4). Similarly, minimum number of bearer tillers with 205.25 was recorded from Rezajo variety (V_3).

Uddin *et al*. (2010) reported that the number of effective tillers hill^{-1} was significantly influenced by single effect of variety. Among the variety, modern variety BRRI dhan–44 produced the highest number of effective tillers hill^{-1} (5.33) and local variety Lalchicon and Mothamota produced the minimum number of effective tillers hill^{-1} (4.00).

Sohel *et al*. (2009) reported that the significantly higher number of bearing tillers hill^{-1} (5.56) was recorded from BRRI dhan41 than BRRI dhan40. The response of difference in producing hearing tillers hill^{-1} might be due to the variation in genetic make up of the variety.

Bakul *et al*. (2009) found that the varietal effects on the production of effective tillers were found significant. BRRI dhan32 possessed the highest no. of effective tillers plant^{-1} (17.10). The second highest was obtained by BINA Dhan 4 (14.0). BINA 250^{-1} 24 mutant produced the third highest (12.1) effective tillers plant^{-1} while the other mutant BINA 250–83 showed the lowest (10.40) no. of effective tillers plant^{-1}.

Islam *et al*. (2007) found that the MR–219 produced the maximum effective tillers hill^{-1} among the varieties. Y^{-1}281 and Q–31 were similar in producing effective tiller. Thus, MR–219 showed more tolerance than other genotypes.

Siddique *et al*. (2002) studied some rice varieties included JPS, SWAT^{-1}, SWAT^{-1}1, DILROSH–97, PARC–3, IETI^{-1}3711, IRRI–4, GOMAL–6 and GHOMAL–7. The data were recorded on number of tillers hill^{-1}, plant height, number of panicles plant^{-1}, 1000–grain weight, sterility percentage, straw yield, biological and grain yield and harvest index. The analysis of data revealed that statistically significant differences were registered for all the parameters studied except number of tillers plant^{-1} and number of panicles plant^{-1}. Yang *et al*. (2001)

studied the grain and yield components of two rice cultivars (JND3 and JND13). They observed JND3 exhibited a higher tillering capacity than JND13.

2.1.3 Panicle length

Hossain *et al*. (2014a) evaluated the five rice cultivars (one hybrid: WR96, three modern: BR16, BR26, and BRRI dhan27 and one local: Pari). Most of the yield–contributing characters examined and showed wide variations among the cultivars whereas modern cultivar BR16 produced the highest panicle length.

Hossain *et al*. (2014b) views that the yield and yield attributes of exotic hybrid rice varieties. Significantly longer panicle was recorded from Heera2 (24.70 cm) which was statistically identical with Aloron (24.52 cm).

Shaha (2014) found significant variation on panicle length due to the effect of varieties. The longest panicle (23.27 cm) was found in both BR11 and BRRI dhan–57 while the shortest panicle (22.68) was found in BRRI dhan56. They reported that the variation in panicle length was obtained might be due to difference in genetic make–up.

Sarkar (2014) reported that the length of panicle was significantly influenced by variety. The results showed that BRRI dhan34 produced longest panicle (22.71 cm) followed by BRRI dhan38 (21.78 cm) and BRRI dhan37 (19.73 cm).

Rahman and Bulbul (2014) reported that the length of panicle had statistically significant due to varieties where the highest length of panicle (22.92cm) was found in BRRI dhan29. The lowest length of panicle was (22.80cm) in BRRI hybriddhan2. Hossaina *et al*. (2013) reported that the modern cultivar BR 16 produced the highest panicle length. At the same time as local cultivar Pari generated the lowest panicle length. Sadeghi and Danesh (2011) found that the length of panicle did not vary significant among the studied varieties. But the highest panicle length 28.12 cm was recorded from Hashemi variety.

Islam *et al*. (2007) found that the panicle length was different among genotypes under salinity stress. The highest panicle length was recorded genotypes MR–219 over Q–31 and Y^{-1}281. This variation might be due to genetic character of genotypes.

Ghosh (2001) studied the performance of four rice hybrids and four high yielding rice cultivars. Hybrids, in general, gave higher values for panicle length compared to that of cultivars.

2.1.4 Number of grains panicle^{-1}

Haque and Pervin (2015b) were determined the rice varieties on yield and yield contributing characters of rice where BRRI dhan51 showed the highest number of grains panicle^{-1} (122.40) followed by Shakorkura (115.30) while it was the lowest (106.0) in Molulata.

Haque and Pervin (2015a) also found significant variation on number of filled grains panicle^{-1}. The maximum number of field grains panicle^{-1} (136.1) was found from the variety BRRI dhan51 which was statistically different from other varieties. On the other hand, the minimum number of filled grains panicle^{-1} (91.43) was obtained from the variety Moulata. Filled grains panicle^{-1} is the main characters for increasing yield incase of more filled grains ensure the higher grain yield. The variation in filled grains production in this study was found for the genetic variation of the studied varieties and also the adaptability ratio with the studied region.

Haque *et al*. (2015) found significant variation in filled grain percentage where inbred BRRI dhan45 was more or less stable at different planting dates. This may be due to intrinsic genotypic characters or the well adaptability of the inbred BRRI dhan45 to the environment.

Hossain *et al*. (2014b) reported that the both hybrid rice varieties Heera2 (119.8) and Aloron (111.8) produced the highest spikelets panicle^{-1} than that of BRRI dhan48 (105.5). In BRRI dhan48, the highest filled spikelets panicle^{-1} (79.53) was recorded. This was may be due to lower sensitiveness of BRRI dhan48 to high temperature and low sunshine hour at grain filling stage compared to test hybrid varieties.

Hossain *et al*. (2014a) evaluated the five rice cultivars (one hybrid: WR96, three modern: BR 16, BR 26, and BRRI hybriddhan2 and one local: Pari) where the modern cultivar BR 16 produced the highest number of grain panicle^{-1}.

Shiyam *et al*. (2014) conducted an experiment to evaluate the performance of four Chinese hybrid rice varieties where FARO 15 showed the highest of 156.17 filled grains panicle^{-1} and highest filled grains (92.17%) compare other varieties of the study.

Shaha (2014) reported that the number of grains panicle^{-1} was significantly influenced by variety. The highest number of grains panicle^{-1} (116.85) was found in BRRI dhan57 and the lowest one (100.83) was found in BRRI dhan56.

Sarkar (2014) found that the number of grains panicle^{-1} had a significant effect due to the effect of variety. The results indicates that variety BRRI dhan34 produced the highest number of grains panicle^{-1} (152.3) followed by BRRI dhan38 (126.2). The lowest number of grains panicle^{-1} (118.0) was found in BRRI dhan37.

Rahman and Bulbul (2014) conducted an experiment on rice production where the highest number of unfilled grains panicle^{-1} (22.64) was found in BRRI dhan29. The lowest number of unfilled grains panicle^{-1} was found from BRRI hybriddhan2.

Garba *et al*. (2013) reported that the variety Ex–China produced significantly higher numbers of seeds spike^{-1} than other variety. Sarker *et al*. (2013) reported that the HYV BRRI dhan28 produced higher grains panicle^{-1} and bolder grains resulted in higher grain yield over the local cultivars.

Rahman *et al*. (2013) studied on some cultivated hybrid *Boro* rice varieties whereas CI–1, Hira 1 and Hira 2 showed better performances in terms of number of filled grains panicle^{-1}

and number of rachis panicle^{-1}. It is noted that the grains of the hybrid rice is heavier than the conventional check varieties. Hira1 also showed the highest filled grains panicle^{-1}.

Gevrek (2012) reported that the highest spikelet number per plant was obtained from Osmancık–97 (562 spikelets per plant) followed by Yavuz (515 spikelet per plant). Sadeghi and Danesh (2011) reported that the highest number of filled grains panicle^{-1} with 80.91 was recorded from Rezajo and the lowest amount of this trait was recorded from Khazar with 57.25.

Uddin *et al*. (2011) who reported that the production of number of filled grains panicle^{-1} was highly significant whereas BRRI dhan44 excelled significant production of filled grains panicle^{-1} (97.67) while Lalchicon produced the lowest (63.00) in his study. They also reported that the variation in filled grains panicle^{-1} was recorded due to genotypic differences of varieties.

Uddin *et al*. (2010) found to be the single effect of variety was significant in respect of number of filled grains panicle^{-1}. Among the variety, BRRI dhan44 gave significantly the highest number of filled grains panicle^{-1} (91.89). Whereas, Lalchicon produced the lowest (60.00) number of grains panicle^{-1}. This may be due to genotypic difference.

2.1.5 1000–grain weight

Haque and Pervin (2015a) reported that the variety BRRI dhan51 produces the highest weight of 1000–grain (31.01 g) followed by Shakorkura (27.02 g). On the other hand, Moulata showed the lowest weight of 1000–grain (25.01 g). The variation in 1000–grain weight might be due to genetic makeup of particular genotype and sink strength.

Haque and Pervin (2015b) found significant variation on 1000–grain weight due to the effect of varieties where BRRI dhan51 had more efficient for getting the highest weight of 1000–grain (28.88 g) than that of Shakorkura (27.67 g) and Moulata (26.49 g).

Hossain *et al*. (2014b) also found that the variety Aloron produced heavier grain size than that of Heera 2 and BRRI dhan48 due to genetic make up. Singh *et al*. (2014) found that there was no significant variation among the cultivars studied (Hybrids SVH 027, SVH 005 and variety PR 115) regarding 1000–grain weight at both the studied year.

Shaha (2014) investigated the effect of varieties on growth and yield of rice where the thousand–grain weight was significant among the varieties. The highest 1000–grain weight (26.82g) was found in BR 11 and the lowest one (17.97g) in BRRI dhan57. The variation in weight of 1000 grains might be due to different size of grains that were partly controlled by genetic make–up of the studied varieties.

Sarkar (2014) reported that the effect of varieties exerted significant effect on 1000–grain weight. It was found that variety BRRI dhan38 produced the highest 1000–grain weight (15.55 g) than the variety BRRI dhan37 (14.6 g). The lowest 1000–grain weight (11.26 g) was recorded in BRRI dhan34. The differences in 1000– grain weight might be due to differences in grain size which is the genetic character of the respective varieties.

Rahman and Bulbul (2014) found that the highest grain yield (137.64) was achieved from BRRI hybriddhan2. The lowest grain yield (118.45) was achieved from BRRI dhan29. They also found that the grain yield was statistically significant at 1% level of probability. The highest grain yield (5.64 t ha^{-1}) was achieved from BRRI hybriddhan2. The lowest grain yield (4.93 t ha^{-1}) was achieved from BRRI dhan29.

Rahman *et al*. (2013) studied on some cultivated hybrid *Boro* rice varieties whereas Aloron showed the highest 1000–seed weight which was closely followed by ACI–1 and Hira 2.

Islam *et al*. (2013) found that the Raniselute produced the highest 1000–grain weight (32.09 g) and the lowest (13.32 g) was recorded from the variety Kalijira.

Garba *et al*. (2013) found that the both variety showed significant variation for 1000–grain weight where NERICA–1 showed the highest weight of 1000–grain than Ex–China. Gevrek

(2012) who reported that the highest 1000 grain weight was obtained from Baldo (38.0 g), it was followed by the Gönen (36.6 g), Kıral (36.5 g) and Kargı (36.2 g), respectively.

Sadeghi and Danesh (2011) found that the studied variety had significant effect on thousand grain weight. The highest 1000 grain weight with 31.23 g was found from Khazar variety (V_4) while the lowest 1000–grain weight was found from Hashemi variety (V_1) with 24.79 g.

Ashrafuzzaman *et al*. (2009) found that there was significant difference of 1000–grains weight among the varieties. The highest 1000–grains weight was recorded in BRRI dhan38 (20.13 g) and the lowest was recorded in BRRI dhan34 (12.17 g). BRRI scientists reported that 1000–grain weight differed among the cultivars.

Hossain *et al*. (2008) conducted an experiment on some local and hybrid rice varieties in relation to growth, yield and yield attributing characters where the maximum 1000–grains weight was observed in BRRI dhan38 (19.23 g) and the lowest 1000–grains weight was found by BRRI dhan34 which was identical to Badshabhog and Chinigura.

2.1.6 Grain yield

Haque and Pervin (2015b) showed that there was a significant variation for grain yield among the varieties. The highest grain yield (5.59 t ha^{-1}) was produced from the variety BRRI dhan51 followed by Shakorkura (5.24 t ha^{-1}) while Moulata showed the lowest yield of grain (5.03 t ha^{-1}).

Haque and Pervin (2015a) also found that the highest grain yield (6.071 t ha^{-1}) was observed in BRRI dhan51 which showed significantly different result among other varieties. On the other hand, Moulata produced the lowest grain yield (4.493 t ha^{-1}) while Shakorkura recorded the average production of rice (5.300 t ha^{-1}). Higher yield of rice was achieved in BRRI dhan51 than other varieties might be attributed to the, production of higher number of effective tillers, filled grains $panicle^{-1}$ and highest weight of 1000–grain as well as larger grains.

Haque *et al*. (2015) investigated the effect of varieties on the aspect of growth and yield of rice. Grain yield ranged from 4.44 to 7.42 t ha^{-1} for BRRI hybriddhan2, 4.37 to 8.03 t ha^{-1} for Heera2 and 4.57 to 6.16 t ha−1 for inbred BRRI dhan45 for all planting dates in both the years. The hybrids Heera2 produced significantly higher grain yield over inbred BRRI dhanS45 at all planting dates except 5 February planting and an almost similar trend was observed for BRRI hybriddhan2. Higher yield of Heera 2 and BRRI hybriddhan2 was attributed to the greater number of spikelets $panicle^{-1}$ along with larger and heavier grain size.

Hossain *et al*. (2014b) also found that the variety BRRI dhan48 gave significantly the higher grain yield 3.51 t ha^{-1} over the tested hybrid varieties Heera 2 (3.03 t ha^{-1}) and Aloron (2.77 t ha^{-1}).

Hossain *et al*. (2014a) found significant variation for the characters grain yield. Among the evaluated five rice cultivars (one hybrid: WR96, three modern: BR 16, BR26, and BRRI dhan27 and one local: Pari), the modern cultivar BR 16 produced the highest grain yield ha^{-1} than that of other all tested varieties.

Singh *et al*. (2014) reported that the grain yield at both the years did not vary significant effect among the varieties of Hybrids SVH 027, SVH 005 and PR 115. However, grain yield ranges from 41.70 and 47.30 q ha^{-1} (PR 115) to 51.0 and 50.7 q ha^{-1} (Hybrid SVH 027) during both the years, respectively.

Shaha (2014) showed that the highest grain yield (6.11 t ha^{-1}) was produced from the variety BR 11 while BRRI dhan57 produced the lowest (4.70 t ha^{-1}) grain yield. The second highest grain yield was obtained from BRRI dhan56 (5.03 t ha^{-1}). Grain yield differences might be genetic characteristics of the varieties.

Sarkar (2014) found that the effect of variety had significant effect on grain yield. The variety BRRI dhan34 produced the highest grain yield (3.71 t ha^{-1}) followed by BRRI dha38 (3.5 t ha^{-1}). The lowest grain yield (3.39 t ha^{-1}) was recorded from BRRI dhan37. The highest grain yield from BRRI dhan34 was due to the highest number of effective tillers $hill^{-1}$ and the highest number of grains panicle^{-1}. Grain yield differences might be due to genetic characteristics of the varieties.

Rahman and Bulbul (2014) studied on growth and yield of rice as influenced by the effect of rice varieties. The result showed that the highest weight of 1000– grain (23.65g) was obtained from BRRI hybriddhan2. The lowest weight of 1000–grain (23.35g) was obtained from BRRI dhan29.

Akter (2014) investigated the growth, yield and nutrient content of 15 *Boro* rice cultivars. BR 15, BRRI dhan29 and BRRI dhan28 were the three rice cultivars having high potentials for grain and straw production during *Boro* season. The highest yield was recorded 5.26 t ha^{-1} which is still very low compared to other rice growing countries of the world.

Sarker *et al*. (2013) reported that the BRRI dhan28 produced higher grain yield (7.41 t ha^{-1}) and Bashful, Poshurshail and Gosi yielded ha^{-1}, respectively. Among the local rice cultivars, Gosi showed the higher yielding ability than Bashful and Poshursail.

Rahman *et al*. (2013) studied on some cultivated hybrid *Boro* rice varieties where Hira 1 gave the highest grain yield (10.77 t ha^{-1}) which was significantly higher than other hybrid rice varieties. However, grain yield of Hira 2 and ACI–1 was statistically higher than those of tested hybrid varieties as well as conventional check varieties. Observation of yield and three other characters indicated that selection for yield together with panicle length, number of grains panicle^{-1} and 1000–seed weight would be the most effective characters for increased yield. In Aman season, in terms of yield and yield contributing characters and found that Sonarbangla–2 showed the higher yield (6.20 t ha^{-1}) along with other yield contributing characters.

Mondal and Puteh (2013) conducted an experiment during the period of December 2011 to May 2012 to evaluate the effect of spacing on assimilate availability, yield attributes and yield of modern rice varieties. Among the four varieties, BRRI dhan29 recorded the grain yield of 7.53 t ha^{-1} while BINA dhan–6 showed the highest grain yield (7.72 t ha^{-1}) due to production of higher number of effective tillers hill^{-1} with second highest filled grains panicle^{-1} (99.2). On the other hand, Iratom24 produced moderate yield (7.20 t ha^{-1}) although it produced the highest number of effective tillers (60.4 m^{-2}) and bolder grains (28.22 g per 1000–grain). This occurred might be due to the lowest number of grains panicle^{-1} (82.4).

Ndjiondjop *et al*. (2012) reported that the More than 90% of plants evaluated resumed growth after drought in both years. TOG6208, TOG5691, TOG5591, TOG6594, and RAM122 were identified as best performing genotypes in terms of grain yield under drought. Their performance was similar to that of most of the 24 top yielding in terms of leaf rolling, leaf tip burning, and plant recovery after drought release.

Gevrek (2012) reported that based on two years means, the highest grain yield was obtained from Osmancik–97 (732 kg/da) followed by Demir (728 kg/da) and Gönen (666 kg/da), respectively.

Ashrafuzzaman *et al*. (2009) reported that the different varieties exhibited significant differences in grain yield. BRRI dhan34 produced the maximum grain yield and Basmati produced the lowest.

Islam *et al*. (2007) reported that the highest grain weight was noticed in MR–219 followed by Q–31and Y^{-1}281. Depending on genotypes, the best yield performance was found in MR–219. The highest grain yield hill^{-1} (4.92 g) was recorded in MR–219 and the lowest (1.67 g) was recorded in Q–31.

Hossain *et al*. (2005) found that the maximum grain weight was observed from BRRI dhan38, which was statistically different from other varieties. The lowest weight of grain was observed from Kalizira.

Shrirame and Muley (2003) conducted correlation studies of different biotic and morphological plant characters with grain yield in rice hybrids, TNRH 10, TNRH 13 and TNRH

18 and cultivar Jaya and observed that grain yield exhibited a very strong positive correlation with harvest index. Grain yield was also significantly correlated with dry matter hill^{-1}, tillers hill^{-1} and number of filled grains panicle^{-1}.

Pruneddu and Spanu (2001) conducted an experiment in Sardinia on varietal comparison of rice. They used 18 varieties and classified into groups according to grain properties (round, medium, long A, long B and aromatic) and highest yields were obtained from the long–grained varieties Alice (9.1 t ha^{-1}, long A) and Elod (8.4 t ha^{-1}, long B).

2.1.7 Straw yield

Haque and Pervin (2015a) found that the analysis of variance data regarding to straw yield showed significant difference among the varieties. Among the varieties, the variety Shakorkura recorded the highest straw yield (10.35 t ha^{-1}) followed by Moulata (8.227 t ha^{-1}) and BRRI dhan51 (8.011 t ha^{-1}) whereas Moulata and BRRI dhan51 were statistically identical. Higher straw yield was achieved in Shakorkura due to tallest plant was found with the variety.

Haque and Pervin (2015b) reported that the data of straw yield was significantly influenced due to the effect of varieties. The highest yield of straw (9.66 t ha^{-1}) was obtained from the variety BRRI dhan51 while Shakorkura and Moulata produced of 8.60 and 8.33 t ha^{-1}, respectively where Shakorkura was better than Moulata.

Singh *et al*. (2014) also found that the yield of straw were numerically similar among the varieties of Hybrids SVH 027, SVH 005 and PR 115 at both the years. Shaha (2014) found significant variation in straw yield among the varieties where significantly the highest straw yield (6.38 t ha^{-1}) was obtained from the variety BR 11 which differed from other varieties and the lowest one (5.10 t ha^{-1}) from BRRI dhan57.

Sarkar (2014) reported that the variety BRRI dhan34 produced the highest straw yield (5.11 t ha^{-1}) followed by BRRI dhan38 (4.86 t ha^{-1}). The lowest straw yield (4.7 t ha^{-1}) was produced by BRRI dhan37.

Kaho *et al.* (2003) observed that the control rice growth and make grain yield uniform and high by precision farming, it is necessary to measure and analyze the relationship among growth index of rice plant and grain and straw yields. In this research, the growth of rice plant and the grain and straw yields were measured in the same paddy field for two years. Based on the data, spatial variability of grain and straw yields was analysed by geo–statistical method, and then the straw yield map was made by kringing. Mean of straw yield was 6.8 t ha^{-1} and CV. was 9.53%.

2.1.8 Biological yield

Haque and Pervin (2015b) found that the biological yield had higher (15.65 t ha^{-1}) in Shakorkura which was statistically identical with BRRI dhan51 (14.08 t ha^{-1}). On the other hand, Moulata recorded the lowest biological yield (12.72 t ha^{-1}) which was also statistically close by the variety BRRI dhan51. This variation result on biological yield was found due to the genetic different.

Haque and Pervin (2015a) found significant variation in biological yield due to the effect of varieties. The highest biological yield (15.27 t ha^{-1}) was found in BRRI dhan–51 compare to Shakorkura (13.82 t ha^{-1}) and Moulata (13.36 t ha^{-1}).

Hossain *et al*. (2014b) reported that the biological yield did not varied significantly among studied hybrid and inbred rice varieties. Shaha (2014) also found significant difference on biological yield among the varieties. The highest biological yield (12.49 t ha^{-1}) was observed in BR 11 which was significantly differed from other varieties. The lowest one (10.10 t ha^{-1}) was found in BRRI dhan57 which was statistically identical with BRRI dhan–56.

Sarkar (2014) also found significant variation on biological yield due to the effect of varieties where the results indicated that BRRI dhan34 produced the highest biological yield (8.83 t ha^{-1}) followed by BRRI dhan38 (8.36 t ha–). The lowest biological yield (8.09 t ha^{-1}) was found in BRRI dhan37. Varietal characteristics of BRRI dhan34 positively influenced grain yield and straw yield which ultimately resulted in higher biological yield.

Roy *et al*. (2014) found non significant variation for biological yield among the studied rice genotypes.

2.1.9 Harvest index (%)

Haque and Pervin (2015b) also found significant variation in harvest index due to the effect of varieties where the highest harvest index (38.07%) was obtained from the variety Shakorkura (13.82 t ha^{-1}) while BRRI dhan51 showed the lowest harvest index (36.76) and Moulata produced average medium harvest index (37.85%).

Haque and Pervin (2015) reported that the harvest index represent comparative yield performance between grain and straw yield. It was also indicate the percent grain yield regarding to biological yield. The variety BRRI dhan51 recorded the highest harvest index (43.17%). Similarly, the variety Shakorkura took the lowest harvest index (35.43%) while Shakorkura obtained the statistically similar harvest index (34.08%). These results revealed that harvest index differed significantly due to the significant differences of the studied varieties and also the variation of grain and straw yield as well as biological yield.

Hossain *et al*. (2014b) showed that the harvest index was significantly influenced due to the effect of varieties where the highest HI was obtained from BRRI dhan48 while it was lowest in Aloron.

Shaha (2014) showed that the harvest index was significantly influenced due to the effect of variety. The highest harvest index (49.64%) was obtained from BRRI dhan56 which was statistically identical with BR 11 and the lowest (46.56%) from BRRI dhan57.

Sarkar (2014) further reported that the harvest index (%) did not vary significant variation due to the effect of varieties in his study. However, numerically BRRI dhan34 gave higher harvest index (42.02 %).

Roy *et al*. (2014) evaluate the 12 rice genotypes where all the varieties showed numerically similar HI due to non significant variation. Ashrafuzzaman *et al*. (2009) found that the variety had significant differences in harvest indices. The highest harvest index was recorded from BR34 (34.94%) and the lowest harvest index was obtained from Basmati (31.51%). Harvest index is a vital character having physiological importance.

In an experiment, Liao–Yaoping *et al*. (2001) compared rice cv. Yuexiangzhan with cv. Qishanzhan and Jingxian 89 and observed that main reason for the high harvest index and yield of Yuexiangzhan was balanced and coordination of sink, source and assimilate flow.

2.2 Varietals performance on nutrient characters of rice

2.2.1 N, P, K content in rice and straw

Akter (2014) investigated the growth, yield and nutrient content of 15 *Boro* rice cultivars. BR 15, BRRI hybrid29 and BRRI hybrid28 were the three rice cultivars having high potentials for grain and straw production during *Boro* season. However, Sada *Boro* and Chola *Boro*, two local cultivars were found very high in grain nitrogen content compared to other test cultivars.

2.2.2 N, P, K uptake by rice and straw

Akter (2014) investigated the growth, yield and nutrient uptake of 15 *Boro* rice cultivars. Among the cultivars, Chola *Boro*, IRATOM 24 and BR 14 are three high straw–K containing varieties having breeding potentials to make our future rice plant strong. Before using these cultivars for breeding, fine tuning of the research findings is required.

2.2.3 NPK content in postharvest soil

Jun *et al*. (2011) conducted an experiment in a rice field with different crop rotation systems and nitrogen application rates, surface water nitrogen content, nitrogen loss via runoff, soil fertility and rice yield were determined. Alfalfa–rice and rye–rice rotation systems enhanced soil nitrogen content, promoted rice nitrogen absorption and significantly improved rice yield.

2.3 Performance of irrigation system on growth, yield and yield attributes of rice

2.3.1 Plant height

Rahman and Bulbul (2014) conducted a field experiment at the Bangladesh Rice Research Institute to find out possible effects of alternate wetting and drying irrigation (AWDI) on the yield, water use and water use efficiency (WUE) of *Boro* rice. The treatments ranged from continuous submergence (T_1) of the field to a number of delayed irrigations (T_2, T_3 and T_4) denoting application of 5 cm irrigation water when water level in the perforated PVC pipe fell 15, 20 and 25 cm below ground level (G.L.), respectively. They found that the irrigation treatments had significant effect on plant height at 5 % level of probability. The highest plant height (105.78cm) was obtained in treatment T_4 (irrigation when water is 25 cm below from the soil surface) and the lowest (103.45cm) in Treatment T_1 (continuous flooding). This result revealed that the treatment having continuous flooding could not improve the plant height.

Ismaila *et al*. (2014) reported that the rice plant height was significantly affected by both water depth and seedling rate at all sampling periods in the three years of study. At the early stage of growth (30 DAT), the highest plant height was obtained when the field was under continuous flow of water, but as plant growth progressed toward maturity, the water depths of 15–20 cm produced significantly taller plants than the other treatments. This result was consistent in the three years of study.

Akter (2014) also found that the plant height was not significantly affected by irrigation types ($p = 0.098$). However, the plant height was recorded 108.5 cm in AWD system and that of 106.1 cm was recorded in CF system.

Tilahun–Tadesse *et al*. (2013) were studied on ten water management treatments included continuous flooding (W_1), draining water after every 15 days and re–flooding after one day (W_2), draining water after every 15 days and re–flooding after two days (W_3), draining water after every 15 days and re–flooding after three days (W_4), draining water after every month and re–flooding after one day (W_5), draining water after every month and re–flooding after two days (W_6), draining water after every month and re–flooding after three days (W_7), draining water after every one and a half month and re–flooding after one day (W_8), draining water after every one and a half month and re–flooding after two days (W_9) and draining water after every one and a half month and re–flooding after three days (W_9). They reported that the shorter heights of 88.2 cm and

89.1 cm, were obtained in W_1 and W_8, respectively. Numerically taller plant height (97 cm) was recorded in W_2.

Rahman *et al*. (2013) conducted a two years field experiments to evaluate the effect of water management on plant growth, N uptake and yield of rice. They found that the plant height increased up to 89 DAT and its value ranged from 30–100 cm, respectively. The increment in plant height was most intensive (80%) between 89–95 DAT. Among the three treatments, the plant height was almost same among the treatments (T_1: flooded, T_2: MSD and T_3: EMSD) and had no significance differences.

Fonteh *et al*. (2013) evaluate the effect of different water management practices on the growth and yield of three local rice varieties. Four water management regimes (continuous flooding maintained at a depth of 3 cm, intermittent flow at depths of, 3, 5 and 7 cm) and three local rice varieties were tested in a split–plot design with three replicates. The height of rice plants under different water management treatments varied from 53.04 to 68.82 cm but the water management regime did not significantly affect plant height ($p>0.05$).

Mannan *et al*. (2012) conducted an experiment at the Bangladesh Rice Research Institute Farm, Gazipur during *Boro* season to determine the critical growth stage where water stress affect on yield reduction and to find out optimum level of nitrogen and to select stress tolerance nitrogen responsive rice variety. Water stress was imposed at i) vegetative stage, ii) reproductive stage, iii) grain filling stages and compared with iv) control (no water stress). The found that the Plant height, tiller number and dry matter of rice varieties varied significantly at different growth stages due to variation of water stress. Water stress imposed at the vegetative stage (20–45 DAT) hampered crop growth and development which reduced plant height, number of tillers and dry matter.

Thakur *et al*. (2011) stated that rice plants grown under alternate wetting and drying were 22 and 24% taller than rice plants grown under continuous flood. Sadeghi and Danesh (2011) found that the comparison of mean between irrigation withholding time treatments showed significant variation in plant height. The highest plant height with 98.41 cm was produced by the irrigation withholding in seed doughy stages (I_3) while the lowest plant height (94.75 cm) was exhibited by irrigation withholding before of panicle existing from sheath (I_1).

Chapagain *et al*. (2011) reported that the alternate wet and dry irrigation (AWDI) is a water management system where rice fields are not kept continuously submerged but are allowed to dry intermittently during the rice growing stage. They studied to assess AWDI and continuous submerged (CS) water management practices for their effects on productivity, the surrounding environment, water savings, and Water Productivity Index (WPI). The found that the water management practices were significantly affected the vegetative and reproductive characteristics of the study. They found that the highest plant height (122 cm vs. 130 cm) was obtained in AWDI vs. CS, respectively.

Fard *et al*. (2010) determined the effects of different irrigation water managements on yield and water use efficiency of rice (*Oryza sativa* L.). Comparison of the mean values of plant height shows that the lowest and the highest plant height is belonged to D_0 and D_5 treatments, respectively. There is no significant difference between D_0 and $D_{2.5}$ treatments and $D_{2.5}$ and D_5 treatments.

Juraimi *et al*. (2009) conducted an experiment to evaluate the effect of different flooding treatments *viz.* namely T_1= continuously flooded condition until maturity, T_2= early flooding until 55 DAS followed by saturated condition until maturity, T_3= early flooding until 30 DAS followed by saturated condition until maturity, T_4= continuous saturated condition until maturity, T_5= continuous field capacity condition throughout the experiment. The height of the rice plant was significantly affected by flooding treatment at all growing stages, except at 15 and 30 DAS. At 45, 60 and 75 DAS, the lowest height of rice plant was observed in T_5, where rice grown under the field capacity condition was approximately 10–15% shorter as compared to the rice plant under other flooding treatments. At 90 DAS, however, rice plants in both T_4 and T_5 pots were significantly lower as compared to the other flooding treatments.

Amiri *et al*. (2009) studied with 8 varieties include local, breeding and hybrid and 4 irrigation management include submerge irrigation with 5, 8 and 11 day interval. They reported that the plant height varied significantly due to the effect of irrigation method where plant height significantly reduced due to the increase in water stress.

Rai and Kushwaha (2008) conducted an experiment with Rainfed (I_0), continuous submergence to maintain 5.0 + 2.5 cm ponded water (I_1), 7.5 cm irrigation water one day (I_2) and three days (I_3) after disappearance of ponded on the performance of growth and yield of rice. Results indicated that the soil water regimes significantly affected the plant height at all the growth stages. Maximum plant height in I_1 was 22.9 and 19.5% more during 1997 and 25.3and 18.9% during 1998 than in I_0 and I_3 treatments, respectively at maturity.

2.3.2 Number of effective tillers hill^{-1}

Rahman and Bulbul (2014) also found that the highest number of effective tillers hill^{-1} (11.06) was found in treatment T_2 (irrigation when water is 15 cm below from the soil surface) followed by treatment T_3: irrigation when water is 20 cm below from the soil surface (8.67) and treatment T_1: continuous submergence (8.06). The lowest number of effective tiller hill^{-1} (7.78) was found in treatment T_4 (irrigation when water is 25 cm below from the soil surface).

Mann *et al*. (2014) used an average of 1410 mm irrigation water against 1850 mm with conventional farmers' practice, a 25% irrigation water saving. At all the three sites, dry seeding resulted in more productive tillers, with site averages of 388–451 m^{-2} and an average increase of 48.6% over puddled transplanted rice.

Karim *et al* (2014) found that the irrigation methods had insignificant effect on number of tillers m^{-2} which indicated that all the irrigation methods (3) were numerically identical.

Akter (2014) evaluated the effects of water and nitrogen fertilizer management the experiment was laid out in a split plot design with two water regimes continuous flooded (CF) and alternate wetting and drying (AWD) in the main plots and 5 fertilizer treatments in the subplot. She found that the irrigation effect was not significant on the production of effective tillers hill^{-1}. In case of the AWD and CF treatments produced equal number of effective tillers hill^{-1} (11).

Tilahun–Tadesse *et al*. (2013) found significant differences in the number of productive tillers m^{-2} due to the water management treatments. Higher numbers of productive tillers m^{-2} were observed with all treatments except for W_1 and W_8 which gave the lowest numbers of productive tillers.

Rahman *et al*. (2013) conducted a two years field experiments to evaluate the effect of water management on plant growth, N uptake and yield of rice. Treatments were T_1:

flooding from transplanting to 20 days before harvest (Flooded), T_2: Early Mid–Season Drainage (EMSD) and T_3: Mid–Season Drainage (MSD). The mean value of the number of tillers m^{-2} indicated that the number of tillers m^{-2} increased up to 57 DAT and thereafter gradually declined. The increase in number of tillers m^{-2} was recorded 39 and 57 DAT was remarkable (50%). The highest average number of tillers m^{-2} was at 50 DAT and among the treatments there was no difference. During the growth stage the trend of tillers m^{-2} was slightly higher in T_2: MSD than Flooded and T_3: EMSD treatments.

Fonteh *et al*. (2013) found that the maximum number of tillers produced was between 13 and 15. The varieties were not significantly different in tillering ability but water management regime significantly ($p<0.05$) affected number of tillers (d_0=8.44, d_1=7.95, d_2=8.51, d_3=8.17).

Al Fakhrul Islam *et al*. (2013) found that the application of irrigation on *Boro* rice cultivation influenced the growth and yield of *Boro* rice. However, the number of effective tillers $hill^{-1}$ was not significantly different between two levels of irrigations.

Chapagain *et al*. (2011) found that the water management practices were significantly affected the vegetative and reproductive characteristics of the study. They found that the number of effective tillers were 310 for AWDI and 338 for continuous submerged.

Fard *et al*. (2010) reported that the number of tillers was significant at 5% level due to the effect of depth of irrigation water. The highest number of tillers is belonged to D_5 and the difference between D_5 and $D_{2.5}$ is not significant.

Juraimi *et al*. (2009) found that the production of tiller at 15 and 30 DAS was not significantly affected by the flooding treatments. At 45 and 60 DAS, rice plants grown in T_3 (flooded until 30 DAS followed by saturated) produced the highest number of tillers (794 and 878 m^{-2} tillers respectively), while the productions of tiller in T_5 (continuous field capacity) were significantly the lowest at 625 and 684 tillers m^{-2}, respectively. Meanwhile, at the reproductive stage (75 and 90 DAS), T_2 (flooded until 55 DAS followed by saturated afterward) produced the most tillers (1003 and 972 tillers m^{-2}, respectively) as compared to the other flooding treatments, while T_5 produced the lowest number of tillers (769 and 772 tillers m^{-2}, respectively).

2.3.3 Number of grains panicle^{-1}

Rahman and Bulbul (2014) found that the highest number of filled grains (141.94) panicle^{-1} was obtained in treatment T_2 (irrigation when water is below 15 cm from the soil surface) followed by treatments T_3 (Irrigation when water is 20cm below from the soil surface) and T_4 (Irrigation when water is 25cm below from the soil surface). The lowest number of filled grains panicle^{-1} (119.32) was found for treatment T_1: continuous submergence.

Karim *et al* (2014) evaluated the yield and resource use efficiency of transplanted *Boro* rice under sprinkler irrigation, alternate wetting and drying (AWD) and flood irrigation. They found significant effect on number of grains panicle^{-1} where the highest number of grains panicle^{-1} was observed in sprinkler irrigation method (104) followed by that of AWD (100) and flood irrigation method (99).

Akter (2014) reported that the number of filled grains panicle^{-1} of BRRI dhan32 was not significantly affected by irrigation regimes used in the experiment. However, the number of filled grains panicle^{-1} was recorded 102 under AWD condition and that of 96 was recorded in CF condition.

Rahman *et al*. (2013) views that the number of spikelets m^{-2} tended to be larger in Flooded treatment than MSD and EMSD treatment in the 2009 but in the 2010 the opposite trend was observed. The number of spikelets m^{-2} in Flooded was 36,000 and 35,000 which was 75% and 102% of that in MSD in 2009 and 2010. The number of spikelets m^{-2} of EMSD and MSD treatment was significantly smaller than control in 2009 but in 2010 the treatments did not show any significant differences.

Sadeghi and Danesh (2011) studied the effect of water deficit role at different stages. Comparison of mean between irrigation withholding time treatments showed that the highest number of filled grain panicle^{-1} with 78.50 was obtained by irrigation withholding in seed doughy stages (I_3). Similarly, the lowest number of filled grain panicle^{-1} (72.33) was obtained by irrigation withholding before of panicle existing from sheath (I_1).

Zhang *et al*. (2010) reported that the percentage of filled grains significantly increased under alternate wetting and drying condition as compared to under continuous flooding. Rezaei *et al*. (2009) investigated the best irrigation method for observing the growth and yield of rice where they found that the interval irrigation affected the total number of grains in a panicle.

Juraimi *et al*. (2009) also found that the responses of rice panicle number m^{-2} were significantly affected by the flooding treatments. The highest number of rice panicles was produced under continuous flooded condition (T_1), which produced 434 panicles m^{-2}, followed by T_2 (426 panicles m^{-2}), T_3 (425 panicles m^{-2}) and T_4 (398 panicles m^{-2}), which were not significantly different among each other. Meanwhile, T_5 was found to significantly produce the lowest rice panicle number (320 panicles m^{-2}) as compared to the other flooding treatments.

Amiri *et al*. (2009) studied the effect of irrigation method on growth and yield of rice where the number of grain panicle^{-1} showed significant variation due to the effect of irrigation method.

Rai and Kushwaha (2008) views that the highest number of grains (153 and149) panicle^{-1} of were obtained under continuous submergence (I_1) during 1997 and 1998, respectively, where as, the lowest of 112 and 115 grains panicle^{-1} were found in rainfed (I_0) treatment.

2.3.4 Length of panicle

Akter (2014) found that the panicle length of BRRI dhan32 was not significantly affected by irrigation ($p = 0.591$). Panicle length of 23.96 cm was recorded in CF system and that of 23.81 cm was recorded in AWD system.

Sadeghi and Danesh (2011) studied the effect of water deficit role at different stages of reproductive growth, yield and yield components of rice. The highest amount of panicle length (28.50 cm) was recorded from irrigation withholding in seed doughy stage (T_3) while it was lowest by irrigation withholding before of panicle existing from sheath (I_1).

Rezaei *et al*. (2009) investigated the best irrigation method (full irrigation, 5 and 8 day interval irrigation). They reported that the interval irrigation didn't affect number of panicle length.

Amiri *et al*. (2009) also found that the effect of irrigation method was significantly influenced the length of panicle where delay irrigation significantly reduced the panicle length.

2.3.5 Weight of 1000–grain

Karim *et al* (2014) showed that all the irrigation methods were produced statistically identical weight of 1000–grain weight and straw yield.

Ismaila *et al*. (2014) who found that the weight of rice grain was significantly higher at 20 cm water depth and decreased with decrease in water depth. The plots that were left unflooded as in free flow and saturated plots, weed competition tended to be higher which could be attributed to low grain weight in those plot.

Akter (2014) evaluated the effects of water and nitrogen fertilizer on BRRI dhan32 where she found that the 1000–grain weight of BRRI dhan32 rice was not influenced significantly by irrigation type. However, the higher 1000–grain weight of rice (23.98 g) was found in CF than at AWD (22.62 g).

Tilahun–Tadesse *et al*. (2013) were studied on ten water management treatments on growth, yield and water use efficiency of rice. They reported that the water management treatment did not affect the 1000–seed weight.

Sadeghi and Danesh (2011) found that the weight of 1000–grain also did not vary significant by the effect of irrigation withholding time where the highest 1000–grain weight (27.35 g) was recorded from irrigation withholding in seed doughy stage (T_3).

Fard *et al*. (2010) also found that the D_0 treatment has the lowest value of 1000–grain weight and there is no significant difference in 1000–grain weight between $D_{2.5}$ and D_5 treatments.

Rezaei *et al*. (2009) reported that the interval irrigation (continuously submerged irrigation or 5–day and 8–day interval) didn't affect the weight of 100–grain while full irrigation showed dissimilarity with interval irrigation.

Juraimi *et al*. (2009) found that the higher 1000–grain weight was obtained under all the flooding regimes (T_1, T_2 and T_3), where T_1 (continuous flooded) was indicated to produce the highest grain weight (26.76 g). The weight of 1000–grain under reduced water conditions (T_4 and T_5) was significantly lower as compared to T_1, T_2 and T_3 with T_5 (continuous field capacity) which produced the lowest 1000–grain weight (18.39 g).

Amiri *et al*. (2009) reported that the weight of 1000–grain did not vary significantly by the effect of irrigation as well as the irrigation treatment produced numerically identical weight of 1000–grain.

Rai and Kushwaha (2008) reported that the 1000–grain had statistically significant among the irrigation treatments. The highest 1000–grain weight was obtained in I_3 water regime and lowest in I_0. This might be due to less number of grains panicle^{-1} in I_3 than in I_1 and I_2 treatments, and due to soil water stress causing limitation in translocation of food materials toward grains in I_0.

2.3.6 Grain yield

Awio *et al*. (2015) conducted an experiment to assess the influence of different water and rice straw management practices and rice genotypes on growth and yield of rice in Uganda. Water management regimes used were alternate wetting and drying (AWD), continuous flooding (CF) and continuous drying (CD). They found that a significant variation in grain yield was observed among rice genotypes and under different water management regimes ($P<0.001$). Higher yield gain was observed under the water–saving technology alternate wetting and drying compared to continuous flooding or drying.

Omwenga *et al.* (2014) studied on the System of Rice Intensification (SRI), as opposed to conventional rice production, involves alternate wetting and drying (AWD) of rice fields. Four treatments and the conventional rice irrigation method were used. These were set as 0, 4, 8, 12 and 16 day–intervals. The results obtained showed that the 8 days drying period gave the highest yield of 7.13 tons ha^{-1} compared with the conventional method of growing rice which gave a yield of 4.87 tons ha^{-1}.

Karim *et al* (2014) evaluated the yield and resource use efficiency of transplanted *Boro* rice under two tillage and three irrigation methods. In irrigation context, sprinkler irrigation (5.90 t ha^{-1}) had the highest yield over AWD (5.72 t ha^{-1}) and flood irrigation (5.45 t ha^{-1}) method. Similarly, they reported that flood irrigation system produced up to 31% less rice than the sprinkler irrigated fields possibly due to excessive leaching of nutrients.

Akter (2014) reported that the grain yield is the most important consideration when judging any technology related to rice. The irrigation type did not have significant effect on grain yield. Between the two irrigation practices used in the experiment grain yield was higher at AWD (4.230 t ha^{-1}) than at CF (4.063 t ha^{-1}).

Ahmed (2014) who conducted an experiment to investigate the effects of water and nitrogen fertilizer management on nitrogen use efficiency in *Boro* rice cv. BRRI dhan28 and porewater nitrogen dynamics. The experiment was laid out in a split–plot design with five fertilizer treatments and three replications under continuous flooding (CF) and alternate wetting and drying (AWD) conditions. The result revealed that the water management practice and its interaction with fertilizer treatment had no significant effect on the growth and yield components of BRRI dhan28. Its appeared that intermittent irrigation like AWD had no negative effect on rice grain yield compared to CF moreover it needed less water compared to CF.

Tilahun–Tadesse *et al*. (2013) conducted a field experiment on growth and yield of rice where results revealed significant differences in grain yield due to the different water management treatments where the lowest grain yields (2.77 and 2.78 t ha^{-1}) were recorded for W_1 and W_8, respectively. Treatment W_2 and W_7 resulted in the highest grain yield of 3.5 t ha^{-1}. However, W_3, W_4, W_5, and W_6 resulted in grain yields that were in statistical parity with each other.

Rezaei *et al*. (2013) studied on the effects of salinity stress as well as water stress on rice a pot experiment was conducted at Rice Research Institute of Iran. Five water salinity levels: fresh water and five irrigation regimes (CF: continues flooding, AWD: Alternative Wetting and Drying, II: intermittent irrigation at 100, 90 and 80 percent of field capacity (FC) were considered as irrigation treatments. The result showed that salinity of irrigation water had statistically significant effects on all traits except of unfilled panicles, but water stress showed significant effects on grain yield.

Rahman *et al*. (2013) found that there was no significant difference in brown rice yield among the three treatments in the year of 2009 and 2010. In the year 2009, the brown rice yield of MSD treatment was very low because of lodging immediately after the flowering stage. The grain yields in the same experiment were 664 and 594 g m^{-2} for Flooded (control) and EMSD, respectively. In the year 2010, the brown rice yield of MSD treatment was larger than flooded (635 g m^{-2}) and EMSD (623 g m^{-2}) treatments.

Al Fakhrul Islam *et al*. (2013) studied to evaluate the effect of fertilizer and manure with different water management on BRRI dhan28. There were 2 irrigation levels (I_0= Alternate wetting and drying, I_1= Continuous flooding) and 8 fertilizer treatment. Irrigation had no significant effect on the yield and yield parameters of BRRI dhan–28. However, interaction effect of irrigation and fertilizer application showed significant variation where the highest grain (5.93 kg $plot^{-1}$) was recorded from I_0T_5 (Alternate wetting and drying + 50% RDCF + 4 t PM ha^{-1}) while the lowest was found in I_1T_0 (Continuous flooding + control treatment) treatment combination.

Zhang *et al*. (2012) reported that the technology options that can help farmers cope with water scarcity at the field level is alternate wetting and drying (AWD). They determine genotypic responses and water use efficiency of rice under two N rates and two water management treatments. They found that the grain yield was not significantly different between AWD and continuous flooding (CF) across the three seasons.

Yao *et al*. (2012) conducted a field experiment in rice with two different levels of water management conditions and he found 7.31 t ha^{-1} rice in continuous flooded condition. Nyamai *et al*. (2012) reported that 71% yield increase with alternate flooding and drying over continuous flooding. Similarly, Thakur *et al*., (2011) reported rice yield increase of 25 to 50% in a non–continuous flooding water management.

Galavi and Moghaddam (2012) investigated the deficit irrigation where analysis of variance showed significant differences between deficit irrigation. The highest grain yield was obtained in D_1 (well–watered) treatment with 3934 kg ha^{-1} and lowest at the D_4 treatment with 1037 kg ha^{-1}. Grain yield under deficit irrigation reduced at vegetative growth stage (D_2) 14%, the reproductive growth stage (D_4) 25% and at both vegetative and reproductive stages (D_3) 39% than well–watered treatment (D_1).

Sadeghi and Danesh (2011) studied by the effect of four types of irrigation withholding time (I_1: before of panicle existing from sheath, I_2: before of flowering, I_3: at seed doughy stages and I_4: without irrigation withholding) and four rice verities. Results of variances analysis showed that the effect of irrigation withholding time had significant differences on grain yield at 1% level of probability. Comparison of mean between irrigation withholding time treatments showed that the highest grain yield with 5.8 t ha^{-1} was obtained by irrigation withholding in seed doughy stages (I_3) while the lowest grain yield (5.20 t ha^{-1}) was obtained by irrigation withholding before of panicle existing from sheath (I_1).

Mahajan *et al*. (2011) reported that High water–use efficiency (WUE) and water productivity have been reported for DSR, whose yield penalty is relatively small compared with the savings in water use. Lin *et al*. (2011) also observed that 10.5 to 11.3% grain yield increase under intermittent water application (aerobic irrigation) compared to continuous flooding which they attributed to the increase in the number of grains per panicle with aerobic irrigation.

Chapagain *et al*. (2011) reported that the AWDI and CS significantly influence the grain yield where the grain yields were 7.2 t ha^{-1} vs. 7.8 t ha^{-1} in conventional water management, respectively.

Fard *et al*. (2010) determined the effects of different irrigation water managements on yield and water use efficiency of rice (*Oryza sativa* L.) in cracked paddy soils of Iran. The sub–treatment was irrigation (D_0, irrigation to fill up the cracks and up to the start of ponding; $D_{2.5}$, irrigation to fill up the cracks and up to 2.5 cm of ponding at the soil surface; D_5, irrigation to fill up the cracks and up to 5 cm of ponding at the soil surface). The results showed that the depth of irrigation water on rice grain yield and water use efficiency were significant at 5% and 1% level, respectively. Among the irrigation treatments, the highest grain yield (2.86 ton ha^{-1}) was belonged to the D_5 treatment and the lowest grain yield (2.628 ton ha^{-1}) was belonged to the D_0 treatment. The difference in grain yield between D_0 and $D_{2.5}$ treatments was not significant and the increase in yield was just 1.79%. The non–significant difference in grain yield between D_0 and $D_{2.5}$ treatments might be related to the statement of Alizadeh and Eisivand (2006).

Bueno *et al*. (2010) carried out an experiment in rice and they found that the highest grain yield (8.59 t ha^{-1}) in continuous flooded condition than the grain yield (8.21 t ha^{-1}) in AWD condition.

Zhang *et al*. (2009) reported 10% higher grain yield when irrigation was applied at 15 kPa 15–20 cm soil depth than CF (814 g m^{-2}) with irrigation water saving of 28%. They argued that the higher yield in AWD was primarily due to higher root oxidation activity, cytokinin concentration in roots and shoots, leaf photosynthetic rate and activities of key enzymes involved in sucrose to starch conversion in grains. However, there was a yield decline when the SWT threshold increased from 15 to 30 k.

Rezaei *et al*. (2009) found that the yield in water treatments fluctuated between 4002 to 4457 kg ha^{-1}. Since yield difference between interval irrigation and full irrigation was not statistically significant, it could be concluded that this methods did year not put any water stress on rice.

Juraimi *et al*. (2009) reported that the maximum grain production was obtained from T_1 (8534.4 kg ha^{-1}), followed by T_2 (7870 kg ha^{-1}) and T_3 (6840.8 kg ha^{-1}). Under T_4, the rice production was significantly reduced to only 6130 kg ha^{-1}, causing a 23.16% reduction as compared to T_1. However, the yield obtained from T_4 was only significant when compared to T_1 and T_2, but not significant when it was compared to T_3. Meanwhile, T_5 produced the lowest rice grains of 3706.2 kg ha^{-1}, which was 56.57% lower than T_1. The result shows that rice grain yield responded differently under different flooding treatments.

Baker (2009) studied on micronutrient content in rice and the effect of water in availability of the nutrients may aid in decreasing global nutrient deficiencies. Rice is grown under different water regimes such as AWD and intermittent flooding, sprinkler and furrow irrigation. Grain weight and grain to stem ratio were significantly increased by AWD and flood water treatments ($p<0.05$).

Zhang *et al*. (2008) observed significantly higher grain yield when irrigation was scheduled at 25 kPa at 15–20 cm soil depth compared to CF. Higher yield under

AWD was associated with more filled grains per panicle and higher average grain weight than in CF. But grain yield decreased when the soil water tension threshold increased from 25–50 kPa.

Yamaji (2008) revealed that Alternate Wet and Dry Irrigation (AWDI) using the proposed irrigation schedule of 10 wet days alternated with 10 dry days used less water (29 % less water) without significant reduction in grain yield (7.2 t ha^{-1}) compared with conventional irrigation (7.8 t ha^{-1}).

Salim and Shehzad (2008) revealed that continuous flooding is not necessary for getting high yield of rice. Alternate wetting and drying (AWD) condition in rice–fields has some advantages include less water–use for paddy–production, high paddy–productivity, and improvement in the environment.

Rai and Kushwaha (2008) found that the grain yields was the highest in I_1 compared to I_3 and I_0 were 16.4 and 45.9% higher during 1997 and 20.1 and 46.3% higher during 1998, respectively. It might be due to water stress during different phenophases under I_3 and I_0 treatments.

Gangwar *et al*. (2008) found maximum rice (5.35 t ha^{-1}) yield from dry seeding with AWD condition compared to the conventional rice production (4.20 t ha^{-1}) practice.

Devkota *et al* (2006) reported that the use of AWD reduced irrigation @ 30% compare continuously flooded. However, yield of residue removed AWD treatments was lower than yield of the continuously flooded treatment by 27% in 2008 and by 40% in 2009. The significant reduction in rice yield in all treatments with AWD was caused by reduced growth rate, resulting in lower biomass, leaf area, panicle density, number of florets $panicle^{-1}$ and floret fertility, with significant differences in the second year. Average grain yield of WSR under continuous flood irrigation was similar each year at 6.6 and 6.2 t ha−1 in 2008 and 2009, respectively. However, yield of all DSR–AWD treatments in 2009 was much lower than in respective treatments in 2008. The yield reduction between 2008 and 2009 for DSR treatments was significant ($p < 0.001$), while it was non–significant in WSRF–R0–FI.

Bouman *et al*. (2005) noticed that the highest grain yield (5.06 t ha^{-1}) was in continuous flooded condition and lowest grain yield (4.36 t ha^{-1}) in AWD condition. Cabangon *et al*. (2003) reported a significant yield decline with AWD when the soil water potential 10 cm depth dropped below –20 kPa. However, in all studies where AWD resulted in a yield decline; the irrigation water productivity was higher with AWD than CF because the reduction in irrigation input was larger than the loss of yield.

McHugh *et al*. (2002) reported that SRI was associated with a significantly higher grain yield of 6.4 t ha–1 compared with 3.4 t ha–1 from conventional practices. On SRI plots, grain yields were 6.7 t ha–1 for AWD irrigation, 5.9 t ha–1 with non–flooded irrigation, and 5.9 t ha–1 for continuously flooded. The results of the study suggested that, by combining AWD irrigation with SRI cultivation practices, farmers could increase grain yields while reducing irrigation water demand.

Van der Hoek *et al*. (2001) reported that over 75 percent of the world's rice is produced using continuous flooding water management practices. They also said that highest yield was obtained in continuous flooding condition.

Aslam & Prathpar (2001) revealed that AWD technology has been developed on the concept that continuous standing–water is not necessary to obtain high yields of paddy. Once the transplanted seedlings are well established, irrigation could be delayed for some period without any loss in yield.

2.3.7 Straw yield

Rahman and Bulbul (2014) also found that the maximum straw yield (6.57t ha^{-1}) was found from the treatment T_2. The minimum straw yield (6.12 t ha^{-1}) was found from treatment T_1. Karim *et al* (2014) found insignificant variation on straw yield due to the effect of irrigation. However, sprinkler irrigation showed little bit higher weight of 1000–grain than that of AWD and flood irrigation.

Akter (2014) studied on growth, yield and water use efficiency of BRRI dhan32 where she found that the straw yield of BRRI dhan32 rice was not significantly affected by irrigation type (p=0.077). However, between the two irrigation practices used in the experiment straw yield (5.49 t ha^{-1}) was higher at CF than at AWD (4.98 t ha^{-1}).

Al Fakhrul Islam *et al*. (2013) also found that the irrigation had no significant effect on the yield and yield parameters of BRRI dhan28 while interaction effect between irrigation and fertilizer significantly influenced the straw yield. The highest straw yields (6.42 kg plot^{-1}) was recorded from I_0T_5 (Alternate wetting and drying + 50% RDCF + 4 t PM ha^{-1}) and the lowest was found in I_1T_0 (Continuous flooding + control treatment) treatment combination.

Juraimi *et al*. (2009) found that the highest rice straw biomass was obtained from T_1 (continuous flooded), which yielded 681.32g m^{-2} of rice straw weight, while T_5 (continuous field capacity) produced the lowest straw yield of 467.03 g m^{-2}. From the observation, the amount of rice straw yielded in T_5 was in average of 20–30% lesser than the rice straw produced under all flooding regimes (T_1, T_2 and T_3) in both the weeded and unweeded pots. Shorter plants and fewer tillers could have attributed to lower straw yield under the field capacity condition.

Rai and Kushwaha (2008) observed that the straw yield in I_1 was 10.3 and 23.0% higher than in I_2 and I_3 but was at par with I_0 treatment. It might be due to maximum vegetative growth in I_1 treatment and poor translocation of food materials from vegetative parts to grains in I_0.

2.3.8 Biological yield

Tilahun–Tadesse *et al*. (2013) reported that the above ground biomass yield responded differently to the different water management treatments where the lowest biomass yields of 7.1 and 7.2 t ha^{-1}, respectively, were recorded for W_1 and W_8. However, all other treatments produced aboveground biomass yields that were higher than the aboveground biomass yields obtained for W_1 and W_8.

Galavi and Moghaddam (2012) reported that the biological yield is a combined contribution of yield components such as number of tillers per plant, plant height, number of grains per spike and 100–grain weight. The analysis of variance showed significant differences between deficit irrigation. Well–watered treatment (D_1) produced higher biological yield with 10470 kg ha^{-1} significantly as compared to biological yield of other treatments.

Sürek and Beser (199) reported that the effect of water stress on total biological yield was similar to grain yield. The lowest total biological yield obtained from treatment (2) and the highest total biological yield achieved in continuous irrigation. There was no significant difference for total biological yield among the treatments in 1995, however the significant difference observed in 1996. Also, the variance analysis of two year's pooled data showed significant difference among irrigation treatments.

2.3.9 Harvest index

Rahman and Bulbul (2014) reported that the irrigation treatments of the experiment did not have any significant effect on the harvest index either at 1% or 5% level of probability. However, the highest value of harvest index (46.96%) was found for the treatment T_3 and the minimum for the T_1 (43.61%).

Tilahun–Tadesse *et al*. (2013) were studied on ten water management treatments on growth, yield and water efficiency of rice where harvest index did not differed significantly among the water management treatment.

Galavi and Moghaddam (2012) also reported that the physiological efficiency of a crop to convert dry matter into economic yield is determined by the harvest index. The maximum harvest index was obtained well–watered treatment when irrigation at the all growth stages by 38% and minimum harvest index belonged to D_4 treatment with 32% when no irrigation after flowering stages.

Chapagain *et al*. (2011) found that the harvest index was significantly influenced to the effect of conventional water management where 43% vs. 44% were for AWDI and CS, respectively.

Rezaei *et al*. (2009) investigated the best irrigation method and nitrogen application in new condition an experiment was conducted in a CRBD with 3 replications where they found that the interval irrigation did not affect the harvest index

2.4 Performance of irrigation system on nutrient characters of rice

2.4.1 N, P, K content in rice and straw

Akter (2014) also found that the N content in both grain and straw of BRRI dhan32 rice was not significantly affected by irrigation type. Between the two irrigation practices used in the experiment the nitrogen content in grain (1.26%) was higher at CF than at AWD (1.23%). On the other hand, the nitrogen content in straw was recorded 0.72% in AWD system and that of 0.68% was recorded in CF system.

Baker (2009) examined the vegetative yield and micronutrient uptake of rice, faba beans, and sesbania using two different soils (Zaca clay and a loam) under flooded and drained conditions. Stem Zn concentration was highest in drained, whereas Fe, Mn and Cu stem concentration were highest in AWD and flood treatments. Manganese stem content was highest in AWD and flood treatments where grain yield and grain to stem ratio were highest, while Zn content was lowest in AWD and flood treatments. Zinc stem content was highest in the drain treatment.

2.4.2 N, P, K uptake by rice and straw

Akter (2014) reported that the N uptake in grain and straw of BRRI dhan32 rice was not significantly due to the irrigation type (AWD and CF system) in her study. The N uptake in grain was recorded 52.74 kg ha^{-1} in CF system and that of 53.23 kg ha^{-1} was recorded in AWD system. On the other hand, the N uptake by straw was recorded 38.25 kg ha^{-1} in CF and that of 37.50 kg ha^{-1} was recorded in AWD condition.

Rahman *et al*. (2013) showed that, in the year 2009, the drainage period the nitrogen uptake in plant was almost same among the three treatments but T_2: MSD treatment showed little bigger value than other treatments and had no significant difference. In the year 2010, nitrogen uptake in plant was larger in T_2: MSD treatment during the drainage period than other treatments specially DAD 17 showed the greater value than other treatments and had no statistically significant differences among the treatments.

Belder *et al*. (2005) compared fertilizer–N uptake and recovery in flooded and aerobic rice systems, and reported that aerobic rice was more limited by N than flooded rice because unaccounted–for N (i.e., not used) was higher in an aerobic system than in a flooded rice system.

2.4.3 NPK content in postharvest soil

Das (2014) found that the soil was silt loam in texture having pH 6.07, organic matter content 1.10%, total N 0.055%, available P 3.8 ppm, exchangeable K 0.24 me% and available S 12.56 ppm under AWD contrition.

Tilahun–Tadesse *et al*. (2013) reported that the organic carbon and total nitrogen contents of soils of both sites were found to be medium to high according to Landon (1991), showing considerable potential of the soil to supply N to plants through mineralization during the growing season. The CEC value of the experimental soil is high according to Hazelton and Murphy (2007), indicating high cation retention and exchange ability for good crop growth. The exchangeable potassium content of the soil is high according to Hazelton and Murphy (2007). Therefore, the nutrient could not have been a factor limiting plant growth and yield at the study sites. The total and available P contents of the soil were, however, medium.

Al Fakhrul Islam *et al*. (2013) reported that the combined effect of different sources of fertilizer and irrigation significantly influenced the pH, OM and S content of post harvest soil. The highest pH of post harvest soil (6.5) was recorded with the treatment combination I_0T_1 (Alternate wetting and drying + 100% RDCF, ($N_{100}P_{15}K_{45}S_{20}Zn_2$)) which was followed (6.4) by I_0T_0 (Alternate wetting and drying + control treatment). On the other hand, the lowest pH of post harvest soil (5.9) was recorded with the treatment combination I_1T_3 (Continuous flooding +50% RDCF plus 5 ton cowdung ha^{-1}).

Baker (2009) examined the vegetative yield and micronutrient uptake of rice, faba beans, and sesbania using two different soils (Zaca clay and a loam) under flooded and drained conditions. All DTPA extractable soil micronutrients except Zn were highest in the flood and AWD water treatments and in the lowest pH value.

Feng & Li (2002) found that total losses of N from paddy–fields with AWD were lower than those with continuous flooding. Although the de–nitrification loss of N increased, but both the leaching loss and ammonia volatilization loss of N was reduced with AWD.

Pangga *et al*. (2000) reported that the breakdown of soil organic matter (SOM) and plant residues is typically slower in submerged than aerobic soil. They also reported that Gross N immobilization is characteristically lower in continuous flooded condition because of the low metabolic requirement of anaerobic microorganisms for N.

CHAPTER III

MATERIALS AND METHODOLOGY

This chapter describes the experimental aspects of the study. The experiment was conducted at Sheer–E–Bangla Agricultural University (SAU), Dhaka during the period from November 2012 to March 2013 to investigate the performance of some modern rice varieties in respect of different irrigation management techniques under the AEZ–28. This section for convenience of presentation has been divided into various sub–sections such as site and soil, climate, crop and variety, land preparation, experimental design, treatments, fertilizer application, sowing and transplanting, intercultural operations, harvesting and threshing, data collection, soil analysis, plant analysis and statistical analysis.

3.1 Site Description

3.1.1 Geographical Location

The experimental area was situated at $23^{0}77^{0}$N latitude and $90^{0}33^{0}$E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004e).

3.1.2 Agro–Ecological Region

The experimental field belongs to the Agro–ecological zone of "The Modhupur Tract", AEZ–28 (Anon., 1998a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1998b). The experimental site was shown in the map of AEZ of Bangladesh (Fig. 3.1).

3.1.3 Soil

The soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive–gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic matter 0.81%. The experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0–15 cm depths were collected from experimental field. Soil samples were analyzed for both physical and chemical properties in the laboratory of the SRDI, Farmgate, Bangladesh. The properties studied included pH, organic matter, total N, available P and exchangeable K. The soil was analyzed following standard methods. Particle–size analysis of soil was done by Hydrometer method and soil pH was measured with the help of a glass electrode pH meter using soil water suspension of 1:2.5. The morphological, physical and chemical characteristics of initial soil are presented in Tables 3.1 and 3.2.

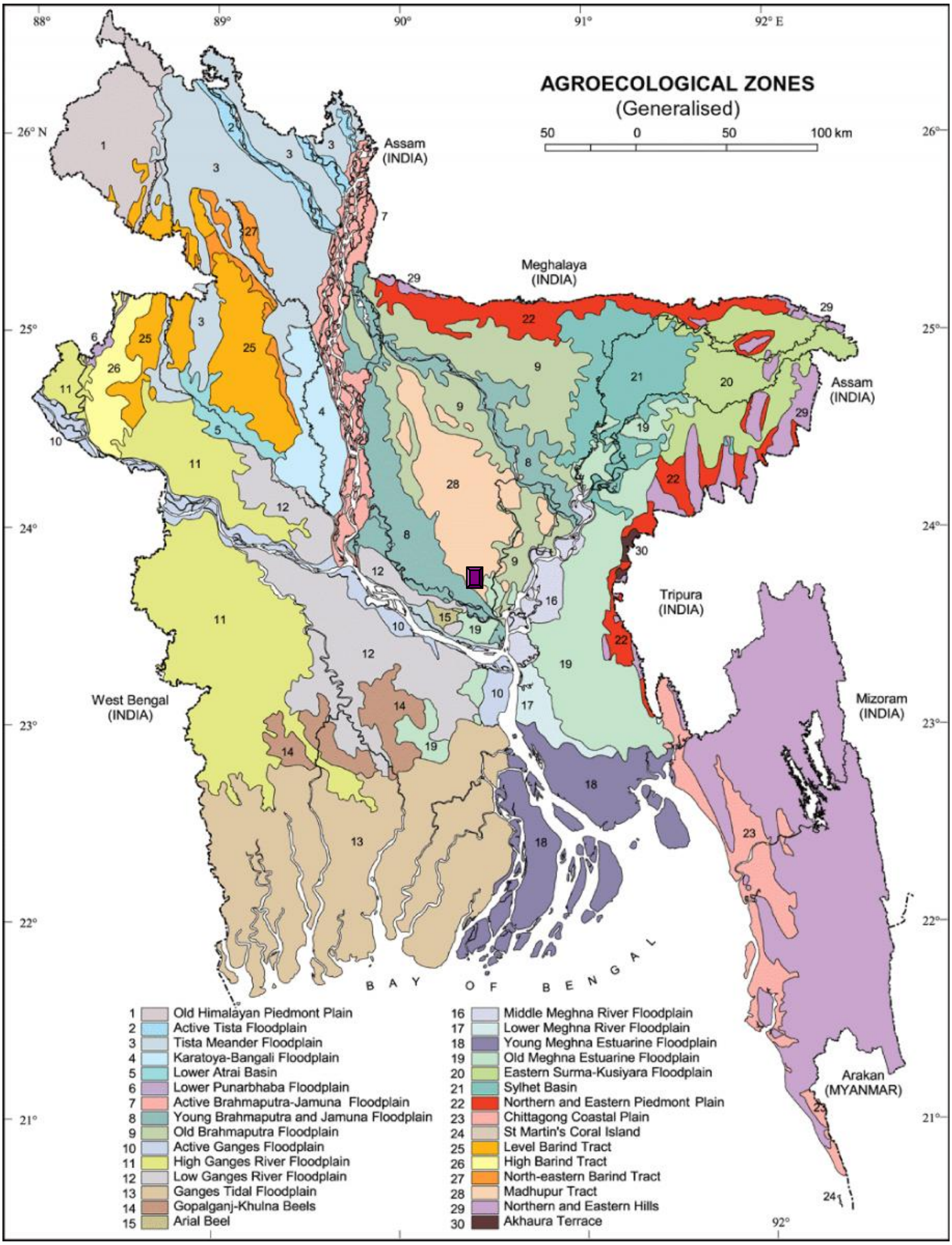
Table 3.1 Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher–e–Bangla Agricultural University Farm, Dhaka
AEZ	Madhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

Table 3.2 Physical and chemical properties of the initial soil samples

Characteristics	Value
Particle size analysis	
% Sand	28.2
% Silt	41.2
% Clay	30.6
Textural class	Silty–clay
pH	5.6
Bulk Density (g/cc)	1.45
Particle Density (g/cc)	2.52

Organic carbon (%)	0.47
Organic matter (%)	0.81
Total N (%)	0.05
Available P (ppm)	18.1
Exchangeable K (meq/100g soil)	0.10
Available S (ppm)	40



Indicated the location of the experiment

Fig. 3.1 Map showing the experimental site under study

3.1.4 Climate

The area has sub tropical climate, characterized by high temperature, high relative humidity and heavy rainfall with occasional gusty winds in Kharif season (April–September) and scanty rainfall associated with moderately low temperature during the Rabi season (October–March). Weather information regarding temperature, relative humidity, rainfall and sunshine hours prevailed at the experimental site during the study period was presented in Table 3.3.

Table 3.3 Monthly record of air temperature, rainfall and relative humidity of the experimental site during the period from November 2012 to March 2013

Months	Air temperature		Relative humidity (%)	Rainfall (mm) (Total)
	Maximum	Minimum		
November, 2012	25.82	16.04	78	00
December, 2013	22.40	13.50	74	00
January, 2013	24.50	12.40	68	00
February, 2013	27.10	16.70	67	30
March, 2013	31.40	19.60	54	21

Source: Bangladesh Meteorological Dept (Climate & weather division) Agargoan, Dhaka – 1212

3.2 Experimental materials

The experiment treatments consisted with two factors i.e. variety as planting materials and water/irrigation management techniques/system as treatment.

3.2.1 Planting materials

In this research work, the seeds of three high yielding (HYV) rice varieties were used as planting materials as level factor A. The seeds of these rice varieties were collected from the Soil Science Department of the SAU and Bangladesh Rice Research Institute (BRRI). So, the experiment consisted of three rice varieties as treatment. They were as follows:

Factor A: Variety (V)

V_1 : BRRI hybriddhan2

V_2 : BRRI hybriddhan3s

V_3 : Heera 4

The characteristics of the above varieties are as follows

BRRI hybrid dhan2: Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur released BRRI hybriddhan2 for *boro* season in the year of 2008 by the approval of BADC. The breeding line number is BR10H. The leaf of the variety is deep green and straight. The grain is medium fat and boiled rice is smooth. The grain contains 9.0% protein and 23.3% amylase. This variety gives a very high yield of 8.0 t ha^{-1} within 145 days and the plant height reaches almost 105 cm. The grains of BRRI hybriddhan2 are medium, thick with light golden husks. The appropriate time of seed sowing is 15 November to 15 December and the transplanting time is 15 December to 15 January and the required seed for sowing is 15–20 kg ha^{-1}. The suitable age of the seedling is 30–35 days for transplanting and the suitable distance is 20 × 15 cm with 1 or 2 seedling $hill^{-1}$ are needed for transplanting.

BRRI hybriddhan3: Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur released BRRI hybriddhan3 for *boro* season in the year of 2009 by the approval of BADC. The breeding line number is BRH2 and it is an advanced hybrid variety. The grain is medium fat and boiled rice is smooth. This variety gives a very high yield of 9.0 t ha^{-1} within 145 days and the plant height reaches almost 110 cm. The grains of BRRI hybriddhan3 are medium, thick with light golden husks. The appropriate time of seed sowing is 15 November to 15 December and the transplanting time is 15 December to 15 January and the required seed for sowing is 15–20 kg ha^{-1}. The suitable age of the seedling is 30–35 days for transplanting and the suitable distance is 25 × 15 cm with 1 or 2 seedling $hill^{-1}$ are needed for transplanting.

Heera 4: Heera4 also known as HSQ–1 which was introduced in Bangladesh by Supreme Seed Company Ltd. from the China. The year of notification/registration is 67^{th} NSB in 2008 (17/9/2008) and 70^{th} NSB in 2009 (4/11/2009). It is mainly cultivated in Comilla, Jessore, Rajshahi and Mymensingh and some other region of Bangladesh during the *Boro* season. The grains of Heera 4 are medium, thick with light golden husks. It takes about 150 days to mature.

3.2.2 Water/irrigation management treatment

Three types of **water/irrigation management treatment** were used for this treatment as level factor B which were as follows

Factor B: Water/irrigation management

I_1 = Continuous wetting;

I_2 = Alternate wetting and drying; and

I_3 = Irrigation only at critical growth stage (panicle initiation, heading, flowering, milk stage, dough stage)

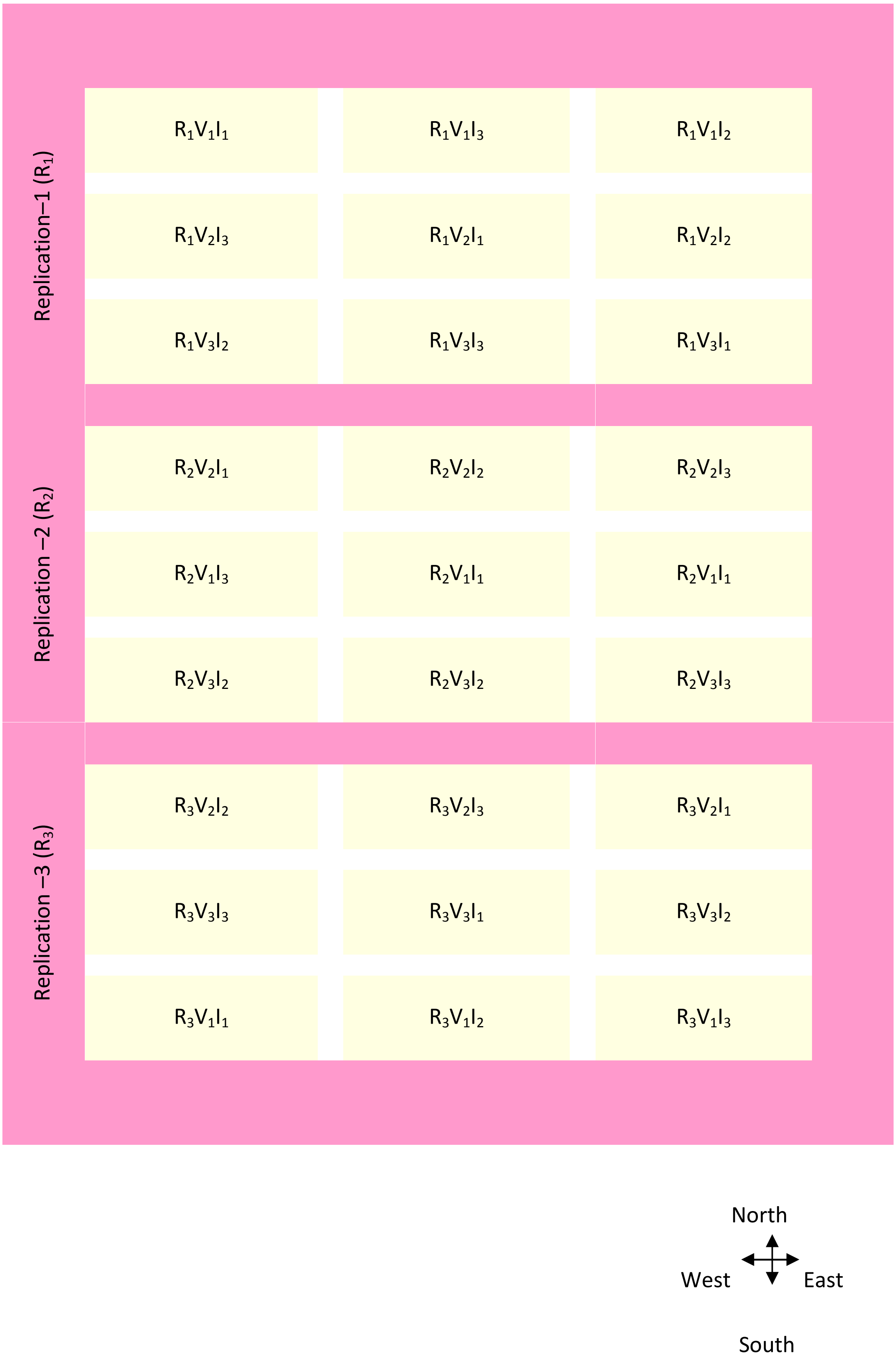
So, the treatments combinations (3 × 3= 9) are as follows

$V_1 I_1$ (BRRI hybriddhan2 × Continuous wetting); V_1I_2 (BRRI hybriddhan2 × Alternate wetting and drying); V_1I_3 (BRRI hybriddhan2 × Irrigation only at critical growth stage); V_2I_1 (BRRI hybriddhan3 × Continuous wetting); V_2I_2 (BRRI hybriddhan3 × Alternate wetting and drying); V_2I_3 (BRRI hybriddhan3 × Irrigation only at critical growth stage); V_3I_1 (Heera 4 × Continuous wetting); V_3I_2 (Heera4 × Alternate wetting and drying) and V_3I_3 (Heera 4 × Irrigation only at critical growth stage)

3.3 Experimental design and layout

The experiment consisted of three rice varieties and three levels of irrigation treatments and was laid out a two factors split–plot (Irrigation should be in the main plot and Variety in the sub–plot) with three replications. The size of plot was 2.5 × 2.0 m (5 m^2) where block to block and plot to plot distance was 1.0 and 0.5 m, respectively. Row to row and plant to plant distances were also 20 and 20 cm, respectively, in each plot. So, the total plot were 27 (varieties 3 × irrigation treatments 3 × replication 3) which layout of plot was given in Fig. 3.2.

Fig. 3.2 Lay out of the experimental field



Legend:

Treatment combinations: 9 (Nine); Replication: 3 (Three); No. of plots: 27

Length of plot: 2.5 m; Width of a plot: 2.0 m; Area of a plot: 5.0 m^2

Replication to Replication and plot to plot distance: 1.0 and 0.5 m, respectively

Row to row distance: 0.20 m; plant to plant distance: 0.20 m

3.4 Seedling establishment

3.4.1 Seed sprouting

Healthy seeds were collected by specific gravity method. The selected seeds were soaked for 24 hours and then these were kept in gunny bags. The seed started sprouting after 48 hours and almost all seeds were sprouted after 72 hours.

3.4.2 Preparation of seedling nursery and seed sowing

A piece of high land was selected in the Soil Science Field Laboratory, SAU, Dhaka for raising seedlings. The land was puddled well with country plough followed by cleaning and leveling with ladder.

3.4.3 Raising of seedlings

The well prepared seedbed(s) were used for raising the seedlings. After sprouting, the seeds were sown in the previously prepared wet seed bed on November 11, 2012. Proper care was taken so that there was no infestation of pest and disease and no damage by birds.

3.5 Land preparation for transplanting

The tidal free land was opened on December 2, 2012 and prepared by ploughing and cross ploughing with power tiller and country plough. Then the land was laddered with traditional tools. Thereafter, the land was ploughed and cross–ploughed and deep ploughing was obtained good tilth, which was necessary to get better yield of this crop. Laddering was done in order to break the soil clods into small pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field. The plots were spaded one day before planting and the whole amount of fertilizers were incorporated thoroughly before planting according to fertilizer recommendation guide (BARC, 2005). The soil was treated with insecticides Furadan 5G was used @ 8 kg ha^{-1} to protect young plants from the attack of mole cricket, ants, and cutworms at the time of final ploughing.

3.6 Fertilizer application

The experimental area was fertilized with 120, 80, 80, 20 and 5 kg ha^{-1} of N, P_2O_5, K_2O, S and Zn applied in the form of urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate, respectively (BRRI, 2011). The entire amounts of TSP, MP, gypsum and zinc sulphate were applied as basal dose at final land preparation. Urea was top–dressed in three equal installments i.e., after seedling recovery, during the vegetation stage and at 7 days before panicle initiation

3.7 Uprooting of seedlings

The seedbeds were made wet by application of water on the previous day before uprooting the seedlings. The seedlings were uprooted carefully without causing dry injury to the roots. The uprooted seedlings were kept on soft mud under shade.

3.8 Transplanting of seedlings

On December 17, 2012, 35 day–old seedlings were transplanted in the tidal free puddled land keeping plant to plant distance 20 cm and row to row distance 20 cm. Seedlings were transplanted as per treatments in each hill.

3.9 Intercultural operations

After transplanting of the seedlings, different operations were carried out for better growth and development of the plant.

3.9.1 Thinning and Gap Filling

After one week of direct seed sowing thinning was done to maintain the constant population number. After transplanting the seedlings of the research field, gap filling was done whenever it was necessary using the seedling.

3.9.2 Irrigation as treatments and its application

The experiment was conducted with water regimes in the main plots. The three water regimes, continuous flooding (CF), alternate wetting and drying (AWD) and irrigation only at critical growth stage (panicle initiation, heading,flowering,milk stage, dough stage) were physically separated to check the movement of water between the water treatments. The total number of unit plots was 27 and the size of the unit plot was 2.5 m × 2 m (5 m^2) each. Irrigation water was added to each plot according to the treatments. Irrigation was done continuously in I_1 (continuous flooding) replicated plot depending of water availability @ 2/3 cm upon the soil surface as maintain the continuous flooding treatment. Irrigation was also provided to the plots from deep tube well. A PVC pipe was placed vertically in the field leaving a part beneath the soil so that available water condition can be observed and determined. It was done to maintain alternate wetting and drying (AWD) condition during the growing period of the crop. Another irrigation was done only at critical growth stage by deep tube well maintaining 2/3 cm water availability on the soil surface for water regime and maintaining the treatment I_3.

3.9.3 Weeding

Few weeds namely, durba, shama and mutha were found in each plot after two weeks of transplanting. They were uprooted immediately by hand pulling.

3.9.4 Plant Protection Measures

Plants were infested with rice stem borer (Scirphophaga incertolus) and leaf hopper (Nephotettix nigropictus) to some extent which were successfully controlled by applying Diazinone @ 10 ml/10 liter of water for 5 decimal lands on February 03 and by Ripcord @ 10 ml/10 liter of water for 5 decimal lands on February 20 and March 25, 2006. Crop was protected from birds and rats during the grain filling period. Field trap and foxtoxin poisonous bait was used to control the rat. For controlling the birds watching was done properly, especially during morning and afternoon.

3.10 Plant sampling at harvest

Plants from 1 m^2 were randomly selected from each plot to record the yield contributing characters like plant height (cm), number of tillers $hill^{-1}$, panicle length (cm), number of grains $panicle^{-1}$, and 1000–grain weight (g). The selected hills were collected before harvesting. Grain and straw yields were recorded plot–wise and expressed at t ha^{-1} on sun dry basis.

3.11 Harvesting

The crop was harvested at maturity on 22 March, 2013. The harvested crop was threshed plot–wise. Grain and straw yields were recorded separately plot–wise and moisture percentage was calculated after sun drying. Dry weight for both grain and straw were also recorded.

3.12 Data collection

The data on the following characters of the studied rice were recorded:

i) Plant height (cm)
ii) Number of effective tillers hill^{-1}
iii) Panicle length (cm)
iv) Number of grains panicle^{-1}
v) 1000–grain weight (g)
vi) Grain yields (t ha^{-1})
vii) Grain yields (t ha^{-1})
viii) Biological yields (t ha^{-1})
ix) Harvest index (%)

3.12.1 Plant height (cm)

The plant height was measured from the ground level to the top of the panicle. Plants of 10 hills (1 m^2) were measured and average for each plot.

3.12.2 Number of effective tillers hill^{-1}

Ten hills were taken at random from each plot and the number of tillers hill^{-1} was counted and thereafter the numbers of effective tillers hill^{-1} was determined.

3.12.3 Panicle length

Measurement was taken from basal node of the rachis to apex of each panicle. Each observation was an average of 10 panicles.

3.12.4 Number of grains panicle^{-1}

Presence of any food material in the spikelet was considered as grain and numbers of grains present in each panicle were counted. Ten panicles were taken at random to count grains and averaged.

3.12.5 1000–grain weight

One thousand clean dried grains were counted from the seed stock per plot and weighed by using an electric balance.

3.12.6 Grain yield (t ha^{-1})

Grains obtained from the harvest area of 1m x lm from the middle of each unit plot were sun dried and weighed carefully and converted to t ha^{-1}.

3.12.7 Straw yield (t ha^{-1})

The collected straw from each plot was sun dried properly to record the final straw yield plot^{-1} and finally converted to t ha^{-1}.

3.12.8 Biological yield (t ha^{-1})

Grain and straw yields are altogether regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield= Grain yield (t ha^{-1}) + Straw yield (t ha^{-1})

3.12.9 Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with the following formula (Gardner *et al*., 1985).

Harvest index (%) = $\frac{\text{Economic yield}}{\text{Biological yield}} \times 100$

Where,

Economic yield = Grain yield and Biological yield = Grain yield + Straw yield

3.13 Chemical analysis of soil samples

Soil samples were analyzed for both physical and chemical properties in the laboratory of Soil Resource Development Institute (SRDI), Farmgate, Dhaka. The properties studied included total N, available P and exchangeable K. The chemical properties (NPK) of the initial soil have been presented in Table 3.2. The soil was analyzed by standard methods:

3.13.1 Total nitrogen (N)

Total nitrogen of soil was determined by Micro Kjeldahl method where soil was digested with 30% H_2O_2, conc. H_2SO_4 and catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Se powder in the ratio of 100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Bremner and Mulvaney, 1982).

3.13.2 Available phosphorus (P)

Available phosphorus was extracted from soil by shaking with 0.5 M $NaHCO_3$ solution of pH 8.5 (Olsen *et al.*, 1954). The phosphorus in the extract was then determined by developing blue colour using $SnCl_2$ reduction of phosphomolybdate complex. The absorbance of the molybdophosphate blue color was measured at 660 *n*m wave length by Spectrophotometer and available P was calculated with the help of standard curve.

3.13.3 Exchangeable potassium (K)

Exchangeable potassium was determined by 1N NH_4OAc (pH 7.0) extract of the soil by using Flame photometer (Black, 1965).

3.14 Chemical analyses of grain and straw

3.14.1 Preparation of samples

The plant samples (grain and straw) were dried in an oven at 65^0C for about 48 hrs before they were ground by a grinding machine. Then the ground samples were passed through a 20–mesh sieve and stored in paper bags and finally they were kept into desiccators. The grain and straw samples were analyzed for determination of N, P, K and S.

3.14.2 Digestion of samples

Exactly, 1g of finally ground plant material was taken into a 250mLconical flask and 10mL of di–acid mixture (HNO_3: $HClO_4$=2:1) was added to it, then it was placed into the electric hot plate for heating at 180–200^0C until the solid particles was disappeared and white fumes were evolved from the flask (Jackson, 1962). It was then cooled at room temperature, washed with distilled water repeatedly and filtered into a 100mL volumetric flask through Whatman No.42 filter paper and the volume was made up to the mark with distilled water. The grain and straw extracts were preserved separately in plastic bottles for the analysis of different elements.

3.14.3 Nitrogen content (%)

The N concentration was determined by Semi–micro Kjeldahl method as described in section 3.16.4.

3.14.4 Phosphorus content (%)

P concentration is digested grain and straw were determined from the extract by adding ammonium molybdate and $SnCl_2$ solution and measuring the colour with the help of spectrophotometer at 660 nm wavelength (Olsen *et al.* 1954).

3.14.5 Potassium content (%)

Potassium concentration in digested grain and straw were determined directly with the help of flame photometer (Black, 1965).

3.14.6 Nutrient uptake

The uptake of N, P and K were calculated by multiplying the concentration of the nutrient in the grain and straw samples with the corresponding yields of grain and straw of crop. So, the uptake was calculated by the following formula:

$$\text{Nutrient uptake (\%)} = \frac{\text{Nutrient content} \times \text{yield}}{100}$$

3.15 Statistical Analysis

Data recorded for yield and yield contributing characters including the nutrient content and uptake were compiled and tabulated in proper form for statistical analyses. Analysis of variance was done with the help of MSTAT–C computer package programme developed by Russel (1986). The mean differences among the treatments were evaluated with DMRT test (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The present research work was to investigate the effect of genotypic differences including the relevance of various types of irrigation as water management practices concerning different yield and yield contributing characters under the AEZ–28 (Dhaka region). After observing the field performance, further investigation was also observed on the aspect of integrated nutrient management in relation to grain, straw and postharvest soil. The results on growth, yield and yield contributing characters and also on nutrient (NPK) characters have been presented in Tables 4.1 through 4.13 and Figures 4.1 to 4.10. Analysis of variance (ANOVA) results was also presented in Appendices I to V. A detailed discussion on the presented results and possible interpretations are given in this chapter under the following headings.

4.1 Responses of varieties and water management practices on various characteristics of rice

Morpho–physiological, yield and yield contributing traits such as plant height (cm), number of effective tillers hill^{-1}, number of grains panicle^{-1}, 1000–grains weight (g), grain, straw and biological yield (t ha^{-1}) and harvest index (%) were recorded at harvest. However, integrated nutrient management data were also obtained after harvest in respect of grain, straw and postharvest soil. The details results were present under the following headings.

4.1.1 Effect of varieties

4.1.1.1 Morpho–physiological, yield and yield attributes

Plant height

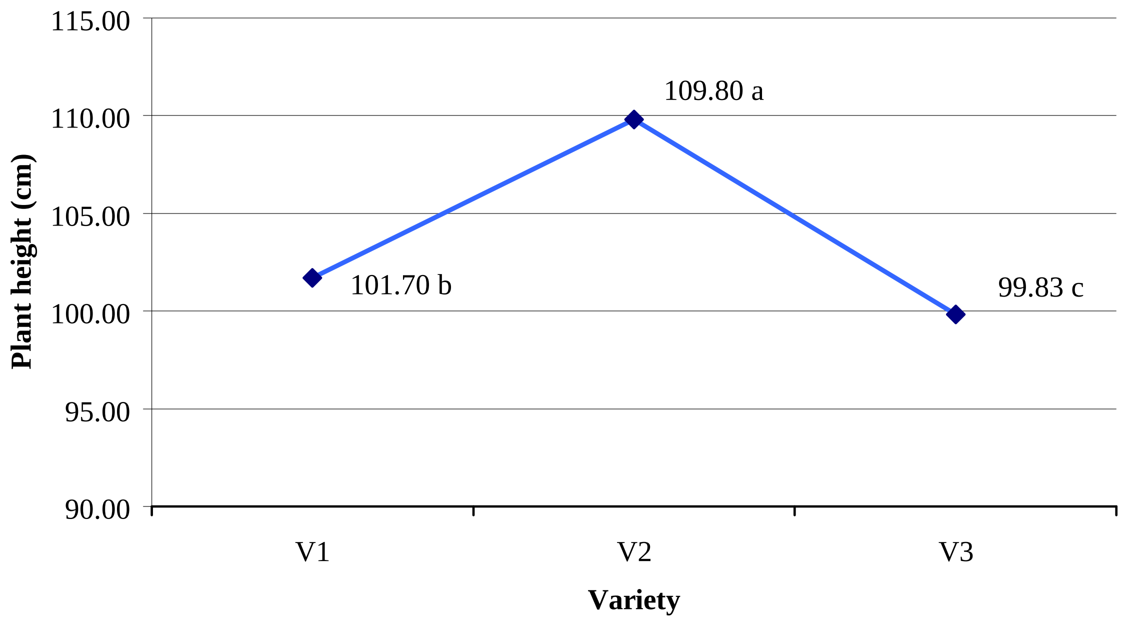
The analysis of variance data on plant height at harvest in Appendix I revealed significant difference due to the tested rice varieties at *Boro* season of 2012–13 (Appendix I and Fig. 4.1). Among the varieties, the variety BRRI hybrid dhan3 had taller (108.80 cm) than BRRI hybriddhan2 (101.70 cm) while the variety Heera 4exhibited the shortest plant (99.83 cm).

Plant height is a growth character of rice which contribution is additional proficient to enhancing the straw yield incase of the tallest plant construct the elevated yield of straw. Such the fact is the plant height act as a most imperative straw yield contributing characters. These result revealed that the genotypic characteristics of BRRI hybriddhan3 had highly adaptable with the regional condition of the AEZ–28 which eventually construct better growth than BRRI hybriddhan2 and Heera4. So the varation in plant height of the present study was found might be due the genetic make up to the studied varieteis and also might be due to the better shoot elongation and higher photosynthesis was also taken by BRRI hybriddhan3. Similarly, Hossain *et al*. (2014b) who studied on five rice cultivars (one hybrid: WR96, three modern: BR 16, BR 26, and BRRI dhan27, and one local: Pari) and found significant variation in plant height might be due to the variation in genetic variability and adaptability in studied area. Statistically similar findings were also obtained by Haque and Pervin (2015a and 2015b); Shaha (2014); Sarkar (2014); Roy et al. (2014); Islam *et al*. (2013) and many workers also found significant and genetic variation among the varieties regarding plant height. Mahamud *et al*. (2013), who found that the variation in plant height was indicated by the differentiation of genotypic characters and their genetic makeup also which result also supported the findings of Hossain *et al*. (2008).

Number of effective tillers hill^{-1}

Effective tiller that i.e. ear bearing tillers is an indispensable stricture which affect the yield of rice in case of the rice plant may produce a number of tillers during its early growth stages but not all of them become effective i.e., they do not bear panicles. So, this character is directly related to yield of rice. Number of effective tillers hill^{-1} had statistically significant due to varieties (Appendix I and Fig. 4.2). Among the varieties, BRRI hybriddhan3 produced significantly the maximum effective tillers (25.14) than BRRI hybriddhan2 (23.89) while Heera4 produced minimum number of effective tillers hill^{-1} (21.89). Present result revealed that BRRI hybriddhan3 produced greater number of effective tillers hill^{-1} than other cultivars for their genetic make up. Similarly, Rahman and Bulbul (2014) reported that the significantly higher number of bearing tillers hill^{-1} was recorded from BRRI hybriddhan2 and the lowest in BRRI dhan29 which might be due to the genetic variation of the studied varieties. The response of difference in producing hearing tillers hill^{-1} might be due to the variation in genetic make up of the variety where also reported by Haque and Pervin (2015a and 2015b); Singh *et al*. (2014); Shaha (2014); Sarkar (2014); Roy *et al*. (2014); Mondal and

Puteh (2013); Garba *et al*. (2013); Alam *et al*. (2012) and more researchers of the home and abroad.



V_1: BRRI hybrid dhan–2, V_2: BRRI hybrid dhan–3 and V3: Heera–4

Fig. 4.1 Effect of varieties on plant height at harvest

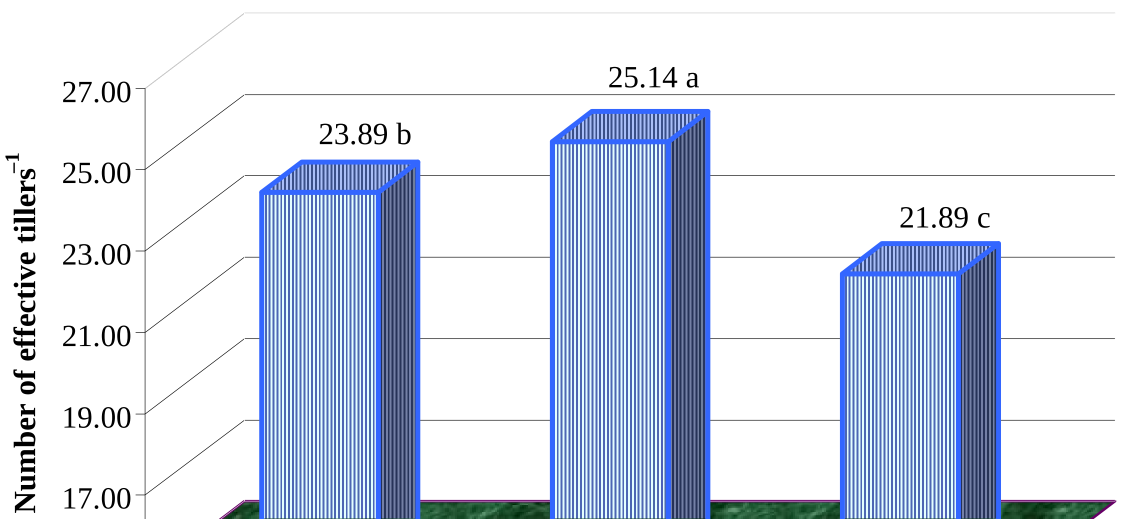


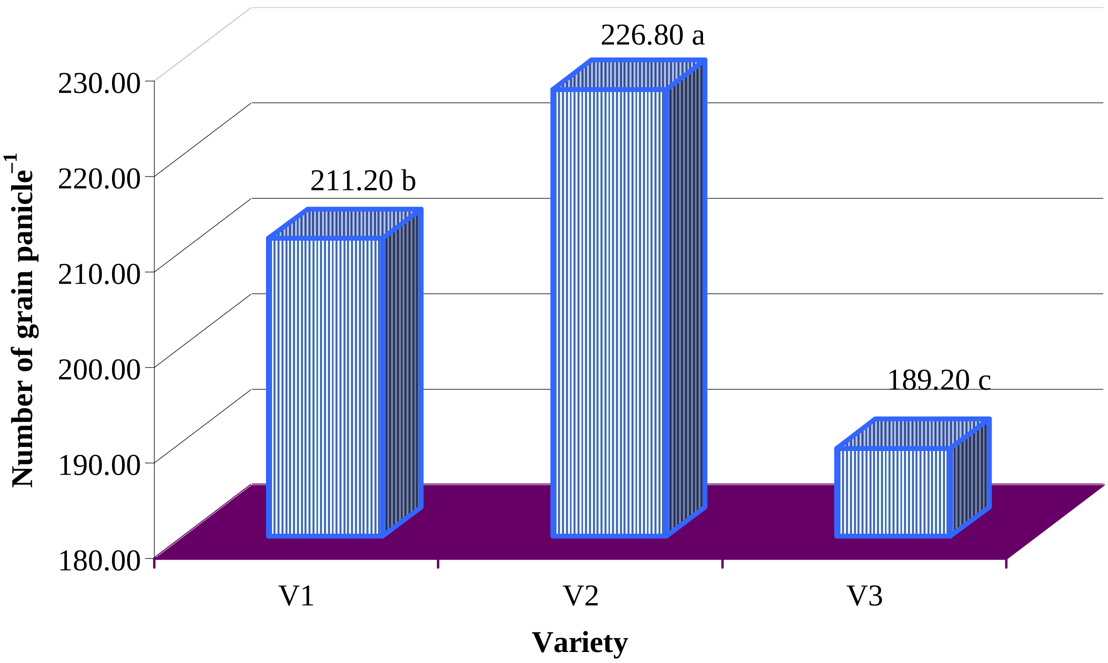
Fig. 4.2 Effect of varieties on number of effective tillers hill^{-1} at harvest

Number of grains panicle^{-1}

Genotypic performance of rice also exerted significant influence on number of grains panicle^{-1} (Appendix I and Fig. 4.3). The significant variation data from the Fig. 4.3, it was appeared that the maximum grains panicle^{-1} (226.80) was found from BRRI hybriddhan3 followed by BRRI hybriddhan2 (211.20). On the other hand, the minimum grains panicle^{-1} (189.20) was obtained from the genotype Heera 4 which was statistically differed from other local genotypes. Grains panicle^{-1} is the principal traits for enhancing the yield incase of more grains ensure the higher grain yield. The variation in grains production was found for the genetic variation of the studied genotypes and also the adaptability ratio with the studied regional condition. This was supported by Hossain *et al*. (2014b) reported that the both hybrid rice varieties Heera2 and Aloron produced the highest spikelets panicle^{-1} than that of BRRI dhan48 which might be due to lower sensitiveness of BRRI dhan48 to high temperature and low sunshine hour at grain filling stage compared to test hybrid varieties. The above findings was also similar to the present study. the variation in grains panicle^{-1} was recorded due to genotypic differences of varieties which were also similar to Haque *et al*. (2015); Shiyam *et al*. (2014); Rahman and Bulbul (2014); Garba *et al*. (2013); Rahman *et al*. (2013); Gevrek (2012); Sadeghi and Danesh (2011) and many other scientist of the country and abroad.

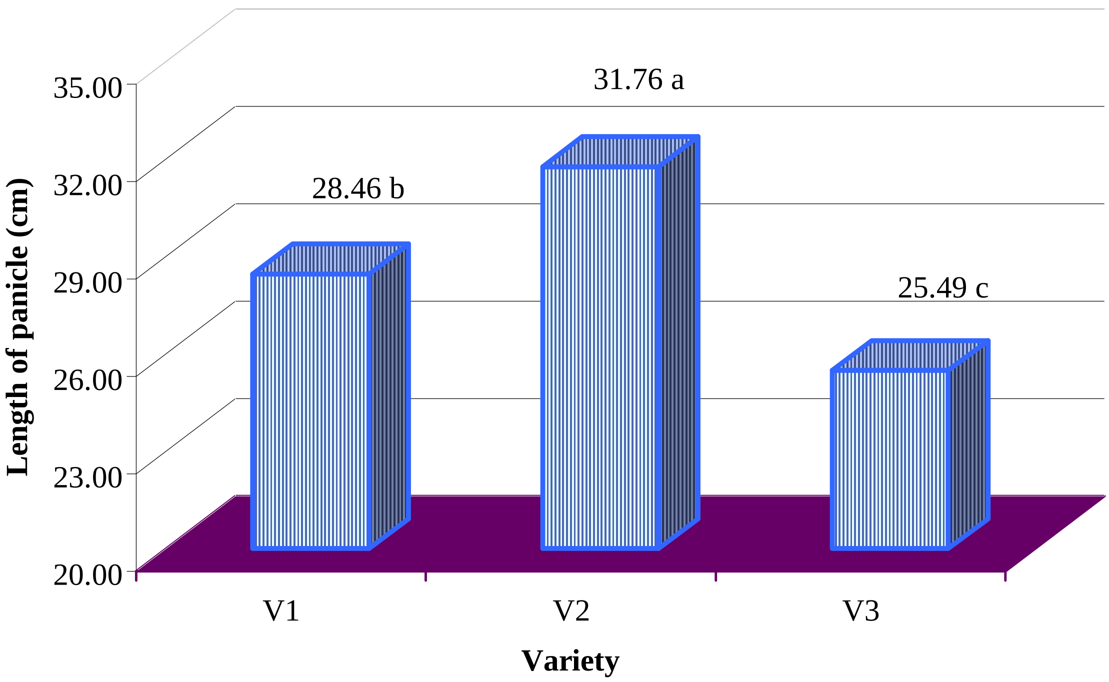
Panicle length

Length of panicle is a yield contributing characters of rice in case of the longest panicle fabricate more grains than shorter one which also make sure the greater yield. Analysis of variation data regarding length of panicle was significantly influenced by the studied genotypes (Appendix I and Fig. 4.4). From the Fig. 4.4, it was found that the genotype BRRI hybriddhan3 exhibited the longest panicle (31.76 cm) while BRRI hybriddhan2 produced the average medium length of panicle (28.46 cm) and Heera4 observed the shortest panicle (25.49 cm). These results revealed that the tested rice genotypes showed variation in panicle length might be due to the variation in their characteristics and also the variation in climatic factors of the studied region which also influence the varietal characteristics. This result is in agreement with the findings Hossain *et al*. (2014a and b); Rahman and Bulbul (2014); Hossaina *et al*. (2013); Sadeghi and Danesh (2011); Islam *et al*. (2007) and many other scientists. They also found variation in panicle length due to the variation in genetic make up of the varieties of rice and also the variation in climatic factors of the studied region.



V1: BRRI hybrid dhan–2, V2: BRRI hybrid dhan–3 and V3: Heera–4

Fig. 4.3 Effect of varieties on number of grains panicle^{-1} at harvest



V_1: BRRI hybrid dhan–2, V_2: BRRI hybrid dhan–3 and V_3: Heera–4

Fig. 4.4 Effect of varieties on length of panicle at harvest

Thousand–grain weight

Performance study of rice varieties had highly significant effect on 1000-grain weight where 1000–grain weight varied from 31.46 to 34.45 g (Appendix II and Table 4.1). Among the varieties, Heera produced thoughtlessly the higher weight of 1000-grain (34.45 g) due to larger size than BRRI hybriddhan3 (34.08 g) while BRRI hybriddhan2 registered the lower weight of 1000–grains (31.46 g) due to small sizes. Thousand grains weight represents grain size and it was ultimately related to grain yield. In that case, grain yield eventually depended on 1000-grain weight. The result regarding 1000-grain weight revealed that Heera 4 produced higher weight of 1000-grain than other genotypes in this study. This was found might be due to the genetic makeup of the particular genotype. Hossain *et al*. (2014 and 2014b) found similar result and they reported that 1000–grain weight differed significantly among the cultivars, which was also supported by Hossain *et al*. (2005 and 2008). Haque and Pervin (2015a and 2015b); Shaha (2014); Sarkar (2014); Rahman and Bulbul (2014); Garba *et al*. (2013) and many scientists of the home and abroad were also found significant variation in 1000–grain weight due to the variation in genetic make up of the variety. These results also revealed that the variety BRRI dhan44 had more efficient to produce bigger sizes grain than other varieties due to the maximum tillers, filled and total grain were achieved which result are also agreed to the findings of Alam *et al*., (2012); Sadeghi and Danesh (2011); Ashrafuzzaman *et al*. (2009).

Table 4.1 Effect of varieties on yield and yield attribues of *Boro* rice at harvest

Variety	Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
BRRI Hybriddhan2	31.46 c	7.208 b	7.682 b	14.89 b	48.40
BRRI Hybriddhan3	34.08 b	8.183 a	8.593 a	16.78 a	48.76
Heera 4	34.45 a	6.644 c	7.461 c	14.11 c	47.06
CV (%)	**2.47**	**1.50**	**1.99**	**1.08**	**1.66**
Level of significance	**	**	**	**	**ns**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability and NS= Not significant

Grain yield

Analysis of variance data on grain yield of the present study had also significant due to studied rice varieties where grain yield data significantly varied from 8.18 to 6.64 t ha^{-1} (Appendix II and Table 4.1). Among the varieties, the variety BRRI hybriddhan3 produced significantly the highest grain yield of 8.18 t ha^{-1} followed by BRRI hybriddhan2 (7.21 t ha^{-1}) while the lowest yield of grain (6.64 t ha^{-1}) was recorded in Heera–4. BRRI hybriddhan3 had higher than other two varieties might be attributed to the production of more effective tillers hill^{-1} along with longest panicle and also the more grains panicle^{-1}. Haque *et al*. (2015); Rahman and Bulbul (2014); Garba *et al*. (2013) and many workers reported that the varieties which produced higher number of effective tillers hill^{-1} and higher number of grains panicle^{-1} enhanced the grain yield. Similar results were also reported by Haque *et al*. (2015); Hossain *et al*. (2014a and 2014b); Islam *et al*. (2013); Aalm *et al*. (2012) in rice. From this result, it was observed that the variety, BRRI hybriddhan3 had remarkable superiority to growth, yield attributes and grain yield over the other varieties. This variation also found for their genetic difference among the varieties in this study. Similarly, Akter (2014); Rahman *et al*. (2013); Mondal and Puteh (2013); Ndjiondjop *et al*. (2012) reported that these variations in yield might be due to genetic make up of the varieties.

Straw yield

Responses of varieties on straw yield had also significant in this study where the straw yield significantly varied from 7.46 to 8.59 t ha^{-1} (Appendix II and Table 4.1). Among the varieties, the variety BRRI hybriddhan3 produced significantly the higher straw yield followed by BRRI hybriddhan2 (7.21 t ha^{-1}) while another variety Heera 4produced the lowest straw yield in the present study (Table 4.1). These result revealed that the yield of straw differed significantly due to cultivars which indicated there was a genetic variation among the varieties. Haque and Pervin (2015b) reported that the straw yield was significantly influenced due to the effect of varieties where the highest yield of straw (9.66 t ha^{-1} was obtained from the variety BRRI dhan51 while Shakorkura and Moulata produced of 8.60 and 8.33 t ha^{-1}, respectively. The variation in straw yield due to genetic make up were also examined by Singh *et al*. (2014); Sarkar (2014); Kaho *et al.* (2003) also found significant variation in straw yield due to the variation in genetic make up of their studied varieties.

Biological yield

Biological yield is the summary of both grain and straw yield which indicated the economical yield of any crop. Analysis of variance data in respect of biological yield had highly significant due to studied genotypes (Appendix II and Table 4.1). From the Table 4.1, it was found that the biological yield varied from 14.11 to 16.78 t ha^{-1} where the higher values of biological yield was obtained from BRRI hybriddhan3 and lower values was registered from the HYV variety Heera4. Results revealed that biological yield differed significantly among the rice varieties might be due to the genetic make up of the studied genotypes which result was also supported by Uddin *et al*. (2011) who reported that the BRRI dhan44 produced higher biological yield than Lalchicon. Similarly, Hossain *et al*. (2014a and 2014b); and many researchers found significant variation in biological yield of T. aman rice which findings were similar to the present study. The variation in biological yield was also found due to the variation in grain and straw yield in this study which results are also in line with the findings of

Harvest index

The data of harvest index after harvest did not vary significant variation among the varieties where harvest index non–significantly varied from 47.06 to 48.76% among the selected rice varieties (Appendix II and Table 4.1). However, BRRI hybriddhan3 showed the highest harvest index than BRRI hybriddhan2 (48.40%) and Heera 4(47.06%) but they were numerically/statistically identical (Table 4.1). These results revealed that harvest index did not differed significantly due to selected rice varieties in this study. Haque and Pervin (2015a and 2015b); Hossain *et al*. (2014b); Roy *et al*. (2014) and many worker also found significant variation in harvest index due to the effect of varieties where genetic variation had highly effective for the variation in HI. Therefore, the findings of the present study were similar with their findings.

4.1.1.2 Integrated nutrient management

4.1.1.2.1 NPK content in rice and straw

NPK content in grain

However, N and P content in grain varied significantly due to the effect of variety where K content did not vary significant (Appendix III). As a result, K content in grain of all tested varieties were numerically identical due to non significant variation while it was varied from 0.246% (Heera4) to 0.324% (BRIR Hybriddhan3). Incase of N content in grain, the grain of BRRI hybriddhan3 showed the highest N content (1.064%) followed by BRRI hybriddhan2 (0.964%) while it was the lowest (0.798%) in Heera4. Similarly, P content in grain had highest (0.377%) in BRRI hybriddhan3 while Heera4 obtained t he lowest P content (0.270%) in grain (Table 4.2). Akter (2014) also found that the variety Sada *Boro* and Chola *Boro*, two local cultivars were found very high in grain nutrient content compared to other test cultivars.

NPK content in straw

Varietals effect of the present study on NPK content in straw had statistically significant where N content varied from 0.598 to 0.864%, P content varied from 0.174 to 0.247% and K content varied from 1.177 to 1.250% (Appendix III and Table 4.2). From the Table 4.2 it was found that the highest values were recorded from the variety BRRI hybriddhan3 and the lowest values were obtained from the variety Heera4 while BRRI hybriddhan2 showed average medium NPK content (0.762, 0.198 and 1.201%, respectively) in this study (Table 4.2). Akter (2014) found that Chola *Boro*, IRATOM 24 and BR 14 are three high straw–K containing varieties having breeding potentials to make our future rice plant strong.

Table 4.2 Effect of varieties on nutrient content (NPK) of grain and straw of *Boro* rice at harvest

Variety	Nutrient content of grain (%)			Nutrient content of straw (%)		
	N	P	K	N	P	K
BRRI Hybriddhan2	0.964 b	0.325 b	0.250	0.762 b	0.198 b	1.201 b
BRRI Hybriddhan3	1.064 a	0.377 a	0.324	0.864 a	0.247 a	1.250 a
Heera 4	0.798 c	0.270 c	0.246	0.598 c	0.174 c	1.177 b
CV (%)	**1.34**	**0.45**	**0.26**	**1.90**	**0.64**	**0.96**
Level of significance	**	**	**NS**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability and NS= Not significant

4.1.1.2.2 NPK uptake in rice and straw

NPK uptake by grain

Nutrient uptake by grain was significantly influenced due to the effect of variety (Appendix IV) where the highest N uptake by grain (87.14 kg ha^{-1}) was found from the variety BRRI hybrid dhan3 and lowest N uptake by grain (53.54 kg ha^{-1}) was obtained from Heera4 (Table 4.3). From the Table 4.3, it was also found that the variety BRRI hybriddhan3 also produced significantly the highest P uptake by grain (30.94 kg ha^{-1}) compare BRRI hybriddhan2 (23.47 kg ha^{-1}) and Heera4 (18.11 kg ha^{-1}). Similarly, the highest K uptake by grain (26.72 kg ha^{-1}) was obtained in BRRI hybriddhan3 and lowest K uptake by grain (16.45 kg ha^{-1}) was produced rom Heera4 while BRRI hybriddhan2 showed the average medium K uptake by grain (18.10 kg ha^{-1}). Similarly, Akter (2014) reported that the nutrient uptake by grain showed variation due to the genetic variation which was fully supported the present findings.

Table 4.3 Effect of varieties on nutrient uptake (NPK) of grain and straw of *Boro* rice at harvest

Variety	Nutrient uptake by grain (kg ha^{-1})			Nutrient uptake by straw (kg ha^{-1})		
	N	P	K	N	P	K
BRRI Hybriddhan2	69.68 b	23.47 b	18.10 b	58.70 b	15.27 b	92.32 b
BRRI Hybriddhan3	87.14 a	30.94 a	26.72 a	74.30 a	21.30 a	107.5 a
Heera 4	53.54 c	18.11 c	16.45 c	45.00 c	13.08 c	87.92 c
CV (%)	**1.94**	**1.88**	**1.04**	**1.45**	**1.88**	**1.45**
Level of significance	**	**	**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

NPK uptake by straw

N, P and K uptake by straw of the pesent study significantly varied from 45.00 to 74.30 kg ha^{-1} (N), 13.08 to 21.30 kg ha^{-1} (P) and 87.92 to 107.50 kg ha^{-1} (K), respectively (Appendix IV and Table 4.4). Above significant variation result of Table 4.3 revealed that BRRI hybriddhan3 showed the above highest values and Heera 4showed the above lowest values while BRRI hybriddhan2 always prodcued statistically average medium NPK (57.70, 15.27 and 92.32 kg ha^{-1}, respectively) content by straw (Table 4.4). The above variation in NPK uptake was found due to the variation in genetic make up of the studied varieties while Akter (2014) found same observation in her study.

4.1.1.2.3 NPK content in postharvst soil

After harvest, the NPK content of the postharvest soil was significantly influenced due to the effect of varieties (Appendix V). Among the varieties, BRRI hybriddhan3 BRRI hybriddhan2 recorded the highest and statistically identical N content in postharvest soil (0.0876 and 0.0804 ppm, respectively) while Heera4 produced the lowest N content in postharvest soil (0.0600 ppm). Similarly, P content in postharvest soil was the highest (35.68 ppm) in BRRI hybriddhan3 followed by BRRI hybrid dhan2 (32.35 ppm) while Heera4 obtained the lowest P content (26.68 ppm). Incase of K content in postharvest soil, BRRI hybriddhan3 also recorded significantly the highest value of 0.0463 meq 100 g^{-1} and Heera4 showed the lowest value of 0.0337 meq 100 g^{-1} (Table 4.4). Jun *et al*. (2011) reported that Alfalfa–rice and rye–rice rotation systems enhanced soil nitrogen content, promoted rice nitrogen absorption and significantly improved rice yield.

Table 4.4 Effect of varieties on nutrient content (NPK) in postharvest soil of the experimental field

Variety	NPK content in postharvet soil		
	N (ppm)	**P (ppm)**	**K (meq 100g^{-1})**
BRRI Hybriddhan2	0.0804 a	32.35 b	0.0432 ab
BRRI Hybriddhan3	0.0876 a	35.68 a	0.0463 a
Heera 4	0.0600 b	26.68 c	0.0337 b
CV (%)	**1.58**	**0.79**	**1.00**
Level of significance	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

4.1.2 Effect of irrigation treatment

4.1.2.1 Morpho–physiological, yield and yield attributes

Plant height

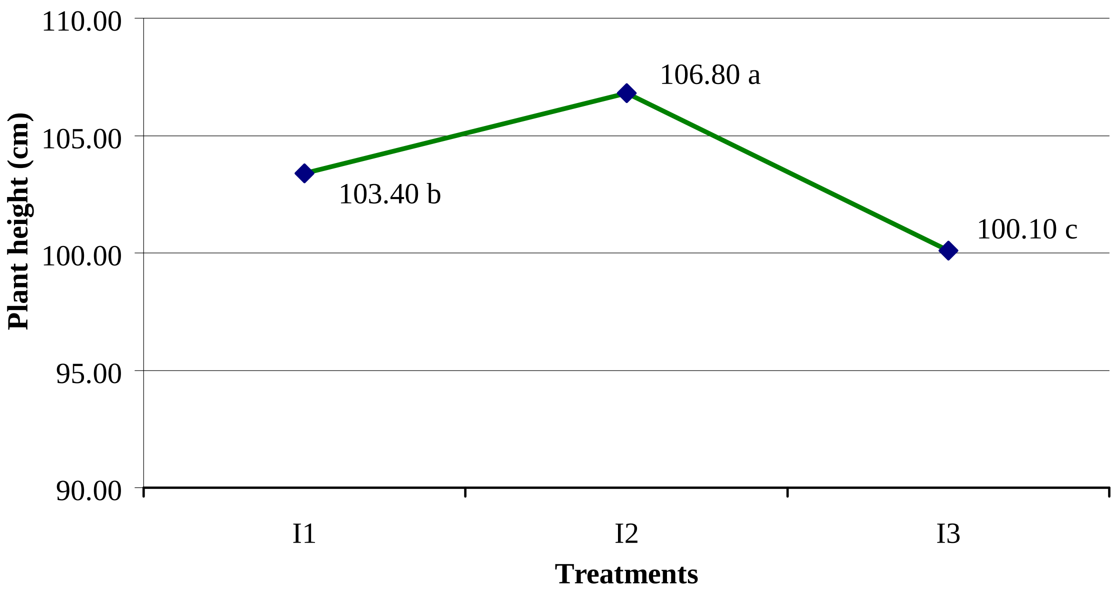
Plant height of the present study was significantly influenced due to the effect of irrigation (Appendix I). Plant height of the present study significantly varied from 100.10 to 106.80 cm due to the various treatments of irrigation system where highest value was for alternate wetting and drying (I_2) and the lowest value was for irrigation only at critical growth stage (I_3). Continuous wetting showed the average medium height of 103.40 cm (Fig. 4.5). This result revealed that both the available water and water stress imposed at the vegetative stage, hampered the crop growth and development which reduced the final plant height while alternate wetting and drying enhance the crop growth and ensure the final height of plant due to time to time getting possibility of water. Thus, the findings of the present study were also similar to the research work of Mannan *et al*. (2012) in rice during *Boro* season. They also found that AWD system had more advantageous than continuous wetting or flooding. Thakur *et al*. (2011) also found that the rice plants grown under alternate wetting and drying were 22 and 24% taller than rice plants grown under continuous flood.

Number of effective tillers hill^{-1}

Different types of irrigation showed significant variation on the production of effective or panicle bearing tillers hill^{-1} where it was significantly ranges from 21.71 to 25.24 due to irrigation treatments (Appendix I). The highest number of effective tillers hill^{-1} was noticed from the treatment I_2 (alternate wetting and drying) followed by T_1: continuous wetting (23.97) while it the lowest number of effective tillers hill^{-1} was found from the treatment I_3 (Fig. 4.6). From the above results, it was found that the AWD system was the most advantageous system than continuous wetting and irrigation at critical growth stage which might be due to the available water and water stress imposed at the vegetative stage, hampered the crop growth and development which reduced the number of total and effective tillers. The above findings of the present study was fully agreed by Rahman *et al*. (2013) who also found that the tillers m^{-2} was slightly higher in MSD than flooded and EMSD treatments. This result was also consigned with the findings of Akter (2014); Mannan *et al*. (2012); Thakur *et al*. (2011) and many other workers.

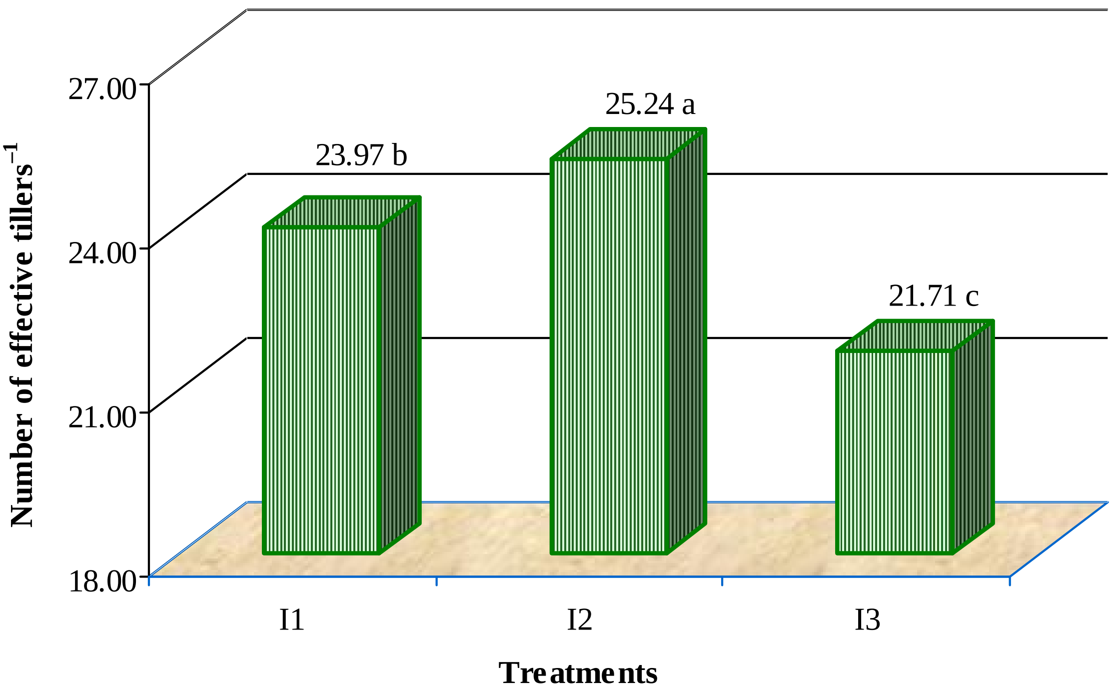
Number of grains panicle^{-1}

Irrigation management practices exhibited the significant difference for the characters number of grains panicle^{-1} (Appendix I). Among the irrigation treatments, treatment I_2: alternate wetting and drying produced the highest number of grains panicle^{-1} (221.90) followed by the treatment I_1: continuous wetting (207.60) while it was the lowest (197.80) in treatment I_3: irrigation only at critical growth stage (Fig. 4.7). Similarly, Karim *et al* (2014) also found significant variation due to sprinkler irrigation, alternate wetting and drying (AWD) and flood irrigation where the highest number of grains panicle^{-1} was observed in AWD produced more grains than flood irrigation method. Akter (2014) also found that the number of filled grains panicle^{-1} was recorded more in AWD than CF condition.



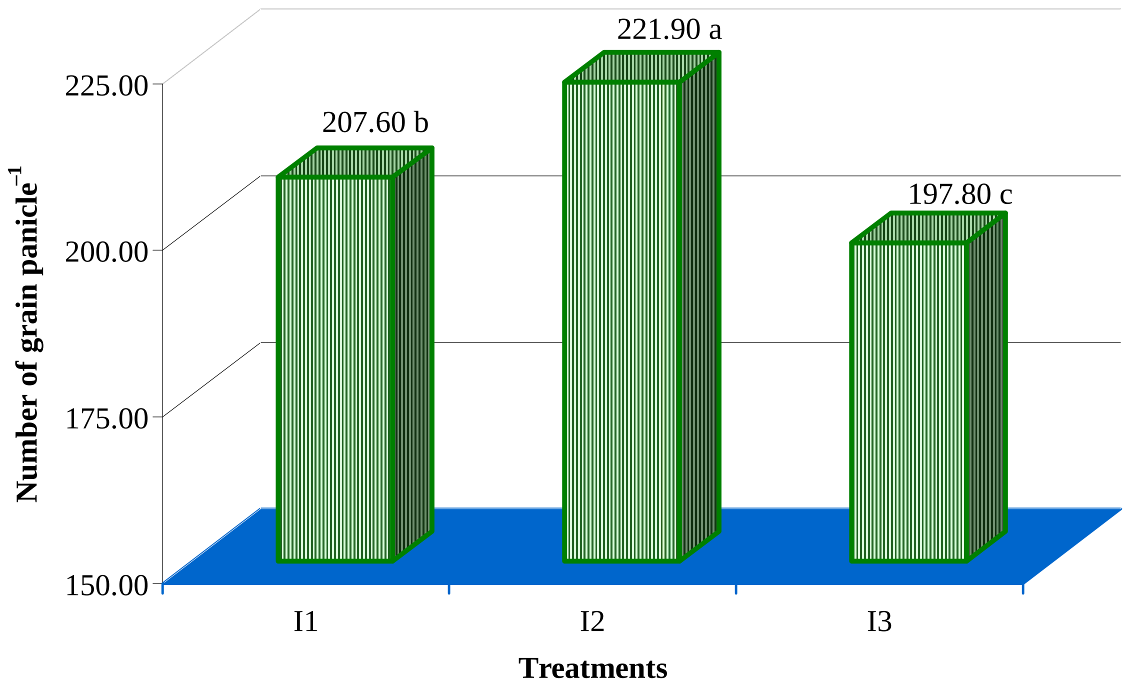
I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

Fig. 4.5 Effect of irrigation management system on plant height at harvest



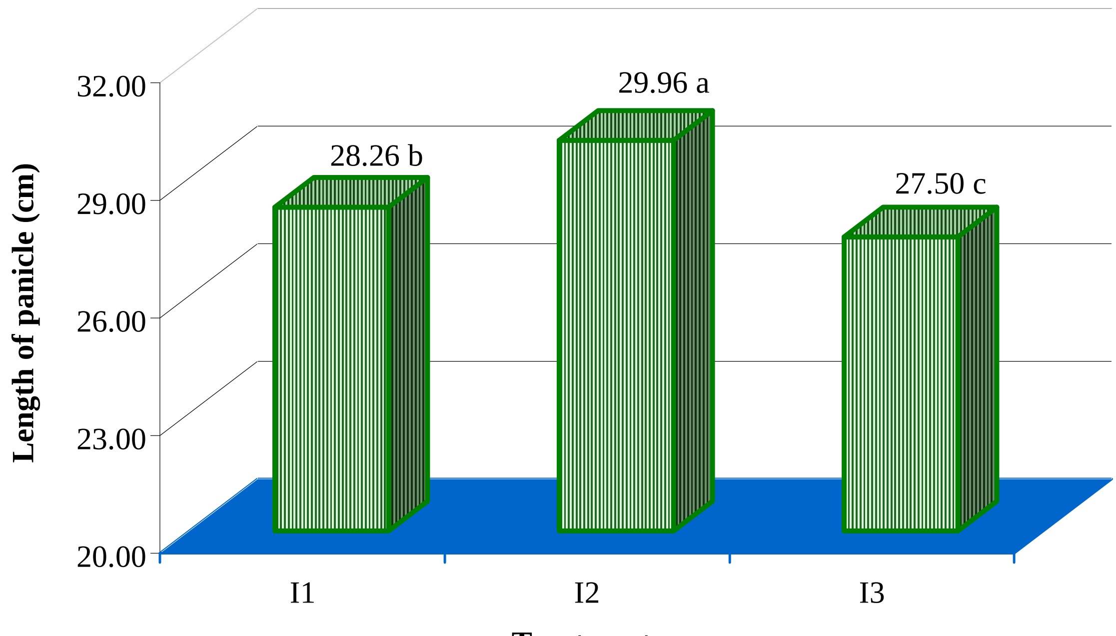
I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

Fig. 4.6 Effect of irrigation management system on number of effective tillers hill^{-1} at harvest



I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

Fig. 4.7 Effect of irrigation management system on number of grains panicle at harvest



I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

Fig. 4.8 Effect of irrigation management system on length of panicle^{-1} at harvest

Panicle length

Continuous wetting, alternate wetting and drying and irrigation only at critical growing stage significantly influenced the panicle length (Appendix I). The highest length of panicle (29.96 cm) was recorded from irrigation treatment of I_2 (alternate wetting and drying) while it was the lowest (27.50 cm) in irrigation only at critical growth stage (I_3). So, the length of panicle showed the ranges from 27.50 to 29.96 cm (Fig. 4.8). The length of panicle had longest in AWD methods which might be due to the higher vegetative growth and development of plant which ultimately produced the longest panicle. Similarly, delay or critical growth stage irrigation hampered the plant growth and reduce the length of panicle. The findings of Amiri *et al*. (2009) was also similar with the present findings in case of they also found significant variation in length of panicle due to irrigation method where delay irrigation significantly reduced the panicle length.

Thousand–grain weight

A significant variation due to the effect of irrigation system was obtained in respect of thousand–grain weight (Appendix II). The highest weight of 1000–grain (35.72 g) was found in treatment I_2: alternate wetting and drying which was statistically differed from the irrigation treatment I_1: continuous wetting and I_3: irrigation only at critical growth stage (33.42 and 30.85 g, respectively) where I_1 showed the better performance than I_3 regarding the size of grain (Table 4.5). Similarly, significant variation in 1000–grain weight due to irrigation methods were also found by Karim *et al* (2014); Ismaila *et al*. (2014); Akter (2014); Tilahun–Tadesse *et al*. (2013); Sadeghi and Danesh (2011); Fard *et al*. (2010); Rezaei *et al*. (2009) and some other workers of the home and abroad. Among them, most of the scientists found that the AWD had more efficient than CF.

Grain yield

Analysis of variance data on grain yield are presented in Appendix II indicated significant difference in this study (Appendix II). Grain yield of the present study significantly varied from 6.92 to 7.90 t ha^{-1} where grain yield was the highest in irrigation treatment of I_2 (alternate wetting and drying) and the lowest in I_3 (irrigation only at critical growth stage) while I_1 (continuous wetting) showed the average medium grain yield of 7.21 t ha^{-1} (Table 4.5). Awio *et al*. (2015) also found significant variation in grain yield due to alternate wetting and drying (AWD), continuous flooding (CF) and continuous drying (CD) where higher yield gain was observed under the water–saving technology alternate wetting and drying compared to continuous flooding or drying. Therefore, the findings of the present study were similar to Awio *et al*. (2015) which results were also supported by Omwenga *et al*. (2014); Karim *et al* (2014); Akter (2014) and other scientists of the home and abroad. Besides, the grain yield had highest in AWD condition which might be due to the variation in effective tillers, number of grains panicle^{-1} and larger grain size. Such the same observation in grain yield of the present study were also reported by Tilahun–Tadesse *et al*. (2013); Rezaei *et al*. (2013); Rahman *et al*. (2013); Al Fakhrul Islam *et al*. (2013) and other workers.

Table 4.5 Effect of water regime treatments on yield and yield attribues of *Boro* rice at harvest

Irrigation treatments	Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
I_1	33.42 b	7.212 b	7.797 b	15.01 b	48.00 b

I_2	35.72 a	7.899 a	8.373 a	16.27 a	48.51 a
I_3	30.85 c	6.924 c	7.567 c	14.49 c	47.72 c
CV (%)	**2.47**	**1.50**	**1.99**	**1.08**	**1.66**
Level of significance	**	**	**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage.

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

Straw yield

The data of straw yield varied significantly due to the effect of irrigation system in this study (Appendix II). The significant variation data of straw yield are presented in Table 4.5 where it was found that the highest yield of straw (8.38 t ha^{-1}) was taken from the treatment I_2 (alternate wetting and drying) followed by I_1: continuous wetting (7.80 t ha^{-1}) while irrigation only at critical growth stage (I_3) obtained the lowest yield of straw (7.57 t ha^{-1}). Similarly, Karim *et al* (2014) also found insignificant variation on straw yield due to the effect of irrigation where AWD had more effective than CF. Rahman and Bulbul (2014) also found that the maximum straw yield was found from the AWD system than CR. The findings of the present study was also agreed by the findings of Juraimi *et al*. (2009); Rai and Kushwaha (2008) where all of them were found significant variation in straw yield due to irrigation system.

Biological yield

Appendix II revealed that there was a significant variation in biological yield among the various treatments of the studied irrigation system (Appendix II). Biological yield is a total of grain and straw yield. As a result, irrigation treatment of I_2 (alternate wetting and drying) showed the highest straw yield (16.27 t ha^{-1}) followed by I_1: continuous wetting (15.01 t ha^{-1}) while the lowest biological yield was found from the treatment I_3: irrigation only at critical growth stage (Table 4.5). Biological yield is a combined contribution of yield components such as number of tillers hill^{-1}, plant height, number of grains spike^{-1} and 1000–grain weight. Therefore, the biological yield had highest in AWD system than CW and ICGS which might be due to the more yield of grain and straw. Such the similar observation was also reported by Galavi and Moghaddam (2012) while well–watered treatment (D_1) produced higher biological yield as compared to biological yield of other treatments. The findings of Sürek and Beser (199) also supported the present findings.

Harvest index

Harvest index of the present study was also significantly affected by the effect of irrigation where it was varied from 47.72 to 48.00% (Appendix II and Table 4.5). From the Table 4.5, it was found that the highest harvest index was obtained in I_2 (alternate wetting and drying) and the lowest was recorded in I_3 (Irrigation only at critical growth stage). This result revealed that the AWD irrigation system had more significant than other treatments of the study while Galavi and Moghaddam (2012) also found significant variation in HI. They found that significantly the maximum harvest index was obtained in well–watered treatment compared other treatments of the study. Rahman and Bulbul (2014) also found that alternate wetting and drying system irrigation showed the highest HI than continuous flooding irrigation.

4.1.2.2 Integrated nutrient management

4.1.2.2.1 NPK content in rice and straw

NPK content in grain

The data of nutrient (NPK) content in grain showed significant variation due to the effect of irrigation system where alternate wetting and drying (I_2) showed the better performance than that of other irrigation system (Appendix III). As a result, treatment I_2 showed significantly the highest content of N, P and K in grain (1.017, 0.350 and 0.307%, respectively) followed (0.941, 0.326 and 0.271%, respectively) by I_1 (continuous wetting) while irrigation only at critical growth stage exhibited the lowest N, P and K content in grain (0.868, 0.297 and 0.243%, respectively) (Table 4.6). Similarly, Baker (2009) also found that the nutrient content in grain had highest in AWD than other irrigation system of the study.

Table 4.6 Effect of water regime treatments on nutrient content (NPK) of grain and straw of *Boro* rice at harvest

Irrigation treatments	Nutrient content of grain (%)			Nutrient content of straw (%)		
	N	P	K	N	P	K
I_1	0.941 b	0.326 b	0.271 b	0.740 b	0.192 b	1.195 b
I_2	1.017 a	0.350 a	0.307 a	0.816 a	0.237 a	1.240 a
I_3	0.868 c	0.297 c	0.243 c	0.668 c	0.190 b	1.193 b
CV (%)	**1.34**	**0.45**	**0.26**	**1.90**	**0.64**	**0.96**
Level of significance	**	**	**	**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

NPK content in straw

N, P and K content in grain had statistically significant due to irrigation management practices (Appendix III). In case of N content in straw, treatment I_2: alternate wetting and drying exhibited the highest content of N (0.816%) while it was statistically differed from I_1: continuous wetting (0.740%) and I_3: irrigation only at critical growth stage (0.668%) where I_1 perform better than T_3 (Table 4.6). In case of P content in straw, however, I_2 showed the highest P content (0.237%) and significantly different from other treatments but rest of the both treatments were showed the lowest and numerically identical P content (0.192 and 0.190%, respectively). Irrigation treatment also produced statistically similar observation in respect of K content where K content of 1.195 was for I_1, 1.240% was for $I_2$and 0.193% was for I_3 (lowest). Similarly, Akter (2014) also found significant variation in nutrient content where the nitrogen content in straw was recorded 0.72% in AWD system and that of 0.68% was recorded in CF system.

4.1.2.2.2 NPK uptake in rice and straw

NPK uptake by grain

Nutrient uptake by grain differed significantly among the irrigation treatments where I_2 perform better than I_1 and I_3 (Appendix IV). As a result, alternate wetting and drying (I_2) recorded the highest N uptake by grain (80.66 kg ha^{-1}) followed I_1: continuous wetting (68.60 kg ha^{-1}) while irrigation only at critical growth stage noticed the lowest (61.09 kg ha^{-1}) N uptake by grain (Table 4.7). Similarly, I_2 further recorded the highest P and K uptake by rice (27.84 and 24.52 kg ha^{-1}, respectively) than that of I_1 (23.78 and 20.91 kg ha^{-1}, respectively) and I_3 (19.81 and 16.94 kg ha^{-1}, respectively). Akter (2014) also found that the most of the nutrient uptake in grain had highest in AWD condition than that of CF system while Rahman *et al*. (2013) supported the present findings. Similarly, Belder *et al*. (2005) found that the nutrient uptake had higher in an aerobic system than in a flooded rice system.

NPK uptake by straw

The recording data of N, P and K uptake by straw after harvest varied significantly by the effect of irrigation treatments in this study (Appendix IV). The data of NPK uptake by straw in Table 4.7 indicated that all the irrigation treatments showed statistically significant variation with each other where treatment I_2: alternate wetting and drying noticed the highest N, P and K uptake by straw (68.58, 20.02 and 104.0 kg ha^{-1}, respectively) followed by I_1: continuous wetting (58.26, 15.13 and 93.33 kg ha^{-1}, respectively) while they were lowest (51.16, 14.50 and 90.39 kg ha^{-1}, respectively) in I_3: irrigation only at critical growth stage (Table 4.7). Similarly, significant variation in nutrient uptake had also found from the study of Akter (2014) where the nutrient uptake in straw had highest in AWD condition than that of CF system while Rahman *et al*. (2013); Belder *et al*. (2005) agreed the present findings.

Table 4.7 Effect of water regime treatments on nutrient uptake (NPK) of grain and straw of *Boro* rice at harvest

Irrigation treatments	Nutrient uptake by grain (kg ha^{-1})			Nutrient uptake by straw (kg ha^{-1})		
	N	P	K	N	P	K
I_1	68.60 b	23.78 b	19.81 b	58.26 b	15.13 b	93.33 b

I_2	80.66 a	27.84 a	24.52 a	68.58 a	20.02 a	104.0 a
I_3	61.09 c	20.91 c	16.94 c	51.16 c	14.50 c	90.39 c
CV (%)	**1.94**	**1.88**	**1.04**	**1.45**	**1.88**	**1.45**
Level of significance	**	**	**	**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

4.1.2.2.3 NPK content in postharvst soil

All the nutrient content (NPK) data in postharvest soil after harvest were statistically significant due to the effect of irrigation system except K content (Appendix V). As a result, all the irrigation system (continuous wetting, alternate wetting and drying and irrigation at critical stage) were obtained statistically identical K content in postharvest soil due to non significant variation. However, it was varied from 0.037 to 0.046 meq 100 g^{-1} (Table 4.8). Among other nutrient content, N content was the highest (0.0862 ppm) in the irrigation system of alternate wetting and drying (I_2) while continuous wetting (I_1) and irrigation at critical stage (I_3) did not vary significant for obtaining the N content in postharvest soil (0.0751 and 0.0667 ppm, respectively). In case of P content in postharvest soil, it was the highest (34.28 ppm) in alternate wetting and drying system (I_2) while it was significantly differed from continuous wetting (31.14 ppm) and irrigation only at critical growth stage (29.29 ppm) where $I_1 > I_3$ (Table 4.8). Significant variation in nutrient content of postharvest soil due to irrigation system were also reported by Das (2014); Tilahun–Tadesse *et al*. (2013); Hazelton and Murphy (2007); Al Fakhrul Islam *et al*. (2013) and other scientists of home and abroad while Tilahun–Tadesse *et al*. (2013) found that the pH 6.07, organic matter content 1.10%, total N 0.055%, available P 3.8 ppm, exchangeable K 0.24 me% and available S 12.56 ppm had highest under AWD contrition than CF and this findings also supported by Al Fakhrul Islam *et al*. (2013); Baker (2009) and Pangga *et al*. (2000).

Table 4.8 Effect of water regime treatments on nutrient content (NPK) in postharvest soil of the experimental field

Irrigation treatments	NPK content in postharvet soil		
	N (ppm)	P (ppm)	K (meq $100g^{-1}$)
I_1	0.0751 b	31.14 b	0.0406
I_2	0.0862 a	34.28 a	0.0457
I_3	0.0667 b	29.29 c	0.037
CV (%)	**1.58**	**0.79**	**1.00**
Level of significance	**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability.

4.1.3 Interaction effect of varieties and irrigation treatment

4.1.3.1 Morpho–physiological, yield and yield attributes

Plant height

Analysis of variance data for plant height at harvest in Appendix I indicated significant variation due to the interaction effect of varieties and irrigation treatments where plant height varied from 95.89 to 112.0 cm (Appendix I and Table 4.9). Among the interaction treatments, the plant of BRRI hybriddhan3 grown under alternate wetting and drying (V_2I_2) exhibited the highest plant height followed (109.40 cm) by same variety grown under continuous wetting (V_2I_1) and significantly differed from other all interaction treatments. On the other hand, the growing plant of Heera4 under irrigation only at critical growth stage (V_3I_3) noticed the lowest plant height which was also statistically differed from other interaction treatments of the study. However, interaction treatment of V_2I_3 (105.10 cm) was statistically identical to V_1I_2 (104.80 cm) and V_3I_1 (99.89 cm) was statistically similar to V_1I_3 (99.15 cm) in this study (Table 4.9).

Number of effective tillers hill^{-1}

Number of effective tiller at harvest was also statistically significant due to the interaction effect of varieties and irrigation treatments where it was significantly varied from 19.50 to 26.87 (Appendix I and Table 4.9). The number of effective tillers hill^{-1} was the highest in BRRI hybrid dhan3 grown in alternate wetting and drying condition (V_2I_2) while it was significantly difference from other all interaction treatments. Similarly, the variety Heera4 grown under irrigation only at critical growth stage (V_3I_3) showed the lowest number of effective tillers hill^{-1} which was also statistically differed from other all interaction treatments. However, interaction treatment of V_2I_3 (22.83) were statistically identical to V_1I_3 (22.80), and V_3I_1 (22.60) while V_1I_1 and V_3I_2 were produced same (23.57) number of effective tillers hill^{-1} (Table 4.9).

Table 4.9 Interaction effect of varieties and water regime treatments on plant height, number of effective tillers, length of panicle and number of grains panicle^{-1} of *Boro* rice at harvest

Variety × treatments		Plant height (cm)	No. of effective tillers hill^{-1}	Length of panicle (cm)	No. of grains panicle^{-1}
BRRI Hybriddhan2	I_1	101.0 e	23.57 d	28.11 e	207.7 d
	I_2	104.8 c	25.30 c	30.11 d	223.0 c
	I_3	99.15 f	22.80 e	27.16 f	203.0 e
BRRI Hybriddhan3	I_1	109.4 b	25.73 b	31.66 b	228.3 b
	I_2	112.0 a	26.87 a	33.03 a	244.0 a
	I_3	105.1 c	22.83 e	30.58 c	208.0 d
Heera 4	I_1	99.89 f	22.60 e	25.00 h	186.7 g
	I_2	103.7 d	23.57 d	26.73 g	198.7 f
	I_3	95.89 g	19.50 f	24.74 i	182.3 h
CV (%)		**0.78**	**0.64**	**0.75**	**0.84**
Level of significance		**	**	**	*

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. * and **= Significant at 5% and 1%, respectively level of probability

Number of grains panicle^{-1}

A significant variation due to the interaction effect of varieties and irrigation treatments was found for number of grains panicle^{-1} (Appendix I). The significant variation data of the number of grain panicle^{-1} have been presented in Table 4.9 where it was the maximum (244.0) in BRRI hybriddhan3 while it was grown under alternate wetting and drying condition (V_2I_2) and it was significantly different from other interactions. Similarly, the variety Heera4 grown under irrigation only at critical growth stage (V_3I_3) produced the minimum number of grains panicle (182.30). From the Table 4.9 it was also found that the interaction treatment of V_2I_3 (208.0) did not differed significantly with V_1I_1 (207.70). So, the number of grain panicle^{-1} significantly varied from 182.30 to 244.0 in this study (Table 4.9).

Panicle length

Significant variation due to the interaction effect of varieties and irrigation treatments was also observed in this study where length of panicle significantly varied from 24.74 to 33.03 cm (Appendix I and Table 4.9). The length of panicle had longest in BRRI hybrid dhan3 grown under the condition of alternate wetting and drying condition (V_2I_2) and it was statistically differed from other all treatment of interaction. On the other hand, the variety Heera4 produced the shortest panicle due to irrigation only at critical growing (V_3I_3).

Thousand–grain weight

Effect of interaction of HYV varieties and irrigation management system had statistically significant on 1000–grain weight and it was ranges from 29.05 to 36.93 cm (Appendix II and Table 4.10). However, 1000–grain weight was the highest in HYV variety Heera 4grown under alternate wetting and drying condition (V_3I_2) but numerically identical highest weight of 1000–grain was also observed in V_2I_2 (36.74 cm). The variety Heera 4 grown under continuous wetting (V_3I_1) showed the numerically second highest weight of 1000–grain (34.32 cm) while it was also numerically similar to V_2I_1 (34.11 cm). The interaction treatment of V_1I_1 (31.82 cm) and V_3I_3 (32.11 cm) were also numerically similar in this study. In the same way, the lowest weight of 1000–grain was recorded from the interaction treatment of V_1I_3 (BRRI hybrid dhan2 grown under irrigation only at critical growth stage condition).

Grain yield

From the Table 4.9, it was found that the yield of grain was significantly varied from 6.23 to 8.72 t ha^{-1} due to the interaction effect of HYV varieties and irrigation management system (Appendix II and Table 4.10). Table 4.10 also indicated that the highest yield of grain was produced from the HYV variety BRRI hybriddhan3 grown under alternate wetting and drying condition (V_2I_2) followed by the interaction treatment of V_2I_1 (8.18 t ha^{-1}). However, interaction treatment of V_1I_2 (7.67 t ha^{-1}) and V_2I_3 (7.65 t ha^{-1}) were also numerically similar and third highest yield in this study. Similarly, the lowest yield of grain was produced from the interaction effect of V_3I_3 (Heera 4× irrigation only at critical growth stage) which was also statistically different from other interaction. The above result indicated the ranking of V_2I_2 > V_2I_1 > V_1I_2 > V_2I_3 > V_3I_2 > V_1I_1 > V_1I_3 > V_3I_1 > V_3I_3.

Straw yield

Appendix I indicated significant variation for straw yield due to the interaction effect of HYV varieties and irrigation management system where the ranges of straw yield was 7.17 to 9.4 t ha^{-1} (Appendix II and Table 4.10). Table 4.10 showed that the highest yield of straw was recorded in V_2I_2 (HYV variety BRRI dhan3 × alternate wetting and drying) followed (8.66 t ha^{-1}) by the same variety grown under continuous wetting condition (V_2I_1) while interaction effect of V_1I_2 (8.11 t ha^{-1}), V_2I_3 (8.08 t ha^{-1}) and V_3I_2 (7.97 t ha^{-1}) were also obtained the third highest and numerically same yield of straw. Similarly, the interaction effect of V_1I_1 and V_1I_3 showed the numerically same and fourth highest yield of straw (7.49 and 7.44 t ha^{-1}, respectively) while interaction treatment of V_3I_1 (7.24 t ha^{-1}) and V_3I_3 (7.17 t ha^{-1}) were also obtained the numerically same and lowest yield of straw.

Table 4.10 Interaction effect of varieties and water regime treatments on yield and yield attribues of *Boro* rice at harvest

Variety × treatments		Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
BRRI Hybriddhan2	I_1	31.82 d	7.060 e	7.493 d	14.55 d	48.51 ab
	I_2	33.50 c	7.670 c	8.110 c	15.78 c	48.60 ab
	I_3	29.05 f	6.893 f	7.443 d	14.34 d	48.08 b

BRRI Hybriddhan3	I_1	34.11 b	8.180 b	8.660 b	16.84 b	48.57 ab
	I_2	36.74 a	8.717 a	9.037 a	17.75 a	49.09 a
	I_3	31.40 e	7.653 c	8.083 c	15.74 c	48.63 ab
Heera 4	I_1	34.32 b	6.397 g	7.237 e	13.63 e	46.91 d
	I_2	36.93 a	7.310 d	7.973 c	15.28 c	47.82 c
	I_3	32.11 d	6.227 h	7.173 e	13.40 e	46.46 d
CV (%)		**2.47**	**1.50**	**1.99**	**1.08**	**1.66**
Level of significance		*	*	**	**	**ns**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. **= Significant at 1% level of probability and ns= non significant.

Biological yield

Biological yield of the present study varied significantly (13.40 to 17.75 t ha^{-1}) due to the effect of interaction of HYV varieties and different system of irrigation (Appendix II and Table 4.10). From the above ranges, it was found that the highest biological yield was found in V_2I_2 and the lowest biological yield was obtained in V_3I_3. However, V_2I_1 showed the second highest biological yield (16.84 t ha^{-1}) but the interaction effect of V_1I_2, V_2I_3 and V_3I_2 (15.78, 15.74 and 15.28 t ha^{-1}, respectively) showed the third highest and numerically same biological yield. Similarly, the variety Heera 4grown under irrigation only at critical growth stage (V_3I_3) and continuous wetting (V_3I_1) showed the numerically identical and lowest biological yield (13.40 and 13.63 t ha^{-1}, respectively) followed by the variety BRRI hybriddhan2 grown under same both treatment (14.34 t ha^{-1} for V_1I_3 and 14.55 t ha^{-1} for V_1I_1).

Harvest index (HI)

Harvest index had also significant due to the interaction effect of varieties and irrigation system while it was significantly varied from 46.46 to 49.09% (Appendix II and Table 4.10). From the Table 4.10 it was appeared that the highest HI was noted from the interaction effect of V_2I_2 (BRRI hybrid dhan3 × alternate wetting and drying) which was closely followed by V_2I_3, V_1I_2, V_2I_1 and V_1I_1 (48.63, 48.60, 48.57 and 48.51%, respectively). On the other hand, the lowest HI recorded from the interaction treatment of V_3I_3 (Heera 4× irrigation only at critical growth stage) which was numerically identical (46.91%) to V_3I_1 (Heera 4× continuous wetting).

4.1.3.2 Integrated nutrient management

4.1.3.2.1 NPK content in rice and straw

NPK content in grain

NPK content in grain of the present study was significantly affected by the effect of interaction of the studied HYV varieties and irrigation system (Appendix III). In case of N content, BRRI hybriddhan3 grown under all irrigation systems of continuous wetting, alternate wetting and drying and irrigation only at critical growth stage (V_2I_1, V_2I_2 and V_2I_3) and BRRI hybrid dhan2 grown under alternate wetting and drying condition (V_1I_2) produced numerically identical and highest N content in grain (1.059, 1.084, 1.048 and 1.037%, respectively) where $V_2I_2 > V_2I_1 > V_2I_3 > V_1I_2$.. Among other interaction treatments, the HYV Heera 4grown under irrigation only at critical growth stage showed the lowest N content in grain (0.638%). Similarly, interaction treatment of V_2I_2 showed the highest P content in grain (0.395%) closely followed by V_2I_1 (0.374%) and followed by V_2I_3 (0.362%) while V_3I_3 noted the lowest P content in grain (0.223%). In case of K content in grain, the variety BRRI hybriddhan2 grown under alternate wetting and drying condition produced the highest (0.373%) and the variety Heera 4grown under irrigation only at critical growth stage condition obtained the lowest (0.223%) in this study (Table 4.11).

NPK content in straw

NPK content in straw was also significantly influenced due to the interaction (Appendix IV). The variety BRRI hybrid dhan3 grown under alternate wetting and drying condition showed the highest N (0.884%), P (0.273%) and K (1.276%) content in straw while it was closely followed by V_2I_3, V_1I_2 and V_2I_1 due to K content in straw (1.244, 1.238 and 1.230%, respectively) and statistically differed from other all interaction due to N and P content in straw. Similarly, the variety Heera 4grown under irrigation only at critical growth stage (V_3I_3) observed the lowest N, P and K content in straw (0.438, 0.155 and 1.158%, respectively) which was numerically identical to V_3I_1 (1.166%) due to K content and statistically differed from other interactions due to N and P content (Table 4.11).

Table 4.11 Interaction effect of varieties and water regime treatments on nutrient content (NPK) of grain and straw of *Boro* rice at harvest

Variety × treatments		Nutrient content of grain (%)			Nutrient content of straw (%)		
		N	P	K	N	P	K
BRRI Hybriddhan2	I_1	0.938 b	0.324 c	0.243 d	0.733 d	0.185 d	1.188 bcd
	I_2	1.037 a	0.345 bc	0.276 c	0.834 bc	0.235 b	1.238 ab
	I_3	0.918 b	0.306 cd	0.232 d	0.718 e	0.173 de	1.176 cd
BRRI Hybriddhan3	I_1	1.059 a	0.374 ab	0.327 b	0.859 b	0.227 b	1.230 abc
	I_2	1.084 a	0.395 a	0.373 a	0.884 a	0.273 a	1.276 a
	I_3	1.048 a	0.362 b	0.271 c	0.848 b	0.241 b	1.244 ab
Heera 4	I_1	0.827 c	0.279 d	0.242 d	0.627 f	0.163 e	1.166 d
	I_2	0.929 b	0.309 cd	0.271 c	0.729 d	0.204 c	1.207 bcd
	I_3	0.638 d	0.223 e	0.225 e	0.438 g	0.155 e	1.158 d
CV (%)		**1.34**	**0.45**	**0.26**	**1.90**	**0.64**	**0.96**
Level of significance		**	ns	ns	ns	Ns	*

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. * and **= Significant at 5% and 1%, respectively level of probability and ns= non significant.

4.1.3.2.2 NPK uptake in rice and straw

NPK uptake by grain

Uptake of N, P and K by grain was significantly influenced by the interaction effect of varieties and irrigation system where N uptake varied from 39.74 to 94.51 kg ha^{-1}, P uptake ranges from 13.91 to 34.46 kg ha^{-1} and K uptake varied from 14.03 to 32.57 kg ha^{-1} (Appendix IV and Table 4.12). From the above ranges of N, P and K uptake it was found that the interaction effect of V_2I_2 (BRRI hybriddhan3 × alternate wetting and drying) obtained the highest and V_3I_3 (Heera 4× irrigation only at critical growth stage) showed the lowest N, P and K uptake by grain (Table 4.12).

NPK uptake by straw

N, P and K uptake by straw was also statistically significant due to the effect of interaction where N uptake varied from 31.43 to 79.90 kg ha^{-1}, P uptake varied from 11.11 to 24.71 kg ha^{-1} and K uptake varied from 83.06 to 115.40 kg ha^{-1} (Appendix IV and Table 4.12). Above ranges of N, P and K uptake indicated the interaction treatment of V_2I_2 showed the highest and V_3I_3 recorded the lowest N, P and K uptake by grain (Table 4.12).

Table 4.12 Interaction effect of varieties and water regime treatments on nutrient uptake (NPK) of grain and straw of *Boro* rice at harvest

Variety × treatments		Nutrient uptake by grain (kg ha^{-1})			Nutrient uptake by straw (kg ha^{-1})		
		N	P	K	N	P	K
BRRI Hybriddhan2	I_1	66.21 e	22.89 e	17.15 e	54.94 e	13.85 e	89.01 e
	I_2	79.52 c	26.46 d	21.17 c	67.68 c	19.05 c	100.4 c
	I_3	63.29 f	21.07 f	15.99 f	53.47 e	12.91 f	87.57 e
BRRI Hybriddhan3	I_1	86.67 b	30.61 b	26.80 b	74.43 b	19.70 b	106.6 b
	I_2	94.51 a	34.46 a	32.57 a	79.90 a	24.71 a	115.4 a
	I_3	80.25 c	27.76 c	20.79 c	68.58 c	19.47 bc	100.5 c
Heera 4	I_1	52.94 g	17.85 g	15.49 f	45.41 f	11.84 g	84.42 f
	I_2	67.95 d	22.59 e	19.82 d	58.16 d	16.30 d	96.27 d
	I_3	39.74 h	13.91 h	14.03 g	31.43 g	11.11 h	83.06 f
CV (%)		**1.94**	**1.88**	**1.04**	**1.45**	**1.88**	**1.45**
Level of significance		**	*	**	**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. * and **= Significant at 5% and 1%, respectively level of probability

4.1.3.2.3 NPK content in postharvst soil

Nutrient (NPK) availability in postharvest soil due to the interaction effect of varieties and irrigation system was statistically significant (Appendix V). Among the interaction treatments, the variety BRRI hybriddhan3 showed the highest content of N, P and K content in postharvest soil (0.0960 ppm, 38.05 ppm and 0.0497 meq 100 g^{-1}) due to alternate wetting and drying condition while BRRI hybrid dhan2 due to same cause showed the numerically same highest K content in postharvest soil (0.0473 meq 100 g^{-1}). Similarly, the HYV Heera 4 took the lowest N, P and K content in postharvest soil (0.0447 ppm, 24.64 ppm and 0.0273 meq 100 g^{-1}) due to irritation only at critical growth stage while it was numerically differed from other all interaction in this study (Table 4.13).

Table 4.13 Interaction effect of varieties and water regime treatments on nutrient content (NPK) in postharvest soil of the experimental field

Variety × treatments		NPK content in postharvet soil		
		N (ppm)	P (ppm)	K (meq 100g^{-1})
BRRI Hybriddhan2	I_1	0.0767 bc	31.06 d	0.0413 ab
	I_2	0.0887 ab	35.86 b	0.0473 a
	I_3	0.0760 bc	30.13 e	0.0410 ab
BRRI Hybriddhan3	I_1	0.0873 ab	35.88 b	0.0467 ab
	I_2	0.0960 a	38.05 a	0.0497 a
	I_3	0.0793 abc	33.11 c	0.0427 ab
Heera 4	I_1	0.0613 cd	26.47 g	0.0337 ab
	I_2	0.0740 bc	28.95 f	0.0400 ab
	I_3	0.0447 d	24.64 h	0.0273 b
CV (%)		**1.58**	**0.79**	**1.00**
Level of significance		**	**	**

I_1: Continuous wetting; I_2: Alternate wetting and drying and I_3: Irrigation only at critical growth stage

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly as adjudged by DMRT. * and **= Significant at 5% and 1%, respectively level of probability

CHAPTER V

SUMMARY AND CONCLUSION

The present study was conducted at the Research Field of the Sheer–E–Bangla Agricultural University, during the *Boro* season of 2012–13 to evaluate the performance of *Boro* rice under different water management system. The experiment was consisted of two factors where three rice varieties namely BRRI hybriddhan2 (V_1), BRRI hybriddhan3 (V_2) and Heera 4 (V_3) and three types of water management system *viz.* continuous wetting (I_1), alternative wetting and drying (T_2) and irrigation only at critical growth stages (T_3) were used as level factor A and B, respectively for the present study. The experiment was laid out in split-plot with three replications and analysis was done by the MSTAT–C package program whereas means were adjudged by DMRT at 5% level of probability. The size of unit plot was 5.0 m^2 (2.5 m × 2.0 m) while block to block and plot to plot distances were 1.0 m and 0.5 m, respectively. The row to row and plant to plant distances were same as 20 cm. The total number of plots were 27.

Main effect of varieties was significantly influenced the studied whole characters where BRRI hybriddhan3 was the most production variety than that of other HYV varieties. The variety BRRI hybriddhan3 exhibited the tallest plant (108.80 cm) along with more effective tillers hill^{-1} (25.14), longest panicle (31.76 cm), more grains panicle^{-1} (226.80), highest weight of 1000–grain (34.08 g) as well as the highest yield of grain, straw and biological (8.18, 8.59 and 16.78 t ha^{-1}, respectively) and highest harvest index (48.76%) followed by BRRI hybriddhan2 while Heera 4 were the lowest performing variety in respect of above indicating whole traits. Similar effect was also found in respect of nutrient management characters. The highest content of NPK in grain (1.064, 0.377 and 0.324%, respectively) and straw (0.864, 0.247 and 1.250%, respectively) were also recorded in BRRI hybrid dhan3 compare BRRI hybriddhan2 and Heera 4 while BRRI hybriddhan3 also produced significantly the highest NPK uptake by grain (87.14, 30.94 and 26.72 kg ha^{-1}, respectively) and straw (74.30, 21.30 and 107.50 kg ha^{-1}, respectively). NPK in postharvest soil had also highest (0.0876 ppm, 35.68 ppm and 0.0463 meq 100 g^{-1}, respectively) in BRRI hybriddhan3 than that of other varieties. Among the above whole studied traits were lower in Heera 4.

Main effect of water management system, alternate wetting and drying (I_2) showed significantly the highest plant height (106.80 cm), more effective tillers hill^{-1} (25.24), longest panicle (29.96 cm), more grains panicle^{-1} (221.90), highest weight of 1000–grain (35.72 g) in conjunction with the highest yield of grain, straw and biological (7.90, 8.37 and 16.27 t ha^{-1}, respectively) and highest harvest index (48.51%) where continuous wetting (I_1) recorded the average medium and irrigation only at critical growth stage (I_3) observed the lowest result. In case of nutrient management, I_2 showed the superior performance for getting the highest content of NPK in grain (1.017, 0.350 and 0.307%, respectively) and straw (0.816, 0.237 and 1.240%, respectively) compare other two irrigation system. Similarly, I_2 further recorded the highest uptake of N (80.66 and 68.58 kg ha^{-1}), P (27.84 and 20.02 kg ha^{-1}) and K (24.52 and 104.00 kg ha^{-1}) in grain and straw, respectively NPK content in postharvst soil had also highest (0.0862 ppm, 34.28 ppm and 0.0457 meq 100 g^{-1}) in I_2. Irrigation only at critical growth stage (I_3) noticed the lowest nutrient content and uptake in grain and straw and also in posthavest soil.

Interaction effect of HYV varieties and water management system, BRRI hybrid dhan3 grown under alternate wetting and drying (V_2I_2) had more significant to produced the highest plant height (112.0 cm), more effective tillers hill^{-1} (26.87), longest panicle (33.03 cm), more grains panicle^{-1} (244.0 0), highest weight of 1000–grain (36.74 g), highest yield of grain, straw and biological (8.72, 9.04 and 17.75 t ha^{-1}, respectively) while HYV Heera 4grown under irrigation only at critical growth stage (V_3I_3) showed the lowest result. However, all the interactions were showed numerically identical HI due to non significant variation. The characters of nutrient management were influenced significantly due to the interaction effect where V_2I_2 further produced the highest content of NPK in grain (1.084, 0.395 and 0.373%, respectively) and straw (0.884, 0.273 and 1.276%, respectively) while the highest uptake of N (94.51 and 79.90 kg ha^{-1}), P (34.46 and 24.71 kg ha^{-1}) and K (32.57 and 115.40 kg ha^{-1}) in grain and straw, respectively. NPK availability in postharvst soil had also highest (0.960 ppm, 38.05 ppm and 0.0497 meq 100 g^{-1}) in V_2I_2. The variety Heera 4grown under irrigation only at critical growth stage (V_3I_3) always perform the lowest in respect of whole characters of the study.

CONCLUSION

Above observing results of the present study it could be concluded that the alternate wetting and drying (AWD) would be the most advantageous irrigation system for highly influencing the HYV variety compare continuous wetting/flooding (CW/CF) system while BRRI hybriaddhan3 also showed understanding superiority than other HYV under irrigated system. This result suggested that AWD irrigation system would be the recommended irrigation system for getting the higher production of *Boro* rice which also could be the significant reduction in use of water including its savings. So, I strongly suggested that the farmer of our country can be follow the AWD irrigation system to reduced their irrigation cost and elevated production which may contribute the reduction of food shortage in our country.

Further study may be needed to ensuring the above performance of HYV BRRI hybriddhan3 (V_2) and alternate wetting and drying (I_2) as singly (V_2/I_2) or their interaction (V_2I_2) under the AEZ–28. So, the following recommendation may be suggested:

1. More HYV/Local varieties or more irrigation system may be needed to include for further study to make sure the performance of their single or interaction effect on rice production in Bangladesh or abroad.
2. Such study is also needed in different agro–ecological zones (AEZ) of Bangladesh for regional adaptability of the HYV varieties under irrigation management system.

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Appendices

Appendix I. Mean square for yield contributing characters of *Boro* rice at harvest

Source of variation	Degrees of freedom	Mean square for			
		Plant height (cm)	No. of effective tillers hill^{-1}	Length of panicle (cm)	No. of grains panicle^{-1}
Replication	2	195.814	12.84	38.939	911.148
Factor A	2	203.42**	24.263**	88.472**	3204.593**
Factor B	2	103.363**	28.807**	14.283**	1323.593**
AB	4	1.698**	1.318**	0.263**	98.537**
Error	**16**	**0.284**	**0.053**	**0.012**	**1.44**

Appendix II. Mean square for yield and yield attributes of *Boro* rice at harvest

Source of variation	Degrees of freedom	Mean square for				
		Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	39.314	0.7	0.617	3.567	13.262
Factor A	2	24.032**	5.456**	3.241**	16.965**	7.203**
Factor B	2	53.436**	2.256**	1.554**	7.555**	1.425**
AB	4	0.291**	0.056**	0.072**	0.242*	0.25*
Error	**16**	**0.035**	**0.006**	**0.011**	**0.112**	**0.06**

Appendix III. Mean square for nutrient content (NPK) of grain and straw

Source of	Degrees	Mean square for

variation	of freedom	Nutrient content of grain (%)			Nutrient content straw (%)		
		N	P	K	N	P	K
Replication	2	0.002	0.001	0.003	0.001	0.002	0.003
Factor A	2	0.162**	0.026**	0.017**	0.162**	0.013**	0.013**
Factor B	2	0.05**	0.006**	0.009**	0.049**	0.007**	0.007**
AB	4	0.015**	0.001**	0.001**	0.015**	0.001**	0.001**
Error	**16**	**0.001**	**0.0001**	**0.0001**	**0.001**	**0.0001**	**0.0001**

**= Significant at 1% level of probability and ns= non significant

Appendix IV. Mean square for nutrient uptake (NPK) of grain and straw

Source of variation	Degrees of freedom	Mean square for					
		Nutrient uptake grain (kg ha^{-1})			Nutrient uptake straw (kg ha^{-1})		
		N	P	K	N	P	K
Replication	2	105.888	17.196	27.987	45.834	16.678	185.419
Factor A	2	2541.153**	373.641**	273.846**	1934.921**	162.807**	948.372**
Factor B	2	876.716**	108.902**	131.886**	690.145**	82.314**	462.017**
AB	4	49.139**	2.119**	10.773**	62.544**	0.28**	5.453**
Error	**16**	**0.943**	**0.378**	**0.095**	**0.836**	**0.065**	**1.212**

Appendix V. Mean square for nutrient content (NPK) in postharvest soil

Source of variation	Degrees of freedom	Mean square for NPK content in postharvest soil		
		N (ppm)	P (ppm)	K (meq $100g^{-1}$)
Replication	2	0.001	3.758	0.001
Factor A	2	0.002**	186.12**	0.001**

Factor B	2	0.001**	57.349**	0.001**
AB	4	0.001**	1.701**	0.001**
Error	**16**	**0.0001**	**0.101**	**0.0001**

**= Significant at 1% level of probability

LIST OF PLATES

Plate no. 1. Main Field Preparation

Plate no. 2. Initial soil sample collection from the experimental plot

Plate no. 3. Seedling Transplanting in the main field

Plate no. 4. Field view of experimental field at ripening stage